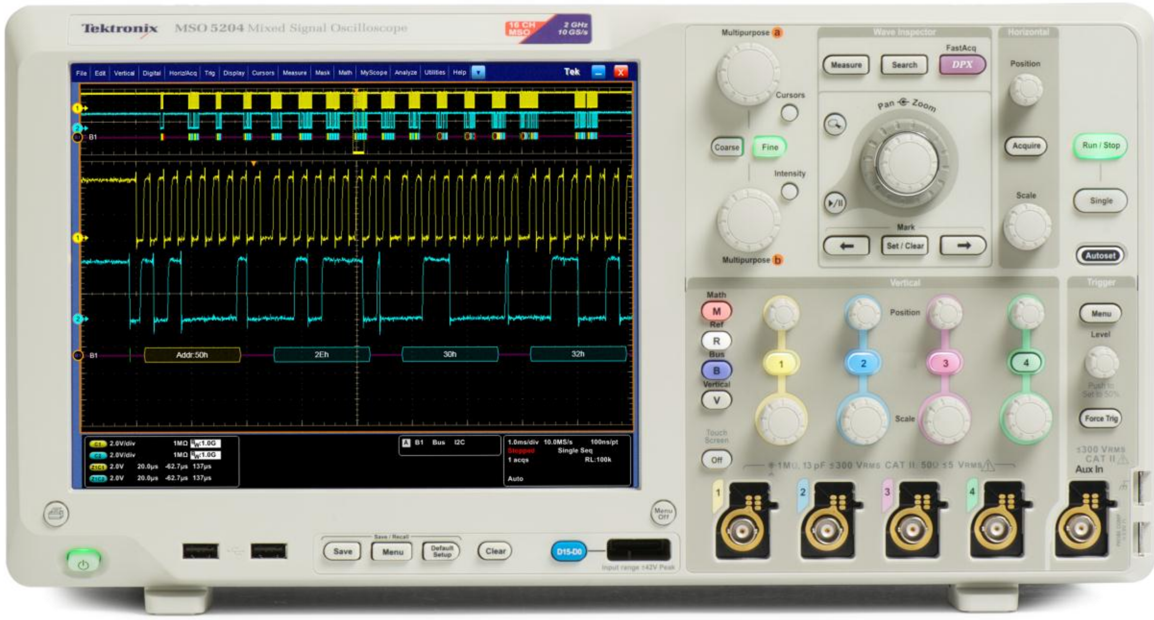
MSO5000/DPO5000 Series

Lab Exercise Book



A collection of lab exercises to help you hone your skills at using the MSO5000/DPO5000 Series Digital Phosphor Oscilloscopes.

NOTE: Always use the latest instrument software for demonstrations. Go to www.tek.com/software and search for "MSO5000" or "DPO5000". Follow the installation instructions on the web page.

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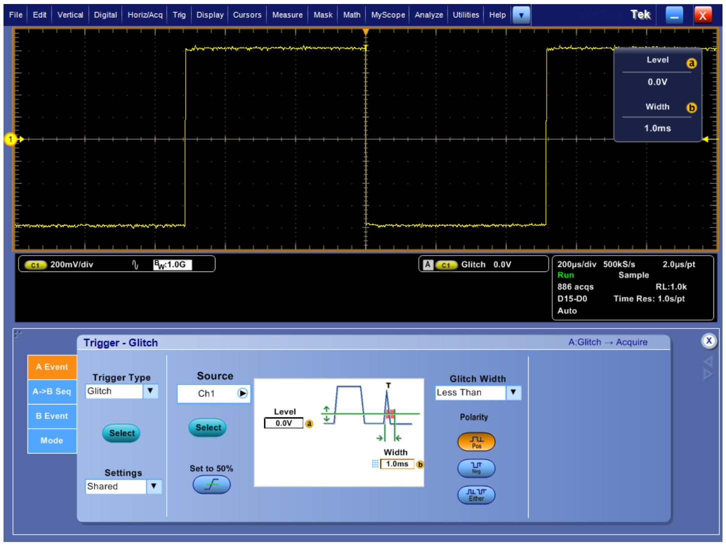
User Interface Exploration Lab



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
One TPP0500 or TPP1000 passive probe
USB keyboard and mouse
Optional stylus (119-6107-00)

Understanding the MSO/DPO5000 Series User Interface

This lab provides an overview of the MSO/DPO5000 Series user interface and outlines a few quick ways to demonstrate important usability advantages of the MSO/DPO5000 family. Learn a few favorites to highlight the products' usability and to improve your productivity when running the instrument.

There are three key themes with respect to this user interface:

- Intuitive operation in any common engineering environment
- Instrument control in a way you prefer
- Achieving results more quickly using efficient controls and shortcuts

Display

In addition to the waveforms, the display contains various status readouts, icons, and other user interface information. Throughout this lab, notice all of the display changes as you control the instrument. For those users who are familiar with the Tektronix DPO7000 and MSO/DSA/DPO70000 Series, the MSO/DPO5000 display interface will seem almost identical.

There are a variety of ways to operate the instrument. Each successive level within the user interface enables a deeper feature set and greater control. This lab will highlight some of the advantages of each type of instrument control.

Direct controls

With the familiar front panel controls, the user has direct access to the most commonly-used controls to set up a stable oscilloscope display of one or more analog channels. Most of the controls are the same as you would find on any analog or digital oscilloscope front panel. For those users who are familiar with the Tektronix MSO/DPO4000/3000/2000 Series, the MSO/DPO5000 front panels will seem almost identical.

Touch screen, toolbar, and multipurpose controls

The next level of controls are available through the on-screen controls. These controls are logically grouped by function and can be accessed either through pressing the on-screen toolbar buttons at the top of the display or by pressing the corresponding front panel buttons, similar to the menu interface on the MSO/DPO4000/3000/2000 Series.

Windows menu interface

The most complete set of instrument controls are available through the Windows menu bar. These controls are logically grouped by function, with familiar File and Edit menus on the left, instrument control menus in the middle, and Utilities and Help on the right. These menus can be operated with the touch screen, but are optimized for use with a mouse. For those users who are familiar with the Tektronix DPO7000 and MSO/DSA/DPO70000 Series, the MSO/DPO5000 Windows menu interface will seem almost identical.

Mouse and right-clicks

A growing number of users prefer mouse-driven operation for anything but the most basic instrument control. This is especially true when an instrument is located on a shelf above a bench. The MSO/DPO5000 series provides a rich array of mouse actions and right-mouse-click menus for context-sensitive direct access to instrument features. The mouse scroll wheel is included as an interactive device to allow fine adjustment without letting go of the mouse. Again, those users who are familiar with the Tektronix DPO7000 and MSO/DSA/DPO70000 Series will find these capabilities familiar.

MyScope™ Control Windows

The MyScope feature allows the user to quickly and easily build their own custom control windows that contain only the controls, features, and capabilities they care about and are important in their job. Again, those users who are familiar with the Tektronix DPO7000 and MSO/DSA/DPO70000 Series will find this capability familiar.

User Preferences

The MSO/DPO5000 also allows the user to customize the user interface behavior with some user preferences and menu settings. This lab will highlight a few of the settings that will make the MSO/DPO5000 behavior more closely match the behaviors of the MSO/DPO4000/3000/2000 products.

This lab does not go through every instance of each of these control mechanisms, but provides examples of each mechanism in the context of common oscilloscope usage.

Objectives

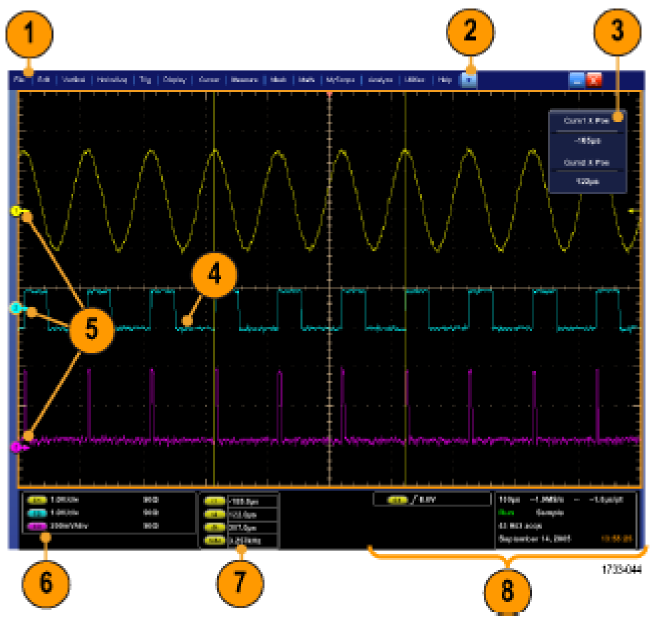
- Learn how to verify instrument status by understanding on-screen readouts and icons.
- Learn basic oscilloscope setup using only the direct front panel controls.
- Learn more complex control techniques using the touch screen and button toolbar.
- Learn full instrument control techniques using the Windows menu bar and a mouse.
- Learn how to adjust the display using mouse actions and right-click menus.
- Learn how to set up some of the more common user preferences.

MSO/DPO5000 Series Display Interface

The MSO/DPO5000 series display interface design includes the learnings of 60+ years of designing oscilloscopes. Although the primary focus of the display is on the acquired waveforms, there are many other important pieces of information presented.

For those users who are familiar with the Tektronix DPO7000 and MSO/DSA/DPO70000 Series, the MSO/DPO5000 display interface will seem almost identical:

1. **Menu Bar:** Access to instrument control functions, file system, and online help
2. **Buttons/Menu:** Click to toggle between toolbar and menu bar modes and to customize the toolbar
3. **Multipurpose Control Readouts:** Adjust and display selected parameters with the multipurpose controls
4. **Display:** Live, reference, math, digital, and bus waveforms are displayed here, along with cursors
5. **Waveform Handle:** Click and drag to change vertical position of a waveform or bus. Click the handle and change the position and scale using the multipurpose controls
6. **Controls Status:** Quick reference to vertical selections, scale, offset, and parameters
7. **Readouts:** Display cursor and measurement readouts in this area. Measurements are selectable from the menu bar or toolbar. If a control window is displayed, some combinations of readouts move to the graticule area
8. **Status:** Display of acquisition status, mode, and number of acquisitions; trigger status; date; time; and quick reference to record length and horizontal parameters

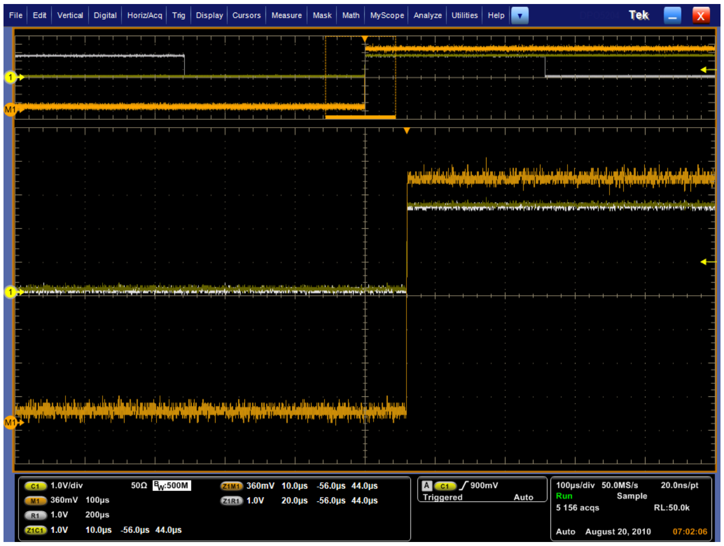


As you work through this lab, refer back to this page and identify the display icon and readout changes that occur as you change the instrument controls.

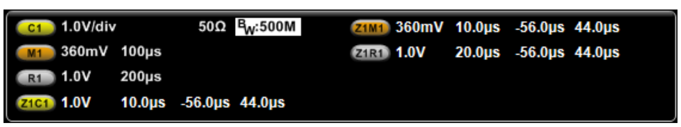
MSO/DPO5000 Series Display Readouts

Key Take Away Points

- As with other Tektronix oscilloscopes, the MSO/DPO5000 status readouts are shown at the bottom of the display:

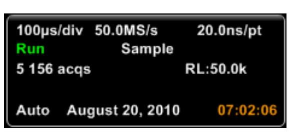


- The vertical readouts are shown in the lower left corner of the display. Vertical scale factors, offset, termination, coupling, and bandwidth information are provided for each analog channel. Horizontal and vertical information is given for all math, zoom, and references.



- The trigger status is shown at the bottom of the display, near the center. As with other Tek oscilloscopes, the trigger source, trigger type, trigger level (if applicable), and horizontal trigger delay (if applicable) are shown.

- The horizontal and acquisition status, including horizontal scale, sample rate, record length, acquisition status (Run, Stop, Single, FastAcq), acquisition mode (Sample, Pk Detect, Hi Res, Envelope, Average, WfmDB), and acquisition counter are shown in the readouts in the lower right corner of the display. The time and date are also shown in this box.

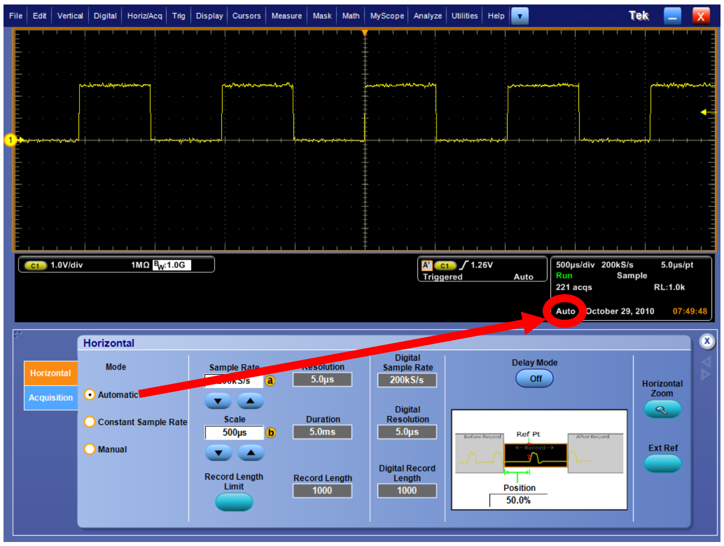


MSO/DPO5000 Series Procedure:

- ❑ Power up the oscilloscope.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- ❑ Connect the probe ground to the **GND** and connect the probe tip to the **PROBE COMP** test point in the lower right corner of the instrument.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button to automatically adjust vertical, horizontal, and trigger settings to get a stable display of the selected channels.
- ❑ As you do the following steps, notice the changes to the readouts at the bottom of the display.
- ❑ Press the white front panel **R** button to turn on the Reference menu.
- ❑ If there is no Reference waveform available, press the **Save** button, press the **Ref1** icon, and press the **Save** button.
- ❑ Press the **Display On** button.
- ❑ Change the Horizontal **Scale** control. Notice that the Reference Horizontal scale does not change and is now different from the acquisition's Horizontal Scale.
- ❑ Press the red front panel **M** button to turn on the Math menu.
- ❑ Press the **Ch1-Ch2** button.
- ❑ Press the **Menu Off** button.
- ❑ Draw a box around the edge at the center of the display and select **Zoom 1 On**.

Key Take Away Points

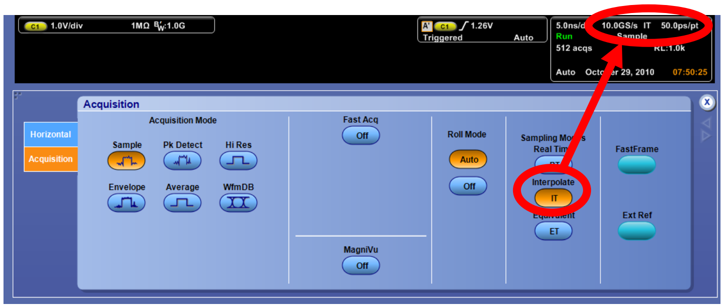
- By default, the Automatic horizontal mode is selected. For this signal, Autoset has selected a horizontal scale of 500 µs/div, a sample rate of 200 kS/s, and a record length of 1000 points, as indicated in the readout in the lower right corner of the display. The Automatic horizontal mode is indicated by the “Auto” text next to the date:



- For most trouble-shooting applications, the Auto horizontal mode is the easiest to use. Up to the maximum real-time sample rate, the front panel Horizontal Scale control adjusts the sample rate.

- At fast horizontal settings, the oscilloscope must make a tradeoff. Since the horizontal scale is the product of the sample rate and the record length, you can either increase the sample rate or decrease the record length.

- By default, the oscilloscope will use interpolation to increase the effective sample rate beyond the maximum real-time value. When the maximum sample rate is reached, the acquisition system begins to interpolate the sampled data, as indicated by the “IT” readout:



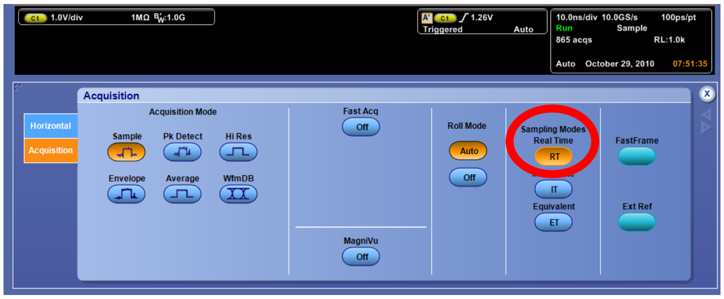
- Notice that in IT mode, the real-time sample rate (which has a maximum value of 10 GS/s in 1- or 2-channel mode on the 1 and 2 GHz models) remains at the maximum value, but the time/point readout in the upper right corner changes with the amount of interpolation.

MSO/DPO5000 Series Procedure:

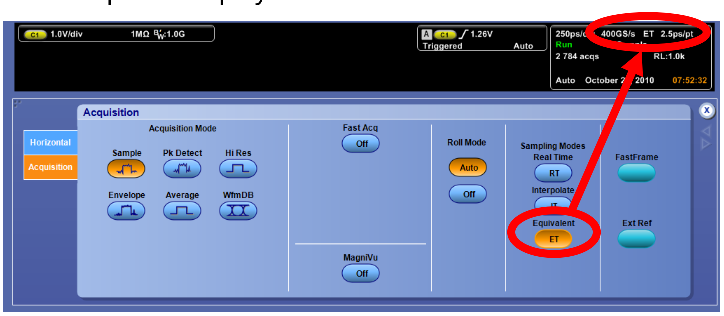
- ❑ Press the **Default Setup** button.
- ❑ Press the **Autoset** button.
- ❑ Select **Horiz/Acq -> Horizontal/Acquisition Setup….**
- ❑ Turn the Horizontal **Scale** control clockwise until you reach **5 ns/div**.
- ❑ Notice that the sample rate increases, while the record length remains at about 1000 points.
- ❑ Press the **Acquisition** tab at the left side of the control window.
- ❑ Notice that the **IT** (Interpolate) Sampling Mode has been selected by default.

Key Take Away Points

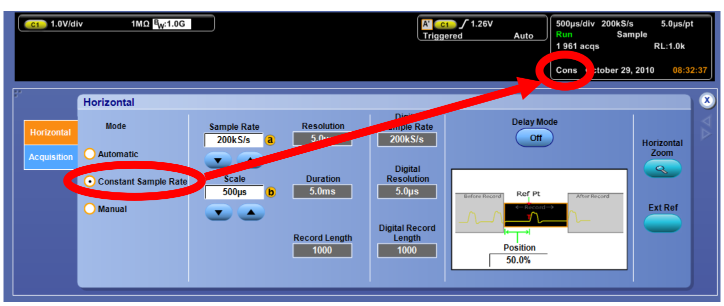
- However, extreme interpolation can add DSP artifacts to the display. To prevent such artifacts, one alternative is to disable the interpolation and simply stop increasing the horizontal scale when the maximum real-time sample rate is reached:



- Another alternative (which only works for repetitive signals!) is to use equivalent time (ET) sampling. ET allows very high effective sample rates (up to 400 GS/s) to sample a few points of each triggered waveform and build up a composite display over time.



- Constant Sample Rate horizontal mode is very convenient when capturing signals with a known single-shot bandwidth, for acquiring data for off-line digital signal processing, or when using software filtering on the scope.

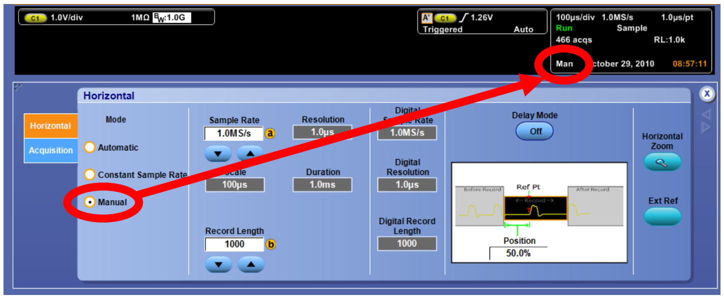


MSO/DPO5000 Series Procedure:

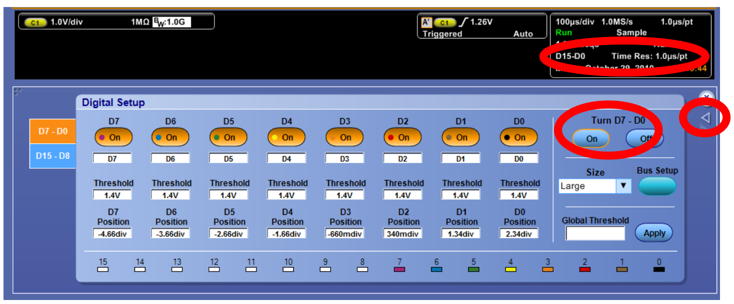
- ❑ Press the **RT** Real Time Sampling Modes button.
- ❑ Turn the Horizontal **Scale** control clockwise.
- ❑ Notice that once the maximum real-time sample rate has been achieved, the horizontal scale does not change.
- ❑ Press the **ET** Equivalent time button.
- ❑ Turn the Horizontal **Scale** control fully clockwise and notice the readout.
- ❑ Press the **Autoset** button.
- ❑ Select the **Constant Sample Rate** mode.
- ❑ You can adjust the Sample Rate with the Multipurpose **a** control.
- ❑ You can adjust the Horizontal Scale with front panel Horizontal Scale or the Multipurpose **b** controls.
- ❑ Turn the Horizontal **Scale** control clockwise and counter-clockwise.
- ❑ Watch the sample rate readout and notice that the sample rate has been limited to the specified value.

Key Take Away Points

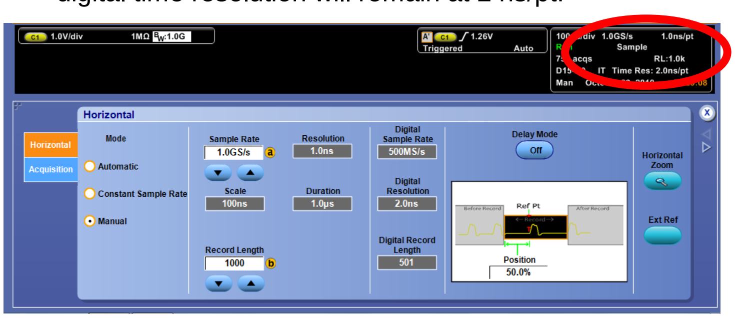
- In some other applications, where predictable/controlled file size is required, you should use Manual mode:



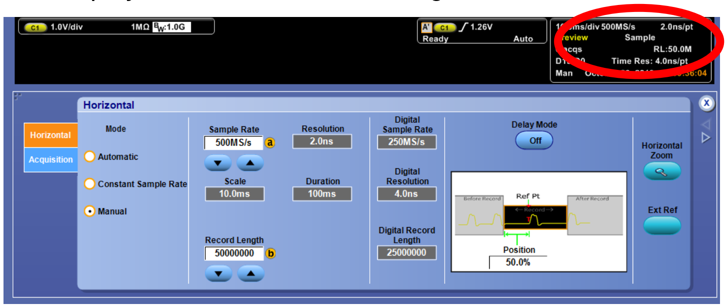
- When you turn on digital channels, a fourth line is added to the horizontal readout, indicating the time resolution (reciprocal of the digital channel sample rate):



- Up to the point where the requested sample rate exceeds the maximum digital sample rate, the analog and digital sample time resolutions will match. Beyond that point, the digital time resolution will remain at 2 ns/pt:



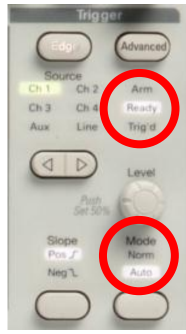
- As you increase the record length, you will hit the digital channel maximum record length, at which point the displayed waveforms will no longer be 10 divisions wide.



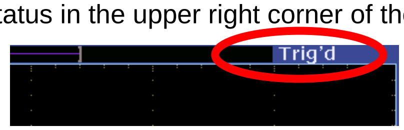
MSO/DPO5000 Series Procedure:

- ❑ Press the **Autoset** button.
- ❑ Select the **Manual** mode.
- ❑ You can adjust the Sample Rate with the Multipurpose **a** control.
- ❑ You can adjust the Record Length with the Multipurpose **b** control.
- ❑ You can adjust the Horizontal Scale with front panel Horizontal Scale control. This also allows you to indirectly change the Sample Rate.
- ❑ Press the front panel **D15-D0** button.
- ❑ Press the **Turn D7 – D0 On** button.
- ❑ Press the left arrow at the right side of the control window to return to the Horizontal/Acquisition control window.
- ❑ Using the Multipurpose **a** control, select **500 MS/s** sample rate. Notice that the analog and digital sample rate readouts both indicate 2 ns/pt (500 MS/s).
- ❑ Continue turning the Multipurpose **a** control and notice that only the analog sample rate increases, because the maximum digital sample rate has been reached.
- ❑ Using the Multipurpose **a** control, select **500 MS/s** sample rate again.
- ❑ Using the Multipurpose **b** control, select **10.0 M** record length.
- ❑ Notice that the analog and digital sample rate readouts both indicate 2 ns/pt (500 MS/s).
- ❑ Continue turning the Multipurpose **b** control and notice that eventually the displayed waveforms are no longer 10 divisions wide when the digital channel maximum record length is reached.

Key Take Away Points



- On the front panel of the DPO7000 and MSO/DSA/DPO70000 Series products, there are three LEDs in the Trigger section which indicate the trigger status and two which indicate the trigger Mode:
- The MSO/DPO4000/3000/2000 Series products show the trigger status in the upper right corner of the display:



- Because these indicators do not exist on the MSO/DPO5000 front panel, the trigger status readout has been expanded to include this trigger status information.
- The cross-reference of trigger readouts looks like this:

	MSO/DPO 4000	**MSO/DPO 5000**	**DPO7000**
Acquisition pre-fill	PrTrig	Armed	Arm
Waiting for A trigger	Trig?	Ready Normal	Ready Norm
Waiting for B trigger	Trig?	Ready Normal	Ready Trig'd
Triggered	Trig'd	Triggered Normal, Triggered Auto	Trig'd Norm, Trig'd Auto
Auto triggering	Auto	Ready Auto	Ready Auto
Stopped	-	None	-

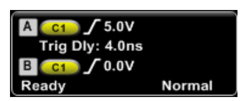
MSO/DPO5000 Series Procedure:

- ❑ After an Autoset, the trigger is in Auto mode. Notice that the trigger readout in the bottom center of the display indicates "Triggered Auto":

- ❑ As you do the following steps, notice the changes to the trigger readout at the bottom of the display.
- ❑ Press the front panel Trigger **Menu** button, the **Mode** tab at the left side of the control window, and the **Normal** Trigger Mode button.

- ❑ Using the front panel Trigger Level control, set the trigger level to about 5V. This will cause the acquisitions to stop.

- ❑ Press the **A->B Seq** tab at the left side of the control window and press the **Time** Trig After Time button.



- ❑ Press the **nth event** Trig on nth Event button. Press the **Horizontal Delay Mode** button.

MSO/DPO5000 Series Direct Controls

The MSO/DPO5000 series front panel design incorporates feedback from significant user testing. The most commonly-used controls are readily available for direct control of the oscilloscope without creating a cluttered look.

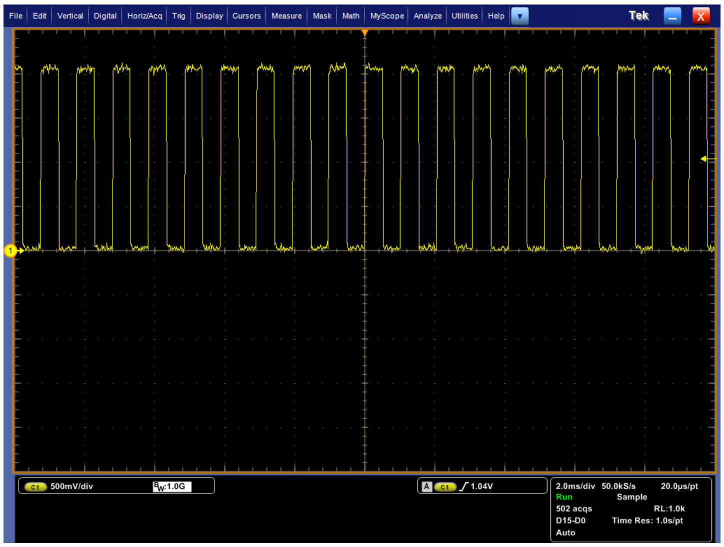
As with most oscilloscopes, the majority of the front panel controls are grouped and graphically outlined by category: Vertical, Horizontal, Trigger, and Wave Inspector.

For those users who are familiar with the Tektronix MSO/DPO4000/3000/2000 Series, the MSO/DPO5000 Series front panels will seem almost identical:

- Wave Inspector manual and automatic search controls
- Dedicated vertical scale and position controls for each analog channel
- Dedicated horizontal scale and position controls
- Autoset – automatically set up the vertical, horizontal, and trigger controls based on selected channels
- Trigger Set to 50%, Force Trigger, and Trigger Level controls – provide additional tools to quickly get a stable display
- Run/Stop and Single acquisition buttons
- FastAcq – toggle in and out of FastAcq mode at the touch of a button
- Default setup – quickly restore the oscilloscope to a known condition
- One-button Save and Print – very fast and convenient
- Menu Off – close all open control windows

Key Take Away Points

- Because you may not know who was last using the oscilloscope or how it is set up, it is often wise to start from a known factory default setup. After restoring the instrument to its default setup and then automatically setting up the instrument, the display should look about like this:



- By default, a single press of the Autoset button will start the Autoset process and a popup menu allows you to easily undo the process if you change your mind. There are User Preferences to require you confirm the Autoset selection and to suppress the undo popup menu.
- With a few adjustments of the front panel controls, you can easily adjust the waveform display to meet your needs:

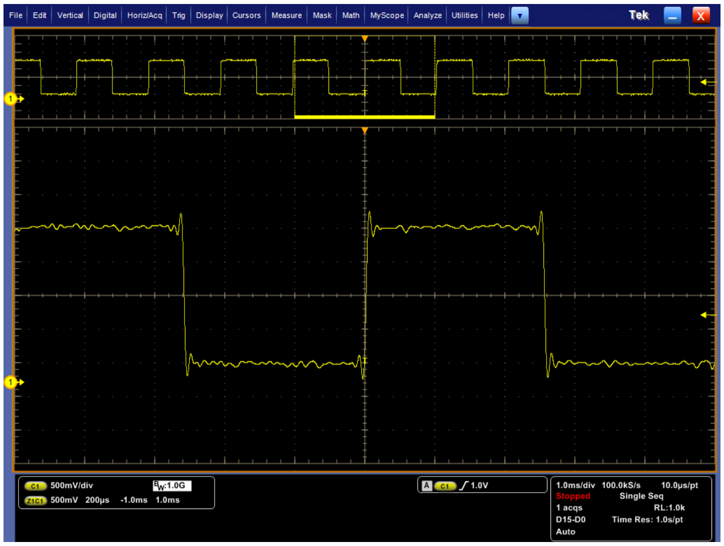
- One unfamiliar item should be the vertical probe bandwidth readout, showing 1 GHz with the standard passive probe!

MSO/DPO5000 Series Procedure:

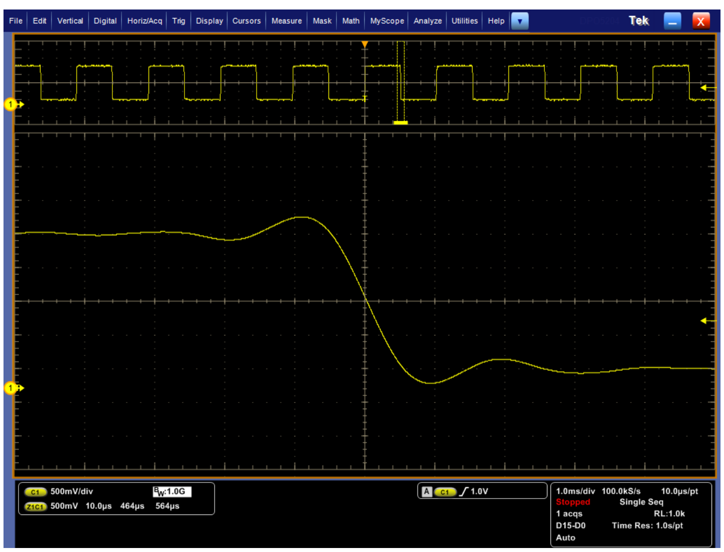
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button to automatically adjust vertical, horizontal, and trigger settings to get a stable display of the selected channels.
- ❑ You can also press the front panel Trigger **Level** control (**Set to 50%**) to automatically set just the trigger level.
- ❑ Using the channel 1 Vertical **Scale** control, set the vertical scale to **500mV/div**, as indicated in the readout in the lower left corner of the display.
- ❑ Using the channel 1 Vertical **Position** control, center the waveform vertically on the display.
- ❑ With the Horizontal **Scale** control, set the horizontal scale to **1ms/div**, as indicated in the readout in the lower right corner of the display.
- ❑ With the Trigger **Level** control, set the trigger level to about **1 V**, as indicated in the readout in the bottom center of the display. Also notice that the trigger level is indicated by the arrow at the right side of the display.
- ❑ The point where the signal crosses through the trigger level is centered on the display.

Key Take Away Points

- When Wave Inspector zoom is turned on, an overview of the entire waveform is show at the top of the display, and the graphically zoomed area (indicated by the yellow box in the overview area) is shown in the lower part of the display, about like this:



- Wave Inspector zoom can provide a detailed display of a small portion of the waveform, such as the falling edge, like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Single** button to capture a single waveform.
- ❑ Turn the inner portion of the Wave Inspector Pan / Zoom control clockwise to turn on zoom and adjust the zoom factor to clearly view a complete cycle of the waveform.
- ❑ Now, turn the inner portion of the Pan / Zoom control clockwise to select a higher zoom factor to view just the rising edge of the waveform.
- ❑ Turn the spring-loaded outer portion of the Pan / Zoom control to position the falling edge of the signal in the center of the display.
- ❑ To automatically scroll through the acquired waveform, press the Wave Inspector run/pause button. You can adjust the direction and speed of the scrolling by turning the outer Pan/Zoom control in the desired direction.
- ❑ When you are done, press the magnifying glass button to turn off Wave Inspector zoom.
- ❑ Press the **Run/Stop** button to restart acquisitions.

Tektronix

MSO/DPO5000 Series Touch Screen, Toolbar, and Multipurpose Controls

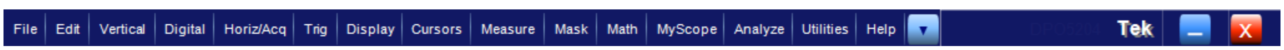
The MSO/DPO5000 series contains many features that are not directly available through the front panel controls. The oscilloscope provides a variety of other control mechanisms. This section of the lab focuses on the touch screen, the front panel menu buttons, the button toolbar, and the multipurpose controls.

Crowded lab benches, carts and floor-standing scope locations can make it difficult to use a mouse. The MSO/DPO5000 embraces touch screen operation as an efficient way to access all instrument features when a mouse is not available or not preferred.

As with the MSO/DPO4000/3000/2000 Series products, there are many MSO/DPO5000 front panel menu buttons which provide access to the first level of control menus. For example:

- The Vertical **Menu** button provides access to the Vertical Setup menu
- The **Acquire** button provides access to the Horizontal / Acquisition Setup menu
- The Trigger **Menu** button provides access to the Trigger Setup menu
- The **Measure** button provides access to the Measurement Setup menu
- The **Search** button provides access to the Wave Inspector automatic Search Setup menu
- The red **Math** button provides access to the Math Setup menu
- The white **Ref** button provides access to the Reference menu
- The purple **Bus** button provides access to the Bus Setup menu
- The blue **D15-D0** button provides access to the Digital channel Setup menu

The on-screen Toolbar provides similar access to the first-level menus. Because these easy-to-touch buttons are right on the display with the setup menus, this alternative makes the touch screen even more effective.



The Windows Menu bar is displayed at the top of the display by default. You can easily select the Toolbar by pressing the down-arrow button at the right side of the Menu bar.

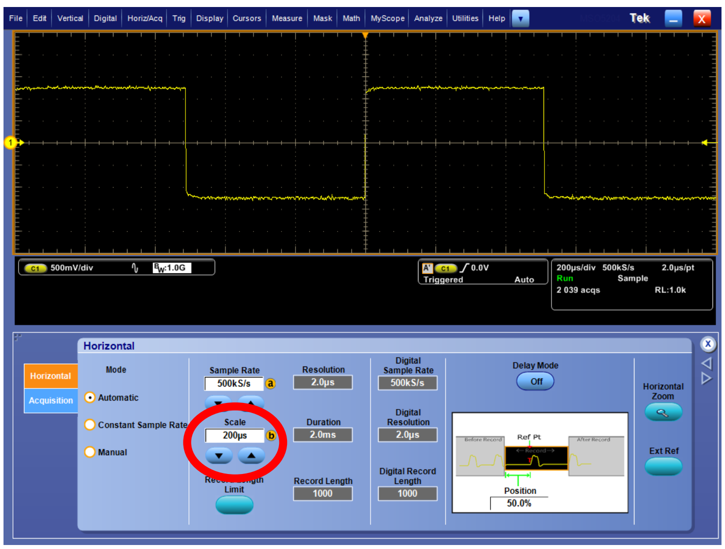
Though many of the controls are simple selections with buttons, there are some parameters such as specific threshold levels or timing offsets that are more convenient if they are easily adjustable by the user. These parameters can be controlled in several ways, including the front panel Multipurpose controls and popup keypads.

The large, comfortable Multipurpose controls merge the direct access of dedicated front-panel controls with the flexibility of on-screen menus. It's easy to assign one of the controls to a parameter, set your hand on top of the instrument, and use your thumb to scroll through values while watching the display and the control readout. With the coarse and fine settings, the multipurpose controls provide a convenient way to make real-time adjustments.

On-demand keypads provide context-sensitive keyboards to allow the touch screen to provide numeric without the need for a physical keyboard. The touchscreen supports the use of your finger or a stylus. You can invoke the appropriate keypad by double-clicking on a numeric readout in a menu or the multipurpose control readout.

Key Take Away Points

- The display should look about like this:

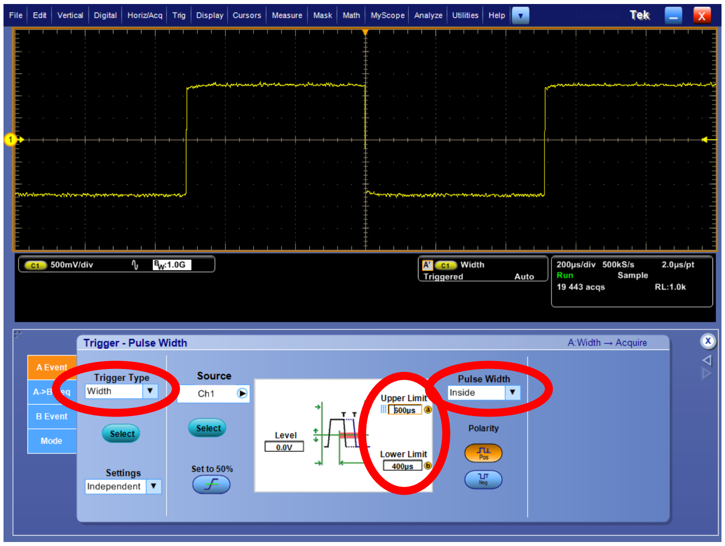


MSO/DPO5000 Series Procedure:

- ❑ Press the **Autoset** button.
- ❑ Press the front panel Vertical **Menu** button to display the vertical setup menu.
- ❑ Press the **AC** Coupling button to remove the DC offset from the signal.
- ❑ Press the **Set to 50%** button.
- ❑ Notice that the Multipurpose controls to the Ch 1 Vertical Position and Scale controls.
- ❑ Using the Multipurpose **b** control, set the vertical Scale to **500 mV/div**.
- ❑ Touch the Position text box once. Notice the keypad icon next to the Position text box indicating that there is an on-screen keyboard available. Click on the text box to display the context-sensitive keypad.
- ❑ Press the **0** button and the green **Enter** button to set the position to exactly 0.
- ❑ Press the front panel **Menu Off** button or click the **X** in the upper right corner of the control window to close it and restore the full-screen waveform display.
- ❑ Select **Horiz/Acq -> Horizontal/Acquisition Setup…** to display the horizontal setup menu.
- ❑ Using the Scale arrow keys, select a **200 µs/div** horizontal Scale setting.
- ❑ Press **Menu Off** or click the **X** in the upper right corner of the control window to close it and restore the full-screen waveform display.
- ❑ Touch and hold somewhere within the Multipurpose control readouts. After a short dwell time, a “right-click” menu pops up. Select **Deassign Multipurpose Knobs** to remove the readout from the display.

Key Take Away Points

- Notice how the familiar front panel button interface parallels the Windows menu interface for launching basic setup control windows.
- The display should look about like this:

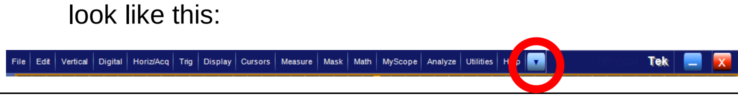


MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button to display the trigger setup menu.
- ❑ Press the front panel **Menu Off** button or click the **X** in the upper right corner of the control window to close it and restore the full-screen waveform display.
- ❑ Select **Trig -> A Event (Main) Trigger Setup…** to display the trigger setup menu.
- ❑ Using the **Trigger Type** drop down menu, select **Width** in the list to select Pulse Width triggering.
- ❑ You can also get directly to this Width trigger setup control window by selecting **Trig -> Width Setup…** which displays the trigger setup menu and pre-selects Width Trigger Type.
- ❑ Double-click on the **Upper Limit** text box.
- ❑ Press **600**, **µ**, and **Enter** to set the pulse width upper limit to **600 µs**.
- ❑ Double-click on the **Lower Limit** text box.
- ❑ Press **400**, **µ**, and **Enter** to set the pulse width upper limit to **400 µs**.
- ❑ Notice that the Multipurpose controls remain attached to the **Upper Limit** and **Lower Limit** controls.
- ❑ Verify that **Inside** is selected in the Pulse Width text box.
- ❑ Press the front panel **Menu Off** button or click the **X** in the upper right corner of the control window to close it and restore the full-screen waveform display.

Key Take Away Points

- The down-arrow button at the top of the display allows you to toggle between the Windows Menu bar and the Toolbar interface. With the Toolbar selected, the interface should look like this:

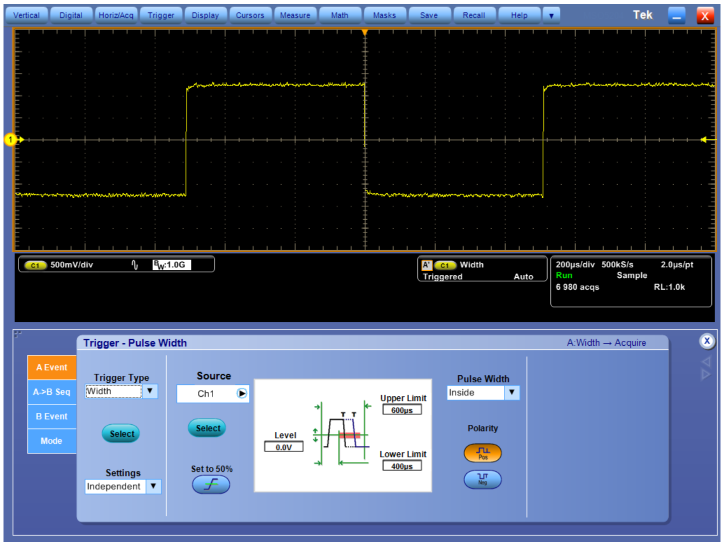


MSO/DPO5000 Series Procedure:

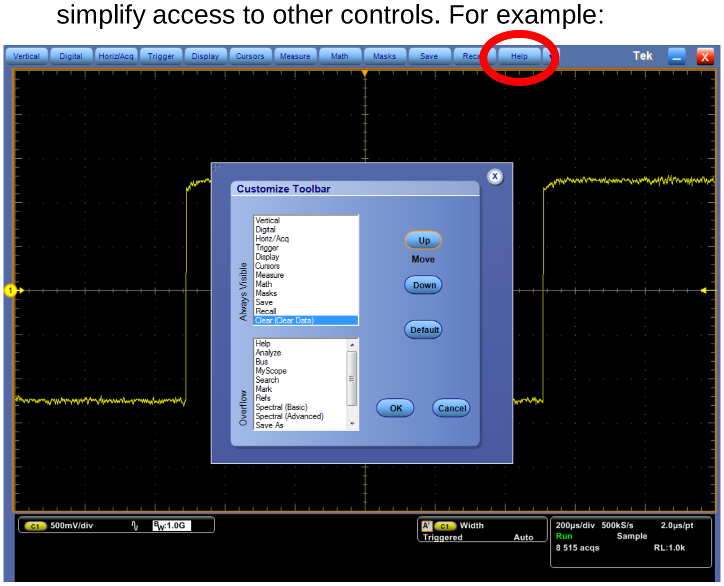
- ❑ Press the down-arrow button at the top of the display and press **Show Buttons** to select the Toolbar interface.

Key Take Away Points

- With the Toolbar selected, the Trigger setup control window interface still looks the same:



- The buttons on the toolbar are the most commonly-used controls. However, you can customize the toolbar to simplify access to other controls. For example:

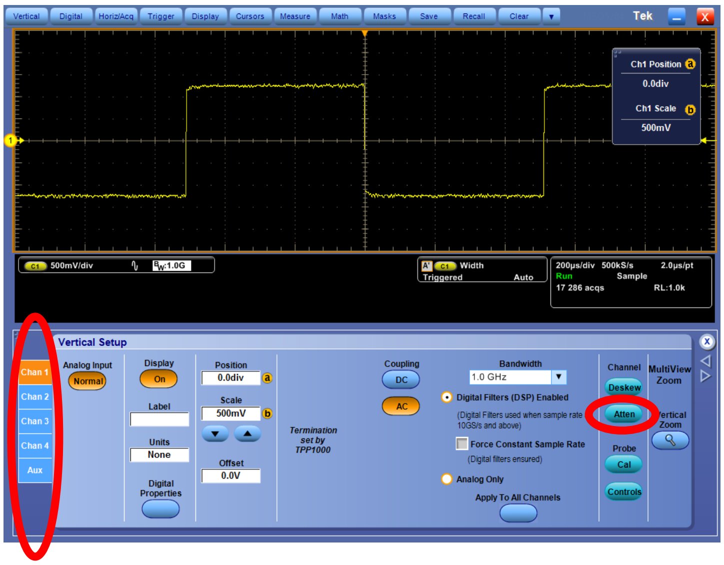


MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Menu Off** button or click the **X** in the upper right corner of the control window to close it and restore the full-screen waveform display.
- ❑ Press the down-arrow button at the top of the display and press **Show Buttons** to select the Toolbar interface.
- ❑ Press the **Trigger** button on the Toolbar. Notice that the same control window is displayed as when you pressed the front panel Trigger **Menu** button.
- ❑ Press the front panel **Menu Off** button or click the **X** in the upper right corner of the control window to close it and restore the full-screen waveform display.
- ❑ Press the down-arrow button at the top of the display and notice the list of additional function buttons.
- ❑ You can press these buttons directly for a single usage. For example, press **Clear** to clear the currently-displayed waveform from the screen.
- ❑ If you want to make one of these additional buttons available on the Toolbar, or you want to customize the Toolbar, press the down-arrow button at the top of the display and select **Customize….**
- ❑ For example, to add the Clear button to the Toolbar, select **Clear** in the lower window and press the Move **Up** button repeatedly until it is in the desired position in the list of Always Visible button.
- ❑ Press the **OK** button. Notice that the Clear button has been added to the Toolbar in the position you specified and Help has been hidden.

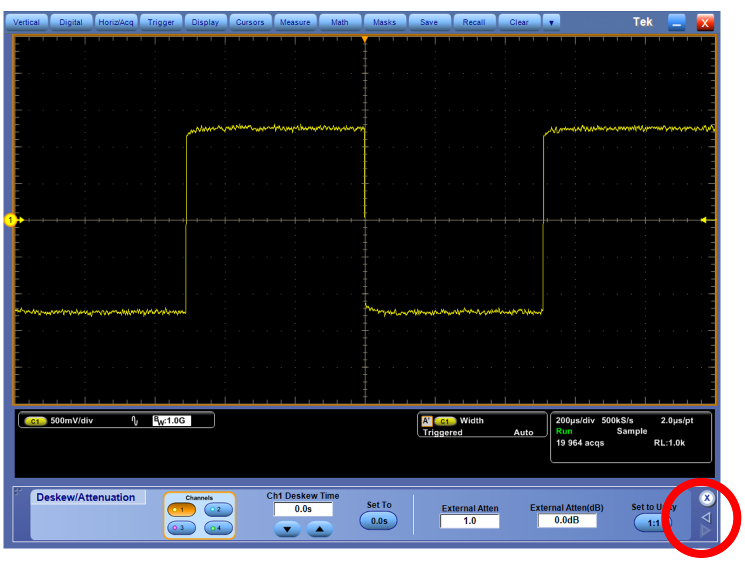
Key Take Away Points

- When you press a front panel menu button or a button on the Toolbar, the waveform graticule is reduced in size to fit in the top half of the display and a first-level menu or control window appears in the lower half of the display:



- In some cases, there are tabs on the left side of the control window to select between categories of controls. In the case of the Vertical Setup menu, these tabs select which analog channel is being controlled.

- When a smaller control window is adequate, the graticule is enlarged and the mini control window appears at the bottom of the display:



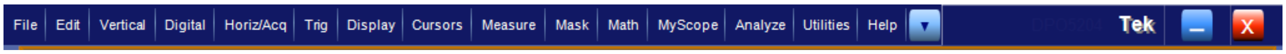
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Vertical **Menu** button or the **Vertical** button on the Toolbar.
- ❑ Press the **Chan 2** tab on the left side of the control window.
- ❑ Notice there are blue buttons, such as Display **Off**, which cause immediate action. Press the Display **Off** button twice to turn channel 2 on and off.
- ❑ There are also cyan buttons which launch another control window.
- ❑ Press the cyan Channel **Atten** button near the right side of the display and notice that the Vertical control menu is replaced with the Deskew/Attenuation menu.
- ❑ Notice the white arrows ("navigation buttons") at the right side of the control window. These arrows provide browser-style navigation back and forth between recently used control windows with one click.
- ❑ Press the left arrow to return to the Vertical control menu.
- ❑ Press the front panel **Menu Off** button or click the **X** in the upper right corner of the control window to close it and restore the full-screen waveform display.

MSO/DPO5000 Series Windows Menu User Interface

For many MSO/DPO5000 Series users, the Windows menu interface will be the most comfortable, especially if their lab environment supports the use of a mouse. These menus can be operated with the touch screen or a keyboard, but are optimized for use with a mouse. This section of the lab focuses on the use of the Windows menu, mouse, and keyboard to control the instrument.

As with most Windows applications, the menu bar at the top of the screen provides convenient access to the first-level menus, but also many second-level menu items. The Windows Menu bar is displayed at the top of the display by default. You can easily toggle between the Windows Menu bar and the Toolbar by pressing the down-arrow button at the right side of the Menu bar.

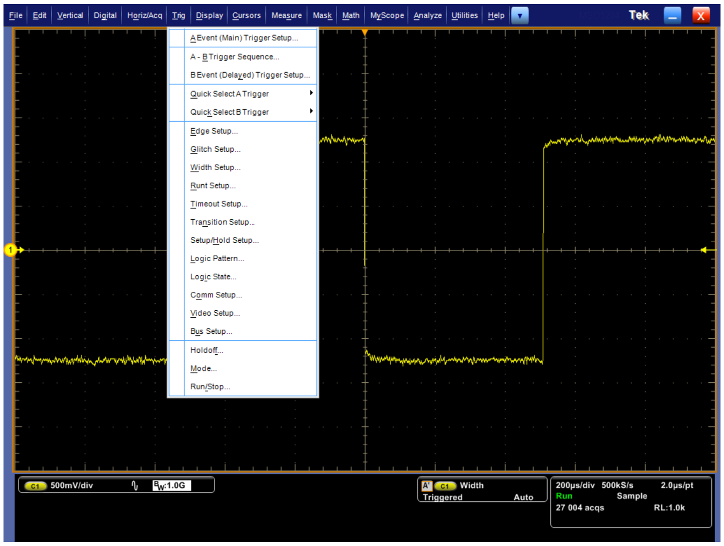


These controls are logically grouped by function, with familiar File and Edit menus on the left, instrument control menus in the middle, and Utilities and Help on the right.

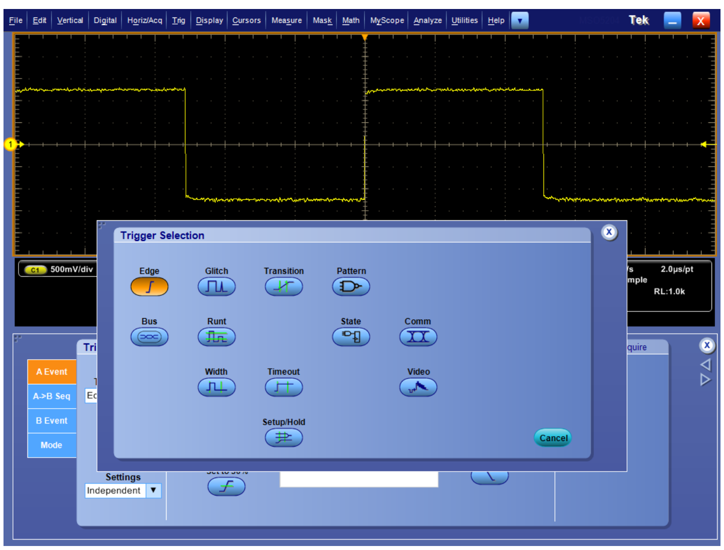
- **File** contains waveform and setup save and recall controls, printer setup, and Windows controls like Minimize, Shutdown, and Exit.
- **Edit** contains Autoset Undo, Clear, Select for Copy, and Copy commands.
- **Vertical** provides access to first-level menus such as Vertical Setup as well as second-level menus such as Bandwidth and Zoom control menus.
- **Digital** (MSO5000 Series only) provides access to Digital Channel and Bus Setup menus, as well as MagniVu acquisition mode.
- **Horiz/Acq** provides access to first-level menus such as Horizontal / Acquisition Setup as well as second-level menus such as Autoset and the FastFrame control menu.
- **Trig** provides access to the first-level Trigger Setup menu as well as second-level menus for each of the trigger modes.
- **Display** provides access to menus to control the waveform display parameters, the graticule, and the on-screen icons.
- **Cursors** provides access to the first-level Cursor Setup menu as well as second-level controls for Cursor Mode and Cursor Type.
- **Measure** provides access to the first-level Measurement Setup menu as well as the direct selection of automatic measurements and the Histogram Setup menu.
- **Mask** provides control of the pass/fail mask testing features via the first-level Mask Setup menu and second-level Pass/Fail and Mask Editing menus.
- **Math** provides access to the first-level Math Setup menu as well as the direct selection of the Predefined Functions and the Equation Editor menu.
- **MyScope** allows customization of the user interface. There is a later lab section devoted to this.
- **Analyze** provides menu access to the optional analysis applications which you are running on the oscilloscope.
- **Utilities** contains controls for configuring the instrument, user preferences, and option installation.
- **Help** provides access to standard Windows-style help files and the About TekScope status window.

Key Take Away Points

- The Trigger Setup menu looks like this:



- The Trigger control window and trigger type select window look like this:



- Sometimes the touchscreen provides the most convenient way to drive the oscilloscope. However, especially on a bench, a mouse might provide easier and more familiar control of a Windows-based oscilloscope.

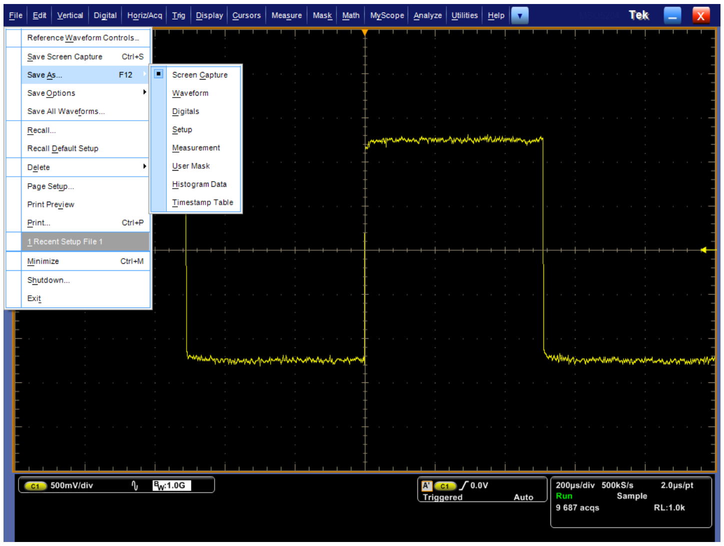
MSO/DPO5000 Series Procedure:

- ❑ Using the touch screen, touch the down-arrow button at the top of the display and touch **Show Menu** to select the Windows menu interface.
- ❑ You can use the touch screen to operate the oscilloscope from the Windows menu bar. It may be easiest to use a stylus or your fingernail to accurately select menu items.
- ❑ Touch the **Trig** menu to display the menu choices.
- ❑ Touch the **A Event (Main) Trigger Setup…** selection.
- ❑ Notice that there is a drop-down menu under Trigger Type. Touch the down arrow to display the list of choices.
- ❑ In the Trigger Type section, press the **Select** button and select **Edge**. When operating this control window with a touch screen, the Select button provides an easier-to-use interface.
- ❑ When you are done, touch the X in the upper right corner of each of the control windows to close them and restore the full-screen waveform display.

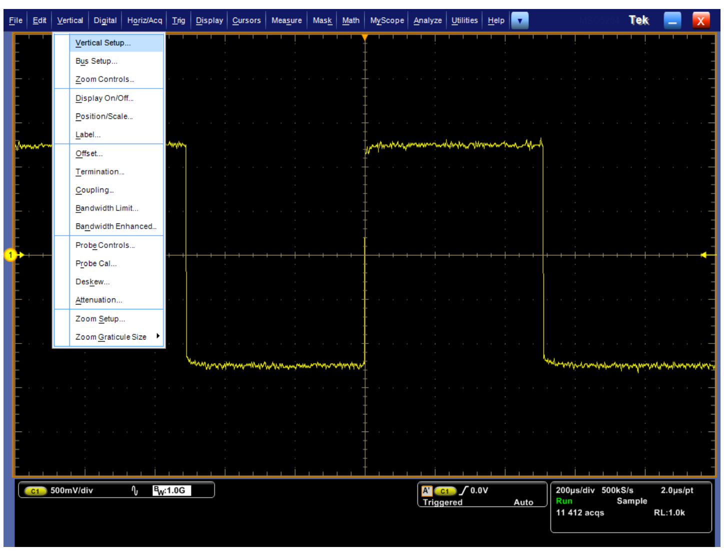
Key Take Away Points	**MSO/DPO5000 Series Procedure:**

Key Take Away Points

- The File menu looks like this:



- Notice that the File menu contains familiar Windows File menu controls, as well as some that are specific to handling files on a Windows oscilloscope.
- The Vertical menu looks like this, with all of the menu items specifically relating to the operation of the vertical section of an oscilloscope:



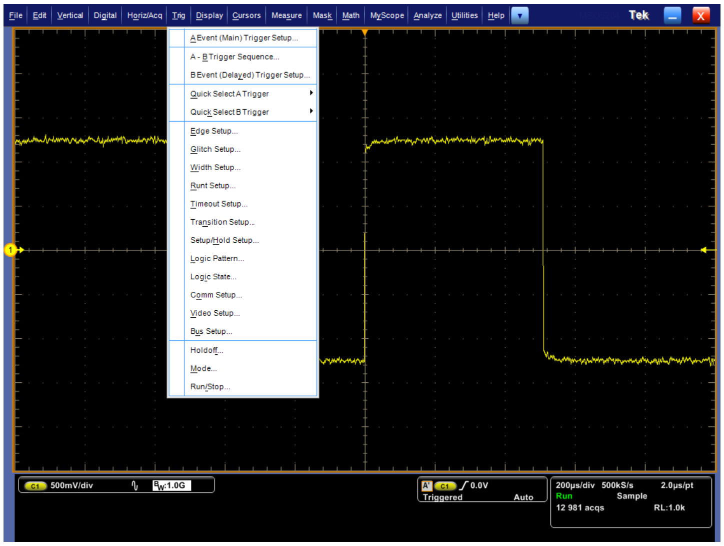
- Notice that the menu items are organized in groups, with the most commonly-used controls near the top of the list and the less-frequently-used controls near the bottom of the list.

MSO/DPO5000 Series Procedure:

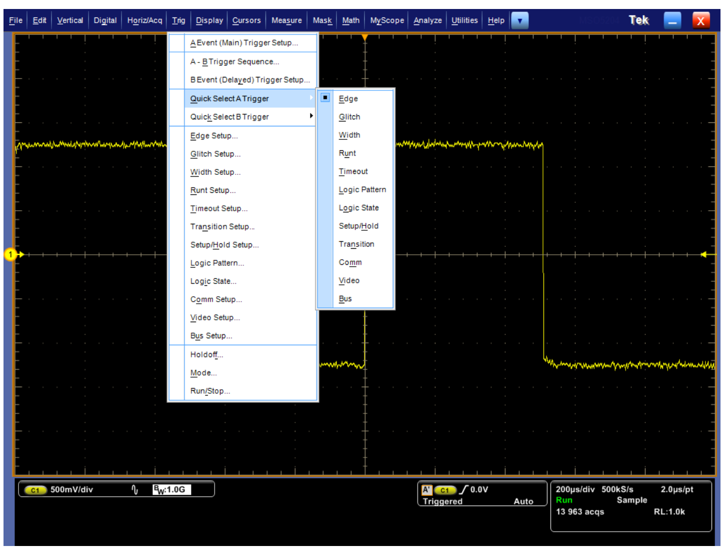
- ❑ Connect a USB mouse to one of the oscilloscope's USB host ports.
- ❑ Using the mouse, position the cursor over the File menu selection.
- ❑ Click the left mouse button once and then slowly move the mouse over the other menu selections to get a quick overview of the available features and their locations in the user interface.
- ❑ Left-click once on the **Vertical** menu to display the menu choices.
- ❑ Notice that the **Vertical Setup…** menu selection is at the top of the list. This selection displays the full Vertical Setup control window.
- ❑ Notice that most of the remaining menu items also end with an ellipsis (**…**) indicating that these selections will launch a control window.

Key Take Away Points

- The Trigger menu looks like this:



- The Trigger Quick Select menu interface allows quick selection of trigger type without launching a control window:

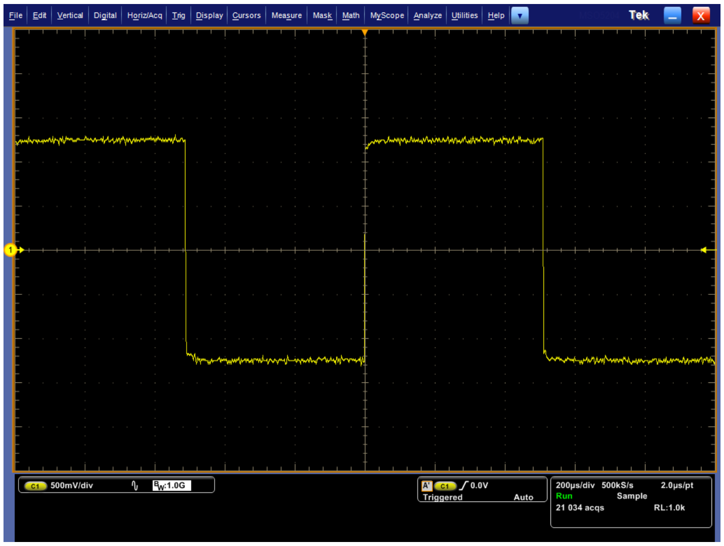


MSO/DPO5000 Series Procedure:

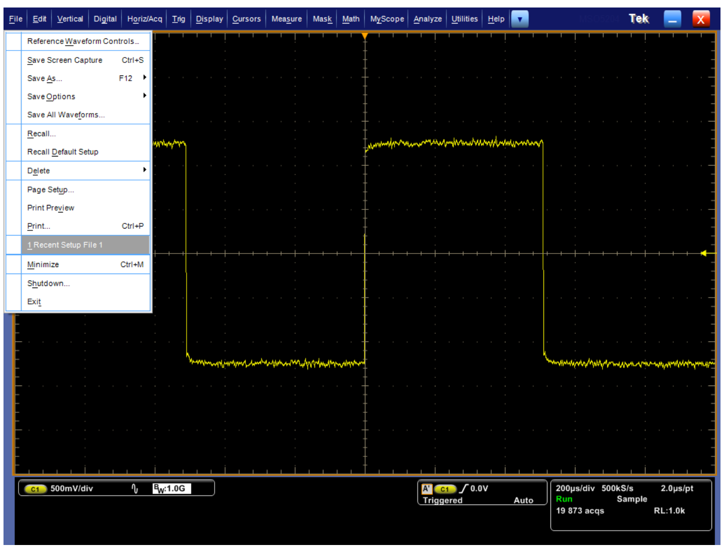
- ❑ Left-click once on the **Trig** menu to display the menu choices.
- ❑ Notice that the **A Event (Main) Trigger Setup…** menu selection is at the top of the list. This selection displays the full Trigger Setup control window, just like pressing the front panel Trigger **Menu** button.
- ❑ Click on the **B Event (Delayed) Trigger Setup…** menu selection. Notice that this launches the Trigger Setup control window, too, but also automatically selects the B Event tab.
- ❑ Click once on the **Trig** menu to display the menu choices again.
- ❑ Notice the **Quick Select A Trigger** selection has a right arrow next to it, indicating that it provides immediate action. Click on **Quick Select A Trigger** and select Edge trigger. Notice the trigger type changes immediately to Edge, without launching a control window.
- ❑ Click on **Quick Select A Trigger** and select Width trigger. Notice the trigger type changes immediately to Width, retaining the Pulse Width trigger setup from earlier in the lab.
- ❑ If you want a simple entrance into the Trigger Setup menu to control the Width trigger, click once on the **Trig** menu and click on **Width Setup….** This launches the Trigger Setup menu with the Width trigger type preselected.

Key Take Away Points

- The Windows menu bar keyboard shortcut interface looks like this:



- The File menu bar keyboard shortcut interface looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Connect a USB keyboard to one of the oscilloscope's USB Host ports. Keyboard shortcuts can be a very efficient user interface for some oscilloscope users.
- ❑ Press down on the **Alt** key on the keyboard. Notice that certain letters in the Windows menu bar are underlined, such as the 'F' in **File,** indicating a keyboard shortcut that can be used with the Alt key.
- ❑ Press the **F** keyboard key to display the File menu.
- ❑ Notice that some of the menu items have letters that are underlined and some have additional text to the right, such as **Print…   Ctrl+P**. This indicates that you can use the keyboard to select the Print menu by either pressing **Alt P** or **Ctrl P**.
- ❑ Also notice **Save As…   F12**, which indicates that the keyboard can launch the Save As menu by pressing **Alt A** or the **F12** function key. Where possible, the standard Windows function keys and keyboard shortcuts are used.
- ❑ And, as with other Windows applications, the **ESC** key closes the menu.

MSO/DPO5000 Series Mouse and Right-click User Interface

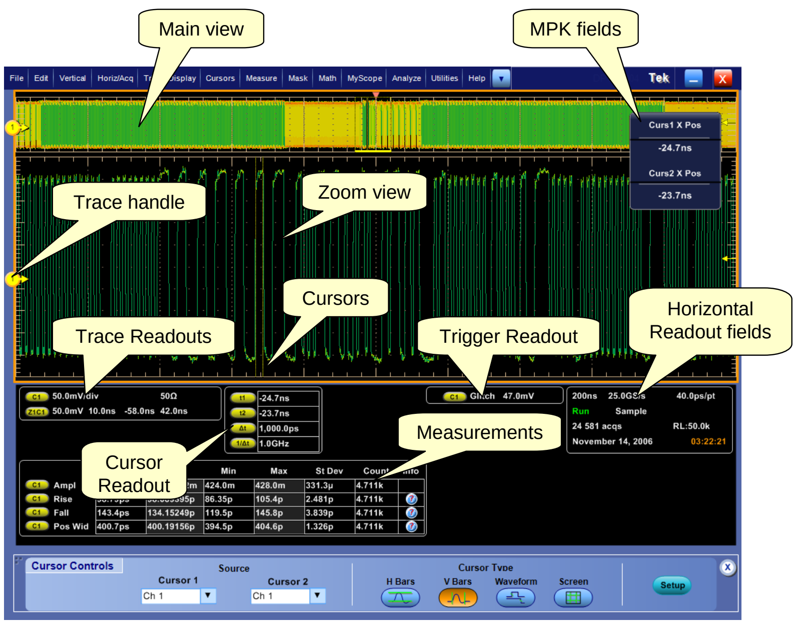
If you have a USB mouse connected to the MSO/DPO5000 series oscilloscope, there are many other control features available. This lab section will highlight the use of a mouse in four specific areas:

- Using a mouse to directly manipulate waveforms and icons on the display
- Using a mouse to graphically select portions of the waveforms for further analysis
- Using a mouse to easily adjust parameter values
- Using a mouse to directly access features without going through menus

You never have to take your hand off the mouse!

Key Take Away Points

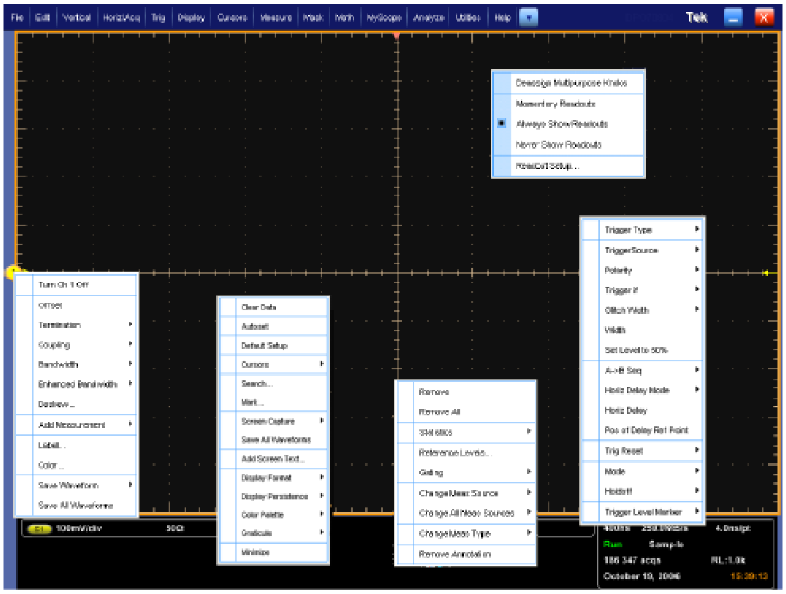
- There are many items on the display which can be manipulated with a mouse.



- Notice that each of these mouse actions also attaches the Multipurpose controls to the appropriate parameters.
- The mouse can also be used to invoke a context-sensitive shortcut menu by right-clicking anywhere in the graticule or on an object.

MSO/DPO5000 Series Procedure:

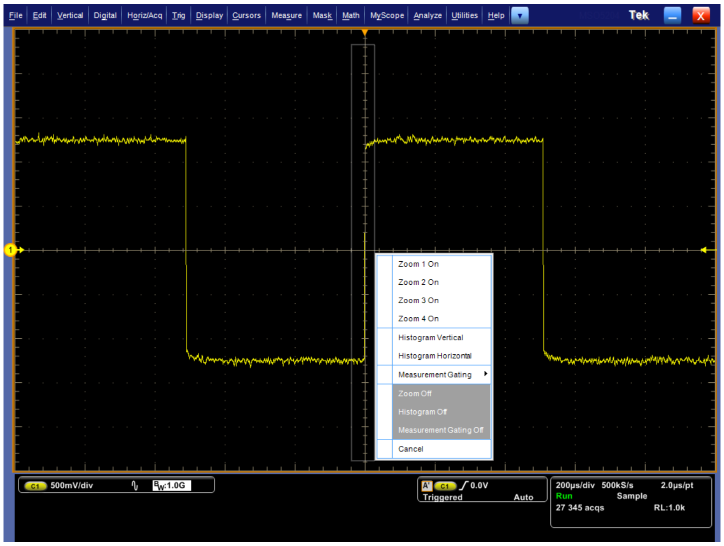
- ❑ You can use a mouse to directly manipulate waveforms and icons on the display:
  - ❑ Position the cursor on the yellow channel 1 ground reference icon at the left side of the display. Press down on the left-mouse button and move the mouse to adjust the vertical position of the selected waveform.
  - ❑ Position the cursor over the trigger level arrow at the right side of the screen. Press down on the left-mouse button and move the mouse to adjust the trigger level.
  - ❑ While the multipurpose control readout is visible, left-click on the text box. If your USB mouse has a wheel, you can use it to adjust the level, just like with the multipurpose controls. You can also click the mouse wheel to switch between fine and coarse increments, just like you can with the front panel Fine button.
  - ❑ Position the cursor over the orange trigger position indicator at the top of the screen. Press down on the left-mouse button and move the mouse to adjust the trigger horizontal position.

Key Take Away Points	MSO/DPO5000 Series Procedure:
• Right-click shortcut menus can also be displayed for the readouts on the display. Some examples are shown below:  1733-050	❑ You can also use right mouse clicks on these same icons to display relevant popup menus: ❑ Position the cursor on the yellow channel 1 ground reference icon. Right click to display the menu of waveform parameter adjustments. ❑ Position the cursor over the trigger level arrow. Right click to display the menu of trigger and graticule settings. ❑ Position the cursor elsewhere. Right click to show a menu of display controls. ❑ Click on **Autoset**. ❑ You can also use right mouse clicks on the display readouts to display a relevant set of controls: ❑ Right-click on the vertical readout in the lower left corner of the display and notice that many of the vertical menu items appear, along with other related functions such as adding a bus, adding a measurement, and saving the waveform. ❑ Similarly, right-click on the trigger readout at the bottom of the screen and notice the trigger menu functions. ❑ There are many different readouts in the lower right corner: ❑ Right-clicking on the horizontal scale readout displays the horizontal controls. ❑ Right-clicking on the Run/Stop status displays the run/stop menu items. ❑ Right-clicking on the acquisition mode displays the choices for acquisition mode.

Tektronix

Key Take Away Points

- The zoom box popup menu display should look about like this:



- The zoom display should look about like this:

MSO/DPO5000 Series Procedure:

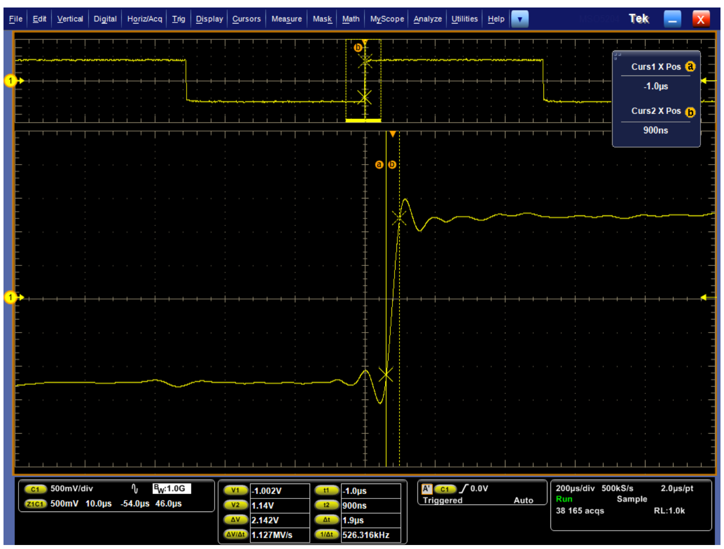
- ❑ You can also use a mouse to select portions of waveforms for analysis:
  - ❑ To view a portion of the signal, press the left mouse button and drag the mouse to draw a box on the display. When you let go of the mouse button, a menu of available actions is displayed. Use the mouse to select **Zoom 1 On**.
  - ❑ Similarly, you can set up vertical or horizontal waveform histogram displays.
  - ❑ Notice the thick bar at the bottom of the zoom area. Press the left mouse button and drag the bar to move the zoom window.

Tektronix

Key Take Away Points

- The dual zoom display should look about like this:

- The cursor display should look about like this:



MSO/DPO5000 Series Procedure:

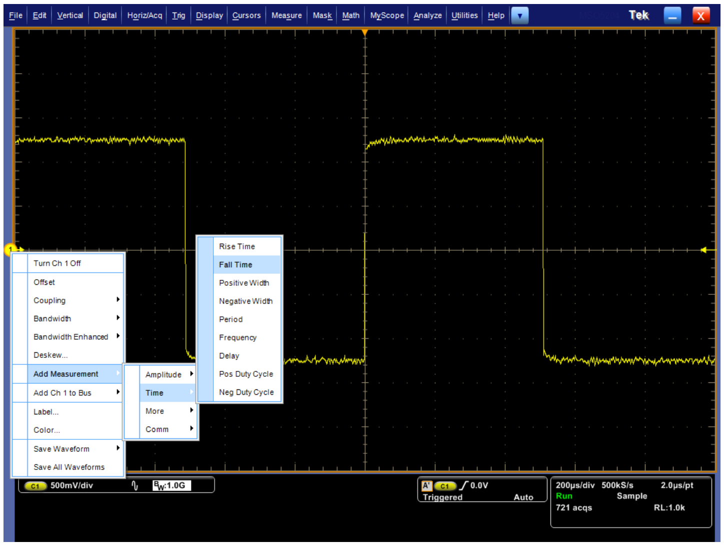
- ❑ To view another portion of the signal, either in the main window or the zoom window, press the left mouse button and drag the mouse to draw a box on the display. When you let go of the mouse button, a menu of available actions is displayed. Use the mouse to select **Zoom 2 On**.
- ❑ Right click on the Zoom 2 waveform and select **Zoom 2 Off**.
- ❑ Right-click in the main graticule, select **Cursors**, and select **Waveform**.
- ❑ Position the Windows cursor over the waveform cursor bars, press down on the left-mouse button, and move the waveform cursors as desired.
- ❑ Right-click on the cursor readouts or a cursor to get a shortcut menu of cursor controls.
- ❑ Position the Windows cursor over a point of interest on the waveform, right-click, and select **Move Cursor 1 Here**.

❑ When you are done with zoom, right-click somewhere in the graticule and select **Zoom Off** and **Cursors Off**.

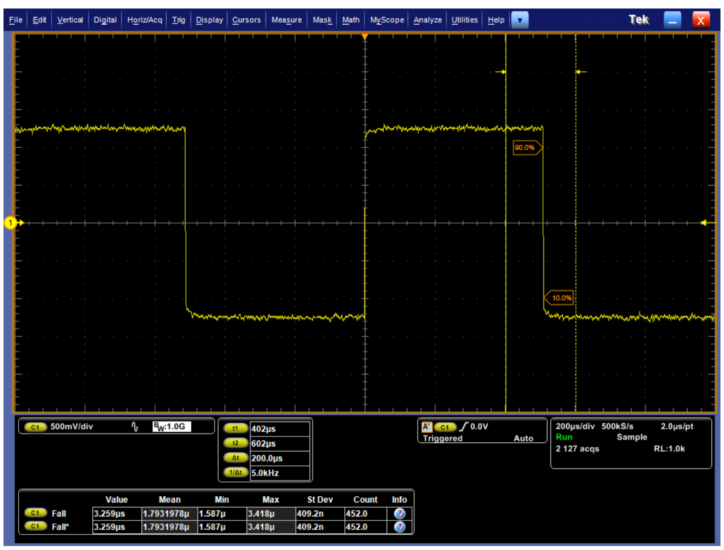
Tektronix

Key Take Away Points

- The fall time measurement display should look about like this:



- With cursor gating, the fall time measurement looks like this:



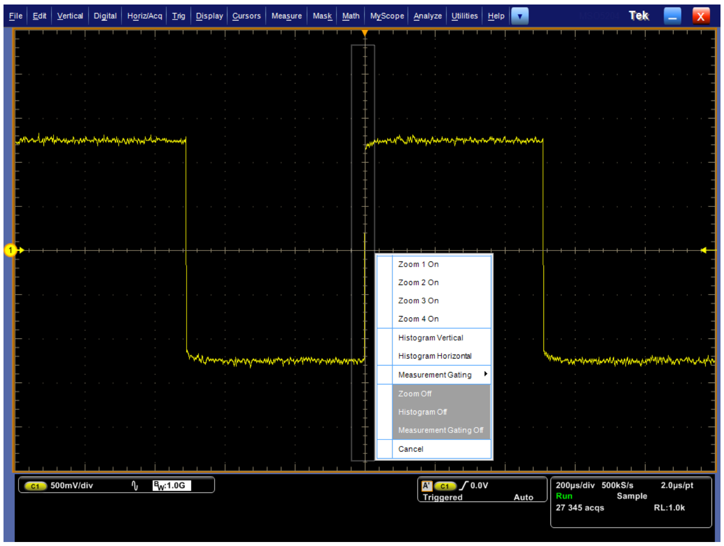
MSO/DPO5000 Series Procedure:

- ❑ Right-click on the channel 1 ground reference icon.
- ❑ Slide the mouse across **Add Measurement** and **Time**, and right-click on **Fall Time**.
- ❑ Notice that the fall time measurement is made on the first falling edge on the waveform.
- ❑ Left-click and drag to draw a box near another falling edge.
- ❑ Select **Measurement Gating** and **Cursor**.
- ❑ Notice that the fall time measurement is now made on the selected edge on the waveform.
- ❑ Left-click and drag the cursors to select a different waveform edge to measure.
- ❑ Right-click on one of the cursors and select **Cursors Off**.
- ❑ Right-click on the **Fall** label in the measurement readout.
- ❑ Select **Remove** or **Remove All** to remove the measurement.

MSO/DPO5000 Series Multiview Zoom User Interface

Key Take Away Points

- When Multiview Zoom™ is turned on, an overview of the entire waveform is show at the top of the display, and the graphically zoomed area (indicated by the yellow box in the overview area) is shown in the lower part of the display, about like this:



- Multiview Zoom allows you to zoom on the zoomed waveform to provide a more detailed display of a small portion of the waveform, such as the rising edge (shown in yellow). But Multiview Zoom allows you to simultaneously zoom on multiple regions, so you can also view a falling edge (shown in green), like this:

MSO/DPO5000 Series Procedure:

- ❑ With the mouse or the touchscreen, draw a rectangle, from the upper left to lower right corner, around a portion of the waveform and select **Zoom 1 On**.
- ❑ Notice that the front panel Multiview Zoom button is now lit.
- ❑ Draw a rectangle on the zoomed waveform, from the upper left to lower right corner, around a portion of the zoomed waveform.
- ❑ Select **Zoom 1 -> Resize**.
- ❑ Now, draw a rectangle on a different part of the overview waveform at the top of the display.
- ❑ Select **Zoom 2 On**.
- ❑ When you are done, right click somewhere in the graticule area and select **Zoom 2 Off**.

Key Take Away Points

- If you want to move the zoom window, you can draw a new zoom window, or you can move the current zoom window with the Multipurpose controls or the mouse.

- Notice that the MSO/DPO5000 Series provides both vertical and horizontal zoom. The MSO/DPO4000/3000/2000 Series provides only horizontal zoom.
- You can also have Multiview Zoom automatically scroll through the acquired waveform using the scroll controls, like this:

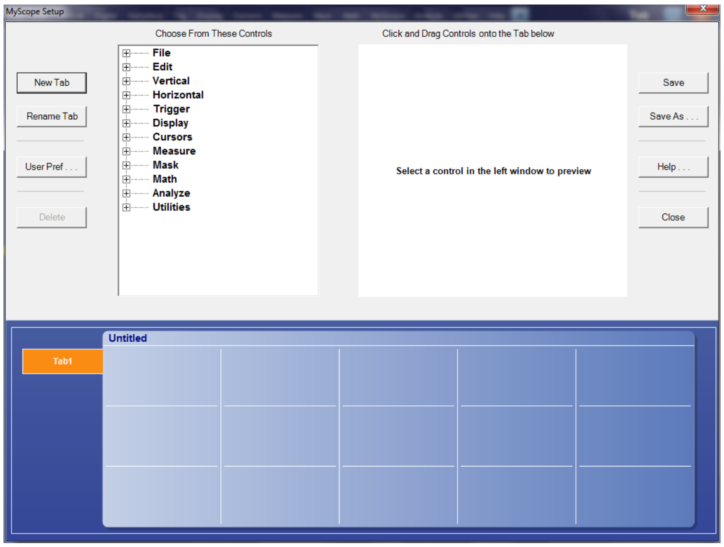
MSO/DPO5000 Series Procedure:

- ❑ Select **Vertical -> Zoom Setup**.
- ❑ Press the **Controls** button to minimize the size of the control window.
- ❑ Press the **Zoom** tab at the left side of the control window.
- ❑ You can use the **Assign Knobs** buttons to assign the Multipurpose controls to either horizontal or vertical zoom position and zoom factor.
- ❑ Adjust the zoom view using the Multipurpose controls.
- ❑ You can also drag the thick line at the bottom of the zoom box with the mouse to horizontally position the zoom window.
- ❑ Press the **Scroll** tab at the left side of the control window.
- ❑ You can use these controls to automatically pan through the acquired waveform.
- ❑ Click on the **Scroll Speed** text box to attach the Multipurpose **a** control.
- ❑ Using the Multipurpose **a** control, set the **Scroll Speed** to **10**.
- ❑ Press the right arrow (Play) button.
- ❑ When you are done, press the magnifying glass button to turn off Multiview Zoom.

MSO/DPO5000 Series MyScope User Interface
Like the end products they're being used to validate, oscilloscopes are constantly expanding, not only in terms of performance capabilities (bandwidth, sample rate, record length, waveform capture rate, etc.), but also in the continual addition of new features and analysis packages. All of this capability, while certainly powerful and useful, can be intimidating to novice users as well as to intermittent users, who generally use only a fraction of an oscilloscope's capabilities. Even experienced power users, who navigate through the same layers of menus to perform similar tasks hundreds of times each day, undoubtedly find the extra steps for each process irritating and a huge waste of time. When using an oscilloscope, have you ever been frustrated because ... • You can't find the feature that you really need, even though you know it's there? • You know where the feature is, but it's buried three or four menu layers deep? • The feature you want is hidden amongst a menu full of other features you don't care about? • You spend as much time navigating menus as you do doing real work? If you answered "yes" to one or more of these questions, then MyScope control windows will make you more efficient with the oscilloscope and more effective at your job. This feature allows you to quickly and easily build your own control windows that contain only the controls, features, and capabilities you care about and are important in your job.

Key Take Away Points

- MyScope allows you to quickly and easily build a custom control window that contains only the features and functions of the oscilloscope which are important to you. Once you have created the control window, you will be more efficient using the oscilloscope because you do not have to search for features or bounce back and forth between numerous menus and control windows while performing your usual tasks.
- The MyScope display should look about like this:



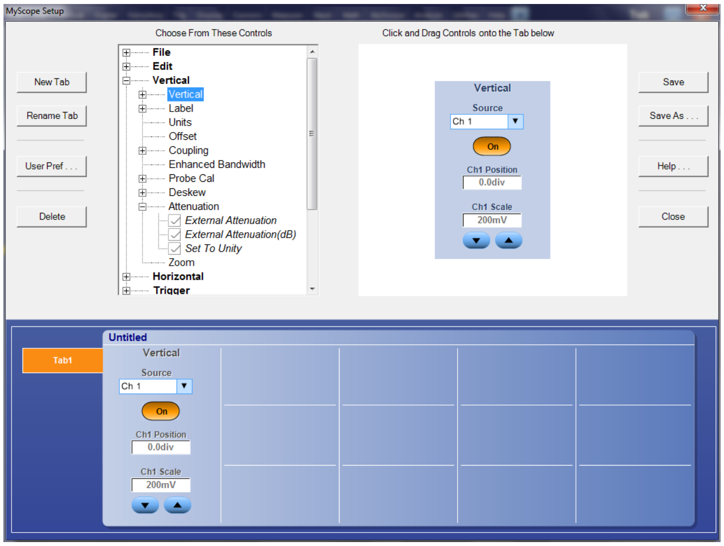
- The control tree includes all of the controls available for use when building your MyScope control window. The first-level items listed in bold font are merely categories, not controls. When you click on the "+" symbol next to one of the categories, you see the list pop open to show the controls available in that category. The tree is organized in the same fashion as the menus in the regular UI to make it easy to find the feature you're looking for. For example, all the controls that you normally find in the Vertical menu are included in the Vertical category.
- When you select a control in the tree on the left, the control is previewed in window on the right. This allows you to see what the control looks like, how many grid locations it requires, and what components are included in it.
- Many controls can be further customized by clicking the "+" symbol next to the control name and then checking and unchecking individual components. As you check and uncheck items, the previewed control changes size based on the number of components included.

MSO/DPO5000 Series Procedure:

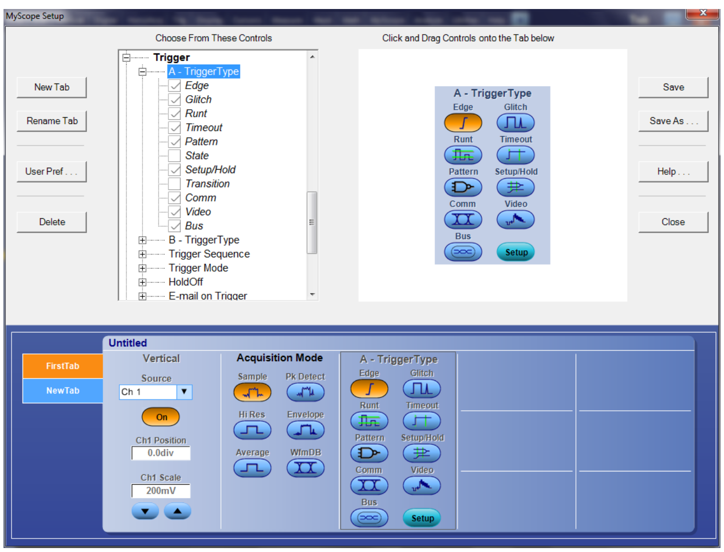
- ❑ Click on **MyScope** in the Windows menu bar.
- ❑ Select **New Control Window….**
- ❑ Click on the "**+**" symbol next to the **Vertical** category.
- ❑ Click on the "**+**" symbol next to the **Attenuation** control.
- ❑ Notice the size of the control in the preview window.
- ❑ Uncheck the **Set To Unity** control. Notice that the Set To Unity button disappears and the size of the control is decreased.
- ❑ Check the **Set To Unity** control. Notice that the Set To Unity button reappears and the size of the control is increased.

Key Take Away Points

- The lower half of the setup screen represents your MyScope control window layout. It is the same size and shape as the standard control windows used throughout the instrument.



- The layout area is divided up into a three-row by five-column grid. Once you have selected a control and configured it the way you want it in the preview window, simply click and drag the previewed control to the desired location in the layout area:



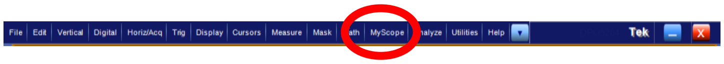
- When you fill up a tab, just click the "New Tab" button to add another tab to your MyScope control window to place additional controls. Up to eight tabs with user defined names can be used in a custom control window.

MSO/DPO5000 Series Procedure:

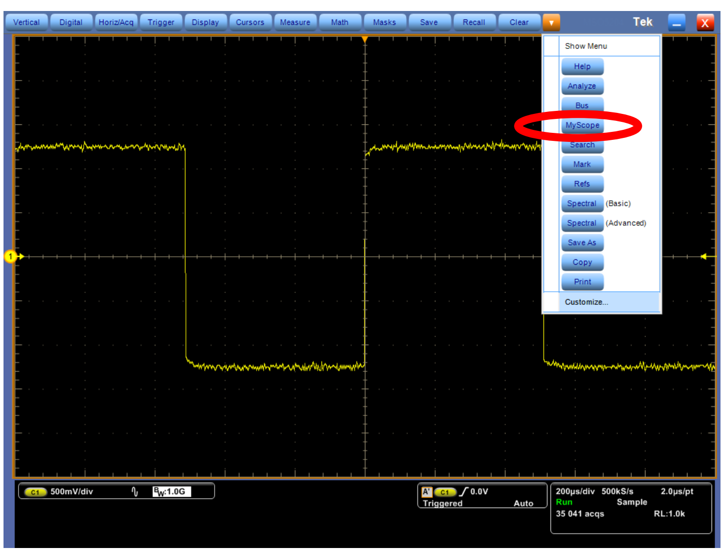
- ❑ Click on the **Vertical** control in the Vertical category in the control tree. Click on the **Vertical** control in the preview window and drag it down to the first column in the control window at the bottom of the display.
- ❑ If you make a mistake, simply drag the control back out of the control window to remove it.
- ❑ Click on the "**+**" symbol next to the **Horizontal** category.
- ❑ Click on the **Acquisition Mode** control in the control tree, click on the **Acquisition Mode** control in the preview window, and drag it down to the second column in the control window at the bottom of the display.
- ❑ Click on the "**+**" symbol next to the **Trigger** category.
- ❑ Click on the "**+**" symbol next to the **A - Trigger Type** control. Check several of the trigger types to add them to the control.
- ❑ Click on the **Trigger** control and drag it down to the control window at the bottom of the display**.**
- ❑ Click the **Rename Tab** button.
- ❑ Notice the tab's text box is highlighted. Type in a name for the tab.
- ❑ Click the **New Tab** button to create a new tab.
- ❑ When you are done, press the **Save As…** button, type in a file name, and press the **Save** button.

Key Take Away Points

- If you are using your oscilloscope in a shared environment, you can also specify your user preferences with your MyScope control window. When you load your MyScope control window, your user preferences are automatically restored.
- One of the most powerful features of MyScope control windows is that you and your co-workers can create as many custom control windows as you like. MyScope windows are stored as files on the oscilloscope's hard drive, making it simple to transfer your custom control windows to other oscilloscopes in your lab, or even to your co-workers around the world, by simply emailing the .TCW file.
- Once you have created and saved a MyScope control window, you can easily launch it from either the Windows menu bar or from the Toolbar. From the menu bar, the MyScope interface looks like this:



- The MyScope interface in the Toolbar looks like this:



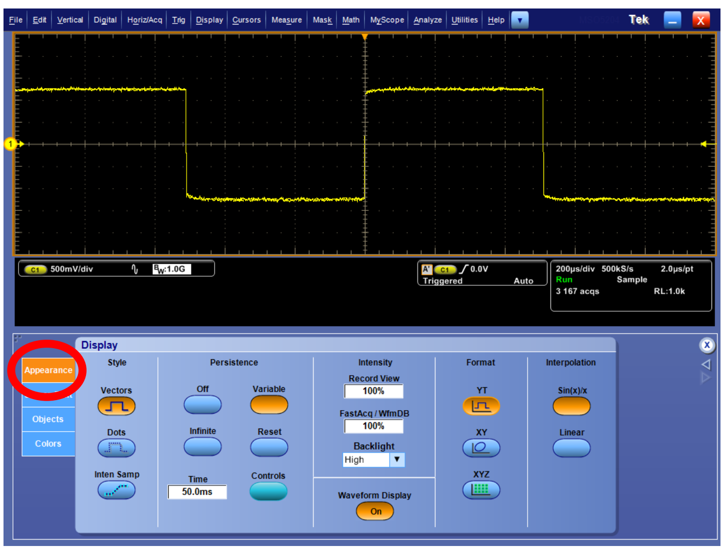
MSO/DPO5000 Series Procedure:

- ❑ Press the **User Pref…** button to display the user preference selections.
- ❑ When you are done looking at this window, press the **Cancel** button.
- ❑ Press the **Close** button to close the MyScope Setup window.
- ❑ Click on **MyScope** in the Windows menu bar.
- ❑ Select **Current…** to display the most recent MyScope control window, or you can select **Open Control Window…** to select a file through the Windows File Open dialog.
- ❑ Click the **X** in the upper right corner of the MyScope control window to close it.
- ❑ Press the down-arrow button at the top of the display and press **Show Buttons** to select the Toolbar interface.
- ❑ Press the **MyScope** toolbar button to display the most recent MyScope control window.

MSO/DPO5000 Series User Preferences

Key Take Away Points

- The use of Windows in the MSO/DPO5000 Series user interface allows much more flexibility than can be supported by other oscilloscopes such as the MSO/DPO4000/3000/2000 Series. Although the MSO/DPO5000 gains user interface familiarity because of the Windows menu system, there are some familiar user interface elements which may not be visible, either by default or by the preferences of the previous user of the oscilloscope.
- This section of the lab highlights a few of the common elements of the MSO/DPO4000/3000/2000 Series user interface which may be missing from the display and explains how to restore them.
- As with many Windows controls, there are multiple ways to change these settings. For this lab, we will focus on the control windows as the control mechanisms.
- The Display Setup control window looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Select **Display -> Display Setup….**
- ❑ Press the **Appearance** tab at the left side of the control window.
- ❑ Press the **Variable** Persistence button and set the Persistence **Time** to about **50 ms** to mimic the MSO/DPO series default display persistence.
- ❑ Make sure **Vectors** Style and **Sin(x)/x** Interpolation are selected.
- ❑ Press the **Objects** tab at the left side of the control window.
- ❑ Press the **Short** Trigger Level Marker and **Trigger 'T'** buttons to mimic the MSO/DPO series display icons. Note that the Trigger T is locked to the trigger source waveform instead of appearing as an orange icon at the top of the display.
- ❑ Press the **Colors** tab at the left side of the control window.
- ❑ Press the **Normal** Record View Palette and **Normal** FastAcq/WfmDB Palette buttons to mimic the colored, intensity-graded MSO/DPO series displays.
- ❑ Select **Horiz/Acq -> Zoom Graticule Size -> 80/20%** to mimic the MSO/DPO zoom display.
- ❑ Press the front panel Trigger **Menu** button.
- ❑ Notice the **Settings** text box in the lower left corner of the control window. When this control is set to **Shared**, the thresholds for the analog channels are tied together. If you want to want to have independent thresholds for the analog channels used for bus inputs, select **Independent**.

Key Take Away Points

- The User Preferences control window looks like this:

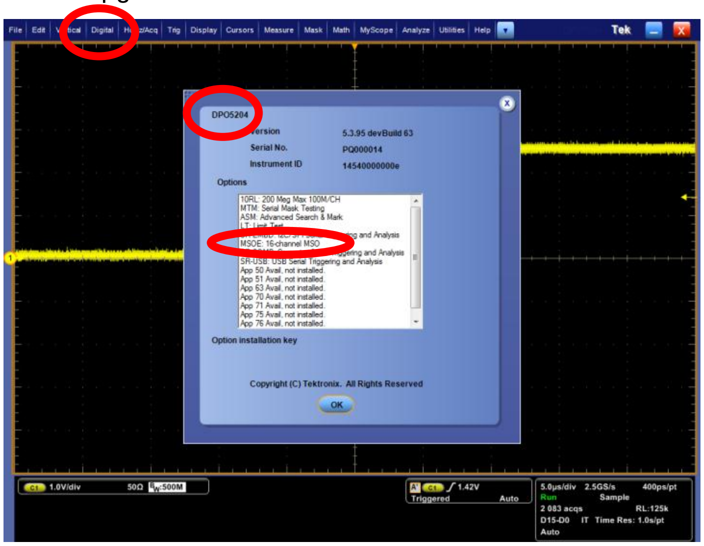
MSO/DPO5000 Series Procedure:

- ❑ Select **Utilities -> User Pref…** to display the user preference control window.
- ❑ Press the **Prompts** tab at the left side of the control window.
- ❑ Make sure that the **Autoset** and **Default/Recall Setup** buttons are set to **Off** to match the MSO/DPO series behavior.
- ❑ Make sure that the **Overwrite/Delete Setup** button is set to **On** to match the MSO/DPO series behavior. You may or may not want to set **Autoset Undo** to **On**, as it will always pop up a notifier.
- ❑ Press the **Readouts** tab at the left side of the control window.
- ❑ Press the **Always Visible** MPK Readout Visibility button.
- ❑ Set **Highlight Readout Changes** to **Off**.
- ❑ Press the **Measurement** tab at the left side of the control window.
- ❑ Press the **Standard** Annotation Type button.
- ❑ Press the **Units** tab at the left side of the control window.
- ❑ Press the **1-2-5** Vertical Scale Knobs button.
- ❑ Press the **Front Panel Buttons** tab at the left side of the control window.
- ❑ Check the **Front Panel Print Button Saves to File** selection to mimic the operation of the MSO/DPO Save button.
- ❑ Select **Factory** in the Default Setup Button drop-down box.
- ❑ Click the **X** in the upper right corner of the control window to close it.

MSO/DPO5000 Series MSO Option

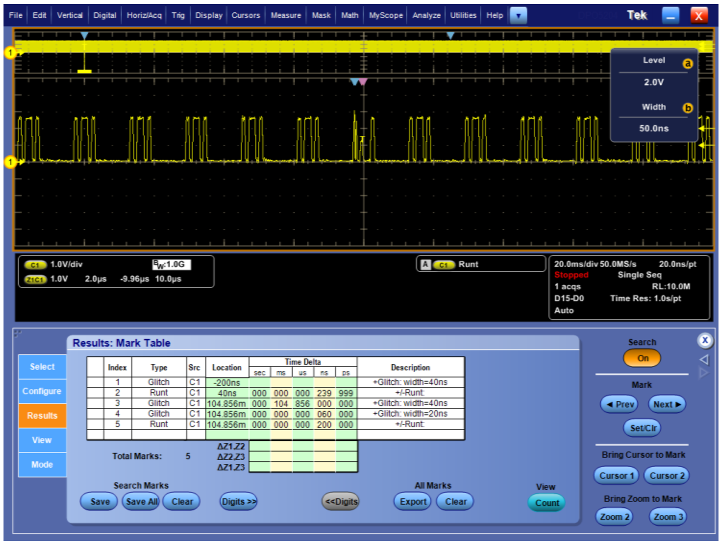
Key Take Away Points

- The 16-channel digital input capability of the MSO/DPO5000 Series is enabled by both hardware and software. This capability is standard with all of the MSO5000 Series products. This same digital input capability is available as an upgrade for the DPO5000 Series. The result is very similar, but not quite identical to an MSO5000.
- A standard DPO5xxx has the following characteristics:
    - "DPO5xxx Digital Phosphor Oscilloscope" front panel label.
    - Help->About_TekScope indicates that the instrument is a "DPO5xxx" and that the MSOE option is not installed.
    - There is no "Digital" menu in the Windows menu.
    - A plastic plug is in the front panel connector.
- An MSO5xxx has the following characteristics:
    - "MSO5xxx Mixed Signal Oscilloscope" front panel label.
    - Help->About_TekScope indicates that the instrument is an "MSO5xxx" and that the MSOE option is installed.
    - There is a "Digital" menu in the Windows menu.
- When a DPO5xxx is upgraded with option MSOE, the front panel label and the instrument name in the Help->About_TekScope will still indicate that the instrument is a "DPO5xxx", but the upgrade comes with a rear-panel label indicating that the option has been installed. There will be a "Digital" menu in the Windows menu, and the MSOE option will appear in the installed options list. And, of course, the upgrade includes the P6616 probe and accessory box.
- An upgraded DPO5xxx looks like:



MSO/DPO5000 Series Procedure:

- ❑ Select **Help -> About TekScope….**



Equipment List
One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
One TPP0500 or TPP1000 passive probe
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this lab were made with the DPO Demo 3 board]

Discover, Capture, and Search

As digital designs become more complex, engineers need tools to help find and diagnose problems quickly. Oscilloscopes are used in the design and debug process to discover problems quickly, capture events of interest, search for and gain insight into those events of interest, and then analyze the circuit behavior and solve the problem. This lab focuses on the first three of the four distinct steps of Discover, Capture, Search, and Analyze.

Discover

To solve a problem, you must first be able to find and visualize the problem. The first step to visualizing signals is accurately getting those signals into the instrument. To do this, you need to use the right probes to maintain high signal fidelity and minimize any loading effects on the circuit.

Then you need a lively display of the signals so you can visualize how the signals are changing over time. Because an oscilloscope displays “snapshots” of the signals, you need an oscilloscope with a fast waveform capture rate. The result is the ability to see glitches or other infrequently occurring transients within seconds, revealing the true nature of faults.

Seeing the problem is only half of the solution. You also need to understand how frequently the signal anomaly is occurring relative to the normal signals. This is where a DPO (Digital Phosphor Oscilloscope) with an intensity-graded display of waveforms shows a “history” of a signal’s activity by intensifying areas of the signal that occur more frequently. This provides a visual display of just how often anomalies are occurring relative to other signals.

Capture

Once you have an event of interest, you want to capture that event in memory and better understand the underlying causes of the event. Oscilloscopes use specialized triggers to narrow your focus to the events of interest by capturing specific digital events such as runts, glitches, pulse widths, setup and hold violations, and serial and parallel patterns.

You will often want to view signals before and after the trigger event so you can understand the context around the event of interest or to capture many events of interest for further analysis. Or you may want to acquire only a few events of interest but retain enough sample point resolution to be able to zoom in on fine signal details. In either case, you will often want to use long record lengths to capture long time periods with high timing resolution. Record length, one of the key specifications of an oscilloscope, is the number of samples it can digitize and store in a single acquisition. The longer the record length, the longer the time window you can capture with high resolution (high sample rate).

In complex designs, you may need to capture several analog, serial, and parallel digital signals to understand the circuit conditions that are causing the trigger event. Mixed Signal Oscilloscopes (MSOs) are ideally suited to these applications. MSOs have unique capabilities for capturing digital signals, including Threshold controls which allow you to specify what voltage represents a digital ‘1’ and which represents a digital ‘0’. Some MSOs can automatically detect multiple transitions on digital edges.

Search

Finding one specific event in a long waveform record can be challenging. The MSO/DPO5000 oscilloscopes shows 1000 points of waveform data at one time on its display. An optional 200 million point record length represents 200,000 screens worth of data! Waveform navigation and search tools, such as Wave Inspector® on the MSO/DPO Series, simplify finding an event of interest. Wave Inspector offers dedicated front panel controls for panning and zooming of records for manual navigation and inspection of long data records. You can add your own marks to any location you want to reference later for further investigation. In addition, the automated search will search through millions of acquired data points looking for your specified event, including analog, digital, and serial bus data. Along the way it will automatically mark every occurrence of the event of interest so you can quickly move between matching events.

Analyze

Once you have discovered, captured, and located events of interest, you need to analyze the signals. Subsequent labs will demonstrate a variety of analysis techniques, including cursor measurements, automated measurements, waveform histograms, limit testing, and waveform math for analyzing signals.

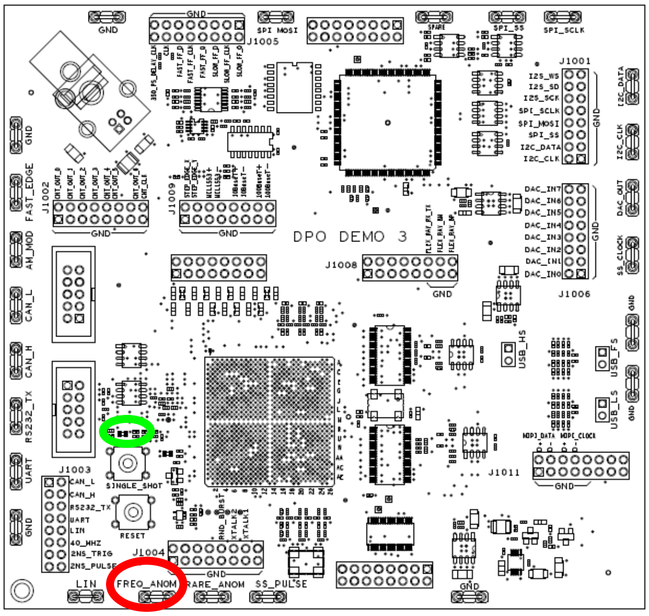
Objectives

- Obtain a basic understanding of the discovery and capture process.
- Learn how to quickly discover anomalies on digital signals.
- Learn how to easily capture those anomalies once you discover them.

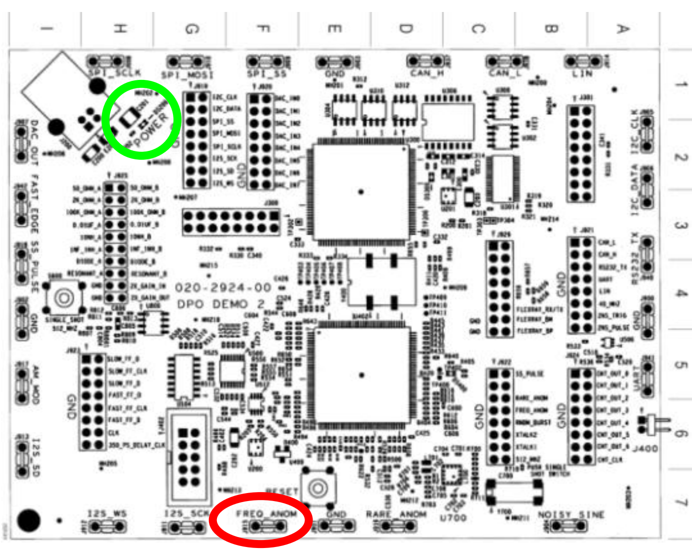
MSO/DPO5000 Series Lab Setup

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a signal with random anomalies which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a signal with random anomalies which we can use for this lab:



DPO Demo Board Procedure:

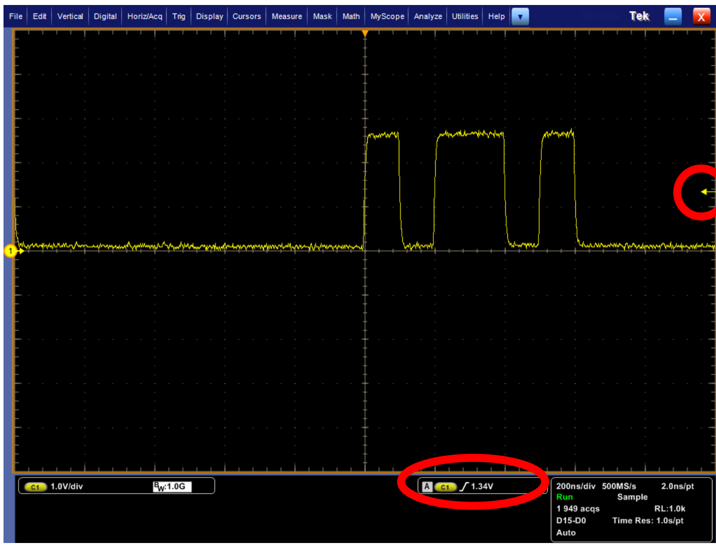
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **FREQ_ANOM** test point.

Tektronix

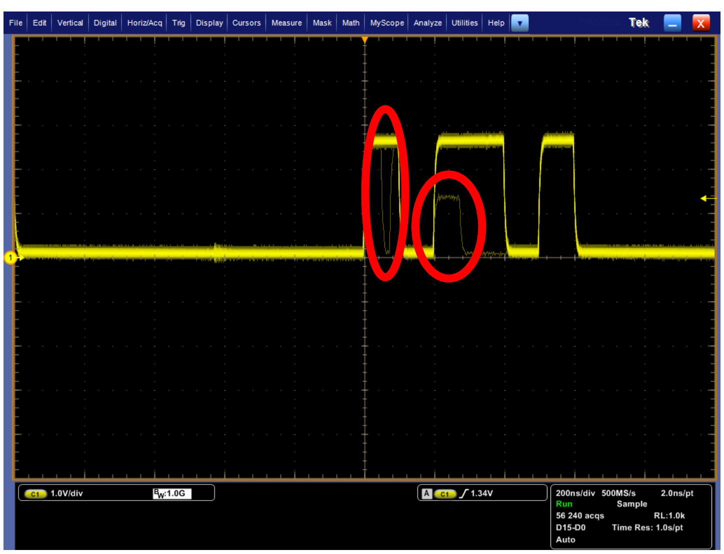
Discovering Intermittent Errors

Key Take Away Points

- By default, the oscilloscope is set to capture the signal whenever the signal rises above the trigger level (shown with the arrow along the right side of the display). The numerical trigger level value is also shown in the readout in the lower right corner of the display.
- The display should look about like this:



- Although this digital signal usually has “low” (about 0 Volts) or “high” (≥3 Volts) rectangular pulses, you will occasionally see narrow (<100 ns wide) pulses (“glitches”) and low-amplitude pulses (“runt pulses”) on the display. To accumulate all of these anomalies for easier viewing, turn on infinite persistence. The resulting display should look about like this:

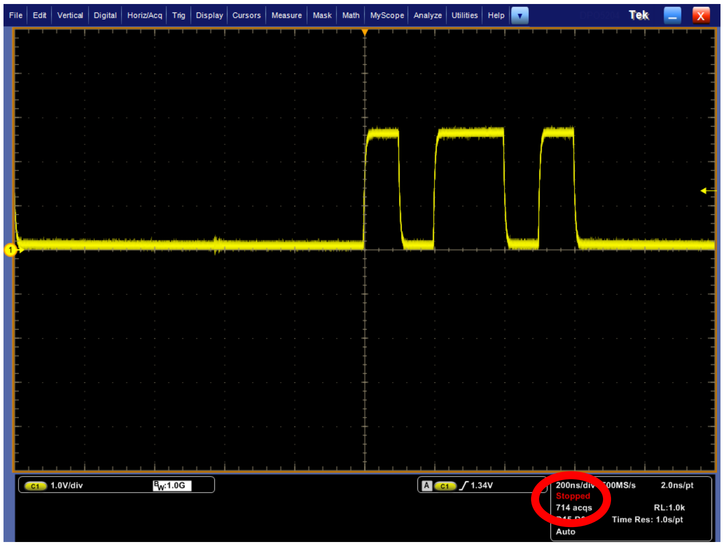


MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button to automatically set up the oscilloscope to get a stable display.
- ❑ Press the front panel **Intensity** button.
- ❑ Turn the Multipurpose **a** control fully clockwise to set the **Waveform Intensity** to **100%**.
- ❑ Press the front panel **Intensity** button.
- ❑ Click on the **Trig** menu, select **Holdoff…**, and press the **Auto** button in the control window at the bottom of the display.
- ❑ Press the **Menu Off** button.
- ❑ Click on the **Display** menu, select **Display Persistence**, and select **Infinite Persistence**.
- ❑ Infinite Persistence displays all captured waveforms on the display, preventing them from flashing on the display and then disappearing.
- ❑ However, you may need to wait quite a while to get the rich display shown at the left. When you get tired of waiting, move on to the next page.

Key Take Away Points

- Notice the acquisition counter in the readout in the lower right corner of the display. Watch the counter for ten seconds. In normal acquisition mode, you will see about 60-70 acquisitions per second.
- The display should look about like this:



- Even when you have infinite persistence enabled, it may take a very long time to capture infrequent anomalies.
- FastAcq provides very high waveform capture rate, often over 250,000 waveforms per second. Notice that we are seeing a similar waveform capture rate with this signal.
- The resulting FastAcq display should look about like this:

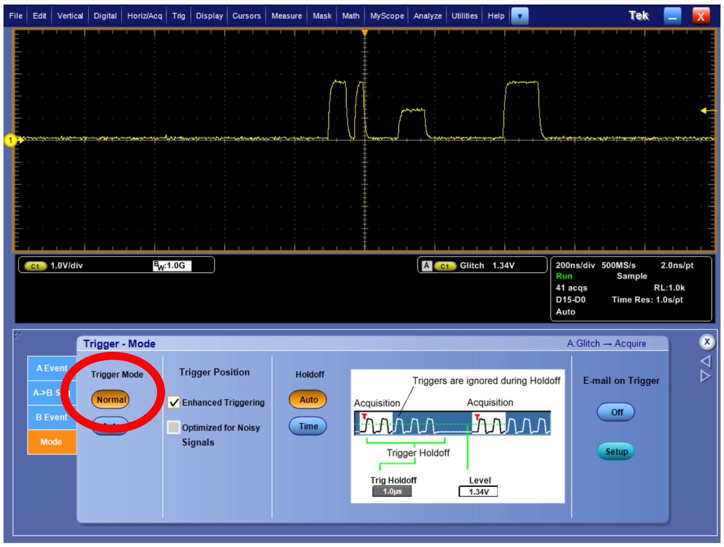
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Run/Stop** button.
- ❑ Press the front panel **Clear** button to clear the acquisition counter.
- ❑ Press the front panel **Run/Stop** button to start acquisitions.
- ❑ Wait for 10 seconds and press the front panel **Run/Stop** button.
- ❑ Divide the contents of the acquisition counter by ten to estimate the waveform capture rate of the oscilloscope with FastAcq Off.
- ❑ Press the front panel **FastAcq** button to turn on FastAcq.
- ❑ Press the front panel **Run/Stop** button to start acquisitions.
- ❑ Press the front panel **Clear** button to clear the acquisition counter.
- ❑ Wait for 10 seconds and press the front panel **Run/Stop** button.
- ❑ Divide the contents of the acquisition counter by ten to estimate the waveform capture rate of the oscilloscope with FastAcq On.
- ❑ When you are done, press the front panel **FastAcq** button to turn off FastAcq.
- ❑ Click on the **Display** menu, select **Display Persistence**, and select **No Persistence**.
- ❑ Press the front panel **Run/Stop** button to start acquisitions.

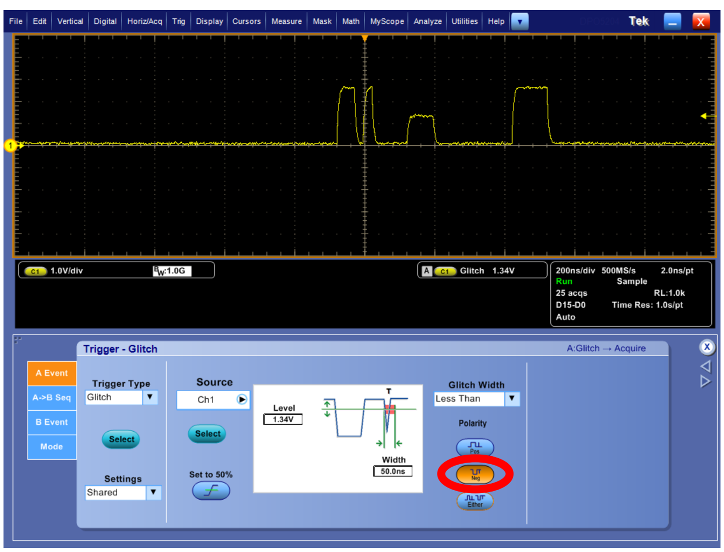
Capturing Intermittent Errors

Key Take Away Points

- One of the anomalies that clearly appears in the display is a narrow pulse or “glitch”.
- To capture a glitch, use Glitch triggering. (Glitch triggering is the same as Pulse Width triggering.) This trigger causes the oscilloscope to capture the signal only when it has a pulse width narrower than a specified value. The pulse width is measured at the amplitude specified by the trigger level.



- Negative glitch triggering looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button to display the Trigger Setup control window.
- ❑ Press the **Trigger Type** drop-down arrow or the **Select** button, and select **Glitch**.
- ❑ Verify that **Glitch Width** is set to **Less Than**.
- ❑ Touch the **Width** text box to attach the Multipurpose controls to the Level and Width controls.
- ❑ Since the normal pulses are about 100 ns wide, set the trigger to find pulse widths that are significantly smaller. Using the Multipurpose **b** control, set the Width value to approximately **50 ns**.
- ❑ Touch the **Mode** tab at the left side of the control window.
- ❑ Press the **Normal** Trigger Mode button.
- ❑ Touch the **A Event** tab at the left side of the control window.
- ❑ Notice that the trailing (falling) edge of the narrow pulse is positioned in the center of the display.
- ❑ By default, the Glitch trigger captures positive pulses. To capture negative pulses, press the **Neg** Polarity button.
- ❑ Notice that the trailing (rising) edge of the narrow pulse is now positioned in the center of the display.
- ❑ Press the front panel Trigger **Menu** button to remove the Trigger Setup control window.

Key Take Away Points

- Another anomaly that appears in the display is a low-amplitude pulse or “runt pulse”.
- To capture a runt pulse, the Runt trigger is used. This trigger causes the oscilloscope to capture the signal only when a pulse back and forth through one threshold level but does not cross through a second threshold level.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button to display the Trigger Setup control window.
- ❑ Press the **Trigger Type** drop-down arrow or the **Select** button, and select **Runt**.
- ❑ Verify that **Runt** is set to **Occurs**.
- ❑ Touch the **Upper Level** or **Lower Level** text box to attach the Multipurpose controls to the Level controls.
- ❑ Since the normal pulses are at least 3V high, and the runt pulses were around half of that, use the Multipurpose **a** control to set the Upper Level value to approximately **2V** and use the Multipurpose **b** control to set the Lower Level value to approximately **1V**.
- ❑ Notice that the trailing (falling) edge of the runt pulse is positioned at the center of the display.
- ❑ By default, the Runt trigger captures positive pulses. To see if there are any negative runt pulses in the signal, press the **Neg** Polarity button.
- ❑ Since the activity on the display stops and the acquisition indicator in the lower right corner of the display turns yellow and says “Preview”, there are apparently no negative runt pulses in this signal.
- ❑ To capture all runt pulses in the signal, press the **Either** Polarity button.

Searching for Intermittent Errors

Key Take Away Points

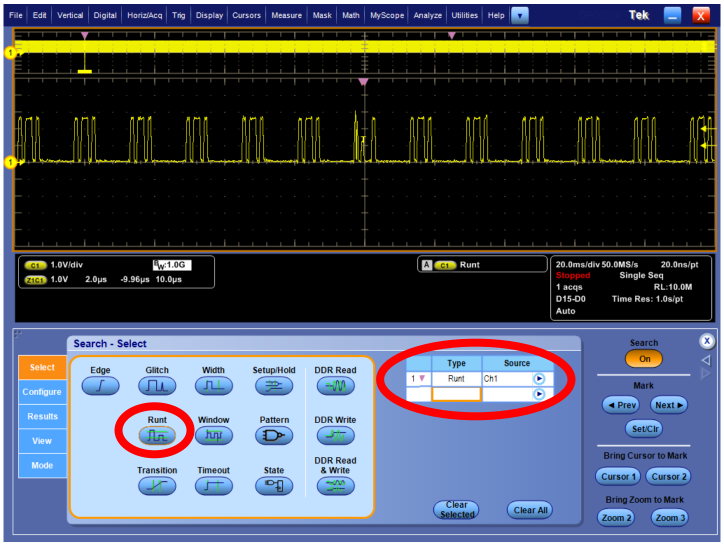
- As you have seen in this lab, triggering provides a way to capture a small time window around every occurrence of a specific anomaly in a signal. Because you have captured only a short time window of the signal and positioned the anomaly in the center of the display, the single anomaly is easy to find.
- But what if you captured a lot of data? How would you find every occurrence of the anomaly, quickly and reliably?
- One way to manually search for a signal event is to horizontally position the waveform on the display by changing the position of the trigger point on the display.
- When horizontal Delay mode is turned On, the trigger point starts in the middle of the display and can be moved with the horizontal position control. The time delay between the trigger point and the center of the display is shown in the trigger readout at the bottom of the display. With Delay mode on, the trigger point can be moved off the display.
- When horizontal Delay mode is Off (the default), the trigger point starts in the middle of the display and can be moved anywhere on the display with the horizontal position control.
- Another way to manually search through a signal is to capture a long time window and then graphically zoom and pan through the displayed waveform.
- Although the pan/zoom operation is easy with the front panel Wave Inspector controls, finding every occurrence of an anomaly is usually not a fast or reliable process.

MSO/DPO5000 Series Procedure:

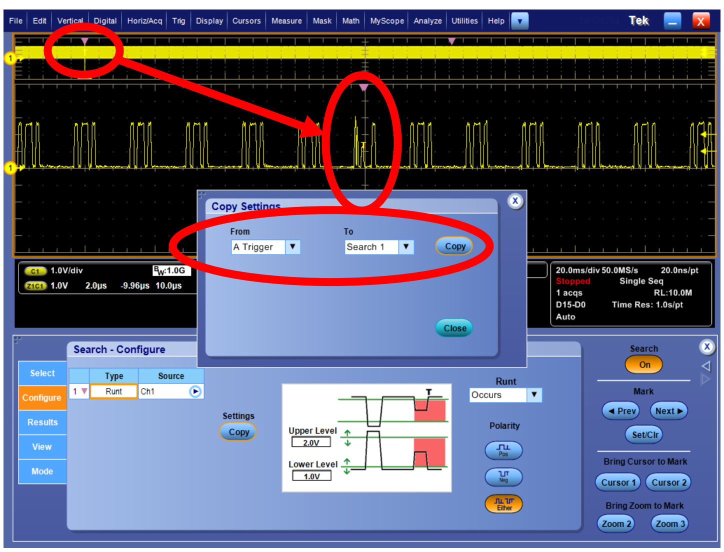
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Delay Mode** button to turn **On** Delay Mode.
- ❑ Rotate the Horizontal **Position** control and notice that the orange triangle at the top of the display remains fixed, but that the trigger point moves, even to a position off-screen.
- ❑ When Delay Mode is On, the trigger delay time appears in the trigger readout.
- ❑ Press the **Delay Mode** button to turn **Off** Delay Mode.
- ❑ Rotate the Horizontal **Position** control and notice that the orange triangle at the top of the display and the trigger point move across the display.
- ❑ A readout of the horizontal position (from 0% to 100% of the screen width) is displayed in the control window.
- ❑ Touch the **Position** text box and use the Multipurpose a control to set the Position to **10%**.
- ❑ Set the Horizontal **Scale** to **20 ms/div**.
- ❑ Using the Sample Rate arrow keys, adjust the sample rate to **50 MS/s**, which will set the Record Length to **10M**, as indicated in the readout in the lower left corner of the display.
- ❑ Press the front panel **Single** button.
- ❑ Turn the inner Wave Inspector control to select a **2µs/div** zoom factor.
- ❑ Using the spring-loaded outer Wave Inspector control, pan through the acquisition and see if you can find a runt pulse other than the one which is displayed at the trigger point.

Key Take Away Points

- The automatic Wave Inspector search quickly and reliably finds every specified occurrence within the acquired signal. The simplest case is to search for the same signal characteristic as the trigger, although it can automatically search on almost any characteristic that it can trigger on.



- In this case, let's just use the same setup for search as we did for triggering. We can enter the parameters manually, or simply copy them with a push of a button:



MSO/DPO5000 Series Procedure:

- ❑ Click the **X** in the upper right corner of the Horizontal Setup control window to close it.
- ❑ Press the front panel **Search** button to display the Search Setup control window.
- ❑ Notice the similarities between the search types and the trigger types you used earlier in the lab.
- ❑ Press the **Runt** button.
- ❑ Press the **Configure** tab to configure the runt search.
- ❑ Press the **Copy** button.
- ❑ Notice **From** is set to **A Trigger** and **To** is set to **Search 1**. Press the **Copy** button to copy the trigger setup into the search setup.
- ❑ Press the **Close** button.
- ❑ In a matter of seconds, the automatic search finds all occurrences of the specified runt pulse. Notice that each occurrence is marked with a little triangle at the top of the display.

Key Take Away Points

- The automatic search provides a tabular display like this, including the number of events found:

- What if there are other anomalies in the signal? At the beginning of the lab, we saw glitches on this signal. Let's search on them, too.

MSO/DPO5000 Series Procedure:

- ❑ Press the **Results** tab on the left side of the control window. Notice that two occurrences of the runt pulse have been found and time-stamped.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Pres the **Glitch** button. Notice that the search table now shows both runt and glitch search types.

Key Take Away Points

- This time, configure the automatic search for positive glitches:

- Now look at the search results for both runts and glitches:

MSO/DPO5000 Series Procedure:

- ❑ Press the **Configure** tab to configure the runt search.
- ❑ Touch **Glitch** in the Type text box.
- ❑ Touch the **Level** text box to attach the Multipurpose controls.
- ❑ Using the Multipurpose **a** control, set the **Level** to about **2V**.
- ❑ Using the Multipurpose **b** control, set the **Width** to about **50 ns**.
- ❑ Press the **Results** tab on the left side of the control window. Notice that the occurrences of the runt pulses and glitches have been found and time-stamped.

MSO5000/DPO5000 Series

I^{2}C Triggering and Decoding Lab

Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-EMBD option installed
Two TPP0500 or TPP1000 passive probes
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo 3 board]

Understanding the I²C Bus

I²C (Inter-Integrated Circuit) bus, developed in the early 1980s by Philips, has become a worldwide standard for communications between integrated circuits in a system. This simple two-wire design has found its way into a wide variety of chips and can be found in many embedded designs today. I²C uses bi-directional serial clock and data lines and supports three bit rates; 100 kbps standard mode, 400 kbps fast mode and 3.4 Mbps high speed mode. Data and clock are sent from the master and the data is clocked on the rising edge of SCLK. I²C supports multiple masters and slaves on the bus, but only one master may be active at any one time while slaves can transmit or receive data to the master. Each device is recognized by a unique address and can operate as either a transmitter or receiver, depending on the function of the device.

Start/ SRep	Addr	R/W	Ack	Data 0	Ack	Data 1	Ack	.....	Data N	Ack	Stop
1 bit	7-bits	1-bit	1-bit	8-bits	1-bit	8-bits	1-bit	0 – 8 bytes	8-bits	1-bit	1 bit

Objectives

- Obtain a basic understanding of the I²C serial bus.
- Learn how to use oscilloscopes to measure and decode I²C.
- Learn how to setup a decoded I²C serial bus display and trigger and search on I²C bus content with an MSO/DPO5000 Series oscilloscope.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

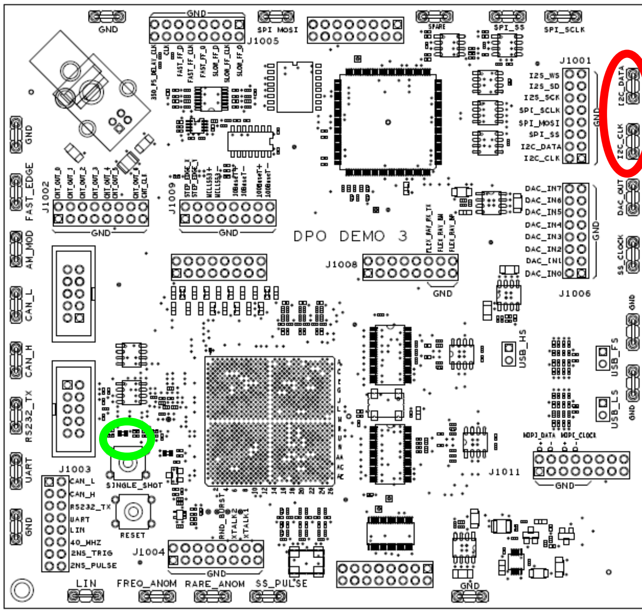
- I²C bus is an industry standard and can be found in many embedded designs today.
- Traditional manual decoding methods to decode I²C buses with an oscilloscope are time-consuming.
- With the SR-EMBD option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search I²C bus traffic.

MSO/DPO5000 Series Procedure:

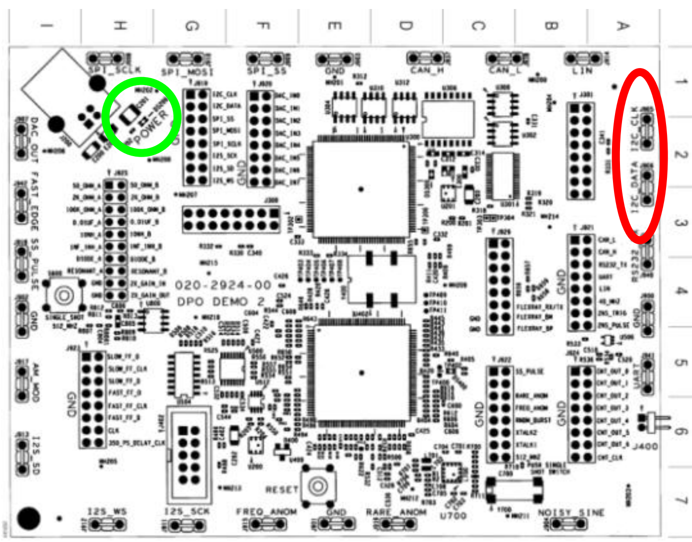
- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope….**
- ❑ Verify that the **SR-EMBD: I2C/SPI Serial Triggering and Analysis** option is installed.
- ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has an I^{2}C signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has an I^{2}C signal which we can use for this lab:

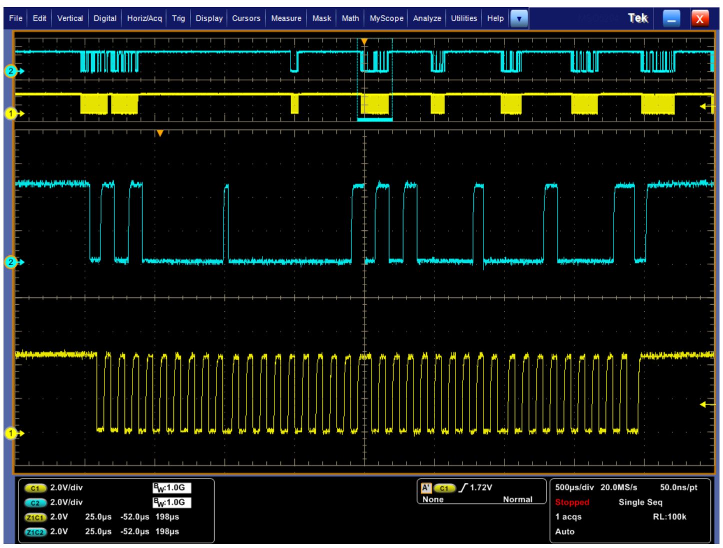


DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **I2C_CLK** (clock) test point.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **I2C_DATA** (data) test point.

Key Take Away Points

- The I^{2}C signal display should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set channel 1 Vertical **Scale** to **2V/div.**
- ❑ Turn on channel 2 by pressing the **2** button.
- ❑ Set channel 2 Vertical **Scale** to **2V/div.**
- ❑ Set the Horizontal **Scale** to **500µs/div.**
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **1.7V**.
- ❑ Position channel 1 (clock) in the lower half of the display and position channel 2 (data) in the upper half of the display.
- ❑ Press the front panel **Single** button.
- ❑ Turn the inner portion of the Pan / Zoom control and adjust the zoom factor to **25µs/div** or until one packet fills most of the display horizontally.
- ❑ Turn the outer portion of the Pan / Zoom control to position the packet in the center of the display.

Manual I^{2}C Bus Decoding

Key Take Away Points

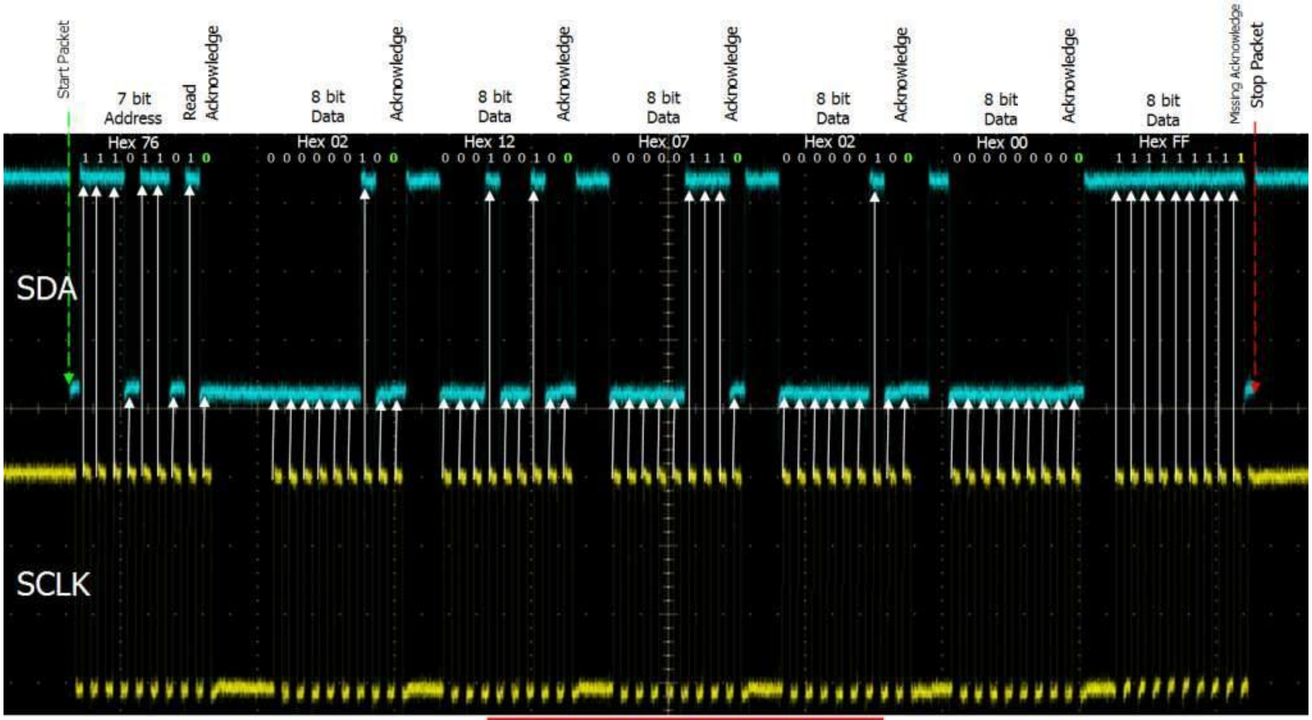
- The I^{2}C bus is one of the easiest buses to manually decode. For years, this has been the way engineers have done this task.

MSO/DPO5000 Series Procedure:

- ❑ Using the I2C Quick Reference Guide below, record the 7 bit binary address of the packet on screen.
- ❑ Record whether the packet is a read or write.
- ❑ Record whether or not the device returned an Acknowledge.

Conclusion: Manually decoding I^{2}C packets is a time-consuming process. Engineers are looking for a better and faster way to do this task.

I2C Quick Reference Guide



Read = 1
Write = 0

Missing ACK = 1
ACK = 0

Start A HIGH to LOW transition on the SDA line while SCL is HIGH

Stop A LOW to HIGH transition on the SDA line while SCL is HIGH

MSO/DPO5000 Series I^{2}C Bus Setup

Introduction

As you personally experienced in the last section, manually decoding I^{2}C can be a time-consuming process. In this section we will learn how to use the MSO/DPO5000 Series oscilloscope to automatically decode I^{2}C packet content.

Key Take Away Points

- Setting up a basic I^{2}C bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog or digital inputs or math signals can be used as a source for the I^{2}C bus. The I^{2}C Bus Setup menu looks like this:

- The I^{2}C bus Display menu looks like this:

MSO/DPO5000 Series Procedure:

- ❑ Continue with same setup as previous lab.
- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under Bus Type, select **Serial**.
- ❑ Using the drop down menu, select **I2C**.
- ❑ Verify that the **SCLK** signal is on Ch1 and the **SDA** signal is on Ch2.
- ❑ Verify that the Threshold settings are about **1.4V**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ For simplicity, under Bus 1 Config, verify that **Include R/W in address** is not checked. If **Include R/W in address** is checked, the decoded address value includes the R/W bit in the LSB.
- ❑ Touch the **Bus 1 Position** text box to attach the Multipurpose **a** control.
- ❑ Using the Multipurpose **a** control, position the bus waveform as desired.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Under Bus 1 Display, verify that **Busform** Style and **Hex** Decode are selected.
- ❑ When you are done with the setup, press the front panel **Menu Off** button or press the **X** in the upper right corner of the control window to close it.

Key Take Away Points

- The decoded I^{2}C signal display should look about like this:

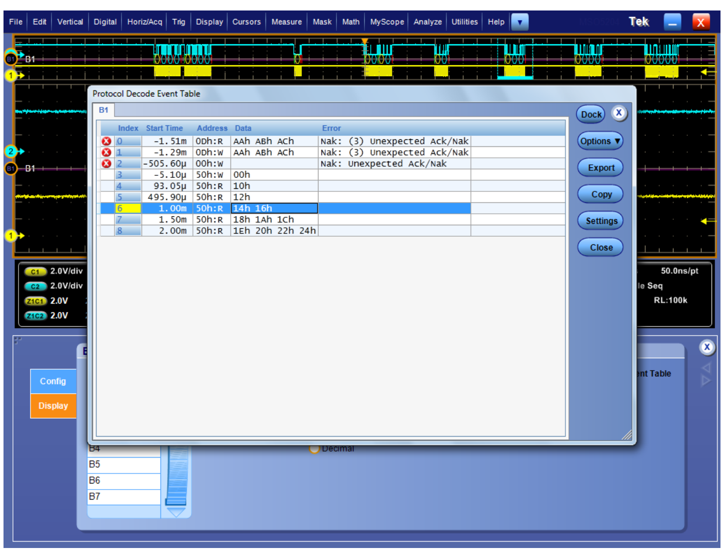
MSO/DPO5000 Series Procedure:

- ❑ Using the Wave Inspector controls, zoom in on one of the packets.
- ❑ The green bar symbol represents the start of packet. Start is a high to low transition on the data signal while the clock is high.
- ❑ Address packets are shown in yellow boxes. [R] Indicates a read and [W] indicates a write.
- ❑ Data packets are shown in cyan boxes.
- ❑ The red bar symbol represents the stop packet. Stop is a low to high transition on the data signal while the clock is high.

MSO/DPO5000 Series I^{2}C Bus Event Tables

Key Take Away Points

- Setting up a basic I^{2}C bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The I^{2}C bus event table display looks like this:



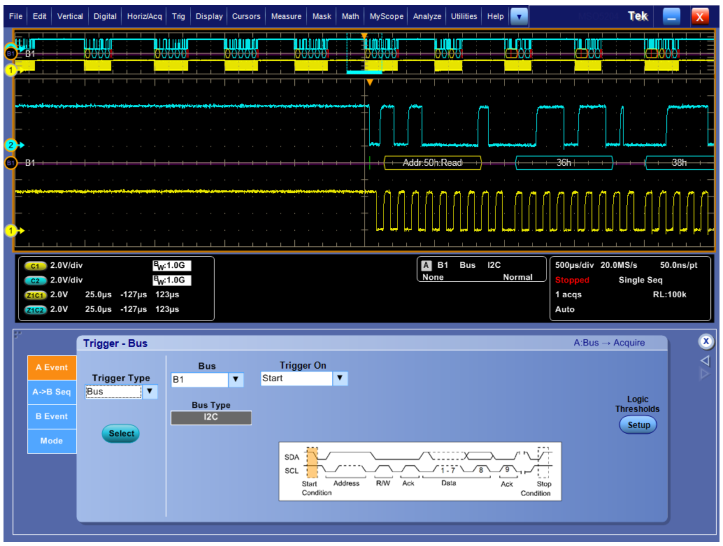
MSO/DPO5000 Series Procedure:

- ❑ Select **Vertical -> Bus Setup…**.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Click on one of the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.
- ❑ When you are done with the setup, press the **X** in the upper right corner of the control window to close it.

MSO/DPO5000 Series I^{2}C Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the I^{2}C serial bus.
- The MSO/DPO5000 Series can trigger on Start, Stop, Repeat Start, Missing Ack, Address (7 or 10 bit), Data (1 – 5 bytes), Address & Data, and Special Addresses.



- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on an I^{2}C signal, capturing each occurrence.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Using the Trigger Type drop down menu, select **Bus** triggering.
- ❑ Using the Bus drop down menu, select **B1**.
- ❑ Notice that, by default, Trigger On **Start** is selected.
- ❑ Press the front panel **Single** button.
- ❑ Using the **Trigger On** drop down menu, select **Address**.
- ❑ The easiest way to enter the address is with the Pattern Editor. Press the **Edit** button at the right.
- ❑ Select **Hex** format.
- ❑ Double click on the **Address** text box and enter the address you recorded in the last section of this lab (for example, 50 hex). As you enter the values, notice that the values in the other radices are also updated.
- ❑ In the **Direction** drop-down menu, select **Write**.
- ❑ When you are done, press **OK**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the I^{2}C packets.

MSO/DPO5000 Series I²C Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the I²C serial bus.

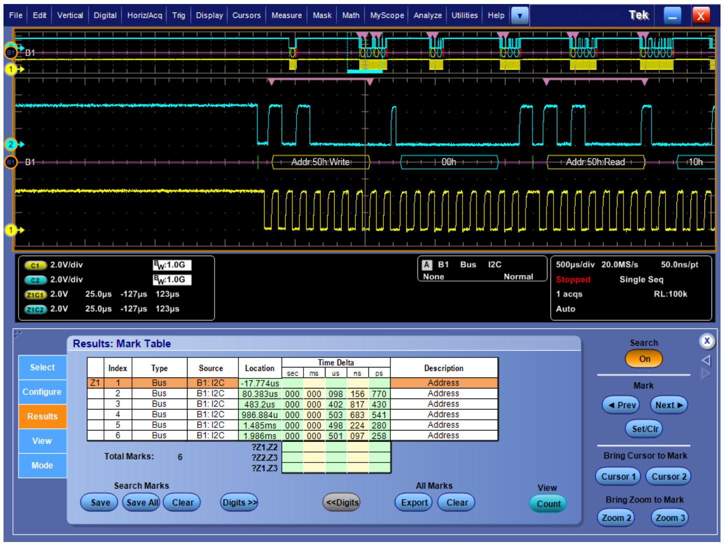
- The MSO/DPO5000 Series can search on Start, Stop, Repeat Start, Missing Ack, Address (7 or 10 bit), Data (1 – 5 bytes), Address & Data, and Special Addresses.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** button in the control window.
- ❑ Press the **Configure** tab at the left side of the control window.
- ❑ Notice that, by default, Search For **Start** is selected.
- ❑ Adjust the zoom window as needed to view the I²C packets and notice the packets which were marked.

Key Take Away Points

- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on an I^2C signal, marking each occurrence.



MSO/DPO5000 Series Procedure:

- ❑ Using the **Search For** drop down menu, select **Address**.
- ❑ The easiest way to enter the address is with the Pattern Editor. Press the **Edit** button at the right.
- ❑ Select **Hex** format.
- ❑ Double click on the **Address** text box and enter the address you recorded in the last section of this lab (for example, 50 hex). As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ In the **Direction** drop-down menu, select **Don't Care (X)**.
- ❑ Using the front panel left and right arrows, navigate between search events.
- ❑ Press the **Results** tab at the left side of the control window to display the table of search results.

MSO5000/DPO5000 Series

SPI Triggering and Decoding Lab

Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-EMBD option installed
Three TPP0500 or TPP1000 passive probes
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo 3 board]

Understanding the SPI Bus

Introduction

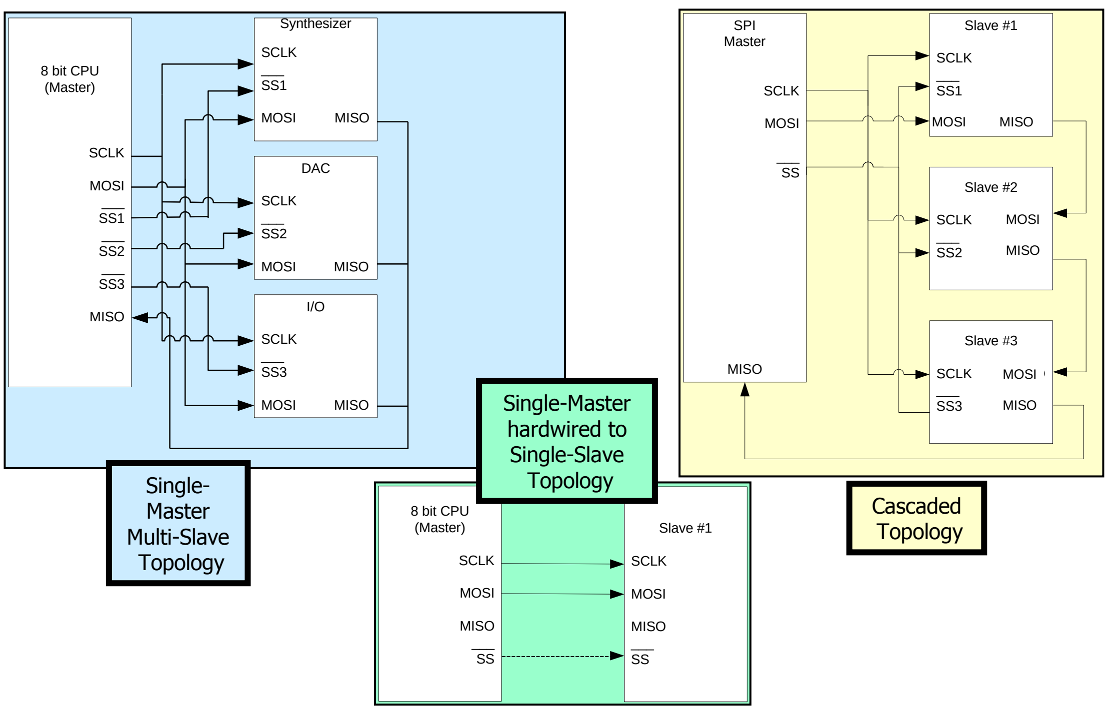
SPI (Serial Peripheral Interface) bus is a 4-wire serial communications interface used primarily in synchronous serial communication for both processors and peripherals. SPI is an interface standard defined by Motorola for use on their microcontrollers. Due to the popularity of the bus other manufacturers have adopted the standard, making a wide variety of parts available in the market. SPI uses a synchronous clock which shifts serial data into and out of the microcontroller, generally in blocks of 8 bits. SPI bus is a master/slave interface. Whenever two devices communicate, one is referred to as the "master" and the other as the "slave". The master drives the serial clock. When using SPI, data is simultaneously transmitted and received, making it a full-duplex protocol.

As you can see in the following block diagrams, SPI is a flexible interface, supporting several different circuit topologies. In general, the master provides a clock to all slaves. When MOSI, SCLK, and SS are used, it is called the “3-wire” SPI connection. (This demo is based on the “3-wire” connection.)

With the single-master, multi-slave topology, the master provides data (Master Out Slave In or MOSI) directly to each slave and controls them separately with slave select signals. In the case of the “4-wire” SPI connection, the MISO signal is routed from the selected slave back to the master so the master can verify the communication path.

With the cascaded topology, the data (MOSI) from the master is “daisy-chained” through each of the slaves. In the case of the “4-wire” SPI connection, the MISO signal is routed from the last slave back to the master so the master can verify the communication path. The chain of slaves is enabled by a single SS signal, usually generated by the master. However, in the “2-wire” SPI connection, the SS inputs to the slave devices are permanently asserted (e.g. tied to ground).

With the single-master-hardwired-to-single-slave topology, the master provides MOSI and SCLK. MISO is generally not used, and often a “2-wire” connection is used for simplicity.

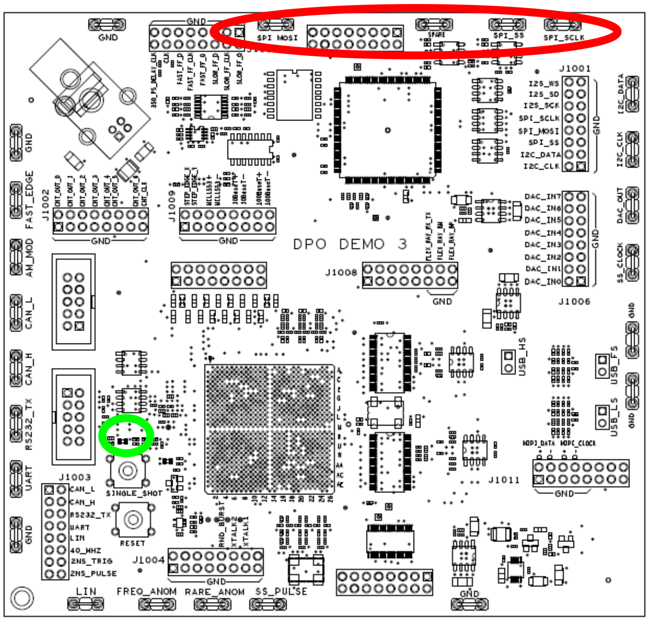


Lab Objectives
- Obtain a basic understanding of the SPI serial bus. - Learn how to use oscilloscopes to measure and decode SPI. - Learn how to setup a decoded SPI serial bus and trigger and search on SPI packet content with an MSO/DPO5000 Series oscilloscope.

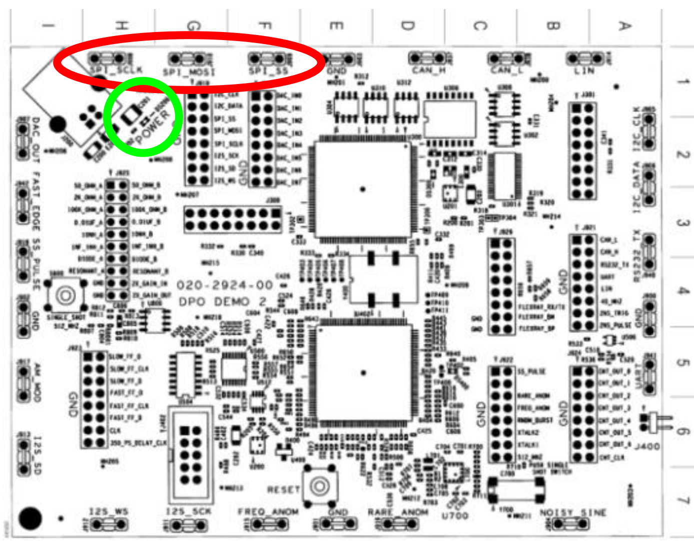
MSO/DPO5000 Series Lab Setup	
Key Take Away Points • SPI bus is an industry standard and can be found in many embedded designs today. • Traditional manual decoding methods to decode SPI buses with an oscilloscope are time-consuming. • With the SR-EMBD option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search SPI bus traffic.	**MSO/DPO5000 Series Procedure:** ❑ Power up the oscilloscope. ❑ Select **Help -> About TekScope…**. ❑ Verify that the **SR-EMBD: I2C/SPI Serial Triggering and Analysis** option is installed. ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has an SPI signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has an SPI signal which we can use for this lab:



DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **SPI_SCLK** test point.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **SPI_SS** test point. Be aware that this signal is called Chip Select (CS) by some and Slave Select (SS) by others.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 3 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **SPI_MOSI** test point.

Key Take Away Points

- The SPI signal display should look about like this:

MSO/DPO5000 Series Procedure:

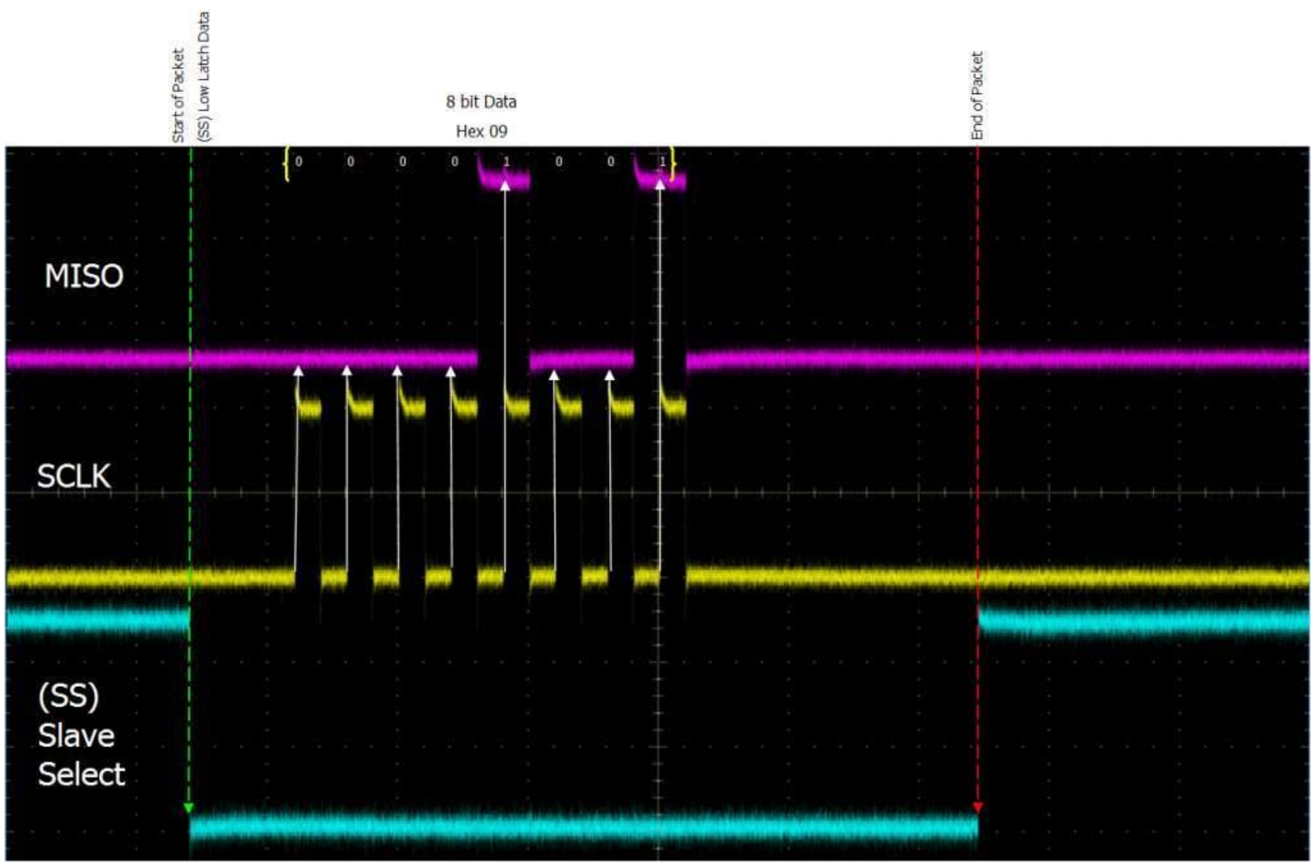
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set the Horizontal **Scale** to **20µs/div.**
- ❑ Press the front panel **2** and **3** buttons to turn on channels **2** and **3**.
- ❑ Set the Vertical **Scale** for channels 1, 2, and 3 to **2V/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **1.7V**.
- ❑ Position the waveforms on the display as shown in the screen shot on the left.
- ❑ Press the front panel **Single** button.
- ❑ Turn the inner portion of the Pan / Zoom control and adjust the zoom factor to about **10 µs/div** to get a single packet in the zoom window.
- ❑ Turn the outer portion of the Pan / Zoom control to zoom in on the beginning of the packet.

Manual SPI Bus Decoding

Key Take Away Points	MSO/DPO5000 Series Procedure:
• The SPI bus is fairly easy to manually decode. For years, this has been the way engineers have done this task.	❑ Decode the data bus values by deciding whether the data signal is high or low on each of the rising edges of the clock signal, as shown below. ❑ Record the decoded data value.

Conclusion: Manually decoding SPI packets is a time-consuming process. Engineers are looking for a better and faster way to do this.

SPI Quick Reference Guide



Tektronix

MSO/DPO5000 Series SPI Bus Setup and Decoding

Introduction

As you personally experienced in the last section, manually decoding SPI can be a time-consuming process. In this section we will learn how to use the MSO/DPO5000 Series oscilloscope to automatically decode SPI packet content.

Key Take Away Points

- Setting up a basic SPI bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog or digital inputs or math signals can be used as a source for the SPI bus. The SPI bus selection menu looks like this:

- The SPI bus Display menu looks like this:

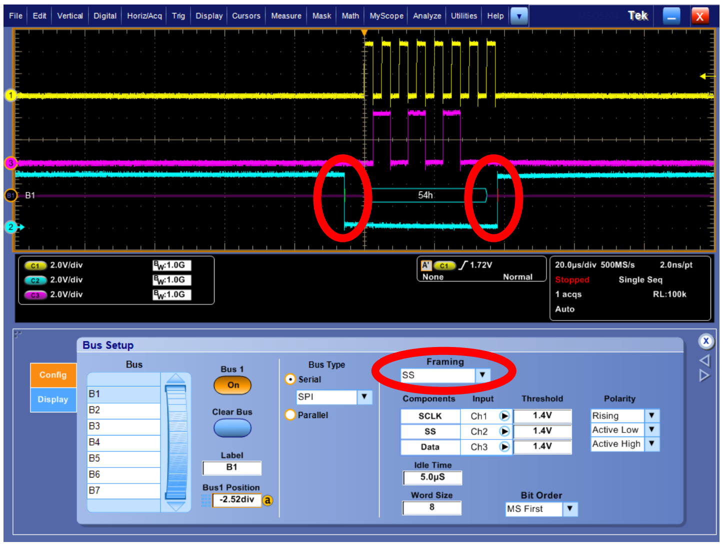
MSO/DPO5000 Series Procedure:

- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under Bus Type, select **Serial**.
- ❑ Using the drop down menu, select **SPI**.
- ❑ Verify that the SCLK is on is on Ch1, SS is on Ch2, and Data signal Ch3.
- ❑ Press the arrow next to the channel 1 label and notice that any of the analog, digital, or math channels can be used as an input.
- ❑ Verify that the **Threshold** settings are all about **1.4V**.
- ❑ Verify that SCLK is set to **Rising** edge, SS is set to **Active Low**, and Data is set to **Active High**.
- ❑ Verify that **Framing** is set to **SS**.
- ❑ Click on the **Word Size** (the number of bits in the packet) text box and set it to **8**.
- ❑ Using the **Direction** drop down menu, select **MS First** so the first bit in the packet is interpreted as the MSB.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Touch the **Bus 1 Position** text box to attach the Multipurpose **a** control.
- ❑ Using the Multipurpose **a** control, position the bus waveform as desired.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Verify that **Busform** Style and **Hex** Decode are selected.

MSO/DPO5000 Series 2-Wire SPI Bus Decoding

Key Take Away Points

- Notice the Framing selection at the top of the control window. The default Framing setting “SS” provides 3-wire SPI functionality.
- Notice that the Data (MOSI) packets are shown in cyan boxes. The green start of packet indicator corresponds to the falling edge of SS (active low) on channel 2 and the red end of packet indicator corresponds to the rising edge of the SS signal:



- Before continuing on with the main lab, we need to stop and review a special case, “2-wire SPI”, which is supported by the MSO/DPO5000 Series.
- In “2-wire SPI”, the framing timing is derived from the clock signal instead of the separate SS signal:
  - The frame ends after the final active clock edge occurs and the specified idle time has elapsed.
  - The frame begins with the first active edge of the clock after the idle state has been reached.

MSO/DPO5000 Series Procedure:

- ❑ Press the **Config** tab at the left side of the control window.
- ❑ Click on the **Framing** down arrow and select **Idle**.
- ❑ Notice the **Idle Time** selection, indicating a default **5µs** idle time.

<table>
<tr>
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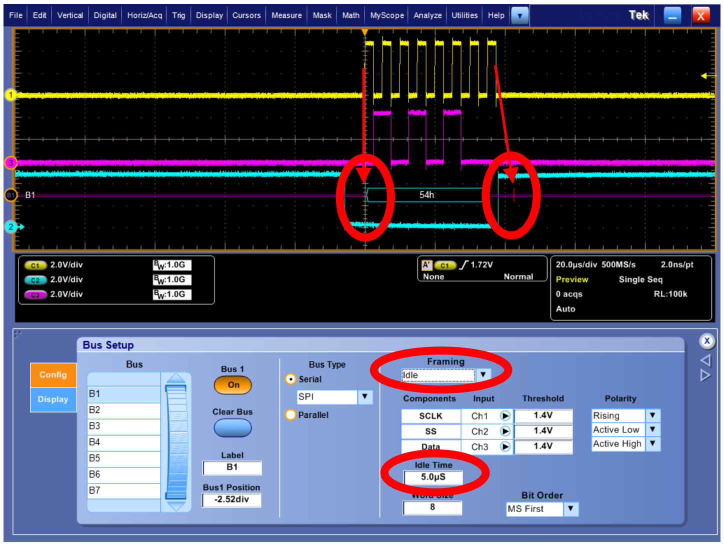
Key Take Away Points

- In “2-wire SPI” mode, notice that the green start of packet indicator corresponds to the first rising edge of the clock on channel 2 and the red end of packet indicator occurs after the final falling edge of the clock signal by an amount specified by the idle time:



- Note that in “2-wire SPI” mode, the available SPI Bus trigger modes are “Start of Frame” and “Data”.

</td>
<td>

MSO/DPO5000 Series Procedure:

❑ When you are done, click on the **Framing** down arrow and select **SS**.

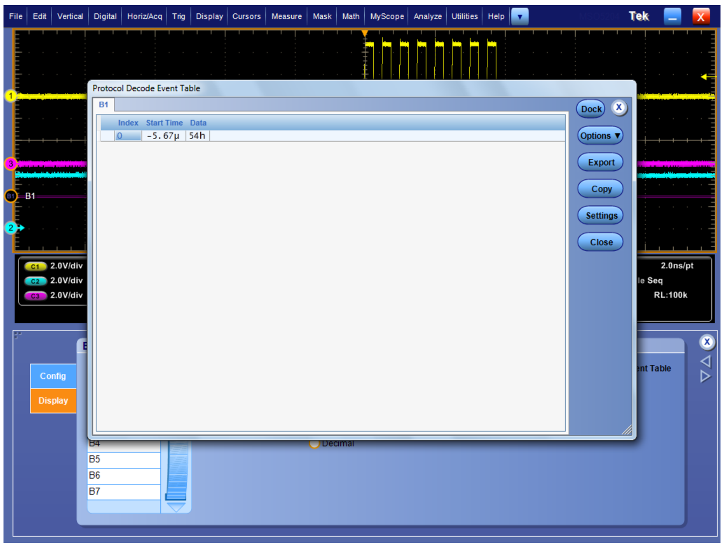
</td>
</tr>
</table>

Tektronix

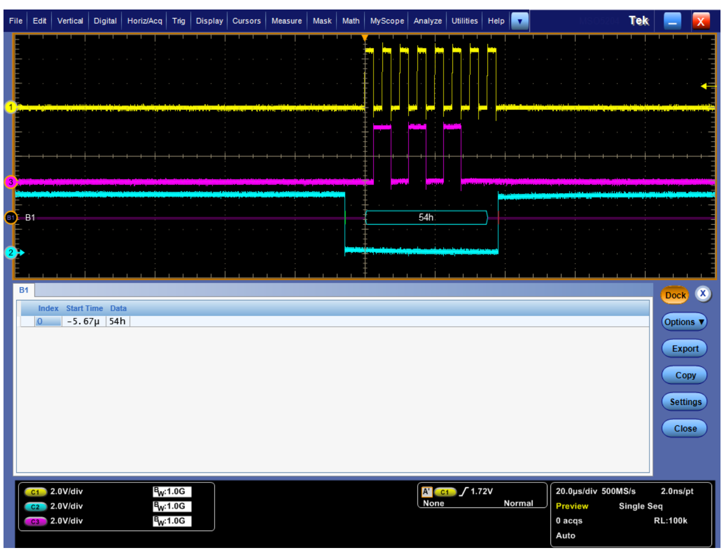
MSO/DPO5000 Series SPI Bus Event Tables

Key Take Away Points

- Setting up a basic SPI bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- With this oscilloscope setup, there is only one SPI packet within the acquisition, so the Event Table is very small. However, you can see what the pop-up SPI bus Display format looks like for the SPI bus:



- You can also dock the Event Table so that it appears below the graticule for easy reference between the two displays:



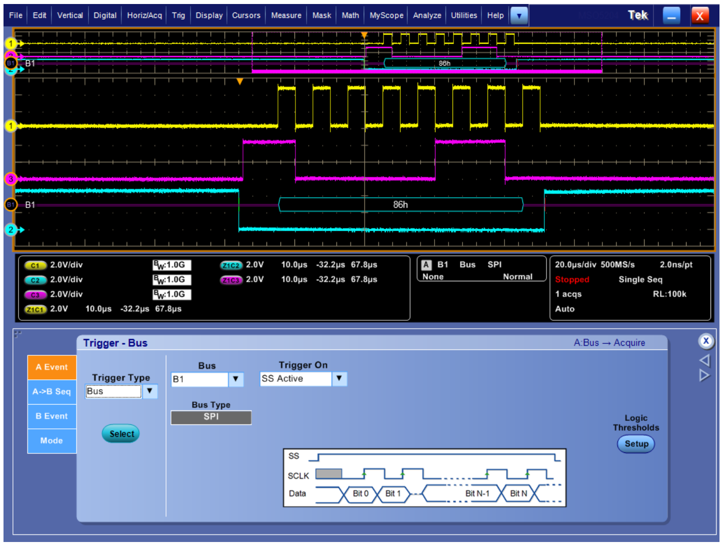
MSO/DPO5000 Series Procedure:

- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Dock** button.
- ❑ Click on the **X** in the upper right corner of the control window to close it.
- ❑ When you are done, press the **X** in the upper right corner of the Event Table to close it.

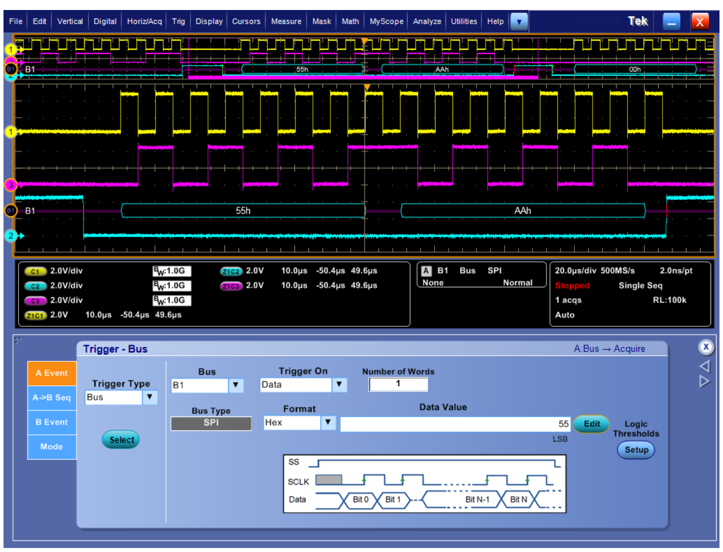
MSO/DPO5000 Series SPI Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the SPI serial bus. The MSO/DPO5000 Series can trigger on SS Active and specific Data values.
- This is what triggering on SS Active looks like:



- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on an SPI signal, capturing each occurrence.



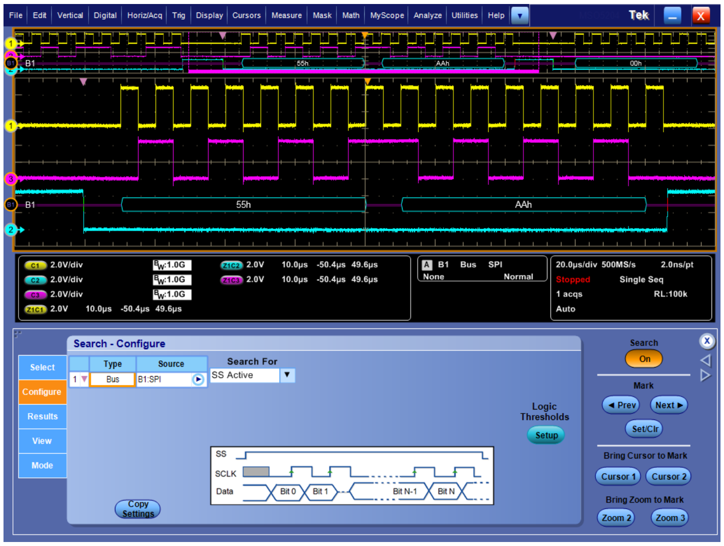
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Using the Trigger Type drop down menu, select **Bus** triggering.
- ❑ Using the Bus drop down menu, select **B1**.
- ❑ The **Trigger On** selection, by default, is set to **SS Active**. (The active polarity was set in the Bus Setup menu.)
- ❑ Press the front panel **Single** button.
- ❑ Using the **Trigger On** drop down menu, select **Data**.
- ❑ The easiest way to enter the address is with the Pattern Editor. Press the **Edit** button at the right.
- ❑ Select **Hex** format.
- ❑ Double click on the **Data Value** text box and enter the address you recorded in the last section of this lab (for example, 55 hex). As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the SPI packets.

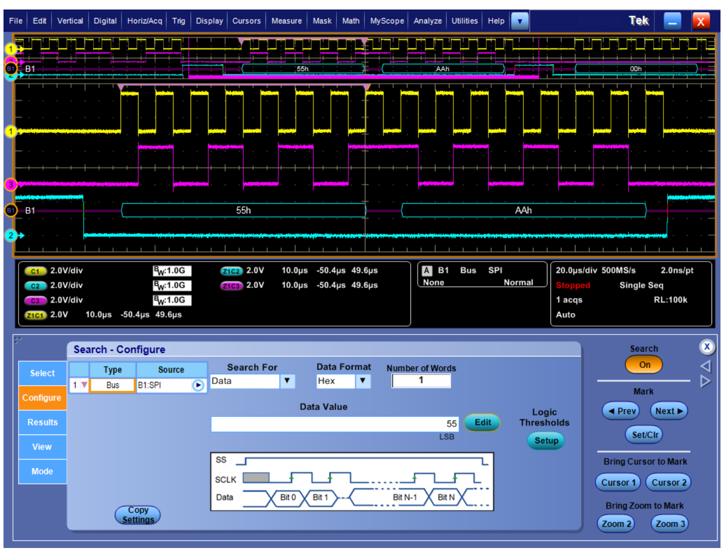
MSO/DPO5000 Series SPI Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the SPI serial bus. The MSO/DPO5000 Series can search on SS Active and specific Data values.
- This is what searching on SS Active looks like:

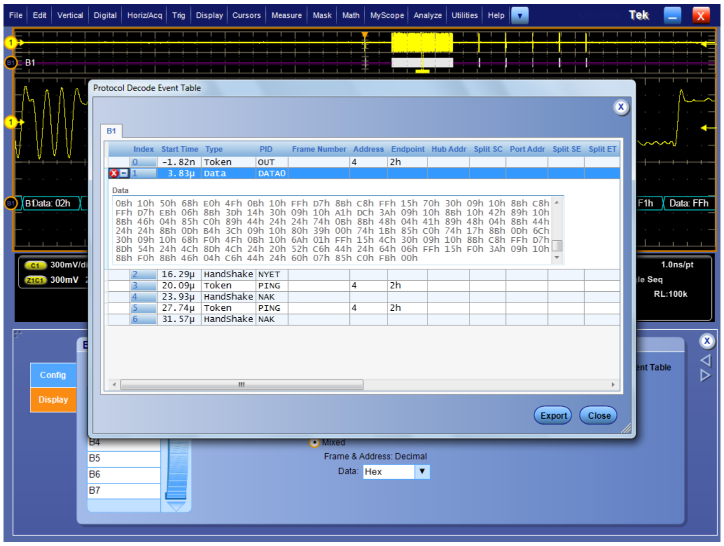


- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on an SPI signal, marking each occurrence.



MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** button in the control window.
- ❑ Press the **Configure** tab at the left side of the control window.
- ❑ The **Search For** selection, by default, is set to **SS Active**. (The active polarity was set in the Bus Setup menu.)
- ❑ Using the **Search For** drop down menu, select **Data**.
- ❑ The easiest way to enter the address is with the Pattern Editor. Press the **Edit** button at the right.
- ❑ Select **Hex** format.
- ❑ Double click on the **Data Value** text box and enter the data value you recorded in the last section of this lab (for example, 55 hex). As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Adjust the zoom window as needed to view the SPI packets.
- ❑ Using the front panel left and right arrows, navigate between search marks.
- ❑ Press the **Results** tab at the left side of the control window to display the table of search results.



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-USB option installed

NOTE: A ≥1 GHz oscilloscope is required for High-speed USB support

Two TPP0500 or TPP1000 passive probes

One TDP1000 differential probe

Optional USB keyboard and mouse

PC with USB2.0 Host ports

DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00)

Understanding the USB Bus

Introduction

Universal Serial Bus (USB) has replaced many of the personal computer external serial and parallel buses. USB is a simple and inexpensive interface that brought plug-and-play ease-of-use in connecting and using external devices with the computer. For example, USB devices can be hot-plugged into the computer with dynamically loadable drivers without the need to reboot.

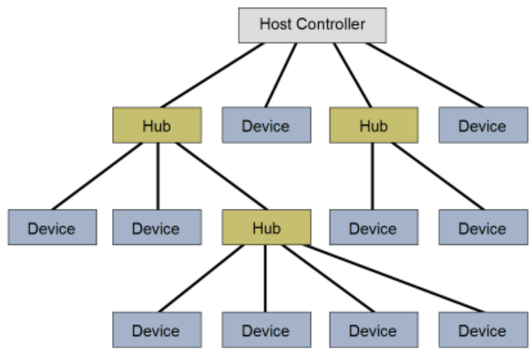
The USB Implementers Forum (USB-IF) manages and promotes USB standards and USB technology. USB specifications are available at the USB-IF web site at www.usb.org.

Since the USB introduction in 1995 USB has grown beyond its original personal computer usage and it has become a ubiquitous interface used in many types of electronic devices. For example, the Inter-Chip USB (IC_USB) and the High-Speed Inter-Chip (HSIC) USB are use for chip-to-chip communications and these implementations do not have connectors, cables, or analog transceivers.

USB 2.0 specifications that were released in 2000 cover most of the USB devices that are being used today. USB 2.0 added a high speed interface to the USB 1.1 specifications. Compliance to USB 2.0 does not require high speed operation. For example, a low-speed USB mouse can be compliant to USB 2.0 and advertise that it is an USB 2.0 device. Supplements to the USB 2.0 specifications cover IC_USB, HSIC and other enhancements.

Controller Configuration

The USB configuration is one host controller with 1 to 127 devices. USB is a tiered-star topology with optional hubs to expand the bus, as shown at the right:



The host is the only master and it controls all bus traffic. The host initiates all communications to devices and devices do not have the capability to interrupt the host.

Enumeration

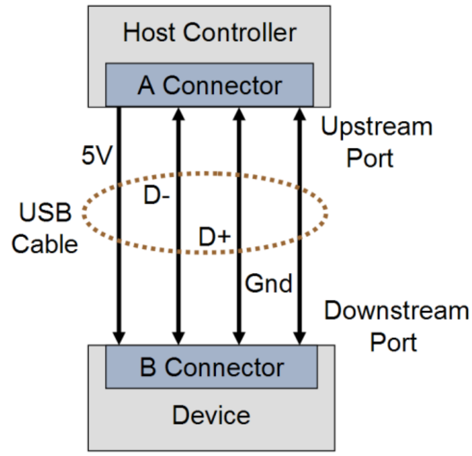
Enumeration is the configuration process that occurs at power-on or when a device is hot plugged. The host detects the presence of the device on the USB bus. Next, the host polls the device with the SETUP token using address 0 and endpoint 0. Then, the host assigns a unique address to a device in the range of 1 to 127. The host also identifies the device speed and data transfer type, and determines the device's class. The device class defines a device's functionality such as printer, mass storage, video, audio, human interface, etc.

Electrical

The host uses an upstream “A” connector and devices use a downstream “B” connector.

The USB 2.0 cable has four wires, shown at the right:

Two wires are used for 5 V power (red wire) and ground (black wire) from the host. The connectors are designed so that the power and ground pins are connected before the data pins. The host provides current from 100 mA to 500 mA with intelligent power management. For example, power to a device can be monitored by the host or hub and switched off if an over-current condition occurs.



A twisted differential pair D+ (green wire) and D- (white wire) is used for bidirectional communications using half-duplex, DC-coupled differential signaling controlled by the host. Signal levels are listed in the table below:

USB Speed	Low State	High State
Low Speed	<0.3V	>2.8V
Full Speed	<0.3V	>2.8V
High Speed	0 V±10%	400 mV±10%

The host pulls down both D+ and D- when no device is connected. This is called single-ended zero (SE0) state. As a result, the oscilloscope will show 0 V when probing a USB bus that has no device connected.

Data transmission uses Non-Return-to-Zero-Inverted (NRZI) encoding. A logic ‘0’ is represented by the signal polarity toggling, while a logic ‘1’ is no change. The least significant bit is transmitted first and the most significant bit is transmitted last. To maintain adequate AC signal content, an extra ‘0’ is inserted after six consecutive 1s (called “bit stuffing”).

Packets

Packets are the fundamental elements of USB communications.

For full-speed and low-speed USB, a packet starts from the idle state with an 8-bit synchronization (SYNC) field. For high-speed USB, a packet starts from the idle state with a 32-bit synchronization (SYNC) field.

Then the Packet IDentifier (PID) is transmitted. The PID is composed of a 4-bit PID and its 4-bit PID complement for error checking. A PID encoding error is when the first PID 4-bits do not match the complement of the last PID 4-bits. The PID 4-bit value identifies 17 types of packets, shown in the table at the right:

PIDs are grouped into four Types: token, data, handshake and special.

Finally, the 3-bit end-of-packet (EOP) is transmitted.

PID Type	PID Name	PID
Token	OUT	0001
	IN	1001
	SOF	0101
	SETUP	1101
Data	DATA0	0011
	DATA1	1011
	DATA2	0111
	MDATA	1111
Handshake	ACK	0010
	NAK	1010
	STALL	1110
	NYET	0110
Special	PRE	1100
	ERR	1100
	SPLIT	1000
	PING	0100
	Reserved	0000

Handshake Packets

Handshake packets such as data packet accepted (ACK) and data packet not accepted (NAK) are composed of the Sync byte, PID byte and EOP.

Token Packets

Host-sent token packets are composed of the PID followed by two bytes composed of a11-bit address and a 5-bit cyclic redundancy check (CRC), as shown here:

Sync	PID	11-bit Address	5-bit CRC	EOP

OUT, IN and SETUP token packet organization

Address zero is special and is for a device that has not been assigned an address at the beginning of the enumeration process. Later in the enumeration process, the host assigns a nonzero address to the device.

All devices have an endpoint zero. Endpoint zero is special and is used for device control and status. Other device endpoints are for data sources and/or sinks.

The host sends an OUT token to a device followed by data packets. The host sends an IN token to a device and expects to receive data packets or handshake packet such as NAK from the device.

Data Packets

Data packets contain a PID byte, data bytes and 16-bit CRC, as shown here:

Sync	PID	Data	16-bit CRC	EOP

Data Packets with the PID defining a DATA0 or DATA1 packet

DATA0 and DATA1 packets have a 1-bit sequence number that is used in stop and wait automatic repeat-request handshake. DATA0 and DATA1 packets alternate in error free transmission. Data packets are resent with the same sequence number when a transmission error occurs.

An error free data transaction is when the host sends a DATA0 packet to the device, the device sends a handshake ACK packet, and then the host sends a DATA1 packet.

If the host does not receive a handshake ACK packet, or receives a NAK from the device, it resends the DATA0 packet. If the device sent an ACK packet and receives the data packet with the same sequence number again, the device acknowledges the data packet but ignores the data as a duplicate.

Start of Frame

Start of Frame (SOF) packet is used to synchronize isochronous and polled data flows. The 11-bit frame number is incremented by one in each consecutive SOF.

Sync	PID	Frame Number	5-bit CRC	EOP

Start of Frame Packet

Lab Objectives

- Obtain a basic understanding of the USB serial bus.
- Learn how to use oscilloscopes to measure and decode USB.
- Learn how to setup a decoded USB serial bus and trigger and search on USB packet content with an MSO/DPO5000 Series oscilloscope.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

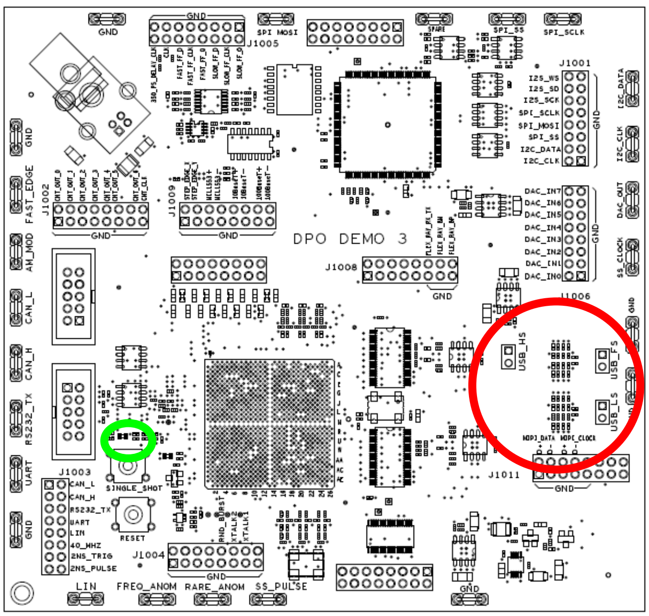
- USB bus is an industry standard and can be found in many embedded designs today.
- Traditional manual decoding methods to decode USB buses with an oscilloscope are time-consuming.
- With the SR-USB option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search USB bus traffic.

MSO/DPO5000 Series Procedure:

- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope….**
- ❑ Verify that the **SR-USB: USB Serial Triggering and Analysis** option is installed.
- ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has USB signals which we can use for this lab:



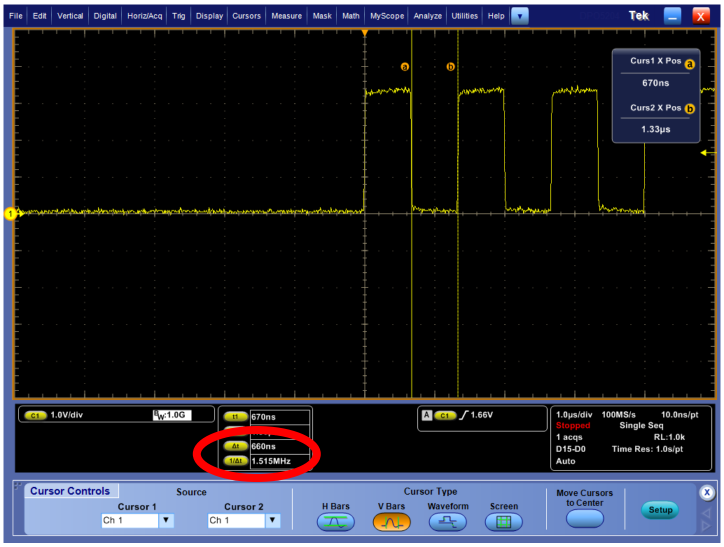
DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER LED** is lit.
- ❑ On this board, the three USB signals are differential signals and are available on pairs of square pins. The positive side of the differential signal is on pin 1 of the connector (identified by the silkscreen arrow and the square pad) and the negative side of the differential signal is on pin 2 of the connector.

Key Take Away Points

(optional) Determining USB Data Rate

- The data rate of USB signals for commonly-available USB computer mice and USB flash drives may be Low-speed (1.5 Mb/s), Full-speed (12 Mb/s), or High-speed (480 Mb/s). In some cases, the devices may specify the speed at which they operate. However, in general, you may need to determine the data rate using this procedure.
- The display should look about like this:



Minimum Pulse Width	USB Bit Rate	USB Speed
667 ns	1.5 Mb/s	Low-speed
83 ns	12 Mb/s	Full-speed
2.08 ns	480 Mb/s	High-speed

MSO/DPO5000 Series Procedure:

- ❑ For this optional bit rate test only:
- ❑ Attach a TPP0500 or TPP1000 passive probe to the Channel 1 input of the oscilloscope.
- ❑ Connect the probe tip to the D+ signal on pin **1** of the **USB_LS** or **USB_FS** connector and the probe ground to **GND**.
- ❑ Press **Autoset**.
- ❑ Adjust the **Horizontal Scale** to clearly display individual cycles of the signal.
- ❑ Press the front panel **Cursors** button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose controls, measure the width of the narrowest pulse, as shown in the screen shot at the left.
- ❑ Read the bit rate (1/Δ time in the cursor readout) and write the value here: ______

Low-Speed USB Bus Setup and Decoding

Key Take Away Points

- NOTE: Low-speed USB triggering and analysis support is offered on all properly-equipped MSO/DPO5000 models. Both single-ended and differential probing of the USB signal is supported. For simplicity, this lab will use single-ended probing with the standard passive probes.
- The Low-speed USB signal display should look about like this:

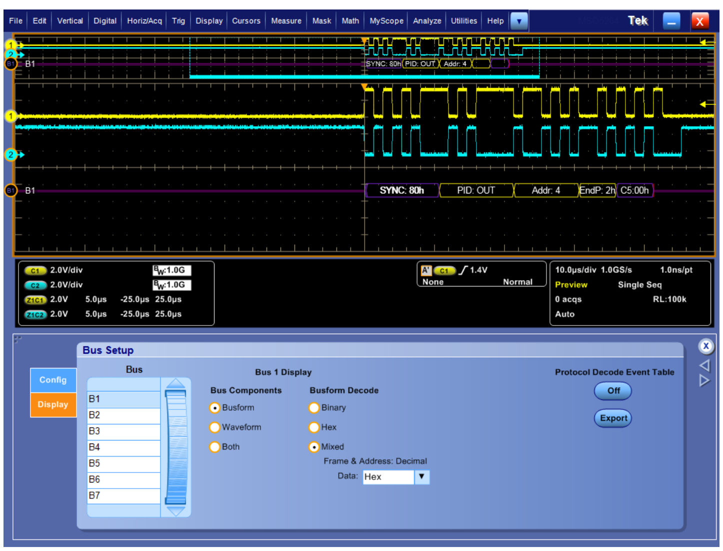
MSO/DPO5000 Series Procedure:

- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin **1** of the **USB_LS** connector on the demo board.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin 2 of the **USB_LS** connector on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Set the Vertical **Scale** for channels 1 and 2 to **2V/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **1.4V**.
- ❑ Position the waveforms in the top half of the display as shown in the screen shot on the left.
- ❑ Set the Horizontal **Scale** to **10µs/div.**
- ❑ Press the front panel **Single** button.

Key Take Away Points

- The USB Bus Setup control window looks like this:

- Setting up a basic USB bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog (single-ended or differential) or digital (single-ended) inputs or math signals can be used as a source for the USB bus.
- The decoded USB bus should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under **Bus Type**, select **Serial**.
- ❑ Using the drop down menu, select **USB**.
- ❑ Verify that the **Speed** is set to **Low (1.5 Mbps)**.
- ❑ Under **Signal Type**, select **Single Ended**.
- ❑ For component **D+**, select **Ch1**.
- ❑ For component **D-**, select **Ch2**.
- ❑ Verify that the Threshold settings are about **1.4V**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.

- ❑ Press the **Display** tab at the left side of the control window. Notice the different display formats that are available.
- ❑ Select **Mixed** Busform Decode.

Full-Speed USB Bus Setup and Decoding

Key Take Away Points

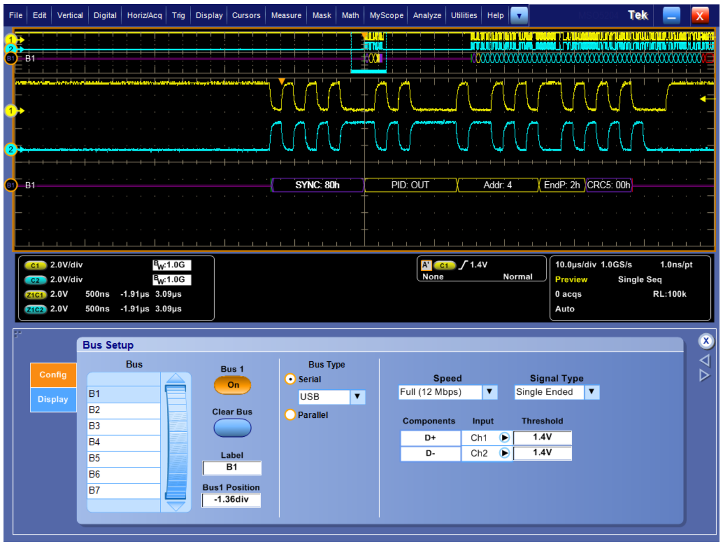
- NOTE: Full-speed USB support is offered on all properly-equipped MSO/DPO5000 models. Both single-ended and differential probing of the USB signal is supported. For simplicity, this lab will use single-ended probing with the standard passive probes.
- The Full-speed USB signal display should look about like this:

MSO/DPO5000 Series Procedure:

- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin **1** of the **USB_FS** connector on the demo board.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to pin 2 of the **USB_FS** connector on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Set the Vertical **Scale** for channels 1 and 2 to **2V/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **1.4V**.
- ❑ Position the waveforms in the top half of the display as shown in the screen shot on the left.
- ❑ Set the Horizontal **Scale** to **10µs/div.**
- ❑ Press the front panel **Single** button.
- ❑ Using the front panel Wave Inspector controls, zoom in on one of the USB packets.

Key Take Away Points

- The USB Bus Setup control window looks like this:



- Setting up a basic USB bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog (single-ended or differential) or digital (single-ended) inputs or math signals can be used as a source for the USB bus.
- When you zoom in on the decoded USB signals, you should see a display about like this:

MSO/DPO5000 Series Procedure:

- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under **Bus Type**, select **Serial**.
- ❑ Using the drop down menu, select **USB**.
- ❑ Verify that the **Speed** is set to **Full (12 Mbps)**.
- ❑ Under **Signal Type**, select **Single Ended**.
- ❑ For component **D+**, select **Ch1**.
- ❑ For component **D-**, select **Ch2**.
- ❑ Verify that the Threshold settings are about **1.4V**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Press the **Display** tab at the left side of the control window. Notice the different display formats that are available.
- ❑ Select **Mixed** Busform Decode.

High-Speed USB Bus Setup and Decoding

Key Take Away Points

- NOTE: High-speed USB support is only offered on the ≥1 GHz MSO/DPO5204 and MSO/DPO5104 models, and requires differential probing of the USB signal.
- The High-speed USB signal display should look about like this:

MSO/DPO5000 Series Procedure:

- ❑ Attach a TDP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe + input to pin **1** and the probe – input to pin **2** on the **USB_HS** connector.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the **Menu** button on the TDP1000.
- ❑ Press the **Range** button on the probe to select **4.25V**.
- ❑ Set the Horizontal **Scale** to **10µs/div.**
- ❑ Set the Vertical **Scale** for channel 1 to **300 mV/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to about **-100 mV**.
- ❑ Position the waveform in the top half of the display as shown in the screen shot on the left.
- ❑ Press **Menu Off**.
- ❑ Press the front panel **Single** button.
- ❑ Turn the inner portion of the Pan / Zoom control and adjust the zoom factor to about 1000X to get a single packet in the zoom window.
- ❑ Turn the outer portion of the Pan / Zoom control to zoom in on the beginning of the packet.

Key Take Away Points

- The USB signal Define Inputs menu looks like this:

- Setting up a basic USB bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog inputs or math signals (since they must be differential signals) can be used as a source for the USB bus.
- When you zoom in on the decoded USB signals, you should see a display about like this:

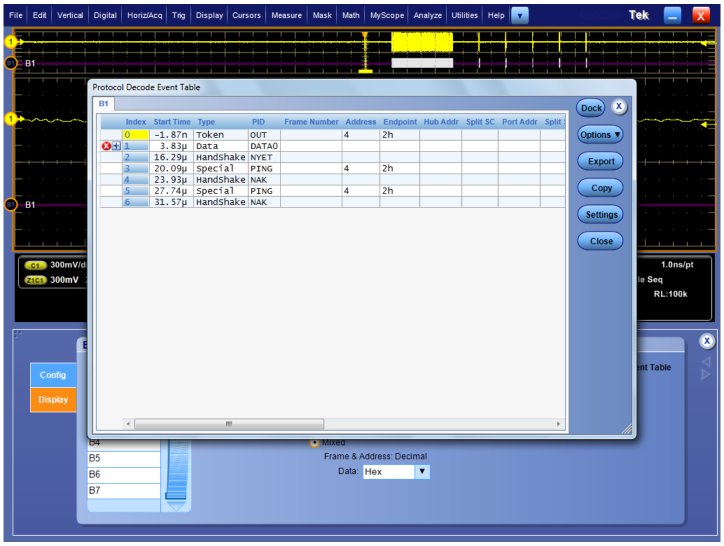
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button and select **Independent** under **Settings**. Or, right-click on the trigger readout and select **Settings->Independent**.
- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under **Bus Type**, select **Serial**.
- ❑ Using the drop down menu, select **USB**.
- ❑ Verify that the **Speed** is set to **High (480Mbps)**.
- ❑ Under **Signal Type**, select **Differential**.
- ❑ For component **D+/D-**, select **Ch1**.
- ❑ Using the Multipurpose **a** control, set the Threshold (H) level to **100 mV**.
- ❑ Use the Multipurpose **b** control to set the Threshold (L) level to **-100 mV**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Press the **Display** tab at the left side of the control window. Notice the different display formats that are available.
- ❑ Select **Mixed** Busform Decode.

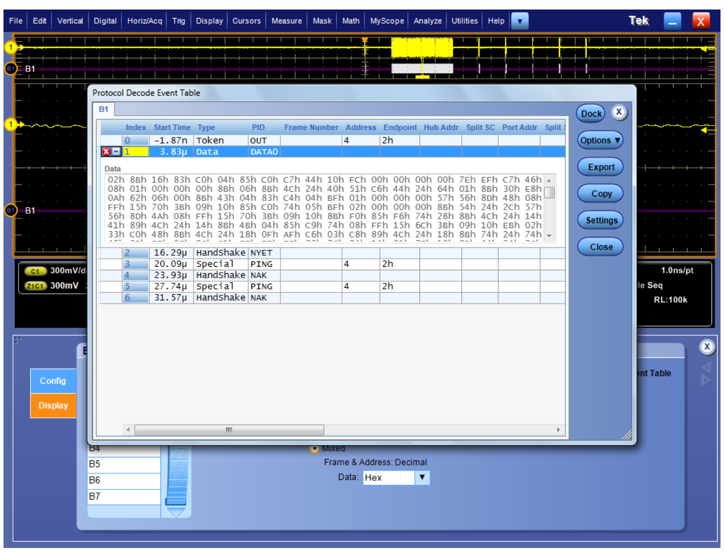
MSO/DPO5000 Series USB Bus Event Tables

Key Take Away Points

- Setting up a basic USB bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The USB bus event table display looks like this:



- When you expand the Data packet display in the USB bus event table, the display looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the **Protocol Decode Event Table** button.
- ❑ When you are done with the setup, press the **Close** button.

MSO/DPO5000 Series USB Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the USB serial bus.
- The MSO/DPO5000 Series can trigger on the following elements of a USB 2.0 bus:
    - Sync
    - Reset
    - Suspend
    - Resume
    - End of Packet
    - Token (address) Packet: Any token type, SOF, OUT, IN, SETUP; Address and End Point can be specified for Any Token, OUT, IN, and SETUP token types.
    - Data Packet: Any data type, DATA0, DATA1.
    - Handshake Packet: Any handshake type, ACK, NAK, STALL, NYET (HS only).
    - Special Packet: Any special type, PRE (FS only), ERR, SPLIT, PING, Reserved.
    - Error: PID check, CRC5 or CRC16, Bit stuffing (LS and FS only).
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on an USB signal, capturing each occurrence.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Touch the **Trigger Type** text box and select **Bus** triggering.
- ❑ Verify that Bus **B1** is selected.
- ❑ Press the **Mode** tab and press the **Normal** Trigger Mode button.
- ❑ Click on the **Trigger On** text box and select **Sync**.
- ❑ Press the front panel **Single** button.
- ❑ Press **Menu Off**.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the USB packets.

MSO/DPO5000 Series USB Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the USB serial bus.
- The MSO/DPO5000 Series can search on the same elements of a USB 2.0 bus:
  - Sync
  - Reset
  - Suspend
  - Resume
  - End of Packet
  - Token (address) Packet: Any token type, SOF, OUT, IN, SETUP; Address and End Point can be specified for Any Token, OUT, IN, and SETUP token types.
  - Data Packet: Any data type, DATA0, DATA1.
  - Handshake Packet: Any handshake type, ACK, NAK, STALL, NYET (HS only).
  - Special Packet: Any special type, PRE (FS only), ERR, SPLIT, PING, Reserved.
  - Error: PID check, CRC5 or CRC16, Bit stuffing (LS and FS only).
- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on a USB signal, marking each occurrence.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** button in the control window.
- ❑ Press the **Configure** tab at the left side of the control window.
- ❑ Verify that Bus **B1** is selected.
- ❑ Click on the **Search For** text box and select **Sync**.
- ❑ Adjust the zoom window as needed to view the USB packets.
- ❑ Using the front panel arrow buttons, navigate between search marks to see all occurrences of the USB Sync.
- ❑ Press the **Results** tab at the left side of the control window to display the table of search results.

MSO5000/DPO5000 Series
RS-232 / RS-422 / RS-485 / UART Triggering and Decoding Lab

Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-COMP option installed
One TPP0500 or TPP1000 passive probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo board]

Understanding the RS-232 Bus

RS-232 stands for **R**ecommended **S**tandard 232, a communication standard from the **E**lectronic **I**ndustries **A**lliance (EIA), which was developed in the early 1960s for interconnection between teletype terminals and modems. The standard was updated to RS-232**C** in 1969 to specify electrical signal characteristics, mechanical interconnects, etc.

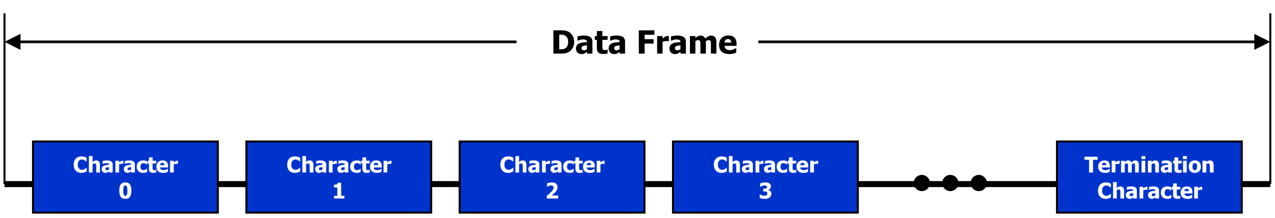
RS-232 provides two single-ended signals for point-to-point, full-duplex communication (simultaneous transmitted and received data). The standard does not specify character encoding, data framing, or protocols. It was designed for short-distance, low-speed serial data communication. Although the maximum cable length is not specified, a distance of less than 15 meters is recommended. The maximum data rate is not also specified, but rates <20 kb/s are recommended.

RS-232 data transmission is asynchronous, meaning that the clock is not transmitted and must be programmed in advance at both the transmitter and the receiver. Each character begins with a start bit, a high value which equates to a logic “0”. The character is comprised of 7 or 8 data bits, which must also be programmed. The data bits are transmitted in least-significant to most-significant bit order. The optional Parity bit is next. If not used, the bit is ignored. If used, the polarity must be programmed, and provides simple error detection by indicating whether there are an odd or even number of “1s” in the data word. Finally, the character is usually terminated in one to two stop bits.

Start	Data 0	Data 1	Data 2	Data 3	Data 4	Data 5	Data 6	opt. Data 7	opt. Parity	Stop	opt. Stop
1-bit	1-bit	1-bit	1-bit	1-bit	1-bit	1-bits	1-bit	1-bit	1-bit	1-bit	1-bit

Each RS-232 character can be encoded in various formats, but ASCII format is most commonly used. ASCII, short for **A**merican **S**tandard **C**ode for **I**nformation **I**nterchange, is a 7-bit code (a range from 0 to 127) which is used to represent characters. Of the 128 possible codes, 95 (numbered 32 to 126) represent printable characters. Many of the remaining non-printing characters are control characters which control how text is processed. (Examples of control characters include backspace, tab, carriage return, and line feed.) Since most computer memories are based on 8-bit bytes, the eighth bit of the stored ASCII character can be used for parity, a simple error-detection scheme. (An ASCII conversion chart is included later in this lab document.)

The RS-232 standard does not specify how data content is framed or grouped, but a common technique is to end a data frame with a pre-determined termination character such as carriage return, line feed, or null.



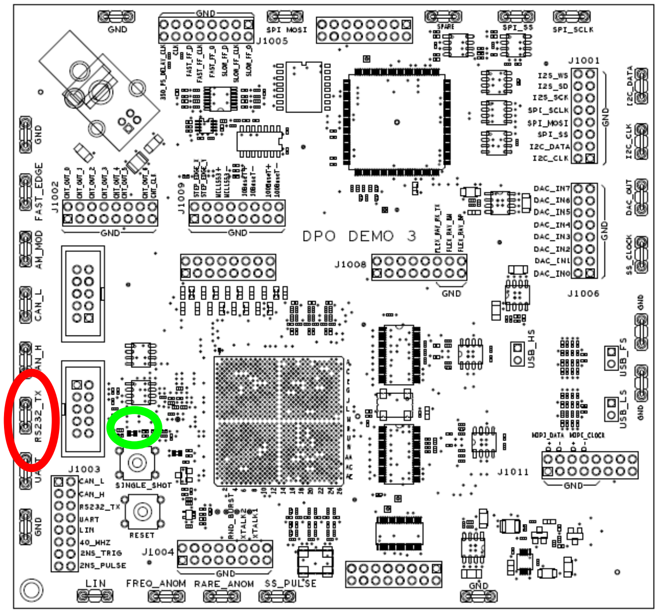
Lab Objectives

- Obtain a basic understanding of the RS-232 serial bus.
- Learn how to use oscilloscopes to measure and decode RS-232 signals.
- Learn how to setup an RS-232 serial bus display and trigger and search on RS-232 packet content with an MSO/DPO5000 Series oscilloscope.

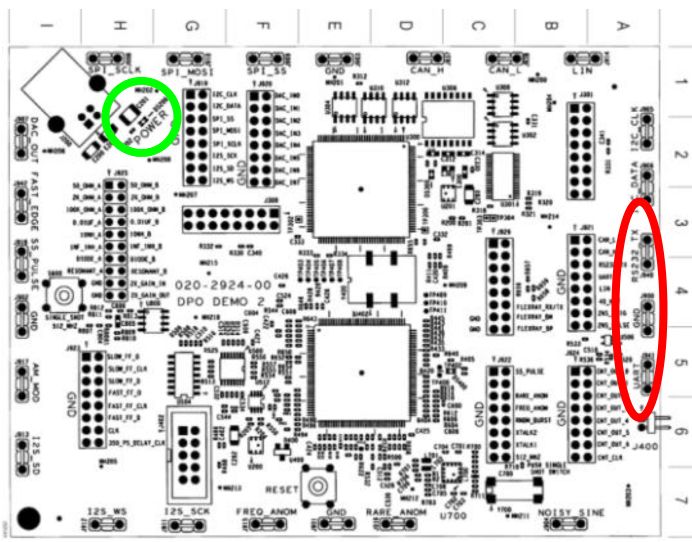
MSO/DPO5000 Series Lab Setup	
Key Take Away Points • RS-232 and related serial buses are industry standards and can be found in many embedded designs today. • Traditional manual decoding methods to decode these buses with an oscilloscope are time-consuming. • With the SR-COMP option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search RS-232, RS-422, RS-485, and UART serial bus traffic.	**MSO/DPO5000 Series Procedure:** ❑ Power up the oscilloscope. ❑ Select **Help -> About TekScope…**. ❑ Verify that the **SR-COMP: Computer Serial Triggering and Analysis** option is installed. ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has an RS-232 signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has RS-232 and UART signals which we can use for this lab:



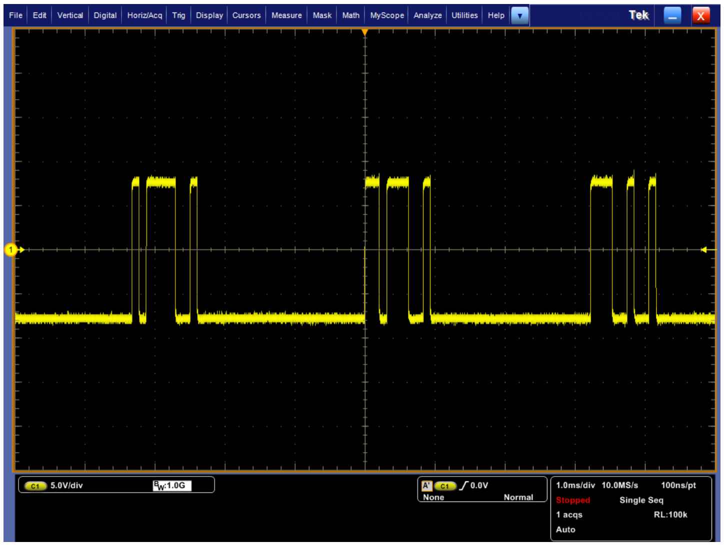
DPO Demo Board Procedure:

- ❑ Power up the DPO demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **RS232_TX** test point.

Manual RS-232 Bus Decoding

Key Take Away Points

- Notice that RS-232 signals are generally large signals, going positive and negative, with amplitudes from 3V to 15V peak. These large amplitudes provide a very simple immunity from noise.
- The display should look about like this:



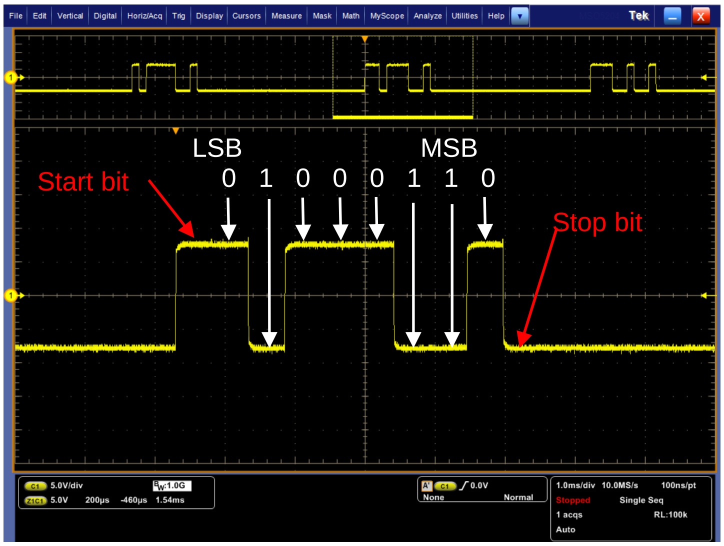
- Zoom in on one of the bursts of activity. This is a single RS-232 character. The display should look something like this:

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set the channel **1** Vertical **Scale** to **5V/div**.
- ❑ Use the Trigger **Level** control to adjust the trigger level to the center of the waveform, about **0V**.
- ❑ Set the Horizontal **Scale** to **1ms/div**. This setting should allow a few bursts (RS-232 characters) to be displayed on screen.
- ❑ Press the front panel **Single** button.
- ❑ Using the **Wave Inspector** pan and zoom controls, zoom in on one whole burst of signal.

Key Take Away Points

- Notice the relatively long idle periods between signal bursts where the signal is low.
- The RS-232 character begins with a positive pulse after the idle period.
- The data bits come next, starting with the least-significant bit and ending with the most-significant bit. (In this case, we know that there are 8 data bits and no parity bit.) Low signals are digital 1s and high signals are digital 0s.



- The binary message above, written in most- to least-significant bit order is 01100010. This can also be written as 62 (hex) or ASCII “b”, as shown below.
- Most engineers would prefer to use hexadecimal or “hex” notation, rather than binary. You can use the following chart to translate each group of 4 binary bits to a hex character:

Binary	Hex		Binary	Hex
0000	0		1000	8
0001	1		1001	9
0010	2		1010	A
0011	3		1011	B
0100	4		1100	C
0101	5		1101	D
0110	6		1110	E
0111	7		1111	F

- Since RS-232 is often used to transmit text characters, an even more popular code is ASCII. You can use the following chart to translate each hex character to a text character:

MSO/DPO5000 Series Procedure:

- ❑ Identify the start bit of the RS-232 character.
- ❑ Visually divide the rest of the character into 8 equal sections.
- ❑ If the signal is low in any of the 8 sections, write a “1” in the corresponding space below. If the signal is high in any of the 8 sections, write a “0” in the corresponding space below. (See example at the left.)

LSB MSB

___ ___ ___ ___ ___ ___ ___ ___

- ❑ Now, swap the order of the bits you wrote down, and divide the 8 bits into two 4-bit groups (“nibbles”). This is the binary representation of the RS-232 character. Write the binary character in the reverse order:

MSB LSB

___ ___ ___ ___ ___ ___ ___ ___

- ❑ Now, using the table at the left, translate the character to hex and write the hex value below.

___ ___

- ❑ Finally, using the hex-to-ASCII table, translate the character to hex and write the value below.

___

Dec	Hx	Oct	Char		Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL	(null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH	(start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX	(start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX	(end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT	(end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ	(enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK	(acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL	(bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB	(horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF	(NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT	(vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF	(NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR	(carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO	(shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI	(shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE	(data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1	(device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2	(device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3	(device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4	(device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK	(negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN	(synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB	(end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN	(cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM	(end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB	(substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC	(escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS	(file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS	(group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS	(record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US	(unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

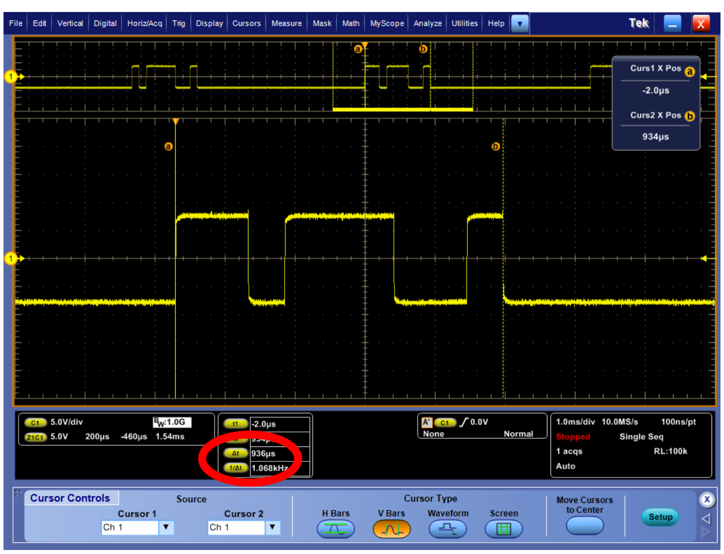
Conclusion: Manually decoding RS-232 data is a time-consuming process. Engineers are looking for a better and faster way to do this.

MSO/DPO5000 Series RS-232 Decoding Setup

(optional) Determining RS-232 Bus Data Rate

- The data rate of the RS-232 signal on both of the DPO demo boards is 9600 bits/second (also sometimes called “9600 baud”). However, in general, you may need to determine the data rate using this procedure.
- In addition to the long list of preset bit rate values from 50 bps to 10 Mbps, the custom bit rate control allows the user to set the bit rate to any value between 50 bps and 10 Mbps in fine steps (which vary with the setting of the front panel Fine mode and also vary with the baud rate).
- The display should look about like this:

- Since the minimum pulse width is 104 μs, the data rate is verified to be 9600 bits/second. This signal uses 8 data bits with no parity. The display should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ Using the **Wave Inspector** controls, zoom in on the narrowest pulse on the display.
- ❑ Press the front panel **Cursors** button.
- ❑ Using the Multipurpose controls, measure the width of the narrowest pulse by positioning the cursor cross-hairs near the center of the rising and falling edges of the pulse.
- ❑ Read the bit rate (1/Δ time in the cursor readout) and write the value here: ______
- ❑ Read the pulse width (Δ time in the cursor readout) and write the value here: ______
- ❑ Using the **Wave Inspector** controls, zoom in on one whole burst of signal.
- ❑ Using the Multipurpose controls, measure the width of the burst.
- ❑ Read the burst width (Δ time in the cursor readout) and write the value here: ______
- ❑ Divide this value by the pulse width value you recorded earlier, and subtract one (for the Start Bit). Assuming that there is no Parity bit being used, the result is the number of data bits (7 or 8).

  ______
- ❑ Press the front panel **Cursors** button once to turn off cursors.

MSO/DPO5000 Series RS-232 Bus Decoding

Key Take Away Points

- As you personally experienced in the last part of the lab, manually decoding RS-232 signals can be a time-consuming process. In this section, you will learn how to use the MSO/DPO5000 Series to automatically decode RS-232 packet content.
- Setting up a basic RS-232 bus waveform display takes only a few simple steps with the MSO/DPO5000 Series. Notice that any of the analog or digital inputs or math signals can be used as a source for the RS-232 bus.
- The display should now look about like this, with the hexadecimal decoded value shown in the bus waveform:

- A lot simpler than manually decoding the data!

MSO/DPO5000 Series Procedure:

- ❑ Continue with same setup as previous lab.
- ❑ Position the channel 1 waveform in the upper half of the display.
- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under Bus Type, select **Serial**.
- ❑ Using the drop down menu, select **RS232**.
- ❑ Set the **Data** Components signal source to **Ch1**.
- ❑ Double-click on the Threshold text box and set the value to **0V**.
- ❑ The default RS-232 bus values in the MSO/DPO5000 Series were chosen to match the signal on the DPO demo board, so many of the steps to the right have already been done for you.
- ❑ For RS-232 transmitted signals which idle in the low-voltage state, select **Normal** Polarity (High = 0). For RS-422, RS-485, and UART signals, select **Inverted** Polarity (High = 1).
- ❑ Using the Baud Rate drop down menu, select **9600** bps.
- ❑ Using the **Data Bits** drop down menu, select **8** bits.
- ❑ Using the **Parity** drop down menu, select **None**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Using the **Bus 1 Position** control, position the bus waveform as desired for easy viewing.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Under Bus 1 Display, verify that **Busform** Style and **Hex** Decode are selected.

Key Take Away Points

- Although the analog waveform display and the busform with hex values is familiar to most hardware engineers, there are another display formats that other engineers, such as software engineers, may find more useful.
- The bus Waveform display shows the digital interpretation of the signal. This can be very useful for verifying that the threshold values are set appropriately.
- In the case of RS-232 transmitted signals, ASCII is a common display format, especially when transmitting text messages. The display should now look something like this, with the ASCII decoded value shown in the bus waveform:

- With this display, you can easily see the transmitted text message “Tektronix Enabling Innovation”:

MSO/DPO5000 Series Procedure:

- ❑ Select **Both Bus Components**.
- ❑ Select the **ASCII** Bus 1 Display format.
- ❑ Change the Horizontal **Scale** to **5 ms/div**.
- ❑ Turn off zoom.
- ❑ Press the front panel **Single** button.

Key Take Away Points

- For some applications, it is more useful to be able to display the text strings that are transmitted.
- With the packet view display, you can easily see the transmitted text message “Tektronix Enabling Innovation”:

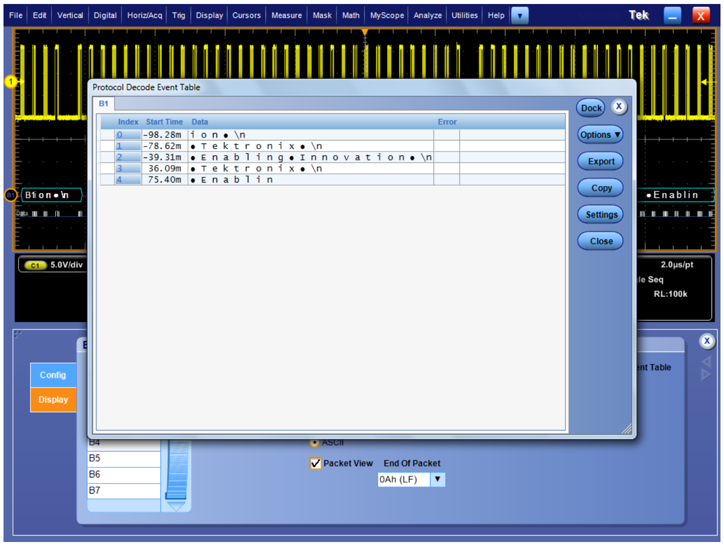
MSO/DPO5000 Series Procedure:

- ❑ Change the Horizontal **Scale** to **20 ms/div**.
- ❑ Press the front panel **Single** button.
- ❑ Select **Packet View**.
- ❑ Press the down arrow next to the End Of Packet text box. Notice the available packet termination characters. In this case, use the default 0Ah (LF) Line Feed character to terminate each packet.

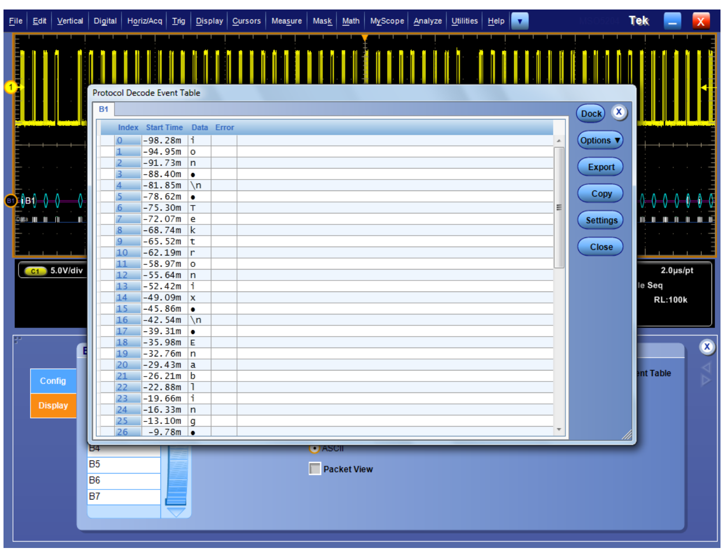
MSO/DPO5000 Series RS-232 Bus Event Tables

Key Take Away Points

- Setting up a basic RS-232 bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The RS-232 bus Event Table display looks like this when the decode is set to Packet View:



- The RS-232 bus Event Table display looks like this when the decode is set to ASCII character display:



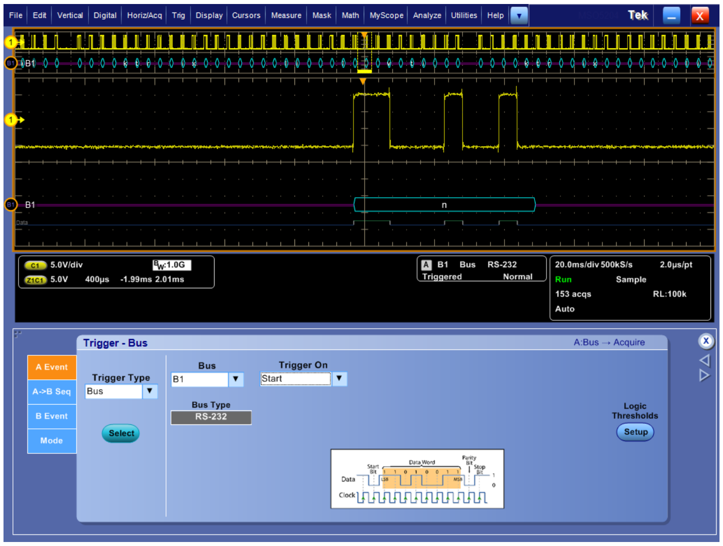
MSO/DPO5000 Series Procedure:

- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Close** button.
- ❑ Deselect **Packet View**.
- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Export** button. Notice that you can save the Event Table information to a file in.CSV format. When you are done, either **Save** the file or press **Cancel**.
- ❑ When you are done with the setup, press the **Close** button.

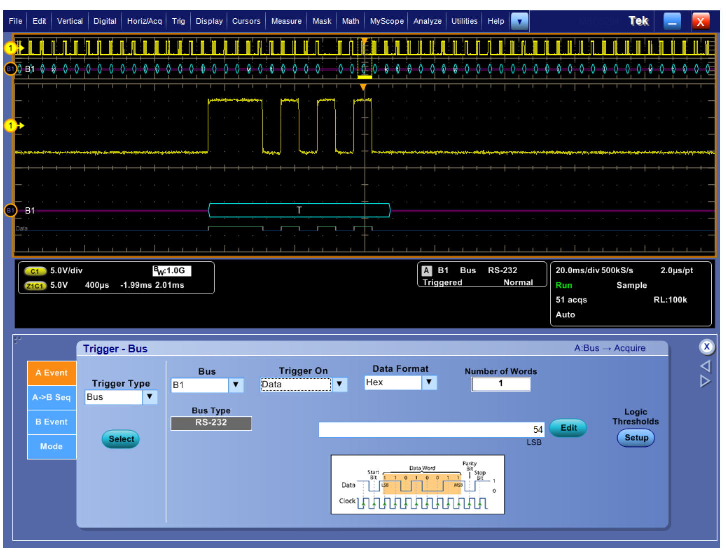
MSO/DPO5000 Series RS-232 Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the RS-232 serial bus.



- The MSO/DPO5000 Series can trigger on the Start Bit, End of Packet, Data value, or Parity Error.
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern, capturing each occurrence.



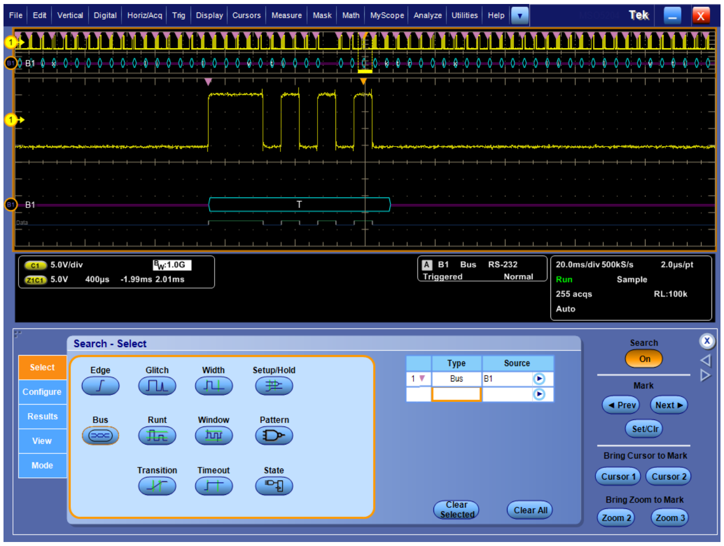
MSO/DPO5000 Series Procedure:

- ❑ Draw a box around the packet at the trigger point and select **Zoom 1 On**.
- ❑ Press the front panel Trigger **Menu** button.
- ❑ Using the Trigger Type drop down menu, select **Bus** triggering.
- ❑ Using the **Bus** drop down menu, select **B1**.
- ❑ Press the front panel **Run/Stop** button to re-start acquisitions.
- ❑ Press the **Mode** tab and press the **Normal** Trigger Mode button.
- ❑ Press the **A Event** tab.
- ❑ Using the **Trigger On** drop down menu, select **Data**.
- ❑ The easiest way to enter the address is with the Pattern Editor. Press the **Edit** button at the right.
- ❑ Select **Hex** format.
- ❑ Double click on the **Data Value** text box and set the ASCII data pattern to 0x54 to capture the 'T' character at the start of the "Tektronix" message.
- ❑ When you are done, press **OK**.
- ❑ Press the front panel **Run/Stop** button to re-start acquisitions.
- ❑ Adjust the Wave Inspector **Pan** control as needed.

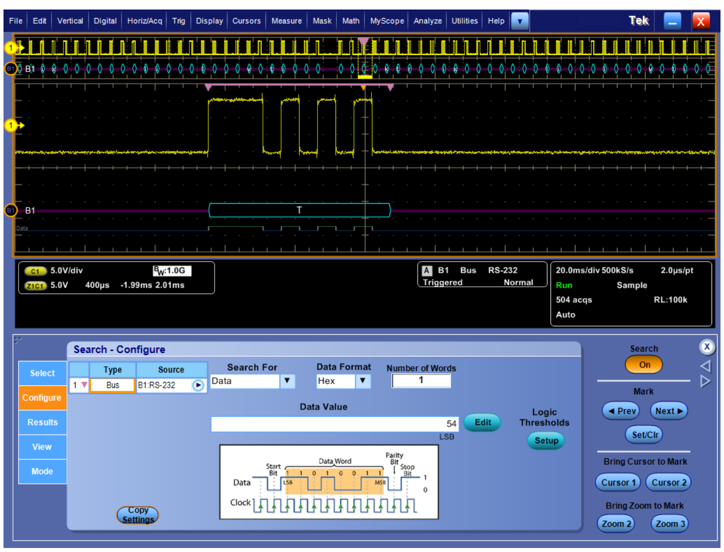
MSO/DPO5000 Series RS-232 Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the RS-232 serial bus.



- The MSO/DPO5000 Series can search on the Start Bit, End of Packet, Data value, or Parity Error.
- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on a RS-232 signal, marking each occurrence.

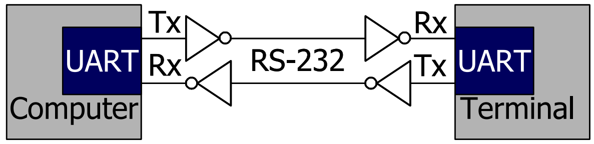


MSO/DPO5000 Series Procedure:

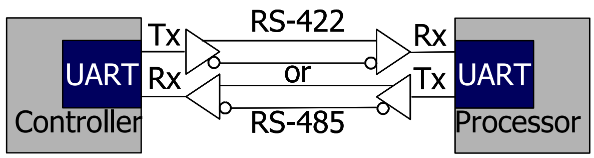
- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** Search button in the control window.
- ❑ Select the **Configure** tab at the left side of the control window.
- ❑ Using the **Search For** drop down menu, select **Data**.
- ❑ The easiest way to enter the address is with the Pattern Editor. Press the **Edit** button at the right.
- ❑ Select **Hex** format.
- ❑ Double click on the **Data Value** text box and set the ASCII data pattern to 0x54 to search for the 'T' character at the start of the "Tektronix" message.
- ❑ When you are done, press **OK**.
- ❑ You can also do the same by pressing the **Copy Settings** button.
- ❑ Press the front panel **Run/Stop** button to restart acquisitions.
- ❑ Adjust the zoom window as needed to view the RS-232 packets.

MSO/DPO5000 Series Support for RS-232-related Standards

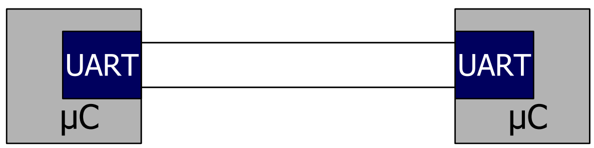
RS-232 is primarily focused on applications where these serial signals are transmitted between modules, over cables, and between products. RS-232 signals are transmitted single-ended, at relatively high voltage (up to ±15V), and inverted (so a digital 0 is a positive voltage and a 1 is a negative voltage).



RS-232 application example



Audio / video application example



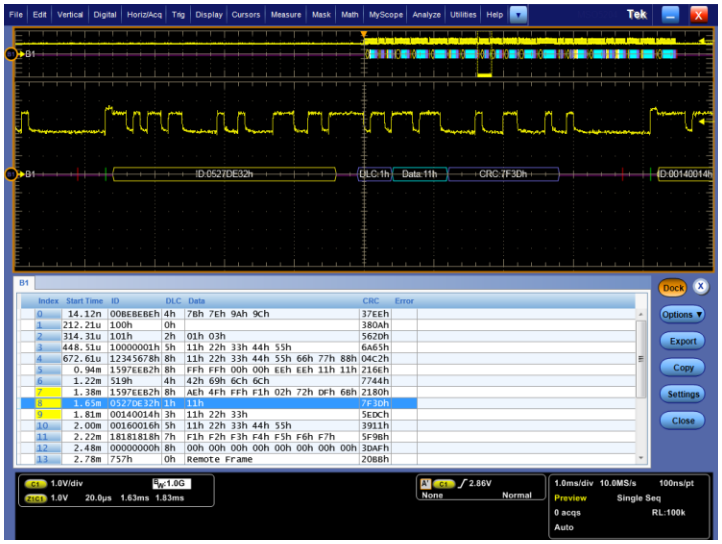
Embedded communication application example

There are two other types of variants on the RS-232 family that are also addressed with the COMP option.

The first is differential signaling, such as with the RS-422 and RS-485 standards. These standards specify transmission of a lower-voltage differential signal which is not inverted. Although one side of these differential signals can be probed with a passive probe, the TDP0500 and TDP1000 differential probes will provide better signal fidelity, especially in noisy environments.

The second variant on RS-232 signals is the transmission of these serial signals between components on a single circuit board. This embedded system application, most commonly communication between a microcontroller and a Universal Asynchronous Receiver / Transmitter (UART) or RS-232 driver/receiver IC. These signals are single-ended and non-inverted, with standard logic levels.

For both of these non-inverting RS-232 variants, you need to select Inverted Polarity in the Bus Setup control window. Otherwise, the signals are treated like RS-232 signals.



Equipment List

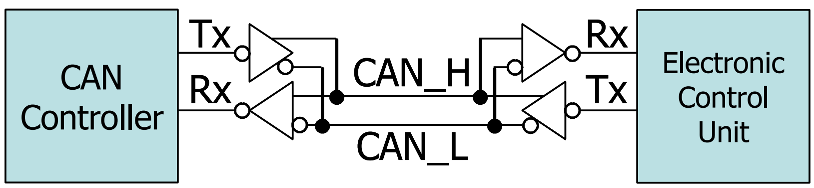
One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-AUTO option installed
One TPP0500 or TPP1000 passive probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo 3 board]

Understanding the CAN Bus

CAN (Controller Area Network) was developed by the Robert Bosch GmbH, in Germany, during the late 1980's. The need to specifically control and communicate with electronic control devices (ECUs) in electrically noisy environments was a driving force behind CAN. In 1992, Mercedes-Benz became the first automobile manufacturer to employ CAN in their higher end cars. Today almost every car manufacturer in the world employs CAN controllers and networks in systems such as windshield wiper motor controllers, rain sensors, airbags, door locks, engine timing controls, anti-lock braking systems, power train controls and electric windows, to name a few. CAN is rapidly expanding into other applications like industrial control, marine, medical, and aerospace.

CAN is a two-wire, half-duplex, high-speed serial communications bus. It is a layered protocol where the transmission and physical layers are of primary interest here. Because CAN is an asynchronous the bus can be utilized as a differential balanced line similar to RS-232 but allows multiple masters on the same network. Data rates range from 10 Kbps (<6km) to 1Mbps (<40m) with a tradeoff between speed and bus length, decreasing the bit rate allows for longer bus lengths. Typically CAN is used for system-to-system communication between nodes (transceivers and receivers) which communicate on the bus by messages similar to Ethernet.

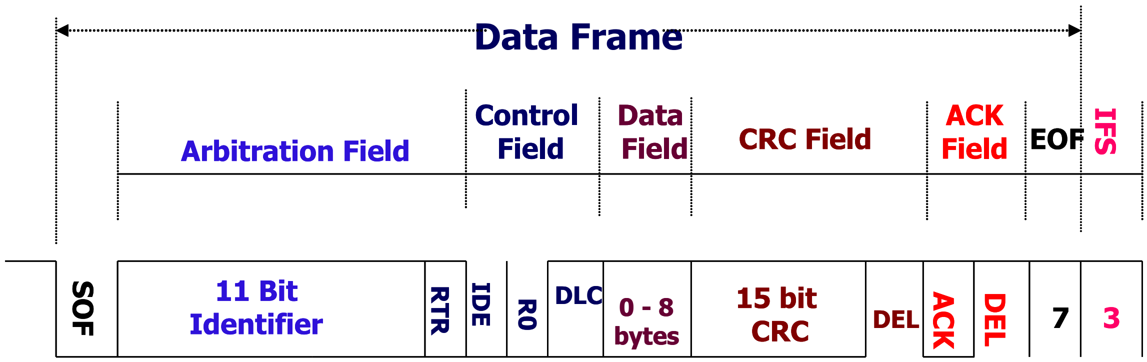
There are a variety of CAN signals, as shown in the figure below. The transmitted data (Tx) and received data (Rx) signals are single-ended digital signals which are found at the inputs and outputs of devices such as CAN controllers and Electronic Control Units (ECUs). The messages transmitted between modules and products are carried on an inverted differential signal. The differential signal can be measured, or the individual signals (CAN_H and CAN_L) can be measured individually (if the signal-to-noise ratio is adequate). Because the signal amplitudes, polarities, and DC offsets vary between these different signals, you need to adjust your measurement setup and decoding method accordingly.



CAN signals

Identifiers, Arbitration and Frames

CAN data messages are transmitted from any node by identifier (ID) not by address or data. Before a node sends a message out to another node it checks if the bus is busy - two nodes on the same network are not allowed to send messages at the same time – a node can detect if it has lost arbitration and stops transmitting, letting the other node, with the higher priority transmit uninterrupted. A CAN message is created using frames. The frames of interest are: Data Frames, Standard (11 bit ID) and Extended (29 bit ID). Both Data Frames can hold 0 to 8 bytes of data and are used when a node wants to transmit data on the network. Remote Frames are used to request information and the node having the information should then respond by sending it on the network. Error Frames are used to signal an error and can be transmitted by any node. Overloaded Frames are used to provide extra delay between data and remote frames when a node is busy.



Bit stuffing

In CAN frames a bit of opposite polarity is inserted after five consecutive bits of the same polarity. This practice is called bit stuffing, and is due to the Non-Return-to-Zero (NRZ) coding. The "stuffed" data frames are un-stuffed by the receiver. Since bit stuffing is used, six consecutive bits of the same type (111111 or 000000) are considered an error. The bits in a CAN message are sent either high or low: high bits are recessive; low bits are dominant.

Lab Objectives

- Obtain a basic understanding of the CAN serial bus.
- Learn how to use oscilloscopes to measure and decode CAN signals.
- Learn how to setup a CAN serial bus display, and trigger and search on CAN bus content with an MSO/DPO5000 Series oscilloscope.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

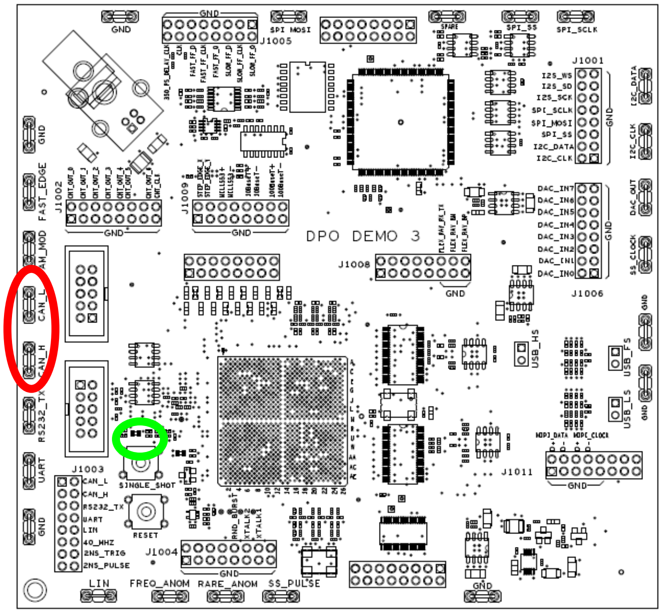
- CAN serial buses are industry standards and can be found in many embedded designs today.
- Traditional manual decoding methods to decode these buses with an oscilloscope are time-consuming.
- With the SR-AUTO option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search CAN bus traffic.

MSO/DPO5000 Series Procedure:

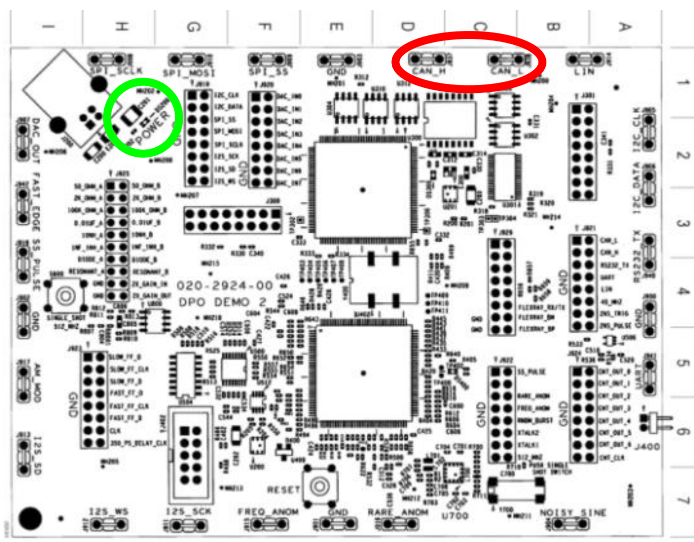
- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope….**
- ❑ Verify that the **SR-AUTO: Automotive Serial Triggering and Analysis (CAN/LIN/FlexRay)** option is installed.
- ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has CAN signals which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has CAN signals which we can use for this lab:



DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **CAN_H** test point.

Manual CAN Bit Rate Measurement

Key Take Away Points

- On the DPO Demo 3 and DPO Demo 2 boards, the CAN bit rate is 500 kbps.
- With the SR-AUTO option, the MSO/DPO5000 provides a list of common bit rate values to choose from, ranging from 10 kbps to 1 Mbps.
- However, in general, you may not know what the bit rate is. Because CAN is an asynchronous bus, you must accurately determine the bit rate before the bus can be properly decoded. This section of the lab explains how to measure the CAN bit rate. The display should look about like this:

- The cursor measurement of the pulse width of the narrowest pulse indicates a 2 µs minimum pulse width. Compare this pulse width with the values in the following chart to determine the CAN bit rate:

Minimum CAN Pulse Width	CAN Bit Rate
1 µs	1 Mbps
1.25 µs	800 kbps
2 µs	500 kbps
4 µs	250 kbps
8 µs	125 kbps
12 µs	83.3 kbps
16 µs	62.5 kbps
20 µs	50 kbps
30 µs	33.3 kbps
50 µs	20 kbps
100 µs	10 kbps

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set channel 1 Vertical **Scale** to **1V/div.**
- ❑ Set the Horizontal **Scale** to **1ms/div.**
- ❑ Press the Trigger **Level** control to automatically adjust the trigger level to the center of the AC portion of the CAN signal, about 3V.
- ❑ Press the front panel **Single** button.
- ❑ Using the mouse or the touch screen, draw a narrow zoom box around the trigger point at the center of the display and select **Zoom 1 On**.
- ❑ If necessary, zoom again on the waveform to resize the zoom box
- ❑ Press the front panel **Cursors** button once.
- ❑ Using the Multipurpose **a** and **b** controls, position the cursors on the rising and falling edge of a narrow pulse to measure the pulse width.
- ❑ When done, press the front panel **Cursors** button once.

MSO/DPO5000 Series CAN Bus Setup and Decoding

Key Take Away Points

- Setting up a basic CAN bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog or digital inputs or math signals can be used as a source for the CAN bus. For example, you can probe CAN_H with a passive probe on channel 1 and CAN_L with a passive probe on channel 2 and decode the differential math signal M1 = Ch1-Ch2.
- The CAN Bus Setup menu looks like this:

- The CAN bus Display menu looks like this:

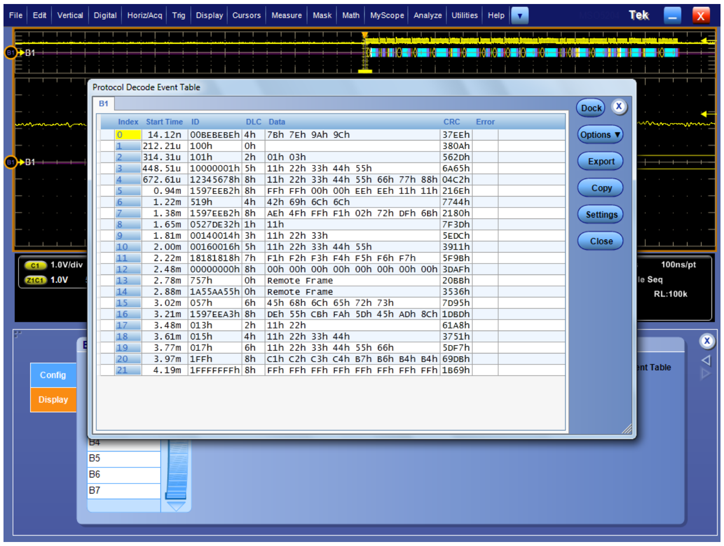
MSO/DPO5000 Series Procedure:

- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under Bus Type, select **Serial**.
- ❑ Using the drop down menu, select **CAN**.
- ❑ Verify that the **CAN_H** input signal is set to Ch1.
- ❑ Verify that the Threshold settings are about **3V**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Under Bus 1 Display, verify that **Busform** Style is selected.
- ❑ Select **Hex** Decode.
- ❑ Adjust the zoom factor and position of the zoom window to view the decoded bus information.
- ❑ The green bar symbol represents the start of packet.
- ❑ ID packets are shown in yellow boxes.
- ❑ Missing Acks are shown as red '!' symbols.
- ❑ Data packets are shown in cyan boxes.
- ❑ DLCs and CRCs are shown in blue boxes.
- ❑ Errors are shown in red boxes.
- ❑ The red bar symbol represents the end of the CAN packet.

MSO/DPO5000 Series CAN Bus Event Tables

Key Take Away Points

- Setting up a basic CAN bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The CAN bus event table display looks like this:



- The docked CAN bus event table display looks like this:

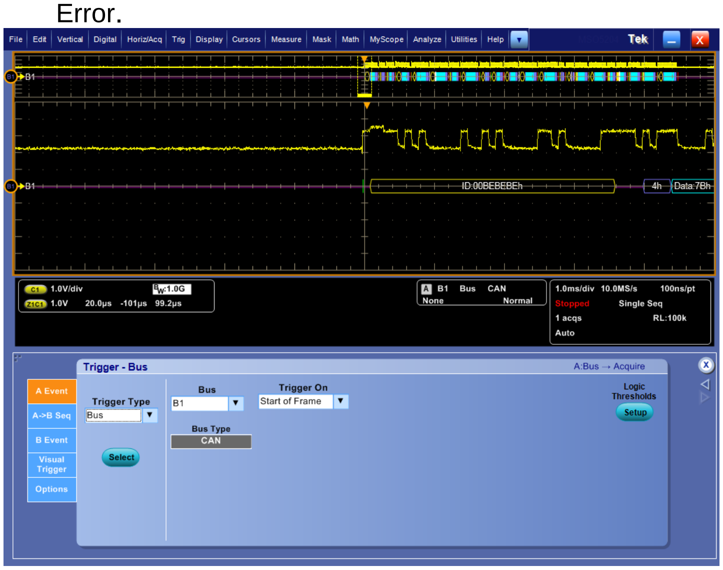
MSO/DPO5000 Series Procedure:

- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Dock** button.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Click on one of the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.
- ❑ When you are done with the event table, press the **X** in the upper right corner to close it.

MSO/DPO5000 Series CAN Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the CAN serial bus.
- NOTE: The trigger source must be an input channel. If you are decoding a bus based on a math signal, simply set up another bus based on an input channel and trigger on that bus.
- The MSO/DPO5000 Series can trigger on Start of Frame, Type of Frame (Data, Remote, Error, Overload), Identifier, Data, Ident & Data, EOF, Missing Ack, and Bit Stuffing Error.



- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a CAN signal, capturing each occurrence.

MSO/DPO5000 Series Procedure:

- ❑ Select **Trig->Bus Setup….**
- ❑ Using the Bus drop down menu, select **B1**.
- ❑ Notice that, by default, Trigger On **Start of Frame** is selected.
- ❑ Press the front panel **Single** button.
- ❑ Using the **Trigger On** drop down menu, select **Identifier**.
- ❑ Select **Hex Standard** format.
- ❑ Press the **Edit** button.
- ❑ Enter the identifier value **757** hex. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ In the **Direction** section, select **Read and Write**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the MultiView Zoom pan and zoom controls as needed to view the CAN packets.

MSO/DPO5000 Series CAN Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the CAN serial bus.

- The MSO/DPO5000 Series can search on Start of Frame, Type of Frame (Data, Remote, Error, Overload), Identifier, Data, Ident & Data, EOF, Missing Ack, and Bit Stuffing Error.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** button in the control window.
- ❑ Press the **Configure** tab at the left side of the control window.
- ❑ Notice that, by default, Search For **Start of Frame** is selected.
- ❑ Using the front panel left and right arrows, navigate between search events.

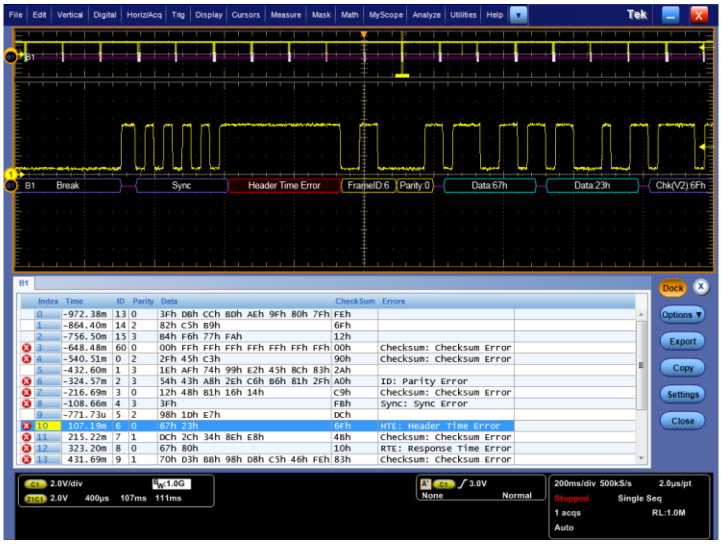
Key Take Away Points

- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on a CAN signal, marking each occurrence.

- The Results Table looks like this:

MSO/DPO5000 Series Procedure:

- ❑ Using the **Search For** drop down menu, select **Identifier**.
- ❑ Select **Hex Standard** format.
- ❑ Press the **Edit** button.
- ❑ Enter the identifier value **057** hex. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ In the **Direction** section, select **Read and Write**.
- ❑ Using the front panel left and right arrows, navigate between search events.
- ❑ Press the **Results** tab at the left side of the control window to display the table of search results.



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-AUTO option installed
One TPP0500 or TPP1000 passive probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo 3 board]

Understanding the LIN Bus

Local Interconnect Network (LIN) is one of the older low-speed serial standards for the automotive industry, developed by the LIN consortium in 1999 as a lower-cost alternative to the CAN bus for applications where CAN's cost, versatility, and speed were overkill. LIN applications typically include communications between intelligent sensors and actuators such as window controls, door locks, rain sensors, windshield wiper controls, and climate control, to name a few. However, due to its electrical noise tolerance, error-detection capabilities, and high speed data transfer, CAN is still used today for engine timing controls, anti-lock braking systems, power train controls and more.

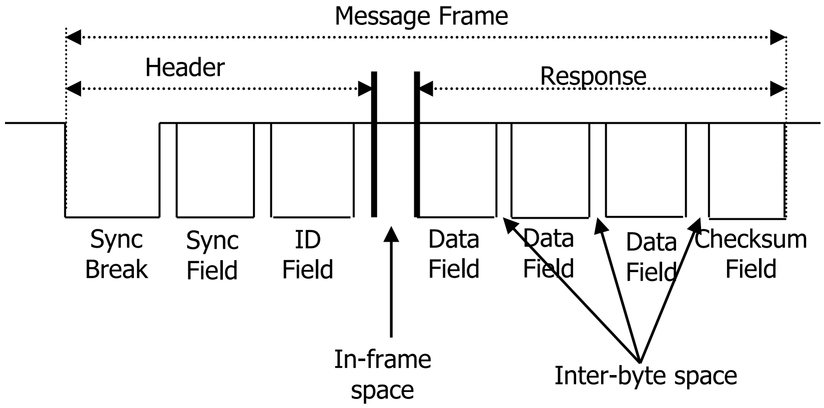
The LIN bus is a low-cost, single-wire implementation based on the Enhanced ISO9141 standard. LIN networks have a single master and one or more slaves. LIN signals can be transmitted over distances up to 40 meters. All messages are initiated by the master with only one slave responding to each message, so collision detection and arbitration capabilities are not needed as they are in CAN. Communication is based on UART/SCI with data being sent in eight-bit bytes along with a start bit, stop bit and no parity. Data rates range from 1kb/s to 20kb/s. While this may sound slow, it is suitable for the intended applications and minimizes EMI.

LIN signal level are defined as follows:

- Recessive (high) ≥0.6 * system supply voltage
- Dominant (low) ≤0.4 * system supply voltage

The LIN bus is always in one of two states: active or sleep. When it's active, all nodes on the bus are awake and listening for relevant bus commands. Nodes on the bus can be put to sleep by either the Master issuing a Sleep Frame or the bus going inactive for longer than a predetermined amount of time. The bus is then awakened by any node requesting a wake up or by the master node issuing a break field.

LIN frames consist of two main parts, the header and the response. The header is sent by the master while the response is sent by the slave. The LIN message frame looks like this:



Header Components:

- Sync Break – marks the beginning of the Message Frame. It activates and instructs all slave devices to listen to the remainder of the header.
- Sync Field – an alternating bit pattern which is used by the slave nodes for determination of the baud rate being used by the master node and synchronize themselves accordingly.
- Identifier Field –specifies which slave device is to take action. The ID Field contains four elements:
  - Message Identifier: identifies the sender, the receiver, the purpose, and data field length 6 Bit
  - 4 classes of 2/4/8 data bytes
  - 16 identifiers
  - 2 parity bits

Response Components:

- Data – the specified slave device responds with one to eight bytes of data
- Checksum – computed field used to detect errors in data transmission. The LIN standard has evolved through several versions that have used two different forms of checksums. Classic checksums are calculated only over the data bytes and are used in version 1.x LIN systems. Enhanced checksums are calculated over the data bytes and the identifier field and are used in version 2.x LIN systems.

The LIN bus transmits signals in three ways:

- **Unconditional**: The most typical LIN frame where the bus master sends the frame header in a scheduled frame slot and the designated slave node fills the frame with data.
- **Event-triggered**: Receives maximum information from slave nodes without overloading bus. Event Triggered Frames can be filled with data from multiple slave nodes.
- **Sporadic**: Sent only from master when a signal is updated in a slave node. Usually the master fills the data bytes of the frame and slave nodes receive information.

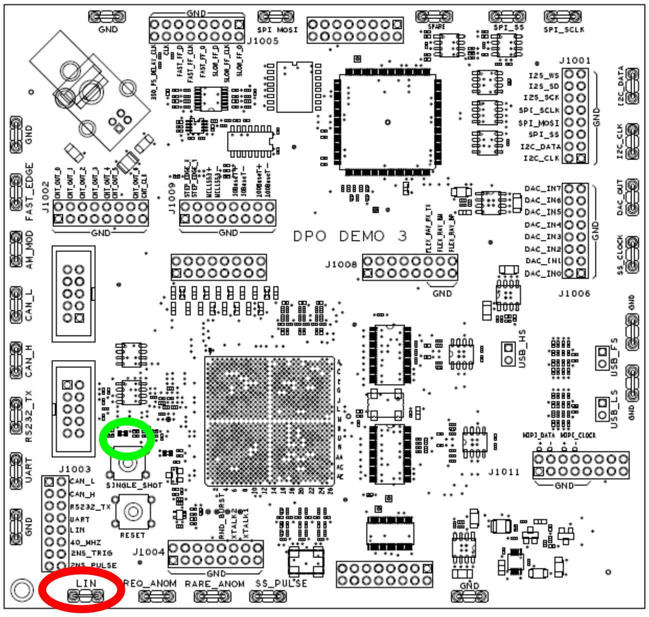
Lab Objectives

- Obtain a basic understanding of the LIN serial bus.
- Learn how to use oscilloscopes to measure and decode LIN signals.
- Learn how to setup a LIN serial bus display and trigger and search on LIN bus content with an MSO/DPO5000 Series oscilloscope.

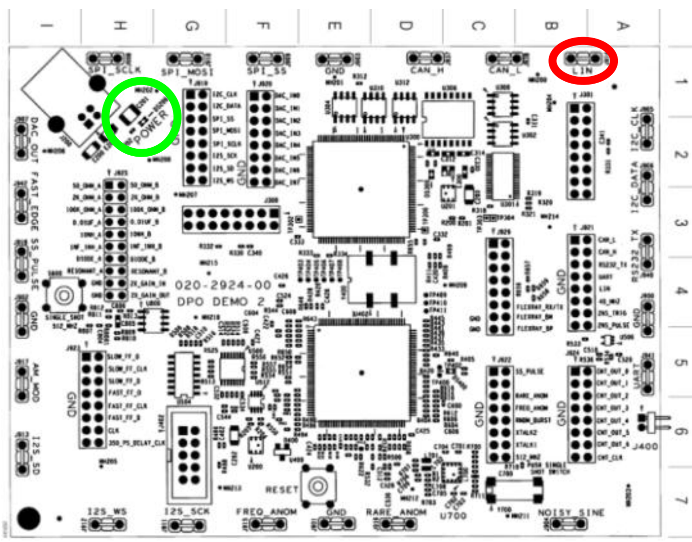
<table>
<tr><th colspan="2">MSO/DPO5000 Series Lab Setup</th></tr>
<tr><td>Key Take Away Points
The LIN bus is an industry standard and can be found in many automotive designs today.
Traditional manual LIN decoding methods are time-consuming.
With the SR-AUTO option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search LIN bus traffic.</td><td>❑ Power up the oscilloscope.
❑ Select Help -> About TekScope….
❑ Verify that the SR-AUTO: Automotive Serial Triggering and Analysis (CAN/LIN/FlexRay) option is installed.
❑ Press the OK button.</td></tr>
</table>

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a LIN signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a LIN signal which we can use for this lab:



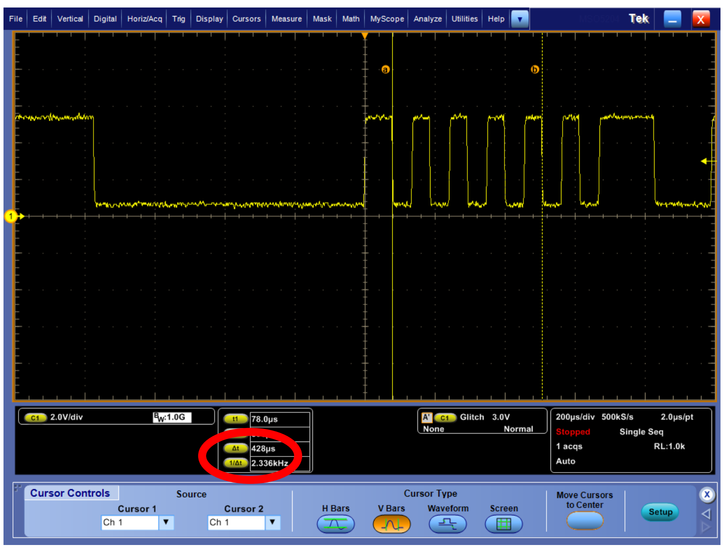
DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **LIN** test point.

Manual LIN Bit Rate Measurement

Key Take Away Points

- The data rate of the LIN signal on the DPO demo board is about 19200 bits/second and this is the default setting in the oscilloscope, as you will soon see. However, in general, you may need to determine the data rate using this procedure.
- With the SR-AUTO option, the MSO/DPO5000 provides a list of common bit rate values to choose from 1.2 kb/s to 19.2 kb/s in fixed steps, and custom bit rates from 800 b/s to 100 kb/s.
- Since LIN slaves depend upon the average bit rate in the sync field, let's measure that. The measurement below indicates that the average single bit width (428 µs / 8 bits) is about 53 µs, so the bit rate is verified to be about 19.2kbps.
- The display should look about like this:



- Look up the data rate in this table:

Average Sync Bit Width	Data Rate (bits / sec)
50 µs	20000
52.1 µs	19200
66.7 µs	15000
100 µs	1000
200 µs	5000
1 ms	1000
2 ms	500

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button.
- ❑ Press the front panel **Autoset** button.
- ❑ Set the Trigger **Level** control to about **3V**.
- ❑ Set the Horizontal **Scale** to **200µs/div**.
- ❑ Trigger on the sync break by triggering on a relatively long negative pulse.
  - ❑ Select **Trig -> Glitch Setup…**.
  - ❑ Under **Glitch Width**, select **Greater Than**.
  - ❑ Press the **Neg** button in the **Polarity** section to trigger on negative pulses.
  - ❑ Double-click on the **Width** text box, type in **500µ**, and press **Enter**.
- ❑ Press the front panel **Single** button.
- ❑ Press the front panel **Cursors** button once.
- ❑ Using the Multipurpose controls, measure the width of the 8-bit sync field (01010101), starting with the negative edge, as shown in the screen shot at the left.
- ❑ Read the sync field burst width (∆ time in the cursor readout) and write the value here: ______
- ❑ Divide the burst width by 8 to get the average sync bit width and write the value here: ______
- ❑ Look up the data rate in the table at the left and write the value here: ______

MSO/DPO5000 Series LIN Bus Setup and Decoding

Key Take Away Points

- Setting up a basic LIN bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog or digital inputs or math signals can be used as a source for the LIN bus. The LIN Bus Setup menu looks like this:

- The LIN bus Display menu looks like this:

- The green bar symbol represents the start of packet and the red bar symbol represents the end of packet.
- Break and Sync are shown in blue boxes, ID and Parity are shown in yellow boxes, Data packets are shown in cyan boxes, Checksum and Wakeup are shown in blue boxes, and errors are shown in red boxes.

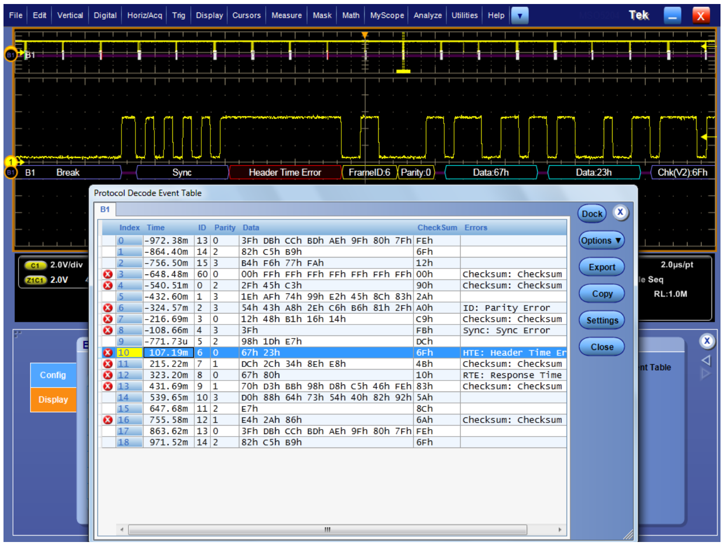
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** and **Autoset** buttons.
- ❑ Set channel 1 Vertical **Scale** to **2V/div.**
- ❑ Set the Trigger **Level** control to about **3V**.
- ❑ Set the **Horizontal Scale** to **200ms/div**.
- ❑ Select **Trig->Mode…** and press the **Norm** button.
- ❑ Select **Horiz/Acq ->Roll Mode Auto** to uncheck it.
- ❑ Select **Horiz/Acq ->Resolution** control.
- ❑ Double-click on the Sample Rate text box and use the Multipurpose **a** control to adjust the Sample Rate to **500 kS/s**, setting the record length to 1.0M points.
- ❑ Press the front panel **Single** button.
- ❑ Press the purple front panel Bus **B** button.
- ❑ Select **Serial Bus Type**, and then select **LIN**.
- ❑ Verify that the **Data** signal is on **Ch1**, the Ch1 Threshold setting is about **1.4V**, the LIN Standard is set to **v2.x**, the Bit Rate is set to **19.2kb/s**, and the **Include Parity Bits with ID** check box is not checked.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Position the bus waveform below the LIN waveform as desired.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Under Bus 1 Display, verify that **Busform** Style and **Mixed** Decode are selected.

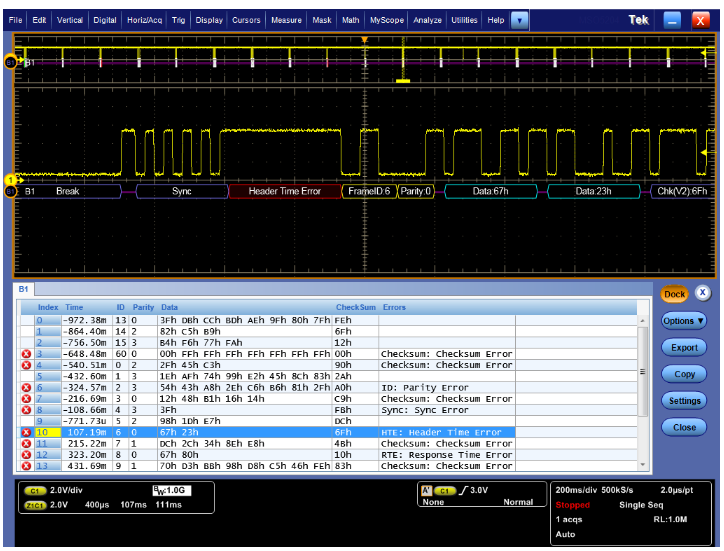
MSO/DPO5000 Series LIN Bus Event Tables

Key Take Away Points

- Setting up a basic LIN bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The LIN bus event table display looks like this:



- The docked LIN bus event table display looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Dock** button.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Click on one of the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.
- ❑ When you are done with the setup, press the **X** in the upper right corner of the control window to close it.

MSO/DPO5000 Series LIN Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the LIN serial bus.
- The MSO/DPO5000 Series can trigger on Sync, Identifier, Data, ID and Data, Wakeup Frame, Sleep Frame, and Error (Sync, ID Parity, Checksum).

- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a LIN signal, capturing each occurrence.

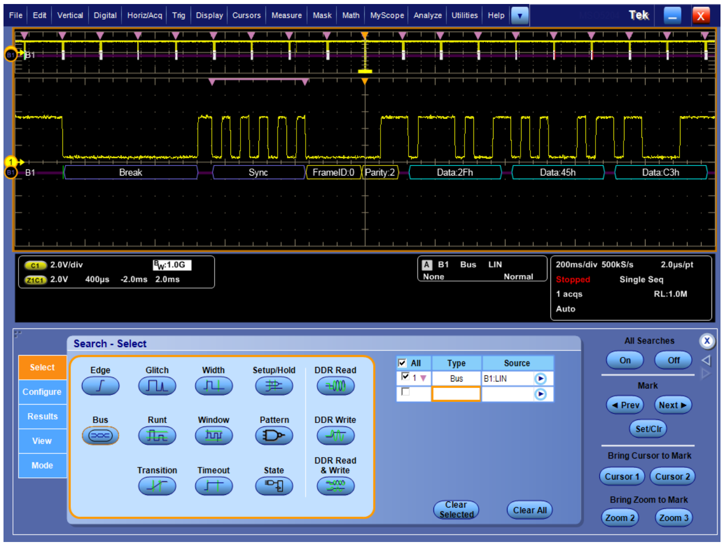
MSO/DPO5000 Series Procedure:

- ❑ Select **Trig->Bus Setup…**.
- ❑ Using the Bus drop down menu, select **B1**.
- ❑ Notice that, by default, Trigger On **Sync** is selected.
- ❑ Press the front panel **Single** button.
- ❑ Using the **Trigger On** drop down menu, select **Identifier**.
- ❑ Select **Hex** format.
- ❑ Press the **Edit** button at the right.
- ❑ Double click on the **Identifier** text box and enter the value **00** hex. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the MultiView Zoom pan and zoom controls as needed to view the LIN packets.

MSO/DPO5000 Series LIN Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the LIN serial bus.



- The MSO/DPO5000 Series can search on Sync, Identifier, Data, ID and Data, Wakeup Frame, Sleep Frame, and Error (Sync, ID Parity, Checksum).

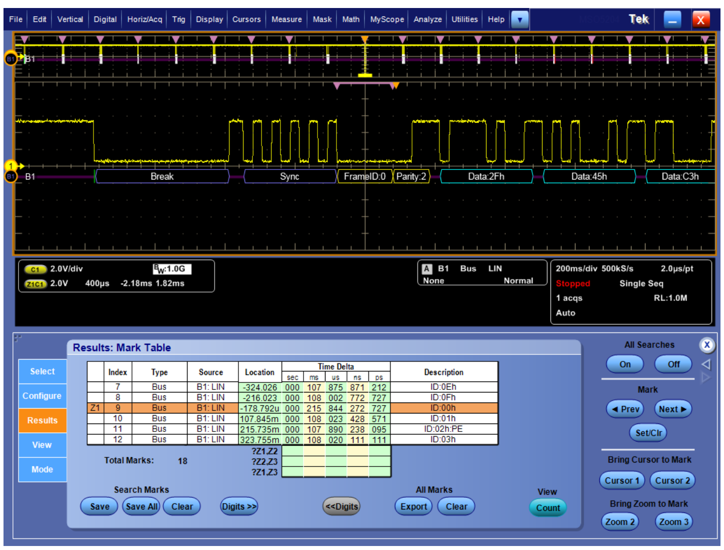
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** button in the control window.
- ❑ Press the **Configure** tab at the left side of the control window.
- ❑ Notice that, by default, Search For **Sync** is selected.
- ❑ Using the front panel left and right arrows, navigate between search events.

Key Take Away Points

- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on a LIN signal, marking each occurrence.

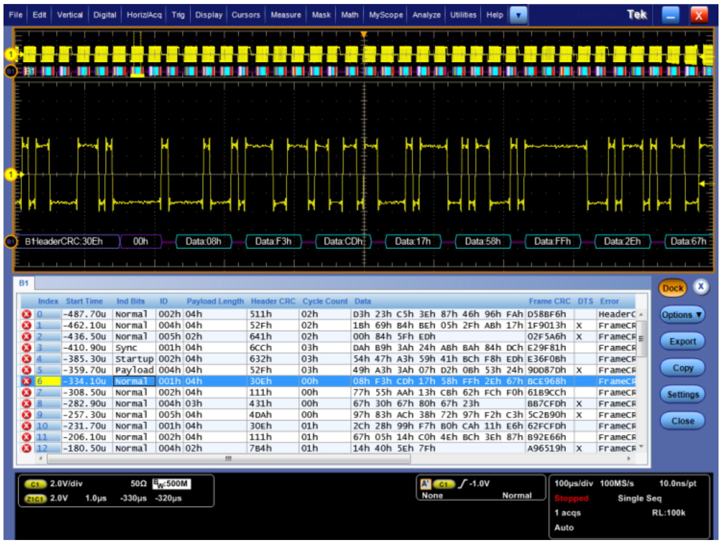
- The Event Table results table looks like this:



MSO/DPO5000 Series Procedure:

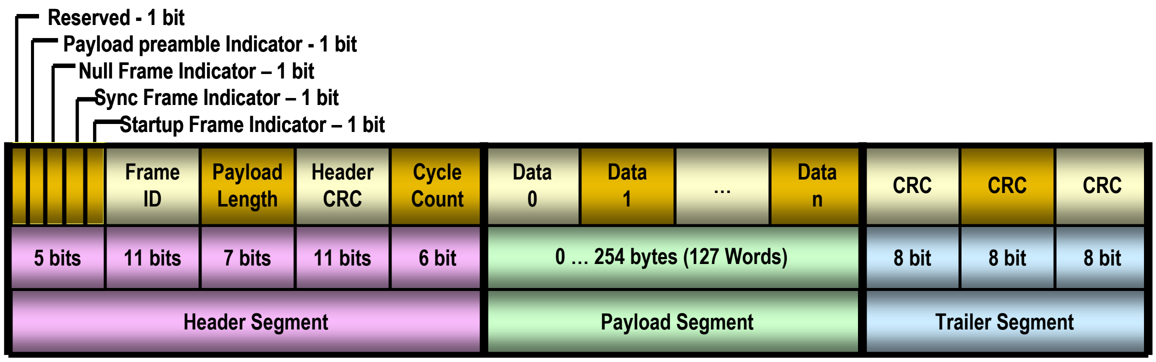
- ❑ Using the **Search For** drop down menu, select **Identifier**.
- ❑ Select **Hex** format.
- ❑ Press the **Edit** button at the right.
- ❑ Double click on the **Identifier** text box and enter the value **0X** hex. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Using the front panel left and right arrows, navigate between search events.
- ❑ Press the **Results** tab at the left side of the control window to display the table of search results.

MSO5000/DPO5000 Series
FlexRay Triggering and Decoding Lab



Equipment List
One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-AUTO option installed
One TDP0500 or TDP1000 differential probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo 3 board]

Understanding the FlexRay Bus
FlexRay is the most significant of several emerging low-speed serial standards for the automotive industry. FlexRay is still being developed by a group of leading automotive companies and suppliers known as the FlexRay Consortium. As cars get smarter and electronics find their way into more and more automotive applications, manufacturers are finding that existing automotive serial standards such as CAN and LIN do not have the speed, reliability, or redundancy required to address X-by-wire applications such as brake-by-wire or steer-by-wire. Today, these functions are dominated by mechanical and hydraulic systems. In the future they will be replaced by a network of sensors and highly reliable electronics that will not only lower the cost of the automobile, but also significantly increase passenger safety due to intelligent electronic-based features such as anticipatory braking, collision avoidance, adaptive cruise control, etc. The SR-AUTO application for the MSO/DPO5000 Series provides optional serial triggering and analysis for FlexRay. This lab will walk you through the most significant of the capabilities of the product.
FlexRay is a differential automotive serial bus which transmits data at rates up to 10 Mbps. The FlexRay information is transmitted over unshielded twisted-pair (UTP) cables and shielded twisted-pair (STP) cables (for better EMC performance). This is significantly faster than LIN's 20 kb/s or CAN's 1 Mb/s rates. FlexRay uses a dual channel architecture which has two major benefits. First, the two channels can be configured to provide redundant communication in safety critical applications such as x-by-wire to ensure the message gets through. Second, the two channels can be configured to send unique information on each at 10 Mb/s, giving an overall bus transfer rate of 20 Mb/s in less safety critical applications. FlexRay uses a time-triggered protocol that incorporates the advantages of prior synchronous and asynchronous protocols via communication cycles that include both static and dynamic frames. Static frames are time slots of predetermined length allocated for each device on the bus to communicate during each cycle. Each device on the bus is also given a chance to communicate during each cycle via a Dynamic frame which can vary in length (and time).



The FlexRay frame is made up of three major recurring segments (Header, Payload, and Trailer), separated by idle periods. At the end of the idle period there is a:

- **TSS** (Transmission Start Sequence): 3-15 bits, which initiates network connection setup
- **FSS** (Frame Start Sequence): 1 bit which immediately follows TSS.

Then Header Segment is 5 bytes long and contains:

- Indicator Bits: 5 bits which provide Header Segment preamble information. The combination of the bits specify the type of frame:
  - Null / Normal / Payload
  - Sync / Startup
- Frame Id (Frame Identifier): 11 bits which define the slot in which the frame is transmitted. Frame IDs range from 1 to 2047 with any individual frame ID being used no more than once on each channel in a communication cycle.
- Payload Length: 7 bits which specify the number of data words being transferred in the frame.
- Header CRC (Header Cyclic Redundancy Code): error-detection protection for part of the Header Segment, calculated over the sync frame indicator, the startup frame indicator, the frame ID and the payload length.
- Cycle Count: the value of the current communication cycle, which can range from 0-63. This value is incremented at the start of each communication cycle.

The Payload Segment contains the data transferred by the frame. The Payload Segment has a variable length, from 0 to a maximum payload length of 127 words (254 bytes). For frames transmitted in the static segment the first 0 to 12 bytes of the payload segment may optionally be used as a network management vector. The payload preamble indicator in the frame header indicates whether the payload segment contains the network management vector. For frames transmitted in the dynamic segment the first two bytes of the payload segment may optionally be used as a message ID field, allowing receiving nodes to filter or steer data based on the contents of this field. The payload preamble indicator in the frame header indicates whether the payload segment contains the message ID.

The Trailer Segment contains a single 24-bit CRC to provide error-detection protection for the Header and Payload segments.

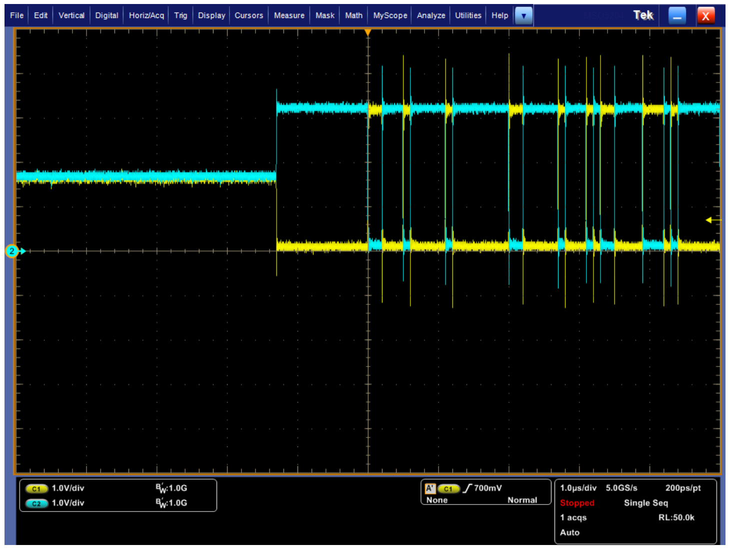
Each frame is delimited with a bus idle signal.

- FES (End of Frame): 2 bits, immediately following the Trailer CRC.
- DTS (Dynamic Trailing Sequence): follows a dynamic frame and prevents premature channel idle detection by the bus receivers.

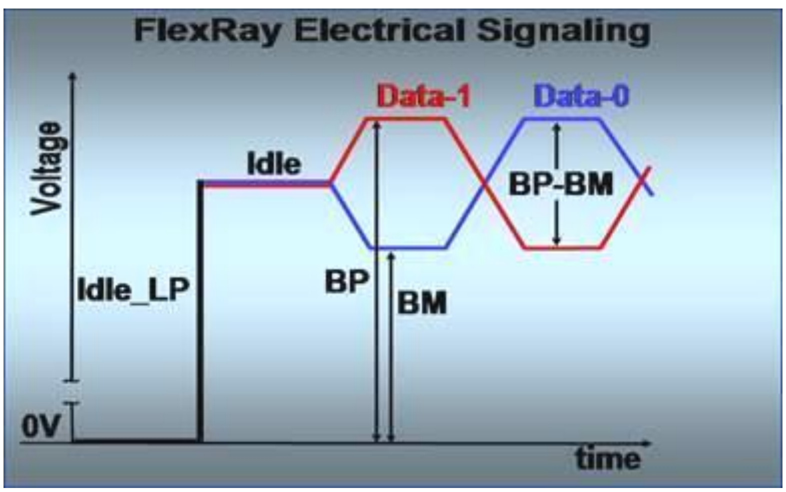
CID (Channel Idle Delimiter): minimum of 11 bits which indicate the beginning of the idle period.

Key Take Away Points

- The FlexRay signals on the demo board look about like this, where the yellow channel 1 signal is the positive FLEX_RAY_BP and the cyan channel 2 signal is the negative FLEX_RAY_BM:



- Notice that FlexRay signals are relatively large signals, with multiple voltage levels.
- FlexRay signal levels are defined as follows:



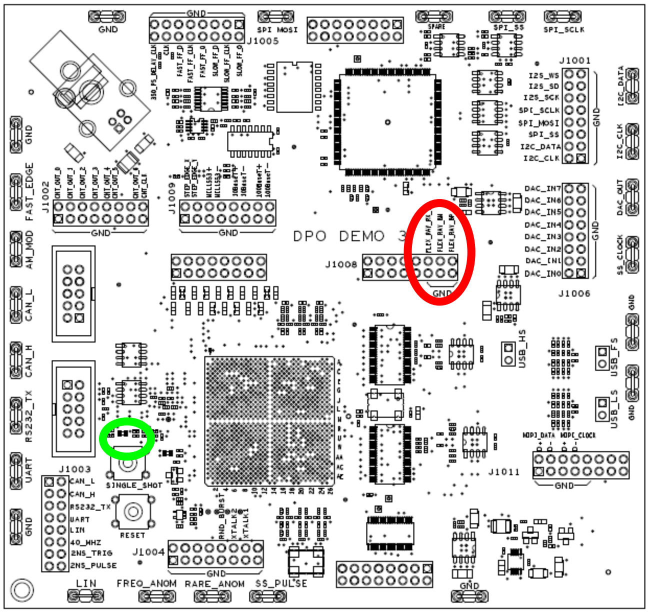
- **BP** (Bus Plus): the positive side of the differential FlexRay signal.
- **BM** (Bus Minus): the negative side of the differential FlexRay signal.
- **Data_1**: positive differential voltage between BP and BM.
- **Data_0**: negative differential voltage between BP and BM.
- **Idle**: biased to a mid-level voltage, BP=BM.
- **Idle_LP** (Low Power): biased to ground. No current to BP or BM.

Lab Objectives
- Obtain a basic understanding of the FlexRay serial bus. - Learn how to use oscilloscopes to measure and decode FlexRay signals. - Learn how to setup a FlexRay serial bus display and trigger and search on FlexRay bus content with an MSO/DPO5000 Series oscilloscope.

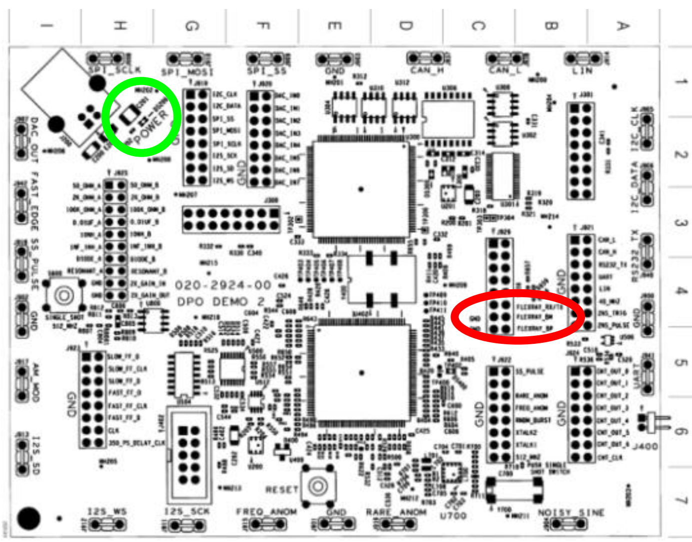
MSO/DPO5000 Series Lab Setup	
Key Take Away Points • The FlexRay bus is an industry standard and can be found in many automotive designs today. • Traditional manual FlexRay decoding methods are time-consuming. • With the SR-AUTO option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search FlexRay bus traffic.	❑ Power up the oscilloscope. ❑ Select **Help -> About TekScope…**. ❑ Verify that the **SR-AUTO: Automotive Serial Triggering and Analysis** (**CAN/LIN/FlexRay)** option is installed. ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a FlexRay signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a FlexRay signal which we can use for this lab:



DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TDP0500 or TDP1000 differential probe to the Channel 1 input of the oscilloscope. Then connect the probe's **+** input to **FLEX_RAY_BP** and connect the probe's **-** input to the **FLEX_RAY_BM** test point.

MSO/DPO5000 Series FlexRay Bus Setup and Decoding

Key Take Away Points

- Setting up a basic FlexRay bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog or digital inputs or math signals can be used as a source for the FlexRay bus.
- The MSO/DPO5000 Series can trigger and decode FlexRay signals at the preset bit rates of 2.5, 5, and 10 Mbps, or at any user-selectable value from 1 Mbps to 10 Mbps (in 10 kbps increments with the front panel Fine mode selected and 100 kbps increments with the Fine mode deselected).
- The FlexRay Bus Setup menu looks like this:

- The FlexRay bus Display menu looks like this:

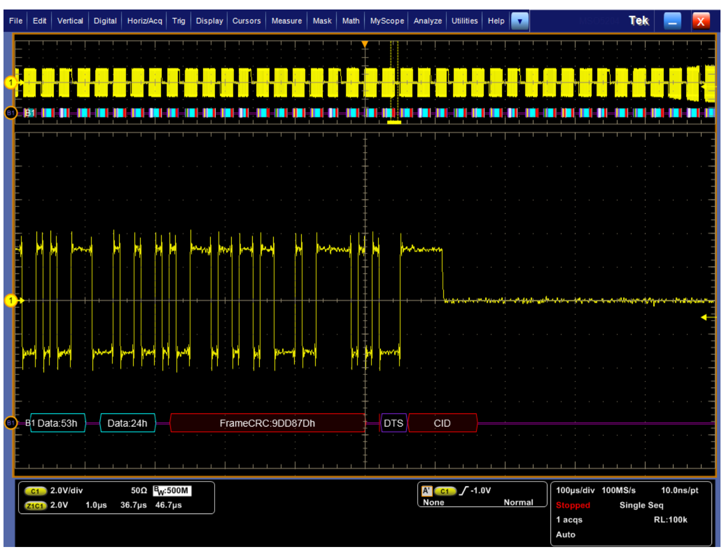
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set channel 1 Vertical **Scale** to **2V/div.**
- ❑ Use the **Trigger Level** control to adjust the trigger level below the center of the waveform, about **-1V**.
- ❑ Set the **Horizontal Scale** to **100µs/div**.
- ❑ Select **Trig->Mode…** and press the **Norm** button.
- ❑ Press the front panel **Single** button.
- ❑ Press the purple front panel Bus **B** button.
- ❑ Select **Serial Bus Type**, and then select **FLEXRAY**.
- ❑ Verify that the **Signal Type** is set to **Bdiff or BP (Polarity Normal: High = 1)** and the **Input** signal is on **Ch1.**
- ❑ Set the **Threshold (H)** value to about **+1.6V**, the **Threshold (L)** value to about **-1.6V**, and the **Channel Type** is set to **B**.
- ❑ Verify the **Bit Rate** is set to **10 Mb/s**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Position the bus waveform below the FlexRay waveform as desired.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Under Bus 1 Display, verify that **Busform** Style and **Mixed** Busform Decode are selected.
- ❑ Zoom in on the signal until you can read the individual decoded signal elements.

Key Take Away Points

- The green bar symbol represents the start of packet and the red bar symbol represents the end of packet.

- Notice that TSS appears in purple, followed by the green start of frame bar. The Header segment begins with the indicator bits in purple, followed by the frame ID in yellow, the payload length and header CRC in purple, and the cycle count in yellow. The data in the Payload segment are shown in cyan. Finally, the Trailer CRC, DTS, and CID are shown in purple and the end of frame bar is red. Errors are shown in red.



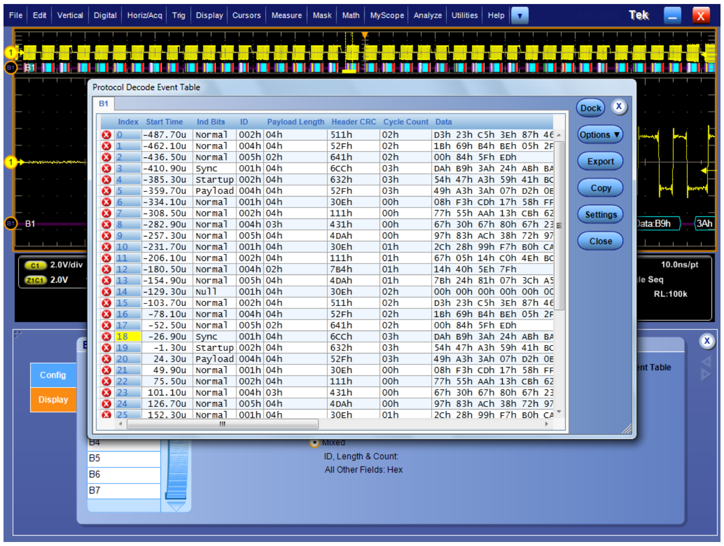
MSO/DPO5000 Series Procedure:

- ❑ Pan through the display to see what the decoded signal elements look like.

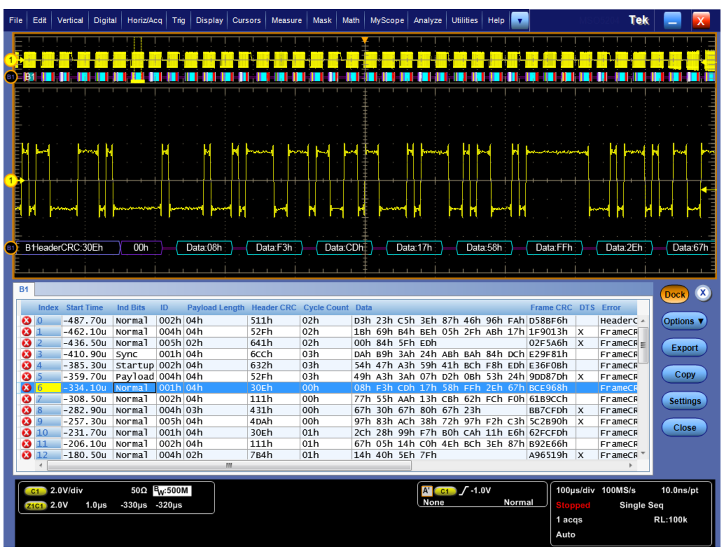
MSO/DPO5000 Series FlexRay Bus Event Tables

Key Take Away Points

- Setting up a basic FlexRay bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The FlexRay bus event table display looks like this:



- The docked FlexRay bus event table display looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Dock** button.
- ❑ Press the **X** in the upper right corner of the control window or press the front panel **Menu Off** button to close the control panel.
- ❑ Click on one of the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.
- ❑ When you are done with the setup, press the **X** in the upper right corner of the control window to close it.

MSO/DPO5000 Series FlexRay Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the FlexRay serial bus.
- The MSO/DPO5000 Series can trigger on:
  - Start of Frame
  - Indicator Bits (Normal, Payload, Null, Sync, Startup)
  - Identifier (=, ≠, <, ≤, ≥, >)
  - Cycle Count (=, ≠, <, ≤, ≥, >)
  - Header Fields
  - Data (=, ≠, <, ≤, ≥, >)
  - ID & Data (=, ≠, <, ≤, ≥, >)
  - End of Frame (All, Static Frame, Dynamic Frame)
  - Error (Header CRC, Trailer CRC, Null Frame(Static), Null Frame (Dynamic), Sync Frame in Dynamic, Startup Frame(No Sync))
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a FlexRay signal, capturing each occurrence.

MSO/DPO5000 Series Procedure:

- ❑ Select **Trig->Bus Setup….**
- ❑ Using the Bus drop down menu, select **B1**.
- ❑ Notice that, by default, Trigger On **Start of Frame** is selected.
- ❑ Using the **Trigger On** drop down menu, select **Identifier**.
- ❑ Select **Hex** format.
- ❑ Press the **Edit** button at the right.
- ❑ Double click on the **Identifier** text box and enter the value **004** hex. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the MultiView Zoom pan and zoom controls as needed to view the FlexRay packets.

MSO/DPO5000 Series FlexRay Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the FlexRay serial bus.

- The MSO/DPO5000 Series can search on Start of Frame, Indicator Bits, Identifier, Cycle Count, Header Fields, Data, Ident & Data, End of Frame, and Error.
- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on a FlexRay signal, marking each occurrence:

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** button in the control window.
- ❑ Press the **Configure** tab at the left side of the control window.
- ❑ Notice that, by default, Search For **Start of Frame** is selected.
- ❑ Under Trigger On, select **Identifier**.
- ❑ Select **Binary** format.
- ❑ Press the **Edit** button at the right.
- ❑ Double click on the binary text box and enter the binary value **000 0000 XXX1**. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Using the front panel left and right arrows, navigate between search events.

Key Take Away Points

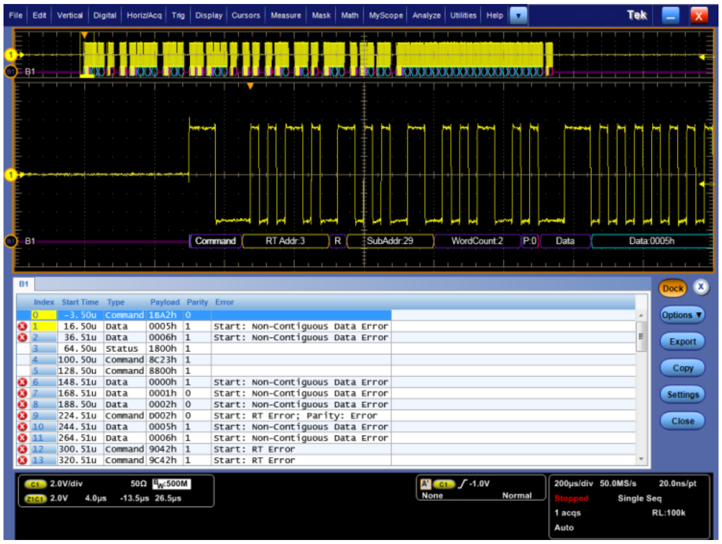
- The search results can also be displayed in tabular format. The Event Table results table looks like this:

- When you select a row in the results table, the display looks like this:

MSO/DPO5000 Series Procedure:

- ❑ Press the **Results** tab at the left side of the control window to display the table of search results.
- ❑ Click on one of the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.

Tektronix



Equipment List
One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-AERO option installed
One TDP0500 or TDP1000 differential probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
a MIL-STD-1553 reference waveform
[Note: screen shots in this document were made with the DPO Demo 3 board]

Understanding the MIL-STD-1553 Bus

Similar to the computer industry's LAN, MIL-STD-1553 is a military standard that defines the electrical and protocol characteristics of a serial bus initially designed for data communication in avionics applications.

MIL-STD-1553 began with the development of the A2-K draft standard by the Society of Automotive Engineers (SAE) in 1970. After government and military reviews and revisions, it was released as MIL-STD-1553 (USAF) in 1973. MIL-STD-1553A was released in 1975 to support all of the branches of the military, and the SAE then released and froze the MIL-STD-1553B standard to enable component manufacturers to build compliant products. The most recent changes, documented as Notice 2, was released in 1986 to provide a common set of operational characteristics. The standard is now overseen by SAE as commercial document AS15531.

Although the standard was widely used in US military applications, it has also been used commercially in mass-transportation, spacecraft, and manufacturing applications, and has been accepted and implemented by NATO and many other governments.

The SR-AERO application for the MSO/DPO5000 Series provides optional serial triggering and analysis for MIL-STD-1553. This lab will walk you through the most significant of the capabilities of the product.

MIL-STD-1553 asynchronously transmits messages of up to thirty-two 16-bit data words at bit rates of up to 10 Mb/s over shielded twisted-pair and twinax cabling. A 1553 network uses time-division multiplexed half-duplex communication to transmit data over a single cable. For safety-critical applications, dual redundant buses are commonly used to provide higher-reliability communications. Manchester II bi-phase encoding is used to allow direct or transformer coupling. Manchester encoding is self-clocking, independent of the bit sequence, and is DC-balanced. Because the information in Manchester coded signals is actually contained in the polarity and timing of the zero-crossings, the 1553 bus is tolerant of large variations in signal levels.

MIL-STD-1553 defines three distinct word types: Command words, Data words, and Status words. All are twenty-bit structures, with a 3-bit synchronization field, a 16-bit information field, and finally an odd parity bit for simple error detection. The sync field is an invalid Manchester signal, with a single transition in the middle of the second bit time. A command/status sync has a negative transition in the middle, while a data sync has a positive transition.

Command words, sent by the active bus controller, specify the function that a remote terminal is to perform. The 16-bit information field contains a 5-bit terminal address which uniquely identifies the terminal, a transmit/receive bit, 5 bits of sub-address or mode, and 5 bits of word count or mode code.

Command Word	Sync	Terminal Address	T/R	Subaddress / Mode	Word Count / Mode Code	Parity
Bits	3	5	1	5	5	1

Data words, transmitted by either a bus controller or remote terminal, are sent with the most-significant-bit first.

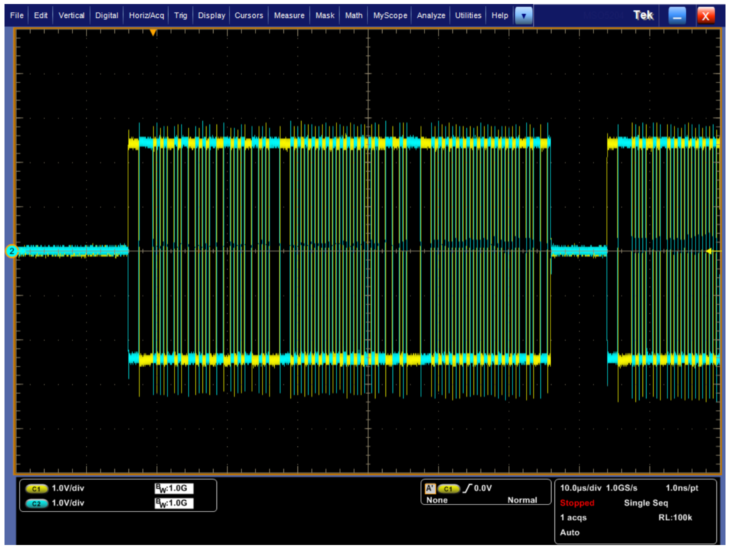
Data Word	Sync	Data (D15 – D0)	Parity
Bits	3	16	1

Status words are returned by remote terminals in response to a valid message from the controller to acknowledge receipt of a message or to convey the remote terminal status. The first 5 bits of the 16-bit information field are the terminal address. The remaining bits represent specific status information, including Message Error, Instrumentation Bit, Service Request, Broadcast Command Received, Busy, Subsystem Flag, Dynamic Bus Acceptance, and Terminal Flag.

Status Word	Sync	Terminal Address	ME	IB	SR	Re-served	BCR	Busy	SF	DBA	TF	Parity
Bits	3	5	1	1	1	3	1	1	1	1	1	1

Key Take Away Points

- The MIL-STD-1553 signals on the demo board look about like this, where the yellow channel 1 signal is the positive MIL1553+ and the cyan channel 2 signal is the negative MIL1553-:



- Notice that the individual MIL-STD-1553 signals are relatively large signals, about ±2.5V_{pk-pk}, with multiple voltage levels.
- These MIL-STD-1553 signals transmit information differentially, and the SR-AERO decoder is designed to work with a single differential signal, so the remainder of this lab will focus on the differential signal, captured with a differential probe, as shown below:

Lab Objectives

- Obtain a basic understanding of the MIL-STD-1553 serial bus.
- Learn how to use oscilloscopes to measure and decode MIL-STD-1553 signals.
- Learn how to setup a MIL-STD-1553 serial bus display and trigger and search on MIL-STD-1553 bus content with an MSO/DPO5000 Series oscilloscope.

MSO/DPO5000 Series Lab Setup

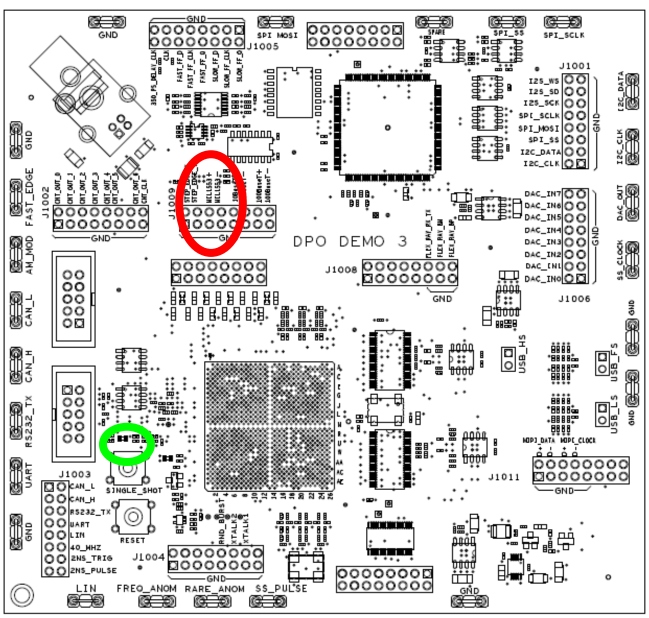
Key Take Away Points

- The MIL-STD-1553 bus is an industry standard and can be found in many aerospace designs today.
- Traditional manual MIL-STD-1553 decoding methods are time-consuming.
- With the SR-AERO option installed, the MSO/DPO5000 Series oscilloscope can trigger on, decode, and search MIL-STD-1553 bus traffic.

- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope….**
- ❑ Verify that the **SR-AERO: MIL-STD-1553 Serial Triggering and Analysis** option is installed.
- ❑ Press the **OK** button.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a MIL-STD-1553 signal which we can use for this lab:



- You can also load a MIL-STD-1553 signal into a reference memory (and define a math waveform to equal that reference waveform) for use in this lab to demonstrate decoding and searching. However, the rest of this lab assumes a live signal.

DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TDP0500 or TDP1000 differential probe to the Channel 1 input of the oscilloscope. Then connect the probe's **+** input to **MIL1553+** and connect the probe's **-** input to the **MIL1553-** test point.
- ❑ For your reference, to load a reference waveform for decoding, after setting up the scope:
  - ❑ Select **File->Recall….**
  - ❑ Enter file name and press **Recall** button.
  - ❑ Press the **Display Off** button.
  - ❑ Select **Math-Math Setup….**
  - ❑ Set **Math 1 = Ref1**.

MSO/DPO5000 Series MIL-STD-1553 Bus Setup and Decoding

Key Take Away Points

- Setting up a basic MIL-STD-1553 bus waveform display takes only a few simple steps with the MSO/DPO5000 Series.
- Notice that any of the analog or math signals can be used as a source for the MIL-STD-1553 bus.
- The MIL-STD-1553 Bus Setup menu looks like this:

- The MIL-STD-1553 bus Display menu looks like this:

MSO/DPO5000 Series Procedure:

- ❑ Set channel 1 Vertical **Scale** to **2V/div.**
- ❑ Use the **Trigger Level** control to adjust the trigger level below the center of the waveform, about **-1V**.
- ❑ Set the **Horizontal Scale** to **200µs/div**.
- ❑ With Horizontal **Delay** mode **Off**, turn the Horizontal **Position** control counter-clockwise until the orange trigger position marker is aligned with the first graticule line at the left side of the display.
- ❑ Press the front panel **Single** button.
- ❑ Press the purple front panel Bus **B** button.
- ❑ Select **Serial Bus Type**, and then select **MIL-1553**.
- ❑ Verify that the Data **Input** signal is set to **Ch1.**
- ❑ Set the **Threshold (H)** value to about **+500mV**, the **Threshold (L)** value to about **-500 mV**, and the **Polarity** is set to **Normal**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Click on the **Bus 1 Position** text box and position the bus waveform below the MIL-STD-1553 waveform as desired.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Under Bus 1 Display, verify that **Busform** Bus Components and **Mixed** Busform Decode are selected.
- ❑ Zoom in on the signal until you can read the individual decoded signal elements.
- ❑ Press the **X** in the upper right corner of the lower control window or press the front panel **Menu Off** button.

Key Take Away Points

- The green bar symbol represents the start of packet and the red bar symbol represents the end of packet.

- Notice that the Sync Word Type, R/T bit, Word Count, Status Bits, and Parity appear in purple. Address bits appear in yellow. Data values are shown in cyan. Errors are shown in red.

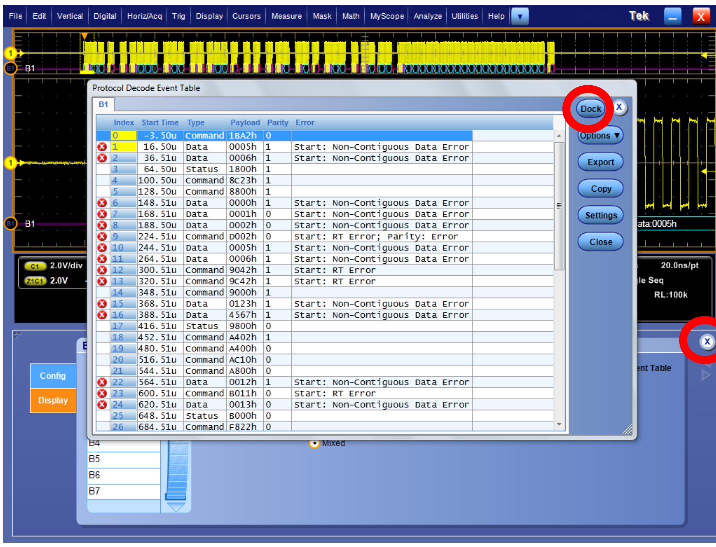
MSO/DPO5000 Series Procedure:

- ❑ Pan through the display to see what the decoded signal elements look like.

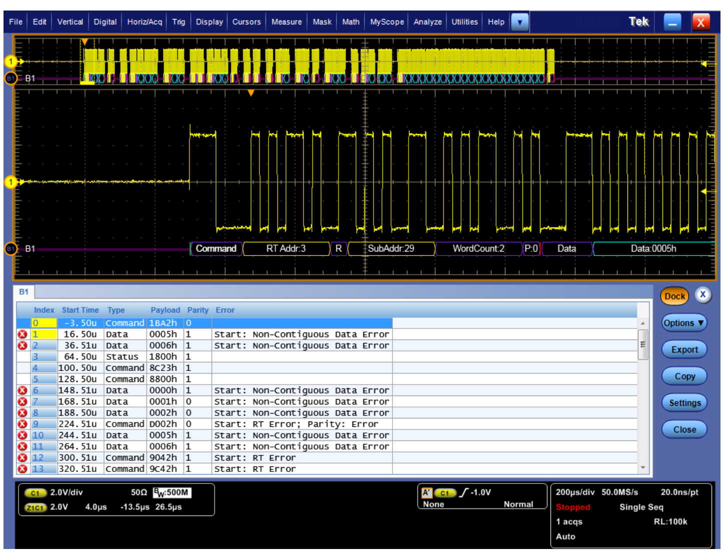
MSO/DPO5000 Series MIL-STD-1553 Bus Event Tables

Key Take Away Points

- Setting up a basic MIL-STD-1553 bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The MIL-STD-1553 bus event table display looks like this:



- The docked MIL-STD-1553 bus event table display looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Select **Vertical->Bus Setup…**.
- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Dock** button.
- ❑ Press the **X** in the upper right corner of the lower control window or press the front panel **Menu Off** button to close the control panel.
- ❑ Click on one of the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.
- ❑ When you are done with the setup, press the **X** in the upper right corner of the Event Table control window to close it.

MSO/DPO5000 Series MIL-STD-1553 Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the transmission of specific content over the MIL-STD-1553 serial bus.
- The MSO/DPO5000 Series can trigger on:
  - Sync
  - Command Word (set RT Address (=, ≠, <, >, ≤, ≥), T/R, Sub-address/Mode, Data Word Count/Mode Code, and Parity individually)
  - Status Word (set RT Address (=, ≠, <, >, ≤, ≥), Message Error, Instrumentation, Service Request Bit, Broadcast Command Received, Busy, Subsystem Flag, Dynamic Bus Control Acceptance (DBCA), Terminal Flag, and Parity individually)
  - Data (user-specified 16-bit data and parity values)
  - Idle Time (< Minimum, > Maximum, Inside Range, Outside Range)
  - Error (Parity Error, Sync Error, Manchester Error, Non-Contiguous Data)
- NOTE: Trigger selection of Command Word will trigger on Command and ambiguous Command/Status words. Trigger selection of Status Word will trigger on Status and ambiguous Command/Status words.
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a MIL-STD-1553 signal, capturing each occurrence.

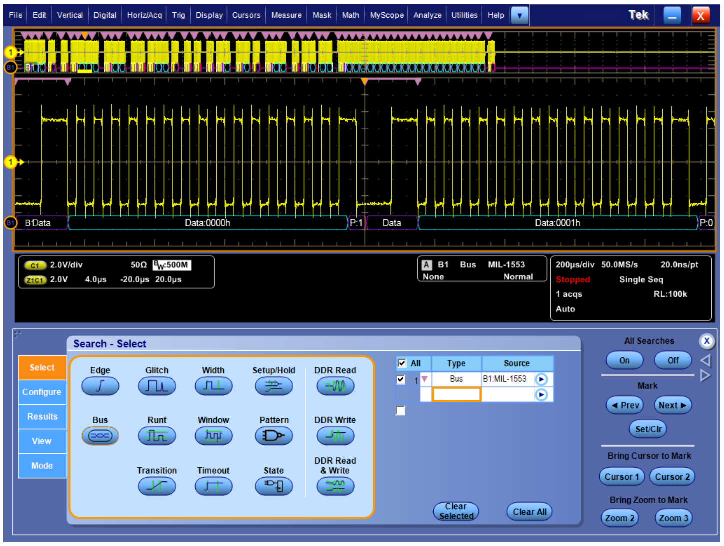
MSO/DPO5000 Series Procedure:

- ❑ Select **Trig->Mode…** and press the **Norm** button.
- ❑ Select **Trig->Bus Setup….**
- ❑ Using the Bus drop down menu, select **B1**.
- ❑ Notice that, by default, Trigger On **Sync** is selected.
- ❑ Using the **Trigger On** drop down menu, select **Data**.
- ❑ Select **Hex** format.
- ❑ Press the **Edit** button at the right.
- ❑ Double click on the **Identifier** text box and enter the value **0000** hex. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the MultiView Zoom pan and zoom controls as needed to view the MIL-STD-1553 packets at the trigger point.

MSO/DPO5000 Series MIL-STD-1553 Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the MIL-STD-1553 serial bus.



- The MSO/DPO5000 Series can search on Sync, Command Word, Status Word, Data, Idle Time, and Error.
- By following this simple procedure, you can easily search an acquisition for a specified serial pattern on a MIL-STD-1553 signal, marking each occurrence:

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** button in the control window.
- ❑ Press the **Configure** tab at the left side of the control window.
- ❑ Notice that, by default, Search For **Sync** is selected.
- ❑ Under Search For, select **Status Word**.
- ❑ Select **Binary** format.
- ❑ Press the **Edit** button at the right.
- ❑ Double click on the binary text box and enter the binary value **X XXX1**. As you enter the values, notice that the values in the other radices are also updated.
- ❑ When you are done, press **OK**.
- ❑ Using the front panel left and right arrows, navigate between search events.

Key Take Away Points

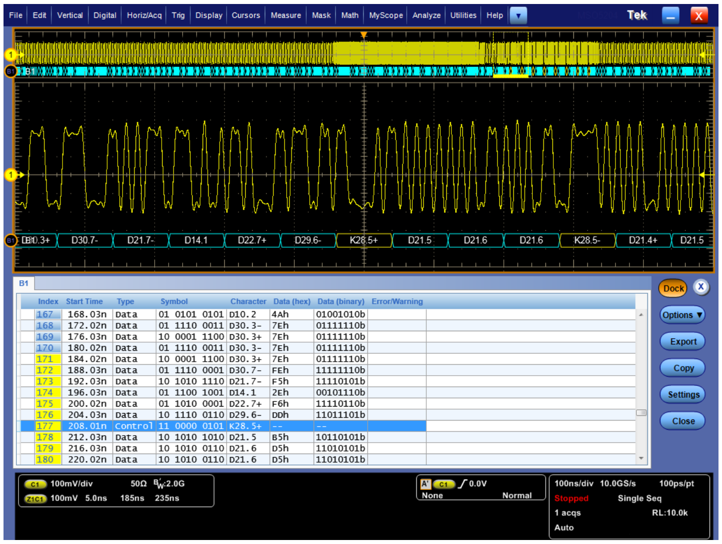
- The search results can also be displayed in tabular format. The Event Table results table looks like this:

- When you select a row in the results table, the display looks like this:

MSO/DPO5000 Series Procedure:

- ❑ Press the **Results** tab at the left side of the control window to display the table of search results.

- ❑ Click on one of the rows in the Event Table and notice the zoom box is repositioned to correspond to the selected row.



Equipment List

One MSO/DPO5204 Series oscilloscope with software version ≥6.4 and with the SR-810B option installed
One SMA-to-BNC cable
Optional USB keyboard and mouse
TB3 demo board and power adapter

Understanding 8b/10b Encoding

8b/10b is an encoding method used in many computer and communications applications which replaces 8-bit data values with 10-bit symbols. In exchange for the 25% overhead, 8b/10b encoding provides a signal with no DC content, limited low-frequency content, limited “disparity”, and enough signal transitions to enable good clock recovery. The resulting bit stream never has more than five 1s or 0s in a row, and the difference between the number of 1s and 0s in any string of at least 20 bits is less than or equal to two. These characteristics combine to allow the signal to be easily transmitted over an AC-coupled channel, ensures that the duty cycle of lasers used in optical transmission is maintained at 50% for optimal performance and power dissipation, and minimizes the sensitivity of receivers to variations in accumulated DC offsets. Another benefit of this overhead is the ability to detect single-bit transmission errors (more effective error-detection than traditional parity).

8b10b line coding was developed and patented by IBM in 1984, but, since the patent expired, it has been used in a variety of communications standards, including Common Public Radio Interface (CPRI), Digital Audio Tape, DisplayPort, DVB Asynchronous Serial Interface (ASI), DVI, Fibre Channel, Gigabit Ethernet, HDMI, HyperTransport, IEEE 1394b, InfiniBand, PCI Express (< v3.0), Serial ATA, Serial RapidIO, Serial Storage Architecture (SSA), USB 3.0, and XAUI.

Because the encoding and decoding is normally done in hardware at the link layer, 8b/10b is used for a wide range of standard and custom applications, and the upper layers of the OSI software stack do not need to be aware that the link layer is using this code.

How it works

The 8 data bits are transmitted as a 10-bit symbol, composed of two groups of bits. The 5 least-significant data bits are encoded into a 6-bit group (“5b/6b”) and the 3 most-significant data bits are encoded into a 4-bit group (“3b/4b”) and then concatenated. The data symbols are often referred to as “D.x.y”, where “x” represents the least-significant 5 bits (with a value of 0–31) and “y” represents the most-significant 3 bits (with a value of 0–7).

Communication standards may define up to 12 control characters (special symbols) which can replace data symbols to represent start-of-frame, end-of-frame, idle, skip, and similar link-level conditions. Symbol framing is done with a special "comma" symbol which defines the alignment of the 10 bit symbols. The control characters are often referred to as “K.x.y” and are distinguished from any of the “D.x.y” symbols by the use of different encodings.

Since 8b/10b encoding uses 10-bit symbols to encode 8-bit words, there are many possible bit combinations which are not used. Of the possible 1024 (2^{10}) 10-bit codes, the “D.x.y” symbols are chosen to uniquely represent the 256 (2^8) data values, to provide a run-length limit of 5 consecutive 1s or 0s, and to limit the “disparity” (the difference of the count of 0s and 1s across two or more symbols) is no more than 2.

Encoding tables

For the following sections, we will represent the bits in the 8-bit data word with the string of capitalized characters “HGFEDCBA”, where A is the least-significant bit and H is the most-significant bit. We will also represent these data bits in lower case when they are part of the encoded symbol, and will include two extra bits, i and j. The bits are sent least-significant to most-significant order, with the extra bits inserted as follows: a, b, c, d, e, i, f, g, h, and j. You can also think of this series as the 5b/6b code followed by the 3b/4b code.

Each 6-bit code can contain equal numbers of 0s and 1s (a disparity of 0), or comes in a pair of forms, one with two more 1s than 0s (four 1s and two 0s) and one with two less 1s than 0s (two 1s and four 0s). Likewise, each 4-bit code can contain equal numbers of 0s and 1s (a disparity of 0), or comes in a pair of forms, one with two more 1s than 0s (three 1s and one 0) and one with two less 1s than 0s (one 1 and three 0s).

The encoder needs to keep track of the difference between the number of transmitted 1s and 0s. This residual count is known as the running disparity (“RD”). By limiting the difference within each code to the range of ±2 and an RD alternating between ±1 at the end of each symbol, the long-term ratio of 1s and 0s is 50% and 8b/10b coding is DC-free.

When a 5b/6b and 3b/4b code has a non-zero disparity, there are two valid bit patterns that can be used to represent the data values, one with a disparity value of +1 and one with a disparity value of -1. As shown in the table below, the value of the running disparity and the disparity value for the code word specify the disparity encoding to be chosen to toggle the running disparity. (If the code word has a zero disparity, there is only one valid bit pattern to use and the disparity would be unchanged.)

Rules for Running Disparity

Previous RD	Disparity of code word	Disparity chosen	Next RD
−1	0	0	−1
−1	±2	+2	+1
+1	0	0	+1
+1	±2	−2	−1

The following (simplified) tables show the coding for the 5b/6b and 3b/4b groups:

5b/6b Code

	nput	RD = −1	RD = +1		Input	RD = −1	RD = +1
	EDCBA	abcdei			EDCBA	abcdei	
D.00	00000	100111	011000	D.16	0000	011011	100100
D.01	00001	011101	100010	D.17	10001	100011	
D.02	00010	101101	010010	D.18	10010	010011	
D.03	00011	110001		D.19	10011	110010	
.0 4	00100	110101	001010	D.20	10100	001011	
D.05	00101	101001		D.21	10101	101010	
D.06	00110	011001		D.22	10110	011010	
D.07	00111	111000	000111	D.23	10111	111010	000101
D.08	01000	111001	000110	D.24	11000	110011	001100
D.09	01001	100101		D.25	11001	100110	
D.10	01010	010101		D.26	11010	010110	
D.11	01011	110100		D.27	11011	110110	001001
D.12	01100	001101		D.28	11100	001110	
D.13	01101	101100		D.29	11101	101110	010001
D.14	01110	011100		D.30	11110	011110	100001
D.15	01111	010111	101000	D.31	11111	101011	010100
				K.28	11100	001111	110000

3b/4b Code

Input	HG	RD = −1 fghj	RD = +1 fghj	Input	HGF	RD = −1 fghj	RD = +1 fghj
D.x.0	000	1011	0100	K.x.0	000	1011	0100
D.x.1	001	1001		K.x.1	001	0110	1001
D.x.2	010	0101		K.x.2	010	1010	0101
D.x.3	011	1100	011	K.x.3	011	1100	0011
D.x.4	100	1101	0010	K.x.4	100	1101	0010
D.x.5	101	1010		K.x.5	101	0101	1010
D.x.6	110	0110		K.x.6	110	1001	0110
D.x.P7	111	1110	0001				
D.x.A7	111	0111	1000	K.x.7	111	0111	1000

Control symbols

"K.x.y" 8b/10b control symbols are valid 10-bit sequences (no more than six 1s or 0s) that do not have a corresponding 8-bit data value. Control symbols are used by communication standards to perform low-level control functions. The transmitted codes for control symbols are also affected by the running disparity. Here are the following 12 control symbols:

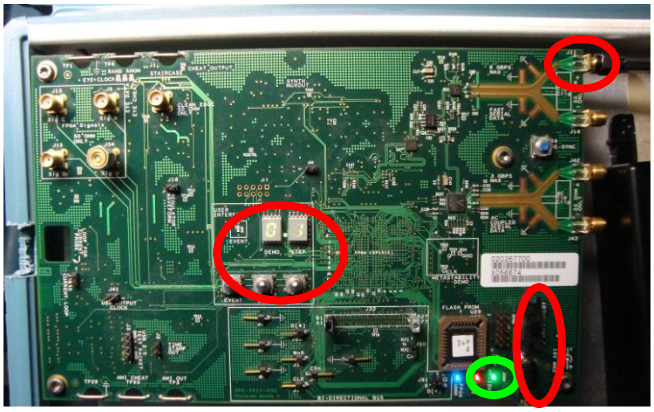
Control Symbols

	Input DEC	Input HGF EDCBA	RD = −1 abcdei fghj	RD = +1 abcdei fghj
K.28.0	28	000 11100	001111 0100	110000 1011
K.28.1	60	001 11100	001111 1001	110000 0110
K.28.2	92	010 11100	001111 0101	110000 1010
K.28.3	124	011 11100	001111 0011	110000 1100
K.28.4	156	100 11100	001111 0010	110000 1101
K.28.5	188	101 11100	001111 1010	110000 0101
K.28.6	220	110 11100	001111 0110	110000 1001
K.28.7	252	111 11100	001111 1000	110000 0111
K.23.7	247	111 10111	111010 1000	000101 0111
K.27.7	251	111 11011	110110 1000	001001 0111
K.29.7	253	111 11101	101110 1000	010001 0111
K.30.7	254	111 11110	011110 1000	100001 0111

Lab Objectives

- Obtain a basic understanding of 8b/10b encoding.
- Learn how to setup an 8b/10b-encoded serial bus display and decode and search on data patterns with an MSO/DPO5000 Series oscilloscope.

MSO/DPO5000 Series Lab Setup	
Key Take Away Points • 8b/10b-encoded serial buses are industry standards and can be found in many designs today. • With the SR-810B option installed on an MSO/DPO5000 Series oscilloscope can automatically decode and search 8b/10b-encoded serial bus traffic.	**MSO/DPO5000 Series Procedure:** ❑ Power up the oscilloscope. ❑ Select **Help -> About TekScope….** ❑ Verify that the **SR-810B: 8B10B Serial Analysis** option is installed. ❑ Press the **OK** button.

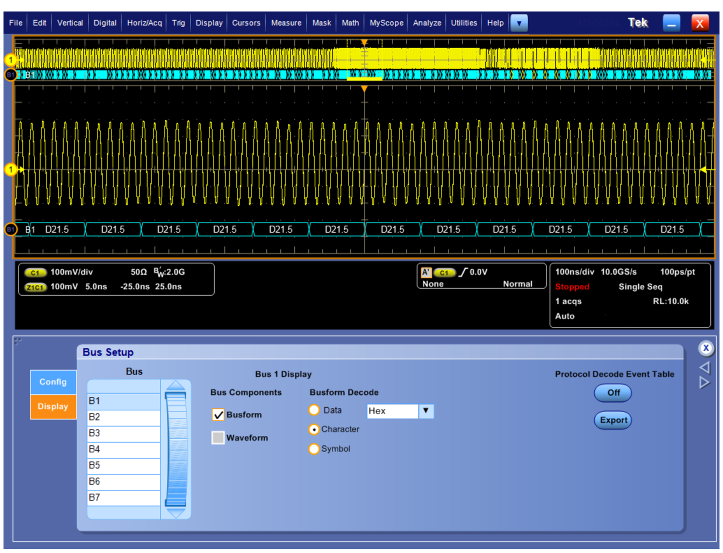
Key Take Away Points • The TB3 demo board has an 8b/10b-encoded 2.5 Gb/s signal which we can use for this lab: 	**TB3 Demo Board Procedure:** ❑ Connect the power adapter to **J2890** on the demo board and connect the adapter to the mains power. ❑ Move power switch **S2780** to the ON position. ❑ Verify the power LEDs are lit. ❑ Attach the BNC connector of an SMA-to-BNC cable to the Channel 1 input of the oscilloscope and the SMA connector to J11 on the demo board. ❑ Press the **DEMO** switch S2 until mode 0 is displayed on the DEMO LED. ❑ Press the **STEP** switch S1 until mode 1 is displayed on the STEP LED.

MSO/DPO5000 Series 8b/10b Bus Setup and Decoding

Key Take Away Points

- In this section, you will learn how to use the MSO/DPO5000 Series to automatically decode 8b/10b-encoded serial bus traffic.
- Setting up a basic 8b/10b bus waveform display takes only a few simple steps with the MSO/DPO5000 Series. Notice that any of the analog or digital inputs or math signals can be used as a source for the 8b/10b bus.
- The display should now look about like this, with the 8b10b character decoded values shown in the bus waveform:

- The data values can also be displayed in Binary, Hex, Character, or Symbol format:



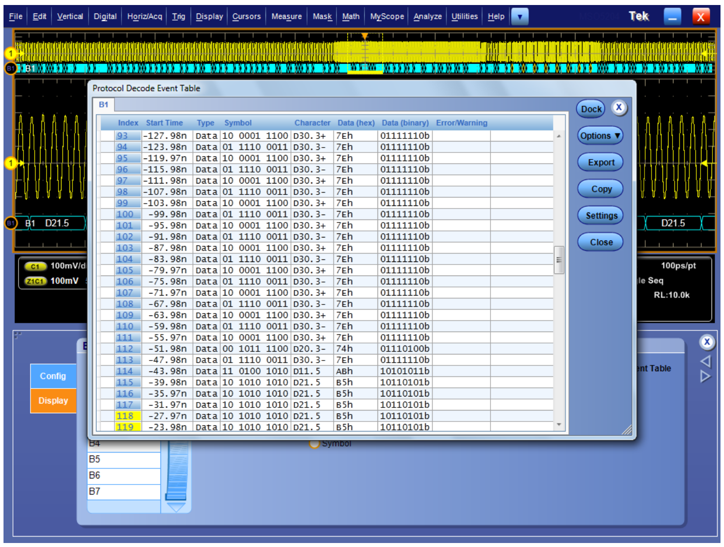
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Select **Vertical->Termination…** and select **50 Ω**.
- ❑ Select **Horiz/Acq->Horizontal/Acquisition Setup….**
- ❑ Set the Horizontal **Scale** to **100 ns/div**.
- ❑ Set the **Sample Rate** to **10.0 GS/s**.
- ❑ Select **Vertical->Bus Setup….**
- ❑ Select **Serial** Bus Type and then select **8B10B**.
- ❑ Select **2.5 Gb/s** Data Rate.
- ❑ Set the Threshold to **0.0V**.
- ❑ Turn **Bus 1** on.
- ❑ Position the bus waveform in the lower half of the display.
- ❑ Press the front panel **Single** button.
- ❑ Using the inner Wave Inspector control, turn on Zoom and zoom in until you can see the decoded values clearly.
- ❑ Press the **Display** tab at the left side of the control window.

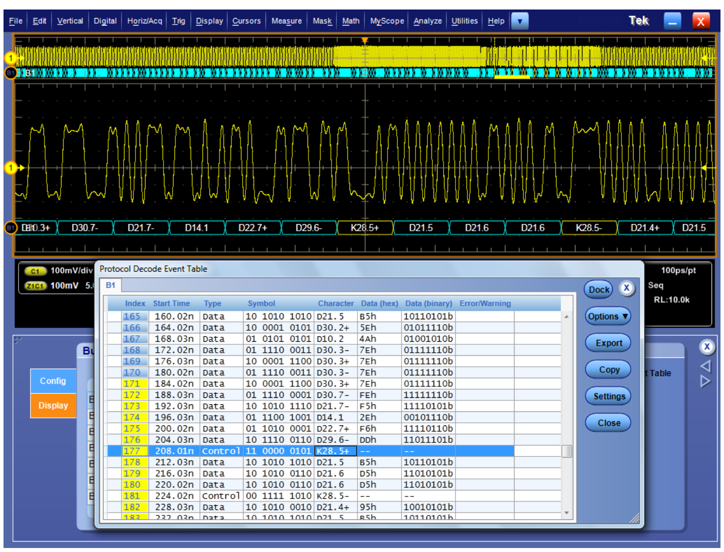
MSO/DPO5000 Series 8b/10b Bus Event Tables

Key Take Away Points

- Setting up a basic 8b/10b bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The Protocol Decode Event Table pop-up display looks like this when it is first enabled:

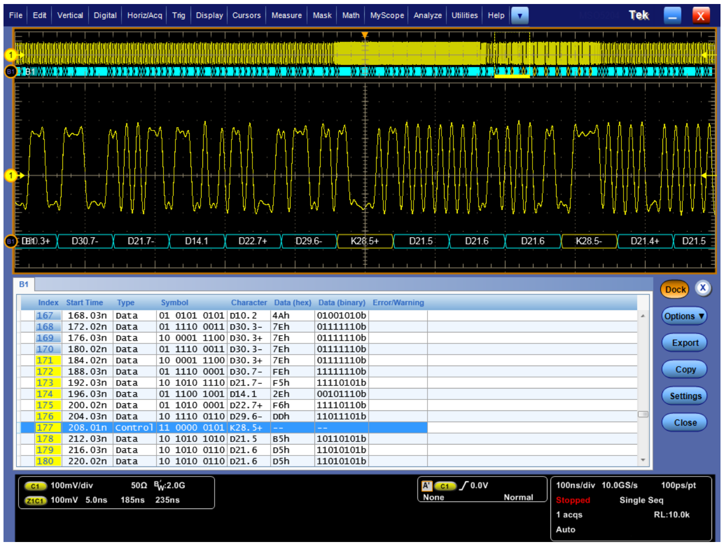
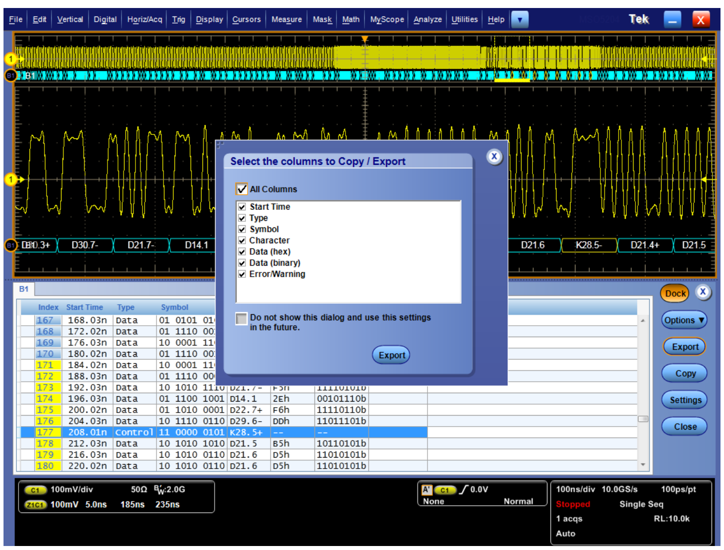


- The Event Table display can be sized and positioned on the screen, and the cursor position in the table is synchronized with the zoom box in the waveform display:



MSO/DPO5000 Series Procedure:

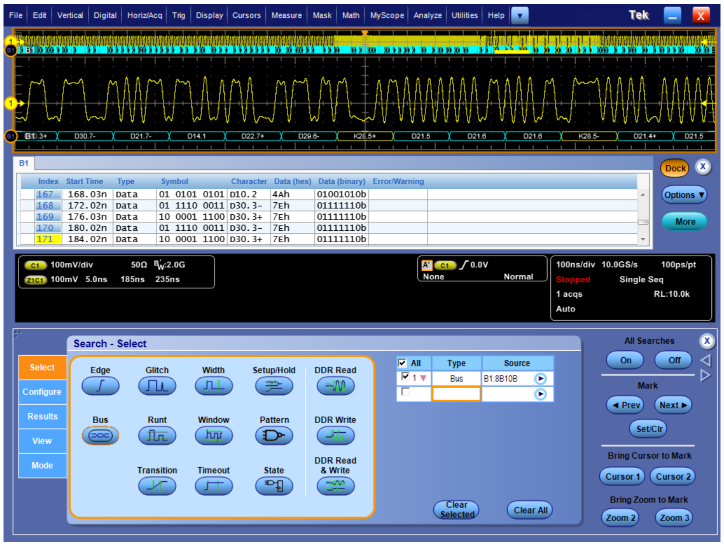
- ❑ Press the **Protocol Decode Event Table** button.
- ❑ The Event Table can be positioned by left-clicking on the top of the pop-up table and dragging it around on the display.
- ❑ The Event Table can also be sized by left-clicking on the lower right corner and dragging it to chance the size and shape of the table.
- ❑ Using the mouse or touchscreen, select lines in the table and show how the zoomed waveform corresponds to the selected line in the Event Table.

Key Take Away Points	MSO/DPO5000 Series Procedure:
• The Protocol Decode Event Table display can also be docked:  	❑ Press the **Protocol Decode Event Table** button. ❑ Press the **Dock** button. ❑ Close the Bus Setup control window using the **X** in the upper right corner of the control window.
• Selected portions of the decoded information in the Event Table can be copied to the Windows clipboard and can be saved to a file in CSV format:  	❑ Press the **Export** button in the Event Table. Notice that you can select which portions of the decoded data to copy or save. ❑ Press the **Export** button in the pop-up window. Notice that you can save the Event Table information to a file in .CSV format. When you are done, either **Save** the file or press **Cancel**.

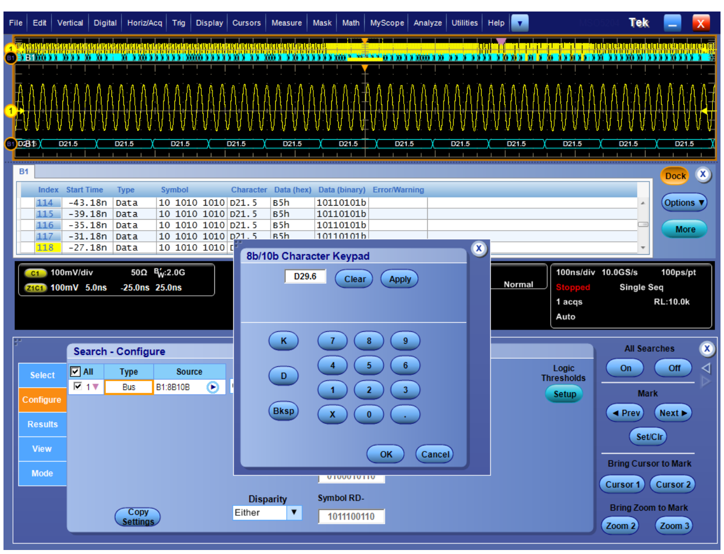
MSO/DPO5000 Series 8b/10b Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific values over the 8b/10b-encoded serial bus.

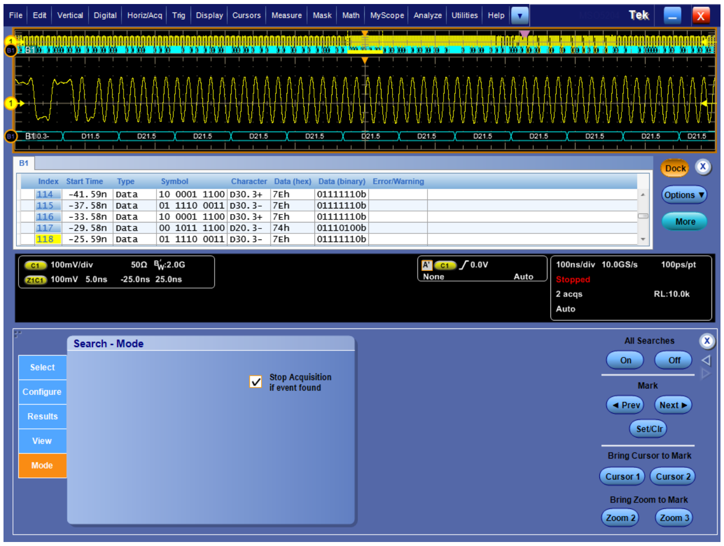


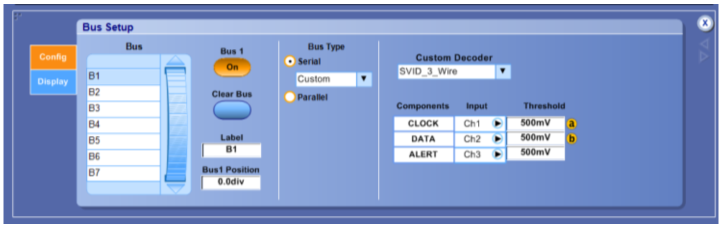
- The MSO/DPO5000 Series can search on a serial Pattern, a specific Character/Symbol, an Error, or Any Control Character.
- By following this simple procedure, you can easily search an acquisition for a specified serial pattern, marking each occurrence. In this case, search finds the only occurrence of the character “D29.6” in the acquisition:



MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** Search button in the control window.
- ❑ Select the **Configure** tab at the left side of the control window.
- ❑ Using the **Search For** drop down menu, select **Character/Symbol**.
- ❑ The easiest way to enter the value is with the 8b/10b Character Keypad. Double-click on the **Character** text box.
- ❑ Using the pop-up keypad, enter “**D29.6**”.
- ❑ When you are done, press **OK**.
- ❑ If the character “D29.6” occurs in the current acquisition, one or more purple triangles will appear at the top of the display.
- ❑ If the character “D29.6” does not occur in the current acquisition, press the front panel **Single** button one or more times until triangles appear at the top of the display. Or you can simply skip to the next section to find a more reliable way to find an event.

MSO/DPO5000 Series 8b/10b Bus Software Triggering	
Key Take Away Points • Although the MSO/DPO5000 Series oscilloscopes do not have an 8b/10b hardware trigger, the 8b/10b bus search gives you similar capability for some applications. By programming search to stop acquisitions when it finds the specified data pattern, search provides a software trigger capability.  • Although the performance of software triggering may not be as effective as hardware triggering in some applications, you can follow this simple search procedure to acquire specified serial patterns.	**MSO/DPO5000 Series Procedure:** ❑ Select the **Mode** tab at the left side of the control window. ❑ Check the **Stop Acquisition if event found** check box. ❑ Press the front panel **Run/Stop** button to re-start acquisitions. ❑ Press the **<**Prev or Next**>** buttons, either in the control window or on the front panel, to jump between search events.



Equipment List
One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with the SR-CUST option installed
Custom decoder file
Custom signal source or custom signal waveforms

Understanding Custom Serial Bus Decoding

Custom serial buses are used in many designs in industry today. In many cases, these custom buses are similar to other industry-standard buses, but have been adapted for a specific purpose. For example, a custom bus may be an industry-standard bus at the physical layer that has a unique number of bits per field. Or it may be a bus that has unique bit encoding.

Although the details of the bus may be different, the basic customer need is often similar: debugging a complex electronic system with industry-standard tools like the time-correlated, multi-domain displays of an oscilloscope.

How it works

Using proprietary programming tools, a Tektronix application engineer builds a custom serial bus decoder definition, delivered as a Windows .DLL file. Working from a bus specification, the AE defines the inputs and characteristics of the bus, much like the Tektronix software engineers did when they built the standard serial bus decoders. The SR-CUST option uses this definition file to implement the bus decoding and search capabilities on the oscilloscope.

The look and feel of the custom decoder will be similar to the standard serial bus decoders and will be familiar to the users. However, the exact layout of the displayed bus waveform and the fields will be specific to the custom bus.

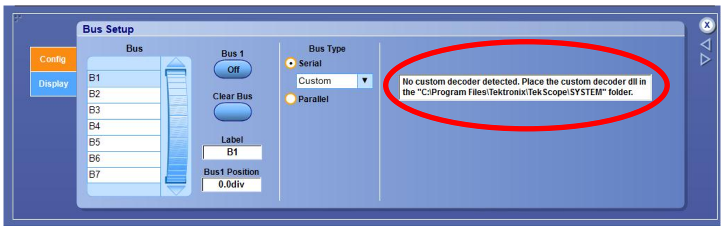
Lab Objectives

- Obtain a basic understanding of the optional custom serial bus decoding and search capabilities of SR-CUST.
- Learn how to use SR-CUST to set up a custom serial bus display and decode and search on data patterns with an MSO/DPO5000 Series oscilloscope.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

- The SR-CUST option, in conjunction with a custom serial decoder designed by a Tektronix Application Engineer, and an MSO/DPO5000 Series oscilloscope can automatically decode and search custom serial bus traffic.
- The custom decoder DLL file must be loaded on the oscilloscope in the C:\Program Files\Tektronix\TekScope\SYSTEM folder.
- If you select Custom Serial Bus Setup and no custom decoder DLL files are properly loaded, you will see the following message displayed:



- The customer decoder files are recognized as the oscilloscope application starts up, so the oscilloscope application must be restarted after loading the custom decoder DLL file.

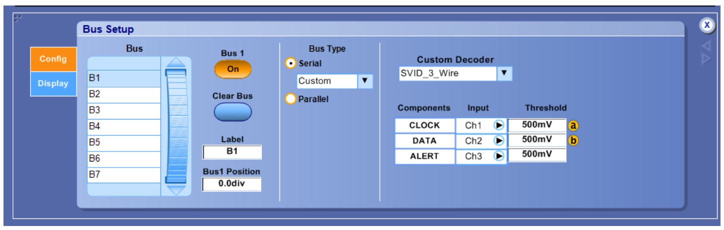
MSO/DPO5000 Series Procedure:

- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope….**
- ❑ Verify that the **SR-CUST: Custom Serial Analysis** option is installed.
- ❑ Press the **OK** button.
- ❑ Load the custom decoder DLL file onto the oscilloscope in the **C:\Program Files\Tektronix\ TekScope\SYSTEM** folder.
- ❑ Press the **X** in the upper left corner of the oscilloscope application or select **File->Exit**, and then press the **Yes** button.
- ❑ Double-click on the TekScope icon on the Windows desktop to restart the oscilloscope application.

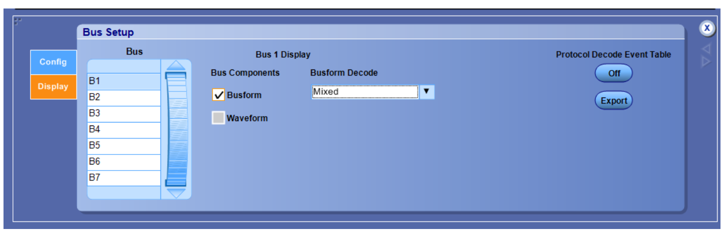
MSO/DPO5000 Series Custom Bus Setup and Decoding

Key Take Away Points

- In this section, you will learn how to use the MSO/DPO5000 Series to automatically decode custom serial bus traffic.
- Setting up a basic custom bus waveform display takes only a few simple steps with the MSO/DPO5000 Series, as with any of the standard serial buses. Notice that any of the analog or digital inputs or math signals can be used as a source for the custom bus.
- This is an example display of the setup control window for a custom SVID serial bus:



- The supported data display formats can be selected in the Display tab. For example, the custom SVID decoder can display data in Binary, Hex, or Mixed format:



- The decoded information in the bus waveform will be color-coded in a similar manner to the displays from the standard serial bus decoders.
- The decoded information can also be displayed in a tabular format with the Event Table. The Event Table display can be sized and positioned on the screen, and the cursor position in the table is synchronized with the zoom box in the waveform display.

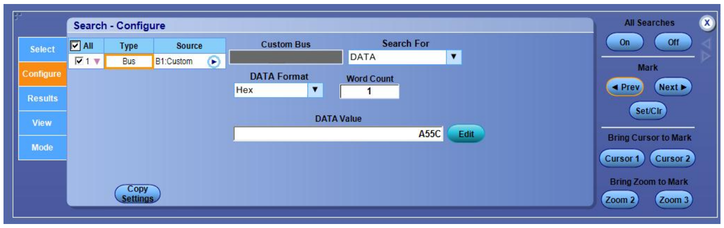
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Connect the custom serial signal to the oscilloscope and adjust the vertical and horizontal scales and triggering to get a stable display of one or more packets of serial data.
- ❑ Press the blue front panel Bus **B** button or select **Vertical->Bus Setup….**
- ❑ Select **Serial** Bus Type and then select **Custom**.
- ❑ Select the desired custom decoder from the Custom Decoder drop-down box.
- ❑ Set the Threshold values appropriately for each of the custom serial bus signals.
- ❑ Turn **Bus 1** on.
- ❑ Position the bus waveform as desired on the display.
- ❑ Press the front panel **Single** button.
- ❑ Using the inner Wave Inspector control, turn on Zoom and zoom in until you can see the decoded values clearly.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Press the **Protocol Decode Event Table** button.
- ❑ The Event Table can be positioned and sized with the mouse, or docked below the display graticule.
- ❑ Using the mouse or touchscreen, select lines in the table and show how the zoomed waveform corresponds to the selected line in the Event Table.

MSO/DPO5000 Series Custom Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific values over the custom serial bus.



- The MSO/DPO5000 Series can search on any serial data value, pattern, or error defined in the custom decoder.
- By following this simple procedure, you can easily search an acquisition for a specified serial pattern, and mark each occurrence.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** Search button in the control window.
- ❑ Select the **Configure** tab at the left side of the control window.
- ❑ Using the **Search For** drop down menu, select the desired bus field.
- ❑ The easiest way to enter the value for the selected field is with the on-screen keypad. Double-click on the selected field's text box.
- ❑ Using the pop-up keypad, enter the desired value.
- ❑ When you are done, press **OK**.
- ❑ If the specified value occurs in the current acquisition, one or more purple triangles will appear at the top of the display.
- ❑ If the value does not occur in the current acquisition, press the front panel **Single** button one or more times until triangles appear at the top of the display. Or you can simply skip to the next section to find a more reliable way to find an event.

MSO/DPO5000 Series Custom Bus Software Triggering

Key Take Away Points

- Although the MSO/DPO5000 Series oscilloscopes do not have a custom serial bus hardware trigger, the custom serial bus search gives you similar capability for some applications. By programming search to stop acquisitions when it finds the specified data pattern, search provides a software trigger capability.

- Although the performance of software triggering may not be as effective as hardware triggering in some applications, you can follow this simple search procedure to acquire specified serial patterns.

MSO/DPO5000 Series Procedure:

- ❑ Select the **Mode** tab at the left side of the control window.
- ❑ Check the **Stop Acquisition if event found** check box.
- ❑ Press the front panel **Run/Stop** button to re-start acquisitions.
- ❑ Press the **<**Prev or Next**>** buttons, either in the control window or on the front panel, to jump between search events.

MSO5000/DPO5000 Series

Parallel Bus Triggering and Decoding Lab

Equipment List

One MSO5000 Series oscilloscope with software version ≥6.4 or
one DPO5000 Series oscilloscope with software version ≥6.4 and with the MSOE option installed
One TPP0500 or TPP1000 passive probe
One P6616 MSO probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo 3 board]

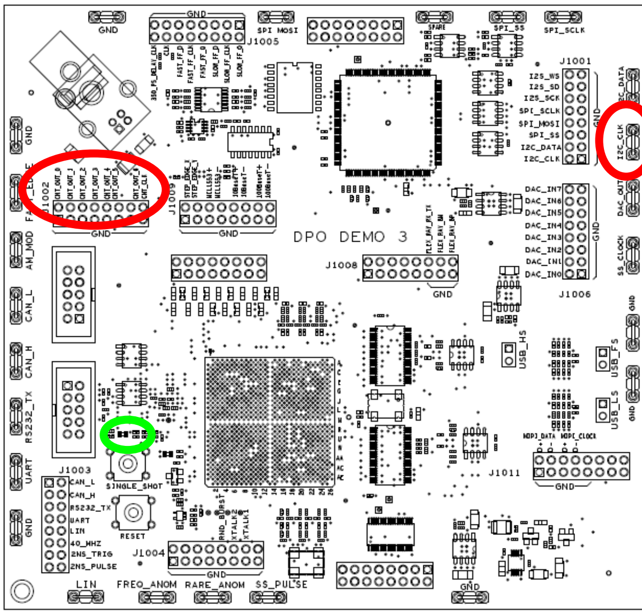
Lab Objectives

- Learn how to set up a parallel serial bus display and trigger and search on parallel bus content with an MSO5000 Series mixed-signal oscilloscope.
- Learn how to use setup & hold triggering to identify timing errors in synchronous buses.
- Learn how to use the MagniVu acquisition mode to maximize measurement timing resolution.

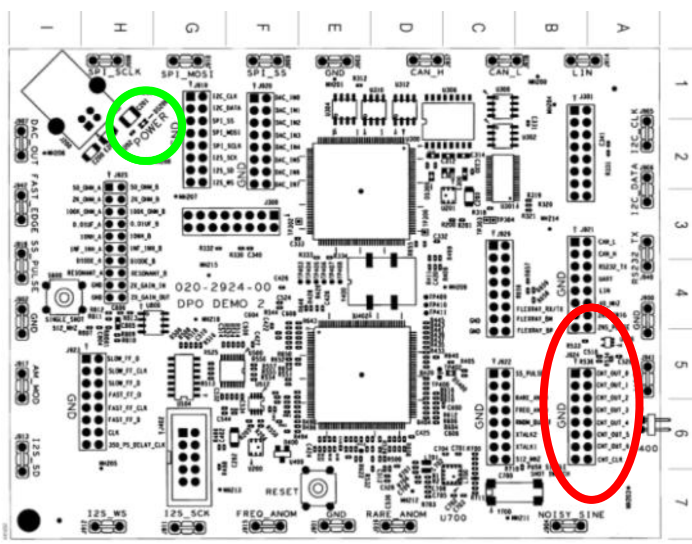
MSO5000 Series Lab Setup

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a parallel bus signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a parallel bus signal which we can use for this lab:

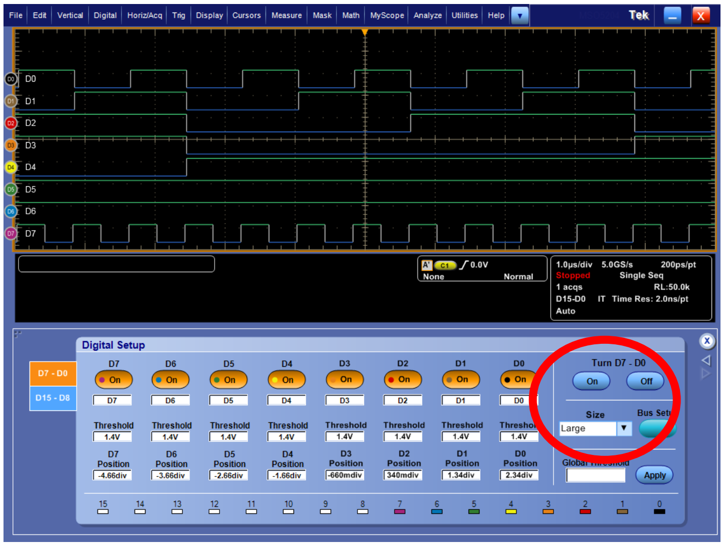


DPO Demo Board Procedure

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Then connect the probe ground to **GND** and connect the probe to the **I2C_CLK** (clock) test point.
- ❑ Attach a P6616 MSO probe to the D15-D0 input on the front of the oscilloscope.
- ❑ On Group 1 of the MSO probe, connect the **D0** input to the **CNT_OUT0** square pin, with the probe ground on the ground pin on the left side of the connector. Similarly, connect inputs **D1** through **D6** to the **CNT_OUT1** through **CNT_OUT6** signals.
- ❑ Connect the **D7** input to the **CNT_CLK** pin.

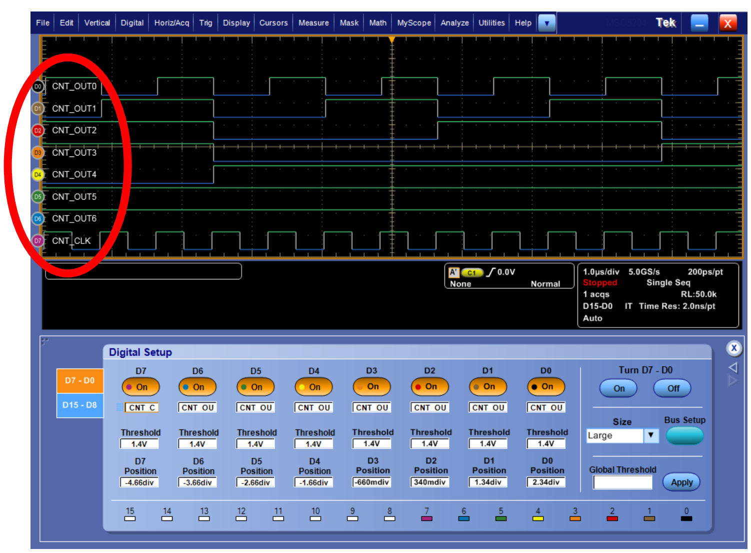
Key Take Away Points

- The display should look about like this:



- There are several key next-generation digital display characteristics to notice in the display. When digital signals are **low**, the waveforms are **colored blue**. When the signals are **high**, the waveforms are **colored green**.

- Digital channels can be displayed in several sizes, from extra small (8 channels occupy about 2 divisions on the display) to large (where 8 channels fill the display).
- As the number of signals on the display increases, it becomes increasingly valuable to be able to attach text labels to the waveforms. There are two ways to add labels:
  - Enter the label, character by character, by double-clicking on the label text box and typing in the label with the popup keyboard using the touch screen or mouse.
  - Enter the label by clicking on the label text box and typing in the label with an attached USB keyboard.

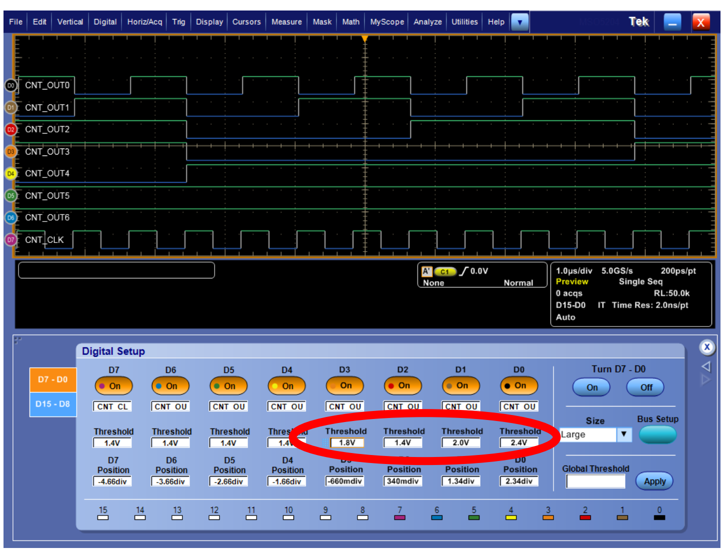


MSO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **1** button to turn off channel 1.
- ❑ Press the blue front panel **D15-D0** button to display the Digital Setup control window.
- ❑ Press the **Turn D7-D0 On** button.
- ❑ Using the **Size** drop down menu, select **Large** display size.
- ❑ Set the Horizontal **Scale** to **1µs/div**.
- ❑ If you have a USB keyboard connected to the oscilloscope, click on the label text box below each of the channel On buttons. Type in a unique label for each channel.
- ❑ If you do not have a USB keyboard connected to the oscilloscope, double-click on the label text box below each of the channel On buttons, type in a unique label, and press the **Enter** button.

Key Take Away Points

- Many digital and mixed signal designs also contain multiple logic families. The signal on each input to the digital logic probe is compared with a threshold value to determine if the input signal is high or low.
- Most MSO products only allow the user to set a single logic threshold per group of 8 channels. If the application has multiple logic families, this would require using channels from each group to acquire the waveform. If more than two logic families are needed another instrument would be needed. The MSO5000 series allows the user to set a unique logic threshold for every digital channel.
- There are various ways to enter a threshold value for each digital channel:
  - Touch the Threshold text box and adjust the value using the Multipurpose controls.
  - Click on the Threshold text box and edit the threshold value with a USB keyboard.
  - Double-click on the Threshold text box and edit the threshold value with the popup keyboard using the touch screen or mouse.
  - Double-click on the Threshold text box and select one of the preset threshold values (TTL, ECL, or USER) with the popup keyboard using the touch screen or mouse.
- The display should look about like this:



- You can also easily set the threshold value for all of the digital channels with a single action using the Global Threshold control.

MSO5000 Series Procedure:

- ❑ If you have a USB keyboard connected to the oscilloscope, click on the Threshold text box for channel D0 and edit the threshold value to be **2.4V**.
- ❑ If you do not have a USB keyboard connected to the oscilloscope, double-click on the Threshold text box for channel D0 and edit the threshold value to be **2.4V**.
- ❑ Double-click on the Threshold text box for channel D1 and edit the threshold value to be **2.0V**.
- ❑ Double-click on the Threshold text box for channel D2 and set the threshold value to **TTL** (1.4V).
- ❑ Click on the Threshold text box for channel D3 and use the Multipurpose **a** control to set the threshold value to **1.8V.**
- ❑ Double-click on the **Global Threshold** text box.
- ❑ Using the popup keyboard, set the threshold value to **1.5V**.
- ❑ Press the **Apply** button and verify that the Threshold value for all of the digital channels changes to 1.5V.

MSO5000 Series Parallel Bus Decoding Setup

Key Take Away Points

- Setting up a basic parallel bus waveform display takes only a few simple steps with the MSO5000 Series.
- Notice that any of the analog or digital inputs or math signals can be used as a source for the parallel bus. To keep this demo simple, we will only use one group of 8 digital signals.
- Zoom in on one of the bus transitions. You may notice that there are some intermediate states on an unclocked bus:

- Since the clock is on channel D7, we can use it to create a clocked bus, which only transitions when the clock edge occurs. The clocked bus display should now look about like this, with the decoded values shown in the bus waveform:

MSO5000 Series Procedure:

- ❑ Press the front panel **B** button or select **Digital -> Bus Setup….**
- ❑ Verify that the **Parallel** Bus Type is selected and that **Clocked** is not checked.
- ❑ Press the Add Sources **Select** button.
- ❑ Add digital channels 7 (MSB) through 0 (LSB) to the parallel bus by pressing the **D7**, **D6**, **D5**, **D4**, **D3**, **D2**, **D1**, and **D0** buttons, in that order, and press **OK**.
- ❑ Press the **Bus 1** button to turn the parallel bus **On**.
- ❑ Using the Multipurpose **a** control, position the bus near the top of the display.
- ❑ Using the Wave Inspector controls, zoom in on the decoded data values.
- ❑ Find and select **D7** in the Bus 1 Contains list and press the **Remove** button.
- ❑ Check the **Clocked** check box control.
- ❑ Touch the Clock Source text box, select **D0-D7**, and select **D7**.
- ❑ Verify that the Clock Polarity is set to **Rising**.
- ❑ When you are done, deselect the **Clocked** check box control and turn off Zoom.

MSO/DPO5000 Series Parallel Bus Symbol Tables	
Key Take Away Points • The MSO/DPO5000 Series also can display decoded parallel bus information symbolically, based on a translation table called a Symbol File. • The symbol file uses a specific format called TLA Symbol Format (TSF) and has a .tsf file extension. Symbol files can be created and edited with any text editor. • The header line for the file begins with the "#+" characters and specifies the file format version, the word "PATTERN", and the numeric radices used to specify the symbol values for display and for interpreting the values in the file. Valid radix values are "HEX", "OCT", "DEC", and "BIN". • Except for lines which begin with the special "#+" pattern, any characters after a '#' character are interpreted as comments. • The remaining lines in the file are used to specify the symbols and values. An 'X' can be used to specify a "don't care" value. The symbol values need to be valid for the radix specified. (For example, only '0', '1', and 'X' are valid for BIN format.) Spaces or tabs are used to separate the fields on a line. • For example, try this symbol file: # ParallelTest.tsf Symbol File Test for Parallel # #+ version 2.1.0 PATTERN BIN BIN # # Symbol Pattern Comments # STATE0 XXXXX00 STATE1 XXXXX01 STATE2 XXXXX10 STATE3 XXXXX11 • Note: The order of the symbols in the file is important. The instrument scans the list of pattern symbols starting at the top of the file and displays the first symbol that matches the bits with numeric values (not Xs). If the instrument cannot find a match, there is no symbol and the numeric value is displayed instead.	**PC Procedure:** ❑ Open a text editor and create a TSF file with symbols and numeric values, as shown at the left. ❑ Save the file in text format and name it **ParallelTest.tsf**.

Key Take Away Points

- The Symbol File display should look about like this:

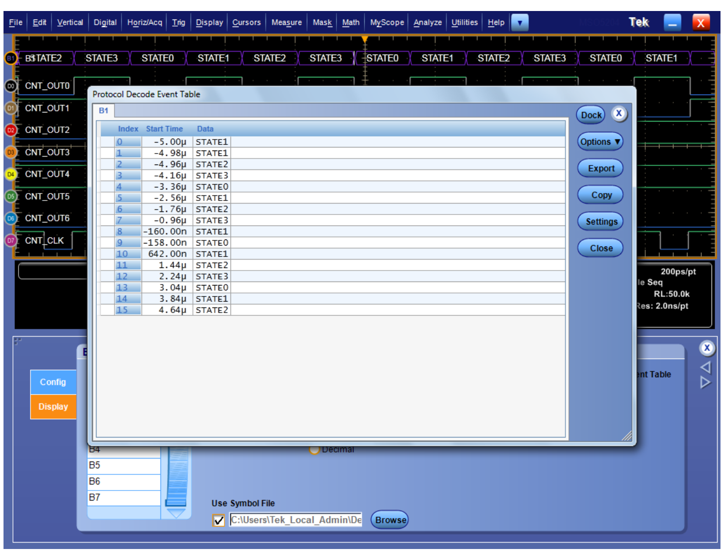
MSO/DPO5000 Series Procedure:

- ❑ Copy the **ParallelTest.tsf** file to the **C:\TekScope\BusDecodeTables** directory on the instrument.
- ❑ From the Bus Setup window, select the **Display** tab and appropriate bus to decode using the symbol file.
- ❑ Select the **Hex** number base to match the Display radix defined in the file.
- ❑ Click the **Use Symbol File** check box.
- ❑ Click the Symbol File box and enter the path to the file with the keyboard or press the **Browse** button to locate the file.

MSO/DPO5000 Series Parallel Bus Event Tables

Key Take Away Points

- Setting up a basic parallel bus event table display takes only a few simple steps with the MSO/DPO5000 Series.
- The parallel bus Event Table display looks like this:



MSO/DPO5000 Series Procedure:

- ❑ Press the **Protocol Decode Event Table** button.
- ❑ Press the **Export** button. Notice that you can save the Event Table information to a file in .CSV format. When you are done, either **Save** the file or press **Cancel**.
- ❑ Press the **Close** button.
- ❑ Uncheck the **Use Symbol** check box.

MSO5000 Series Parallel Bus Triggering

Key Take Away Points

- When debugging a system, you often want to capture the state of some key signals when a certain event occurs. One key event may be the data value on the parallel bus.
- You can use Logic triggering, setting up the desired digital trigger pattern bit-by-bit. However, since the parallel bus is already set up, it is much easier to use parallel bus triggering.
- By following this simple procedure, you can easily trigger the oscilloscope on a specified serial pattern on a parallel bus signal, capturing each occurrence.

- Notice that, in this case, the trigger point is positioned at the end of the 0X bus value.

MSO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Using the **Trigger Type** drop down menu, select **Bus** triggering.
- ❑ Using the Bus drop down menu, select Bus **B1**.
- ❑ Press the **Edit** button.
- ❑ Select **Hex**, enter the pattern **0X**, and press **OK**.
- ❑ Click on the **Pattern** text box and select **>**.
- ❑ Double click on the **Time** text box and type in **100 ns**.
- ❑ Press the front panel **Single** button.

MSO/DPO5000 Series Parallel Bus Searching

Key Take Away Points

- Once you have acquired a serial signal, you often want to find all occurrences of a certain event, such as the transmission of specific content over the parallel bus. In this case, notice the locations of all data values matching the XX11 pattern in the acquisition.

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Search** button.
- ❑ Press the **Bus** search button in the control window.
- ❑ Select the **Configure** tab at the left side of the control window.
- ❑ The easiest way to enter the address is with the Pattern Editor. Press the **Edit** button at the right.
- ❑ Select **Binary** format.
- ❑ Double click on the **Data Value** text box and set the pattern to **XXX XX11**.
- ❑ When you are done, press **OK**.
- ❑ Press the front panel **Run/Stop** button to restart acquisitions.

MSO5000 Series MagniVu Acquisition

Key Take Away Points

- The normal sample rate for the MSO5000 digital channels is 500 MS/s per channel (2 ns timing resolution) over the full record length. This sample rate provides adequate sample rate for most applications involving widely-spaced digital signals.
- Notice the digital timing resolution (displayed at the bottom of the screen):

MSO5000 Series Procedure:

- ❑ Set the horizontal Scale to **5 ns/div**. As you change the scale, notice that the digital sample rate reaches a maximum 500 MS/s (2.0ns/pt timing resolution, indicated in the readout at the bottom of the display).
- ❑ Press the front panel **Single** button.
- ❑ Press the front panel **B** button.
- ❑ Press the Add Sources **Select** button, press the **D7** button, and press **OK** to add channel D7 back into the parallel bus.
- ❑ To restore it to the MSB position in the bus, click on the **D7** entry in the **Bus 1 Contains** graphic and repeatedly press the up arrow next to it until D7 appears at the top of the list.
- ❑ Notice that intermediate decoded bus values may appear on the display, and the bus transitions occur where the data bit values change, not just on the clock edges. You can use zoom to look at these intermediate values in more detail.
- ❑ Press the **Cursors** front panel button once to turn on vertical bar cursors.
- ❑ Using the Multipurpose controls, place the **a** and **b** cursors on events of interest.
- ❑ Notice that we are displaying the time delay between the edges, with single-pixel timing resolution.

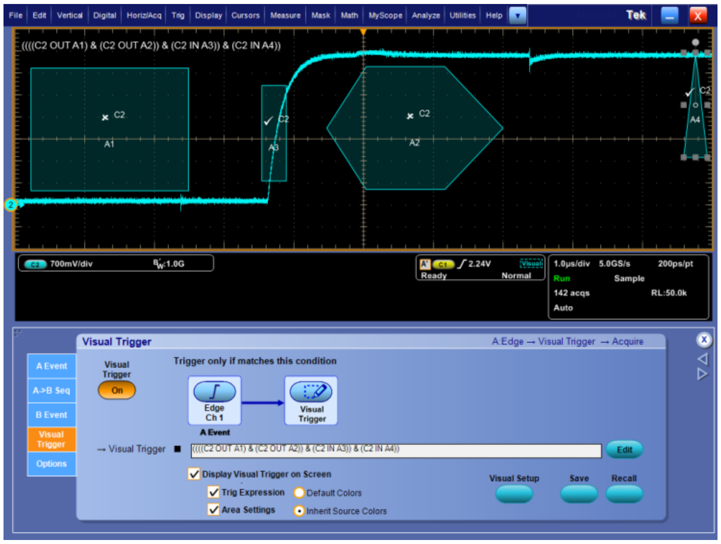
Key Take Away Points

- For high-resolution timing measurements between timing events that are close together, such as setup & hold time or propagation delay measurements, MagniVu acquisition mode provides the highest timing resolution available in a mixed signal oscilloscope. MagniVu provides up to 16.5 GS/s sample rate (60.6 ps timing resolution) over a 10k record length centered around the trigger point.
- With the higher MagniVu timing resolution, you can now accurately measure the timing differences between edges that occur within a single 2 ns digital sample period.

- And, because normal and MagniVu acquisitions are always taken at the same time, you can switch back and forth between acquisition modes, even after acquisitions are stopped.

MSO5000 Series Procedure:

- ❑ Press the front panel **Single** button.
- ❑ Select **Digital -> MagniVu** to select it.
- ❑ Notice the 60.6 ps/pt digital timing resolution in the readout at the bottom of the display.
- ❑ Select **Digital -> MagniVu** to toggle between normal and MagniVu modes.



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.4 and with option VET installed
Two TPP0500 or TPP1000 passive probes
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this document were made with the DPO Demo 3 board]

Overview of Visual Trigger

Finding the right characteristic of a complex signal can require hours of collecting and sorting through thousands of acquisitions for the event of interest. Defining a trigger that isolates the desired event and shows data only when the event occurs speeds up this process. The optional Visual Trigger makes the identification of the desired waveform events quick and easy by scanning through all waveform acquisitions and comparing them to on-screen areas (geometric shapes).

The visual trigger option adds an additional dimension to the standard trigger system that provides an intuitive method of triggering based on shapes in the oscilloscope's graticule. It enables the user to define shapes on the oscilloscope's display that qualify trigger events for the incoming signals. Visual trigger can qualify any trigger setup, simple or complex. Areas can be created using a variety of shapes including triangles, rectangles, hexagons or trapezoids to fit the area to the particular trigger behavior desired. Once shapes are created on the oscilloscope's display, they can be positioned and/or re-sized dynamically while the oscilloscope is in run mode to create ideal trigger conditions. Visual triggers can be combined with the standard triggers and act as a Boolean logic qualifier for the "A" and “B” events.

More specifically, Visual Trigger is a software post-process that graphically compares acquired analog input waveform(s) to the areas you draw on the display. The process always begins with setting up the oscilloscope’s hardware trigger system to acquire the waveforms. The trigger can be as simple as an edge trigger or as complex as a multi-state trigger, or parallel, serial, or video trigger. For predictable operation, the scope should always be in Normal trigger mode. The maximum possible waveform capture rate is determined by this hardware trigger rate. The actual waveform capture rate will be reduced by the software processing time and the percentage of waveforms that do not meet the visual trigger criteria.

Each of the visual trigger areas is associated with a specific input channel. By default, the areas are rectangular and are associated with the “selected channel” when created. You can then change the shape of the area, the associated channel, and whether the signal must go inside or stay outside of the area. Finally, you can write a logical equation to describe how Visual Trigger will use the various areas to determine which waveforms are displayed and which are discarded.

Visual triggers can speed up complex debugging situations for high speed serial signaling by creating a series of ones and zeros using up to 8 shapes that simulate a serial pattern trigger. For DDR debugging situations, Visual Trigger can be helpful for accurately capturing bursty read/write traffic. It also can detect patterns in the memory data buses using the dynamic shaping of Visual Trigger to localize the cause of reduced setup and hold margins. Using Visual Trigger, hours of waiting to capture the right signal can be reduced to seconds or minutes.

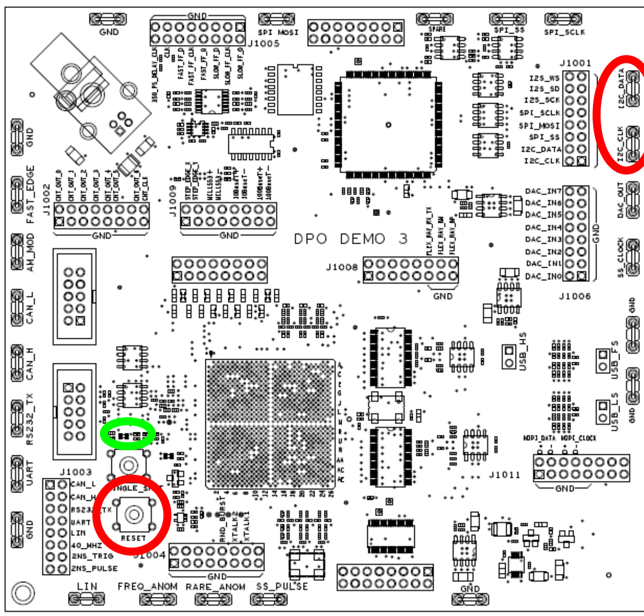
Lab Objectives

- Obtain a basic understanding of Visual Trigger capabilities.
- Learn how to graphically set up and demonstrate a simple Visual Trigger.
- Learn how to set up a complex Visual Trigger using the equation editor.
- Learn how to use the Save on Event feature to save the results of each trigger event.
- Learn how to use the Mark All Trigger Events in Record feature.

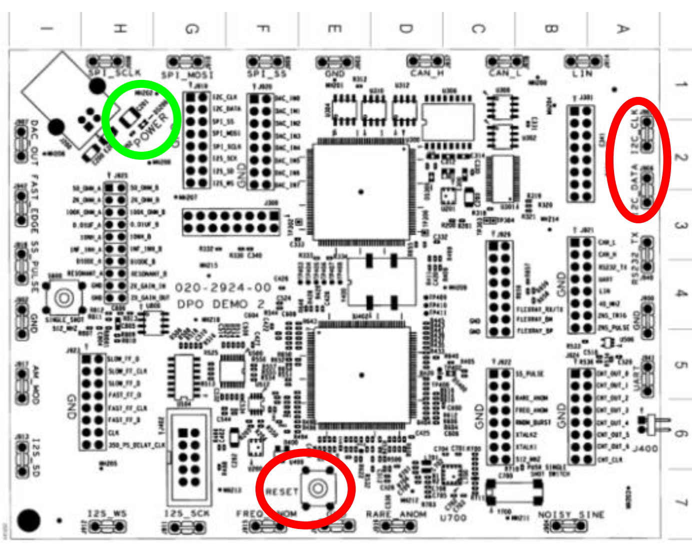
MSO/DPO5000 Series Lab Setup

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has I^2C digital clock and data signals which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has I^2C digital clock and data signals which we can use for this lab:



DPO Demo Board Procedure

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the DPO Demo 3 board.
- ❑ Verify the power LED is lit.
- ❑ Attach TPP1000 or TPP0500 probes to the Channel 1 and Channel 2 inputs of the oscilloscope.
- ❑ Attach the probe grounds to the **GND** test point on the test board.
- ❑ Connect the channel 1 probe tip to the **I2C_CLK** test point on the test board.
- ❑ Connect the channel 2 probe tip to the **I2C_DATA** test point on the test board.
- ❑ Press the **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the **RESET** button.

Key Take Away Points

- With option VET installed, the MSO/DPO5000 Series oscilloscope allows you to refine the oscilloscope's hardware-based triggering with a graphical definition of the desired trigger signal.

MSO/DPO5000 Series Procedure

- ❑ Select **Help -> About TekScope….**
- ❑ Verify that option **VET: Visual Trigger and Search** is installed.
- ❑ Press the **OK** button.

Simple Waveform Triggering

Key Take Away Points

- Let's start by examining an I^2C clock signal. This signal consists of bursts of digital pulses, with various lengths of bursts. As such, it is difficult to get a stable display using standard triggering techniques.

- Remember that, in normal acquisition mode, the oscilloscope only acquires signals when a valid trigger occurs. Once the oscilloscope has acquired a waveform, the oscilloscope can then process the signal. Normally this would be a measurement or display. But it can also be further refinement of the trigger criteria using Visual Trigger.
- Notice the orange circle around the channel 1 icon at the left side of the display. This indicates that channel 1 is the "selected channel". (Since there is only one signal on the display, this should not be a surprise.) The concept of "selected channel" is important to Visual Trigger and will become clearer as you move through the lab.

MSO/DPO5000 Series Procedure:

- ❑ Set the channel 1 Vertical Scale to about **700 mV/div** and center the position of the waveform vertically on the display.
- ❑ Set the Horizontal **Scale** to **20 µs/div**.
- ❑ Press the **Trigger Level** control to automatically set the trigger level to 50%.
- ❑ Select **Trig->Edge Setup….**
- ❑ Press the **Options** tab at the left side of the control window.
- ❑ Press the **Normal Trigger Mode** button. This step is very important. If you leave the scope in Auto Trigger Mode, you may be very confused by the behavior of visual trigger.
- ❑ Notice that the display is similar to the screen shot at the left, and is fairly stable, but there are a few different patterns which meet this trigger criterion.
- ❑ Just to prove the point, press the purple front-panel **DPX** button.
- ❑ When you are done, press the **DPX** button again to return to normal acquisitions.

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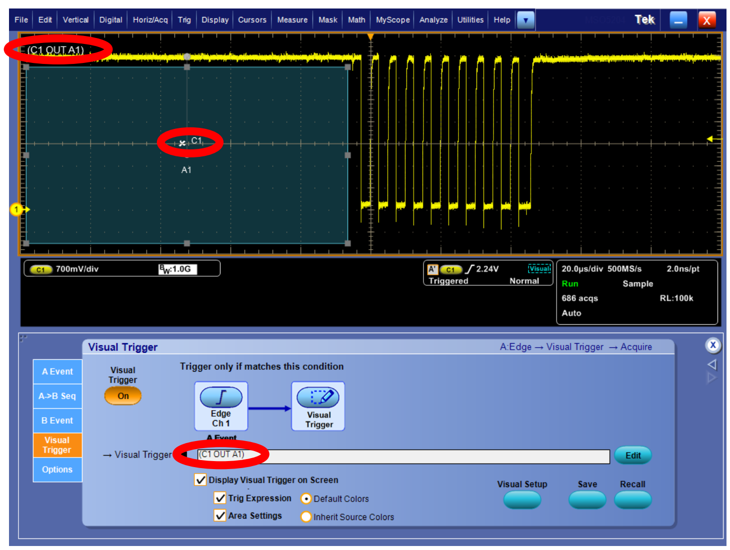
Simple Visual Trigger Setup

Key Take Away Points

- The optional Visual Trigger allows you to graphically specify areas on the display through which the signal must or must not cross.

- Notice that the Visual Trigger was automatically turned on and the specified Visual Trigger area is now displayed:



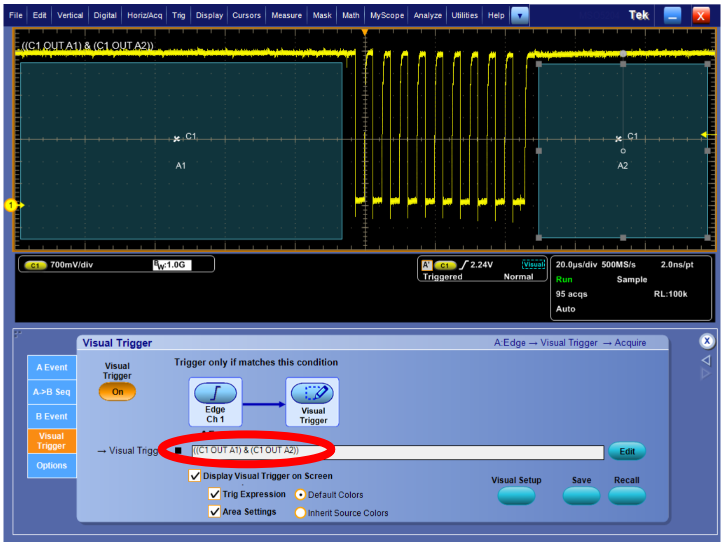
- The readouts on the A1 area display indicate that the Visual Trigger area is operating on channel C1 (the "selected channel"), and the X indicates that the signal must be outside the area.
- The equation readouts at the top of the display and in the Visual Trigger control window indicate the current setup of the Visual Trigger.

MSO/DPO5000 Series Procedure:

- ❑ Press the **Visual Trigger** tab at the left side of the control window.
- ❑ Press the left mouse button and draw a rectangle below the waveform at the left side of the display, as shown at the left, and select **Visual Trigger->Add Visual Trig Area**.
- ❑ Notice that the visual trigger area A1 appears. The check-mark and C1 readout in the upper right corner of the area indicates that, by default, Visual Trigger is requiring the channel 1 ("selected channel") signal to cross through the area.
- ❑ Right-click on this shape and select **Visual Trigger Area 1 -> Must be outside -> C1**. This specifies that the Channel 1 signal must stay outside of this area. Notice that the signal no longer occurs in this area and the area readout now shows "X C1".

Key Take Away Points

- After enabling two Visual Trigger areas, the display should look about like this:



- Notice the Visual Trigger equation at the top of the display: “((C1 OUT A1) & (C1 OUT A2))”. This would be interpreted as the (channel 1 is OUTside area A1) AND (channel 1 is OUTside area A2). This equation looks a lot like Boolean math in the oscilloscope’s math equation editor!
- This is an example of using to Visual Trigger to simply and graphically setting up the trigger system to capture a specific burst width on a complex signal.

MSO/DPO5000 Series Procedure:

- ❑ Press the left mouse button and draw a rectangle below the waveform at the right quarter of the display, as shown at the left, and select **Visual Trigger->Add Visual Trigger Area**.
- ❑ Right-click on this shape and select **Visual Trigger Area 2 -> Must be outside -> C1**. This specifies that the Channel 1 signal must stay outside of this area. Notice that the signal no longer occurs in this area.
- ❑ Right-click on this shape again and notice that this pop-up menu provides a way to show or hide the trigger expression (shown at the top left corner of the display), show or hide the visual trigger areas, and show or hide the area settings in these visual trigger areas.

Key Take Away Points

- In addition to graphical definition with the mouse or touchscreen, the Visual Trigger areas can be edited with the Visual Qualification Setup control window:

- From this control window, you can change the size and position of the area, as well as add and delete vertices to create your own shape!
- Finally, you can make the areas' colors match the source waveform for easy recognition. This can be especially helpful when the Visual Trigger specification includes multiple channels.

MSO/DPO5000 Series Procedure:

- ❑ Right-click on area 1 and select **Visual Trigger Area 1 -> Visual Setup….**
- ❑ Click on the **Edit Logic** tab at the left side of the control window.
- ❑ Click on the **Inherit Source Colors** radio button in the lower right corner of the control window.
- ❑ When you are done, right-click on area **A1** and select **Visual Trigger Area 1->Delete All Areas**.

More Complex Visual Trigger Setup

Key Take Away Points

- Now let's look at a more random signal – the I^2C Data signal.
- Since we need a stable trigger signal to work with Visual Trigger, we'll continue to use the I^2C clock on channel 1 as the trigger source (even though we're not going to display it).

- Again, we'll start with a Visual Trigger area and we'll specify that the channel 2 signal must stay outside of it:

MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Ch 1** button to turn it off.
- ❑ Press the front panel **Ch 2** button to turn it on.
- ❑ Notice the orange circle around the channel 2 icon at the left side of the display. This indicates that channel 2 is now the "selected channel".
- ❑ Set the channel 2 Vertical **Scale** to about **700 mV/div** and center the position of the waveform vertically on the display.
- ❑ Set the Horizontal **Scale** to **1 µs/div**.
- ❑ Select **Trig->Visual Trigger Setup….**
- ❑ Press the left mouse button and draw a rectangle in the blank area near the left side of the display, as shown at the left, and select **Add Visual Trigger Area**.
- ❑ Notice that the visual trigger area A1 appears. The check-mark and C2 readout in the upper right corner of the area indicates that, by default, Visual Trigger is requiring the channel 2 ("selected channel") signal to cross through the area.
- ❑ Right-click on this shape and select **Visual Trigger Area 1 -> Must be outside -> C2**. This specifies that the Channel 2 signal must stay outside of this area. The area readout now shows "X C2".

Key Take Away Points

- Then we'll add a second area and specify that the C2 signal must remain outside it:

- We have some choices about the shapes of the Visual Trigger areas, including rectangles, triangles, hexagons, and trapezoids. To provide a little margin for variations in risetimes, let's change area A2 to a hexagon:

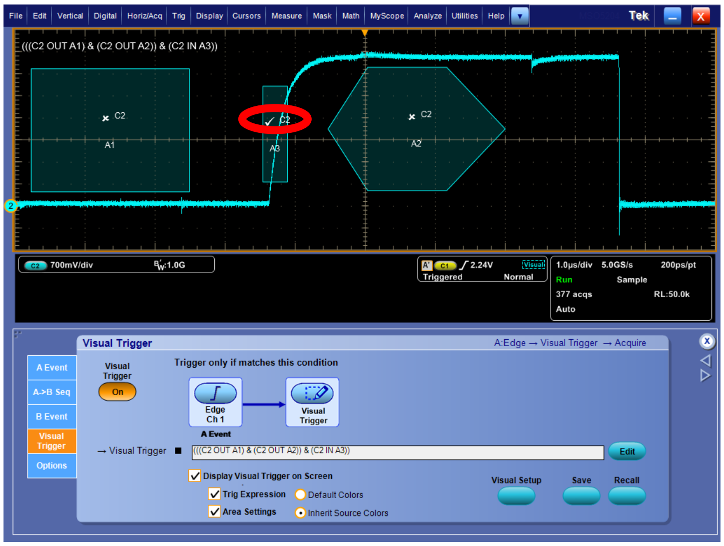
MSO/DPO5000 Series Procedure:

- ❑ Right-click on Visual Trigger area A1 and select **Visual Trigger Area 1 -> Duplicate Area**. This places a copy of the area on the display.
- ❑ Left-click on area A2 and drag it near to the center of the display, as shown at the left.
- ❑ Notice that, while you are moving the area, the coordinates of the area become time and voltage readouts. The vertical scale and position for the area are related to the channel associated with the area. (If you were to associate the area with a different channel, the position and/or the size of the area would change accordingly.)
- ❑ Right-click on area A2 and select **Visual Trigger Area 2 -> Edit Shape -> Hexagon**. This changes the shape from a rectangle to a hexagon.
- ❑ From the same right-click menu, you can also flip the shape horizontally or vertically.
- ❑ Using the left mouse button, click and drag the squares ("handles") on the sides and corners of area A2 to resize it horizontally and vertically, and to adjust the position of area A2.
- ❑ You can also click on any of the vertices and adjust the position of just that vertex, as shown at the left.

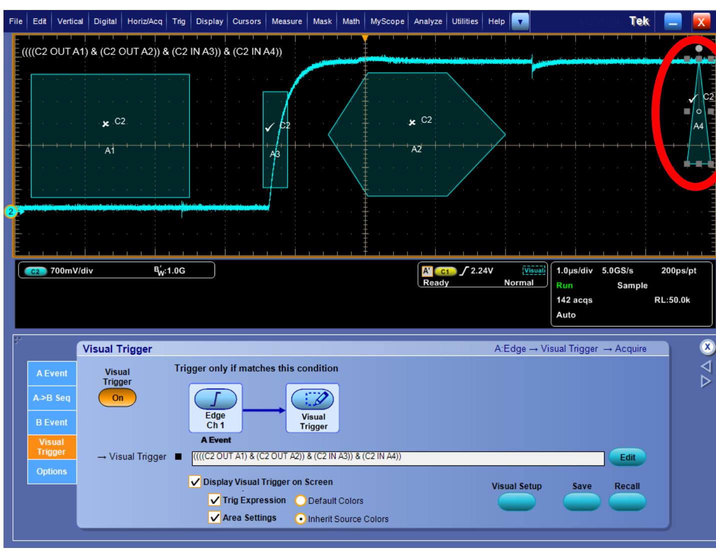
Key Take Away Points	**MSO/DPO5000 Series Procedure:**

Key Take Away Points

- Visual Trigger can be used to graphically specify where signals must occur, as well as where they must not occur. Area A3 is defined to be an area in which the signal must occur, with either a rising or a falling edge occurring within the rectangle.



- Notice the signals to the right of area A2. Some of the signals have very fast risetimes, while others are slower. We can use Visual Trigger to manually select the signals of interest:



- You can also add more areas to the display (up to 8 areas) to further refine the trigger definition.
- Also, Visual Trigger allows you to save and recall the setup of the Visual Trigger areas and other settings without having to save the entire oscilloscope setup. The setups are text files and can be saved on the oscilloscope or on an external drive such as a USB flash drive.

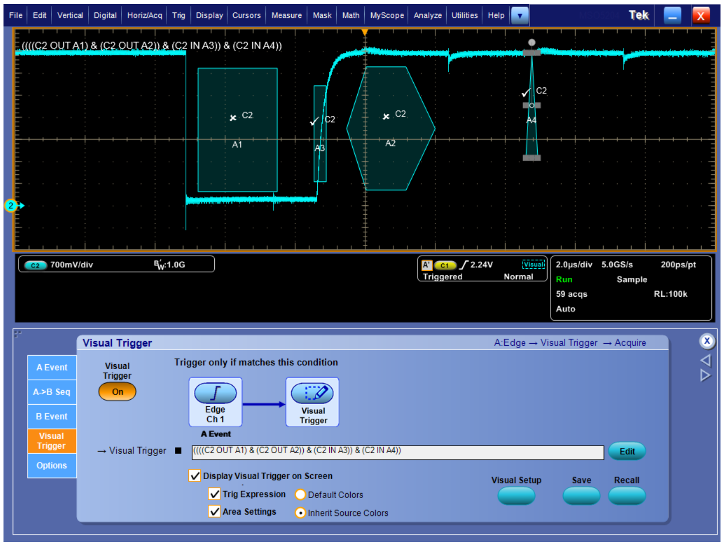
MSO/DPO5000 Series Procedure:

- ❑ Notice that the signal is appearing between areas A1 and A2. Draw a rectangle between A1 and A2, and select **Add Visual Trigger Area**. Notice that, by default, this area is specifying that the signal "Must be inside", as indicated by the check mark.
- ❑ Press the left mouse button and draw a rectangle in the blank area near the right side of the display, as shown at the left, and select **Add Visual Trigger Area**.
- ❑ Right-click on area A4 and select **Visual Trigger Area 4 -> Edit Shape -> Triangle**. The triangular shape is especially useful for manually selecting details of signals.
- ❑ Press the left mouse button and drag the triangular area A4 to select specific signals, such as those with slow risetimes, as shown at the left.
- ❑ Notice that you can use a Visual Trigger region, especially a triangle, to interactively investigate the characteristics of a complex signal.

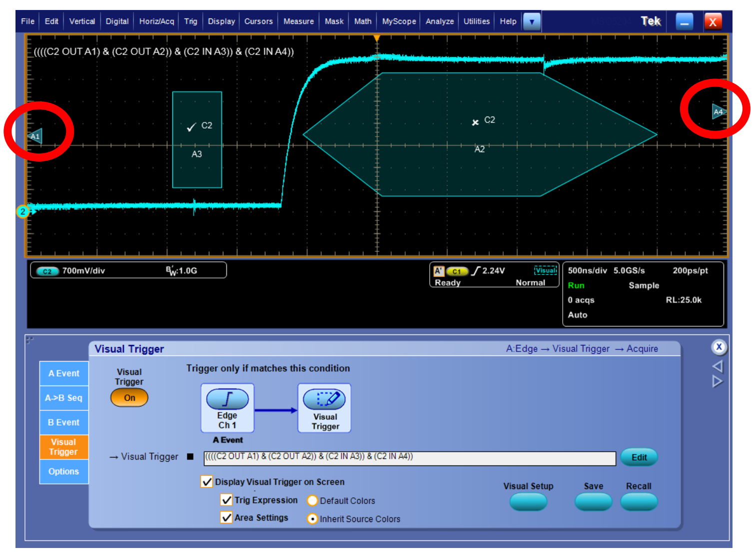
Key Take Away Points	**MSO/DPO5000 Series Procedure:**

Key Take Away Points

- As noted earlier, the coordinates of the areas are based on the oscilloscope horizontal and vertical scales and units, not merely screen position.
- For example, the Visual Triggers are scaled horizontally when you adjust the Horizontal Scale control:



- Changing scales can also force the Visual Trigger areas off-screen. When the regions are off-screen, you can click on the triangular icons and drag them back onto the display with the mouse.



MSO/DPO5000 Series Procedure:

- ❑ Turn the Horizontal **Scale** control counter-clockwise and notice that the Visual Trigger areas are scaled along with the waveforms on the display.
- ❑ Turn the Horizontal **Scale** control clockwise and notice that the Visual Trigger areas are scaled along with the waveforms on the display. Some of the areas are eventually pushed off of the screen and are displayed as small triangles. You can use the mouse to drag these areas back onto the display.
- ❑ Return the Horizontal **Scale** control to **1 µs/div**.
- ❑ When you are done, right-click on area **A1** and select **Visual Trigger Area 1->Delete All Areas**.

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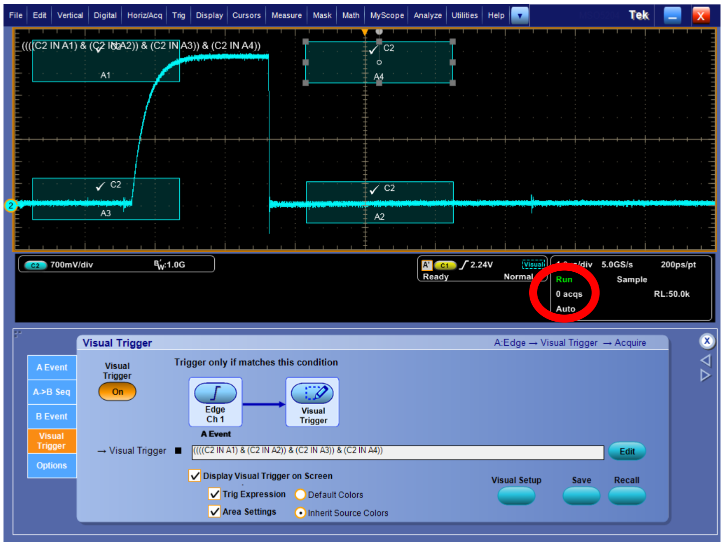
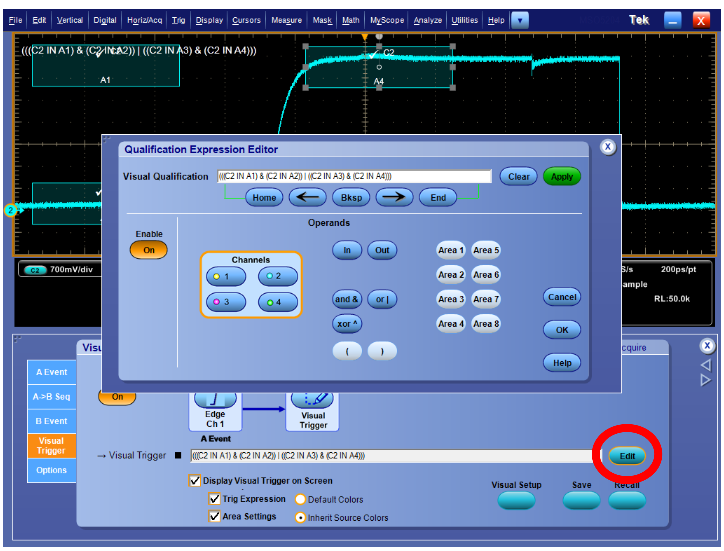
Editing Visual Trigger Expressions

Key Take Away Points

- As a final step to this Visual Trigger lab, let's use Visual Trigger to program the oscilloscope to trigger when the digital signal starts high AND then goes low OR where the signal starts low AND then goes high.
- To do this, we need to define four Visual Trigger areas:



- And edit the equation to implement the appropriate logic:



- As you can see in the editor control window, you can build an equation using any of the four analog channels, the In or Out operands, the logical AND, OR, and XOR operands, and any of the eight areas.

MSO/DPO5000 Series Procedure:

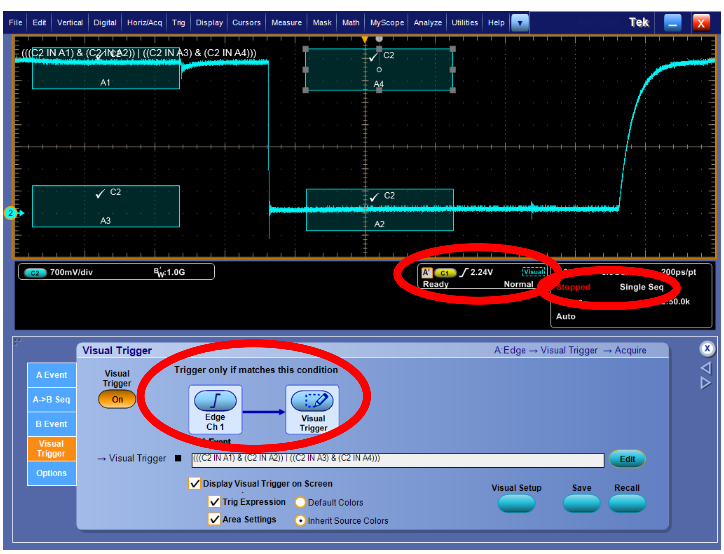
- ❑ Using the mouse or touchscreen, define four Visual Trigger areas, approximately as shown at the left, to specify the high and low digital signal levels at the left side of the display and near the middle of the display.
- ❑ As you add these areas, the triggering will stop. This is expected, since you've just asked the trigger system to find digital signals that are simultaneously "low" and "high" at the same time, as indicated by the default visual trigger equation.
- ❑ Let's now edit the visual trigger expression to implement the desired logic.
- ❑ Press the **Edit** button to launch the **Qualification Expression Editor** control window.
- ❑ Either clear the equation and enter it, or simply edit the equation to achieve the desired logical expression.
- ❑ Assuming you entered the four areas in the same order as shown, the equation triggers the scope when the digital signal starts high AND then goes low OR where the signal starts low AND then goes high:

  (((C2 IN A1) & (C2 IN A2)) |
  ((C2 IN A3) & (C2 IN A4))).
- ❑ When you are done, press **Apply** and **OK**.

Debugging Visual Trigger Setups

Key Take Away Points

- Perhaps it would be useful to review a few key points about Visual Trigger and use this knowledge to help debug common Visual Trigger setup issues.
- First of all, Visual Trigger is a software post-process operating on a properly triggered acquisition.
  - Verify the trigger is in Normal mode.
  - Verify the oscilloscope is triggering, by temporarily disabling Visual Trigger. This can be done by enabling FastAcq mode or by turning Visual Trigger off, either through the Visual Trigger Setup control window or through the right-click menu. If the oscilloscope is not triggering, debug your setup as you normally would. Then, turn Visual Trigger back on.
  - Make sure the overall setup is as expected. You can do this by examining the graphical representation in the Visual Trigger Setup control window.
- Second, the logic must make sense. For example, if you are edge triggering on the signal as shown below and you draw the boxes as shown below, you will never get a visual trigger unless you specify (C1 OUT A1) and (C1 IN A2) and (C1 OUT A3). If you specify (C1 IN A1) or (C1 OUT A2) or (C1 IN A3), you create a condition that is never true.
  - If all else fails, simplify the Visual Trigger setup by removing areas one at a time. You can do this via the right-click menu or by removing areas from the Visual Trigger equation with the equation editor.
- A working setup might look something like this:



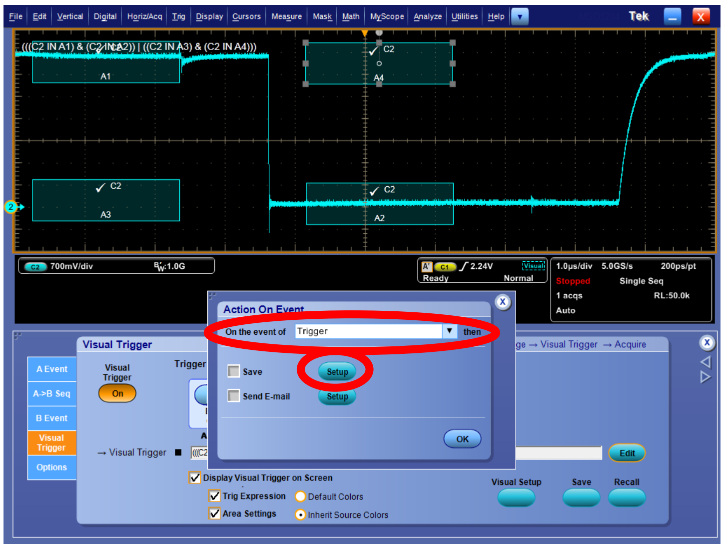
MSO/DPO5000 Series Procedure:

- ❑ Verify trigger readout shows “Normal”.
- ❑ Temporarily turn off Visual Trigger to check the signal and setup:
  - ❑ Press the front panel **FastAcq** button, or
  - ❑ Select **Trig->Visual Trigger Setup…** and press **Visual Trigger Off**, or
  - ❑ Right-click on a visual trigger area and select **Visual Trigger Area -> Visual Trigger Off**.
- ❑ Verify the instrument is triggering. The waveform should be updating and the trigger readout shows “Triggered”.
- ❑ Turn Visual Trigger back on:
  - ❑ Press the front panel **FastAcq** button again, or
  - ❑ Select **Trig->Visual Trigger Setup…** and press **Visual Trigger On**, or
  - ❑ Right-click on a visual trigger area and select **Visual Trigger Area -> Visual Trigger On**.
- ❑ Select **Trig->Visual Trigger Setup…** and verify that the **Trigger only if matches this condition** graphic is as you expect.
- ❑ Finally, examine the setup for each of the areas and examine the visual trigger expression to verify you have implemented the desired logic.
- ❑ If necessary, delete areas one at a time until the logic starts to work.
- ❑ Finally, if you want to save a waveform captured by Visual Trigger, use **Single Sequence** and then save the file.

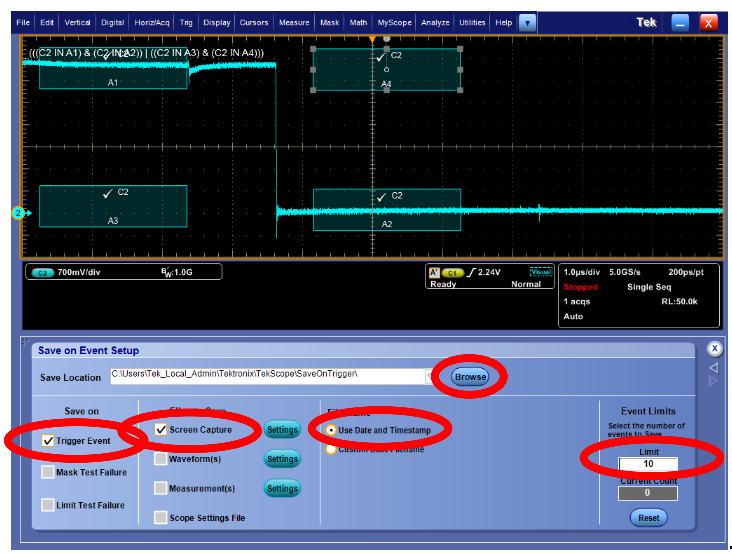
“Save On Trigger” Setup

Key Take Away Points

- Now, let’s take a look at a related and very useful feature – Action on Event. Action On Event allows you to program the oscilloscope to save or email specific information (such as screen shots or waveform data) each time a specific event (such as a Trigger, Limit Test violation, or Mask Test violation) occurs. For this example, we will save screen shots of a series of 10 Visual Trigger events.



- The Save on Event Setup control window allows you full control of the actions to take when the specified event occurs:



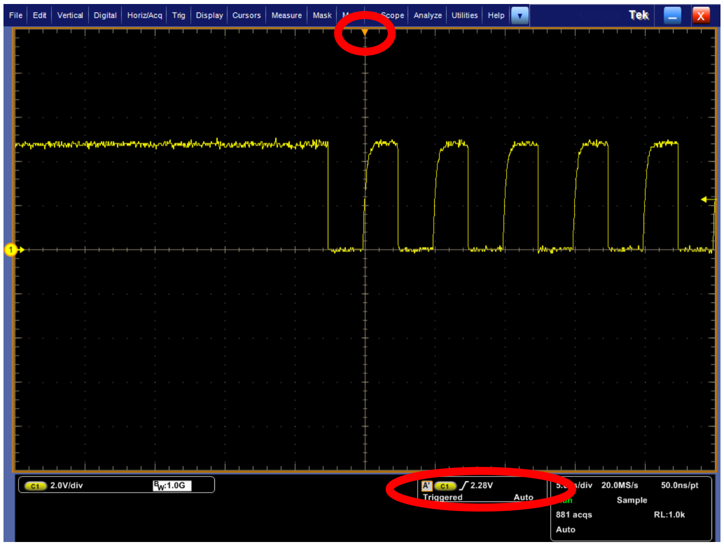
MSO/DPO5000 Series Procedure:

- ❑ If the front panel **Run/Stop** button is green, press it to stop acquisitions.
- ❑ Select **File->Action On Event…** and verify that Trigger is selected in the **On the event of** text box, or select **Trig->A Event (Main) Trigger Setup…** and select the **Save on Trigger** check box.
- ❑ Press the **Setup** button next to the Save check box.
- ❑ Press the **Browse** button next to the Save Location text box and select the desired file path.
- ❑ Verify that **Screen Capture** is selected under **Files to Save**. To verify or change the file properties, press the **Settings** button next to Screen Capture.
- ❑ Under File Name, verify that **Use Date and Timestamp** is selected. If you prefer to give the files a specific name (such as “SaveOnTrigger”) with the event number appended to it, select **Custom Base Filename** and type in the desired base file name.
- ❑ Verify that the **Limit** value under Event Limits is set to **10**.
- ❑ Check the **Save On Trigger Event** check box.
- ❑ Press the front panel **Run/Stop** button to restart acquisitions.
- ❑ You can watch the **Current Count** readout to monitor progress. When the limit is reached, the Save on check box will be automatically cleared.
- ❑ Finally, minimize the scope application and navigate through the Windows file system to find and verify that the screen shots were saved as expected.

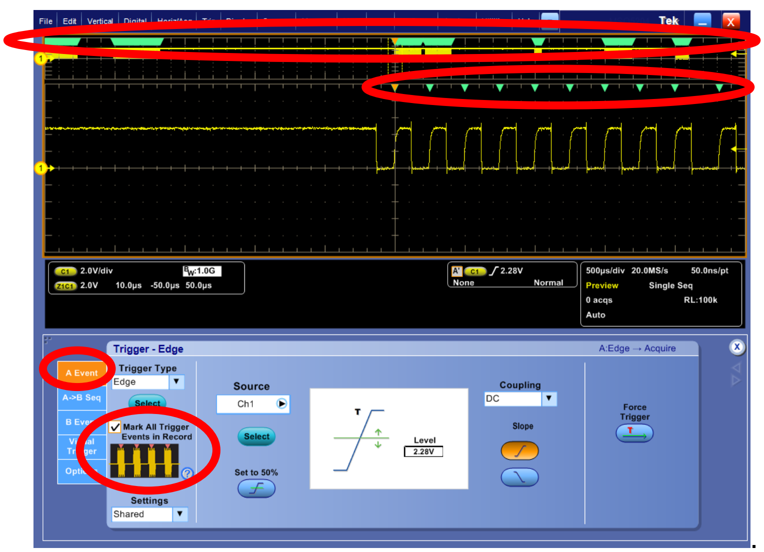
“Mark All Trigger Events in Record” Setup

Key Take Away Points

- After autosetting the I^2C clock signal, notice that the oscilloscope is triggering on a positive edge and has positioned this edge and the orange triangle (at the top of the display) halfway across the display. This is not the only edge in the waveform; it is just the one that the oscilloscope is triggering on.



- Notice that each event (in this case, positive edges) is marked with a green triangle at the top of the display:

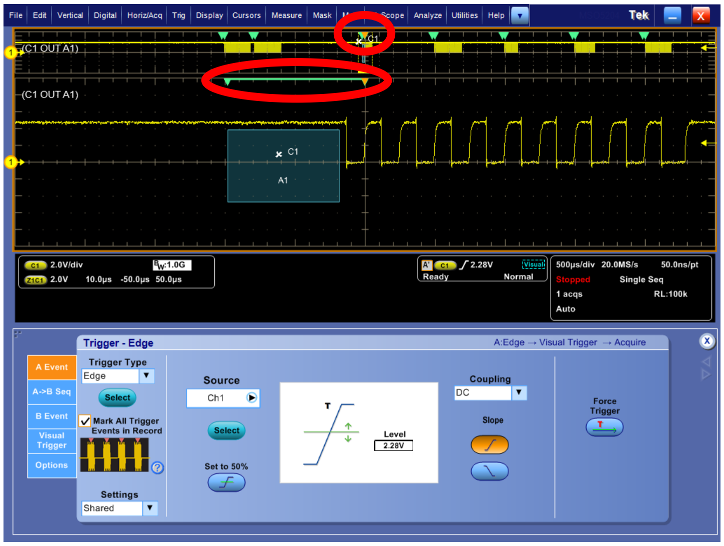


MSO/DPO5000 Series Procedure:

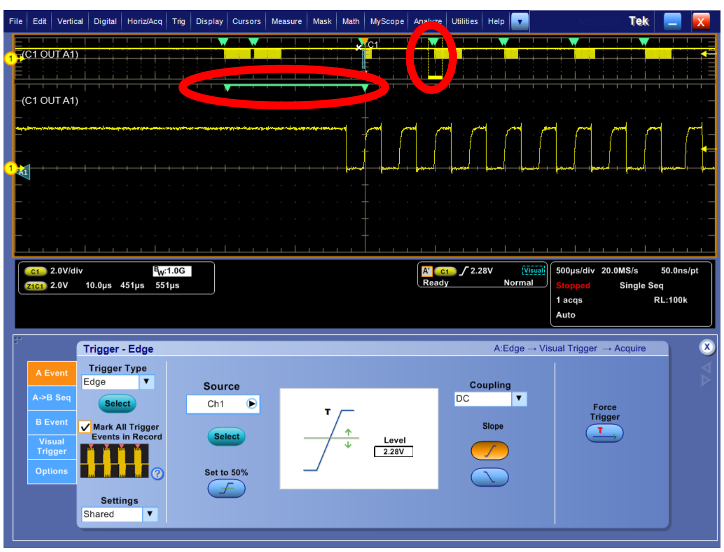
- ❑ Press the **Default Setup** and **Autoset** buttons to get a stable display.
- ❑ Set the Horizontal **Scale** to **500 µs/div**.
- ❑ Select **Trig->A Event (Main) Trigger Setup….**
- ❑ Press the **Options** tab at the left side of the control window.
- ❑ Press the **Normal Trigger Mode** button.
- ❑ Press the front panel **Single** button.
- ❑ Press the **A Event** tab at the left side of the control window.
- ❑ Check the **Mark All Trigger Events in Record** check box.
- ❑ Zoom in on the center of the display at the trigger point.

Key Take Away Points

- Using Visual Trigger, set up the oscilloscope to keep only acquisitions that are high for an extended amount of time followed by a positive edge, like this:



- Notice that the green bar now starts with the left edge of the Visual Trigger area and ends with the edge trigger point in the screen shot above.
- Notice that all of the other composite trigger events (in this case, a Visual Trigger followed by a positive edge) is marked with a green bar with triangles on each end. This is what the green bar to the right of the trigger point looks like:



- In general, the green bar will start at the left-most side of the composite trigger definition and will end at the right-most side of the composite trigger definition, whether the composite trigger definition is just hardware triggering or if it includes Visual Triggering. And, the regions can overlap, since there is no sense of trigger holdoff in this mode.

MSO/DPO5000 Series Procedure:

- ❑ In the zoom window, draw a box, as shown in the screen shot on the left, and select **Visual Trigger-> Add Visual Trigger Area**.
- ❑ Right click on the box and select **Visual Trigger Area 1->Must be outside->C1**.
- ❑ Press the front panel **Run/Stop** button.
- ❑ Verify that this Visual Trigger setup is indeed allowing you to isolate the first positive edge in each burst of clock pulses.
- ❑ Press the front panel **Single** button.
- ❑ Press the front panel Search right arrow button once.
- ❑ Notice that the Mark All Trigger Events in Record feature is integrated with Visual Trigger. The blue Visual Trigger box and the orange hardware trigger indicator are shown only at the center of the screen, the Mark All Trigger Events in Record feature has marked all matching events with the green bars at the top of the display.

Equipment List

One MSO5000 Series oscilloscope with software version ≥6.1.1 and the SR-EMBD option installed or
one DPO5000 Series oscilloscope with software version ≥6.1.1
and the MSOE and SR-EMBD options installed

Four TPP0500 or TPP1000 passive probes

One P6616 MSO probe

Optional USB keyboard and mouse

DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)

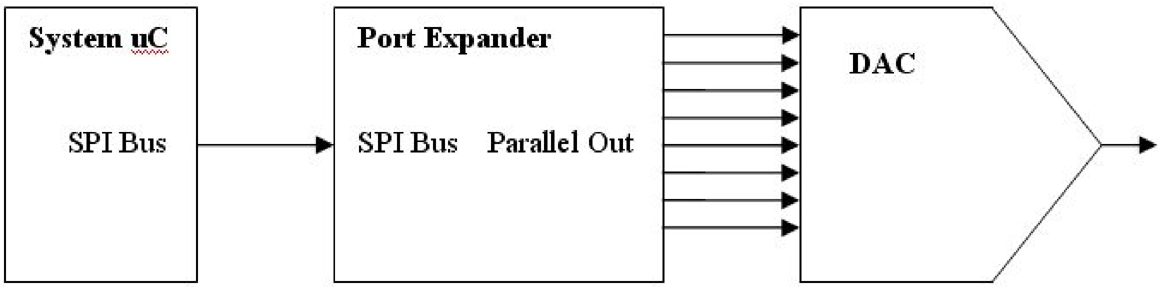
[Note: screen shots in this lab were made with the DPO Demo 3 board]

A Mixed-Signal Application Circuit

The DPO Demo 3 and DPO Demo 2 boards have a circuit which enables you to do a demo of a complete, fairly typical embedded mixed-signal application.

The system microcontroller generates digital waveform values and sends them out over the SPI serial bus. The port expander translates the serial information from the SPI bus to its parallel bus representation. The parallel bus drives the inputs to a Digital-to-Analog Converter (DAC), which generates an analog representation of the digital values.

The block diagram for the circuit is shown below:



By using a Mixed-Signal Oscilloscope, you can trace the signal path from start to finish to verify the circuit operation and, if necessary, debug the circuit.

MSO5000 Series Lab Setup

Key Take Away Points

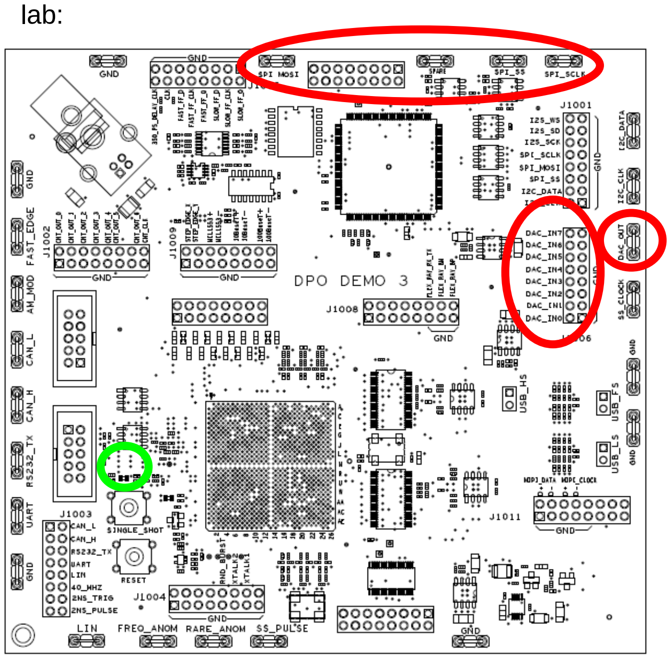
- Parallel and serial buses are often combined with analog circuitry in many mixed-signal, embedded designs. An MSO provides unique insight into the operation of these systems.
- With the MSOE option installed, the MSO5000 or DPO5000 Series oscilloscope can trigger on, decode, and search parallel bus traffic.
- With the SR-EMBD option installed, the MSO5000 Series oscilloscope can trigger on, decode, and search SPI bus traffic.

MSO5000 Series Procedure

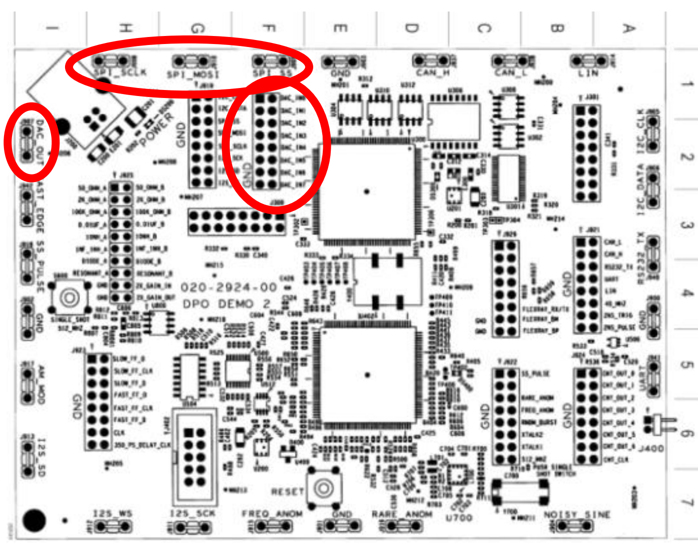
- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope…**.
- ❑ Verify that the **MSOE: 16-Channel MSO** option is installed.
- ❑ Verify that the **SR-EMBD: I2C/SPI Serial Triggering and Analysis** option is installed.
- ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a complete mixed-signal application circuit which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has a complete mixed-signal application circuit which we can use for this lab:

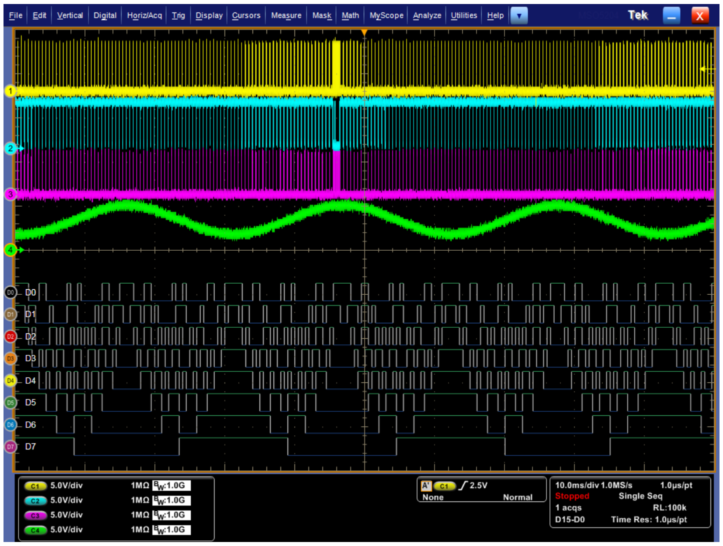


DPO Demo Board Procedure

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **SPI_SCLK** test point on the test board.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **SPI_SS** test point on the test board.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 3 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **SPI_MOSI** test point on the test board.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 4 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **DAC_OUT** test point on the test board.
- ❑ Attach a P6616 MSO probe to the front of the MSO.
- ❑ Connect probe Bit 0 to **DAC_IN0**, probe Bit 1 to **DAC_IN1**, and so on, up to Bit 7 to **DAC_IN7**.
- ❑ If the probe inputs have the ground extenders attached, make sure that the probe ground pins are all connected to the connector's GND pins on the left side of the connector. If the probe inputs do not have ground extenders attached, connect a ground wire from the automotive spade on the side of the probe to a GND test point on the board.

Key Take Away Points

- The display should look about like this:



- Here you can see many SPI serial signals (channels 1-3), and analog sine wave (channel 4), and some digital signals (D7-D0). However, it is difficult to interpret the meaning of the digital data, especially the serial data, from this display.
- Let's look at an easy way to interpret the serial data.

MSO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Turn on all of the analog channels by pressing the front panel **2**, **3**, and **4** buttons.
- ❑ Set the Vertical **Scale** for channels 1, 2, 3, and 4 to **5V/div**.
- ❑ Position channels 1, 2, 3, and 4 in the upper half of the display.
- ❑ Press the front panel Trigger **Level** control to set the trigger level to 50%.
- ❑ Press the front panel **D15-D0** button.
- ❑ Press the Turn D7-D0 **On** button.
- ❑ Using the Size drop down menu, select **Medium** display size.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Set the Horizontal **Scale** to **10 ms/div** to display a couple of cycles of the sine wave on channel 4.
- ❑ Press the front panel **Single** button.

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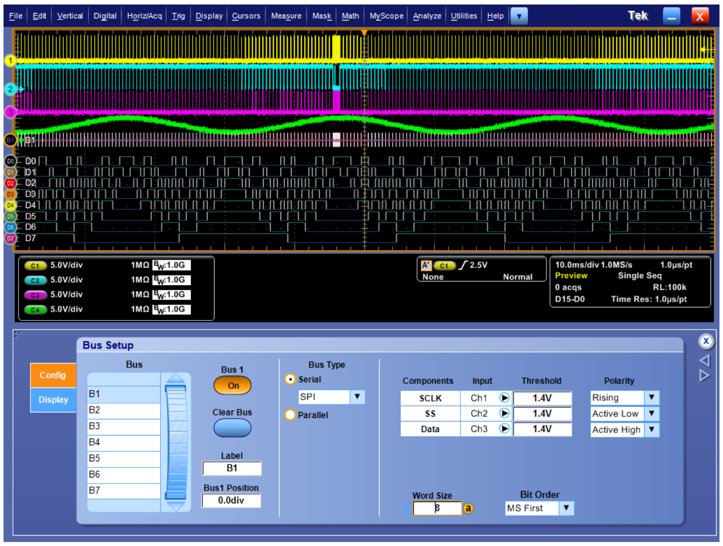
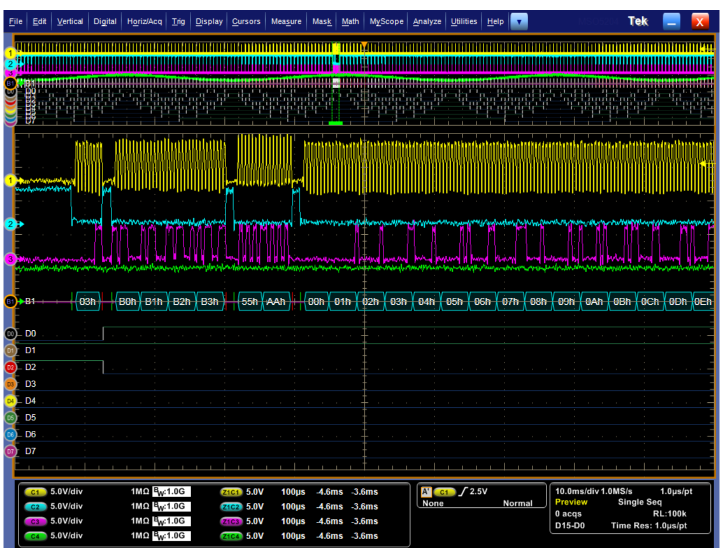
MSO5000 Series SPI Bus Decoding

Key Take Away Points

- The MSO5000 Series can automatically decode SPI bus data. Setting up a basic SPI bus waveform display takes only a few simple steps.
- The decoded serial bus (B1) is shown at the center of the display:



- When you use Wave Inspector to zoom in on the serial bus details, you can see the individual decoded data bytes:



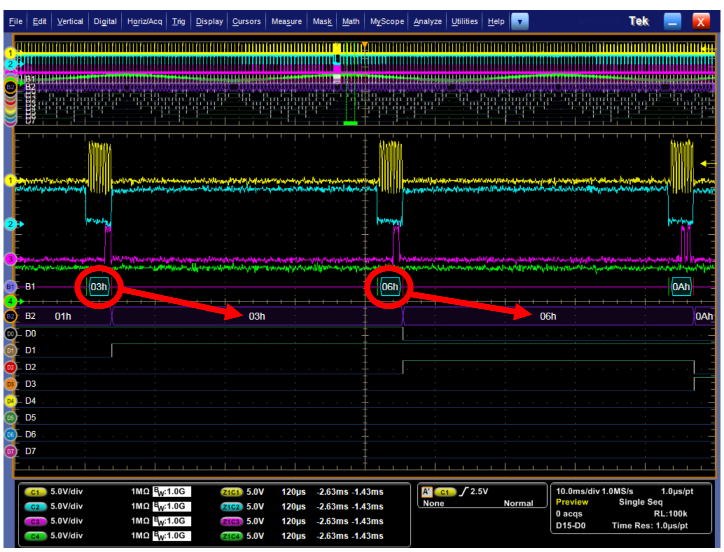
MSO5000 Series Procedure:

- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Under Bus Type, select **Serial**.
- ❑ Using the drop down menu, select **SPI**.
- ❑ Verify that the SCLK signal is on Ch1, SS is on Ch2, and MOSI Data is on Ch3.
- ❑ Verify that the Threshold settings are all about **1.4V**.
- ❑ Verify that SCLK is set to **Rising** edge, SS is set to **Active Low**, and MOSI Data is set to **Active High**.
- ❑ Set the Word Size (the number of bits in the packet) to **8.**
- ❑ Verify that **MSB First** is the selected **Bit Order**.
- ❑ Press the **Bus 1** button to turn bus B1 **On**.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Using the **Wave Inspector** pan and zoom controls, zoom in on one word of the decoded serial signal.

MSO5000 Series Parallel Bus Decoding

Key Take Away Points

- The MSO5000 Series can automatically decode parallel buses, too. Setting up a basic parallel bus waveform display takes only a few simple steps.
- The decoded parallel bus (B2) is shown just below the center of the display. When you use Wave Inspector to zoom in on the decoded values on the serial and parallel buses, you can see the individual decoded data bytes:



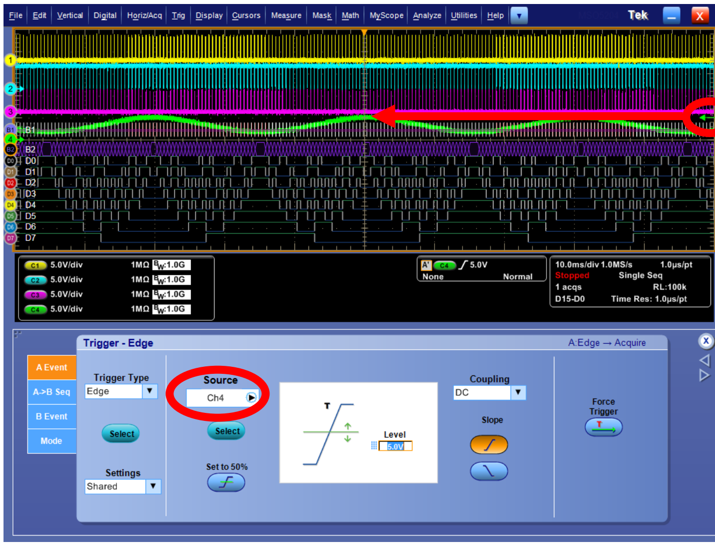
MSO5000 Series Procedure:

- ❑ Press the purple front panel Bus **B** button to display the Bus Setup menu.
- ❑ Select Bus **B2** at the left side of the control window.
- ❑ Verify that **Parallel** is selected and **Clocked** is not checked.
- ❑ Press the Add Sources **Select** button.
- ❑ Add digital channels 7 (MSB) through 0 (LSB) to the parallel bus by pressing the **D7**, **D6**, **D5**, **D4**, **D3**, **D2**, **D1**, and **D0** buttons, in that order, and press **OK**.
- ❑ Press the **Bus 2** button to turn the parallel bus **On**.
- ❑ Press the **Display** tab at the left side of the control window.
- ❑ Notice that the data can be displayed in **Hex**, **Binary**, or **Decimal**.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Position Bus B2 below Bus B1.
- ❑ Using the Wave Inspector pan and zoom controls, zoom in on one word of the decoded serial signal and notice the relationship to the decoded values on the parallel bus.
- ❑ When you are done with zoom, press the Wave Inspector zoom button or turn the inner zoom control fully counter-clockwise to turn off zoom.

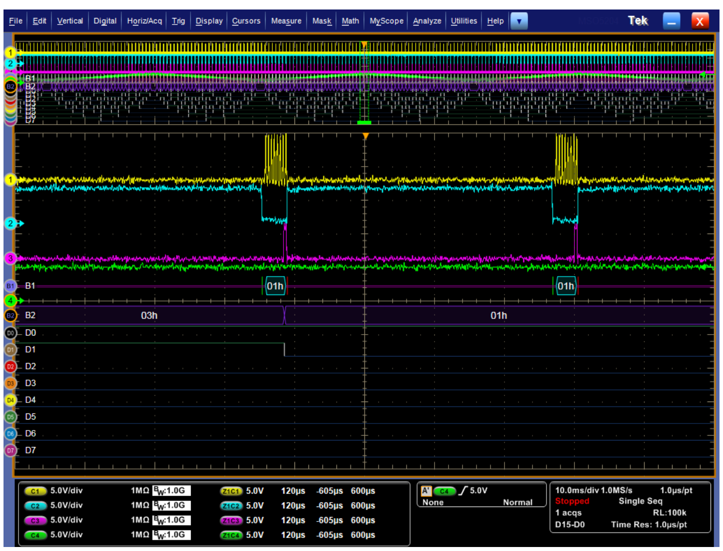
MSO5000 Series Mixed-Signal Triggering

Key Take Away Points

- What serial or parallel data values relate to the positive peak on the analog waveform? You can easily find out by triggering on the analog waveform and examining the decoded bus data, as shown below:



- Zooming in, we see that the digital value of 01 hex corresponds to the positive peak of the DAC output voltage:

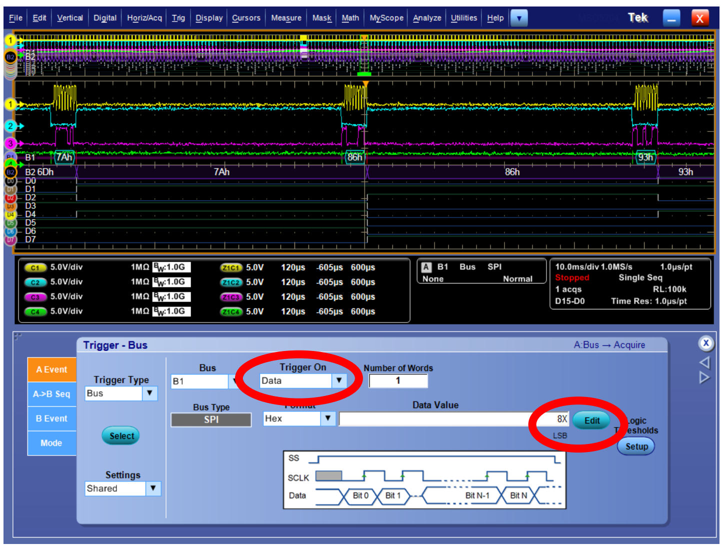


MSO5000 Series Procedure:

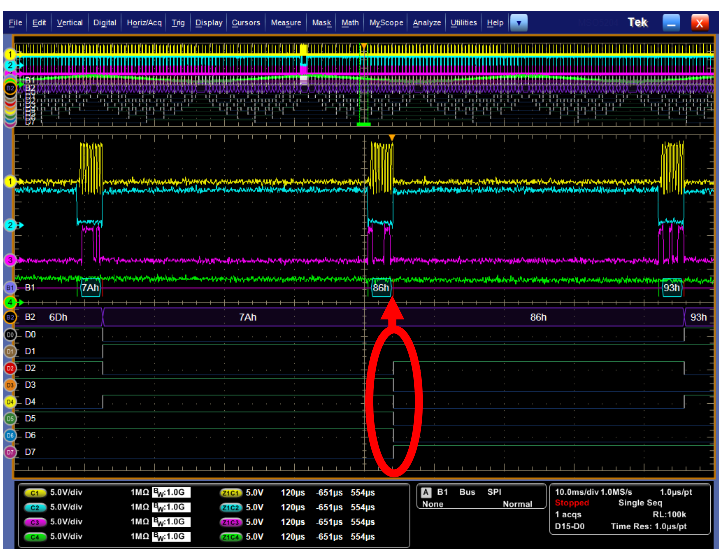
- ❑ Press the front panel **Run/Stop** button.
- ❑ Press the front panel **Trigger Menu** button.
- ❑ Press the Source **Select** button, press **Ch4**, and press **OK**.
- ❑ Press the **Mode** tab and press the **Normal** Trigger Mode button.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Using the front panel Trigger **Level** control, set the trigger level at the top edge of the green channel 4 waveform.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the decoded data values at the time of the trigger event.

Key Take Away Points

- What does the analog waveform look like when many of the digital inputs to the DAC are transitioning simultaneously?
- Many DACs generate glitches on their analog outputs when multiple digital inputs change at the same time. This is especially critical at mid-scale, where the 8-bit digital data values might be transitioning from 7F hex (0111 1111 binary) to 80 hex (1000 0000) binary.
- You can easily find out by triggering on the decoded digital values (in this case, either on the serial or parallel bus) and examining the analog waveform, as shown below:



- In this case, the DAC circuit is well-designed and there is no large mid-scale glitch on the analog output.

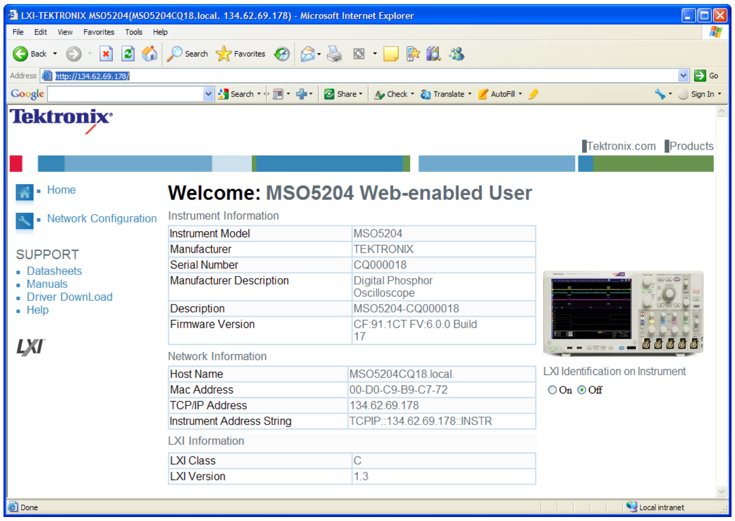


MSO5000 Series Procedure:

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the Trigger Type **Select** button and press the **Bus** button.
- ❑ Using the Bus drop down menu, select Bus **B1** as the trigger source.
- ❑ Using the **Trigger On** drop down menu, select **Data**.
- ❑ Press the Data Value **Edit** button.
- ❑ Select **Hex** format and set the trigger data value to **8X** hex. (It turns out that the exact values of 7F and 80 hex do not occur in this design.)
- ❑ Press **OK**.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Press the front panel **Single** button.
- ❑ Adjust the Wave Inspector pan and zoom controls as needed to view the decoded bus values and the corresponding analog waveform.

MSO5000/DPO5000 Series

LXI Class C Compliant
Web Interface Lab



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
One TPP1000 or TPP0500 passive probe
One PC with Internet browser installed
One standard or cross-over Ethernet cable to connect the oscilloscope directly to the PC,
or two standard Ethernet cables to connect both PC and oscilloscope to LAN

Overview of MSO/DPO5000 Web Interface

Increasingly, companies are finding that distributed design teams are an efficient way to bring the right resources together for a design project. Engineers around the world need to share design details at the outset, and evaluation and measurement results as the project progresses.

The MSO/DPO5000 Series can be connected to the Internet via the LAN port and a standard web browser. This LXI Class-C-compliant web interface enables control of network configuration.

Overview of LXI Class C Compliance

LXI (which stands for LAN eXtensions for Instrumentation) defines the communications protocols for instrumentation and data acquisition systems using Ethernet. LXI is a standard developed by the LXI Consortium, who maintain the LXI specification, promote the use of LXI, and ensure interoperability.

LXI-compliant devices can also interoperate with devices that are not LXI-compliant, as well as instruments that employ other remote interfaces such as GPIB, VXI, and PXI. To simplify communication with non-LXI instruments, every LXI instrument must have an Interchangeable Virtual Instrument (IVI) driver. The IVI Foundation defines a standard driver Application Programming Interface (API). There are two IVI driver formats in use in the industry: IVI-COM for working with COM-based (usually Windows) development environments and IVI-C for working in traditional programming languages and many industry-standard analysis tools.

LXI Class C is the baseline standard which provides LAN capabilities, a web interface, and IVI drivers. (Class B adds expanded triggering and communication capabilities. Class A devices build upon Class B devices by adding a wired trigger bus for precision triggering.) The MSO/DPO5000 Series interface is LXI Class C compliant.

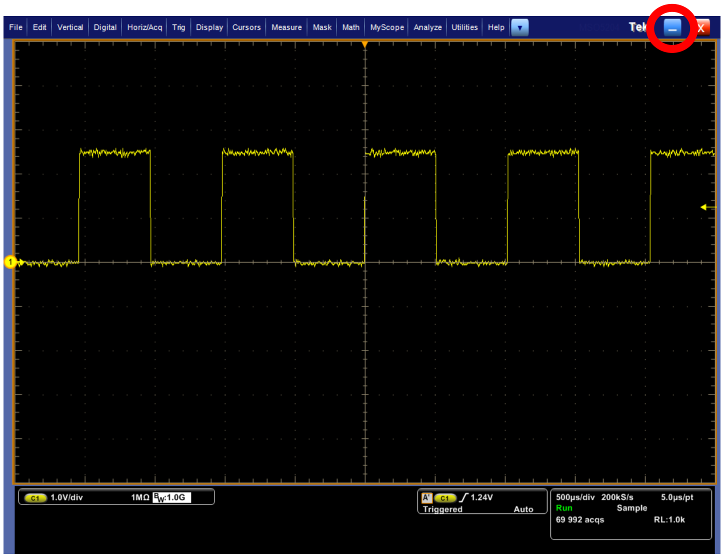
Objectives

- Obtain an overview of LXI Class C compliance
- Learn how to connect an oscilloscope to a PC via Ethernet.
- Obtain a basic understanding of the web interface connectivity.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

- You can connect to the MSO/DPO5000 Series via Ethernet connection through a standard PC web browser by simply entering the oscilloscope's IP address in the address bar of the browser.
- There are two ways to physically connect the oscilloscope and PC via Ethernet: through an existing IP network or directly (“peer-to-peer”).
- Either way, the next step in connecting an oscilloscope to a PC via Ethernet is to obtain the Internet Protocol (IP) address of the oscilloscope.
- NOTE: You should always discuss plans for network connections with the network administrator. If Dynamic Host Configuration Protocol (DHCP) is available to automatically supply the IP address, the network administrator can tell you. If you need a static IP address, you should get it from the network administrator.
- The next few step require access to the Windows desktop, so minimize the TekScope application:



MSO/DPO5000 Series Procedure:

- ❑ Connect the TPP0500 or TPP1000 probe to channel 1.
- ❑ Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- ❑ Connect the probe ground to the ground connection just above the PROBE COMP signal.
- ❑ For an IP network connection:
  - ❑ Connect a standard Ethernet cable between the network connection and the Ethernet connector on the oscilloscope’s rear panel.
- ❑ For direct connection to your PC:
  - ❑ Connect a standard or cross-over Ethernet cable between the PC’s Ethernet connector and the Ethernet connector on the oscilloscope’s rear panel.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state. Note that this operation does not affect the Ethernet connection settings.
- ❑ Press the front panel **Autoset** button to get a stable display.
- ❑ Minimize the TekScope application by clicking on the minimize icon in the upper right corner of the display.
- ❑ The TekScope icon will then appear at the bottom of the Windows display:

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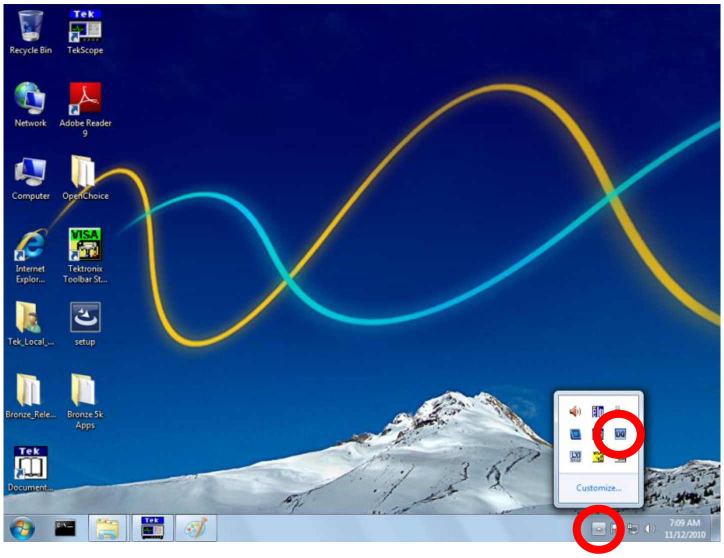
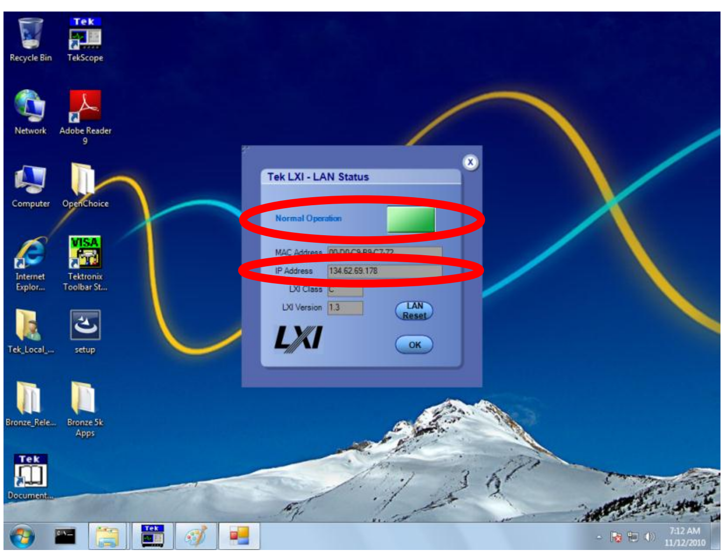
Key Take Away Points

- The next step is to verify the LXI status.



- Display the LXI LAN status indicator

- and verify that the status is green and find the IP address:



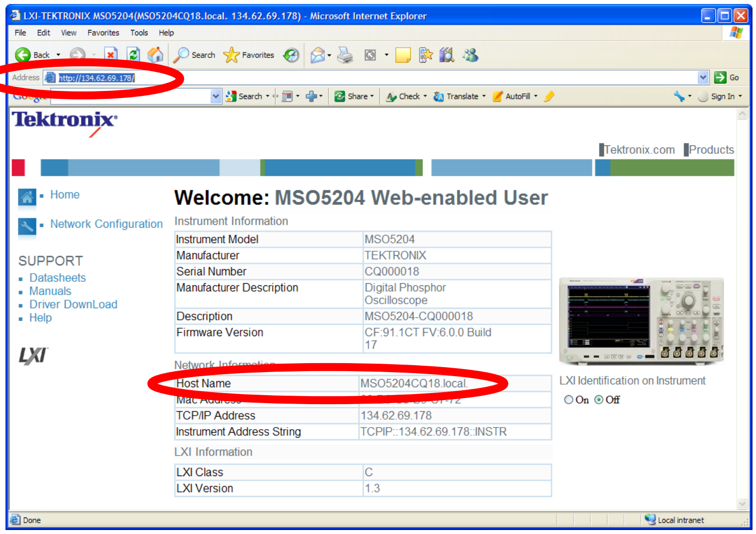
MSO/DPO5000 Series Procedure:

- ❑ Click on the **Show hidden icons** up arrow at the bottom of the display.
- ❑ Right click on the **LAN Status Indicator** icon.
- ❑ Select **Show LAN Status Indicator**.
- ❑ Notice that this window displays the same IPv4 address as if you selected **Start -> Control Panel -> Network and Internet -> View network status and tasks -> Local Area Connection -> Details**.
- ❑ Write down the IP address.
- ❑ Close the status window by clicking on the **X** in the upper right corner.

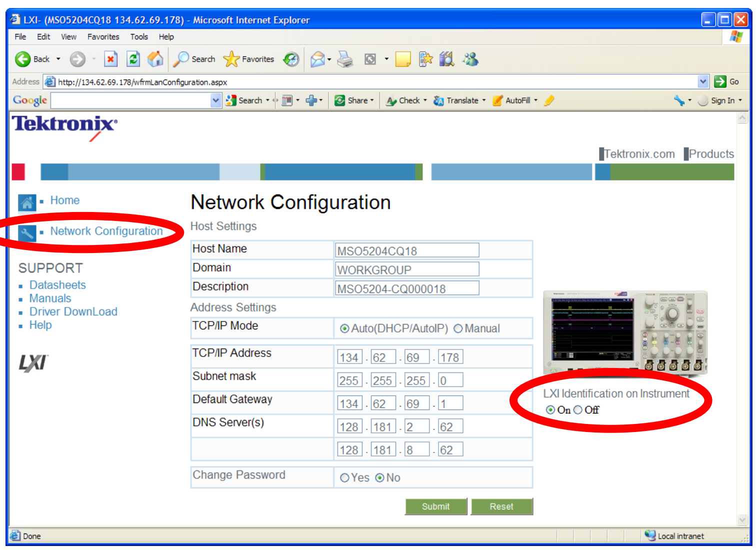
LXI-enabled Instrument Control

Key Take Away Points

- When you enter the oscilloscope's IP address into the browser's address box, you should see the Instrument Welcome Page for the oscilloscope:



- The LXI Network Configuration page should look about like this:



- Notice that the LXI Status Indicator is displayed on the oscilloscope and that the green status indicator is flashing:

PC Procedure:

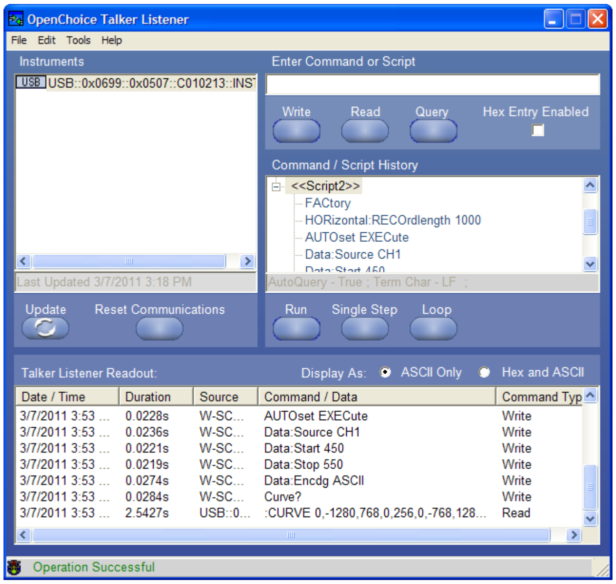
- ❑ Launch your Internet browser (e.g. Microsoft Internet Explorer) program on the PC.
- ❑ Type the oscilloscope's IP address into the web browser's address box. For example:

  http://134.62.69.178

- ❑ The oscilloscope's LXI web page is displayed in your browser.
- ❑ Notice the oscilloscope's Host Name is also shown. Once you know this name, you can enter it into the web browser's address box instead of the IP address. For example:

  http://MSO5204CQ18

- ❑ Click on the **Network Configuration** link at the left side of the web page.
- ❑ From this web page, you can change the host settings, such as the Host Name, Description, or IP address. When you have made the change, press the **Submit** button at the bottom of the page.
- ❑ Click on the **LXI Identification on Instrument On** radio button to remotely turn on the LXI status display on the oscilloscope.



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
One TPP1000 or TPP0500 passive probe
One PC with TekVISA installed (software is available for free download from www.tek.com)
One USB cable (174-4401-00)

Overview of OpenChoice PC Connectivity Tools

For oscilloscope / PC connectivity, the OpenChoice Instrument Manager programs provide many low-level features that most users are looking for when verifying and debugging simple test programs. With just a few clicks of a mouse, the free OpenChoice Call Monitor and Talker/Listener programs provide easy methods to remotely control the oscilloscope, test small programs, and monitor the results on a PC.

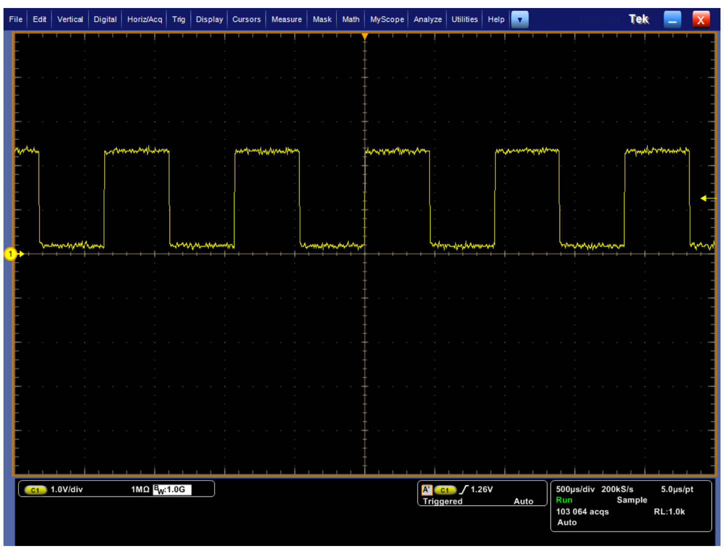
Objectives

- Learn how to launch OpenChoice Instrument Manager applications and connect an oscilloscope to a PC.
- Learn how to remotely control an oscilloscope using Talker/Listener scripts.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

- For this lab, set up a simple display, such as the PROBE COMP signal:

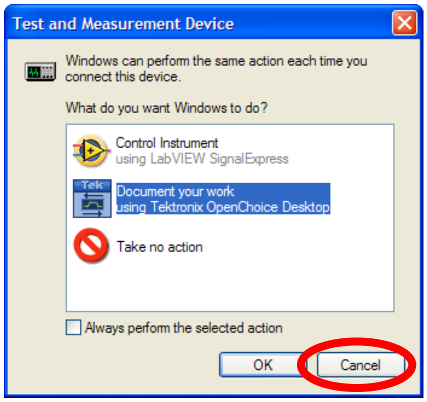


MSO/DPO5000 Series Procedure:

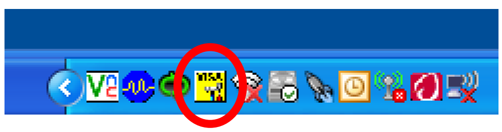
- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Connect the TPP1000 or TPP0500 probe to channel 1.
- ❑ Connect the probe tip to the PROBE COMP signal on the front of the oscilloscope.
- ❑ Connect the probe ground to the ground connection next to the PROBE COMP signal.
- ❑ Press the front panel **Autoset** button.

Key Take Away Points

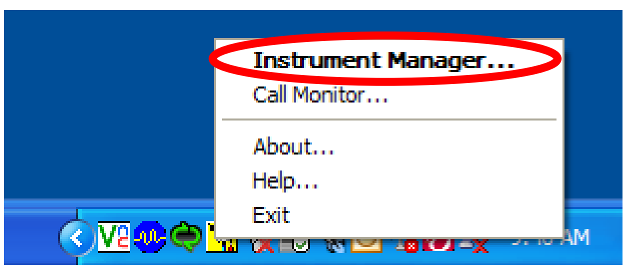
- After you connect the USB cable between the oscilloscope and the PC, the USB plug-n-play driver should launch a Test and Measurement Device window like this:



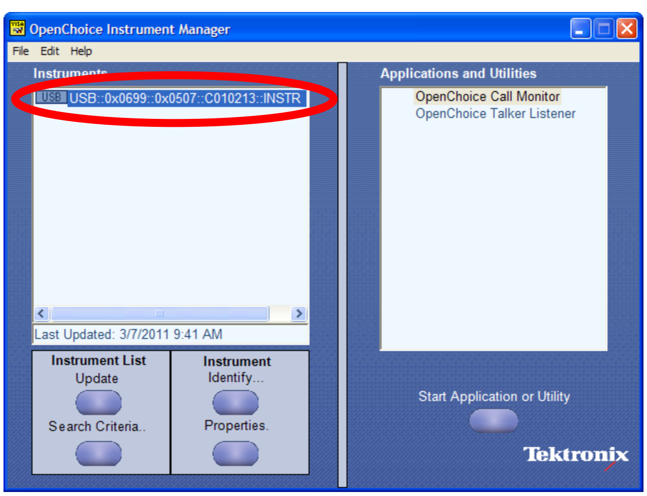
- Press the Cancel button. The OpenChoice Desktop program does not support the MSO/DPO5000 Series.
- Click on the yellow VISA Resource Manager icon:



- and you should see the following pop-up:



- This is the OpenChoice Instrument Manager screen:



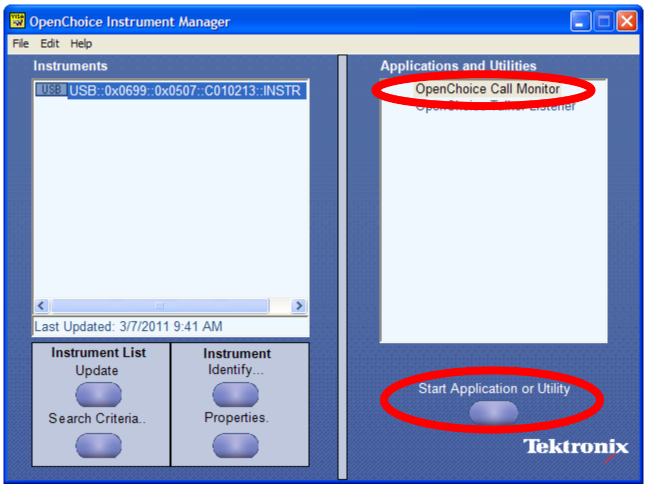
PC Procedure:

- ❑ Connect the rectangular end of the USB cable to a USB Host port on the PC and connect the 'D' shaped connector to the USB Device port on the back of the oscilloscope.
- ❑ Click on the **Cancel** button.
- ❑ Click on the yellow VISA Resource Manager icon in the Windows taskbar in the lower right corner of the display.
- ❑ Select **Instrument Manager…**.
- ❑ Notice that the instrument you connected (and maybe others) is shown in the list at the left.

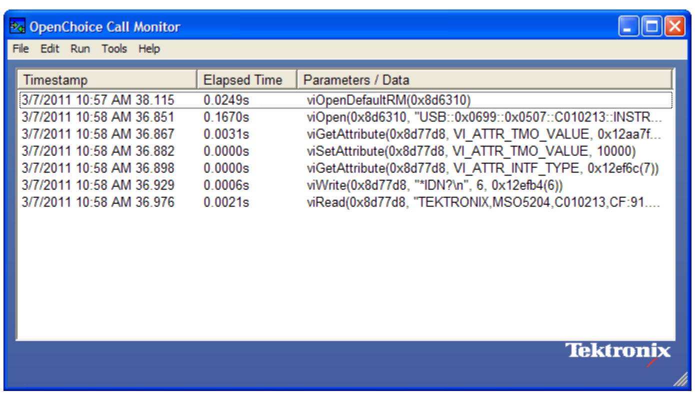
Call Monitor and Talker / Listener Lab

Key Take Away Points

- The OpenChoice Instrument Manager program provides two applications, the Call Monitor and the Talker Listener.



- The first application is the OpenChoice Call Monitor. This program monitors the communications between the oscilloscope and the PC:



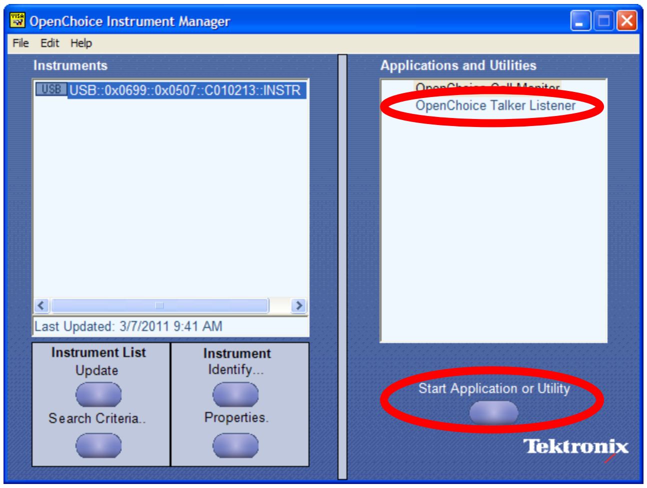
- The call monitor can be used to capture, time, and log the low-level communications. For example, the screen shot above captures all of the steps when the “*IDN?” query is sent to the oscilloscope. (You’ll see how to send the “*IDN?” query in the next section.)

PC Procedure:

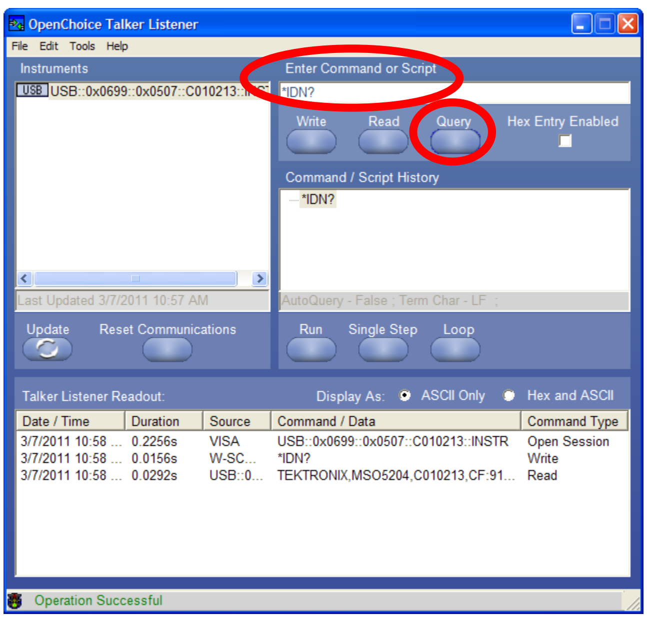
- ❑ In the Instrument Manager program, click on the **OpenChoice Call Monitor** entry to highlight it and click on the **Start Application or Utility** button.

Key Take Away Points

- Now, let's go back to the OpenChoice Instrument Manager screen and start the Talker Listener application:



- This is the OpenChoice Talker Listener screen. From this screen, you can directly control the oscilloscope by typing in commands and queries (found in the Programmer's Manual).



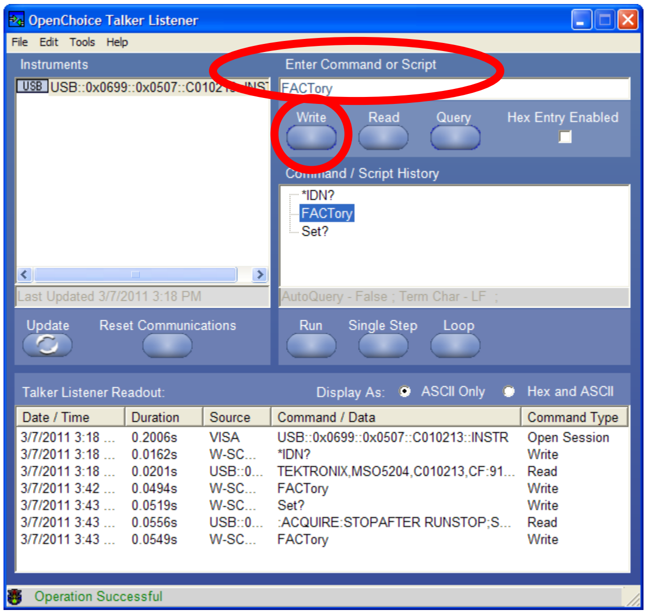
- By default, the "*IDN?" query is loaded into the text box at the top of the screen.
- As shown in the bottom section of the display, the query opens a VISA session (first line), sends the command to the oscilloscope (second line), and reads back the oscilloscope's response (third line).

PC Procedure:

- ❑ In the Instrument Manager program, click on the **OpenChoice Talker Listener** entry to highlight it and click on the **Start Application or Utility** button.
- ❑ Click on the **Query** button to send the "*IDN?" query to the oscilloscope.
- ❑ Notice the commands and responses as they appear at the bottom of this screen.
- ❑ Also, notice the lower level of detail that appears in the OpenChoice Call Monitor window (shown on the previous page of this lab).

Key Take Away Points

- The second application is the OpenChoice Talker Listener which allows you to interact with the oscilloscope using the programmable interface. For details, see the MSO/DPO5000 Programmer's Manual.
- You can type other commands and queries, one at a time, into the text box at the top. Click on the **Write** button if it is a command or the **Query** button if it is a query.



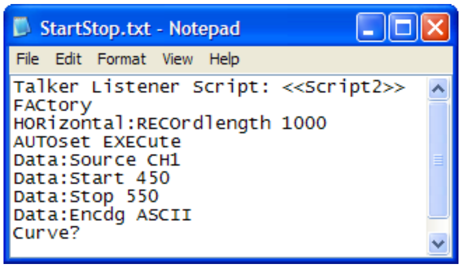
- The commands are logged in the Command / Script History window. To repeat any of those commands, simply click on them to copy them into the text box at the top and then click on the **Write** or **Query** button.

PC Procedure:

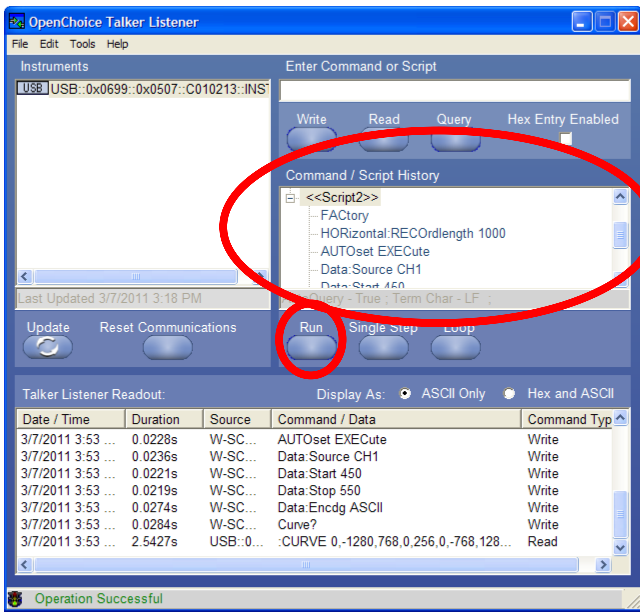
- ❑ Type "**FACtory**" into the text box at the top of the screen and click on the **Write** button.
- ❑ Type "**SET?**" into the text box at the top of the screen and click on the **Query** button.
- ❑ Click on "**FACtory**" in the Command / Script History window in the center of the screen and click on the **Write** button.

Key Take Away Points

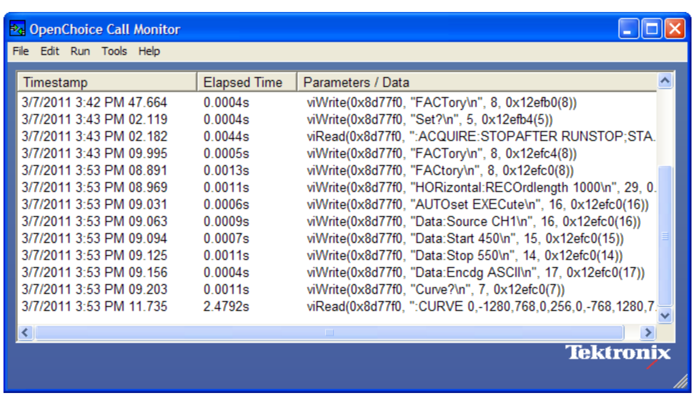
- If you have repetitive or complex tasks, you may find it easier to save the commands into a script file and reload them from the file.
- Here is a simple example program which extracts the middle 101 samples out of a 1000 point acquisition:



- You can read and execute a command script with just a few clicks of the mouse:



- Now, go back and look at the OpenChoice Call Monitor. Notice it has logged all of the communications between the oscilloscope and the PC:

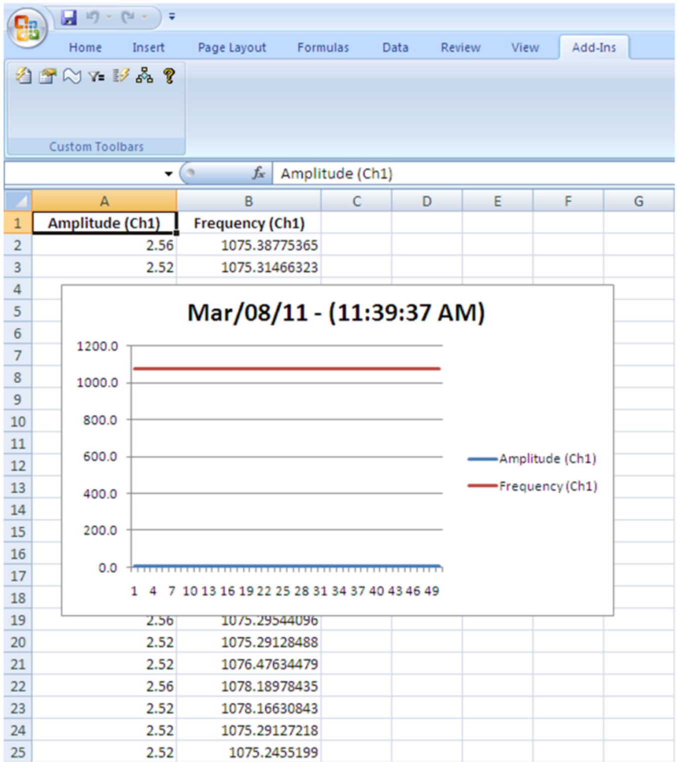


PC Procedure:

- ❑ Click on the **Tools** menu at the top of the screen, select **Options…**, check the **AutoQuery** box, and click **OK**.
- ❑ Using a simple text editor like Windows Notepad, create a text file called "**StartStop.txt**" with the following contents:

  Talker Listener Script: <<Script2>>
  FACtory
  HORizontal:RECOrdlength 1000
  AUTOset EXECute
  Data:Source CH1
  Data:Start 450
  Data:Stop 550
  Data:Encdg ASCII
  Curve?

- ❑ Click on the **File** menu at the top of the screen, click on **Open Script…**, navigate to and select the file you just created, and click on the **Open** button.
- ❑ Notice that the script file text has been loaded into the center Command / Script History window on the display.
- ❑ Press the **Run** button to run the script.
- ❑ In the OpenChoice Call Monitor program, click on **File**, click on **Save…**, type in a file path and file name, and click **Save** to save the log file.



Equipment List

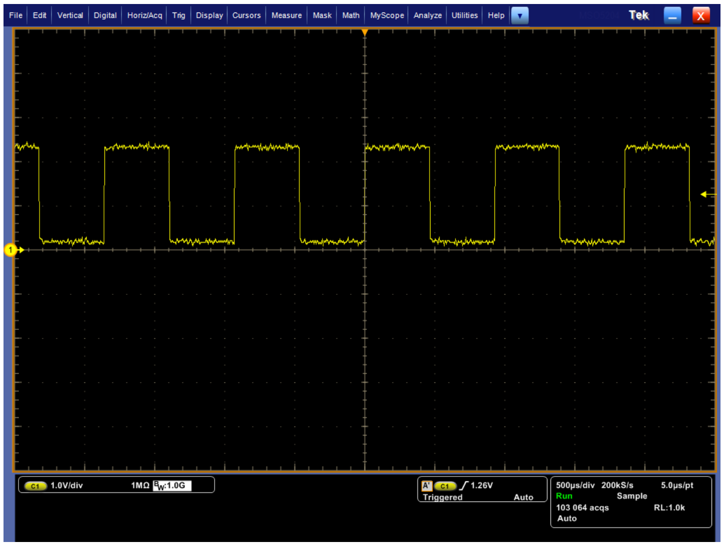
One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
One TPP1000 or TPP0500 passive probe
One PC with Microsoft Office, TekXL and TekW toolbars, and TekVISA installed
(This Tektronix software is available for free download from www.tek.com)
One USB cable (174-4401-00)

Overview of PC Connectivity with TekXL and TekW Toolbars
For simple connectivity between an oscilloscope and Microsoft Word and Excel applications on the PC, the TekW and TekXL toolbars provide most of the features that most users are looking for. With just a few clicks of a mouse, the free toolbars easily transfer screen shots, waveform data, measurements, and setup files to the PC and insert them directly into Word documents and Excel spreadsheets. The TekW Word toolbar allows you to: • Connect the oscilloscope to the PC over USB. • Get oscilloscope settings from the oscilloscope, save them to a file, and send them back to the oscilloscope, all from within Word. • Capture an acquired waveform, graph the data values, and insert the graph into the document. • Capture automatic measurement values at regular time intervals and insert a table of values into the document. • Capture triggered waveforms, graph the data, and insert the graph into the document. • Capture triggered automatic measurement data and insert a table of values into the document. • Capture the oscilloscope's screen image and insert it into the document. The TekXL Excel toolbar allows you to: • Connect the oscilloscope to the PC over USB. • Get oscilloscope settings from the oscilloscope, save them to a file or workbook, and send them back to the oscilloscope, all from within Excel. • Capture an acquired waveform, insert the data values into the spreadsheet, and optionally graph the data. • Capture automatic measurement values at regular time intervals, insert a table of values into the spreadsheet, and optionally graph the measurement data. • Capture triggered waveforms and insert the data values into columns in the spreadsheet. • Capture triggered automatic measurements and insert the data values into the spreadsheet. • Capture the oscilloscope's screen image and insert it into the spreadsheet.
Objectives - Learn how to install the Tek toolbars into the Microsoft Office applications and connect the oscilloscope to the PC via USB. - Learn how to transfer oscilloscope screen shots, waveform data, and automatic measurement results directly into a Word document on a PC. - Learn how to transfer oscilloscope waveform data, timed measurements, triggered waveform captures, and screen shots directly into an Excel spreadsheet on a PC.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

- For this lab, set up a simple display, such as the PROBE COMP signal:



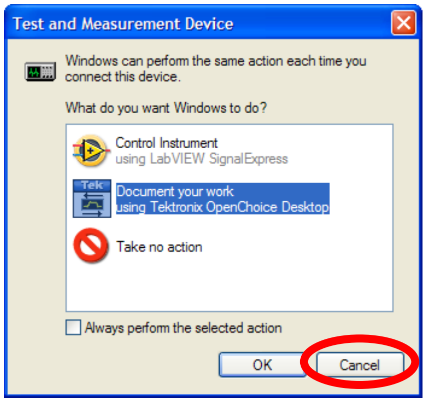
MSO/DPO5000 Series Procedure:

- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Connect the TPP1000 or TPP0500 probe to channel 1.
- ❑ Connect the probe tip to the PROBE COMP signal on the front of the oscilloscope.
- ❑ Connect the probe ground to the ground connection next to the PROBE COMP signal.
- ❑ Press the front panel **Autoset** button.

Tektronix

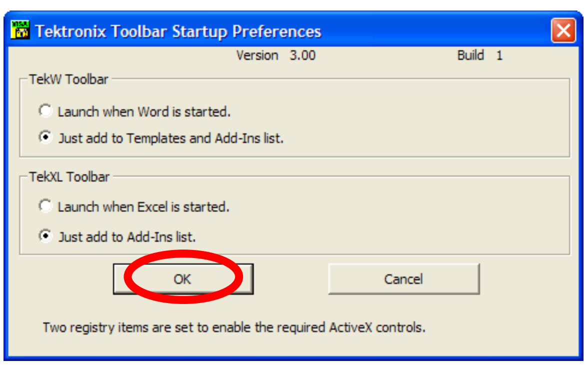
Key Take Away Points

- After you connect the USB cable between the oscilloscope and the PC, the USB plug-n-play driver may launch a Test and Measurement Device window like this on the PC display:



- When you installed the toolbars on your PC, the following icon was probably installed on your PC desktop:

- From this configuration window you can specify whether or not the toolbars will be launched automatically or manually (through the Tools->Templates and Add-ins list):



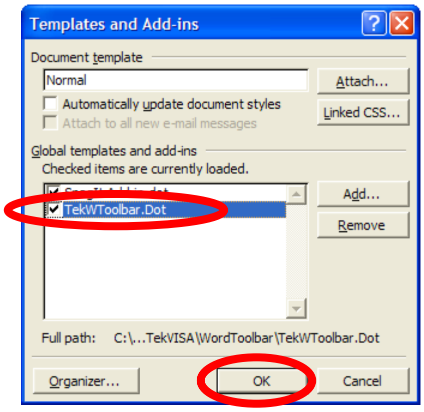
PC Procedure:

- ❑ Connect the rectangular end of the USB cable to a USB Host port on the PC and connect the ‘D’ shaped connector to the USB Device port on the back of the oscilloscope.
- ❑ If the Test and Measurement Device popup appears, click on the **Cancel** button.
- ❑ Double-click on the **Tektronix Toolbar Startup** icon.
- ❑ When you are done, click on the **OK** button.

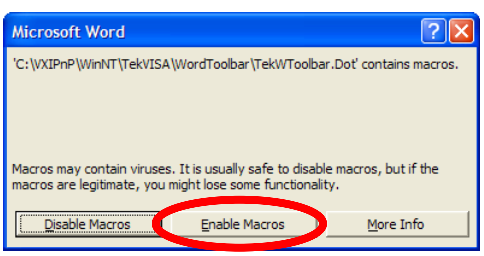
TekW Toolbar Lab

Key Take Away Points

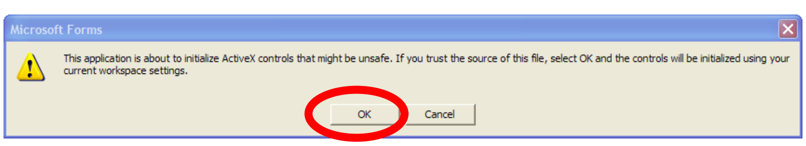
- If you need to add the TekWToolbar template add-in, you should see the following popup:



- Then you may see a security warning that macros have been disabled. If this happens, click on the Enable button:



- Finally, you may see this popup:



- When the TekWToolbar is properly installed, you should see it appear at the top of the display:

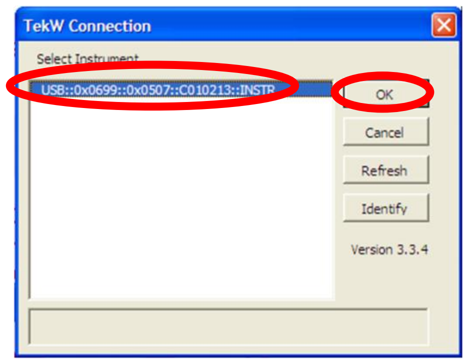
PC Procedure:

- ❑ Launch Microsoft Word.
- ❑ If the TekW toolbar does not appear near the top of the Word window:
  - ❑ The interface varies between versions of Word, but for Word 2002:
    - ❑ Click on **Tools** and then click on **Templates and Add-ins….**
    - ❑ Check the box next to **TekWToolbar.Dot**.
    - ❑ Click on **OK**.
    - ❑ Right click in the menu area at the top of the Word window and click on **TekWToolbar** to display the toolbar.
  - ❑ For Word 2007:
    - ❑ Click on the **Office Button** and **Word Options**.
    - ❑ Select **Add-Ins.**
    - ❑ Select **Templates** in the **Manage** text box and press **Go….**
    - ❑ Check the box next to **TekWToolbar.Dot**.
    - ❑ Click on **OK**.
    - ❑ Click on the new **Add-Ins** tab at the top of the screen.
  - ❑ For Word 2010:
    - ❑ Select **File-> Options-> Add-Ins.**
    - ❑ Select **Word Add-ins** in the **Manage** text box and press **Go….**
    - ❑ Check the box next to **TekWToolbar.Dot**.
    - ❑ Click on **OK**.
    - ❑ Click on the new **Add-Ins** tab at the top of the screen.
- ❑ If you see a warning popup about macros, click on the **Enable Macros** button.
- ❑ If you see a warning popup about initializing ActiveX controls, click on the **OK** button.

Key Take Away Points

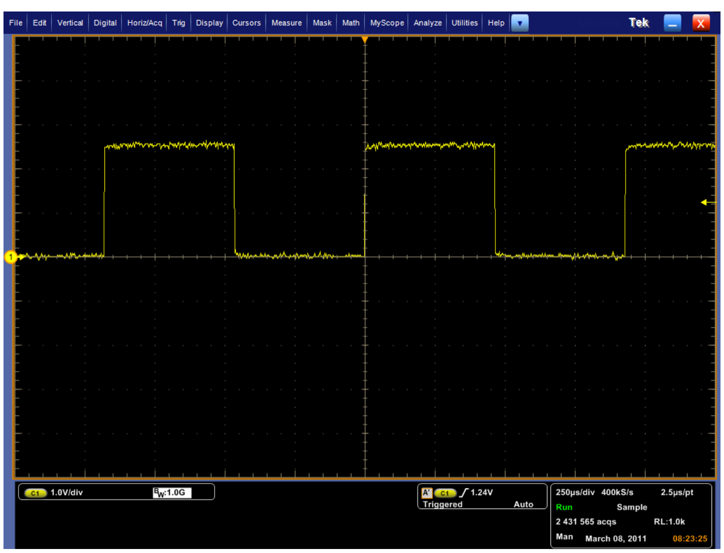
- Work from left to right across the TekWToolbar to set up and use the toolbar features:

- The first step is to connect to the oscilloscope. Simply select it from the list of connected devices:



- For documentation tasks in Word, the most useful feature will likely be the TekW Screen Capture button:

- When you click on the TekW Screen Capture button, the oscilloscope screen image will be inserted into the Word document at the cursor, much more easily than saving the image to a flash drive and copying it into the document:

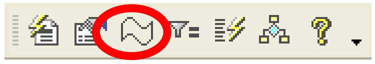


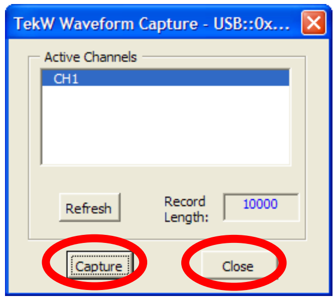
PC Procedure:

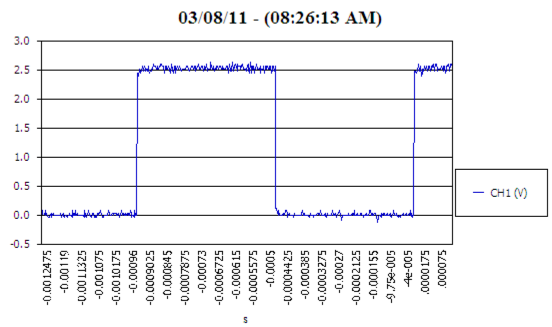
- ❑ Mouse over each of the buttons in the TekWToolbar to discover their functions.
- ❑ Click on the left-most button in the TekWToolbar. A mouse-over will identify it as **TekW Connection**.
- ❑ Highlight the oscilloscope in the list and click on the **OK** button.
- ❑ Place your cursor in your Word document at the location where you would like to insert an oscilloscope screen image.
- ❑ Click on the sixth button from the left in the TekWToolbar. A mouse-over will identify it as **TekW Screen Capture**.

Key Take Away Points

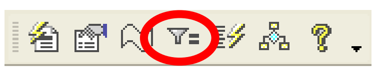
- You can also graph the waveform data with the TekW Waveforms feature:



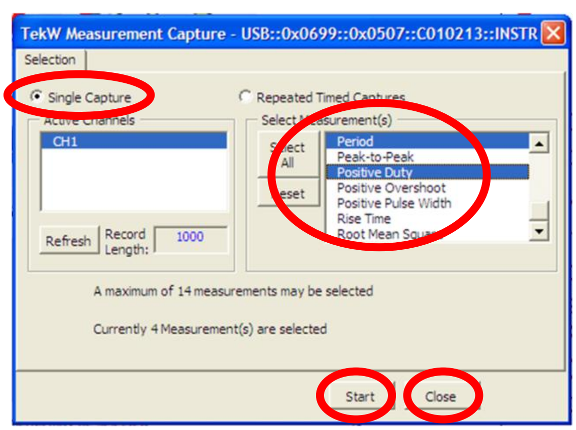




- The other very useful TekW feature for most documentation tasks is to quickly and remotely capture waveform measurements using the TekW Measurements button:



- Select up to 14 automatic measurements from the list:



- When you click Start, you will automatically insert a table of measurement values at the cursor:

CH1 Amplitude	CH1 Frequency	CH1 Period	CH1 Positive Duty
2.52	1075.37722217	0.00092990625	49.99474235935

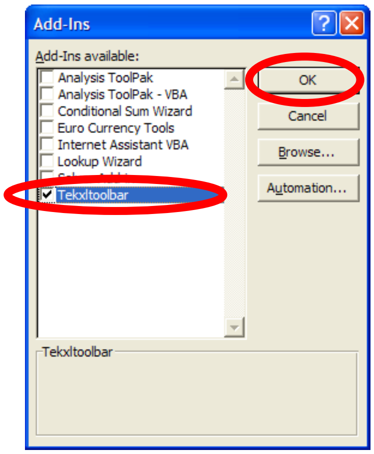
PC Procedure:

- ❑ Click on the third button from the left in the TekWToolbar. A mouse-over will identify it as **TekW Waveforms**.
- ❑ Click on the **Capture** button to capture the selected waveform data, graph it, and insert it into the document at the cursor.
- ❑ When you are done, click on the **Close** button.
- ❑ Click on the fourth button from the left in the TekWToolbar. A mouse-over will identify it as **TekW Measurements**.
- ❑ Click on the **Single Capture** radio button at the top of the window.
- ❑ You select and deselect measurements from the list by clicking on them. **Amplitude** is already highlighted. Click on the **Frequency**, **Period**, and **Positive Duty** measurements in the list at the right side of the screen.
- ❑ Click on the **Start** button to insert the measurement table.
- ❑ Click on the **Close** button when you are done.

TekXL Toolbar Lab

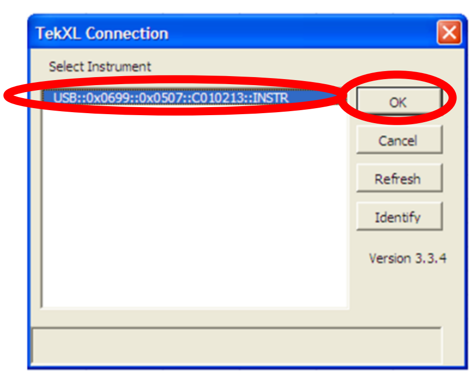
Key Take Away Points

- If you need to add the TekXLToolbar add-in, you should see the following popup:



- When the TekXLToolbar is properly installed, you should see it appear at the top of the display. Work from left to right across the TekXLToolbar to set up and use the toolbar features:

- The first step is to connect to the oscilloscope. Simply select it from the list of connected devices:

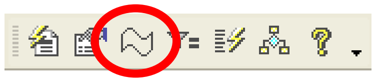


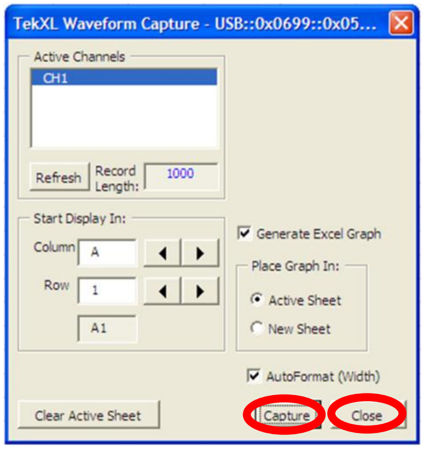
PC Procedure:

- ❑ Launch Microsoft Excel.
- ❑ If the TekXL toolbar does not appear near the top of the Word window:
  - ❑ The interface varies between versions of Excel, but for Excel 2002:
    - ❑ Click on **Tools** and then click on **Add-ins….**
    - ❑ Check the box next to **Tekxltoolbar**.
    - ❑ Click on **OK**.
  - ❑ For Excel 2007:
    - ❑ Click on the **Office Button** and **Excel Options**.
    - ❑ Select **Add-Ins.**
    - ❑ Select **Excel Add-ins** in the **Manage** text box and press **Go….**
    - ❑ Check the box next to **Tekxltoolbar**.
    - ❑ Click on **OK**.
    - ❑ Click on the new **Add-Ins** tab at the top of the screen.
- ❑ Mouse over each of the buttons in the TekXLToolbar to discover their functions.
- ❑ Click on the left-most button in the TekXLToolbar. A mouse-over will identify it as **TekXL Connection**.
- ❑ Highlight the oscilloscope in the list and click on the **OK** button.

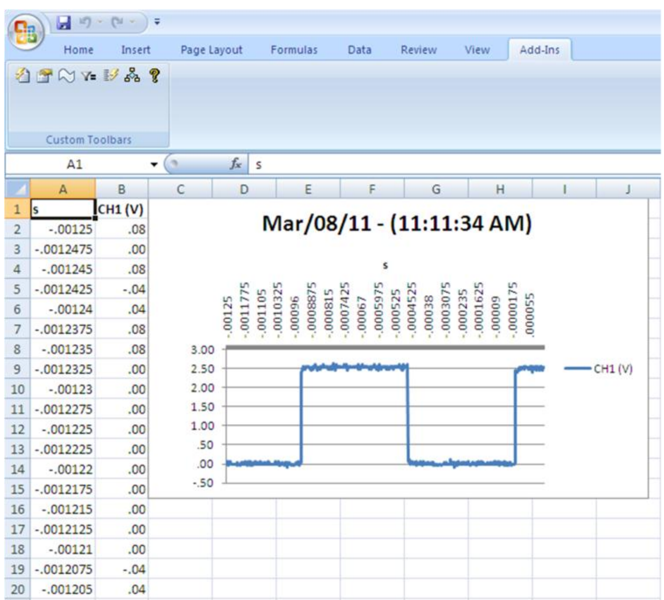
Key Take Away Points

- For analysis tasks in Excel, one of the most useful features will be the TekXL Waveforms button:





- By default, the TekXL Waveforms feature will insert the data values in the active Excel tab and automatically generate a graph of the data values, starting at the specified column and row coordinates:

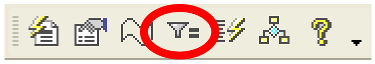


PC Procedure:

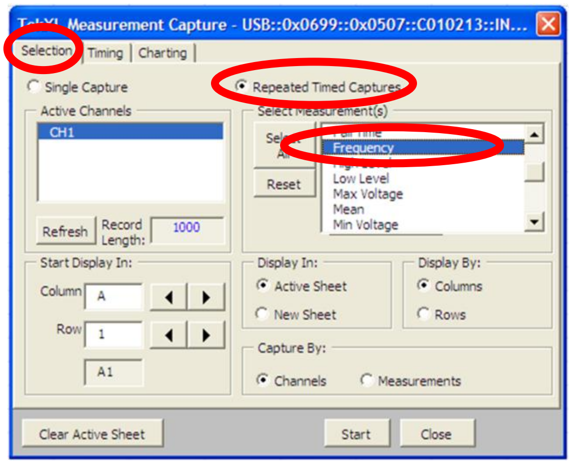
- ❑ Click on the third button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Waveforms**.
- ❑ Click on the **Capture** button to capture the selected waveform data, graph it, and insert it into the document at the cursor.
- ❑ When you are done, click on the **Close** button.

Key Take Away Points

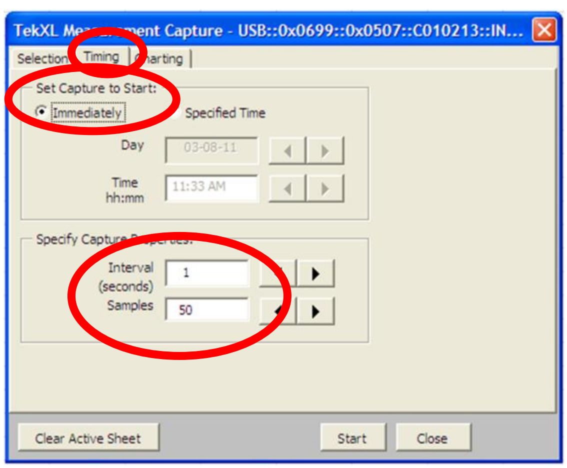
- Another very useful TekXL feature for analysis tasks is to automatically log regularly-scheduled waveform measurements using the TekXL Measurements button:



- Select up to 14 automatic measurements from the list:



- On the Timing tab, you can select how many measurements to make, how often, and when to start the measurements. By default, you will get 50 measurements, taken once a second, starting as soon as you click on the Start button:

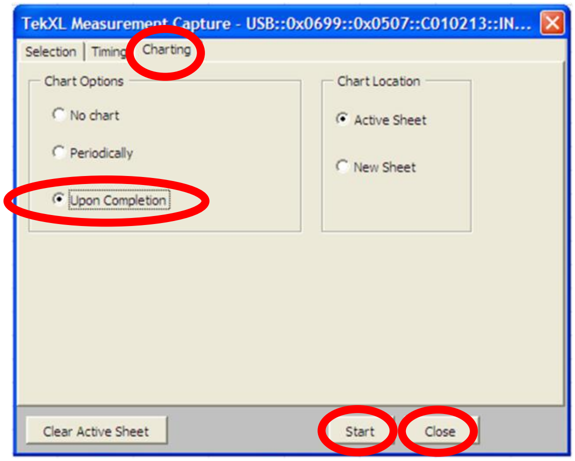


PC Procedure:

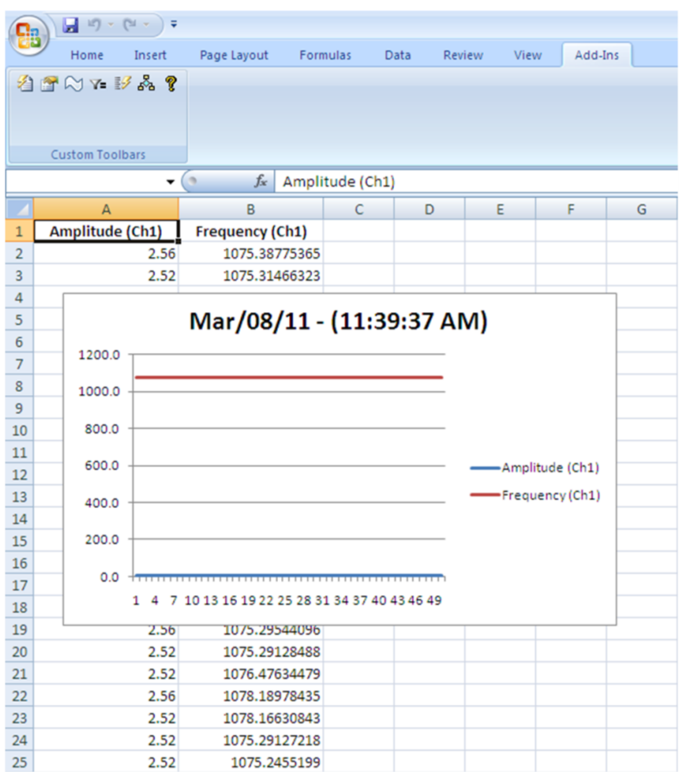
- ❑ Click on the fourth button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Measurements**.
- ❑ On the **Selection** tab, click on the **Repeated Timed Captures** radio button at the top of the window.
- ❑ You select and deselect measurements from the list by clicking on them. **Amplitude** is already highlighted. Click on the **Frequency** measurement in the list at the right side of the screen.
- ❑ Click on the **Timing** tab at the top of the window.

Key Take Away Points

- On the Charting tab, you can select whether or not you automatically generate a graph of the measurement values:



- By default, the TekXL Measurements feature will insert the measurement values in the active Excel tab and automatically generate a graph of the values, starting at the specified column and row coordinates (specified on the Selection tab):



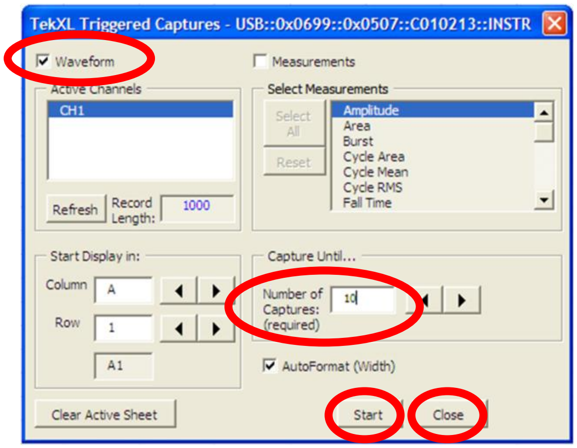
PC Procedure:

- ❑ Click on the **Charting** tab at the top of the window.
- ❑ Click on the **Upon Completion** radio button to specify that the graph will be generated after all of the measurement values are acquired.
- ❑ Click on the **Start** button to insert the measurement table.
- ❑ Click on the **Close** button when you are done.

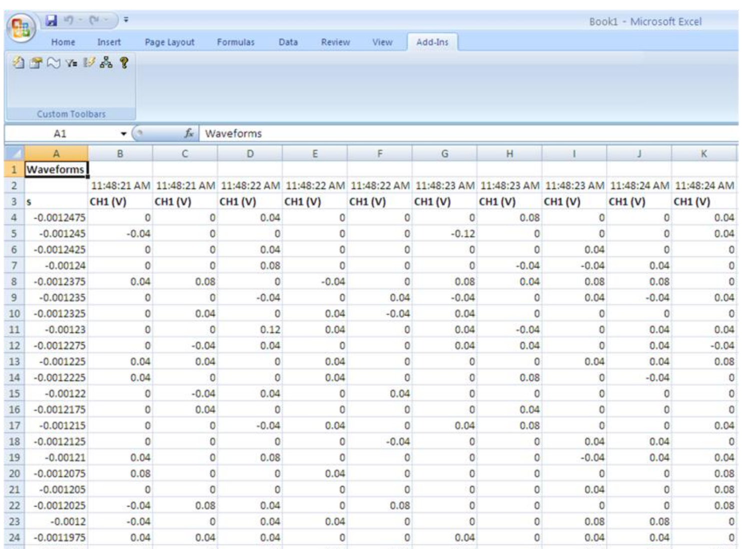
Key Take Away Points

- If you want to intermittently capture waveform or measurement data only when the oscilloscope triggers, you will find the TekXL Triggered Captures feature to be useful:

- The TekXL Triggered Captures feature allows you to select among the active waveforms or among the list of automatic measurements. You can specify how many triggered sets of data you want to log:



- By default, the TekXL Triggered Captures feature will insert the measurement values in the active Excel tab and automatically generate a graph of the values, starting at the specified column and row coordinates:



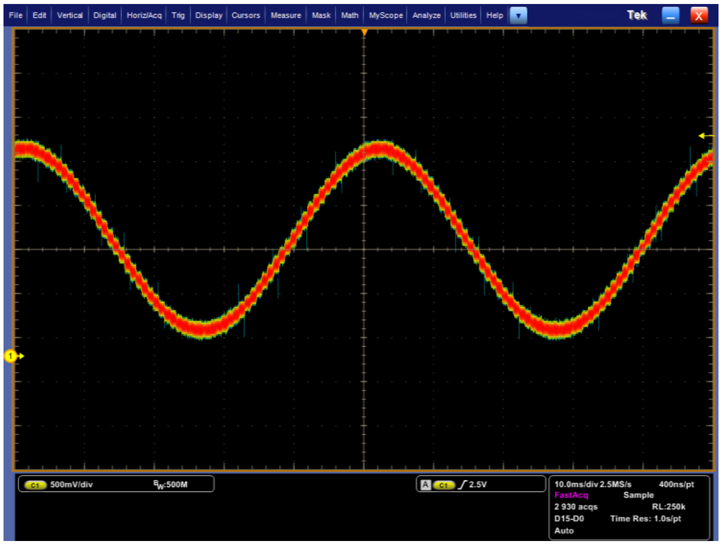
- Finally, just like with TekW toolbars, you can insert an oscilloscope screen shot into the document with the TekXL Screen Capture button:

PC Procedure:

- ❑ Click on the fifth button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Triggered Captures**.
- ❑ Click on the **Waveform** radio button at the top of the window.
- ❑ Set the **Number of Captures** to **10**.
- ❑ Click on the **Start** button to insert the triggered waveform data table.
- ❑ Click on the **Close** button when you are done.
- ❑ Click on the sixth button from the left in the TekXLToolbar. A mouse-over will identify it as **TekXL Screen Capture**.

MSO5000/DPO5000 Series

Acquisition Lab



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
Two TPP0500 or TPP1000 passive probes
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this lab were made with the DPO Demo 3 board]

Understanding the MSO/DPO5000 Series Acquisition Modes

You are probably familiar with the analog (hardware) bandwidth-limit filters on the inputs of most oscilloscopes. The MSO/DPO5000 Series has such bandwidth filters in the analog channel menu (20 MHz, 250 MHz, and 500 MHz low-pass filters) which can be used to remove high-frequency noise from a signal. For example, the 20 MHz filter can be very useful to eliminate stray RF signals from low-frequency circuits like power supplies.

However, the MSO/DPO5000 Series also provides several more powerful acquisition tools that enable you to control the acquisition of a complex signal. This lab goes through some of these features step-by-step to allow you to see the capabilities.

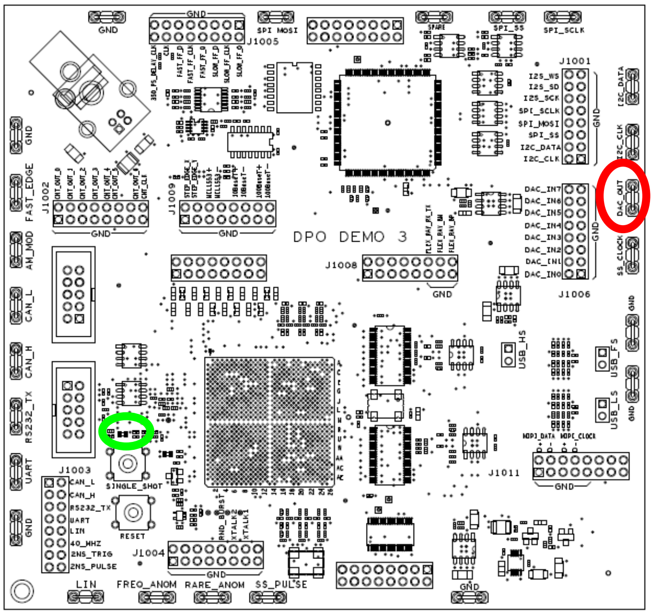
Lab Objectives

- Obtain a basic understanding of MSO/DPO5000 Series acquisition mode controls.
- Learn how to apply peak detect to reliably capture signal spikes.
- Learn how to apply averaging techniques to remove noise from signals.
- Learn about the FastFrame segmented memory acquisition mode.

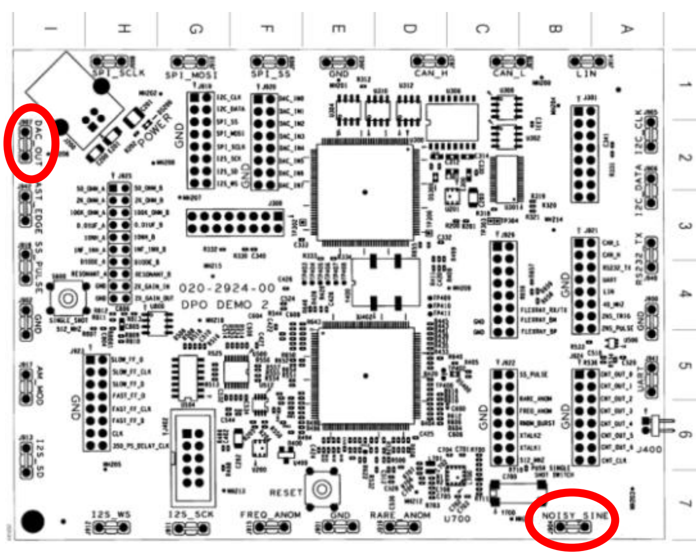
MSO/DPO5000 Series Lab Setup

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a DAC_OUT signal which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has NOISY SINE and DAC_OUT signals which we will use for this lab:

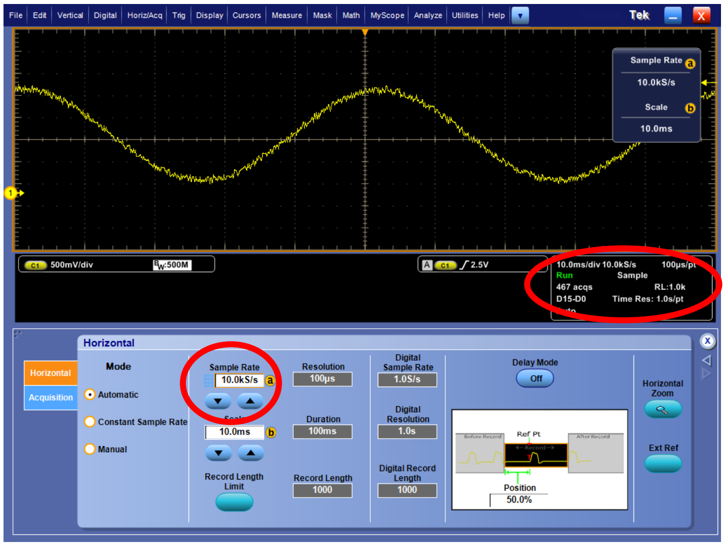


DPO Demo Board Procedure

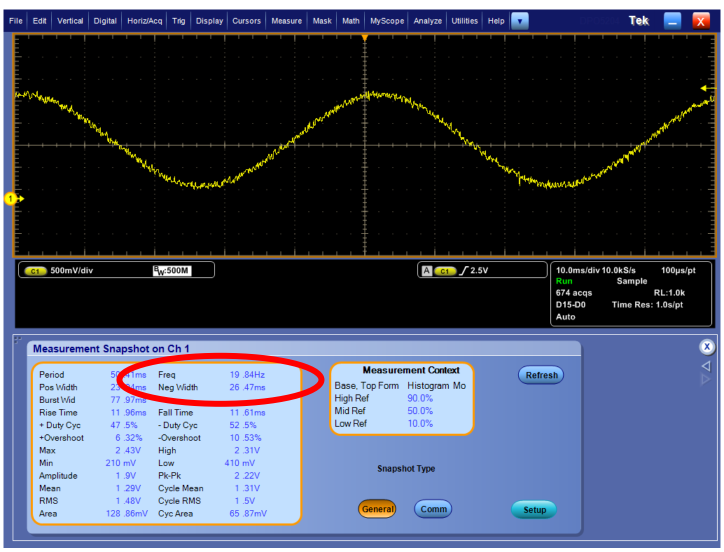
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- ❑ Attach the probe ground to the **GND** test point on the test board.
- ❑ Connect the probe tip to the **NOISY SINE** (or **DAC_OUT**) test point on the test board.
- ❑ NOTE: The instructions in this lab were written around the NOISY SINE signal. If you use the DAC_OUT signal, you will need to adjust the vertical controls a little differently.

Key Take Away Points

- Notice the readouts of sample rate and record length at the bottom of the display. The NOISY SINE signal should look about like this:



- Let's take a quick look at the signals parameters. From the Measurement Snapshot, we can see that the signal is a ~20 Hz sine wave.



- At first glance, this may look like a reasonable setup. We are sampling the 20Hz sine wave at 10 kS/s, which is plenty fast to represent the sine wave accurately.
- However, if you watch the display carefully, you will occasionally see relatively large, fast spikes at various locations on the waveform.

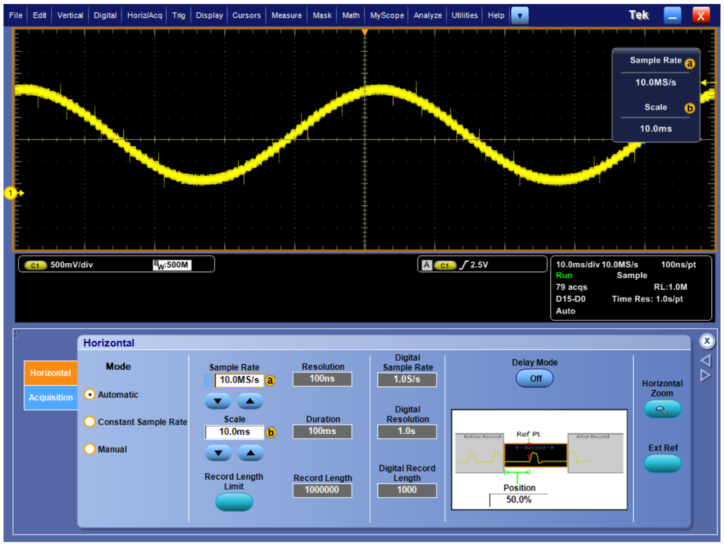
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set the channel 1 vertical scale to **500 mV/div**.
- ❑ Set the horizontal scale to **10 ms/div**.
- ❑ With the channel 1 Vertical **Position** control, center the waveform on the display.
- ❑ Press the **Trigger Menu** button.
- ❑ Press the **Mode** tab and press the **Normal** button.
- ❑ Using the Trigger **Level** control, adjust the trigger level to the top of the waveform, about **2.5V**, to stabilize the waveform display.
- ❑ Press the front panel **Acquire** button.
- ❑ Touch the Sample Rate text box to attach the Multipurpose **a** control to **Sample Rate**.
- ❑ Using the Multipurpose a control, reduce the Sample Rate to **10.0kS/s**. Notice that this has the side effect of reducing the record length to 1k samples.
- ❑ Press the front panel **Measure** button to display the Measurement Setup menu.
- ❑ Press the **Snapshot** button.
- ❑ When finished, press the **X** in the upper right corner of the measurement window to close it.

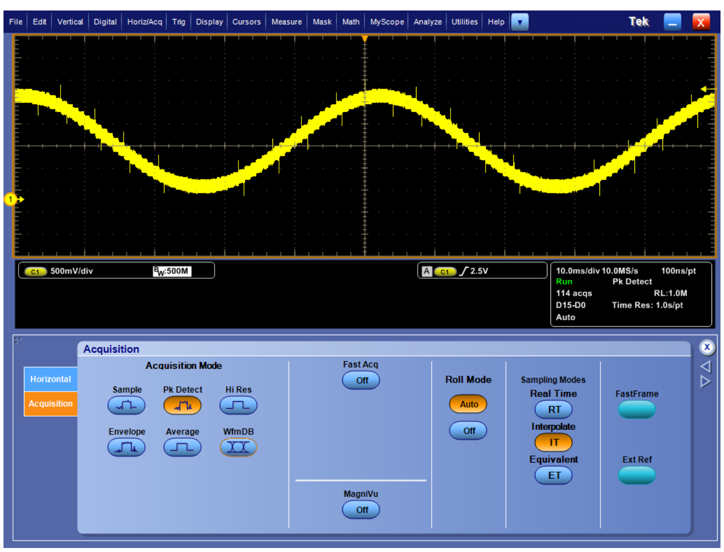
MSO/DPO5000 Series Peak Detect

Key Take Away Points

- One way to see more horizontal detail is to increase the record length. This also has the effect of raising the sample rate, which in turn raises the single-shot bandwidth. By selecting 1M record length, notice that we have also increased the sample rate to 10 MS/s. With the increased record length, you can now see a more realistic view of the noisy signal:



- You can see that the displayed trace is now quite thick, and there are some stationary spikes on it. To investigate these spikes more closely, we can use Peak Detect, which assures that we capture and display all of the peaks of the signal. With Peak Detect, the display should now look about like this:



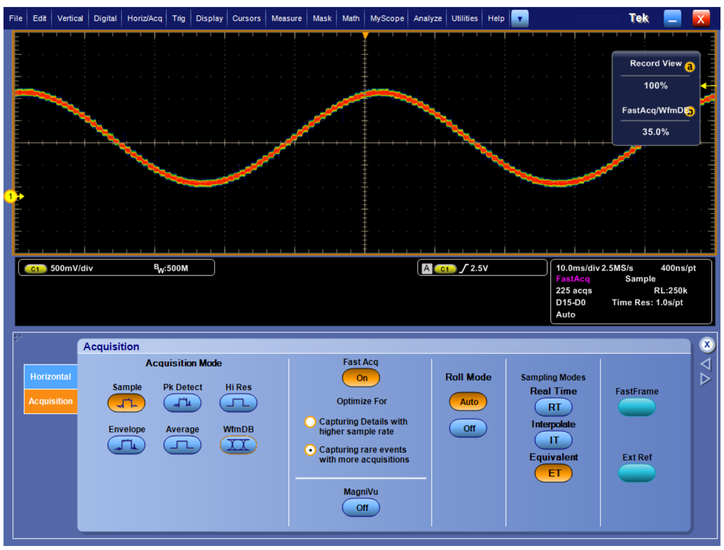
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Acquire** button.
- ❑ Touch the Sample Rate text box to attach the Multipurpose **a** control to **Sample Rate**.
- ❑ Using the Multipurpose a control, increase the Sample Rate to **10.0MS/s**. Notice that this has the side effect of increasing the record length to 1M samples.
- ❑ Touch the **Acquisition** tab.
- ❑ Press the **Pk Detect** button.
- ❑ This digital peak detect captures and displays peaks at the maximum sample rate of the product, capturing pulses as narrow as 1/(sample rate).
- ❑ You can also try **Envelope** acquisition mode, which provides a similar display, but accumulates the peaks between a specified number of acquisitions, as if Peak Detect and infinite persistence were turned on.

MSO/DPO5000 Series FastAcq

Key Take Away Points

- By using high sample rate and peak detect, you could see that there were a few random noise spikes on the signal. By carefully watching the flashes on the display, you can infer that the noise spikes are infrequent. But the oscilloscope is only capturing a few waveforms every second, so you may not be seeing all of the infrequent occurrences.
- The MSO/DPO5000 products have a special acquisition mode called FastAcq which can capture up to hundreds of thousands of waveforms every second.
- And, by color-grading the display, you can easily judge the relative frequency-of-occurrence of the waveform characteristics. In the screen shot below, notice that the frequently-occurring sine wave is displayed in red, while the infrequent noise spikes are shown in yellow.



- You can alter the color mapping by adjusting the display intensity control. For example, if you turn down the intensity, the infrequent spikes can be displayed in blue, the more frequent random noise in green and yellow, and the most frequent sine wave in red.
- Other display formats are also available in the **Display -> Colors…** control window.

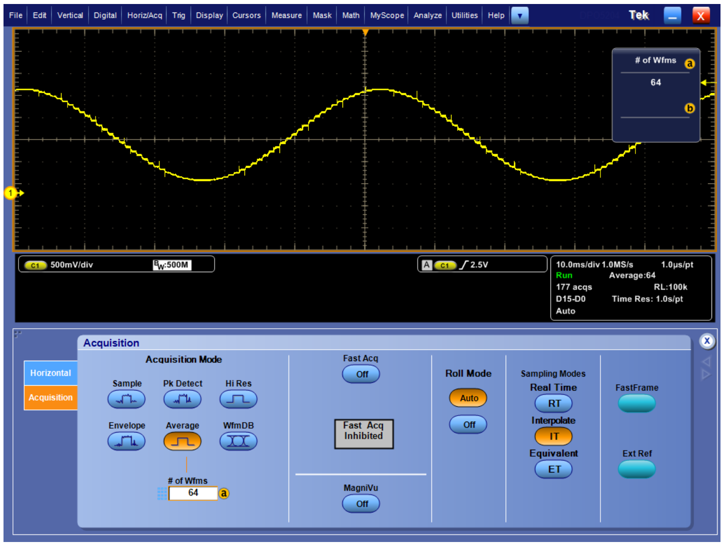
MSO/DPO5000 Series Procedure:

- ❑ Press the purple front panel **FastAcq** button or the FastAcq button in the Acquisition control window.
- ❑ Press the front panel **Intensity** button.
- ❑ Turn the Multipurpose **b** control counterclockwise to reduce the display intensity. This will have the effect of changing the mapping of the frequency-of-occurrence information to the different colors used in the display.
- ❑ Press the front panel **Intensity** button to turn off the intensity control.
- ❑ When you are done, press the purple front panel **FastAcq** button or the FastAcq button in the Acquisition control window to turn off FastAcq mode.

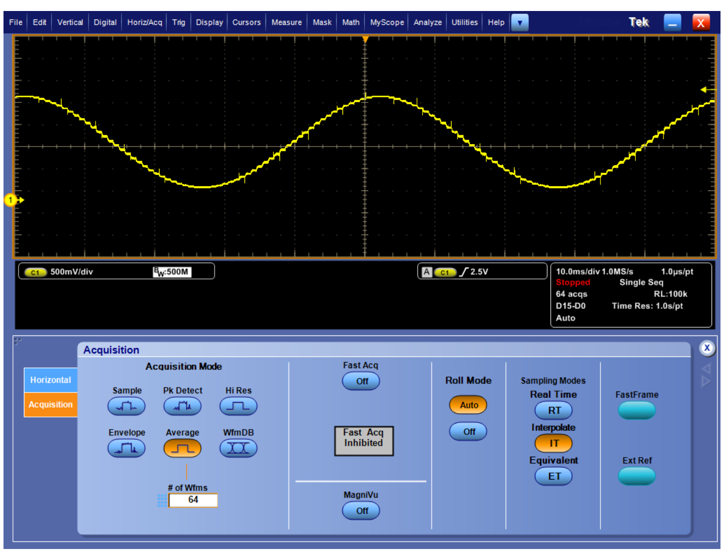
MSO/DPO5000 Series Averaging

Key Take Away Points

- Because this signal appears to be repetitive, we can use averaging (which averages successive acquisitions together, point by point, and displays the result).



- Notice how averaging removes random variations between acquired waveforms and preserves the stationary events such as the sine wave and the spikes. In this display, we can see the discrete voltage steps on the output of the circuit.
- If you want to see the result of exactly 64 averages, you can use Single sequence to acquire only that many waveforms. This takes a few seconds to complete.



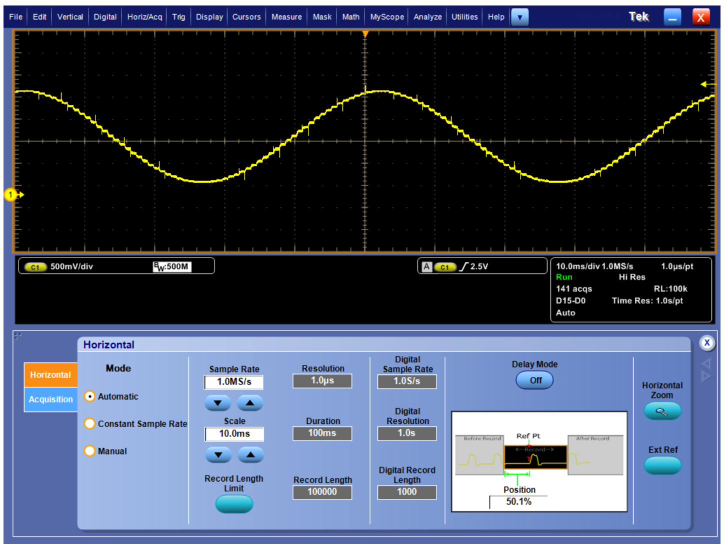
MSO/DPO5000 Series Procedure:

- ❑ If necessary, press the front panel **Acquire** button to display the Horizontal/Acquisition menu.
- ❑ Press the **Acquisition** tab.
- ❑ Press the **Average** acquisition button.
- ❑ Touch the **# of Wfms** text box to attach the Multipurpose **a** control to the number of averages control.
- ❑ Using the Multipurpose **a** control, set the number of averages to **64**.
- ❑ Press the front panel **Single** button.
- ❑ Notice the acquisition counter in the lower right corner readout as the 64 acquisitions are made.

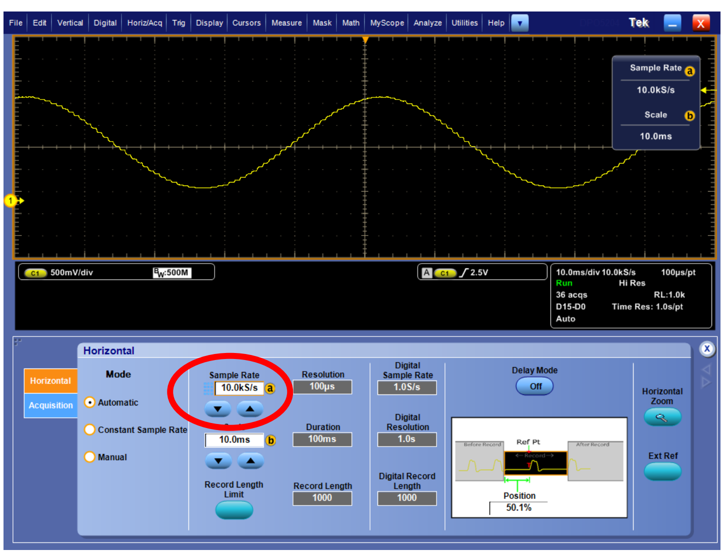
MSO/DPO5000 Series Hi Res Acquisition

Key Take Away Points

- Because averaging mode averages samples between acquisitions, a repetitive signal is required. However, it does retain the full bandwidth of the signal, as long as you substantially over-sample the signal.
- Another type of averaging, called Hi Res or "box-car averaging" averages groups of samples within a single acquisition and replaces them with the higher-vertical-resolution mean value. The tradeoff is that the bandwidth of the signal is reduced. However, this method does work on single-shot acquisitions.



- We can control the bandwidth of Hi Res by adjusting the sample rate and record length. Here, the bandwidth has been limited to about 4.4 kHz:



MSO/DPO5000 Series Procedure:

- ❑ Select **Hi Res** acquisition mode.
- ❑ Press the front panel **Run / Stop** button to start the acquisitions.
- ❑ Press the **Horizontal** tab.
- ❑ Use the arrow buttons to reduce the **Sample Rate** to **10 kS/s**.
- ❑ From the equation on the next page, we can calculate the Hi Res bandwidth as 0.44 * 10kS/s = 4.400 kHz.
- ❑ Slowly increase the Sample Rate (and therefore the Record Length) and notice the increasing bandwidth, as indicated by the increased noise on the signal.

The bandwidth limiting and the increase in vertical resolution due to Hi Res varies with the maximum sample rate and the actual sample rate of the instrument. The actual sample rate is displayed near the bottom of the screen.

The resulting -3 dB bandwidth is 0.44 * sample rate and the increase in bits of vertical resolution is $0.5 \log_2$ (maximum sample rate / actual sample rate).

For example, when all analog channels of the MSO/DPO5000 series are in use, the maximum sample rate is 5 GS/s, and Hi Res provides the following performance:

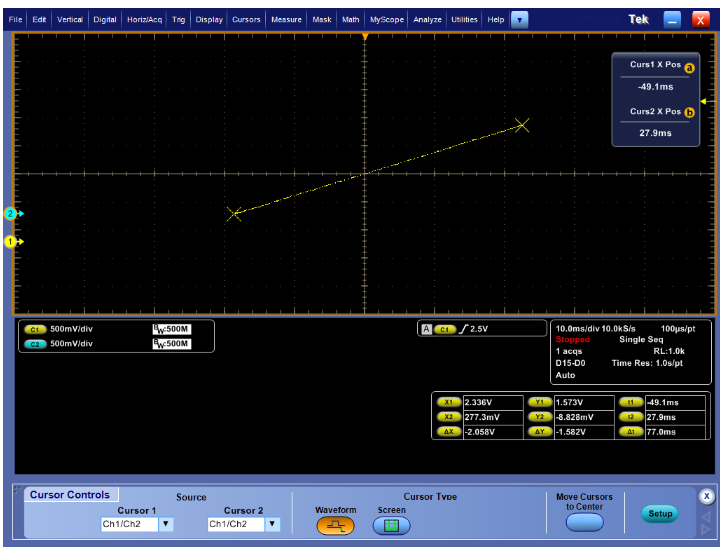
Sample Rate	**Bits of Vertical Resolution**	**3 dB Bandwidth Limit (0.44 x Sample Rate)**
2.5 GS/s	8.5 bits	1.1 GHz *
1 GS/s	9 bits	440 MHz*
250 MS/s	10 bits	110 MHz
50 MS/s	11 bits	22 MHz
10 MS/s	12 bits	4.4 MHz
2.5 MS/s	13 bits	1.1 MHz
1 MS/s	14 bits	440 KHz
250 KS/s	15 bits	110 KHz
25 KS/s	>15 bits	11 KHz
250 S/s	>15 bits	110 Hz
25 S/s	>15 bits	11 Hz
2.5 S/s	>15 bits	1.1 Hz

* The maximum Hi Res bandwidth may be further limited by the analog bandwidth.

MSO/DPO5000 Series XY Display

Key Take Away Points

- Most oscilloscope displays show voltages on the vertical ("Y") axis and time on the horizontal ("X") axis, since the user is most often interested in signal behavior over time. This type of display is often called a "YT" display.
- However, sometimes the relative behavior of two signals is more critical. Examples are measuring relative frequency or phase between two signals. The XY display allows the user to plot one signal on the vertical axis and the second on the horizontal axis.
- In this first setup, the same signal is plotted on the X and Y axes, so the resulting display is a straight line at 45 degrees.
- The XY display provides a unique set of waveform cursor measurements, including readouts in both rectangular and polar coordinates on the XY display, as well as matching cursor indications on the YT waveforms at the top of the screen:



MSO/DPO5000 Series Procedure:

- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 2 input of the oscilloscope. Connect the probe ground to the **GND** test point and the probe tip to the **NOISY SINE** (or **DAC_OUT**) test point on the test board.
- ❑ Press the front panel **2** button to turn on channel 2.
- ❑ Set the channel 2 vertical scale to **500 mV/div**.
- ❑ With the channel 1 and 2 Vertical **Position** controls, center the waveforms on the display.
- ❑ Select **Display -> Display Format -> XY**.
- ❑ Press the front panel **Single** button.
- ❑ Press the front panel **Cursors** button.
- ❑ Using the Multipurpose controls, notice how the waveform cursors move around on the XY display.

Key Take Away Points

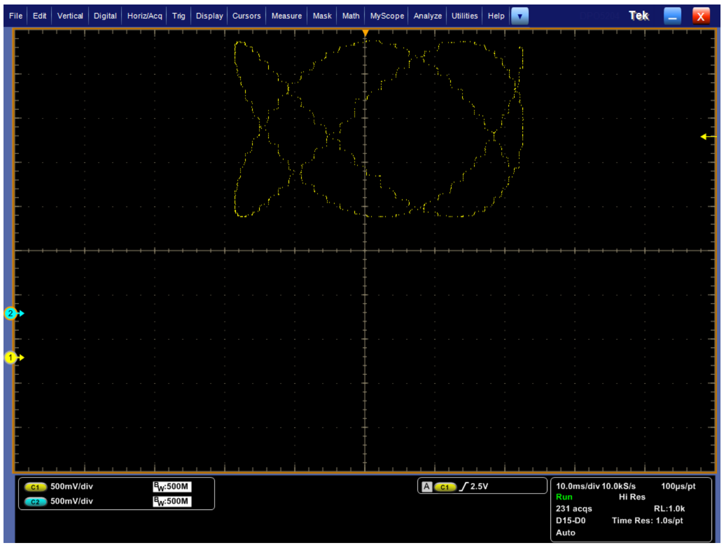
- There are also screen-based cursor measurements:

MSO/DPO5000 Series Procedure:

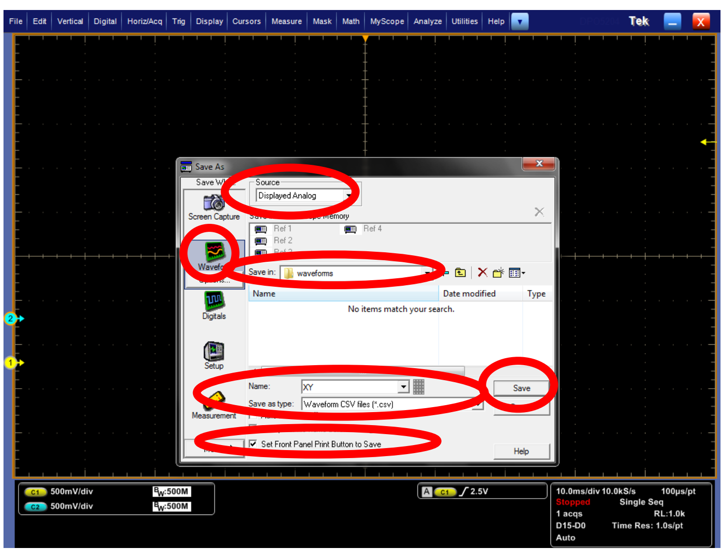
- ❑ Press the **Setup** button.
- ❑ Press the **Screen** Cursor Type button.
- ❑ Because there are four screen cursor lines to control, you use the text boxes in the Cursor Setup control window to select which cursor is controlled by the Multipurpose controls.
- ❑ Touch the **H Position** text box in the Cursor 1 section.
- ❑ Using the Multipurpose controls, adjust the position of cursor **1.**
- ❑ Touch the **H Position** text box in the Cursor 2 section.
- ❑ Using the Multipurpose controls or the mouse, notice how the screen cursors move around on the XY display.
- ❑ When you are done, press the **Cursors** button to turn off the cursor display.

Key Take Away Points

- If we display two different signals, we get a more interesting XY display. In this example, we are displaying two sinusoidal signals with different fundamental frequencies. Because the frequencies are not integer multiples of one another, the relative phases of the signals are constantly moving, and the XY display is also moving:



- Because the XY display is simply a different way of displaying pairs of waveforms, the underlying data values are still available for measurements, as well as for saving for off-line analysis. Waveforms can be saved individually in binary or spreadsheet (CSV) format, or all active waveforms can be saved in a single CSV file:



- Since there are two waveform files, they will be saved as XY_Ch1.csv and XY_Ch2.csv.

MSO/DPO5000 Series Procedure:

- ❑ Move the Channel 2 probe tip to the **DAC Out** (or a different signal) test point on the test board.
- ❑ Press the front panel Vertical **Menu** button to display the Vertical Setup menu and press the **Chan 2** tab to display the channel 2 controls.
- ❑ Press the front panel **Run/Stop** button.
- ❑ There are several ways to do save all of the waveform data:
  - ❑ Press the **Save/Recall Menu** button below the display and then press the Waveform button.
  - ❑ Select **File -> Save As -> Waveform**.
  - ❑ Select **File -> Save All Waveforms….**
- ❑ Select **Displayed Analog** as the Source.
- ❑ Select the file location for **Save In:**.
- ❑ Type in the file **Name:** as "**XY**" and select **Save As Type: Waveform CSV files (*.csv)**.
- ❑ If you are going to do this repetitively, check the **Set Front Panel Print Button to Save** check box.
- ❑ Press the **Save** button.
- ❑ When you are done, select **Display -> Display Format -> YT** display format.

MSO/DPO5000 Series Bandwidth Limit

Key Take Away Points

- Each of the vertical channels has bandwidth limit filters available. These filters limit the range of frequencies that the oscilloscope can acquire and display accurately with less than 3 dB of attenuation.
- Some filters are implemented in hardware (labeled with “HW”) and will limit the input signal bandwidth at any oscilloscope setting.
- NOTE: The bandwidth readout will display the probe tip bandwidth if the probe is limiting the bandwidth of the selected channel.

- Other filters use Digital Signal Processing (DSP) to filter the signal. The bandwidth readout displays in reverse video if the bandwidth is not what you selected. If you want the bandwidth to be what you selected, make sure that the sample rate is high enough to enable DSP filters (DSP).

MSO/DPO5000 Series Procedure:

- ❑ Move the Channel 1 and 2 probe tips to the **40 MHz** test point on the test board.
- ❑ Set the Channel 1 and 2 Vertical Scales to **500 mV/div**.
- ❑ Press the Trigger **Level** control to set the trigger level to 50%.
- ❑ Set the Horizontal **Scale** to **100ns/div**. Notice that the sample rate in the readout in the lower right corner of the display.
- ❑ Click on the **Vertical** menu and select **Bandwidth Limit….**
- ❑ Press the Channels **2** button.
- ❑ Click on the down arrow next to the Bandwidth text box and notice the available bandwidth limit choices.
- ❑ Select **20.0 MHz (HW)** from the Bandwidth drop down menu. Notice how the channel 2 signal is attenuated.
- ❑ Slowly rotate the Horizontal Scale control counter-clockwise while watching the bandwidth readouts in the lower left corner of the display. When you reduce the sample rate below the maximum value, notice that the bandwidth readout displays the value in reverse video, indicating insufficient sample rate for the DSP filtering (which is the default).
- ❑ Click on the **Vertical** menu and select **Vertical Setup….**
- ❑ Check **Force Constant Sample Rate** to ensure DSP filtering.
- ❑ Select **Analog Only** to ensure only hardware filtering is used.

Key Take Away Points

- When 1MΩ termination is used, the input amplifier limits the signal bandwidth to a maximum of 500 MHz. However, when 50Ω termination is used, the input amplifier limits the signal bandwidth to the bandwidth of the oscilloscope.
- On this 2 GHz MSO5204, notice that the maximum bandwidth setting in the 50Ω mode is 2.0 GHz:

- In the vertical readout section, notice that the choice of input termination has also set the channel's bandwidth.

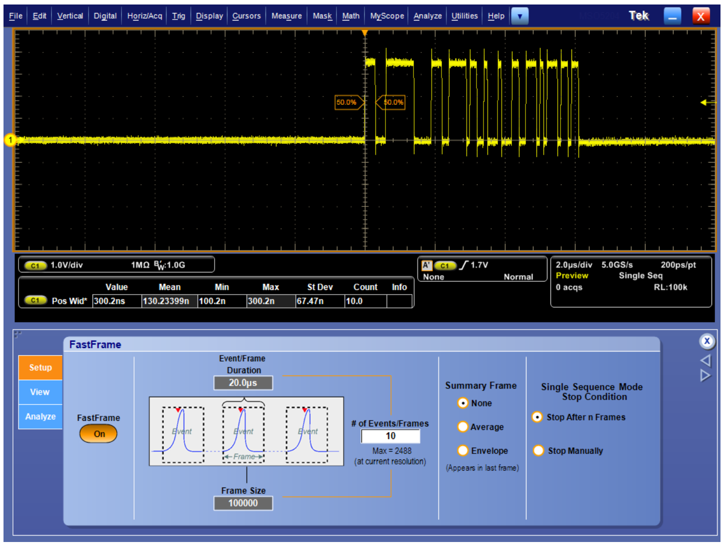
MSO/DPO5000 Series Procedure:

- ❑ Remove the probes from channels 1 and 2.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Select **Vertical -> Vertical Setup….**
- ❑ Press the **Chan 2** tab on the left side of the control window.
- ❑ Select **1MΩ** Termination.
- ❑ Click on the down arrow next to the Bandwidth text box and notice that the highest available bandwidth is **500 MHz**.
- ❑ Press the **Chan 1** tab on the left side of the control window.
- ❑ Select **50Ω** Termination.
- ❑ Click on the down arrow next to the Bandwidth text box and notice that the highest available bandwidth is now the same as the bandwidth of the oscilloscope.
- ❑ Reconnect the probes to channels 1 and 2.

MSO/DPO5000 Series FastFrame Acquisition Mode

Key Take Away Points

- FastFrame is a segmented-memory acquisition mode which provides high-resolution capture of a series of intermittent, triggered events while ignoring the dead-time between the events. FastFrame can acquire over 310,000 waveforms per second.
- The setup can be very simple. Just set up the oscilloscope to capture one event and then specify the number of frames.



- After the frames have all been acquired, you can easily examine them one by one:

- You can also specify that an average or envelope waveform appear in the final frame.

MSO/DPO5000 Series Procedure:

- ❑ Connect the Channel 1 probe tip to the **RNDM_BURST** test point on the test board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set the channel 1 vertical scale to **500 mV/div**.
- ❑ Set the Horizontal **Scale** to **2 µs/div**.
- ❑ With the channel 1 Vertical **Position** control, center the waveform on the display.
- ❑ Press the Trigger **Level** control to automatically set the trigger level to the center of the waveform.
- ❑ Press the Trigger **Menu** button.
- ❑ Press the **Mode** tab and press the **Normal** button.
- ❑ Press the front panel **Measure** button.
- ❑ Click on the **Time** tab and select the **Pos Width** measurement.
- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Acquisition** tab.
- ❑ Press the **FastFrame** button.
- ❑ Double-click on the **# of Events/Frames** text box and select 10 Frames.
- ❑ Press the **FastFrame** button to turn it **On**.
- ❑ Press the front panel **Single** button to acquire 10 frames.
- ❑ Touch the **View** tab and touch the **Display Selected Frame** text box to attach the Multipurpose **a** control to the frame selection.
- ❑ As you turn the Multipurpose **a** control, notice that the pulse width measurement of the first pulse is made on each frame.

Key Take Away Points

- One of the capabilities of FastFrame is the ability to overlay all of the acquired waveforms in one display for a quick comparison. For example, in this display, you can see that the pulse widths of all of the initial pulses are the same:

- In this display, you can see that the widths of the first pulses are not all the same:

MSO/DPO5000 Series Procedure:

- ❑ Set the Horizontal **Scale** to **100 ns/div**.
- ❑ Notice that the scope doesn't always trigger on the first rising edge on the screen. To assure that it does, we need to increase the trigger holdoff.
- ❑ Select **Trigger -> Holdoff…**.
- ❑ Press the Holdoff **Time** button.
- ❑ Double-click on the **Trig Holdoff** text box, enter **7.5 µs**, and press **Enter**. For this signal, this should assure that the first edge appears at the trigger point.
- ❑ Select **Horiz/Acq -> Fast Frame Setup…**.
- ❑ Press the **View** tab on the left side of the control window.
- ❑ In the View Multiple Frames section, select **Overlay Only**.
- ❑ Click on the Start Frame text box to attach the Multipurpose controls.
- ❑ Using the Multipurpose **a** control, set the Start Frame to **1**.
- ❑ Using the Multipurpose **b** control, set the Number of Frames to **10**.
- ❑ Press the front panel **Single** button to acquire 10 frames. If necessary, press **Single** again to get a display of various overlaid waveforms that do not all match. This might take a few tries.
- ❑ When you are done, press the front panel **Measure** button and press the **Display** button to turn off the display of measurements.

Key Take Away Points

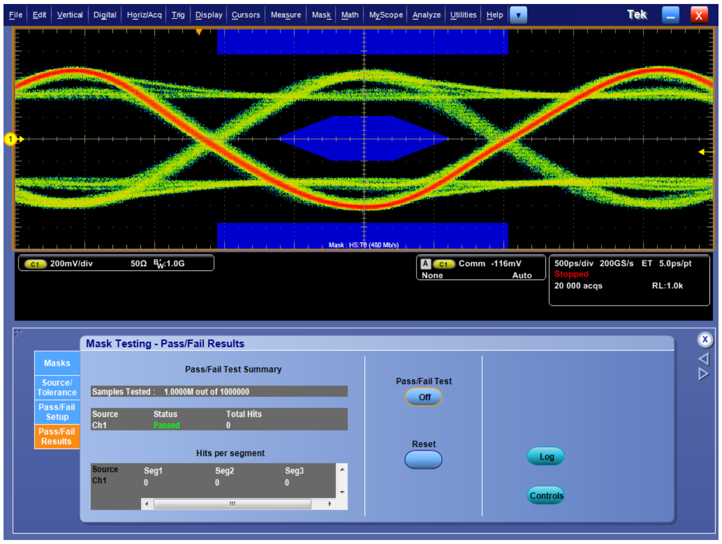
- There are two unique analysis tools provided with FastFrame, a Frame Delta Calculator and a Frame Finder.
- The Frame Delta Calculator calculates the time difference between two specified frames in the acquisition. This can be very useful for verifying repetition rates of infrequent events. Notice the readout of the time between the first and last frames in this acquisition:

- The Frame Finder uses a binary search algorithm to guide you through the frames. In this case, the pulse width of some of the initial pulses in the bursts are approximately 100 ns, while some of the other initial pulses are wider. After you press Start, the Frame Finder presents an overlay display of a subset of the frames and asks if you see the anomaly. Simply answer Yes or No. When the algorithm has guided you to the first frame with an anomaly, it stops. Here, frame 2 had the wider pulse width:

MSO/DPO5000 Series Procedure:

- ❑ Select **Horiz/Acq -> Fast Frame Setup….**
- ❑ Press the **Analyze** tab on the left side of the control window.
- ❑ In the **Frame Delta Calculator To:** section, click on the **Selected Frame** text box and set the value to **10**.
- ❑ Notice the time readout at the bottom of the Frame Delta Calculator section.
- ❑ In the **Frame Finder** section, set the **From Frame #** to **1** and the **To Frame #** to **10**.
- ❑ Press the **Start** button.
- ❑ Follow the on-screen instructions, pressing the Yes and No buttons, to do a binary search for frames that are different from the Reference Frame.

MSO5000/DPO5000 Series
Limit and Mask Testing Lab



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1 and with options LT and MTM installed
One TPP0500 or TPP1000 passive probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this lab were made with the DPO Demo 3 board]
Quick Start 7 demo board or other comm. signal generator

Introduction

This lab contains simple demos of the optional limit testing and mask testing applications of the MSO/DPO5000 Series.

In the cases of both limit testing and mask testing, the tests actually are remarkably complex. The graphical comparison of a live waveform to a template or mask requires the signal be triggered, and that the amplitude, rise-time, fall-time, delay, and the jitter measurements all be made simultaneously and that the results fall within the specified tolerances.

Limit Testing compares a live waveform to a “template” waveform, where the template is specified by a single Y-T waveform and horizontal and vertical tolerances around the waveform. Limit testing is commonly used in manufacturing and engineering for unattended monitoring circuit behavior over variations of time (like over the weekend) and temperature (as you vary the circuit’s ambient temperature from 0 to 50 Celsius). Although Limit Testing is simple to set up, it is limited to working with single-valued Y-T waveforms, so it does not work with eye diagrams.

Mask Testing is generally used to verify compliance to industry standards, most commonly used with communication signals. As you will see, many industry-standard masks are provided, but you can also specify your own to match your application.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

- With option LT installed, the MSO/DPO5000 Series oscilloscope can provide waveform limit testing.
- With option MTM installed, the MSO/DPO5000 Series oscilloscope can provide mask testing.

MSO/DPO5000 Series Procedure

- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope…**.
- ❑ Verify that option **LT: Limit Test** is installed.
- ❑ Verify that option **MTM: Serial Mask Testing** is installed.
- ❑ Press the **OK** button.

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the DPO Demo 2 board. Verify the USB cable is plugged into the MSO/DPO5000 Series oscilloscope and the demo board.
- ❑ Verify the power LED is lit.
- ❑ Connect a TPP0500 or TPP1000 10x passive probe to channel 1.
- ❑ Connect the probe ground to **GND**.
- ❑ Connect the channel 1 probe to the **FREQ_ANOM** test point.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **Autoset** button.

Limit Testing in the MSO/DPO5000 Series

Key Take Away Points

- The MSO/DPO5000 Series' Limit Test provides automated monitoring and capture of signals which vary outside a predetermined tolerance from a standard or "template" waveform. The signal under test is typically one of the analog channels, although math and reference signals can be used. The template waveform is typically stored in a reference, but it can also be stored in a file.
- In the MSO/DPO5000, limit testing is done on a waveform sample-by-sample basis, not display pixel-by-pixel, as is done in some other oscilloscopes.
- For simplicity, this lab uses a template based on a single waveform acquired in sample mode. For a smoother template, you might want to base the template on an averaged waveform. However, if you want to build a template that accommodates some noise on a signal with overshoots, you might want to base the template on an envelope waveform.
- After creating a limit test template and storing it in Reference 1, the Limit Test application begins comparing the live Channel 1 waveform with the template:

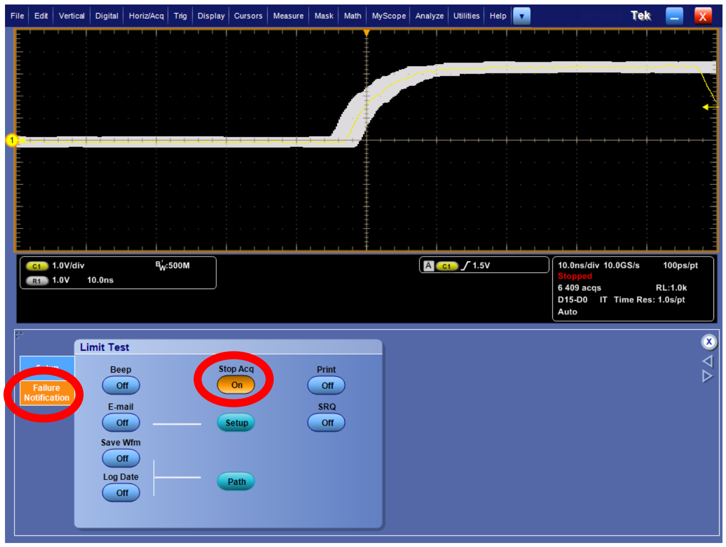
- While the Limit Test is running, the test status is indicated in the text box in the control window. As you can see in the screen shot above, the limit test is initially "Passing".

MSO/DPO5000 Series Procedure

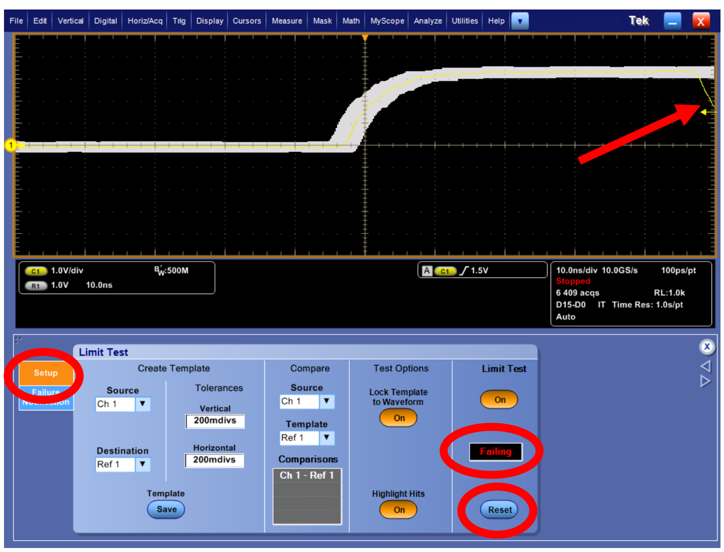
- ❑ Set the Horizontal **Scale** to **10 ns/div**.
- ❑ Select **Mask -> Limit Test Setup….**
- ❑ In the **Create Template** section, verify that the **Source** is set to **Ch 1** and the **Destination** is set to **Ref 1**.
- ❑ The next step in creating a template is to specify a vertical and horizontal tolerance band around the template.
- ❑ In the **Tolerances** section, touch the **Vertical** text box to attach the Multipurpose controls to the tolerances.
- ❑ Using the Multipurpose **a** and **b** controls, set the vertical and horizontal tolerances to **200mdiv**, or two tenths of a division around the waveform.
- ❑ Press the Template **Save** button. Notice the white reference waveform appears on the display, showing the limit test template.
- ❑ Press the Channel **1** button twice to turn it off and back on. This has the side-effect of bringing this waveform to the foreground, in front of the white limit test template waveform.
- ❑ In the **Compare** section, verify that the **Source** waveform is set to **Ch 1**.
- ❑ Select **Ref 1** in the **Template** drop-down menu.
- ❑ In the **Test Options** section, verify that **Lock Template to Waveform** and **Highlight Hits** are both **On**.
- ❑ Press the **Limit Test** button to turn on limit testing.

Key Take Away Points

- Although you can watch limit test run, the true power of a limit test is to automatically take specified actions whenever a failure is detected. For example, let's stop the acquisitions as soon as an error is detected. That way, even in unattended operation, you will be sure to capture any violations when they occur.



- When a limit test failure does occur, the acquisitions stop and you can see where the violation occurred:



MSO/DPO5000 Series Procedure

- ❑ Press the **Failure Notification** tab at the left side of the control windows.
- ❑ Notice all of the choices of actions when the limit test fails.
- ❑ Press the **Stop Acq** button.
- ❑ Press the **Setup** tab at the left side of the control windows.
- ❑ Press the **Reset** button to restart the limit test.
- ❑ After a limit test violation occurs and the acquisition is stopped, you have the acquired waveform with the violation.
- ❑ Select **File->Reference Waveform Controls…**, and press the **Display On** button to turn off the template.
- ❑ You can now analyze or store the waveform.

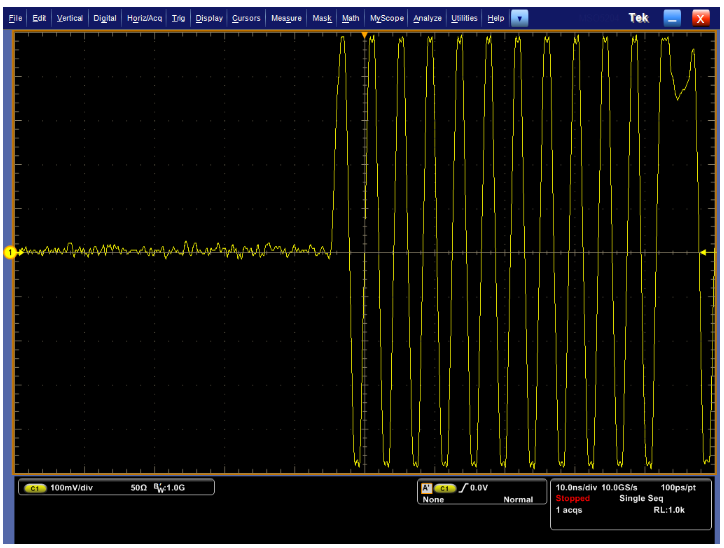
Mask Testing in the MSO/DPO5000 Series

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, there are few appropriate signals available on easily-accessible demo. For this lab, we will use the USB High-speed signal on the DPO Demo 3 board. If another communication signal source is used, adapt the instructions accordingly.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 1.
- ❑ Connect the probe's + input to pin1 and the – input to pin 2 of the USB_HS connector on the demo board.

Key Take Away Points

- The USB High-speed signal on the demo board should look about like this after a Default Setup:



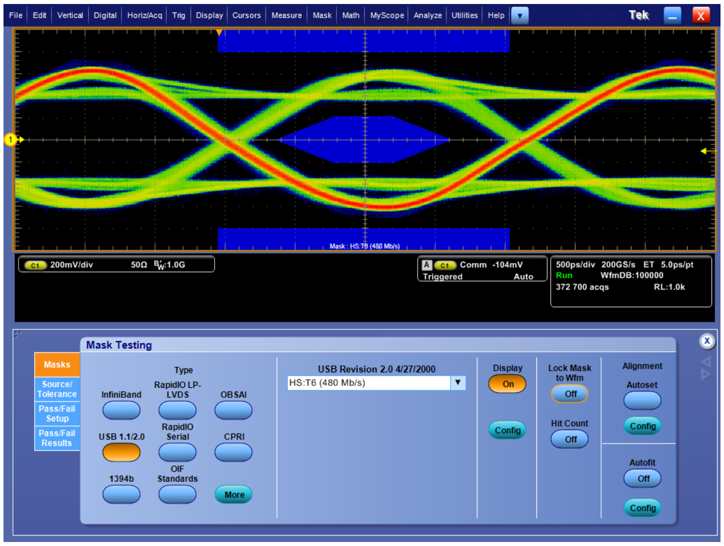
- When you select a standard mask, the oscilloscope will automatically adjust the oscilloscope for a standard signal, so there is no need to adjust the controls at this time.

MSO/DPO5000 Series Procedure

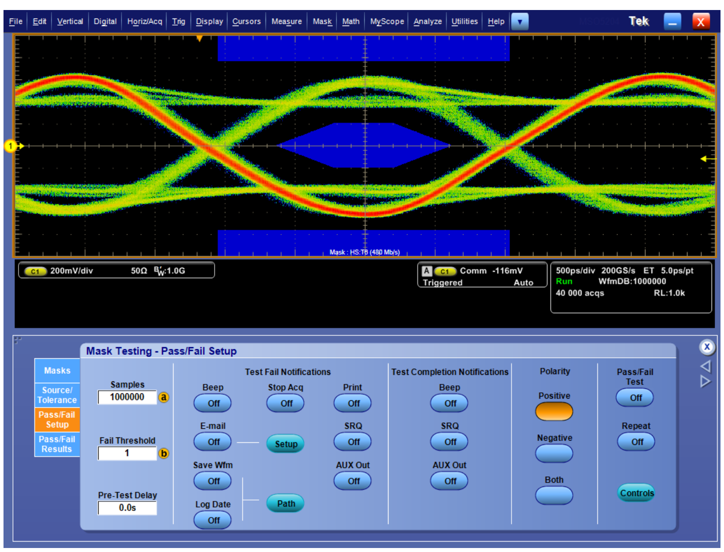
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.

Key Take Away Points

- The USB High-speed signal and appropriate standard mask should look about like this after manually adjusting the vertical scale and trigger level:



- Notice that the WfmDB acquisition mode has been turned on, providing a color-graded waveform display. (FastAcq is not supported in Mask Testing.)
- Although you can manually view the mask test results, the real power of mask testing is automated pass/fail testing. By default, the automated test will compare 100,000 samples to the mask and consider the test a failure if there is even 1 failure.

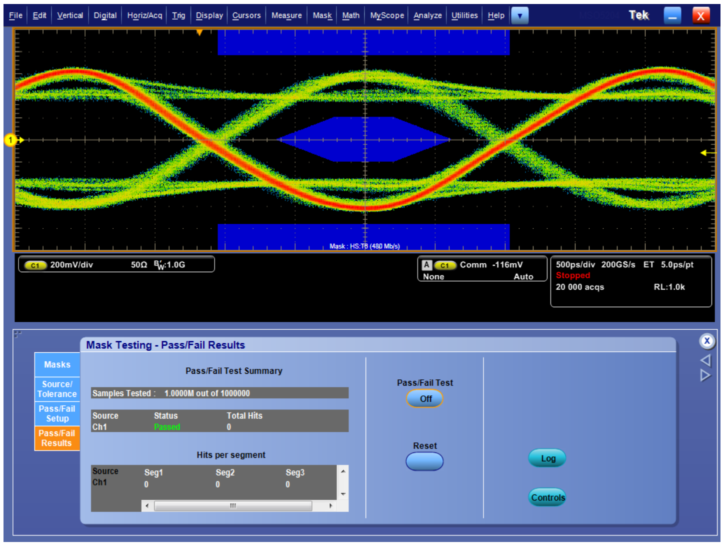


MSO/DPO5000 Series Procedure

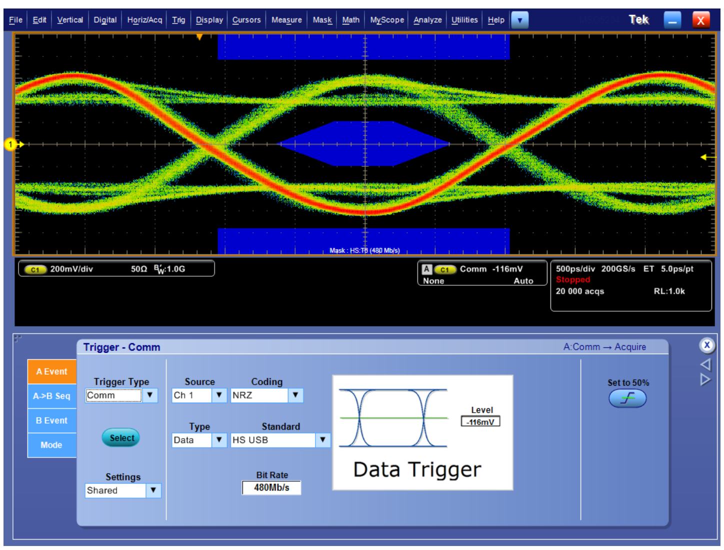
- ❑ Select **Mask -> Mask Setup…..**
- ❑ Press the **More** button to select the second page of standards.
- ❑ Press the **USB 1.1/2.0** button.
- ❑ Press the down arrow by the drop-down menu in the middle of the control window and notice the selection of standard USB masks available.
- ❑ Select **HS: T6 (480Mb/s)** from the drop-down menu. (This is the least-demanding USB HS mask and therefore the easiest to use for a demonstration.)
- ❑ Press the **Lock Mask to Wfm** button to turn it off.
- ❑ Set the Trigger **Level** to about **-100 mV**.
- ❑ Because the signal on the demo board is not terminated, the amplitude of the signal does not match the mask, so you need to adjust the amplitude to match the mask.
- ❑ Set the Vertical **Scale** to **200 mV/div**.
- ❑ Press the front panel **Clear** button (under the display) to clean up the display.
- ❑ Press the **Pass/Fail Setup** tab on the left side of the control window.
- ❑ Set the **Number of Samples** to **1,000,000**.
- ❑ Verify the **Fail Threshold** is set to **1**.
- ❑ In the **Test Fail Notifications** section, press the **Stop Acq** button to turn it on.

Key Take Away Points

- The Pass/Fail Results control window shows the details of the mask test results:



- Before we leave this test setup, let's see how the mask test setup automatically configured the communication trigger to capture the USB High-speed signal:



MSO/DPO5000 Series Procedure

- ❑ Press the **Pass/Fail Results** tab on the left side of the control window.
- ❑ Press the **Pass/Fail Test** button in the middle of the control window.
- ❑ After 1,000,000 samples are compared to the mask, notice that the acquisitions stop.
- ❑ Select **Trig -> A Event (Main) Trigger Setup….**

MSO5000/DPO5000 Series
Math Application Lab

Equipment List
One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
Four TPP0500 or TPP1000 passive probes
One TDP0500 or TDP1000 high-voltage differential probe
One TCP0030 current probe
Optional USB keyboard and mouse
One 878-0544-XX or 3PQS power demo board and 12VAC power adapter
One video generator, 75 Ohm cable, and 75 Ohm feed-through terminator
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this lab were made with the DPO Demo 3 board]

Introduction

This lab contains a few waveform analysis applications of the MSO5000 / DPO5000 Series highlighting the capabilities of the math system. Step-by-step instructions and a few application hints are provided. Although the setup information for each application is fairly complete, the labs do build on previous setups, so reading through the document may help. Some screen shots are provided to help you if you are unable to get the equipment to actually complete a lab experiment.

The math system has three separate sections, Predefined Math Functions, Spectral Analysis, and Equation Editor. Each has different capabilities, and these labs will cover some highlights from each.

Predefined Math Functions in the MSO/DPO5000 Series

Many basic waveform math requirements can be addressed with the basic math capabilities found under the Predefined Functions in the Math menu. Basically, these capabilities include subtraction of paired channels, multiplication of paired channels, and spectral analysis.

In this section, we will start with some of the most common applications for dual waveform math: pseudo-floating and instantaneous power measurements.

Pseudo-Floating Measurements

All voltage measurements are differential measurements. That is, the measurements are always comparing the voltage of one point to another (reference) point. Often, the reference point is ground, and most oscilloscope probes connect their reference or ground lead to the power line ground through the oscilloscope.

However, in some applications, you need to measure the voltage difference between two points where neither point is at ground. This is sometimes called a “floating” measurement. The highest performance solution is to use an active differential probe, especially for high-speed and high-voltage signals. These probe inputs are carefully matched for high-frequency response and loading, and may be capable of safely measuring much higher voltages than passive probes. But active differential probes are more expensive than the standard passive probes, and you may not have any available.

Within certain limits, such as low frequencies (less than a few MHz) and small ratios between common-mode and differential signal amplitudes (less than 10 or so), you can make good differential voltage measurements with two passive probes and math subtraction. By calculating the difference between two ground-referenced signals, the oscilloscope can calculate the floating voltage difference.

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board. Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Connect TPP0500 or TPP1000 10x passive probes to channels 1 and 2.
- ❑ Connect the probe grounds to **GND**.
- ❑ Connect the channel 1 probe to the **CNT_CLK** test point.
- ❑ Connect the channel 2 probe to the **CNT_CLK** test point.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **2** button to turn on channel 2.
- ❑ Press the front panel **Autoset** button.
- ❑ In this case, the signals on channel 1 and channel 2 are very similar. Using the front panel vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, and position them so they overlap.

Key Take Away Points

- The MSO/DPO5000 Series' Predefined Functions provide simple waveform math capabilities with just a few controls in this one simple menu. The display should look something like this:

- Notice that when you compare two similar signals, located across the circuit board from one another, the amplitude is slightly different (as indicated by the square wave component of the difference signal) and the timing of the edges are slightly different (as indicated by the positive and negative spikes on the difference signal). The display should look something like this:

- As expected, the math difference waveform represents the instantaneous voltage differences between the two input signals.

MSO/DPO5000 Series Procedure

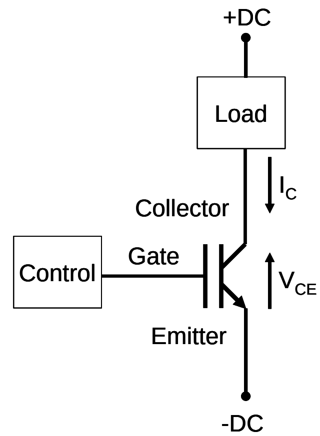
- ❑ Press the red front panel **Math** button.
- ❑ Select the **Ch1-Ch2** Predefined Function.
- ❑ Notice that the difference between the two probes is nearly zero when the probes are connected to the same signal, as expected.
- ❑ However, notice that the mathematical difference waveform provides a very sensitive measure of the voltage differences between these two logic signals.
- ❑ Select **Math -> Position/Scale….**
- ❑ Using the Multipurpose **b** control, set the math vertical **Scale** to match the channel vertical scale settings.
- ❑ Move the channel 2 probe to the **FAST_FF_CLK** test point.
- ❑ Notice that the math difference waveform makes even small amplitude and/or timing differences very apparent.

Instantaneous Power Measurements

Another common oscilloscope measurement which requires simple math is measurement of instantaneous power. One specific measurement is the power dissipation in the switching device in a switch-mode power supply.

In this lab, you will measure the power dissipated in an Insulated Gate Bipolar Transistor (IGBT) or MOSFET switching device. The instantaneous power is the product of the current flowing through the device (the Collector or Drain current, I_C or I_D) and the voltage across the device (the Collector voltage relative to the Emitter, V_{CE}, or the Drain voltage relative to the Source, V_{DS}).

When the switching device on turned on, the voltage across the device is very small and the current is large. When the device is turned off, the voltage across the device is large and the current is very small.



MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the power demo board. Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 1.
- ❑ Connect the **+** and **–** inputs together. Make sure that the **Range** is set to **42.0 V**.
- ❑ Press the **Menu** button on the probe's comp box, and press the **AutoZero** button on the display.
- ❑ Connect the **+** input of the differential probe to the **Collector** or **Drain** test point.
- ❑ Connect the **-** input of the differential probe to the **Emitter** or **Source** test point.
- ❑ Connect a TCP0030 current probe to channel 2.
- ❑ Make sure that the current probe's jaw is closed. Press the **Degauss AutoZero** button on the probe.
- ❑ Connect the current probe around the **Collector Current** or **Drain Current** loop and close the jaws.
- ❑ Set the channel 1 positive edge trigger level to about **15V**.
- ❑ Press the front panel **2** button to turn on channel 2.
- ❑ In this case, the voltage and current waveforms are square waves, 180 degrees out of phase. If the channel 2 signal is in phase with the channel 1 signal, remove the current probe, turn it over, and reconnect it.
- ❑ Using the front panel horizontal and vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, and position them so they overlap.

Key Take Away Points

- The instantaneous power waveform should look something like this:

- Notice that, because the voltage and current are out of phase (one waveform has a value of zero, so the product of waveforms is zero), the instantaneous power is very small except during the turn-on and turn-off transitions.

MSO/DPO5000 Series Procedure

- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Acquisition** tab at the left side of the control window.
- ❑ Select **Hi Res Acquisition Mode**.
- ❑ Press the red front panel **Math** button.
- ❑ Press the **Ch1*Ch2 Predefined Functions** button.
- ❑ Use the Multipurpose **a** control to select adjust the math waveform vertical position and the Multipurpose **b** control to adjust the vertical scale.

Spectral Analysis in the MSO/DPO5000 Series

Introduction

The MSO/DPO5000 Series provides a frequency-domain or spectral analysis display of any analog channel or internal reference waveform. Simple spectral analysis, calculated using a Fast Fourier Transform (FFT), is found under the Spectral Mag Predefined Function button in the Math menu.

The MSO/DPO5000's FFT function provides eight different window functions. The windows are listed in the order of their ability to resolve frequencies (resolution bandwidth).Here is a general guideline for choosing between the most common of the windows:

- **Rectangular:** This is the best type of window for resolving frequencies that are very close to the same value but worst for accurately measuring the amplitude of those frequencies. It is the best type for measuring the frequency spectrum of non-repetitive signals and measuring frequency components near DC. Use Rectangular for measuring transients or bursts where the signal levels before and after the event are nearly equal. Also, use this window for equal-amplitude sine waves with frequencies that are very close and for broadband random noise with a relatively slow varying spectrum.
- **Hamming:** This is a very good window for resolving frequencies that are very close to the same value with somewhat improved amplitude accuracy over the rectangular window. It has a slightly better frequency resolution than the Hanning. Use Hamming for measuring sine, periodic, and narrow band random noise. This window works on transients or bursts where the signal levels before and after the event are significantly different.
- **Hanning:** This is a very good window for measuring amplitude accuracy but less so for resolving frequencies. Use Hanning for measuring sine, periodic, and narrow band random noise. This window works on transients or bursts where the signal levels before and after the event are significantly different.
- **Blackman-Harris:** This is the best window for measuring the amplitude of frequencies but worst at resolving frequencies. Use Blackman-Harris for measuring predominantly single frequency waveforms to look for higher order harmonics.

Simple Spectral Display of a Square Wave

If you want to display the frequency domain representation of a square wave, the FFT function can calculate and display the spectrum. This display will include a representation of all of the signal components, including the desired square wave as well as the noise and amplitude modulation of the signal.

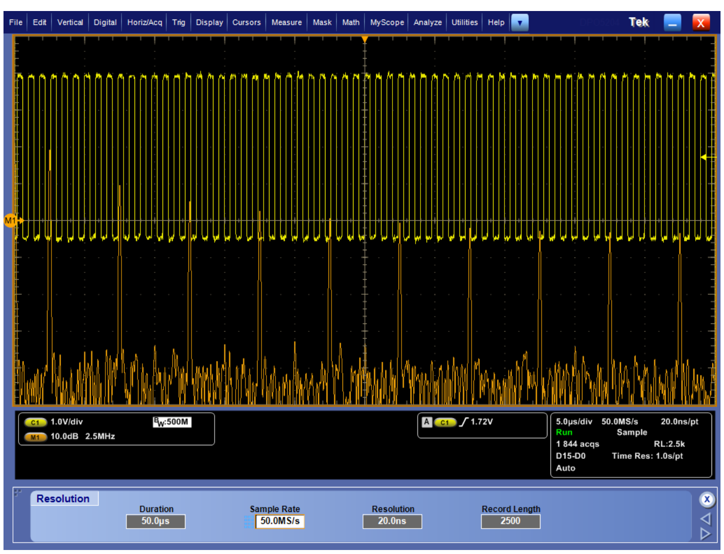
MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Connect a TPP0500 or TPP1000 10x passive probe to channel 1.
- ❑ Connect the probe ground to **GND** on the demo board.
- ❑ Connect the channel 1 probe to the **CNT_CLK** signal on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **Autoset** button to automatically set up a stable display.

Key Take Away Points

- The peak at the left side of the display represents the DC (0 Hz) content of the signal. The next FFT peak, about 1/8 of a division from the left side of the display, is the “fundamental” frequency of the input square wave signal. Since the math horizontal scale is 10 MHz/div, the fundamental frequency is about 1.25 MHz. Since the remaining major peaks are at odd integer multiples of this frequency (“odd harmonics”), from Fourier analysis theory we know that this input signal is indeed a square wave.

- The FFT’s frequency resolution can be dramatically improved by increasing the amount of input data. This is done by increasing the record length. With a 10X increase in record length, notice that the FFT peaks are much sharper and better defined:



MSO/DPO5000 Series Procedure

- ❑ Press the red front panel **Math** button.
- ❑ Press the **Basic Spectral** to display the spectral analysis control window.
- ❑ Select **Magnitude** to enable the spectral magnitude display.
- ❑ Touch the **Scale** text box in the Vertical Controls section to allow the Multipurpose **b** control to adjust the Vertical Scale.
- ❑ Using the Multipurpose **b** control, adjust the Spectral Vertical Scale to **10 dB/div**.
- ❑ Touch the **Level** text box in the Vertical Controls section to allow the Multipurpose **a** control to adjust the Reference Level.
- ❑ Using the Multipurpose **a** control, adjust the vertical position of the spectral display, setting the Reference Level to about **50 dB**.
- ❑ Notice that the Resolution BW displayed in the center of the control window is 400 kHz.
- ❑ In the horizontal readout in the lower right corner of the display, notice that the horizontal scale is 500 ns/div and the record length is 1.0k points.
- ❑ Adjust the **Horizontal Scale** control until the horizontal scale is **5.0 µs/div**.
- ❑ Notice that the Record Length has increased to 10.0k and the Resolution BW displayed in the center of the control window has decreased to 40 kHz.
- ❑ Select **Horiz/Acq->Resolution…**.
- ❑ Double-click on the Sample Rate text box and set the value to **50 MS/s**.
- ❑ Notice that the Spectral Horizontal Scale is now **2.5 MHz/div**.

Key Take Away Points

- The increased FFT frequency resolution helps identify the exact harmonic frequencies, but it also accentuates the appearance of some of the noise. Although the vertical scale is logarithmic (10 dB/div), it is possible to reduce the random noise in the FFT display. One way is to average the input signal. With 512 averages, the noise is much less noticeable.

- Cursors can be used to measure the amplitudes and frequencies of the harmonics in the FFT display:

MSO/DPO5000 Series Procedure

- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Acquisition** tab at the left side of the control window.
- ❑ Press the **Average** button.
- ❑ Double-click on the # of Wfms text box and select **512** averages.
- ❑ Press the front panel **Cursors** button once.
- ❑ Set the Cursor 1 and Cursor 2 Sources to **Math 1**.
- ❑ Using the Multipurpose controls or the mouse, position the cursors on the fundamental and third harmonics, as shown at the left.
- ❑ Select the **Waveform** Cursor Type.
- ❑ Notice the cursor readouts in the lower right corner of the display, showing the absolute and relative frequencies and amplitudes.

FFT of a Complex Waveform

The MSO/DPO5000 Series FFT calculates the frequency domain representation of the entire input signal. If you want to display the frequency domain representation of a portion of a very complex waveform, you need to first adjust the acquisition to capture only that portion of the signal.

For this lab, you need to verify the spectrum of the positive sin(x)/x video test signal. This sin(x)/x pulse occurs on only half of a video line, and you do not want to include the rest of the video signal, such as the video's horizontal and vertical intervals, in the FFT analysis.

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use a standard analog video generator that can provide a frequency response signal. For this example, a Sin(x)/x pulse was used, but a multiburst signal could be used instead. To demonstrate the math, connect the video generator directly to the MSO/DPO5000 Series oscilloscope through a 75 Ohm cable and 75 Ohm feed-through terminator on channel 1.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.

Key Take Away Points

- For this lab, we're using a sin(x)/x video signal, Theory predicts that a sin(x)/x time-domain pulse has a flat frequency response across the entire baseband video bandwidth. This is what the signal looks like:

- By default, the MSO/DPO5000 Series FFT calculates the frequency domain representation of the entire acquired waveform. We want to examine the spectral magnitude of only the sin(x)/x pulse, so we gate the waveform using the acquisition controls. In this case, the FFT analysis is run on only the positive sin(x)/x video signal. As theory would predict, a sin(x)/x time-domain pulse has a flat frequency response across the entire baseband video bandwidth, as shown below:

MSO/DPO5000 Series Procedure

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the **Select** button and the **Video** button.
- ❑ In the **Autoset** section, press the **Lines** button.
- ❑ In the **Trigger On** drop-down menu, select **Line #**.
- ❑ Touch the **Line No** text box to attach the Multipurpose **a** control.
- ❑ Using the Multipurpose **a** control, select line **31**.
- ❑ Set the Horizontal Scale to **5 µs/div**.
- ❑ Press the front panel **Acquire** button.
- ❑ Set the **Sample Rate** to **20 MS/s**. This will also set the record length to **1000** points.
- ❑ Press the **Acquisition** tab on the left side of the control window.
- ❑ Press the **Average** button.
- ❑ Double-click on the **# of Wfms** text box, enter **512**, and press **Enter**.
- ❑ Press the red front panel **Math** button.
- ❑ In the **Spectral Analysis** section, press the **Advanced** button.
- ❑ Press the **Magnitude**, Channels **1**, and **Apply** buttons to enable the spectral magnitude display.
- ❑ Press the **Vert Axis** tab on the left side of the control window.
- ❑ Double-click the **Level** text box and set it to about **0 dB**.
- ❑ Double-click the **Scale** text box and set it to **10 dB/div**.
- ❑ Touch the **Gate Duration** text box.
- ❑ Using the Multipurpose **b** control, use the gating indicators to select just the Sin(x)/x pulse, as shown at the left.

Advanced Math in the MSO/DPO5000 Series

Introduction

In addition to the basic waveform math and spectral analysis capabilities, the MSO/DPO5000 Series provides Advanced Math, which allows the user much more flexibility in specifying the mathematical function.

In this section, we will look at several common applications for advanced waveform math:

- comparison of a signal to a reference
- scaling and offsetting transducer signals
- instantaneous power measurements using pseudo-floating voltage measurements
- video linearity testing
- logarithms
- integration
- creating digital signals
- FFTs of idealized digital signals
- binary math with digital signals

Hints for Using Math with Reference Waveforms

Reference waveforms and live channel waveforms act a little differently in math. Here are a few hints for applying math with references:

- Math is always calculated point-by-point, starting at the left of the waveforms. Even if the reference waveform is displayed with a different horizontal scale and/or position (which can be adjusted in the Reference waveform menu), the math is calculated point-by-point.
- Because math always starts at the left side of the waveform, trigger points are ignored.
- Because math is done on points only, time/div and sample rate differences are ignored.
- Because math is done point-by-point, if the input waveform record lengths are different, the math system will point-replicate to interpolate values so it can operate on equal-length waveforms. (For example, if you are adding a 1k record to a 10k record, each sample in the 1k record will be repeated 10 times.)
- So, to minimize confusion, it is recommended that you acquire reference waveforms exactly the way you plan to acquire the live waveforms, with the same record length, time/div, and trigger setup and position.

If you are going to save or post-process the math waveform, there are a few other details which could be important. Each waveform has a “header” which contains information about the way the waveform was acquired and how it should be displayed (such as vertical and horizontal scales, record length, trigger position, and acquisition mode). Since the math waveform header must contain "something reasonable" under all circumstances, a simple algorithm to select the "main source" is performed by the MSO/DPO5000 Series oscilloscope before each math calculation that goes like this:

- If all source waveforms are live, set main source to the lowest numerical channel,
- else, if one source is live, set main source to that channel,
- else, set main source to the non-live source with the fastest timebase.

Then the math waveform header is formed using information from the main source waveform header, as well as the math parameters.

Comparison of a Signal to a Reference Another common use of waveform math is to compare a live waveform to a stored reference. Although a simple comparison can be done with Dual Wfm Math, this lab shows how a comparison can be done with Advanced Math. As well as a simple introduction to the use of Advanced Math, this technique also opens up possibilities such as comparing pseudo-floating voltage measurements to references.
MSO/DPO5000 Series Setup Procedure ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board. ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board. ❑ Verify the power LED is lit. ❑ Connect a TPP0500 or TPP1000 10x passive probe to channel 1. ❑ Connect the probe ground to **GND** on the demo board. ❑ Connect the channel 1 probe to the **XTALK1** signal on the demo board. ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.

Key Take Away Points

- The MSO/DPO5000 Series' Advanced Math editor allows you to build the math expression out of simple operators and waveforms with the on-screen user interface. The display should look about like this:

- Notice how the math comparison of the live waveform to a reference highlights the positive and negative glitches on the waveform, as shown below:

MSO/DPO5000 Series Procedure

- ❑ Press the front panel **Autoset** button to automatically get a stable display.
- ❑ Press the front panel Save/Recall **Menu** button.
- ❑ Press the **Waveform** button.
- ❑ Select **Ref1** icon.
- ❑ Press the **Save** button. If you see the popup warning "Do you want to overwrite Ref1?", press the **Yes** button.
- ❑ Press the white front panel **R** button to display the reference menu.
- ❑ Press the **Display** button until **On** is selected. Notice that a white reference waveform is displayed.
- ❑ Press the red front panel **M** button.
- ❑ Press the **Editor** button.
- ❑ Enter the math expression "Ch1-Ref1":
  - ❑ Select Channels **1**.
  - ❑ Select the minus sign.
  - ❑ Touch the **Ref** tab and select References **1**.
  - ❑ Press **OK**.
- ❑ Press the **Single** button a few times, noticing the resulting math difference waveforms.

Scaling and Offsetting Transducer Signals

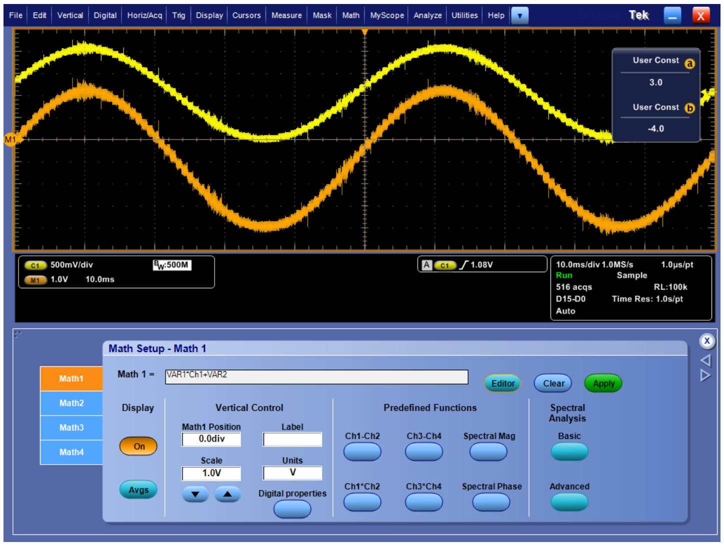
Transducers are electronic devices which output a voltage that represents some physical quantity. Examples include thermocouples, pressure sensors, tachometers, and accelerometers. The output voltages of these devices are often at vertical scale factors or DC offsets which do not provide the desired display on the oscilloscope. Advanced Math provides a simple way to correct the vertical scale and/or offset, often more practical than adjusting the oscilloscope controls or external signal conditioning accessories.

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Connect a TPP0500 or TPP1000 10x passive probe to channel 1.
- ❑ Connect the probe ground to **GND** on the demo board.
- ❑ Connect the channel 1 probe to the **NOISY SINE** (or **DAC_OUT**) signal on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.

Key Take Away Points

- The MSO/DPO5000 Series’ Advanced Math editor allows you to easily scale and offset a channel waveform. The NOISY SINE signal display should look about like this:

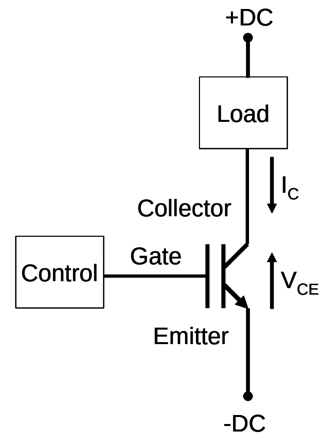


- Notice how the VAR1 and VAR2 controls can be used to provide simple control of numeric factors at high resolution, over a very wide dynamic range.

MSO/DPO5000 Series Procedure

- ❑ Press the front panel **Autoset** button to automatically get a stable display.
- ❑ Set the Horizontal Scale to **10 ms/div**.
- ❑ Press the red front panel **M** button.
- ❑ Press the **Editor** button.
- ❑ Press the **Var** tab in the Primitive section.
- ❑ Enter the math expression “**Var1 * **ch**1 + Var2**”:
  - ❑ Press the **Clear** button.
  - ❑ Press the **Var1** button.
  - ❑ Press the ***** (multiply) button.
  - ❑ Press the Channels **1** button.
  - ❑ Press the **+** (addition) button.
  - ❑ Press the **Var2** button.
  - ❑ Touch the **Var1** text box to attach the Multipurpose controls to Var1 and Var2.
  - ❑ Press the **OK** button.
- ❑ Notice that the Multipurpose controls remain attached to the variables.
- ❑ Double-click on the Var1 readout in the upper right corner of the display. With the keypad, type **2** and press the **Enter** button.
- ❑ Press the Multipurpose **a** control until the Fine LED next to the control is lighted.
- ❑ With the Multipurpose **a** control, change VAR1 to **3.0**.
- ❑ Press the Multipurpose **b** control until the Fine LED next to the control is off.
- ❑ With the Multipurpose **b** control, set VAR2 to **-4.0**.

Instantaneous Power Measurements Using Pseudo-floating Voltage Measurements



Another common oscilloscope measurement which requires simple math is measurement of instantaneous power. One specific measurement is the power dissipation in the switching device in a switch-mode power supply, as shown in the diagram at the right, an Insulated Gate Bipolar Transistor (IGBT). Measurements on a MOSFET would be similar, but the upper terminal is called the Drain and the lower terminal is called the Source.

As with many other power supply signals, the signals you are looking at are not referenced to ground. In fact, there is no ground reference on this power demo board. Therefore, you will be making "floating" measurements. But because you will be using math to measure these floating voltages, the measurements are sometimes called "pseudo-floating" or "A-B" measurements.

Although V_{CE} is usually best measured with an active differential probe and I_C is usually best measured with a current probe, you don't always have these probes available. Advanced Math provides another way to make this instantaneous power measurement with standard passive voltage probes, using the Pseudo-floating technique described in an earlier lab.

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the power demo board. Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Connect a TPP0500 or TPP1000 passive probe to each of the four analog channel inputs.
- ❑ To measure the floating voltage across the switching device, you will subtract channel 2 from channel 1 to calculate the voltage:
  - ❑ Connect the channel 1 probe to the **Collector** or **Drain** test point.
  - ❑ Connect the channel 2 probe to the **Emitter** or **Source** test point.
  - ❑ Connect each of the probe grounds to the **Neutral** test points.
- ❑ To measure the current flowing through the switching device (which equals the current flowing through the 300 Ohm load), you will measure the voltage across the load (again, a floating measurement) and divide by the load resistance (according to Ohm's Law).
  - ❑ Connect the channel 3 probe to the high side of the load (**+DC** test point).
  - ❑ Connect the channel 4 probe to the low side of the load (**Collector** or **Drain** test point).
  - ❑ Connect each of the probe grounds to the **Neutral** test points.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **2**, **3**, and **4** buttons to turn on channels 2, 3, and 4.
- ❑ Using the front panel vertical **Position** controls, place the ground references for all four analog channels near the center of the display.
- ❑ Using the front panel vertical scale controls, scale the signals so they occupy at least half of the screen vertically, and position them so they overlap.
- ❑ Using the front panel vertical scale and position controls, scale the signals so they occupy about half of the screen vertically, keeping all of the scale factors set to the same values.

Key Take Away Points

- Advanced math allows simple instantaneous power measurements to be made, using only passive probes, as shown below:

- In this case, the differential voltage across the switching device is multiplied by the current flowing through it. The current is measured by dividing the differential voltage across the load by the 300Ω load resistance.
- As previously noted, the performance of the pseudo-floating measurements is limited, but for many debug applications it is adequate and convenient.)

MSO/DPO5000 Series Procedure

- ❑ Press the front panel **Acquire** button.
- ❑ Press the **Acquisition** tab and select the **Hi Res** Acquisition Mode.
- ❑ Press the red front panel **MATH** button.
- ❑ Select the math **Editor**.
- ❑ Enter the math expression "**(**Ch**1 –** Ch**2) * ((**Ch**3 -** Ch**4) / 300)**"":
  - ❑ Press the **Clear** button.
  - ❑ Press the left parenthesis button.
  - ❑ Press the Channels **1** button.
  - ❑ Press the minus button.
  - ❑ Press the Channels **2** button.
  - ❑ Press the left parenthesis button.
  - ❑ Press the ***** (multiply) button.
  - ❑ Press the left parenthesis button twice.
  - ❑ Press the Channels **3** button.
  - ❑ Press the minus button.
  - ❑ Press the Channels **4** button.
  - ❑ Press the left parenthesis button.
  - ❑ Press the **/** (divide) button.
  - ❑ Type in "**300**".
  - ❑ Press the left parenthesis button.
  - ❑ Press the **OK** button.

Video Linearity Testing

A common video test is to drive a piece of video equipment with a staircase or linear ramp test signal and differentiate the output signal to identify any linearity distortion in the equipment. These distortions might be analog in nature, such as clipping in an amplifier, or quantization errors or calculation errors in digital video processing equipment.

Because differentiation is done by subtracting adjacent samples (output[n] = input[n-1] – input[n]), it is usually best to lower the number of samples so the differences stand out above the noise. In this case, we set the record length to 1000 points and average the signal to minimize random noise so the signal characteristics will be more visible.

MSO/DPO5000 Series Setup Procedure

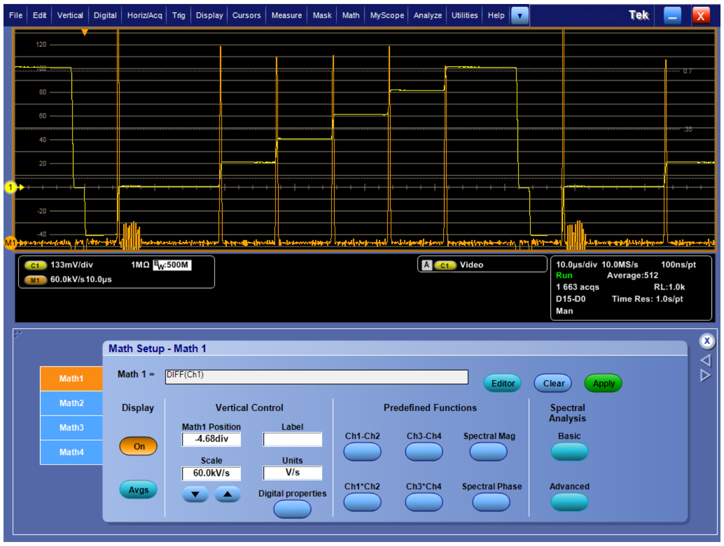
- For this lab, use a standard analog video generator that can provide a linearity signal. For this example, a 5-step linearity staircase signal was used, but a 10-step staircase or luminance ramp signal could be used instead. To demonstrate the math, connect the video generator directly to the MSO/DPO5000 Series oscilloscope through a 75 Ohm cable and 75 Ohm feed-through terminator on channel 1.
- Press the front panel **Default Setup** button to set the oscilloscope to a known state.

Key Take Away Points

- Notice how the math waveform allows you to see very minor differences in the heights of each step, often caused by non-linearities in video equipment:

MSO/DPO5000 Series Procedure

- ❑ Press the front panel Trigger **Menu** button.
- ❑ Press the **Select** button and the **Video** button.
- ❑ In the **Autoset** section, press the **Lines** button.
- ❑ In the **Trigger On** drop-down menu, select **Line #**.
- ❑ Touch the **Line No** text box to attach the Multipurpose **a** control.
- ❑ Using the Multipurpose **a** control, select line **31**.
- ❑ Set the Horizontal Scale to **5 µs/div**.
- ❑ Press the front panel **Acquire** button.
- ❑ Set the **Sample Rate** to **20 MS/s**. This will also set the record length to **1000** points.
- ❑ Press the **Acquisition** tab on the left side of the control window.
- ❑ Press the **Average** button.
- ❑ Double-click on the **# of Wfms** text box, enter **512**, and press **Enter**.

Key Take Away Points	MSO/DPO5000 Series Procedure
• Notice how the math waveform allows you to see very minor differences in the heights of each step, often caused by non-linearities in video equipment: 	❑ Press the red front panel **Math** button. ❑ Press the **Editor** button. ❑ Press the **Derivative dy/dt** button, the Channels **1** button, the right parenthesis button, and the **OK** button. ❑ Adjust the Math 1 **Position** and **Scale** controls so the spikes of the derivative expression fill most of the display, as shown at the left. ❑ Notice how sensitive this math function is to slight differences in the heights of the steps.

Integration without Accumulating Offsets

Integration is a mathematical technique to find the area under a curve. The integration function always starts at a zero value, and calculates the integral by adding new input data points to the current value of the integral (output[n] = output[n-1] + input[n]).

One common application is to calculate energy delivered by a signal by integrating the instantaneous power waveform over time. However, over time, any offsets in the signal are accumulated. In some cases, the user would like to be able to ignore these offsets.

The Advanced Math system allows the use of waveform measurements to be used as scalar arguments. One such use is with integration, where you can use an equation like Integral(ch1 – mean(ch1)).

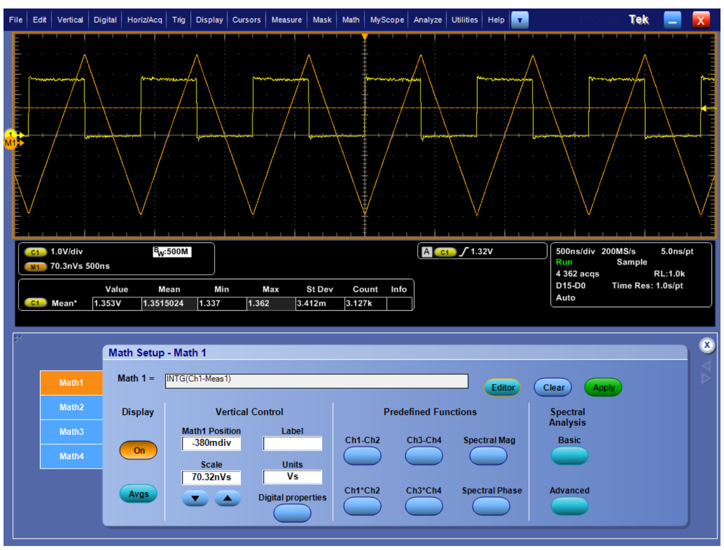
MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Connect a TPP0500 or TPP1000 10x passive probe to channel 1.
- ❑ Connect the probe ground to **GND** on the demo board.
- ❑ Connect the channel 1 probe to the **CNT_OUT0** signal on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **Autoset** button to automatically get a stable display.

Key Take Away Points

- Notice how the integral continues to accumulate the offsets in the input signal across the display (because the input signal has a DC offset):

- Although there are other ways to remove the offset, advanced math can use the automatic measurement system to calculate the value for each waveform and subtract it out:



MSO/DPO5000 Series Procedure

- ❑ Press the front panel **Measure** button.
- ❑ Press the **More** and the **Mean** measurement buttons.
- ❑ Press the red front panel **MATH** button.
- ❑ Press the **Editor** button.
- ❑ Enter the math expression "**INTG(C**h**1 – Meas1)**".
  - ❑ Press the **Clear** button.
  - ❑ Press the **Integral** button.
  - ❑ Press the Channels **1** button.
  - ❑ Press the **-** (minus) button.
  - ❑ Click on the **Meas** tab in the Primitive section.
  - ❑ Press the **1** (Mean(Ch1) button.
  - ❑ Press the left parenthesis button.
  - ❑ Press the **OK** button.

Tektronix

Creating Digital Signals – The Logic of Greater Than (or Less Than)

When working with digital signals, you sometimes want to see all of the analog characteristics. But when you don't, Advanced Math allows you to transform them into ideal binary waveforms for further analysis.

The Advanced Math system relational operators are >, <, >=, and <=. These operators compare a waveform to a scalar value (a fixed number, a variable value you specify, or a measurement value) and output a digital signal which is a digital high when the equation is true and a digital low when the equation is false. The simplest is a digital comparator such as "ch1 > 2" which creates a digital high signal whenever channel 1 exceeds 2.0 V.

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Connect a TPP0500 or TPP1000 10x passive probe to channel 1.
- ❑ Connect the probe ground to **GND** on the demo board.
- ❑ Connect the channel 1 probe to the **XTALK1** signal on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Adjust the Vertical and Horizontal Scale and Position and Trigger Level to get a stable display.

Key Take Away Points

- Notice that the math waveform is the digital representation of the analog channel 1 signal. In this example, the glitch crosses through the threshold value and is interpreted as a transition in the digital signal, as it would in the hardware receiver in the circuit:

MSO/DPO5000 Series Procedure

- ❑ Press the front panel **MATH** button.
- ❑ Select the math **Editor**.
- ❑ Enter the math expression "**C**h**1 > VAR1**".
  - ❑ Press the **Clear** button.
  - ❑ Press the Channels **1** button.
  - ❑ Press the **>** (greater than) button.
  - ❑ Click on the **Var** tab in the Primitive section.
  - ❑ Press the **Var1** button.
  - ❑ Touch the **Var1** text box to attach the Multipurpose **a** control to this variable.
  - ❑ Press the **OK** button.
- ❑ With the Multipurpose a control, set **VAR1** to the desired digital threshold value, such as 2V (**2.0**).
- ❑ Vary the threshold value and notice how the glitches on the signal are interpreted as different logic threshold levels.

FFTs of Idealized Digital Signals

FFTs provide the frequency domain representation of the input signal. In the case of a real square wave, the FFT display includes the spectral representation of all of the signal components, both the desired square wave as well as the noise and amplitude modulation of the signal. In some cases, this is desirable, but in others you are really most interested in the spectrum of the idealized square wave.

The standard math FFT allows you to display the spectral representation of any of the analog channels or reference waveforms. The FFT function in advanced math allows an arbitrarily complex argument. (However, the FFT function itself cannot be part of an argument, so it must be the outer-most function in a complex math equation.)

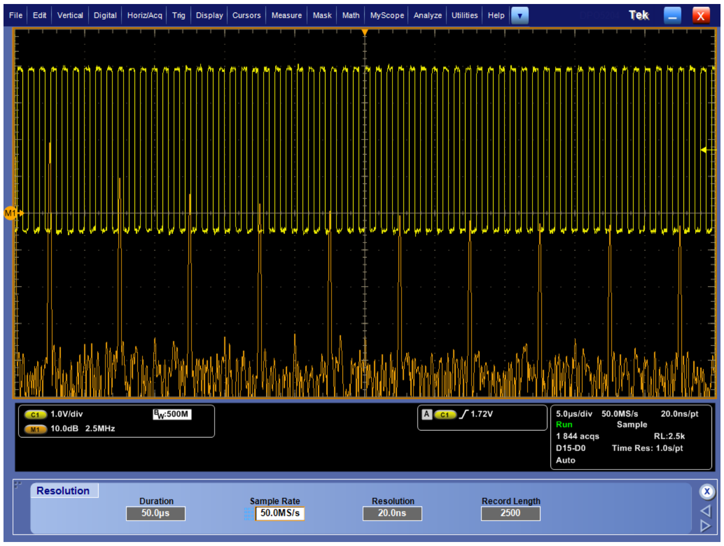
As seen in the last lab, the Advanced Math system allows the creation of idealized digital waveforms. These waveforms can also be analyzed by the FFT function.

MSO/DPO5000 Series Setup Procedure

- ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Connect a TPP0500 or TPP1000 10x passive probe to channel 1.
- ❑ Connect the probe ground to **GND** on the demo board.
- ❑ Connect the channel 1 probe to the **CNT_CLK** signal on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **Autoset** button to automatically get a stable display.

Key Take Away Points

- This is the FFT of the real square wave, from earlier in the lab:



- Notice how much "cleaner" the FFT display of the idealized square wave is:

MSO/DPO5000 Series Procedure

- ❑ Adjust the Horizontal Scale to **5 µs/div.**
- ❑ Select **Horiz/Acq->Resolution….**
- ❑ Double-click on the Sample Rate text box and set the value to **50 MS/s**.
- ❑ Press the front panel **MATH** button.
- ❑ Select the math **Editor**.
- ❑ Enter the first math expression "**C**h**1 > VAR1**".
  - ❑ Press the Channels **1** button.
  - ❑ Press the **>** (greater than) button.
  - ❑ Click on the **Var** tab in the Primitive section.
  - ❑ Press the **Var1** button.
  - ❑ Double-click on the Var1 text box and type in "2" and Enter to set the threshold value to 2V and to attach the Multipurpose **a** control to this variable.
  - ❑ Press the **OK** button.
- ❑ Set the Math1 Vertical **Scale** to **1 unit/div**.
- ❑ Click on the **Math2** tab at the left of the control window.
- ❑ Select the math **Editor**.
- ❑ Enter the second math expression "SpectralMag(Math**1)**".
- ❑ Set the Math2 Vertical **Scale** to **10 dB/div** and position the Math2 waveform on the display.

Binary Math with Digital Signals

Advanced Math provides other operators that work with idealized digital waveforms, allowing you to do other analysis. The Advanced Math system binary operators are !, ==, ≠, ||, and &&.

- The **!()** operator inverts the logic of the expression in the parentheses. For example, !(ch1 > 1.6) inverts the idealized digital waveform with a 1.6V digital threshold.
- The **||** operator provides the logical OR function on the preceding and following arguments. For example, (ch1 < 0) || (ch1 > 5) provides a high output whenever the channel 1 signal is outside the range of 0V to 5V.
- The **&&** operator provides the logical AND function on the preceding and following arguments. For example, (ch1 >= 1) && (ch1 <= 2) provides a high output whenever the channel 1 signal is between 1.0V and 2.0V.

MSO/DPO5000 Series Setup Procedure

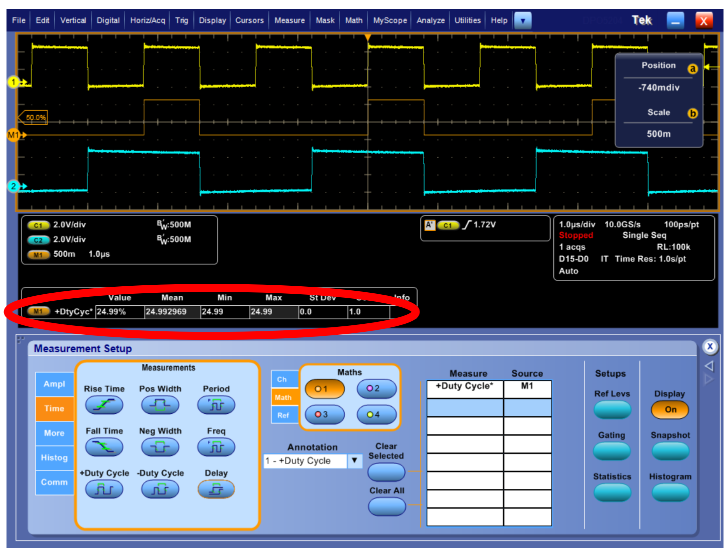
- ❑ For this lab, use the DPO Demo 3 or DPO Demo 2 board.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Connect TPP0500 or TPP1000 10x passive probes to channels 1 and 2.
- ❑ Connect the channel 1 probe to the **CNT_OUT0** signal on the demo board.
- ❑ Connect the probe ground to **GND** on the demo board.
- ❑ Connect the channel 2 probe to the **CNT_OUT1** signal on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel channel **2** button to turn on channel 2.
- ❑ Press the front panel **Autoset** button to automatically get a stable display.

Key Take Away Points	MSO/DPO5000 Series Procedure

Key Take Away Points

- Notice that the math waveform is the logical AND of the digital representations of the analog channel 1 and 2 signals:

- Now that you have a math waveform, you can make measurements on it. For example, you can measure the resulting duty cycle:



MSO/DPO5000 Series Procedure

- ❑ Press the front panel **MATH** button.
- ❑ Double-click on the Math 1 = text box.
- ❑ Enter the math expression "**(**Ch**1 > VAR1) && (**Ch**2 > VAR2)**".
- ❑ Press the **Apply** button to complete the equation and calculate the result.
- ❑ Position and scale the math waveform on the display for easy viewing.
- ❑ Select the math **Editor**, click on the **Var** tab in the Primitive section, and click on the **Var1** text box to attach the Multipurpose controls to the variables.
- ❑ With the Multipurpose controls, set the digital threshold values to about 2V.
- ❑ Then, press the front panel **Measure** button.
- ❑ Press the **Time** tab at the left side of the control window.
- ❑ Press the **+ Duty Cycle** button.

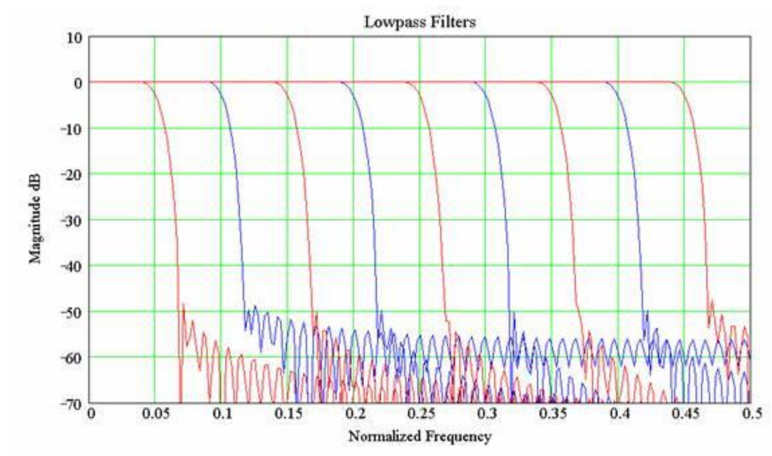
User-defined Arbitrary Filters

Advanced Math also provides the ability to digitally filter a signal with a user-defined arbitrary FIR filter.

The oscilloscope comes with a library of standard filters, found in the **C:\Users\[Username]\Tektronix\TekScope\Math Arbitrary Filters\<filename>** directory. The filename of each filter identifies its type as low-pass, high-pass, etc., and also identifies its normalized cutoff frequency (relative to the real-time sample rate) or other identifying factors. The precise magnitude characteristics of these filters are shown in the following graphs. These are all linear phase filters.

Low Pass Filters

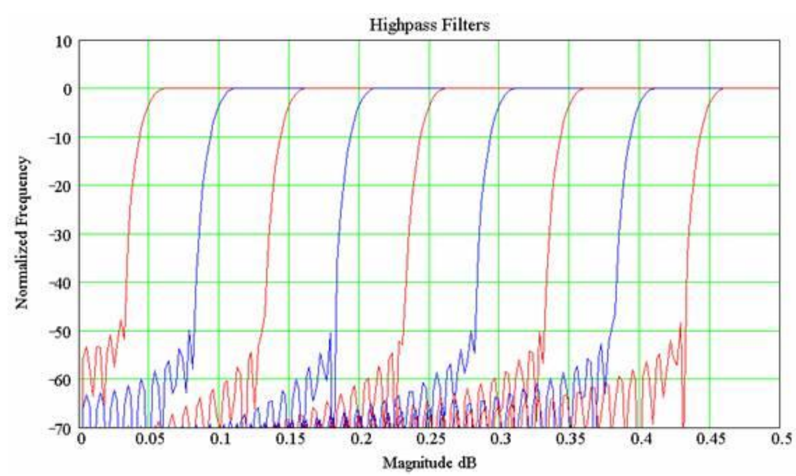
The following graphs show the available set of low pass filters. Their normalized frequency response is shown from 0 to ½ the sample rate. These filters will operate at any sample rate with cutoff frequency scaled as shown below on the graphs. The filters have normalized cutoff frequencies of 0.05, 0.1, 0.15, 0.20, 0.25, 0.3, 0.35, 0.40, and 0.45. Stop band rejection is typically between –50 and –60 dB.



Frequency response of the available low-pass filters

High Pass Filters

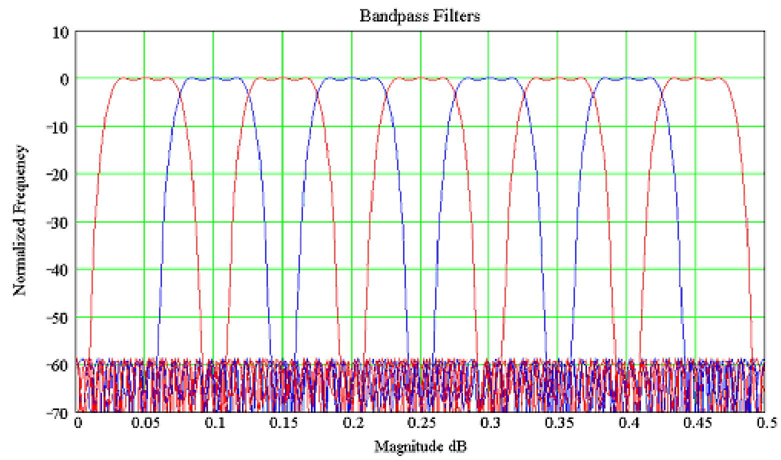
The following graphs show the available set of high pass filters. Their normalized frequency response is shown from 0 to ½ the sample rate. These filters will operate at any sample rate with cutoff frequency scaled as shown below on the graphs. The filters have normalized cutoff frequencies of 0.05, 0.1, 0.15, 0.20, 0.25, 0.3, 0.35, 0.40, and 0.45. Stop band rejection is typically between –50 and –60 dB.



Frequency response of the available high-pass filters

Band Pass Filters

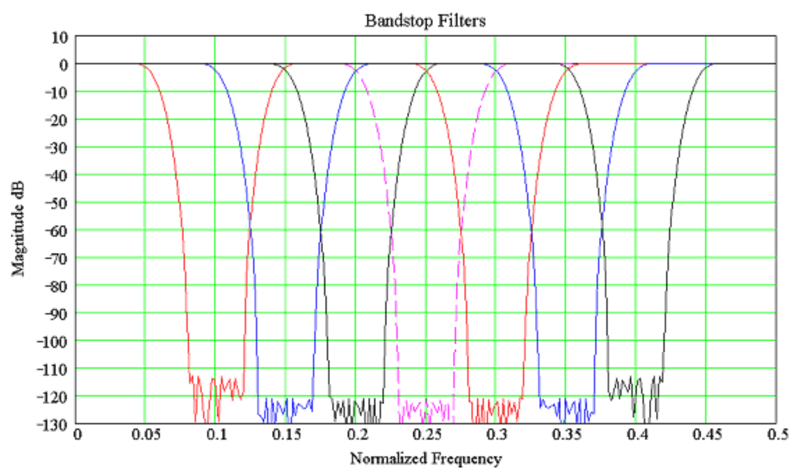
Each filter has a bandwidth of 0.05 times the sample rate. They will operate at any sample rate. The available center frequencies are 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, and 0.45. Stop band attenuation is approximately -60 dB and pass band ripple is around 1dB.



Frequency response of the available band-pass filters

Band Stop Filters

Each filter has a bandwidth of 0.1 times the sample rate. They will operate at any sample rate. The available center frequencies are 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, and 0.40. Stop band attenuation is approximately -110 dB, however, the noise floor of the oscilloscope will not allow for that depth. With an FFT and long record length, and averaging turned on, one can approach noise floors in the -110 dB range on an 8-bit oscilloscope. However, the oscilloscope will have some spurious signals above that floor. This is possible because the FFT is an average calculation internally and the averaging function increases the vertical bits of resolution.

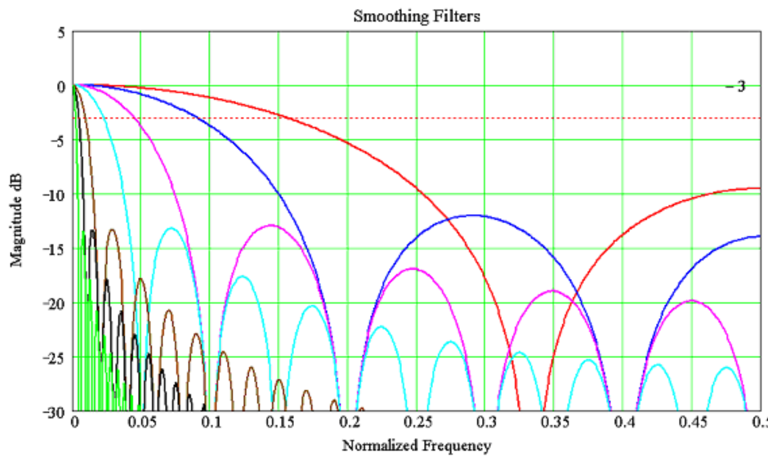


Frequency response of the available band-stop filters

Smoothing Filters

These are sometimes called box-car filters. They simply average together adjacent samples along the time record. The filter coefficients for these filters are all equal to 1/ M where M is the length of the filter. The name of the files indicates the length of the smoothing filter.

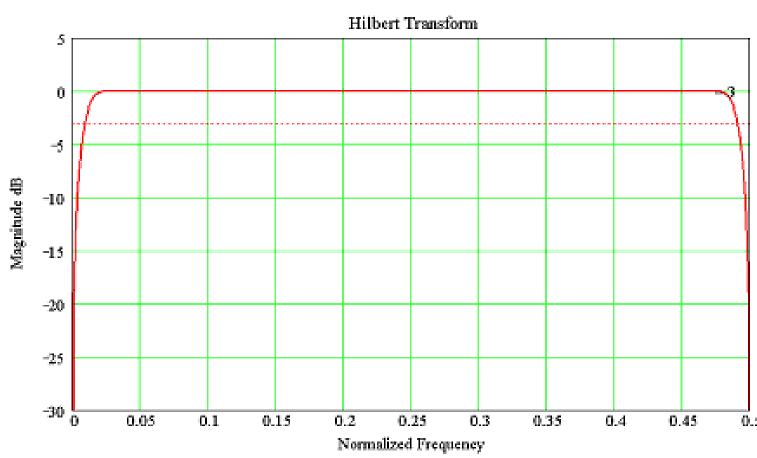
Smoothing filters are low pass filters with a somewhat less than optimal stop band characteristic. However, they are commonly used to remove high frequency noise from a displayed trace. Take care in using to insure that the pass band of the signal you are filtering is well within the pass band of the filter you choose. That will insure that only noise is removed. Lengths of 3, 5, 10, 20, 50, 100, and 200 are provided in the library. The red trace is for filter length 3, followed by blue trace at 5, followed by magenta trace for 10, and so on.



Frequency response of the available smoothing filters

Hilbert Transform Filter

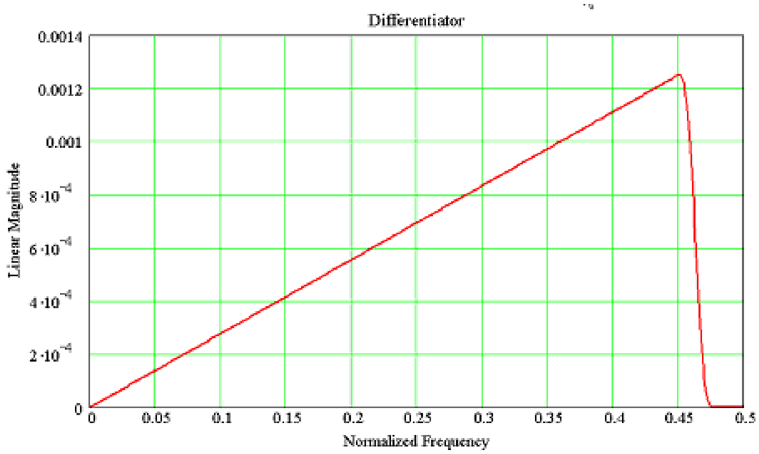
The ideal Hilbert transform filter has a gain of one at all frequencies and shifts the phase of all frequencies by 90 degrees. This type of filter is one of the types that may be specified in the Remez Exchange algorithm. This filter departs from its desired behavior in the frequency range of 0 to 0.025 times the sample rate and also in the range of about 0.475 to 0.5 times the sample rate. This type of filter can be used to create quadrature signals over a wide frequency range. The filename for this filter is HilbertTransform90PhaseShift.flt.



Frequency response of the Hilbert Transform filter

Differentiator

The ideal differentiator is a high pass filter that shifts phase by 90 degrees and its frequency response would be linear from DC to 0.5. Since this is not easily realized, the filter provided in the library makes a good differentiator for the frequency range of DC to 0.45.



Frequency response of the differentiator filter

Filter File Format

Filters are defined in text files on the oscilloscope, where a single file format allows the user to specify a different set of coefficients for each sample rate that the filter operates at. If the desired sample rate is not in the file list, then the filter will not be applied to the data. Comments are preceded by # symbol. The file format also allows the user to specify that the set of filter coefficients is normalized. This allows the same set of filter coefficients to operate at all sample rates. The ASCII file format is specified as follows:

< sampleRate > coef1, coef2, …. coefN

Each set of filter coefficients in a file are specified in one row preceded by the sample rate value at which that set will operate. If the user specifies the @ symbol for the sample rate then the filter will operate at all sample rates. If the @ symbol is specified then there should only be one set of filter coefficients in the file. However, the user may have other rows with sample rates specified and they will be ignored. There will be a separate row for each sample rate the filter is to operate at. Each row may have a different number of coefficients with a maximum of 1000. The file may contain up to 20 rows.

An example of file content for a normalized filter is the smooth5.flt file:

@ 0.2, 0.2, 0.2, 0.2, 0.2

An example of a filter that is setup to operate at a specific sample rate is given as follows. This is the contents of a file named 200MHz_mult_sample_rates.flt that is included in the library directory on the oscilloscope.

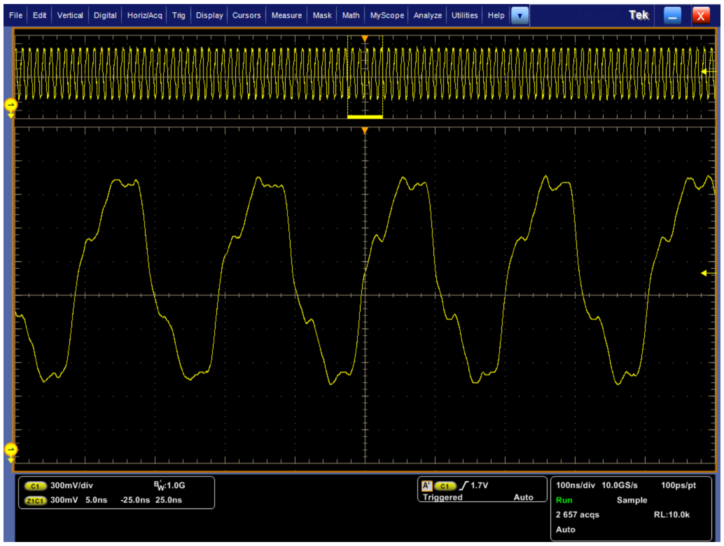
```
#This is a 4th order Bessel-Thompson low pass filter.
#200MHz bandwidth, will operate at any of the following sample rates:
# 40 GS/s, 20 GS/s, 10 GS/s, 5 GS/s, 2.5 GS/s, 1 GS/s, 500 MS/s
5e8; 1.968e-007,1.008,-0.00978,0.002267,-0.0002208,1.643e-005,-1.397e-006,1.434e-007
1e9; 9.524e-008,0.3899,0.4877,0.1304,-0.004733,-0.004566,………………………….
2.5e9; 3.868e-008,0.01885,0.1081,0.1982,0.2284,0.1981,………………………
5e9; 1.935e008,0.0007332, 0.009428, 0.02874, 0.05408, 0.07921, ……………………….
1e10; 9.673e-009,3.445e-006,0.0003666,0.001831,0.004714,0.008978,0.01437,0……………….
2e10; 4.837e-009, 1.657e-008, 1.723e-006, 4.274e-005, 0.00018334-009, ……………….
4e10; 2.418e-009, -3.524e-009, 8.284e-009, -1.795e-008,8.613e-007, ……………….
```

MSO/DPO5000 Series Setup Procedure

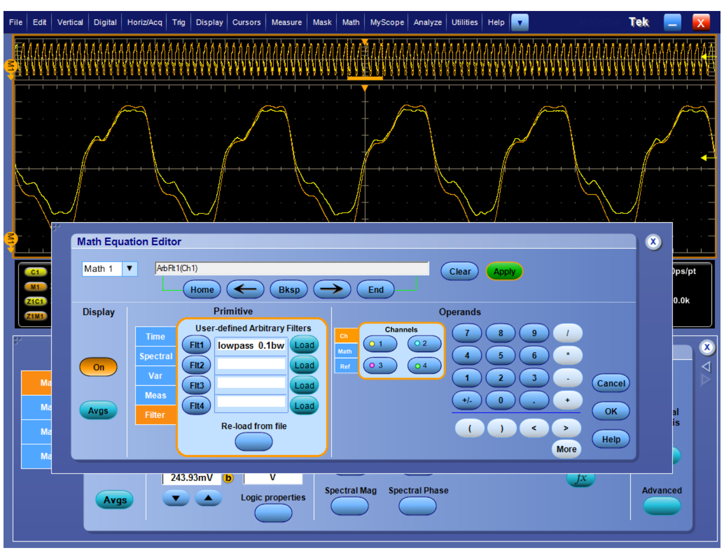
- ❑ For this lab, use the DPO Demo 3 board.
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the DPO Demo 3 board and verify the power LED is lit.
- ❑ Connect a TPP1000 or TPP0500 10x passive probe to channel 1.
- ❑ Connect the channel 1 probe to the **SS_CLOCK** signal on the demo board.
- ❑ Connect the probe ground to **GND** on the demo board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Press the front panel **Autoset** button to automatically get a stable display and press OK.
- ❑ Adjust the Vertical **Scale** and **Position** controls until the clock signal fills most of the screen vertically.

Key Take Away Points

- The 100 MHz spread-spectrum clock signal SS_CLOCK should look about like this:



- The harmonics on the 100 MHz clock signal (primarily the 3rd and 5th harmonics, at 300 and 500 MHz, respectively) distort the shape of the fundamental 100 MHz sine wave. One way to view just the fundamental signal is to low-pass filter the signal and remove the harmonic content.
- You can use the math equation editor to build a math waveform based on the standard arbitrary filters included with the oscilloscope. In this case, we are going to use a low-pass FIR filter with a corner frequency at 10% of the sample rate to remove the harmonics from the clock signal:



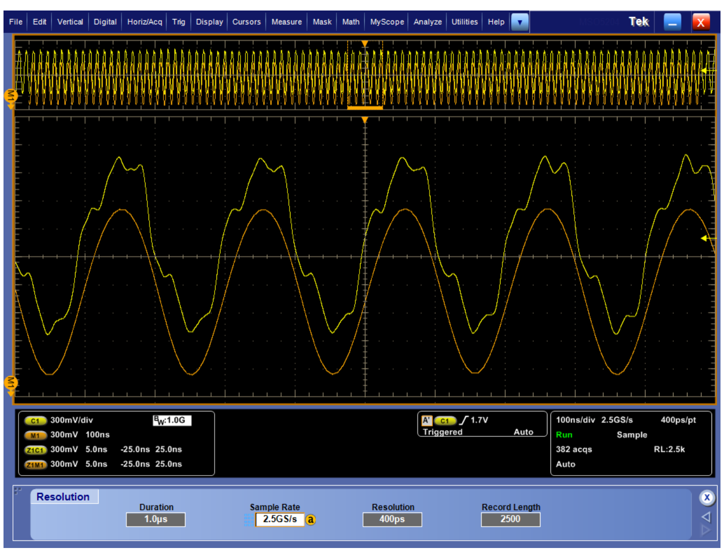
MSO/DPO5000 Series Procedure

- ❑ Set the Horizontal **Scale** to **100 ns/div**.
- ❑ Select **Horizontal->Horizontal Modes->Real Time Only**.
- ❑ Turn on zoom and select a Zoom Factor of about 10-20 so you can clearly see a few cycles of the clock signal.
- ❑ Select **Math -> Math Setup….**
- ❑ Press the **Editor** button.
- ❑ Click on the **Filter** tab.
- ❑ Click on the **Load** button at the top of the User-defined Arbitrary Filters table.
- ❑ Double-click on the **LowPass-Norm** folder and select the **lowpass_0.1bw.flt** filter file. This selects a low-pass FIR filter that has a corner frequency at 10% of the sample rate.
- ❑ Press the **Flt1 button** to define the math expression as this filter applied to the channel 1 signal.
- ❑ Press the green **Apply** button.
- ❑ Press the **OK** button to close the equation editor control window.
- ❑ Set the Math1 **Scale** to match the channel 1 Vertical Scale setting.
- ❑ Click on the white **X** in the upper right corner of the control window to close it.

Key Take Away Points

- Here is the user-defined arbitrary filter math waveform. The corner frequency of the low-pass filter is 10% of the sample rate. In the following example, the filter bandwidth is 1 GHz (so the system bandwidth is actually being limited by the analog bandwidth of the probe and oscilloscope, in this case). The orange math signal looks about the same as the yellow channel 1 signal, like this:

- When the sample rate is reduced to 2.5 GS/s, the bandwidth of the FIR filter is reduced to 250 MHz. This corner frequency is below the frequency of the 3rd harmonic but above the 100 MHz fundamental frequency of the clock signal:

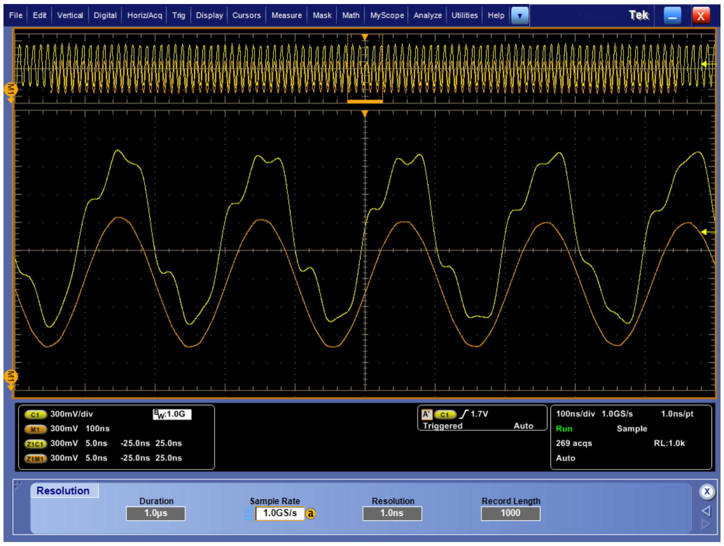


MSO/DPO5000 Series Procedure

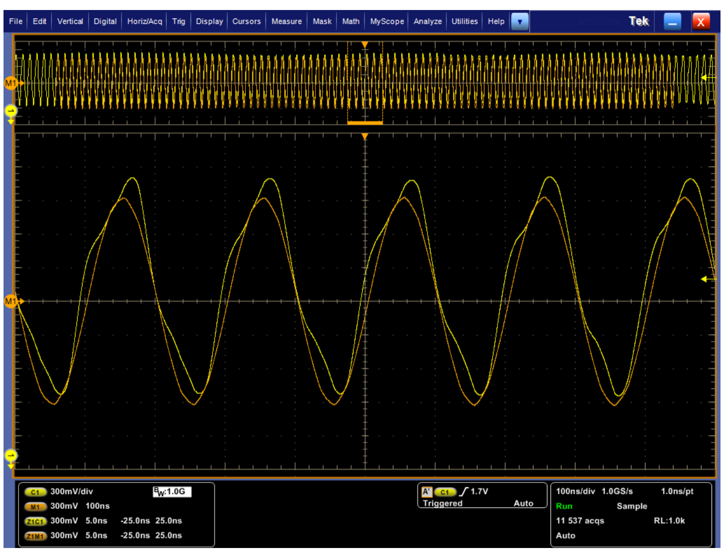
- ❑ Select **Horiz/Acq->Resolution…**.
- ❑ Click on the Sample Rate text box to attach the Multipurpose **a** control.
- ❑ Turn the Multipurpose **a** control fully clockwise to select the maximum real-time sample rate.
- ❑ Notice that the shape of the math waveform is the same as the clock signal.
- ❑ Gradually turn the Multipurpose **a** control counter-clockwise until the sample rate has been reduced to about **2.5 GS/s**.
- ❑ Notice that the filtered signal now looks sinusoidal, and yet the amplitudes of the waveforms are about the same.

Key Take Away Points

- When the sample rate is further reduced to 1 GS/s, the bandwidth of the FIR filter is reduced to 100 MHz. Remember that the corner frequency is the frequency at which the signal is attenuated by 3 dB, or about 30%. When the 100 MHz fundamental frequency of the clock signal is aligned with the corner frequency of the FIR filter, notice that the amplitude has been reduced:

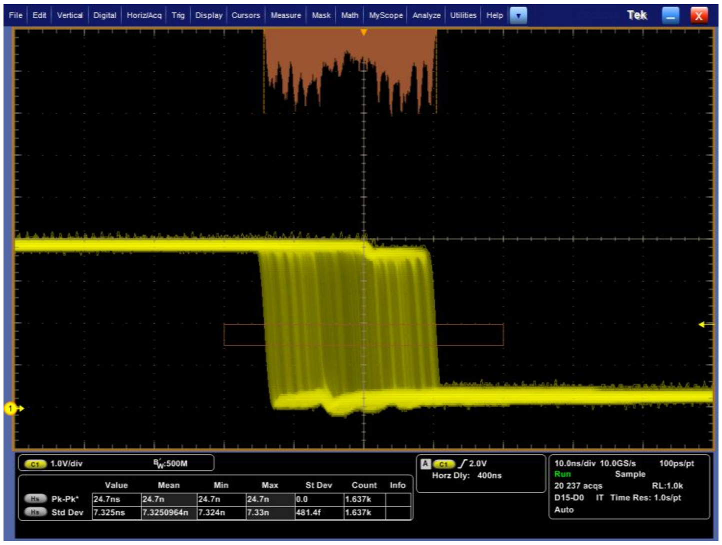


- But for a signal like this, a band-pass filter would also be an appropriate choice to remove harmonics, as well as noise and DC offset from the clock signal.
- At a sample rate of 1 GS/s, the band-pass filter is centered on the 100 MHz clock fundamental. Notice that the harmonics have been removed, but also notice that the DC offset of the signal has been removed (the signal is now centered around the ground reference point):



MSO/DPO5000 Series Procedure

- ❑ Turn the **Resolution** control counter-clockwise until the sample rate has been reduced to **1 GS/s**.
- ❑ Notice that the filtered signal still looks sinusoidal, but the amplitude of the filtered waveform is now substantially reduced.
- ❑ Select **Math -> Math Setup….**
- ❑ Press the **Editor** button.
- ❑ Press the **Clear** button.
- ❑ Click on the **Filter** tab.
- ❑ Click on the **Load** button at the top of the User-defined Arbitrary Filters table.
- ❑ Navigate to the **BandPass-Norm** folder and select the **bandpass_0.05bw_0.1Center.flt** filter file. This selects a band-pass FIR filter that has a center frequency at 10% of the sample rate and a bandwidth of 5% of the sample rate.
- ❑ Press the **Flt1 button** to define the math expression as this filter applied to the channel 1 signal.
- ❑ Press the green **Apply** button.
- ❑ Press the **OK** button to close the equation editor control window.
- ❑ Set the Math1 **Scale** to match the channel 1 Vertical Scale setting.
- ❑ Click on the white **X** in the upper right corner of the control window to close it.



Equipment List
One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
One TPP0500 or TPP1000 Passive Probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: screen shots in this lab were made with the DPO Demo 3 board]

Tektronix

Overview of Waveform Histograms

A histogram is a graphical display which shows the density or relative proportions of cases of a varying quantity falling into each of several bins or categories. For example, in a Digital Phosphor Oscilloscope, the waveform intensity at each picture element (or pixel) on the display represents the relative frequency-of-occurrence. In this way, the brightness of the pixels is a statistical representation of a time-varying signal.

Waveform histograms show the density of the waveform samples in a row or column of pixels ("hits") in a specified area on the oscilloscope display. The user specifies the portion of the displayed waveform to be analyzed by positioning a rectangle or box on the display.

A vertical histogram shows the number of waveform samples which occur at each of the 252 digitizer levels on the display. The box specifies the waveform samples that are analyzed.

A horizontal histogram shows the number of waveform samples which occur in each of the 1000 pixel columns on the display. The box specifies the waveform samples that are analyzed.

In either case, the waveform histogram data is normalized such that the display of the bin with the highest number of hits is scaled to a specified number of divisions tall. The default scaling is 2 divisions, but the scale can vary from 0.1 to 10 divisions. The default display format scales the histogram data linearly, but a logarithmic display format is also available which can improve visibility of details of bins with few hits.

In addition to the waveform histogram display, automatic measurements on the histogram data are available:

Wfm Ct: Displays the number of waveforms that contributed to the histogram.

Hts in Box: The number of samples or hits within the histogram box or on its boundaries.

Peak Hits: The number of samples in the bin that contains the most hits.

Median: The middle histogram data value, where half of all histogram data points are less than this value and half are greater than this value.

Max: The voltage of the highest nonzero bin in vertical histograms or the time of the right-most nonzero bin in horizontal histograms.

Min: The voltage of the lowest nonzero bin in vertical histograms or the time of the left-most nonzero bin in horizontal histograms.

Pk-to-pk: Vertical histograms display the voltage of the highest nonzero bin minus the voltage of the lowest nonzero bin. Horizontal histograms display the time of the right-most nonzero bin minus the time of the left-most nonzero bin.

Mean: The average of all histogram data points within or on the histogram box.

Std Dev: The standard deviation (Root Mean Square deviation) of all histogram data points within or on the histogram box.

μ±1σ: The % of the hits in the histogram that are within one standard deviation of the histogram mean.

μ±2σ: The % of the hits in the histogram that are within two standard deviations of the histogram mean.

μ±3σ: The % of the hits in the histogram that are within three standard deviations of the histogram mean.

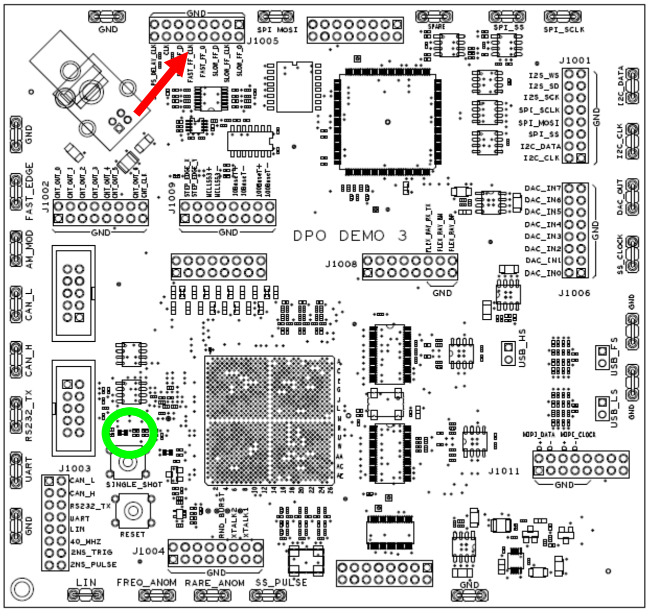
Objectives

- Obtain a basic understanding of waveform histogram displays and automatic measurements on histogram data.
- Learn how to set up and demonstrate waveform histograms with an MSO/DPO5000 Series oscilloscope.

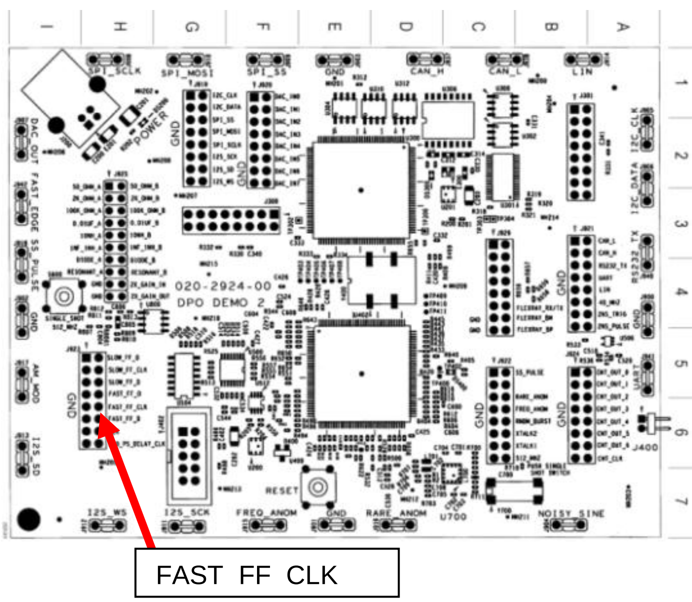
MSO/DPO5000 Series Lab Setup

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a FAST_FF_CLK signal which we will use for this lab. This is a 1.25 MHz signal with a slow variation in duty cycle. (The timing of the falling edges vary at about a 1 Hz rate.)



- The DPO Demo 2 board (020-2924-XX) also has a FAST_FF_CLK signal:



Demo Board Procedure

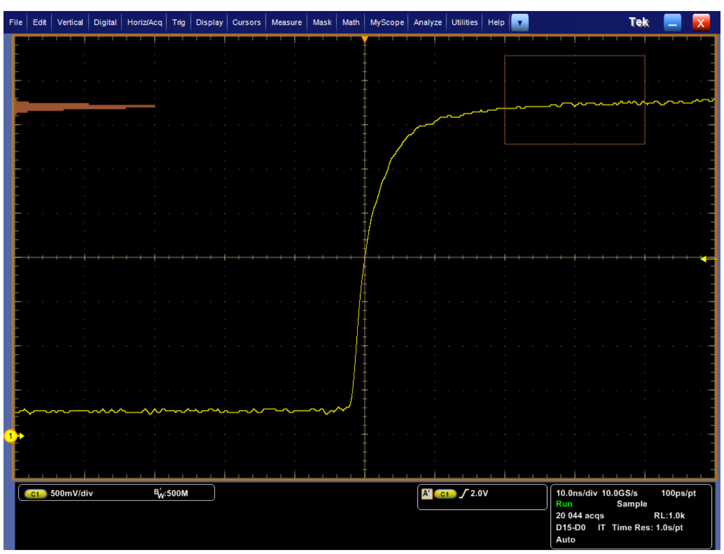
- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- ❑ Attach the probe ground to the **GND** test point on the test board.
- ❑ Connect the probe tip to the **FAST_FF_CLK** test point on the test board.

Vertical Waveform Histograms

Key Take Away Points

- Vertical waveform histograms allow you to evaluate the distribution of voltage values on a signal over time. For example, on this digital signal, the “high” voltage is approximately 4V, but there is some noise superimposed on the signal, as shown below:

- The vertical histogram display provides a way to measure and characterize this noise over a region on the waveform over many acquisitions, specified by the graphical box. The noise can be displayed as a linear or logarithmic histogram, shown at the left side of the display, aligned with the box. Notice that the noise histogram appears to be a fairly bell-shaped curve:



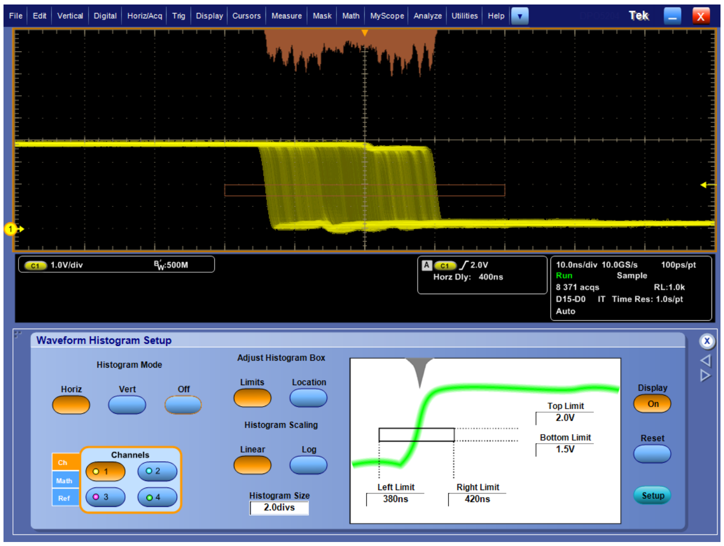
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Set the Vertical **Scale** to **500mV/div** and center the position of the waveform vertically on the display.
- ❑ Press the **Trigger Level** control to automatically set the trigger level to 50%.
- ❑ Set the Horizontal **Scale** to **10ns/div**.
- ❑ Press the front panel **Measure** button.
- ❑ Press the **Histogram** button.
- ❑ Press the **Vert** histogram mode button.
- ❑ Double-click on the **Left Limit** text box and set the value to **20 ns**.
- ❑ Double-click on the **Right Limit** text box and set the value to **40 ns**.
- ❑ Double-click on the **Top Limit** text box and set the value to about **4.3 V**.
- ❑ Double-click on the **Bottom Limit** text box and set the value to about **3.3 V**.
- ❑ Another way to define the histogram box is to use the mouse or touchscreen to graphically define the box. Using either the mouse or touchscreen, draw a box around a portion of the waveform and select **Histogram Vertical**.

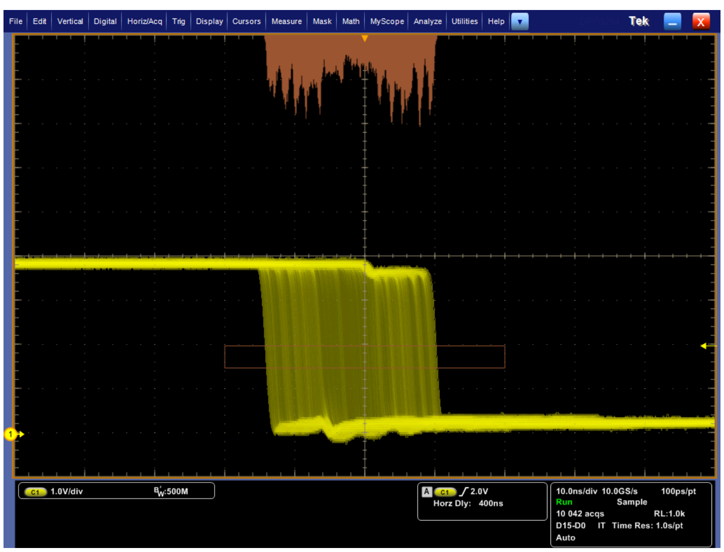
Horizontal Waveform Histograms

Key Take Away Points

- Horizontal waveform histograms allow you to evaluate the changes in position of a signal over time. In many cases, this is referred to as "jitter". For example, on this digital signal, the falling edge is varying back and forth by over 20 ns:



- The horizontal histogram display below shows the jitter on the falling edge of the FAST_FF_CLK signal. The histogram is positioned at the top of the display and is aligned with the box. The histogram is always scaled such that the peak value is 2 divisions high.



- Notice that the histogram is not at all bell-shaped, suggesting that the edge jitter is not due to random noise.

MSO/DPO5000 Series Procedure:

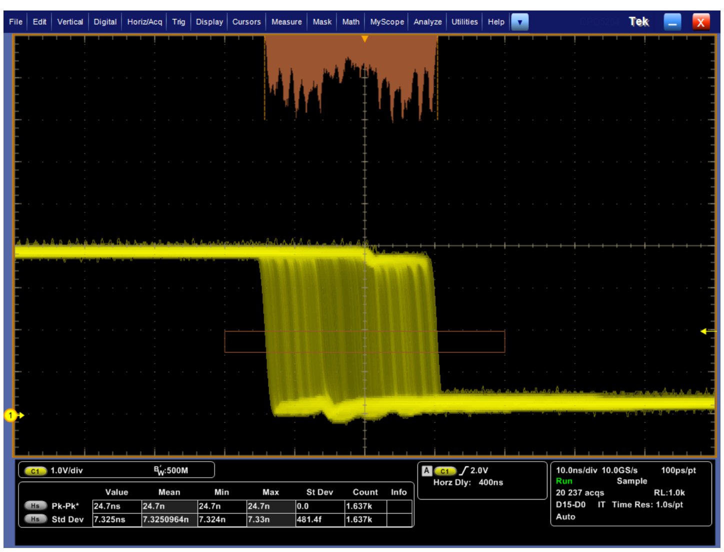
- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the front panel **Acquisition** button.
- ❑ Press the **Delay Mode** button to turn it **On**.
- ❑ Turn the horizontal **Position** control clockwise until the falling edge of the signal is centered on the display. The trigger delay readout should indicate about 400 ns, shown at the bottom of the display.
- ❑ Set the Vertical **Scale** to **1 V/div**.
- ❑ Select **Display->Display Persistence->Infinite Persistence**.
- ❑ Press the front panel **Measure** button.
- ❑ Press the **Histogram** button.
- ❑ Press the **Horiz** histogram mode button.
- ❑ Double-click on the **Left Limit** text box and set the value to **380 ns**.
- ❑ Double-click on the **Right Limit** text box and set the value to **420 ns**.
- ❑ Double-click on the **Top Limit** text box and set the value to about **2.0 V**.
- ❑ Double-click on the **Bottom Limit** text box and set the value to about **1.5 V**.
- ❑ Watch the histogram build as the position of the falling edge of the signal varies.

Automatic Measurements on Histogram Data

Key Take Away Points

- In addition to graphing the waveform histogram data, the oscilloscope can make automatic measurements on the data.
- When the histogram data is selected as the source for the measurements, the list of appropriate measurement types appears:

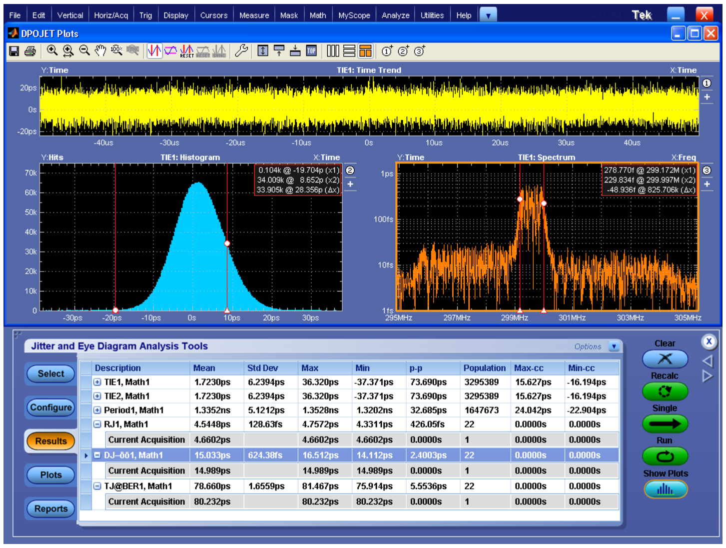
- The measurements on the histogram data appear at the bottom of the screen, in the same color as the histogram display:



- In this case, the peak-to-peak and RMS jitter measurements on the edge are made automatically.

MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ In the Waveform Histogram Setup window, press the Measurement **Setup** button.
- ❑ Click on the **Histog** tab in the Measurements section.
- ❑ Press the **Peak-to-peak** button.
- ❑ Press the **More** button.
- ❑ Press the **Std Dev** button.
- ❑ To indicate where the Peak-to-peak measurement is made on the waveform histogram, select **1 – Pk-Pk** from the **Annotation** drop down menu or select **Measure->Annotation->Peak to Peak**.
- ❑ To indicate where the Peak-to-peak measurement is made on the waveform histogram, select **2 – Std Dev** from the **Annotation** drop down menu or select **Measure->Annotation->Standard Deviation**.



Equipment List

One MSO5000 Series oscilloscope with software version ≥6.4 or
one DPO5000 Series oscilloscope with software version ≥6.4 and with the MSOE option installed
DPOJET application (version ≥3.6.0) installed on the oscilloscope
One TPP0500 or TPP1000 Passive Probe
One P6616 MSO Probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00) or
DPO Demo 2 board and USB cable (020-2924-XX and 174-4401-00)
[Note: most of the screen shots in this lab were made with the DPO Demo 3 board]

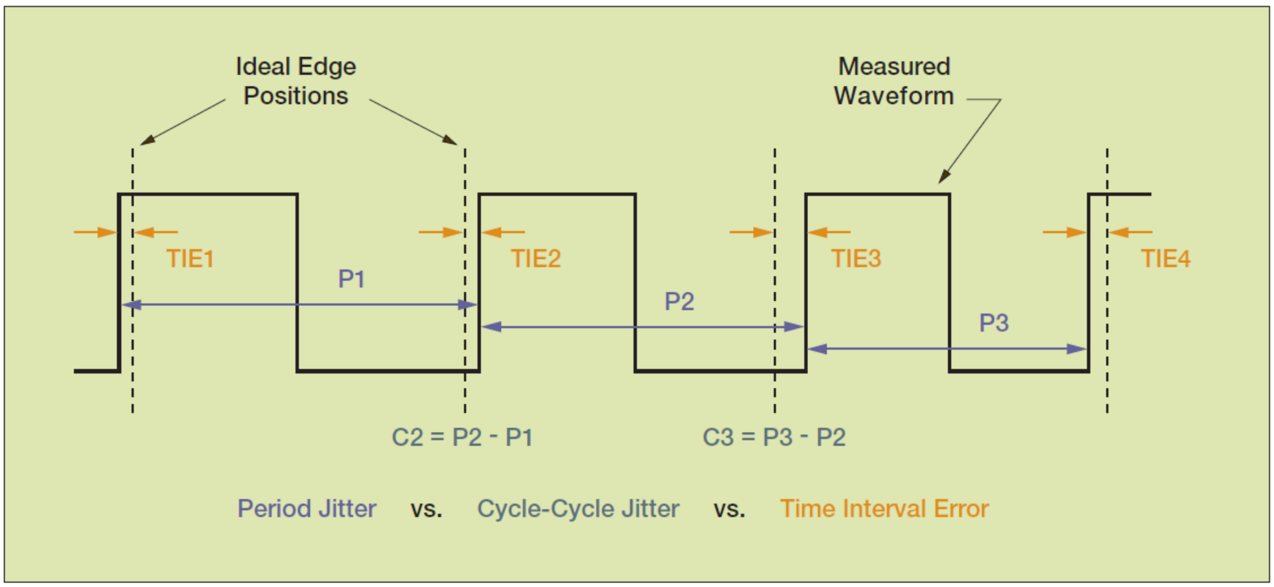
Introduction to Jitter and Timing Measurements

Timing jitter is the unwelcome companion of all electrical systems that use voltage transitions to represent timing information. Historically, electrical systems have lessened the ill effects of timing jitter (or, simply “jitter”) by employing relatively low signaling rates. As a consequence, jitter-induced errors have been small when compared with the time intervals that they corrupt. The timing margins associated with today’s high-speed digital designs and high-speed serial buses and data links reveal that a tighter control of jitter is needed throughout the system design.

The simple definition of jitter is the deviation of timing edges from their “correct” locations. In a timing-based system, timing jitter is the most obvious and direct form of non-idealness. As a form of noise, jitter must be treated as a random process and characterized in terms of its statistics.

Before a digital signal’s deviations from ideal positions can be measured, those ideal positions must be identified. For a clock-like signal (alternating 1’s and 0’s), the ideal positions conceptually correspond to a jitter-free clock with the same mean frequency and phase as the measured one. More care must be used for a data signal, since no event (transition) occurs when the same bit repeats two or more times in a row. Clock Recovery is the name given to the process of establishing the timing of the reference clock.

There are several ways in which jitter may be measured on a single waveform. These are period jitter, cycle-cycle jitter, and time interval error (TIE). It is important to understand how these measurements relate to each other and what they reveal.



This figure shows a clock-like signal with timing jitter. The dotted lines show the ideal edge locations, corresponding to a jitter-free version of the clock.

The period jitter, indicated by the measurements P1, P2 and P3, simply measures the period of each clock cycle in the waveform. This is the easiest and most direct measurement to make. Its peak-to-peak value may be estimated by adjusting an oscilloscope to display a little more than one complete clock cycle with the display set for infinite persistence. If the scope triggers on the first edge, the period jitter can be seen on the second edge.

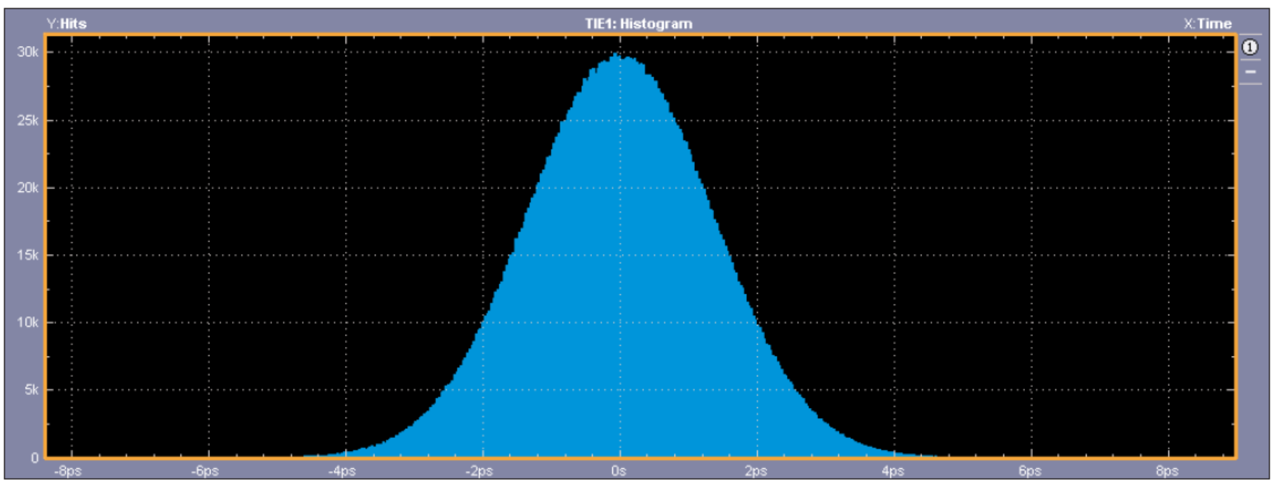
The cycle-cycle jitter, indicated by C2 and C3, measures how much the clock period changes between any two adjacent cycles. As shown, the cycle-cycle jitter is simply the difference operation between adjacent period jitter measurements.

The time interval error is shown by the measurements TIE1 through TIE4. The TIE measures how far each active edge of the clock varies from its ideal position. For this measurement to be performed, the ideal edges must be known or estimated. For this reason, it is difficult to observe TIE directly with an oscilloscope, unless some means of clock recovery or post-processing is available. The TIE may also be obtained by integrating the period jitter, after first subtracting the nominal (ideal) clock period from each measured period. TIE is important because it shows the cumulative effect that even a small amount of period jitter can have over time.

Since all known signals contain jitter that has a random component, statistical measures are required to properly characterize the jitter. Some of the commonly used measures are:

- Mean: The arithmetic mean, or average, value of a clock period is the nominal period. This is the reciprocal of the frequency that a frequency counter would measure.
- Standard Deviation: The standard deviation, represented by the Greek character sigma (σ), is the average amount by which a measurement varies from its mean value.
- Maximum, Minimum and Peak-Peak Values: The Max and Min values generally refer to values actually observed during a measurement interval, and the Peak-Peak value is simply the Max minus the Min.
- Population: The population is the number of individual observations included in a statistical data set. For a random process, a high population intuitively gives greater confidence that the measurement results are repeatable.

Because the measurements are describing a statistical quantity, a histogram of the measurement values can be a helpful way to display the measurement values. A histogram is a diagram that plots the measurement values in a data set against the frequency of occurrence of the measurements. If the number of measurements in the data set is large, the histogram provides a good estimate of the probability density function (pdf) of the set.



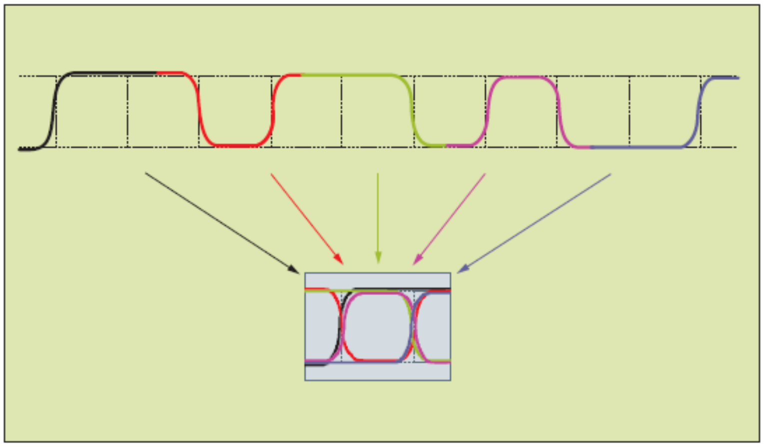
Since the jitter histogram doesn’t show the time-order in which the measurement observations occur, it cannot reveal repeating patterns that might indicate a modulation or other periodic component. A plot of jitter values versus time can make such a pattern obvious. For example, a time trend of jitter measurements can make a pattern of jitter variation becomes apparent, and its correlation with one of several possible sources of coupled noise might become clear.

Since the jitter measurements can be plotted versus time, an obvious extension is to apply a Fourier transform to these measurements and display the results in the frequency domain. This results in a jitter spectrum, with the modulation frequency displayed on the horizontal axis and the amplitude of modulation shown on the vertical axis. One of the benefits of spectral analysis is that periodic components that otherwise might be hidden by wideband noise can often be clearly distinguished.

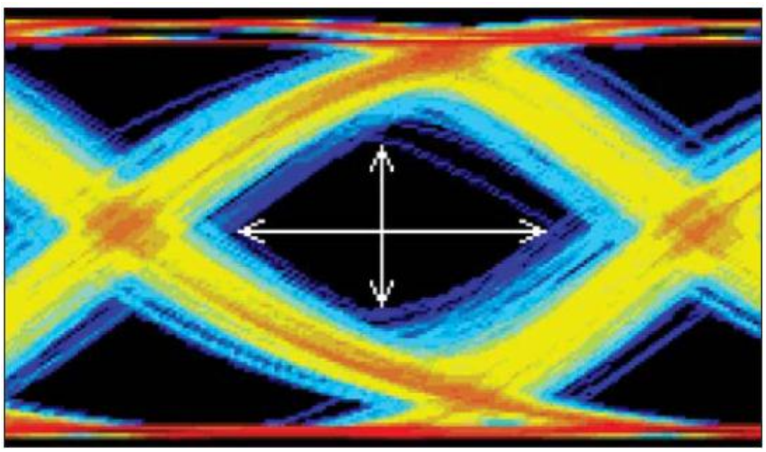
Introduction to Eye Diagrams

All of the methods discussed so far rely on edge locations only. These locations are extracted from a waveform by detecting when the waveform crosses one or more amplitude thresholds. The eye diagram is a more general tool, since it gives insight into the amplitude behavior of the waveform as well as the timing behavior.

An eye diagram is created when many short segments of a waveform are superimposed such that the nominal edge locations and voltage levels are aligned, as shown below. Usually, a horizontal span of two unit intervals is shown. The waveform segments may be adjacent ones, as shown in the figure, or may be taken from more widely spaced samples of the signal. If the waveform is repetitive, an oscilloscope can use equivalent time sampling to build an eye diagram from individual samples taken at random delays on many waveforms.



Eye diagrams usually use either intensity-graded monochrome displays or color-graded displays to indicate the density of waveform samples at any given point on the display. The eye diagram below shows such a color density display for a waveform that exhibits several types of noise.



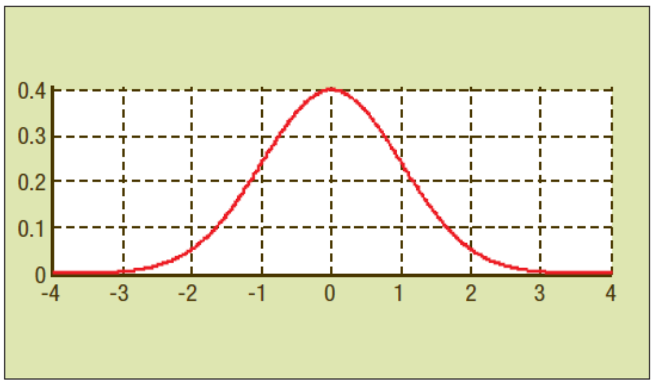
In this diagram, white arrows are used to show the vertical and horizontal extent of the eye opening. As the noise on a signal increases, the eye becomes less open, either horizontally, vertically or both. The eye is said to be closed when no open area remains in the center of the diagram.

Introduction to Jitter Analysis

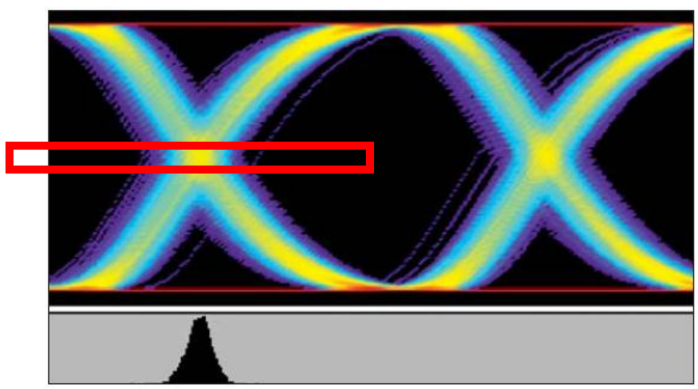
Jitter separation, or jitter decomposition, is an analysis technique that uses timing measurements to model and predict system behavior. The most commonly used jitter model is based on a hierarchy where the total jitter (TJ) is separated into random jitter (RJ) and deterministic jitter (DJ).

Random Jitter: Random jitter is timing noise that cannot be predicted, because it has no discernable pattern. Random jitter is usually assumed to have a Gaussian distribution. One reason for this is that the primary source of random noise in many electrical circuits is thermal noise, which has a Gaussian distribution. Another, more fundamental reason is that the composite effect of many uncorrelated noise sources, no matter what the distributions of the individual sources, approaches a Gaussian distribution according, to the central limit theorem.

Although most samples of a random variable are clustered around its mean value, the peak value that it might attain is infinite. The more samples one takes of such a distribution, the larger the measured peak-to-peak value will be. For this reason, a better approach is to fit the measured values to the assumed Gaussian distribution and describe it in terms of its mean and standard deviation. The Gaussian distribution, also known as the normal distribution, has a PDF that is described by the familiar bell curve, as shown below.



If you display an eye diagram of a signal affected only by random jitter, you will see a display similar to this:

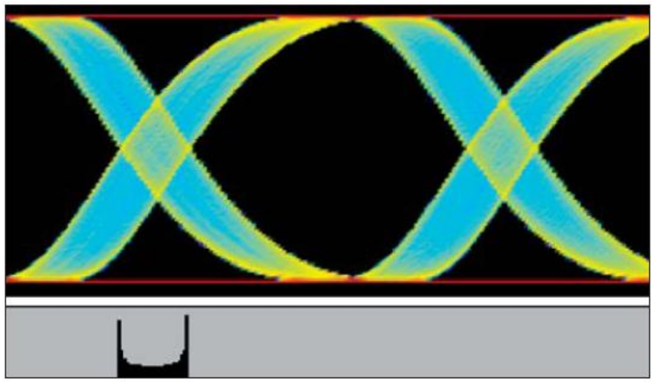


If you plot the position of the waveform samples in the red box at the left side of the eye diagram above, you will create the horizontal histogram shown at the bottom of the figure. Notice how the shape of the histogram approximates a normal or bell curve.

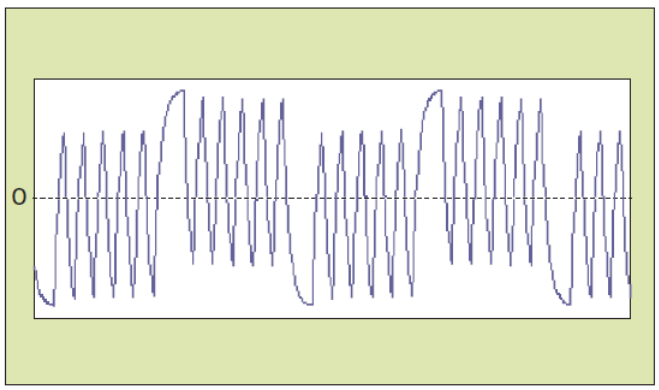
Deterministic Jitter: Deterministic jitter is timing jitter that is repeatable and predictable. Because of this, the peak-to-peak value of this jitter is bounded, and the bounds can usually be observed or predicted with high confidence based on a reasonably low number of observations. This category of jitter is further subdivided in the paragraphs that follow, based both on the characteristics of the jitter and the root causes.

Deterministic jitter is further subdivided into several categories: periodic jitter (PJ), duty-cycle dependent jitter (DCD), and data-dependent jitter (DDJ, also known as inter-symbol interference, ISI).

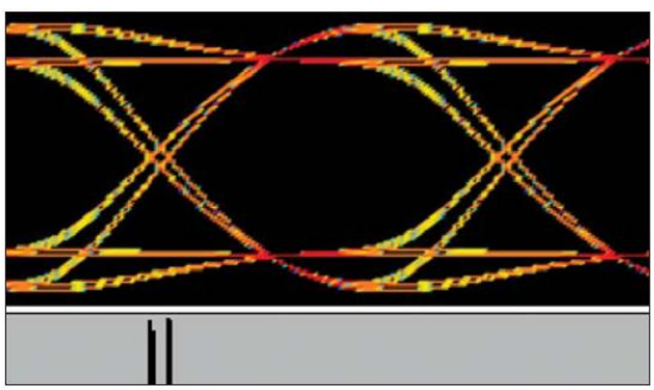
Periodic Jitter: Jitter that repeats in a cyclic fashion is called periodic (or sinusoidal) jitter. Periodic jitter is typically caused by external deterministic noise sources coupling into a system, such as switching power-supply noise or a strong local RF carrier. It may also be caused by an unstable clock-recovery PLL. Periodic jitter may also be intentionally designed into a system, such as a spread-spectrum clock, to spread RF energy across a frequency band.



Data-Dependent Jitter: Any jitter that is correlated with the bit sequence in a data stream is termed Data-Dependent Jitter, or DDJ. DDJ is often caused by the frequency response of a cable or device. Consider the following data sequence where the waveform doesn't reach a full HIGH or LOW state unless there are several bits in a row of the same polarity. This has the effect of shifting the timing of the signal crossing through the threshold.



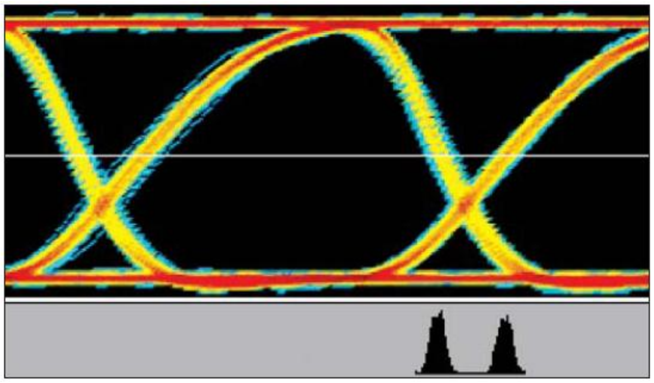
Since this timing shift is predictable and is related to the particular data values preceding the transition, it is an example of DDJ. Another common name is Inter-Symbol Interference, or ISI. The eye diagram of a signal with 0.2 unit intervals of DDJ, together with the associated TIE histogram, is shown below:



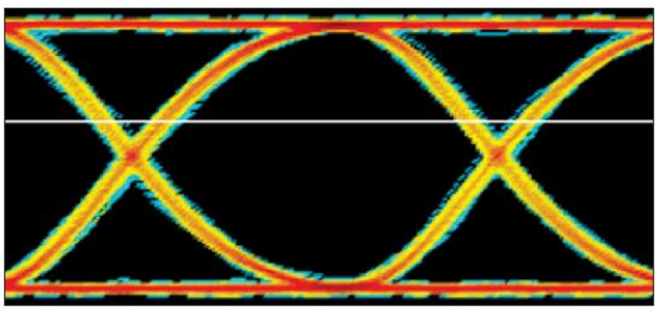
Duty-Cycle Dependent Jitter: Jitter that may be predicted based on whether the associated edge is rising or falling is called Duty-Cycle Dependent Jitter (DCD). There are two common causes of DCD:

1. The slew rate for the rising edges differs from that of the falling edges.
2. The decision threshold for a waveform is higher or lower than it should be.

The screen shot below is an eye diagram demonstrating the first case. Here, the decision threshold is at the 50% amplitude point but the slow rise time of the waveform causes the rising edges to cross the threshold later than the falling edges. As a result, the histogram of an edge crossing (gray) shows two distinct groupings. (This eye diagram also shows some Gaussian noise in addition to the duty-cycle jitter.)



The screen shot below illustrates the second case, in which the waveform has balanced rise and fall times but the decision threshold is not set at the 50% amplitude point. However, the edge-crossing histogram would look very much like that shown above.

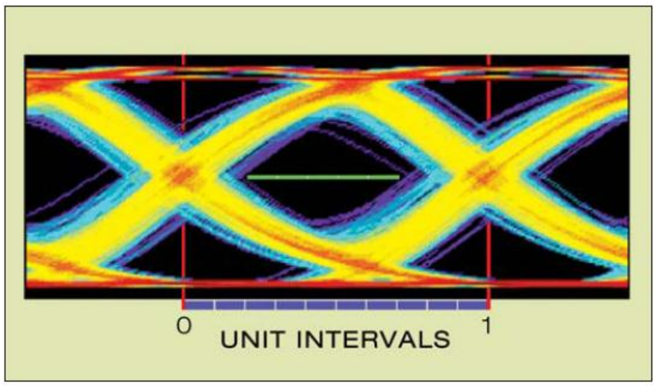


Introduction to Bit Error Rates and Bathtub Curves

Earlier in this document, we discussed the concepts of eye diagrams and eye openings. The Gaussian probability distribution, with its theoretically unbounded peak-to-peak value, was also covered. Considering these two topics together leads to an interesting thought:

For any signal that contains some Gaussian jitter, the eye diagram should close completely if you accumulate samples for a long enough time. This would render the concept of eye opening useless as a basis for comparison. Fortunately, the usefulness of the eye diagram is restored if a confidence level is applied to the eye opening.

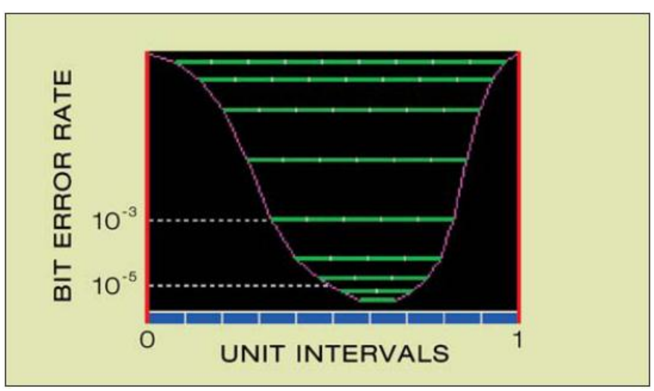
Consider the figure below, in which a green ruler 0.5 unit intervals long has been placed horizontally in the center of the eye. Suppose that it is regarded a failure if any waveforms cross this ruler, either rising or falling. In the figure, it appears that this ruler has not been crossed by any waveforms yet, but such a crossing is inevitable if waveform samples continue to accumulate and the signal contains some Gaussian jitter.



Now suppose instead that the test was considered successful if no more than one waveform out of every 1000 waveforms crossed over the ruler. It would no longer matter how long the test ran. If 50,000 waveforms were allowed to accumulate and 50 or less crossed over the ruler, the test would have passed. One could say that, aside from one waveform in 10^3, the eye was 50% open. Since each crossing is assumed to represent a bit error, this would be a bit error rate (BER) of 10^{-3}.

If the same signal were tested with a shorter ruler, say, 0.25 unit intervals long, then the ruler would certainly be crossed less frequently. Perhaps only one waveform out of every 100,000 waveforms, on average, would cross this shorter ruler. One could say that, aside from one waveform in 10^5, the eye was 25% open.

Continuing along these lines and using a series of rulers, one could fully characterize the eye opening versus the bit error rate. (Note that each ruler should be allowed to slide left or right to obtain the best possible fit.) If the rulers are all plotted against their corresponding bit error rates on a single chart, with the ends of the rulers connected, a plot something like this results:



A plot like this is called a Bathtub Plot, since the pink lines can be imagined to look like a bathtub. Using such a figure, one can tell what horizontal portion of the eye will remain completely free of signal transitions, for a given confidence level.

Finally, note that it can take a long time to accumulate enough data to directly measure the eye openings near the bottom of the chart. For this reason, the mathematical model for total jitter, based on the individual jitter component measurements, can be used to predict performance on the basis of a much smaller sample set.

Lab Objectives

- Learn how to make simple timing measurements, along with measurement trend plots and measurement histograms, with the DPOJET application.
- Learn how to do basic jitter analysis with the DPOJET wizards.
- Learn how to use advanced jitter measurements can be used to identify signal characteristics.

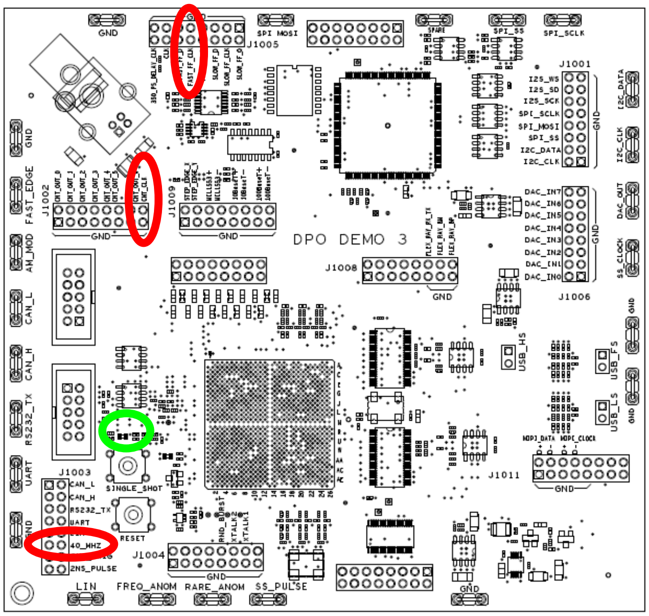
For further reference:

- See the on-line help material: **Help -> Help on Jitter And Eye Analysis**
- See related materials on http://www.tek.com/applications/computing/jitter.html, especially the following:
  - Tektronix Jitter Primer "Understanding and Characterizing Timing Jitter" (55W-16146)
  - DPOJET Data Sheet (61W-21170)

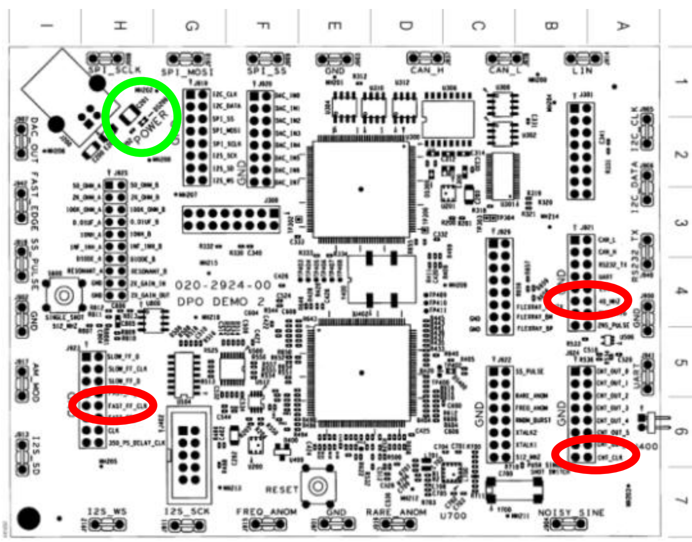
MSO/DPO5000 Series Lab Setup	
Key Take Away Points • With the optional DPOJET application installed, the MSO/DPO5000 Series oscilloscopes can make a variety of automatic jitter and timing measurements.	**MSO/DPO5000 Series Procedure:** ❑ Power up the oscilloscope. ❑ Select **Help -> About TekScope….** ❑ Verify that the optional **DJA: Jitter and Eye Diagram Tools - Advanced** application is installed. ❑ Press the **OK** button.

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has several clock signals which we can use for this lab:



- The DPO Demo 2 board (020-2924-XX) also has several clock signals which we can use for this lab:

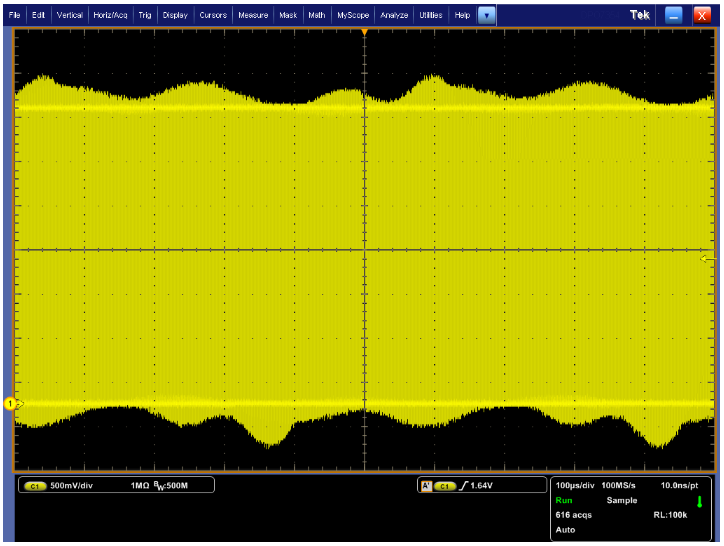


DPO Demo Board Procedure:

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the green **POWER** LED is lit.
- ❑ Attach a TPP0500 or TPP1000 probe to the Channel 1 input of the oscilloscope.
- ❑ Attach the probe ground to the GND test point on the test board.
- ❑ Connect the probe tip to the **CNT_CLK** test point on the test board.
- ❑ NOTE: The signals on each demo board may be slightly different, so the exact measurement details may differ. However, the concepts should still be valid.

Key Take Away Points

- We need to get a stable display of the signal on the oscilloscope. Then we need to adjust the acquisition system so there are many cycles in each acquisition.
- The oscilloscope display should look about like this:



- Next, you're going to measure the frequency of every cycle in the acquisition with a few clicks of the mouse!

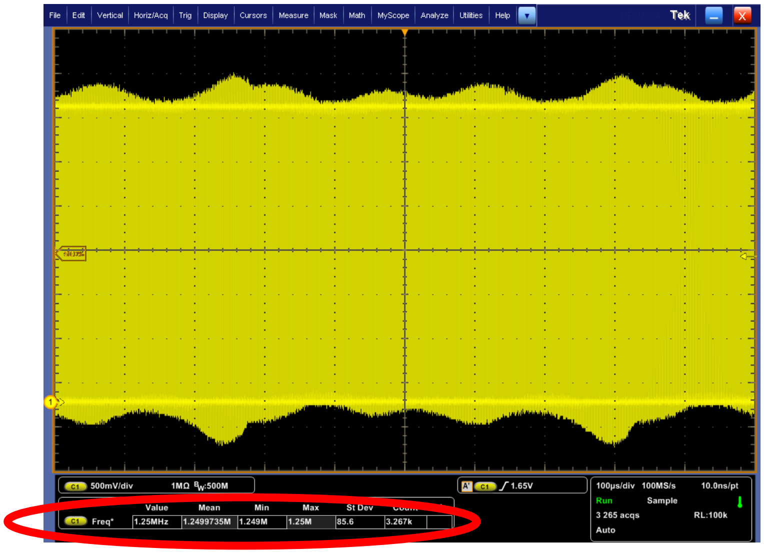
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button.
- ❑ Set the Vertical **Scale** to **500 mV/div**.
- ❑ Using the Vertical **Position** control, center the waveform on the display.
- ❑ Set the Horizontal **Scale** to **100 µs/div**.

Making Automatic Frequency Measurements

Key Take Away Points

- When you run the automatic measurement, notice the measurement results with measurement statistics. With adequate sample rate and record length, you can easily make a very accurate measurement. Over time, the measurement statistics enable you to build up a fairly high-resolution (Mean) frequency measurement value:



- However, it is important to note that there is only one frequency measurement made on each acquired waveform. Notice the annotation market at the left side of the display.
- The statistics are building up across acquisitions, adding a single measurement value with each acquisition.
- If you look carefully at this screen shot, you will realize that the oscilloscope is not optimally set up to make automatic measurements. While it is true that the sample rate is indeed much higher than the frequency you are measuring, the time window and therefore the record length are unnecessarily long, providing no advantage for this measurement.
- Let's zoom in to see what is really happening.

MSO/DPO5000 Series Procedure:

- ❑ Turn on the automatic frequency measurement by selecting **Measure -> Time -> Frequency**. You can also do this with the keyboard shortcuts **Alt-S**, **Alt-T**, **Alt-Q**.

Key Take Away Points

- When you zoom in on the first cycle of the acquisition, you can clearly see where the automatic measurement. Notice that indeed the frequency measurement is being made on the first full cycle of the waveform and that the measurement reference level is at about half of the signal amplitude:

- With all of the cycles in this acquisition, wouldn't it be great to be able to measure the frequency of all of them?
- Wouldn't it be great to use measurement statistics to describe the variations in the measurements within the acquisition, and average the measurement values to get a higher-resolution result?
- Wouldn't it be great to be able to plot the trend of the measurement values over time to see how the frequency is changing?
- These are some of the basic capabilities of the DPOJET Essentials application, which is standard with the MSO/DPO5000 Series oscilloscopes.
- DPOJET Advanced is an option to the instruments which adds significant jitter measurement capabilities.

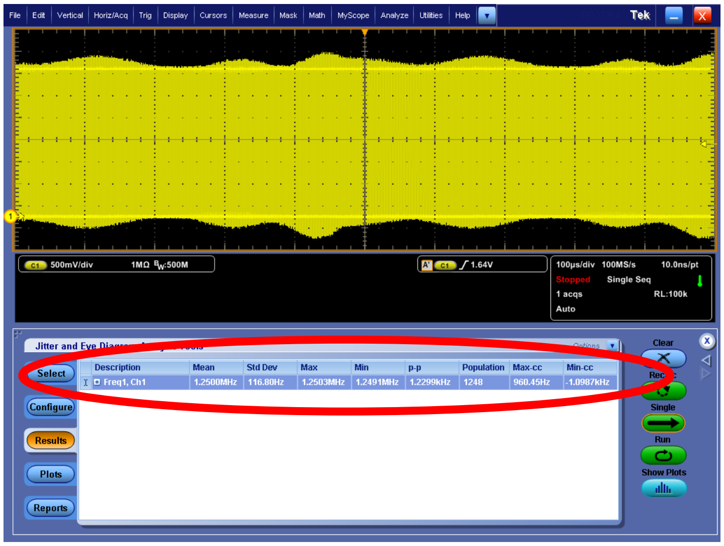
MSO/DPO5000 Series Procedure:

- ❑ Press the **Single** button.
- ❑ Notice that a single acquisition is made (shown in the status box in the lower right corner of the display) and that a single measurement has been made (Value = Mean = Min \ Max, and Count = 1).
- ❑ Zoom in on the left edge of the display. If necessary, you can do a zoom-on-zoom to get adequate magnification to display the first cycle of the acquisition.
- ❑ When you are done, right click on the measurement readout area and select **Remove**.
- ❑ Turn off zoom.
- ❑ Press the **Run/Stop** button.

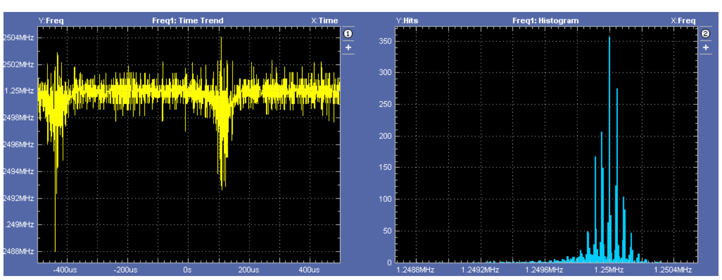
Making Frequency Measurements with DPOJET

Key Take Away Points

- When you run the measurement, notice the measurement results with measurement statistics. With this test setup, notice that a population of 1248 frequency measurements are made on the acquired waveform:



- Notice that the measurement readout provides the rich measurement statistics data, even in Single acquisition mode, since the measurements are based on all of the full cycles of the waveform within the acquisition.
- Each time you press the DPOJET Single button, you accumulate the results of 1248 more frequency measurements.
- When you display the plots, you can see the variation of the measurement values over time (measurement trending) in the left plot, and the distribution of measurement values (measurement histograms) in the right plot:



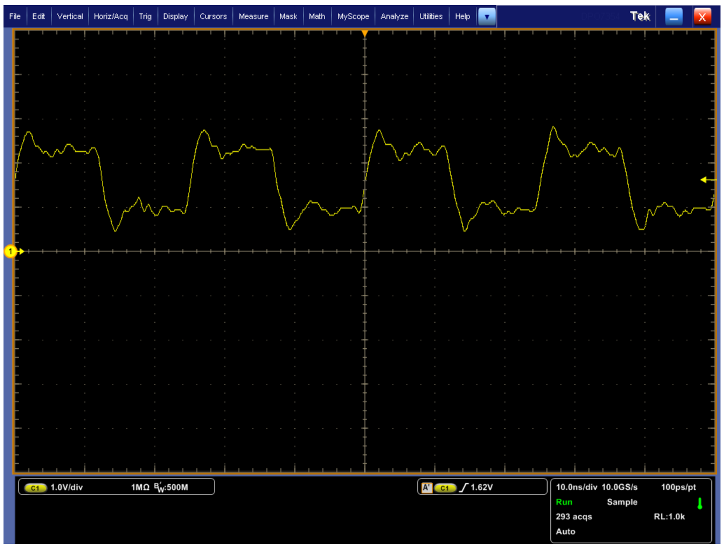
MSO/DPO5000 Series Procedure:

- ❑ Launch the DPOJET application by selecting **Analyze -> Jitter and Eye Analysis -> Select….** You can also do this with the keyboard shortcuts **Alt-A**, **Alt-J**, **Alt-S**.
- ❑ With the Select button at the left side of the control window selected, press the **Freq** button to select the Frequency measurement.
- ❑ Press the **Plots** button at the left side of the control window.
- ❑ Press the **Time Trend** button to display the graph of frequency measurements over time.
- ❑ Press the **Histogram** button to display the histogram display of the frequency measurements.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ Press the **Single** button again and notice that the number of measurements (population) doubles.

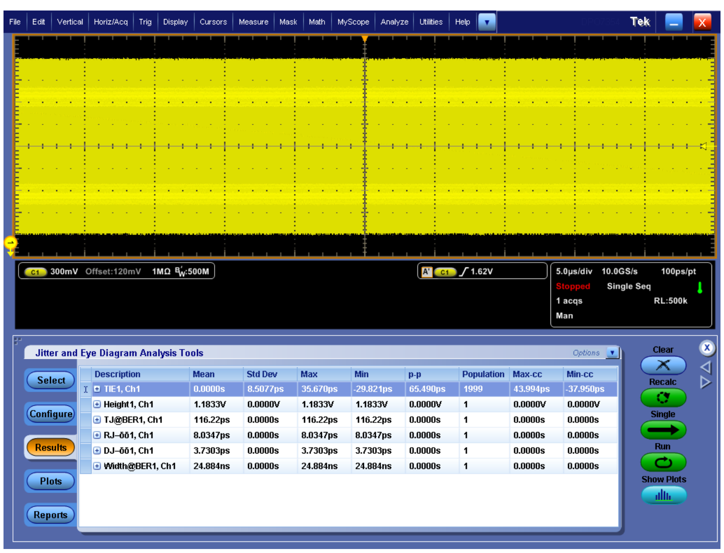
Using the DPOJET One-Touch Jitter Wizard

Key Take Away Points

- You can use the One-Touch Jitter Wizard to automatically perform a repeatable, complex jitter analysis with a single menu selection. The process selects a waveform source, sets the horizontal and vertical scales, chooses measurements, generates statistical results, and creates summary plots.
- Simply get a stable signal and launch the wizard:



- Notice that six measurements are selected, the signal is Autoset to optimize the measurements, and the measurement results are tabulated and plotted:

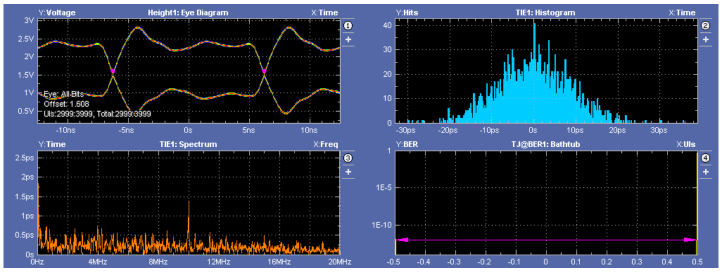


MSO/DPO5000 Series Procedure:

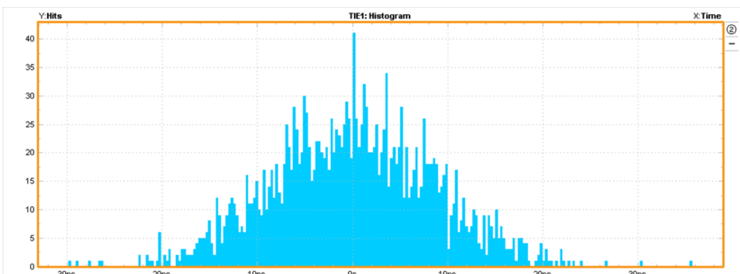
- ❑ Move the probe tip to the **40 MHZ** test point on the test board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button.
- ❑ Launch the DPOJET One-Touch Jitter Wizard application by selecting **Analyze -> Jitter and Eye Analysis (DPOJET) -> Wizard -> One Touch Jitter**. You can also do this with the keyboard shortcuts **Alt-A**, **Alt-J**, **Alt-J**.

Key Take Away Points

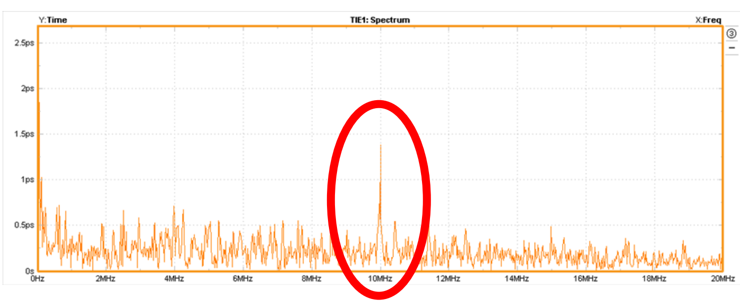
- The automatically-generated plots at the top of the display look about like this:



- The first automatic measurement in the measurement table is Time Interval Error (TIE). TIE is the difference in time between an edge in the waveform and the corresponding edge of a reference clock, (usually determined by a clock recovery process). In other words, TIE indicates how much the frequency of each single cycle is varying from the ideal frequency value. One way to easily visualize this variation is to plot the values as a histogram, as shown in the upper right plot.



- The lower left plot is the spectrum of the TIE measurements:



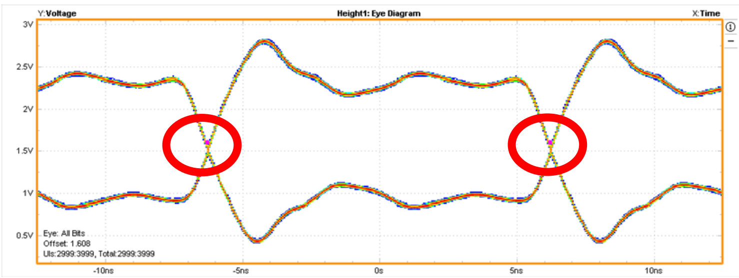
- The broad spectrum of values in this plot would indicate that some of the variation in frequency is fairly random (also suggested by the general bell-shaped histogram), but that there is a strong 10 MHz component to the frequency variation, too. In a debug situation, this might suggest that there is a cross-talk issue between this signal and a 10 MHz signal that needs to be resolved.

MSO/DPO5000 Series Procedure:

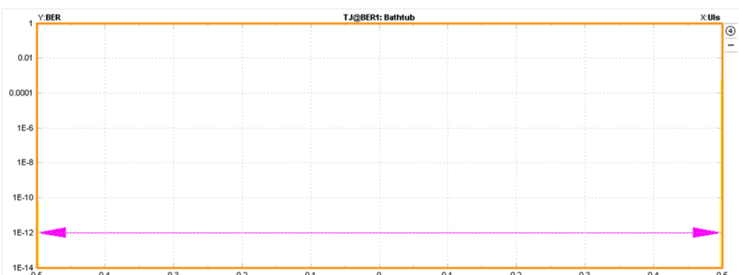
- ❑ You can find more details about these measurements in the Help system. **Select Help -> Help on Jitter and Eye Analysis**, or **Alt-H** and **Alt-T**, and looking under the **Algorithms** topic.

Key Take Away Points

- The upper left plot is the Eye Diagram. This display shows the eye opening for the signal. The pink dots indicate the location of the recovered clock signal. Since we are measuring a rising-edge clock signal, it is reassuring to find that the recovered clock is aligned with the rising edges of the waveform:



- The second measurement in the measurement table is Eye Height. Eye Height is the measured minimum vertical eye opening at the center of the Unit Interval (UI).
- The third measurement is called TJ@BER which stands for the Total Jitter at a specified Bit Error Rate. This value is a prediction of the total jitter on a signal based on the bathtub curve (shown in the lower right plot on the display), and may differ from the actual jitter measurement for a single acquisition.

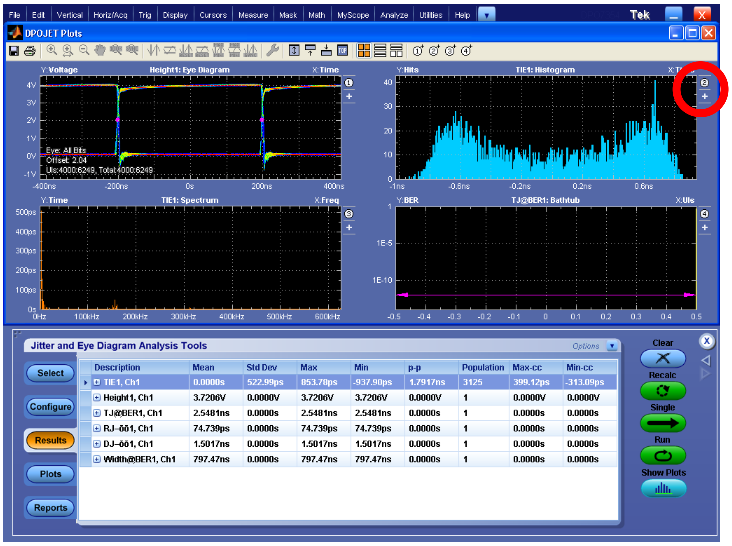


- The fourth and fifth measurements are Random Jitter (RJ) and Deterministic Jitter (DJ). These RJ and DJ values are determined for each acquisition. Since this signal is repetitive, the jitter analysis is based on the spectral analysis of the measurements.
- Random Jitter is the RMS magnitude of all timing errors not exhibiting deterministic behavior. Random jitter shows up as the noise floor in the spectral display of timing measurements, as you saw in the TIE spectrum display above.
- Deterministic Jitter is the peak-to-peak amplitude of all timing errors that follow deterministic behavior. An example of this is the 10 MHz component in the TIE spectrum display above, where that component clearly rose above the noise floor of the spectrum display.

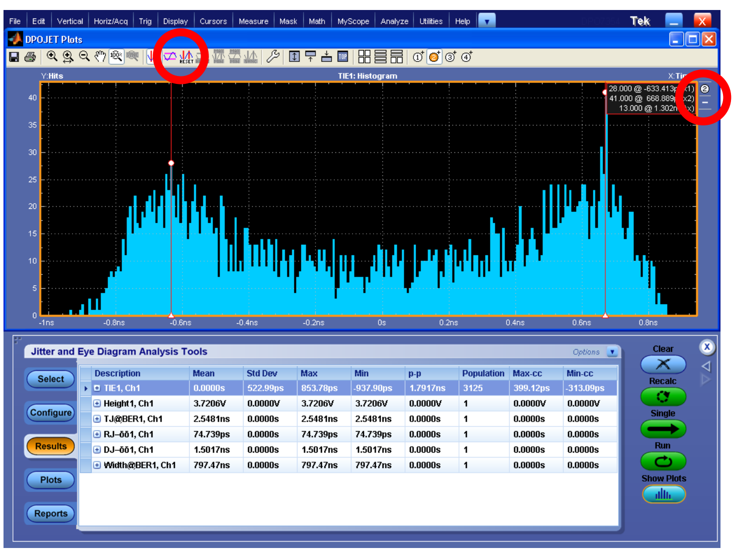
MSO/DPO5000 Series Procedure:

Key Take Away Points

- The last lab section used a low-jitter clock signal, and the jitter measurements were not very dramatic.
- If you do the same experiment with a modulated clock, you will find that the histogram of the TIE measurement is much more interesting:



- As described in the introduction, this display clearly indicates Periodic Jitter, especially the histogram display.
- You can zoom in on the individual graphs for further analysis, such as with the cursors:

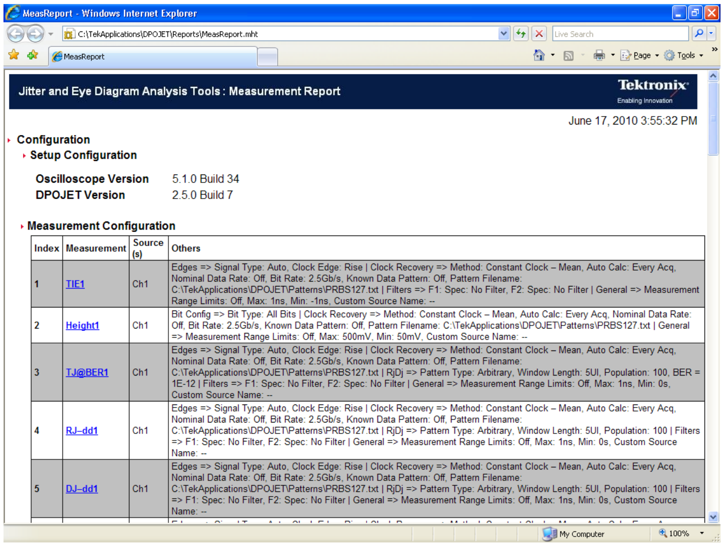


MSO/DPO5000 Series Procedure:

- ❑ Move the probe tip to the **FAST_FF_CLK** test point on the test board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button.
- ❑ Launch the DPOJET One-Touch Jitter Wizard application by selecting **Analyze -> Jitter and Eye Analysis (DPOJET) -> Wizard -> One Touch Jitter**. You can also do this with the keyboard shortcuts **Alt-A**, **Alt-J**, **Alt-J**.
- ❑ During the wizard's Autoset process, it will increase the record length to increase the number of edges to measure. It is possible that it will continue to increase the record length until it hits the maximum value. If this happens, you will see a warning pop up. Don't worry about it. It will go away and the routine will work correctly.
- ❑ On certain signals, especially those with a lot of overshoot or ringing, it is also possible that the Autoset routine will not vertically scale the signal correctly and you will get an error message about the signal clipping and the accuracy of the jitter measurements may be compromised.
- ❑ Click on the **+** sign next to the plot in the upper left corner of the display to expand it.
- ❑ Click on the toolbar button with the red vertical cursors to make measurements on the plot.
- ❑ When you are done, click on the **-** sign next to the plot to restore the display.

Key Take Away Points

- You can also document the test results in a compliance report. Save and open the report. In the report, you will see details about the test setup, measurement results, and the plots of the measurements.
- You can examine the details in the report, or you can examine the individual plots on the display in more detail.



Jitter and Eye Diagram Analysis Tools : Measurement Report

Tektronix
Enabling Innovation

June 17, 2010 3:55:32 PM

Configuration

Setup Configuration

Oscilloscope Version	5.1.0 Build 34
DPOJET Version	2.5.0 Build 7

Measurement Configuration

Index	Measurement	Source (s)	Others
1	TIE1	Ch1	Edges => Signal Type: Auto, Clock Edge: Rise | Clock Recovery => Method: Constant Clock – Mean, Auto Calc: Every Acq, Nominal Data Rate: Off, Bit Rate: 2.5Gb/s, Known Data Pattern: Off, Pattern Filename: C:\TekApplications\DPOJET\Patterns\PRBS127.txt | Filters => F1: Spec: No Filter, F2: Spec: No Filter | General => Measurement Range Limits: Off, Max: 1ns, Min: -1ns, Custom Source Name: --
2	Height1	Ch1	Bit Config => Bit Type: All Bits | Clock Recovery => Method: Constant Clock – Mean, Auto Calc: Every Acq, Nominal Data Rate: Off, Bit Rate: 2.5Gb/s, Known Data Pattern: Off, Pattern Filename: C:\TekApplications\DPOJET\Patterns\PRBS127.txt | General => Measurement Range Limits: Off, Max: 500mV, Min: 50mV, Custom Source Name: --
3	TJ@BER1	Ch1	Edges => Signal Type: Auto, Clock Edge: Rise | Clock Recovery => Method: Constant Clock – Mean, Auto Calc: Every Acq, Nominal Data Rate: Off, Bit Rate: 2.5Gb/s, Known Data Pattern: Off, Pattern Filename: C:\TekApplications\DPOJET\Patterns\PRBS127.txt | RjDj => Pattern Type: Arbitrary, Window Length: 5UI, Population: 100, BER = 1E-12 | Filters => F1: Spec: No Filter, F2: Spec: No Filter | General => Measurement Range Limits: Off, Max: 1ns, Min: 0s, Custom Source Name: --
4	RJ–dd1	Ch1	Edges => Signal Type: Auto, Clock Edge: Rise | Clock Recovery => Method: Constant Clock – Mean, Auto Calc: Every Acq, Nominal Data Rate: Off, Bit Rate: 2.5Gb/s, Known Data Pattern: Off, Pattern Filename: C:\TekApplications\DPOJET\Patterns\PRBS127.txt | RjDj => Pattern Type: Arbitrary, Window Length: 5UI, Population: 100 | Filters => F1: Spec: No Filter, F2: Spec: No Filter | General => Measurement Range Limits: Off, Max: 1ns, Min: 0s, Custom Source Name: --
5	DJ–dd1	Ch1	Edges => Signal Type: Auto, Clock Edge: Rise | Clock Recovery => Method: Constant Clock – Mean, Auto Calc: Every Acq, Nominal Data Rate: Off, Bit Rate: 2.5Gb/s, Known Data Pattern: Off, Pattern Filename: C:\TekApplications\DPOJET\Patterns\PRBS127.txt | RjDj => Pattern Type: Arbitrary, Window Length: 5UI, Population: 100 | Filters => F1: Spec: No Filter, F2: Spec: No Filter | General => Measurement Range Limits: Off, Max: 1ns, Min: 0s, Custom Source Name: --

MSO/DPO5000 Series Procedure:

- ❑ Press the **Reports** button at the left side of the control window.
- ❑ Press the **Save As** button, navigate to the desired file location, and press the **Save** button.

Using the DPOJET Serial Data / Jitter Wizard

Key Take Away Points

- DPOJET provides a second wizard which gives the user more control of the testing, but still guides them through the few the steps necessary to make valid jitter and timing measurements.
- The Serial Data / Jitter Wizard uses some basic information and then prompts you to assemble information about your signal, optimizes the horizontal and vertical settings, then defines a number of common measurements and plots.
- Depending on how much you need to enter, you can select Next to move down to the next configuration detail; or press Finish to move forward and begin measurements.
- Once the setups are complete, DPOJET sequences the scope acquisition system and analyzes the signal, displaying the results in statistical and graphical form.
- The value is that the process is nearly automatic and requires very little jitter and measurement expertise, especially of complex topics like RJ/DJ, allowing better use of technical lab resources.
- For the first usage of the Serial Data / Jitter Wizard, we'll just use the default settings. The wizard interface looks like this:

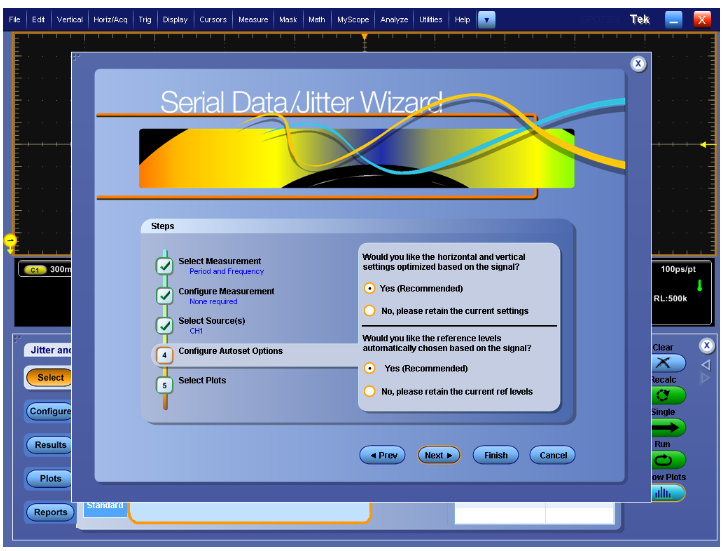
MSO/DPO5000 Series Procedure:

- ❑ Move the probe tip to the **40 MHZ** test point on the test board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button.
- ❑ Launch the DPOJET Serial Data / Jitter Wizard application by selecting **Analyze -> Jitter and Eye Analysis (DPOJET) -> Serial Data/Jitter Wizard….** You can also do this with the keyboard shortcuts **Alt-A**, **Alt-J**, **Alt-W**.
- ❑ Verify that **Period and Frequency** is selected.
- ❑ Press the **Next >** button.

Key Take Away Points

- By default, the analysis will be done on channel 1:

- By default, the application will Autoset on the signal, and then automatically set the measurement reference levels:



MSO/DPO5000 Series Procedure:

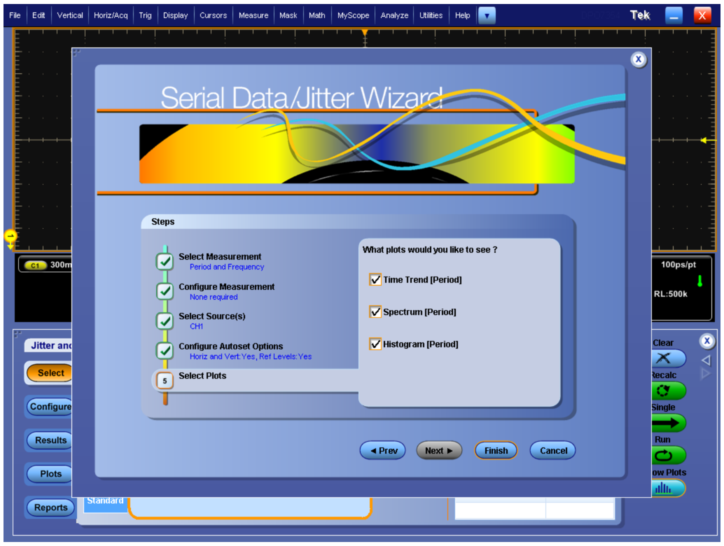
- ❑ Because the measurements have already been selected, the interface jumps to the third selection, Select Source(s).
- ❑ Verify that Channel **1** is selected.
- ❑ Press the **Next >** button.

- ❑ Press the **Next >** button.

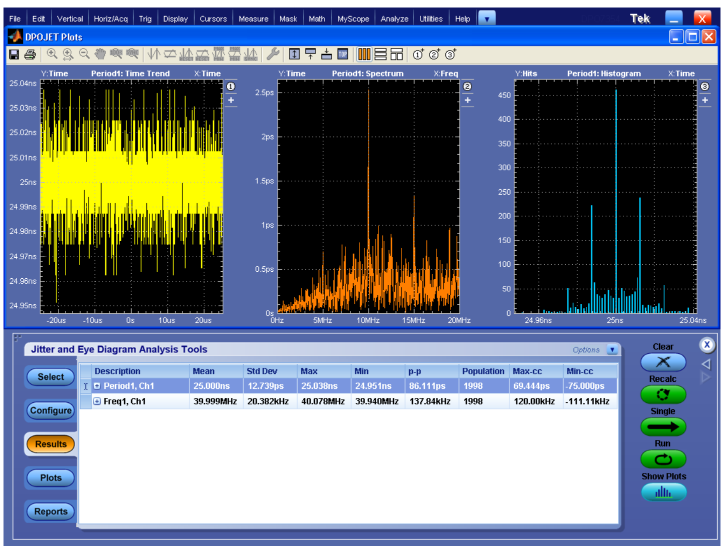
Key Take Away Points	MSO/DPO5000 Series Procedure:

Key Take Away Points

- For the selected measurements, a default set of plots are selected:



- By using all of the default settings, we easily get a consistent set of timing jitter measurements:



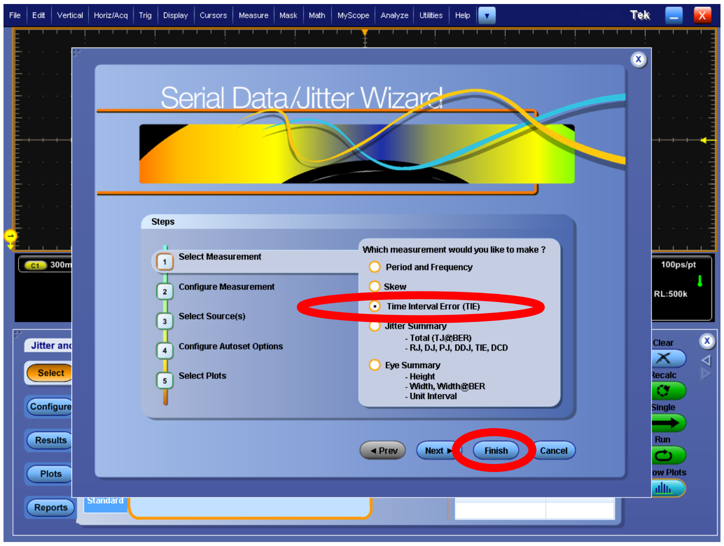
- As expected, the time trend at the left and the histogram at the right both indicate that the period is consistently around 25 ns (which is the period of a 40 MHz signal).
- But we also notice that the measurements are moving a little, because the time trend is not a flat horizontal line and the histogram is not a single vertical line.

MSO/DPO5000 Series Procedure:

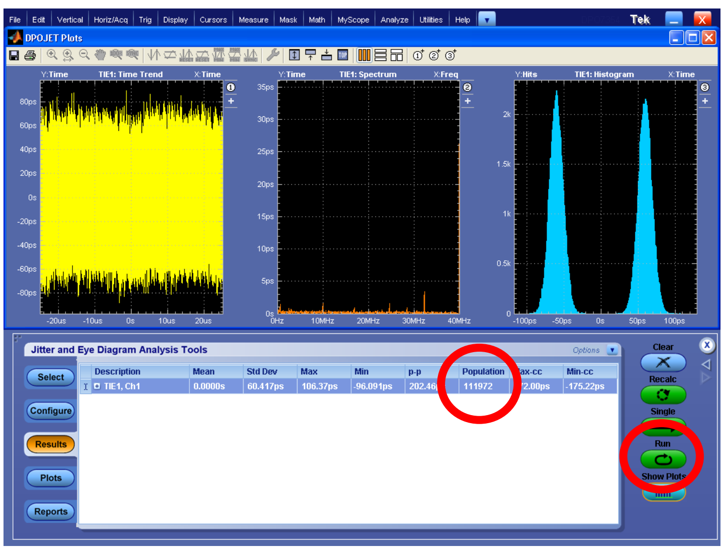
- ❑ By default, the application will plot the Time Trend, Spectrum, and Histogram of the Period measurement.
- ❑ Press the **Finish** button.

Key Take Away Points

- Let’s use the Serial Data / Jitter Wizard to analyze the signal with the TIE measurement:



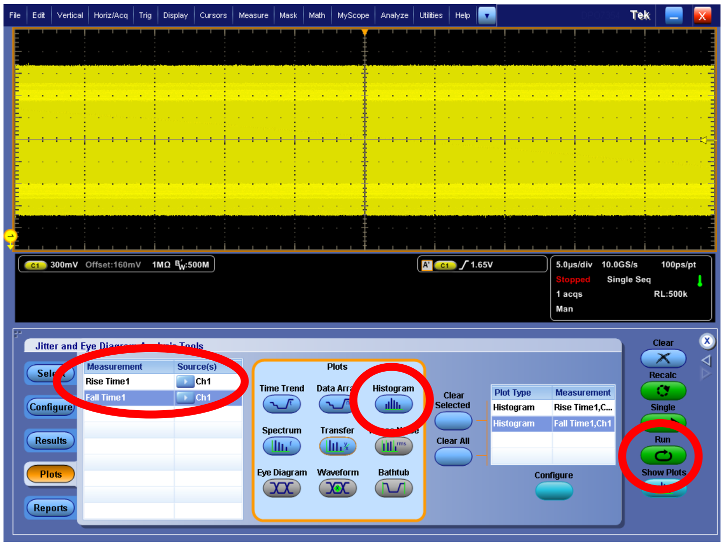
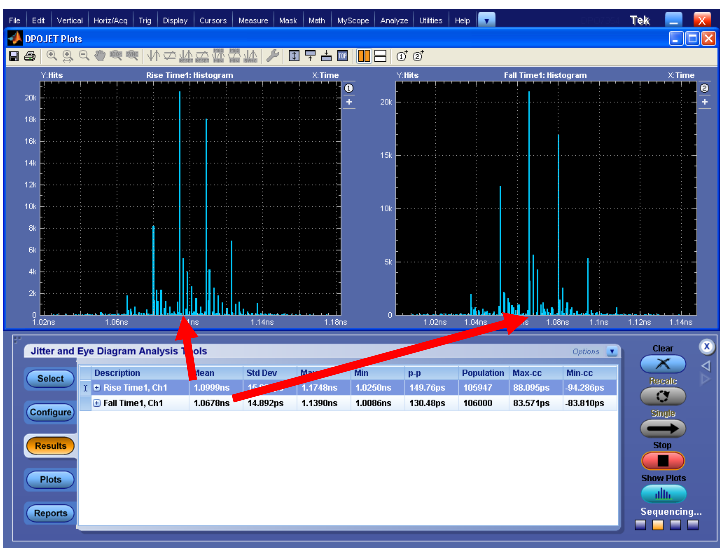
- As the histogram of the Time Interval Error (TIE) analysis fills in, notice that two clear bell curves have appeared:



- This looks a lot like the Duty Cycle Dependent Jitter we discussed in the introduction. Let’s use DPOJET to verify our conclusions.

MSO/DPO5000 Series Procedure:

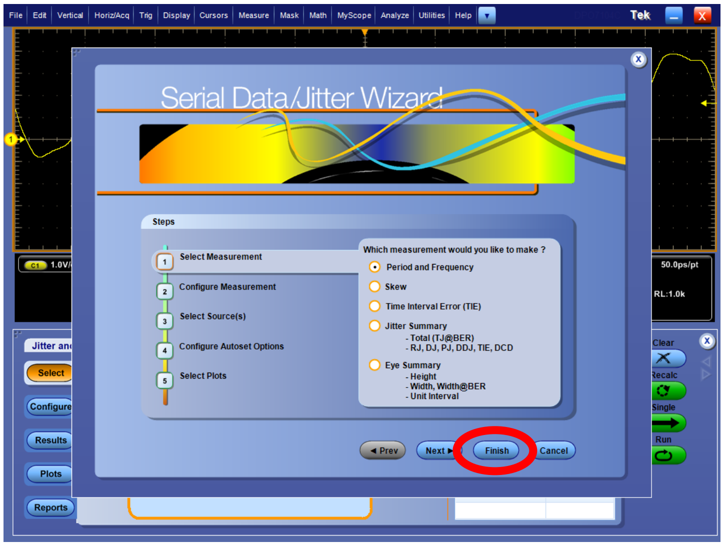
- ❑ Launch the DPOJET Serial Data / Jitter Wizard application again by selecting **Analyze -> Jitter and Eye Analysis -> Serial Data/Jitter Wizard…**. You can also do this with the keyboard shortcuts **Alt-A**, **Alt-J**, **Alt-W**.
- ❑ Select **Time Interval Error (TIE)**.
- ❑ For simplicity, since we don’t plan to change any other settings for this simple demo, press the **Finish** button.
- ❑ To accumulate the measurement results over multiple acquisitions, press the **Run** button.
- ❑ Watch as the population of TIE measurements grows and the plots fill in.

Key Take Away Points	**MSO/DPO5000 Series Procedure:**
• Let's use DPOJET to measure the rise- and fall-times of the signal to see if we can verify that differences in the edge speeds is indeed contributing to the jitter.  • Here is what the histograms of the rise- and fall-time measurements look like:  • Notice that there is indeed a significant difference in the mean of the rise- and fall-time measurements on this signal. Although these timing differences would be difficult to easily or repeatably measure with standard oscilloscope measurement techniques, we were able to do them with only a few clicks of the mouse when using DPOJET.	❑ Press the **Select** button at the left side of the control window to select different measurements. ❑ Press the **Clear All** button. ❑ Press the **Time** tab to select the time-related measurements. ❑ Press the **Rise Time** and **Fall Time** buttons to select them. ❑ Press the **Plots** button to select the plots. ❑ Click on the **Rise Time1** measurement in the table at the left of the control window. ❑ Press the **Histogram** button. ❑ Click on the **Fall Time1** measurement in the table at the left of the control window. ❑ Press the **Histogram** button. ❑ Press the **Run** button. ❑ Watch as the population of rise- and fall-time measurements grows and the plots fill in.

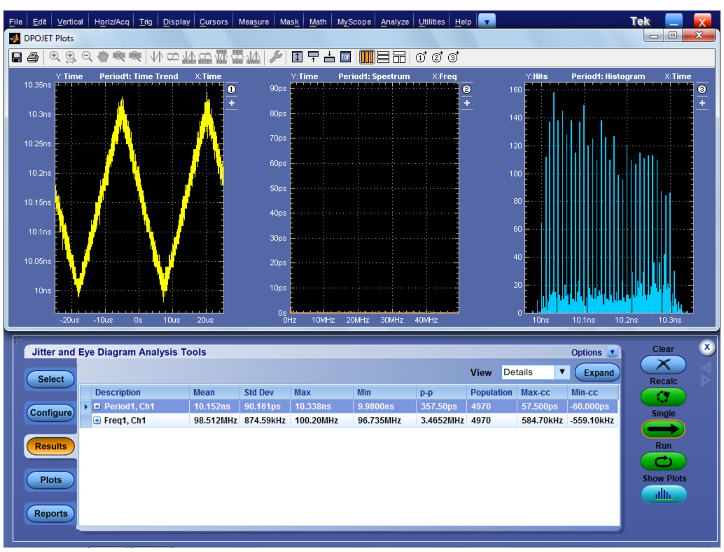
Spread Spectrum Clock Verification with the DPOJET Serial Data / Jitter Wizard

Key Take Away Points

- A great application of the DPOJET Serial Data / Jitter Wizard is a simple measurement demo on the spread spectrum clock on the DPO Demo 3 board. The clock frequency is around 100 MHz, but is being purposely modulated to spread the spectral energy around – a popular design technique to improve electromagnetic compatibility.



- After the application does a specialized autoset, it measures the period and frequency of every cycle in a single waveform:



- The left graph shows that the period of the signal is ramping up and down at a very controlled rate, about 30 kHz. The histogram in the graph at the right indicates that the period is consistently around 10 to 10.3 ns (which is the period of a 97 to 100 MHz signal).

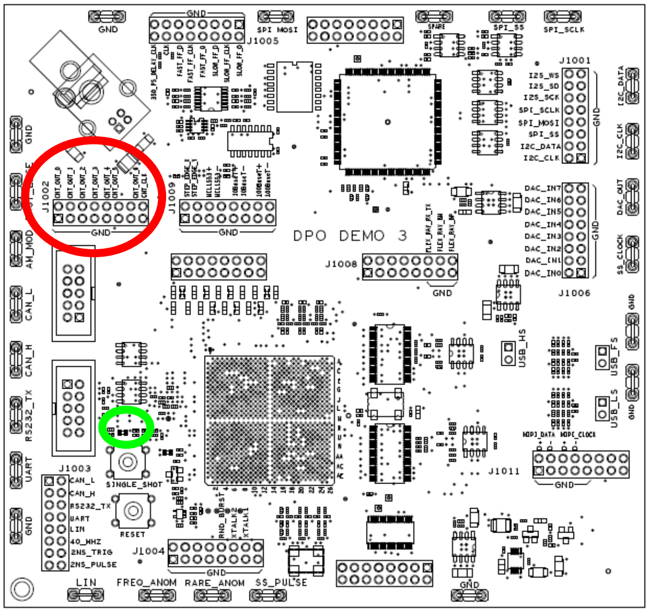
MSO/DPO5000 Series Procedure:

- ❑ Move the probe tip to the **SS_CLOCK** test point on the DPO Demo 3 board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the front panel **Autoset** button.
- ❑ Launch the DPOJET Serial Data Jitter Wizard application by selecting **Analyze -> Jitter and Eye Analysis (DPOJET) -> Serial Data/Jitter Wizard….** You can also do this with the keyboard shortcuts **Alt-A**, **Alt-J**, **Alt-W**.
- ❑ For this analysis, we're going to use all of the default settings for the wizard, so simply press the **Finish** button.
- ❑ Notice the measurement values in the table in the lower half of the display.
- ❑ With a single acquisition, DPOJET has made period and frequency measurements across thousands of cycles of the waveform, and provided all of the statistics for those measurements.

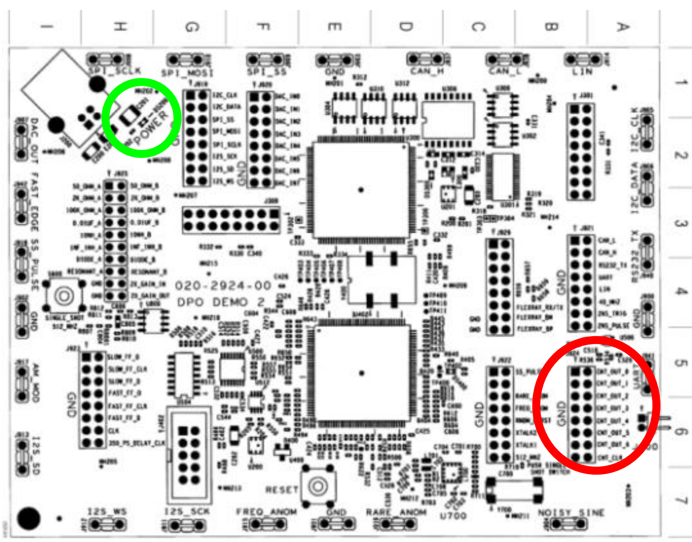
Digital Channel Parametric Measurements with DPOJET	
Key Take Away Points	**DPO Demo Board Procedure:**

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has many interesting digital clock and data signals which we can use for this lab. One of the most predictable groups of signals is the 7-bit counter output on J1006:



- The DPO Demo 2 board (020-2924-XX) also has many interesting digital clock and data signals which we can use for this lab. One of the most predictable groups of signals is the 7-bit counter output on J924:

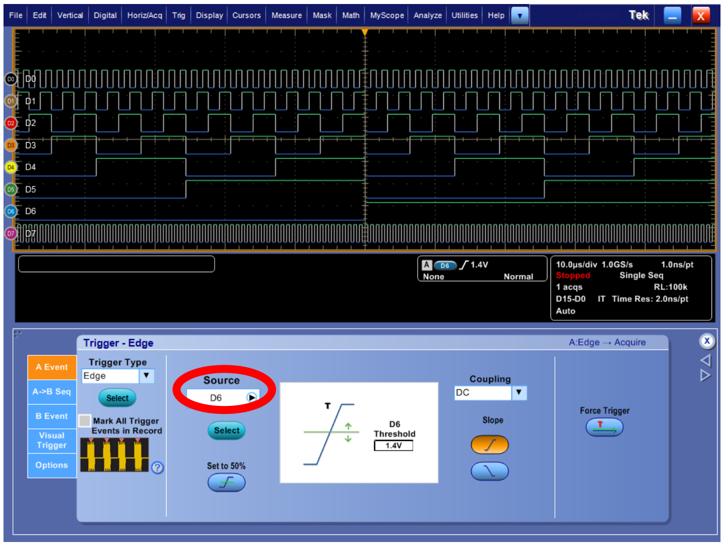


DPO Demo Board Procedure:

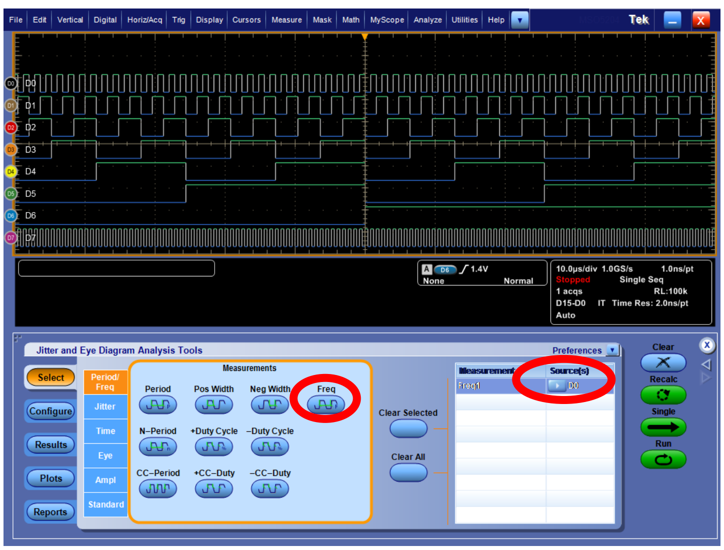
- ❑ Attach the P6616 digital probe to the input on the front of the oscilloscope.
- ❑ Connect digital channel D0 (on probe Group 1) to the CNT_OUT_0 signal, being careful to attach the ground side of the digital probe to the adjacent GND pin on the connector.
- ❑ Connect D1 to the CNT_OUT_1.
- ❑ Connect D2 to the CNT_OUT_2.
- ❑ Connect D3 to the CNT_OUT_3.
- ❑ Connect D4 to the CNT_OUT_4.
- ❑ Connect D5 to the CNT_OUT_5.
- ❑ Connect D6 to the CNT_OUT_6.
- ❑ Connect D7 to the CNT_CLK.

Key Take Away Points

- The current version of the DPOJET application also supports advanced timing measurements on the digital channels of the MSO5000 Series.



- The DPOJET application can measure the frequency (or any of the other timing parameters shown) of every cycle in a waveform:

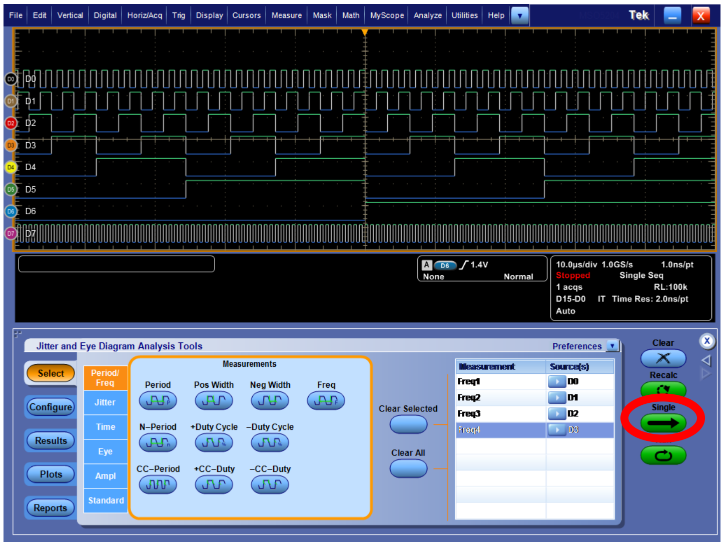


MSO/DPO5000 Series Procedure:

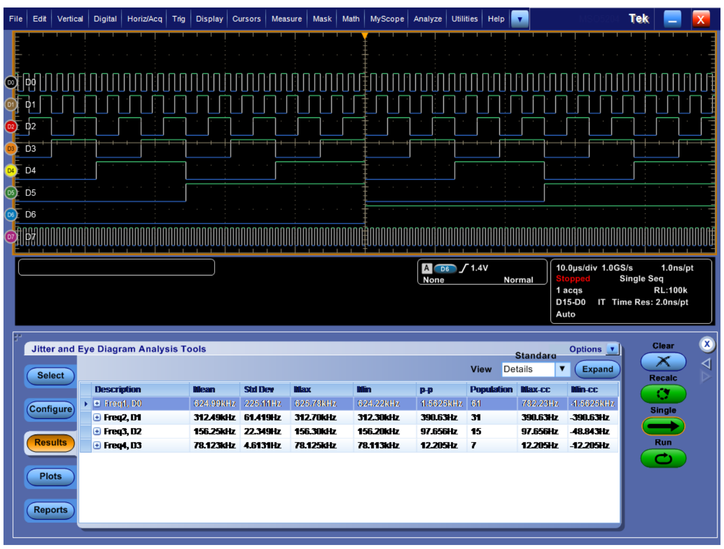
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Press the yellow channel **1** button to turn off channel 1.
- ❑ Press the blue front panel **D15-D0** button.
- ❑ Press the Turn D7-D0 **On** button.
- ❑ Press the Trigger **Menu** button.
- ❑ In the **Source** selector box, select **D0-D7->D6**.
- ❑ Press the **X** in the upper right corner of the control window to close it.
- ❑ Set the Horizontal **Scale** to **10 µs/div**.
- ❑ Press the front panel **Single** button.
- ❑ Launch the DPOJET application by selecting **Analyze -> Jitter and Eye Analysis (DPOJET) -> Select…**. You can also do this with the keyboard shortcuts **Alt-A**, **Alt-J**, **Alt-S**.
- ❑ Press the **Freq** button to add the Freq1 frequency measurement.
- ❑ Click on the **Source** button, click on the **Digital** tab of the selector, press the **D0** button, and press the **Close** button.

Key Take Away Points

- DPOJET can also make measurements on multiple signals:



- With the press of the Single button, the application measures the frequency of every cycle in each of the selected waveforms:

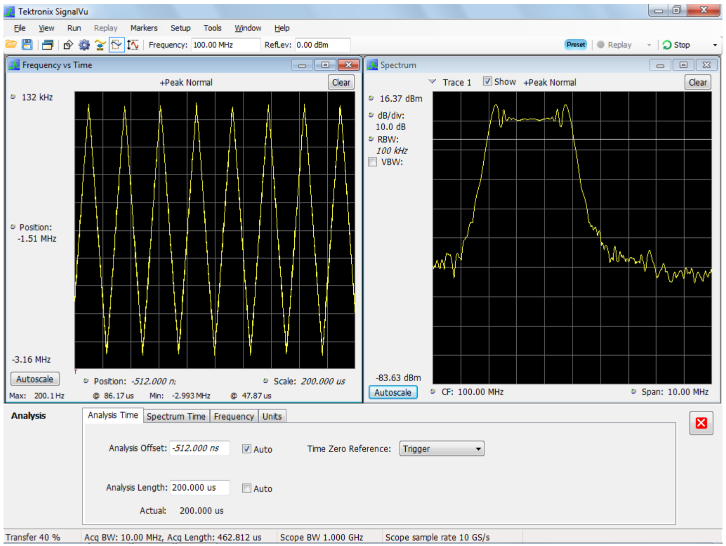


MSO/DPO5000 Series Procedure:

- ❑ Press the **Freq** button to add the Freq2 frequency measurement.
- ❑ Click on the Freq2 **Source** button, press the **D1** button, and press the **Close** button.
- ❑ Press the **Freq** button to add the Freq3 frequency measurement.
- ❑ Click on the Freq3 **Source** button, press the **D2** button, and press the **Close** button.
- ❑ Press the **Freq** button to add the Freq4 frequency measurement.
- ❑ Click on the Freq4 **Source** button, press the **D3** button, and press the **Close** button.
- ❑ Press the green **Single** button at the right side of the control window.
- ❑ Notice the measurement values in the table in the lower half of the display.
- ❑ With a single acquisition, DPOJET has made frequency measurements across many cycles of the four selected waveforms, and provided all of the statistics for those measurements.

Tektronix

MSO5000/DPO5000 Series
SignalVu Lab



Equipment List

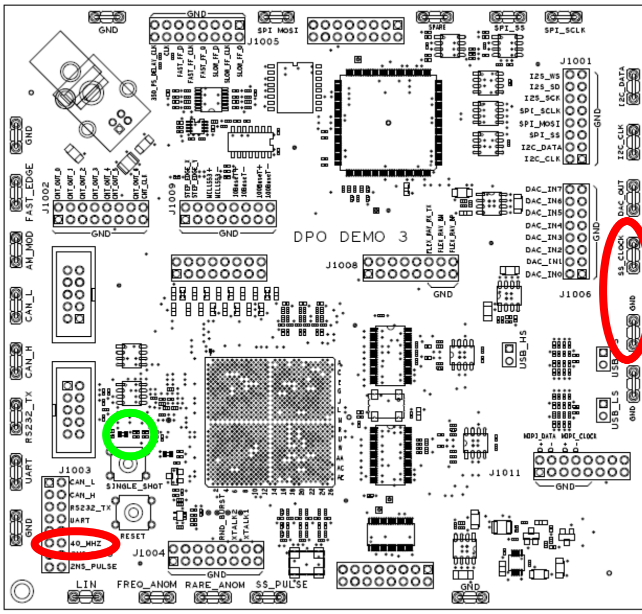
One MSO/DPO5000 Series oscilloscope with software version ≥6.1.3
and with SignalVu application (version ≥2.5.0089) installed
One TPP0500 or TPP1000 Passive Probe
Optional USB keyboard and mouse
DPO Demo 3 board and dual-A-to-single-B USB cable (679-6506-XX and 174-5959-00)

Overview of Wideband Vector Signal Analysis
SignalVu vector signal analysis software helps you easily validate wideband designs and characterize wideband spectral events. By combining the signal analysis software of the RSA Real-Time Spectrum Analyzer with that of the industry's widest bandwidth digital oscilloscopes, designers can now evaluate complex signals without an external down converter. You get the functionality of a vector signal analyzer and spectrum analyzer combined with the powerful trigger capabilities of a digital oscilloscope — all in a single package. Whether your design validation needs include wideband radar, high data rate satellite links or frequency hopping communications, SignalVu vector signal analysis software can speed your time-to-insight by showing you the time variant behavior of these wideband signals.
Objectives - Obtain a basic understanding of SignalVu spectrum analysis. - Learn how to set up and demonstrate marker measurements on a spectrum analyzer display of a clock signal. - Learn how to easily make magnitude vs. frequency and frequency vs. time measurements on a spread spectrum clock signal.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

- The DPO Demo 3 board (679-6506-XX) has a 40 MHz clock and a 100 MHz spread-spectrum SS_CLK signal which we will use for this lab.



Demo Board Procedure

- ❑ Attach the two host connectors on the USB cable to the oscilloscope and then connect the device connector on the cable to the demo board.
- ❑ Verify the power LED is lit.
- ❑ Attach a passive probe to the Channel 1 input of the oscilloscope.
- ❑ Attach the probe ground to the **GND** test point on the test board.
- ❑ Connect the probe tip to the **40_MHz** test point on the test board.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.

Key Take Away Points

- The SignalVu application provides vector signal analysis software and spectrum analysis capabilities for Windows-based real-time oscilloscopes such as the MSO/DPO5000 Series.
- SignalVu Essentials provides the basic RF measurement capabilities. Additional wideband RF analysis tools are also available, such as SVM Modulation Analysis, SVP Pulse Measurements, and SVT Setting Time Measurements.

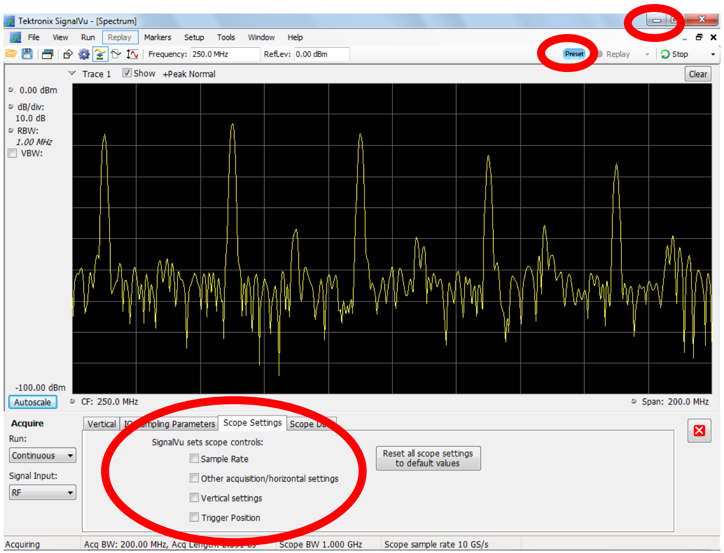
MSO/DPO5000 Series Procedure:

- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope….**
- ❑ Verify that the **SVE: SignalVu Essentials** option is installed.
- ❑ See if options **SVM**, **SVP**, and **SVT** are also installed.
- ❑ Press the **OK** button.

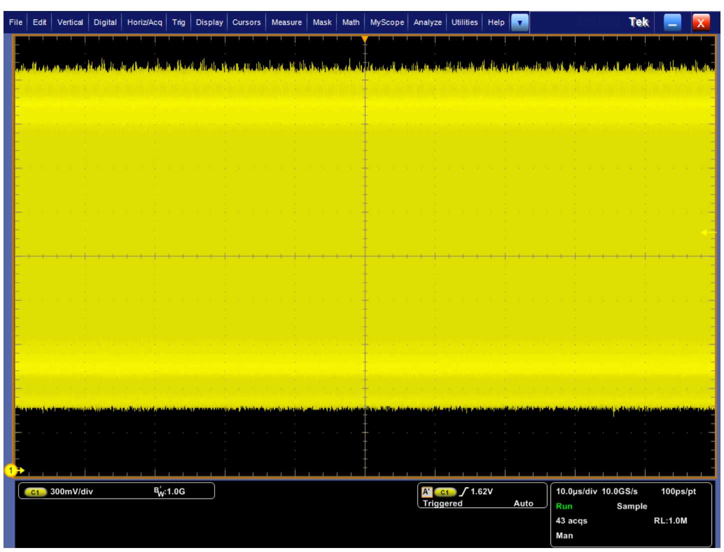
One-Time SignalVu Setup for Oscilloscopes

Key Take Away Points

- First, as a one-time setup activity, we need to disable SignalVu from over-riding the oscilloscope settings. SignalVu's defaults are optimized for RF signals at 50Ω impedance levels, not general-purpose scope settings and high-impedance probes.

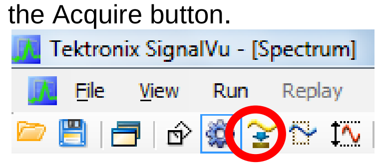


- Now we need to optimize the oscilloscope's acquisition of the signal. To get the best signal-to-noise ratio performance, you want to scale and position the signal so it fills most of the screen vertically. Signal Vu has already set the sample rate to the maximum real-time sample rate of the oscilloscope. To improve the time-resolution (and therefore the frequency resolution), increase the record length significantly:



MSO/DPO5000 Series Procedure:

- ❑ Select **Analyze->SignalVu Vector Signal Analysis Software** to launch the SignalVu application.
- ❑ Press the blue **Preset** button at the top of the display to restore the SignalVu application to a known starting point.
- ❑ Select **Setup->Acquire** or press the Acquire button.

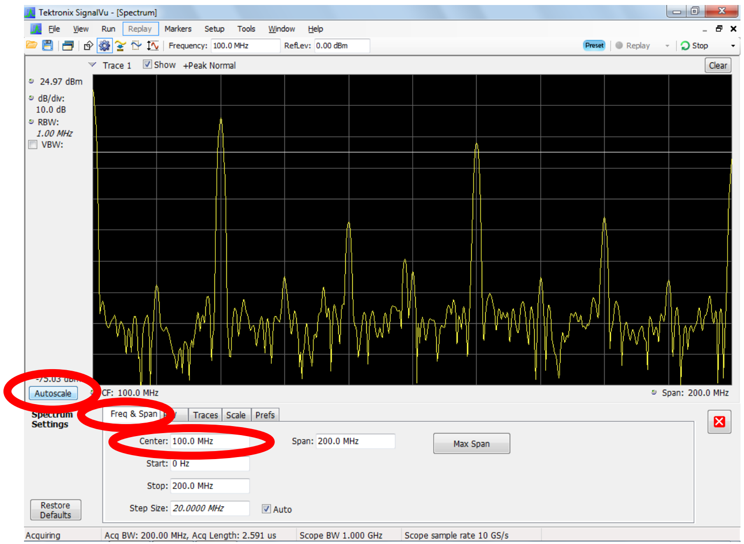


- ❑ Click on the **Scope settings** tab and remove the check marks next to **Sample Rate**, **Other acquisition/horizontal settings** and **Vertical settings**, and **Trigger Position**.
- ❑ Minimize the SignalVu application.
- ❑ Adjust the Vertical **Scale** and **Position** so the signal fills about 80% of the display.
- ❑ Notice that SignalVu has already set the **Sample Rate** to **10 GS/s**.
- ❑ Set the Horizontal **Scale** to **10µs/div**. Notice that this also sets the Record Length to 1 Mpoints.

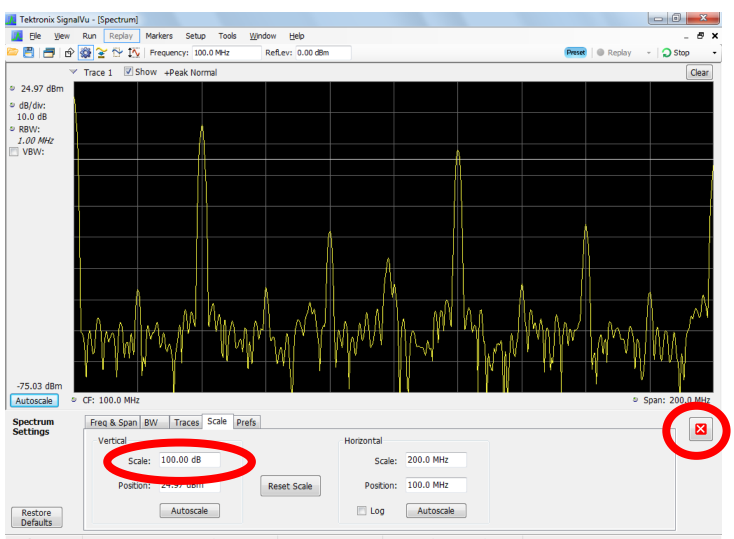
SignalVu Spectrum Analysis Measurements

Key Take Away Points

- We know that the signal is nominally a 40 MHz clock, so we set the center frequency to 100 MHz so we can easily see the 40 MHz fundamental and the first few harmonics:

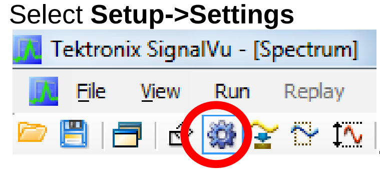


- Notice the horizontal Center Frequency and Span readouts just below the display.
- Also notice the vertical Scale, Position, and Resolution Bandwidth readouts at the upper left side of the display:



MSO/DPO5000 Series Procedure:

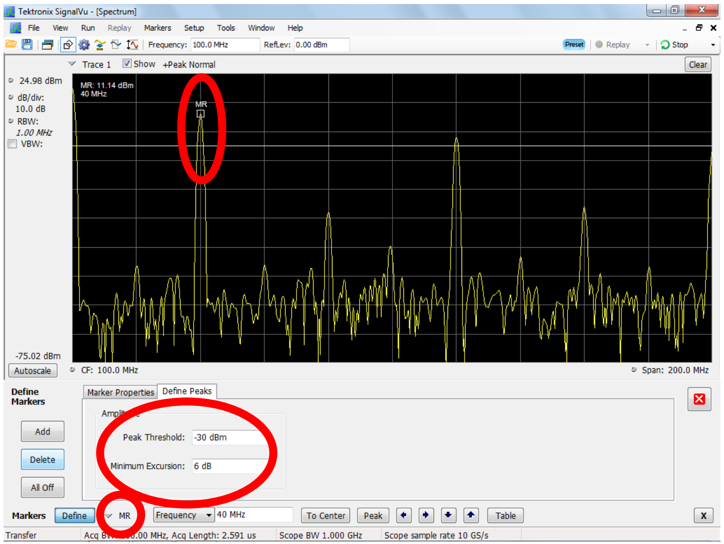
- ❑ Maximize the SignalVu application. One way to do this is to use the keyboard's **Alt-Tab** to select the application.
- ❑ Select **Setup->Settings**



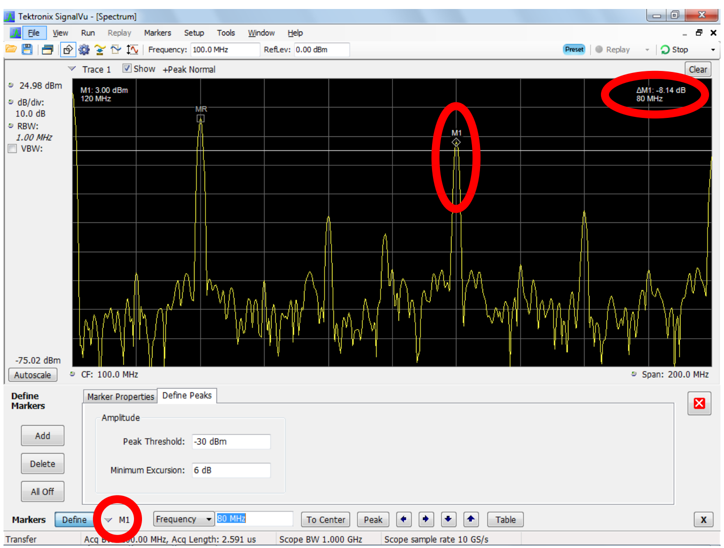
- ❑ Click on the **Freq & Span** tab.
- ❑ Click on the **Center:** text box and set the value to **100 MHz**. You can also edit this value directly in the CF text box at the lower left corner of the graticule.
- ❑ Press the **Autoscale** button at the left side of the display to automatically scale the display vertically.
- ❑ Click on the **Scale** tab.
- ❑ Notice that the Vertical Scale is set to 100.00 dB. This corresponds to 10 dB/div. You can also edit this value directly in the dB/div text box at the upper left corner of the graticule.
- ❑ Click on the red **X** in the upper right corner of the control window.

Key Take Away Points

- We can easily make magnitude and frequency measurements on the SignalVu spectrum display by turning on markers:



- By turning on a pair of markers, we can make relative magnitude and frequency between the two markers:

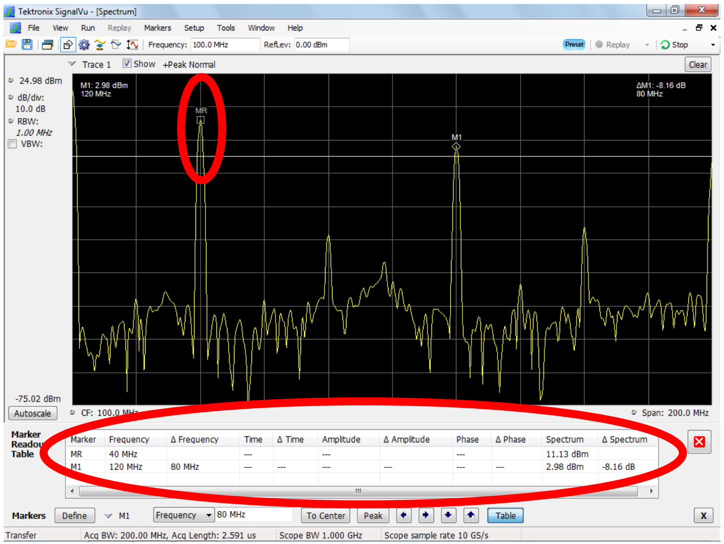


MSO/DPO5000 Series Procedure:

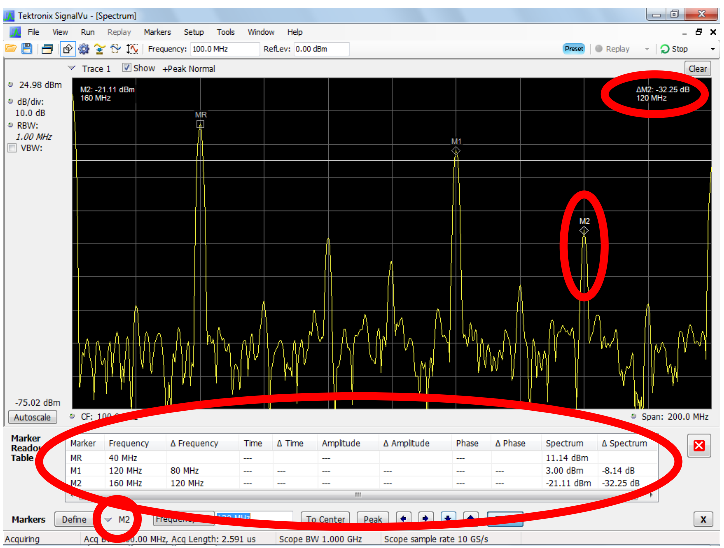
- ❑ Right click on the graticule and select **Marker to peak**. Notice that a square reference marker (MR) is positioned on the highest peak of the spectrum, probably at the left side of the display (DC).
- ❑ Left click on the marker and drag it horizontally. Position the marker on the first peak to the right of DC (the clock's fundamental frequency at about 40 MHz).
- ❑ Also, notice that the Markers control window is displayed at the bottom of the display.
- ❑ Press the **Define** button.
- ❑ Click on the **Define Peaks** tab.
- ❑ Set the **Peak Threshold** value to **-30 dBm**. This defines peaks as those signals which exceed the -30 dBm level.
- ❑ Verify that the **Minimum Excursion** value is **6 dB**. This specifies how much the signal must decrease and then increase before another peak can be declared.
- ❑ Press the **Add** button at the left side of the control window to add a second marker.
- ❑ Click the right and left arrow buttons to automatically move the second marker (M1) between peaks.
- ❑ Notice the readout in the upper right corner of the graticule which shows the relative magnitude and frequency between the two markers.

Key Take Away Points

- SignalVu also provides a tabular display of marker measurements:



- The table display can be used to show multiple absolute and relative magnitude and frequency measurements:



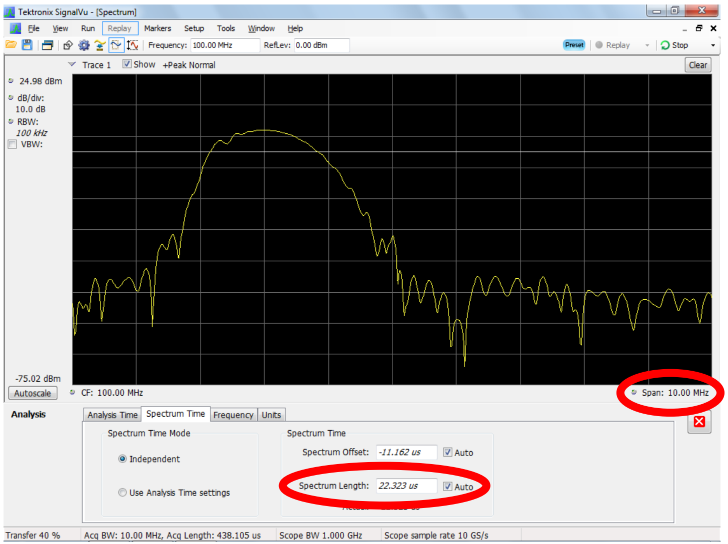
MSO/DPO5000 Series Procedure:

- ❑ Press the **Table** button at the bottom of the display.
- ❑ Right click on the graticule and select **Add marker**. Notice that a square marker (M2) has been added at the center of the display.
- ❑ Using the right and left arrow buttons, position marker M2 on another peak.
- ❑ Notice the absolute and relative magnitude and frequency readout in the table.
- ❑ Also notice the readout in the upper right corner of the graticule. Since marker M2 is the selected marker, the readout shows the relative magnitude and frequency between markers M2 and MR.
- ❑ When you are done, right click on the graticule and select **All markers off**.
- ❑ Click on the red **X** in the upper right corner of the control window.

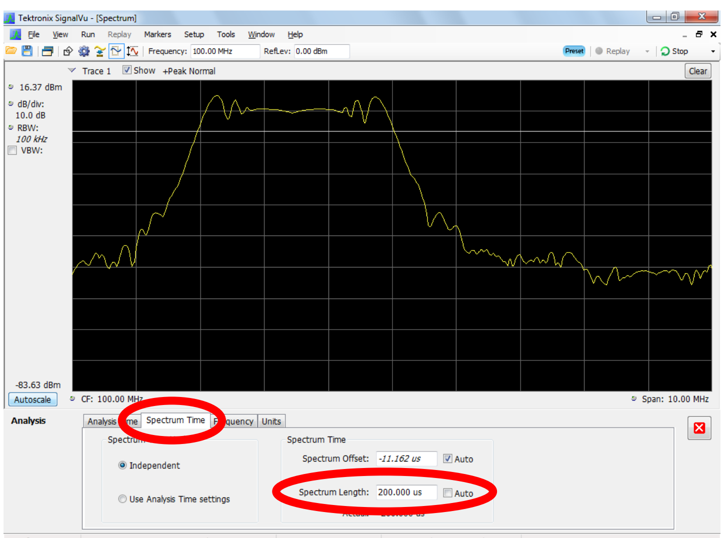
Analyzing Spread Spectrum Clock Signal

Key Take Away Points

- This is the SignalVu spectrum analyzer display of the 100 MHz spread spectrum clock signal:

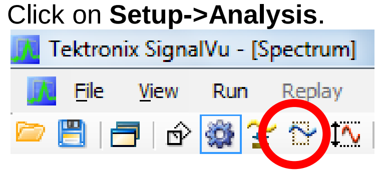


- The side-to-side motion of the spectrum indicates that the spectrum length may be less than the period of the frequency modulation.
- By increasing the spectrum length, we see the flat spectrum we saw in the DPOJET lab, indicating that the frequency is being swept between about 97 and 100 MHz:



MSO/DPO5000 Series Procedure:

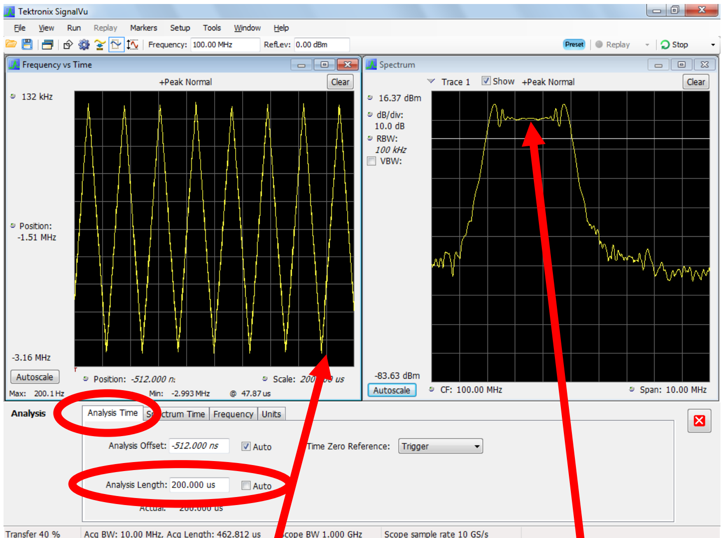
- ❑ Minimize the SignalVu application.
- ❑ Move the probe tip to the **SS_CLOCK** test point on the test board.
- ❑ Adjust the Vertical **Scale** and **Position** so the signal fills about 80% of the display.
- ❑ Set the Horizontal **Scale** to **50µs/div**. Notice that this also sets the Record Length to 5 Mpoints.
- ❑ Press the keyboard's **Alt-Tab** to maximize the SignalVu application.
- ❑ Click on the Span readout in the lower right corner of the display and type in "**10M**" to set the span to 10 MHz.
- ❑ Click on **Setup->Analysis**.



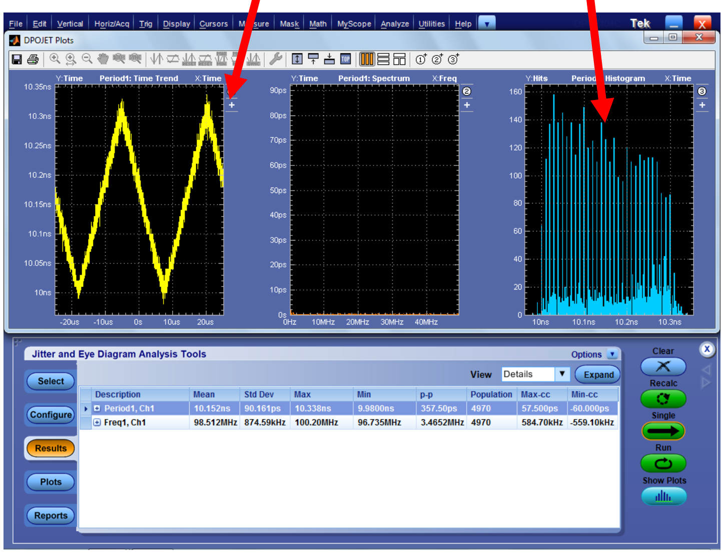
- ❑ Click on the **Spectrum Time** tab.
- ❑ Notice that the Spectrum Length is only about 22 µs of time. The side-to-side motion of the spectrum indicates that the spectrum length may be less than the period of the frequency modulation.
- ❑ Deselect the **Auto** check box next to Spectrum Length.
- ❑ Double-click on the **Spectrum Length** text box and set the value to **200.000 us**.
- ❑ Press the **AutoScale** button at the left side of the display.

Key Take Away Points

- Notice how the SignalVu displays of Frequency vs. Time and Magnitude vs. Frequency:



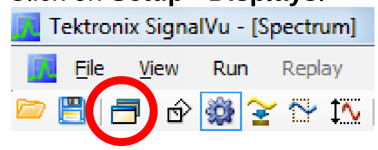
- Compare these to the corresponding plots in the DPOJET lab:



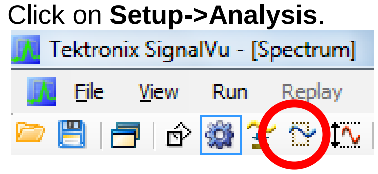
- In this lab section, we easily analyzed the spread spectrum clock signal and verified that this is the same triangular modulation we saw in the DPOJET lab. (Note that the default histogram plot in DPOJET is of period measurements, the reciprocal of the frequency displayed with SignalVu, but the shapes are similar.)

MSO/DPO5000 Series Procedure:

- ❑ Click on **Setup->Displays**.



- ❑ Double-click on the **Frequency vs Time** icon and press **OK**.
- ❑ Click on **Setup->Analysis**.



- ❑ Click on the **Analysis Time** tab.
- ❑ Notice that the Freq vs Time display is showing only about 5 µs of time.
- ❑ Deselect the **Auto** check box next to Analysis Length.
- ❑ Set the **Analysis Length** to **200.000 us**.
- ❑ Press the **AutoScale** button in the Frequency vs Time display.

TEK-DPG

Deskew Pulse Generator
Application Lab
Minimizing Skew in Power Measurements

Equipment List
One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
One TEK-DPG Deskew Pulse Generator
One 067-1686-00 Power Measurement Deskew and Calibration Fixture
One TDP0500 or TDP1000 Differential Probe
One TCP0030 Current Probe

The Importance of Probe Deskew for Power Measurements

Introduction

When engineers are making critical high-speed timing measurements between channels, they usually recognize the need to carefully match the delays through their probes. This may be simplified by using the same kind of probes whenever possible. The actual skew can be verified by connecting all of the probes to a common signal source, even the PROBE COMP signal on the front of the oscilloscope and verifying that the timing of all of the waveforms is matched.

But why is probe skew a concern for low-speed applications such as power measurements? First, even if the power supply's switching frequency is below 1 MHz, the rise-times of the switching waveforms may be on the order of 1 ns. Second, the phase relationships between voltages and currents in a switching device are very critical in determining the amount of power instantaneously dissipated in the switching device.

The 067-1686-00 Power Measurement Deskew and Calibration Fixture

The 067-1686-00 fixture converts a pulse signal into a set of test point connections. These connections provide you with a convenient way to compensate for timing differences between voltage and current probes and the signal paths within the oscilloscope.

This fixture can be used with a variety of passive, active, differential, and current probes. In this lab, we will concentrate on some of the most common power probes used with the DPO5000 and MSO5000 Series products. Please refer to the 067-1686-00 Instructions on www.tek.com for more information about other supported probes.

The TEK-DPG Deskew Pulse Generator

The TEK-DPG Deskew Pulse Generator is a signal-generating accessory for select Tektronix oscilloscopes that feature the TekVPI interface.

- In this lab, we will use the TEK-DPG and the 067-1686-00 to manually optimize power probe deskew. We will also demonstrate the measurement errors that can occur because of probe skew.

Manual Deskew Procedure for Power Probes with the MSO/DPO5000 Series

Oscilloscope Setup Procedure:

- ❑ Plug in and turn on the oscilloscope.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope to a known state.
- ❑ Connect the TDP1000 or TDP0500 differential probe to channel 1.
- ❑ Press the front panel **2** button to display channel 2.
- ❑ Connect the TCP0030 current probe to channel 2. (Notice that the vertical readout automatically shows the correct units of Amperes.)
- ❑ Connect the TEK-DPG to channel 3.
- ❑ Press the front panel **3** button to display the trigger signal on channel 3.
- ❑ Connect the TEK-DPG's BNC connector to Port A on the deskew fixture.
- ❑ NOTE: For best results, warm up the equipment for 20 minutes before making critical adjustments.

Key Take Away Points

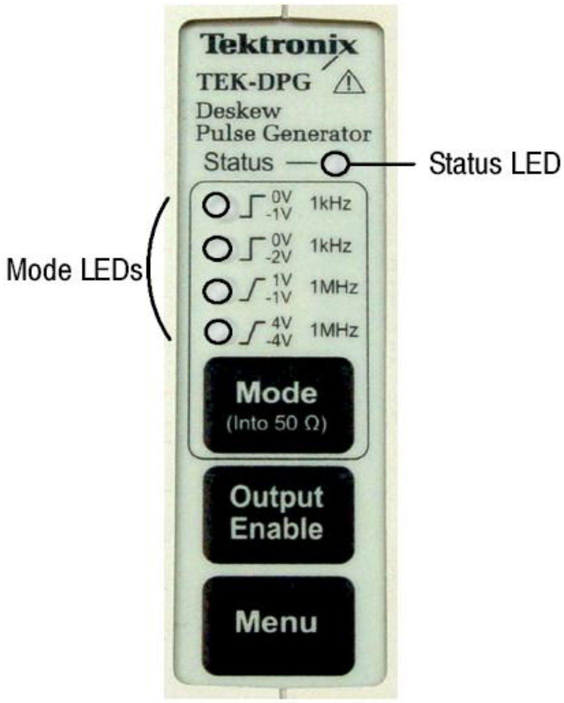
- TDP0500 / TDP1000 and TCP0030 connections:

Test Procedure:

- ❑ Short the TDP0500 or TDP1000 probe tips together.
- ❑ Press the **Menu** button on the TDP probe.
- ❑ Make sure that the **Range** is set to **4.25 V**. If necessary, change the mode to **Manual**.
- ❑ Press the **AutoZero** side bezel button to remove any DC offsets from the probe and channel input.
- ❑ Connect the TDP probe to the long square pins on the deskew fixture as shown at the left, with the **–** input to ground.
- ❑ Press the **Menu** button on the TCP0030 current probe.
- ❑ Select the **5A** range, either by pressing the **Range** button on the probe or the side bezel button on the oscilloscope until the **5A range** is selected.
- ❑ Make sure that the current probe's jaw is closed.
- ❑ Press the **Degauss AutoZero** button on the probe.
- ❑ Connect the TCP0030 probe to the deskew fixture as shown at the left.

Key Take Away Points

- To more precisely set the propagation delays, let's see how to use the TEK-DPG and deskew fixture with these probes.
- Controls and readouts on the TEK-DPG:

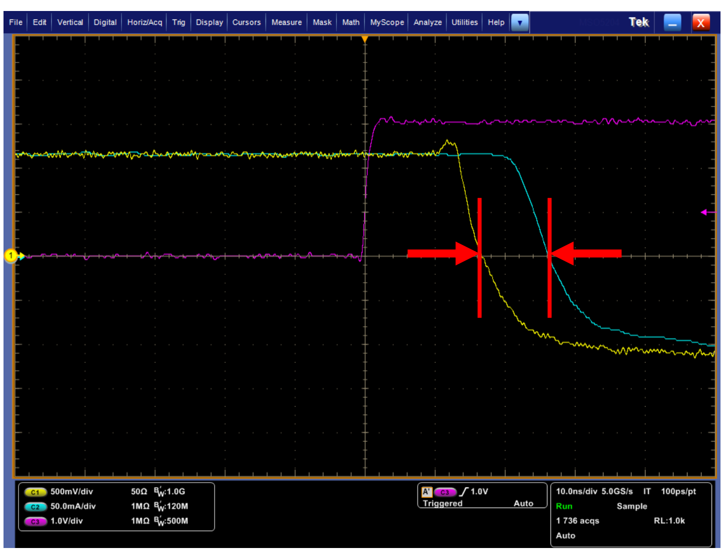


Test Procedure:

- ❑ Notice the interface of the TEK-DPG.
- ❑ The Status LED glows amber at power-on to indicate the generator is on and the output at the BNC cable is not enabled.
- ❑ Press the **Mode** button until the 3rd green Mode LED (±1V_{pk-pk} 1 MHz signal with <1 ns risetime) is lit.
- ❑ Press the **Output Enable** button and notice that the Status LED is now green. If the LED glows red, disconnect and reconnect the generator to clear the fault that may have occurred.

Key Take Away Points

- The TEK-DPG and deskew test fixture provide a very simple and convenient way to provide a timing signal to multiple probes at a time:



- Notice that the skew between channels in the screen shot above is about 10 ns.

MSO/DPO5000 Series Procedure:

- ❑ Set the channel 1 Vertical **Scale** to about **500 mV/div**.
- ❑ Set the channel 2 Vertical **Scale** to about **50 mA/div**.
- ❑ Set the channel 3 Vertical **Scale** to about **1 V/div**.
- ❑ Set the Horizontal **Scale** to **10 ns/div**.
- ❑ Select **Trig->Edge Setup….**
- ❑ Since the signal from the TEK-DPG is the timing reference for deskewing the probes, we will select it as the trigger source. Press the right arrow in the **Source** selection text box and select **Ch3**.
- ❑ Set the Trigger **Level** to about **1V**.

Key Take Away Points

- For some low-frequency applications, adequate measurement performance can be achieved simply by ignoring the differing propagation delays of the probes.
- And, the propagation delays between probes tend to be fairly small, when all of the probes are the same model.
- However, for most high-speed applications and whenever you use a combination of different probes, it is very important to correctly account for these timing differences.
- Using the TEK-DPG signal as the timing reference, and deskew test fixture provide a very simple and convenient way to manually remove skew between channels. First, we align channel 1 to the signal source:

MSO/DPO5000 Series Procedure:

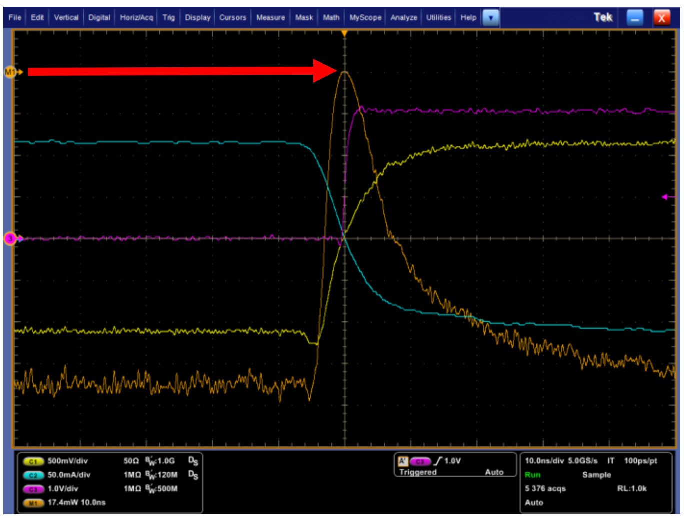
- ❑ Select **Vertical->Deskew….**
- ❑ Click on the **Ch1 Deskew Time** text box to attach the Multipurpose **a** control.
- ❑ Adjust the Multipurpose **a** control until the falling edge of the channel 1 signal is centered in the graticule.
- ❑ Notice that the **DS** icon appears next to the channel 1 vertical readout, indicating that deskew is in use.

- Next we align channel 2 to the signal source:

- ❑ Press the **Channels 2** button in the control window.
- ❑ Adjust the Multipurpose **a** control until the falling edge of the channel 2 signal is centered in the graticule.
- ❑ Notice that the **DS** icon also appears next to the channel 2 vertical readout, indicating that deskew is in use.

Key Take Away Points

- So why is proper deskew important for low-frequency power measurements?
- Consider that a typical power measurement is made by measuring the voltage across a power switching device (like with the differential probe on channel 1) and the current flowing through the switching device (like with the current probe on channel 2) and multiplying the waveforms together to get the instantaneous power, as shown below.
- The voltage across and the current flowing through a typical switching device are square waves that are 180 degrees out of phase. To simulate this, we will use the higher-frequency deskew pulse signal and invert the channel 1 signal.
- With properly deskewed probes, when the math multiply waveform is calculated, we would expect that a positive signal times a negative signal would result in a negative product, which it does in the display below.
- Notice that the math product of the two waveforms is zero at the point where the two signals are both crossing through zero volts:

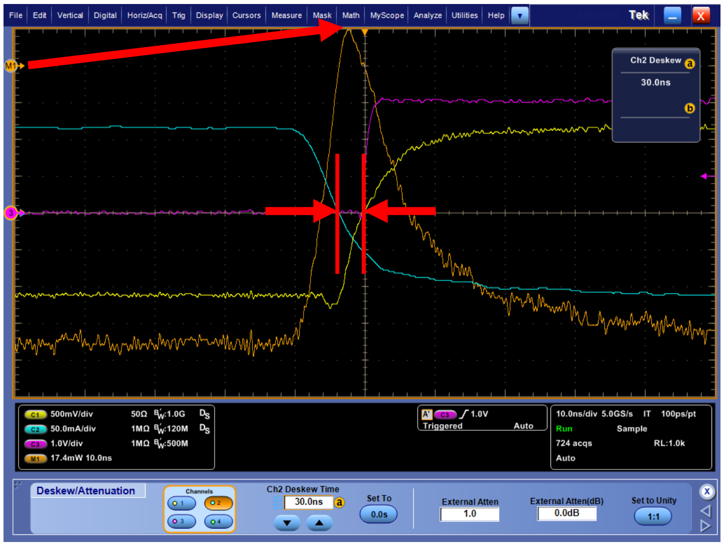


Test Procedure:

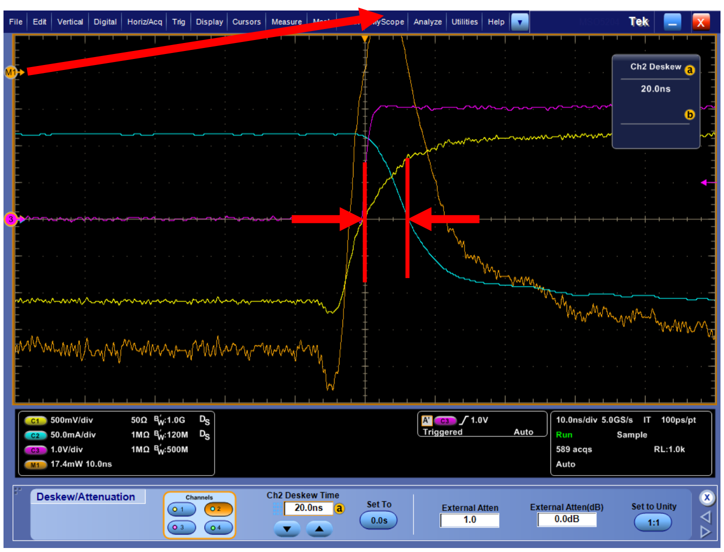
- ❑ Reverse the TDP0500 / TDP1000 connection on the deskew test fixture, such that the **+** input is connected to ground and the **–** input is connected to the signal.
- ❑ Select **Math->Ch1 * Ch2**.

Key Take Away Points

- However, when the probes are not properly deskewed, notice that the product becomes positive during the transitions when the signals are both negative:



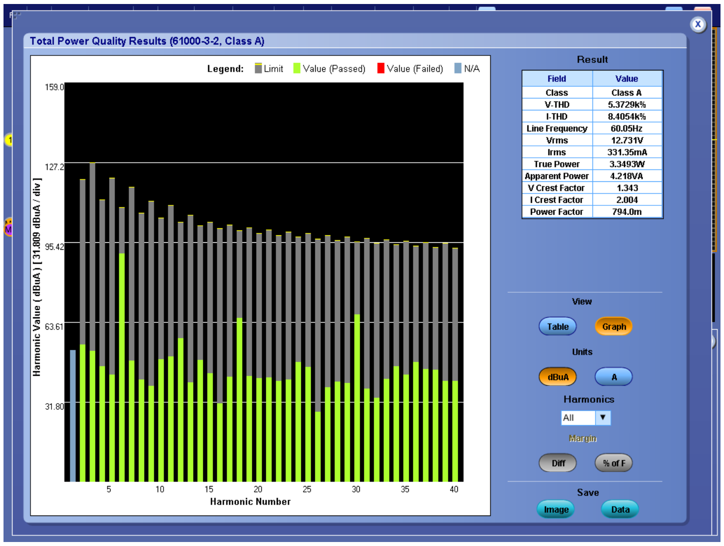
- Notice that the product also becomes positive during the transitions when the signals are both positive:



- Notice the substantial change in shape and amplitude of the math waveform. As you can see from this very simple example, it is critical to properly deskew your probes to make accurate timing measurements, or measurements such as power which are very sensitive to timing errors.
- Also, remember that timing errors in YT displays correspond to phase errors in XY displays. For example, when looking at a 10 MHz signal, a deskew error of only 1 ns results in a 3.6 degree error.

Test Procedure:

- ❑ Select **Vertical->Deskew….**
- ❑ Press the **Channels 2** button in the control window.
- ❑ Click on the **Ch2 Deskew Time** text box to attach the Multipurpose **a** control.
- ❑ Turn the Multipurpose **a** control clockwise to increase the value of the channel 2 deskew.
- ❑ Notice that the peak value of the math product becomes positive as the signals cross at a negative voltage.
- ❑ Turn the Multipurpose **a** control counter-clockwise to decrease the value of the channel 2 deskew.
- ❑ Notice that the peak value of the math product also becomes positive as the signals cross at a positive voltage.
- ❑ Double-click on the **Ch2 Deskew Time** text box to display the pop-up keypad.
- ❑ Click on the **Max** button and then click on the **Min** button. Notice that the total available deskew range is ±75 ns.



Equipment List

One MSO/DPO5000 Series oscilloscope with software version ≥6.1.1
and with the DPOPWR application (version ≥1.0.10) installed
Optional USB keyboard and mouse
One TPP0500 or TPP1000 Passive Probe
One TDP0500 or TDP1000 Differential Probe
One TCP0030 Current Probe
One 878-0544-XX power demo board or 3PQS power demo board, and 12VAC power adapter
[Note: screen shots in this document were made with 878-0544-XX demo board]

For the optional power efficiency section, the following additional equipment is needed:
Another TDP0500 or TDP1000 Differential Probe
Another TCP0030 Current Probe
An external power supply accessory (Tek Part Number 119-7465-xx).

Overview of Automatic Power Measurements

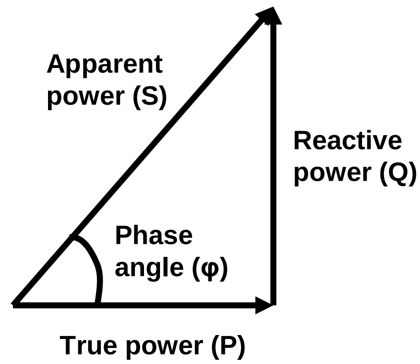
The DPOPWR application module enables consistent, automatic measurements of most common power supply measurements, including:

- Power Device Measurements
  - Switching Loss, which provides a table of measurements and measurement statistics for the losses across each acquired waveform, including:
    - Turn-on, Turn-off, and Total Power Loss
    - Turn-on, Turn-off, and Total Energy Loss
  - Hi-Power Finder
  - Safe Operating Area (SOA), which includes:
    - an X-Y display of the switching device voltage and current
    - mask testing of the signals relative to a graphical description of the device specification limits
  - dv/dt and di/dt Measurements,
    - a slew rate measurement, added to the cursor readout, between the cursors on the selected waveform
  - RDS(on)
  - Modulation Analysis, which generates a graphical display of the specified measurement values across the acquired waveform, showing the variations in the modulated switching signal
    - Pulse Width
    - Duty Cycle
    - Period
    - Frequency

- Magnetics Measurements
  - Inductance
  - Magnetic Property
  - Magnetic Loss
  - I vs. ∫V

- Report Generator

- Input/Output Analysis
    - Power Quality, which provides a single table of measurements and measurement statistics for the AC input section of a power conversion circuit, including:
        - the RMS voltage and current
        - true power (P), the actual power delivered to the resistive part of the load, measured in Watts. It is also V_{RMS} * I_{RMS} * cos(φ)
        - apparent power (S), the product of the RMS voltage and current (mathematically, the absolute value of the vector sum of the true and reactive power), measured in Volt-Amperes or VA
        - voltage and current crest factors, which are the peak-to-RMS ratios for the signals
        - frequency
        - power factor, the ratio of true power to apparent power. (If the signals are pure sine waves, the power factor is the cosine of the phase angle between the current and voltage waveforms.)
        - NOTE: reactive power and phase angle are not explicitly measured and displayed by DPOPWR, but can be easily derived from the other measurement results.
            - reactive power (Q), the power delivered to and temporarily stored in the reactive (inductive or capacitive) elements of the load, measured in Volt-Amperes Reactive or VAR
            - phase angle (φ), which is the angle between the real and apparent power vectors, equal to the impedance phase angle



    - Current Harmonics, which provide a frequency-domain view of the AC input and pre-compliance to the following standards:
        - IEC 61000-3-2
        - IEC 61000-3-2 with AM14
        - MIL-STD-1399
    - Total Power Quality, which provides Power Quality and Current Harmonics measurements in a single display.
    - Line Ripple
    - Switching Ripple
    - Spectral Analysis
    - Turn On Time

In this lab, we will go through each of these measurement areas, starting with the input circuitry, going through the switching circuit, and finally measuring the output circuitry. This lab is based on the 878-0544-XX power demo board. However, similar steps can be used to make these measurements on another power demo board or a power supply circuit. (Be sure to use probes with appropriate maximum ratings.)

There is a lot of information about the DPOPWR application available through the MSO/DPO5000 Help system. Select **Help -> Help on Power Analysis**.

Objectives

- Obtain a basic understanding of power measurements.
- Learn how to use oscilloscopes to measure power supply parameters.
- Learn how to set up and demonstrate power supply measurements with an MSO/DPO5000 Series oscilloscope.

MSO/DPO5000 Series Lab Setup

Key Take Away Points

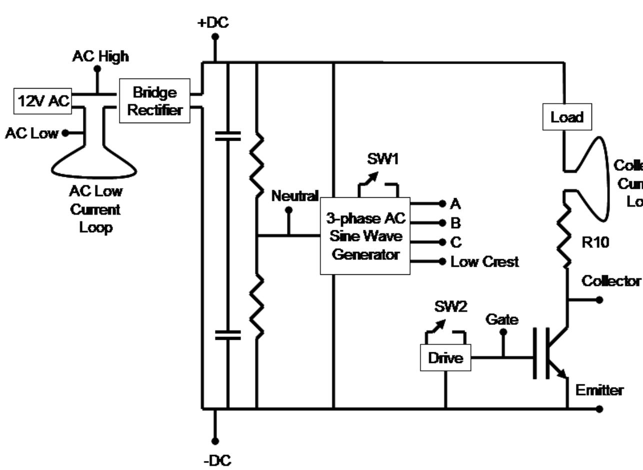
- With the optional DPOPWR application installed, the MSO/DPO5000 Series oscilloscope can make a variety of automatic power measurements.

MSO/DPO5000 Series Procedure:

- ❑ Power up the oscilloscope.
- ❑ Select **Help -> About TekScope….**
- ❑ Verify that the optional **DPOPWR: Power Measurement and Analysis Software** application is installed.
- ❑ Press the **OK** button.

Key Take Away Points

- The 3PQS Power Demo board has a variety of power signals which we can use for this lab. However, this demo board does not support some measurements such as the magnetics measurements.



- The switching device on the 3PQS Power Demo board is an Insulated Gate Bipolar Transistor (IGBT) and has a V_{CEsat} of about 1.8V.

3PQS Power Demo Board Procedure:

- ❑ Connect the 12VAC power adapter to the demo board and plug it in. NOTE: This must be an AC-output adapter. A normal DC-output adapter will not work.
- ❑ NOTE: Most voltages on this power demo board are not referenced to ground. Do not use standard passive probes and do not connect probe grounds on this board. Instead, use the recommended differential and current probes.
- ❑ NOTE: No voltage potential on the board exceeds 30 Volts. However, some of the components on this board do get very warm.

Key Take Away Points

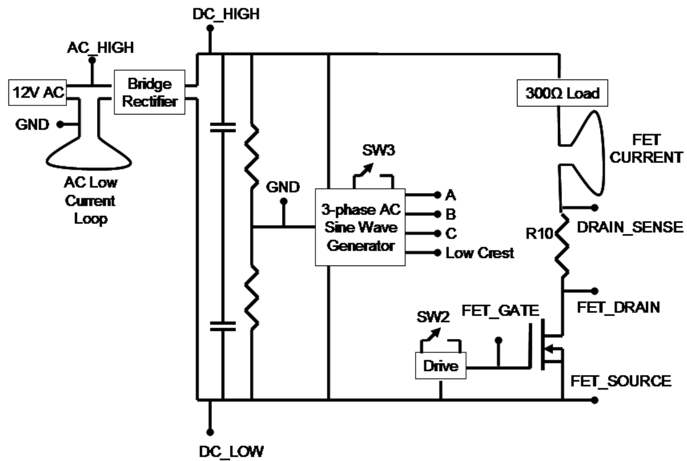
- The 878-0544-XX Power Demo board is the preferred demo took and has a variety of power signals which we can use for this lab:

878-0544-XX Power Demo Board Procedure:

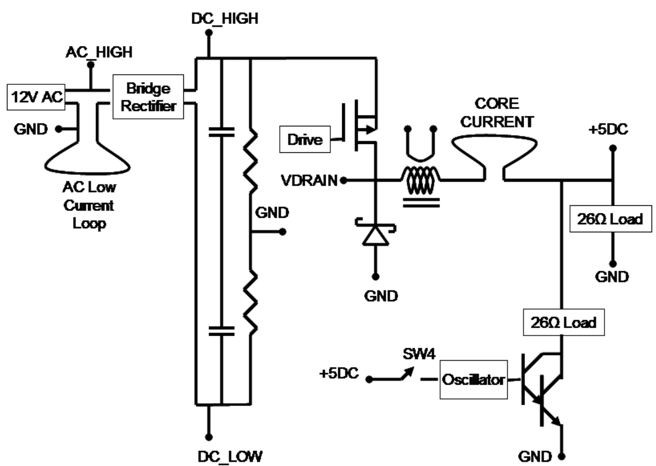
- ❑ Connect the 12VAC power adapter to the demo board and plug it in. NOTE: This must be an AC-output adapter. A normal DC-output adapter will not work.
- ❑ NOTE: Most voltages on this power demo board are not referenced to ground. Do not use standard passive probes and do not connect probe grounds on this board. Instead, use the recommended differential and current probes.
- ❑ NOTE: No voltage potential on the board exceeds 30 Volts. However, some of the components on this board do get very warm.

Key Take Away Points

- The 878-0544-XX Power Demo board combines most of the features of two previous power demo boards, the 3PQS board (which was introduced with the TPS2000 Series oscilloscopes) and the PQS board (which was introduced with the TDSPWR power measurement application.
- When SW1 is in the left position, the board functions much like the 3PQS board. The simplified schematic looks like this:



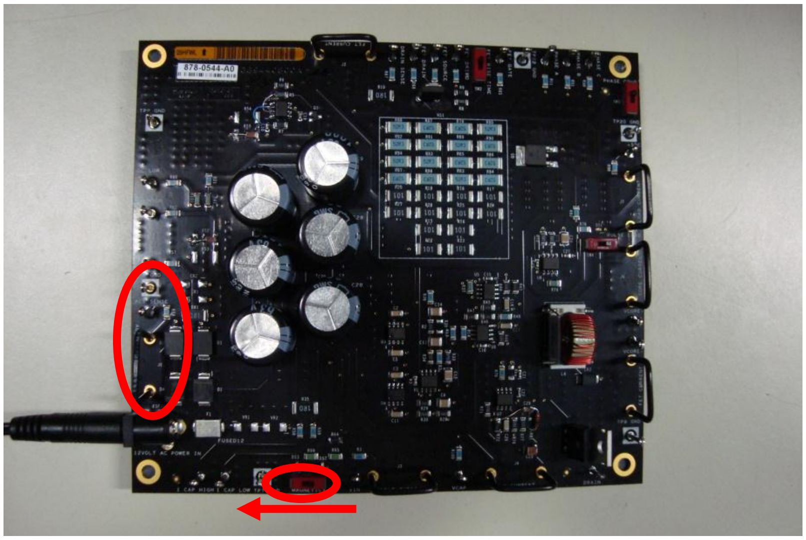
- The switching device on the 878-0544-XX Power Demo board is a MOSFET and has an R_{DSon} of about 26mΩ.
- When SW1 is in the right position, the board functions much like the PQS board. The simplified schematic looks like this:



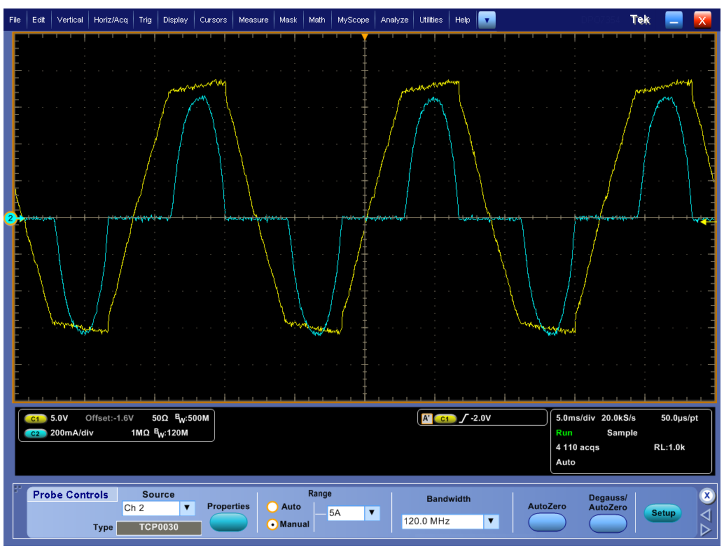
878-0544-XX Power Demo Board Procedure:

Key Take Away Points

- To demonstrate power quality measurements, this section of the lab measures the input voltage and current to the demo board.



- The display should look about like this:



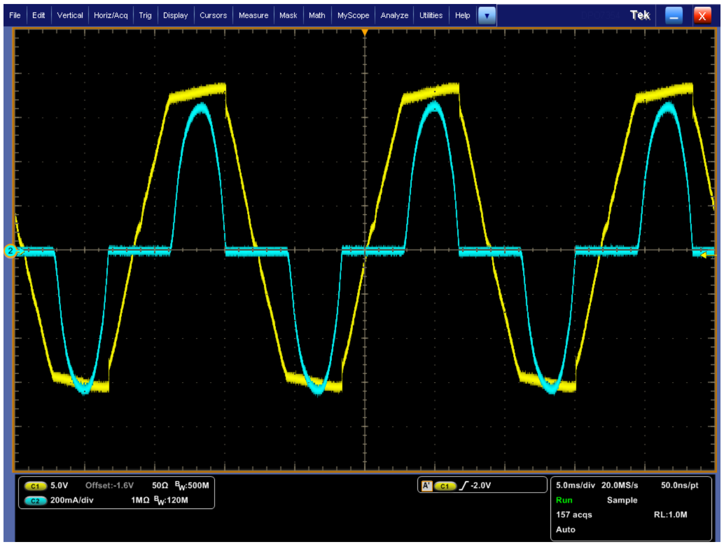
- For simple and good quality high-voltage and current measurements, let the oscilloscope automatically choose the probe attenuation ranges. However, to optimize the performance (such as improving signal-to-noise ratio of the current measurement, in this case), it is better to choose manual probe range selection and set the range so the signal fills most of the probe range. For example, in this case, the current is less than 1 Amp, so the measurement quality in the 5 Amp range will be better than if the 30 Amp range is used.

MSO/DPO5000 Series Procedure:

- ❑ On the demo board, move **SW1** to the left position.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 1 of the oscilloscope.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ In the **Range** section of the control window, select **Manual**.
- ❑ Make sure that the **Range** is set to **42V**.
- ❑ Connect the **+** and **–** inputs.
- ❑ Press the **AutoZero** button.
- ❑ Connect the **-** input of the differential probe to the **GND** test point.
- ❑ Connect the **+** input of the differential probe to the **AC High** test point.
- ❑ Set the Horizontal **Scale** to **5ms/div**.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Connect a TCP0030 current probe to channel 2 on the oscilloscope.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ In the **Range** section of the control window, select **Manual**.
- ❑ Set the **Range** to **5A**.
- ❑ Make sure that the current probe's jaw is closed. Press the **Degauss AutoZero** button on the probe.
- ❑ Connect the current probe around the **AC_CURRENT** current loop and close the probe jaws.
- ❑ Scale and position the signals as shown at the left.

Key Take Away Points

- The display should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ In this case, the voltage and current waveforms are <u>in</u> phase. If the phase of channel 2 signal is opposite of the channel 1 signal, remove the current probe, turn it over, and reconnect it.
- ❑ Select **Horiz/Acq->Resolution…** or **Horiz/Acq->Horizontal/Acquisition Setup….**
- ❑ Set the **Sample Rate** to **20 MS/s**. This will set the record length to **1M points**.

Power Probe Deskew

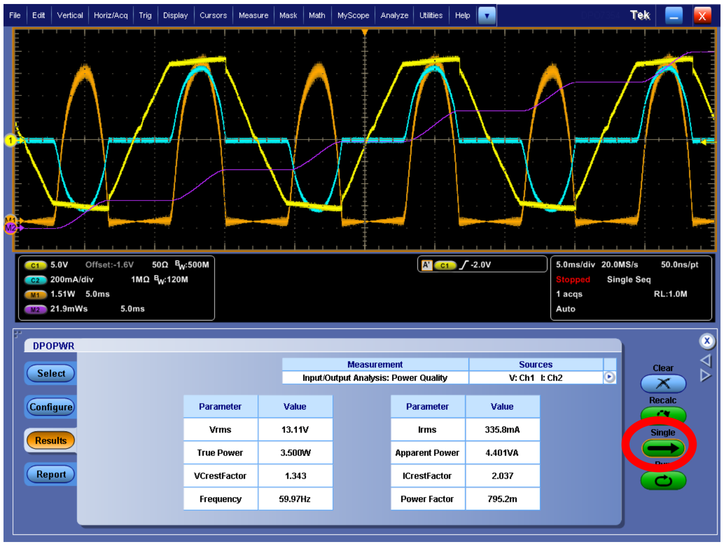
Key Take Away Points

- To make accurate power measurements, it is important to deskew the probes. This operation matching the propagation delays of the signals through the power probes. For most power measurements, it is adequate to use nominal deskew values, which can be manually selected from a long list of supported probes:

- For this lab, the display should look about like this:

MSO/DPO5000 Series Procedure:

- ❑ Select **Analyze -> Power Analysis -> Deskew**.
- ❑ Press the **Static** tab near the left side of the control window.
- ❑ In the **From** section of the control window, press the down arrow on the **Probe** drop-down box and select the appropriate probe (for example, TDP1000).
- ❑ In the **To** section of the control window, press the down arrow on the **Probe** drop-down box and select the appropriate probe (for example, TCP0030).
- ❑ Press the **Single** button at the right side of the control window to set the static deskew values.
- ❑ Notice that the vertical readout section indicates that the deskew operation has completed.

Power Quality Measurements	
Key Take Away Points • With the Power Quality measurements enabled, the display should look about like this: 	**MSO/DPO5000 Series Procedure:** ❑ Select **Analyze -> Power Analysis -> Select**. ❑ Press the **Input/Output Analysis** tab near the left side of the control window. ❑ Press the **Power Quality** button. ❑ Notice that the Sources text box shows that the voltage is on channel 1 and the current is on channel 2. ❑ Press the **Configure** button on the left side of the control window. ❑ Notice that the power waveform will appear in Math 1 and the energy waveform will appear in Math 2. ❑ Press the **Single** button on the right side of the control window.

Tektronix

Current Harmonics Measurements

The DPOPWR application makes current harmonics pre-compliance measurements according to three standards: IEC 61000-3-2, IEC 61000-3-2 with AM14, and MIL-STD-1399.

IEC-61000-3-2 Pre-compliance

IEC 61000-3-2 is a standard that defines permitted harmonic-current limits. It categorizes equipment into four classes (A, B, C and D) and imposes different harmonic-current limits on each class. It also defines cases where no limits apply. The standard was initially released in 1995, and then substantially revised in 2000, and again in 2006.

Equipment Examples:
Class A:

- Balanced 3-phase equipment
- Household appliances (not in Class D)
- Non-portable tools
- Dimmers
- Audio equipment

Class B:

- Portable Tools
- Arc Welding

Class C:

- Lighting
  - Incandescent lighting with dimmers (Power > 25 W) use Table1
  - Lighting equipment (Power > 25 W) use Table2
  - Lighting ≤ 25 W use Table3

Class D: (Input power P ≤ 600 W)

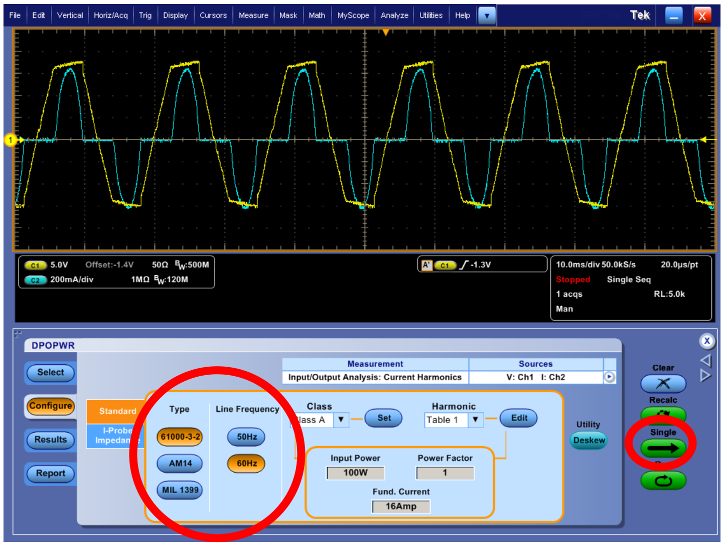
- PC
- Monitors
- TV Receivers

Input current harmonic levels are checked using both the average and maximum values over the whole test interval. Any harmonic is allowed to fluctuate up to a maximum of 150% of its limit, provided that its average value is below 100% of the limit.

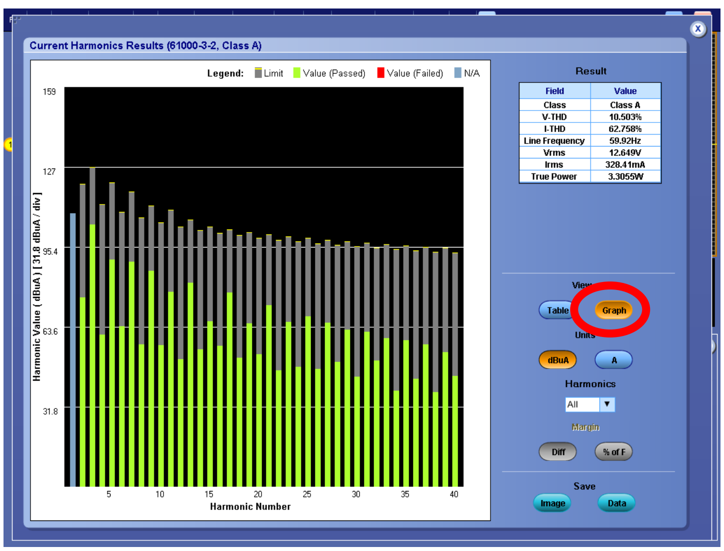
In addition, some trade-off between harmonics is allowed for odd harmonics ranging from 21 to 39, based on a value called the Partial Odd Harmonic Current (POHC), which is the RMS sum of all the odd harmonics between 21 and 39. This RMS sum is compared to the Partial Odd Harmonic Limit (POHL), which is the RMS sum of the limits for the same set of harmonics. If the actual POHC is less than the POHL, then the average value of any individual harmonic in this group may exceed 100% of its limit, again provided that no individual measurement exceeds 150% of the limit throughout the test. Obviously one or more of the other harmonics must be correspondingly less than 100% of its limit - otherwise the POHC will not be less than 100% of the POHL.

Key Take Away Points

- To demonstrate harmonics measurements, this section of the lab measures the input voltage and current to the demo board, as with the power quality measurements.
- The current harmonics can be measured according to three different industry standards. For simplicity in this demo, we will use the default IEC 61000-3-2 standard.



- With the Harmonics measurements enabled, the graphical display should look about like this:



- The harmonics can also be displayed in table format.

MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Current Harmonics** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that the **61000-3-2** Standard **Type** is selected.
- ❑ In the **Line Frequency** section, press the appropriate button for the local AC power.
- ❑ Press the **Single** button on the right side of the control window.
- ❑ You can display the current harmonic measurements in table or graph form. Press the **Graph** button.

MIL-STD-1399 Pre-compliance

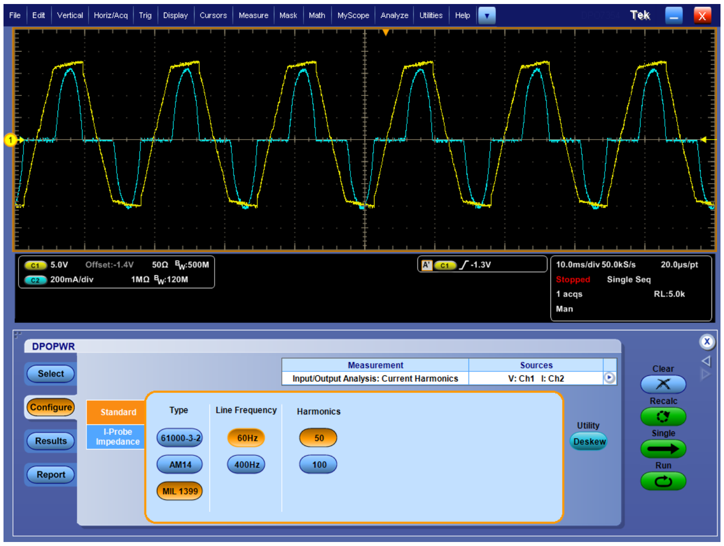
MIL-STD-1399 establishes electrical interface characteristics for shipboard equipment utilizing AC electric power to ensure compatibility between user equipment and the electric power system. The main types of shipboard electric power to be supplied from the electric power system are as follows:

- Type I – 440V or 115V, 60 Hz ungrounded (the standard shipboard electric power source).
- Type II – 440V or 115V, 400 Hz ungrounded (limited application).
- Type III – 440V or 115V, 400 Hz ungrounded, with tighter tolerances than types I and II (restricted use).

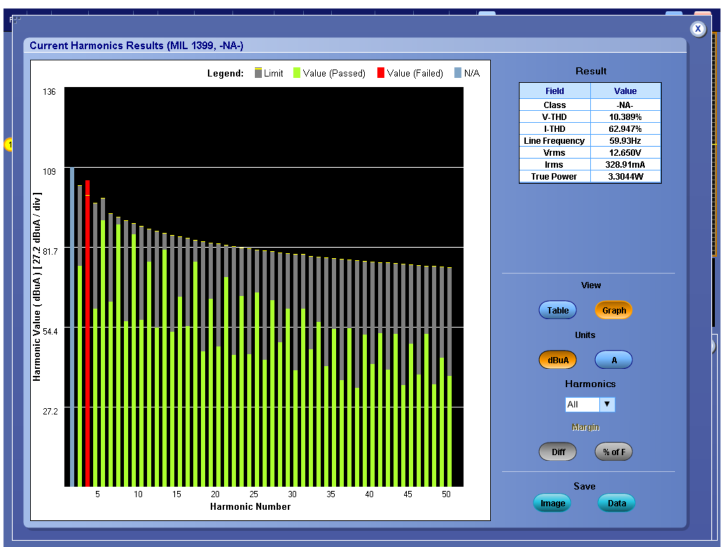
The input current waveform for all types must not cause single harmonic line currents to be generated that are greater than 3% of the unit's full rated load fundamental current between the 2^{nd} and 32^{nd} harmonic.

Key Take Away Points

- The MIL-STD-1399 harmonics measurements enabled, the display should look about like this:



- The harmonics measurements can also be displayed in table format:



- In this case, notice that the third harmonic violates the limit for that frequency and is clearly shown in red.

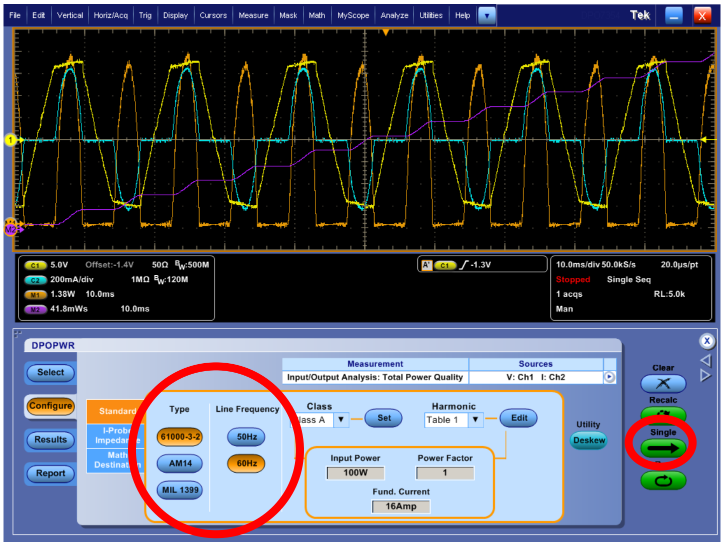
MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Select the **MIL 1399** Standard **Type**.
- ❑ In the **Line Frequency** section, press the appropriate button for the local AC power.
- ❑ The next control to the right allows you to analyze either 50 or 100 harmonics. For simplicity, you can use the default value of **50**.
- ❑ Press the **Single** button on the right side of the control window.
- ❑ You can display the current harmonic measurements in table or graph form. Press the **Graph** button.

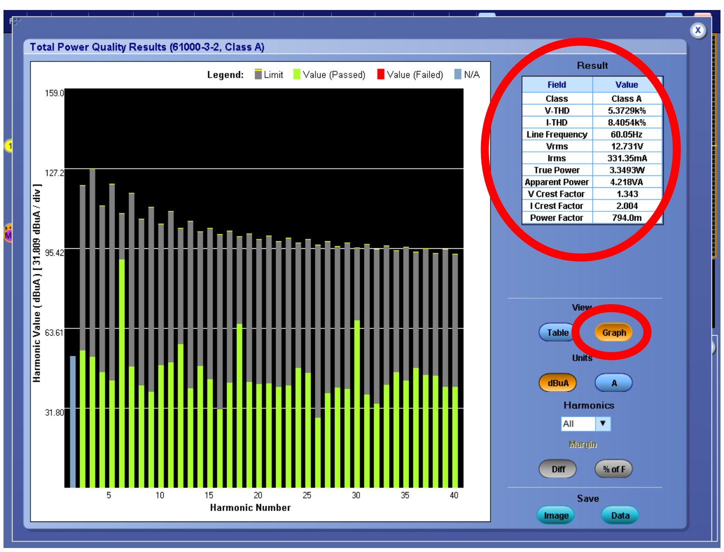
Total Power Quality Measurements

Key Take Away Points

- The DPOPWR application also provides a single measurement set which includes input power measurements and current harmonics results in a single display. Again, for simplicity in this demo, we will use the default IEC 61000-3-2 standard for the harmonics measurements:



- The graphical display of the harmonics in the Total Power Quality measurements should look about like this:



- The harmonics can also be displayed in table format.

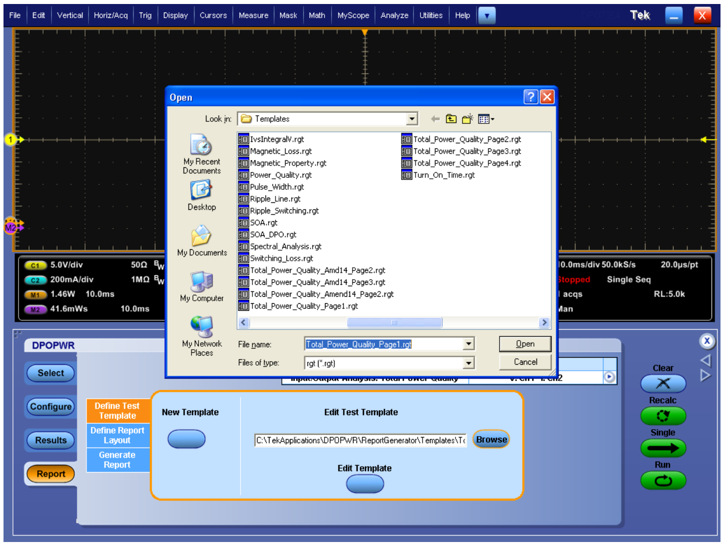
MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Total Power Quality** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that the **61000-3-2** Standard **Type** is selected.
- ❑ In the **Line Frequency** section, press the appropriate button for the local AC power.
- ❑ Press the **Single** button on the right side of the control window.
- ❑ Notice that the power quality measurements have been added to the table in the upper right corner of the display.
- ❑ You can display the current harmonic measurements in table or graph form. Press the **Graph** button.
- ❑ When you are done, press the **X** in the upper right corner to close the results display.

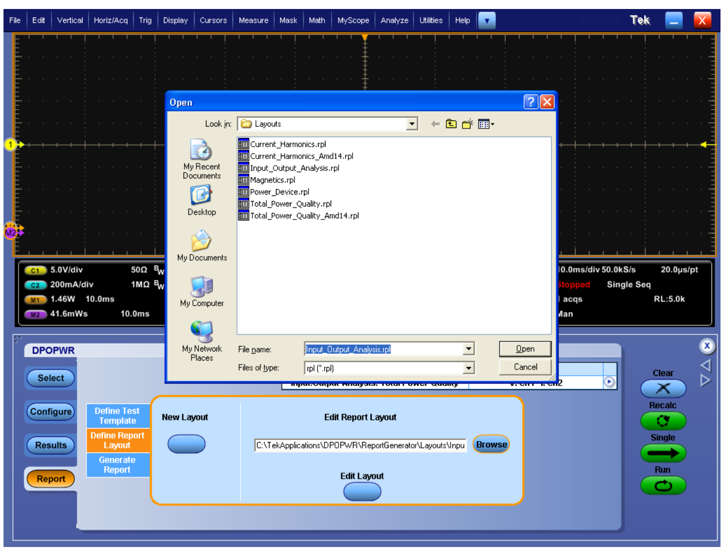
DPOPWR Report Generator

Key Take Away Points

- The DPOPWR application also provides a built-in report generator for documenting your test results. As an example of its use, you will use the report generator to document the Total Power Quality measurements you just made.
- The Define Test Template control window looks like this:



- The Define Report Layout control window looks like this

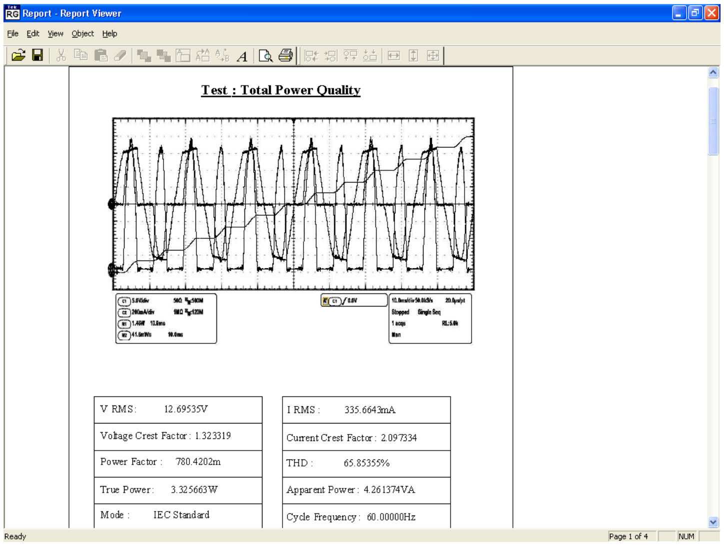


MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Report** tab on the left side of the control window.
- ❑ The first tab in the control window is the **Define Test Template**. This tab allows you to specify the document template, including the screen shots and measurement values you want to include in your report. You can view the template by pressing the **Edit Template** button. Click on the **X** in the upper right corner when you are done.
- ❑ Press the **Define Report Layout** tab near the left side of the control window. This tab allows you to specify the document layout template. Each page of the report is assigned a title and a test template file. You can view the template by pressing the **Edit Layout** button. Click on the **X** in the upper right corner when you are done.

Key Take Away Points

- The first page of the Total Power Quality report should look about like this:



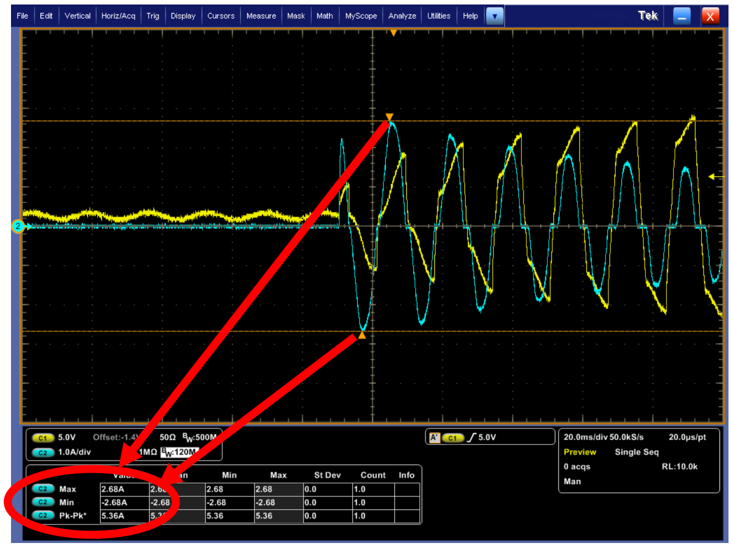
MSO/DPO5000 Series Procedure:

- ❑ Press the **Generate Report** tab near the left side of the control window. This tab allows you to generate, view, and print the report.
- ❑ Press the **Generat…** button.
- ❑ In the case of the Total Power Quality measurement, there are four pages in the default report. In this case, the summary is on page 1, so select it. Double-click on **Total_Power_Quality_Page1**.
- ❑ From this control window, you can save or print this file, or export it in RTF format.

Inrush Current and I²t Measurements

Key Take Away Points

- Before leaving the topic of power measurements on the input section of a power supply, we should mention inrush current measurements. Although these measurements are not made with features of the power application, some engineers will want to make the measurements.
- The instantaneous peak inrush current can be easily measured with the standard automatic measurements such as Max, as shown at the lower left side of the display:



- The instantaneous inrush current is often measured to verify that the power supply's input capacitor's charging current does not exceed the maximum current rating for the capacitor or any other components in the input path. This high initial current is the result of the capacitor appearing as a short circuit when the power is first applied. This current is often much greater than the steady-state current drawn by the power supply.

MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Close the DPOPWR power application by clicking on the **X** in the upper right corner of the control window.
- ❑ Right-click on the **M1** icon at the left of the display and select **Turn Math 1 Off**.
- ❑ Right-click on the **M2** icon at the left of the display and select **Turn Math 2 Off**.
- ❑ Reduce the channel 2 vertical sensitivity to **1 A/div**.
- ❑ Set the horizontal scale to **20 ms/div**.
- ❑ Move the Trigger **Level** to about **5V**.
- ❑ Select **Trig->Mode….**
- ❑ Press the **Normal** Trigger Mode button.
- ❑ Remove the power from the demo board.
- ❑ Press the front panel **Single** button.
- ❑ Apply power to the demo board.
- ❑ Select **Measure -> Measurement Setup….**
- ❑ Press the Channels **2** button.
- ❑ Press the **Max**, **Min**, and **Pk-Pk** buttons.
- ❑ Click on the **X** in the upper right corner of the control window.

Key Take Away Points

- For other applications, such as determining whether or not the inrush current will open the line fuse or circuit breaker, the peak inrush current may be defined as the RMS current over a specified time period, such as the first 100 ms after power is applied. For example, this time period may be chosen to model the thermal time-constant of the critical device. Such a device will not respond to very short pulses, but rather the $I_{RMS}{}^2$*R heating.
- This measurement is most easily measured with gated automatic measurements, as shown at the lower left side of the display:

- Other vendors, such as Littlefuse, in their Introduction to Circuit Protection http://www.littelfuse.com/data/en/Product_Catalogs/Chapter1IntroductiontoCircuitProtection.pdf, recommend that the peak energy pulse measurement be used instead.

MSO/DPO5000 Series Procedure:

- ❑ Select **Measure -> Measurement Setup….**
- ❑ Press the **Clear All** button.
- ❑ Press the **AC RMS** button.
- ❑ Press the **Gating** button.
- ❑ Press the **Cursor** button.
- ❑ Using the Multipurpose **a** control, place the **a cursor** just to the left of the first cycle of current.
- ❑ Using the Multipurpose **b** control, place the **b cursor** near the right edge of the display where the cursor delta time readout indicates a time delta of **100 ms**.
- ❑ When you are done, select **Measure -> Measurement Setup….**
- ❑ Press the **Clear All** button.
- ❑ Press the **Gating** button.
- ❑ Press the **Off** button.
- ❑ Click on the **X** in the upper right corner of the control window.
- ❑ Press the front panel **Cursors** button to remove the cursors.

Key Take Away Points

- Nominal melting I^2t is a measure of the energy required to melt the fusing element and is expressed as “Ampere Squared Seconds” (A^2 Sec.). This nominal melting I^2t, and the energy it represents (within a time duration of 8 milliseconds or less for circuit-board-mounted fuses and 1 millisecond or less for thin film fuses), is a value that is constant for each different fusing element.
- For trouble-free, long-life fuse protection, it is good design practice to select a fuse such that the I^2t of the waveform is no more than 20% of the nominal melting I^2t rating of the fuse in use.
- The I^2 math function should look about like this:

- This gated automatic area measurement of the squared current shows a value of approximately 38 mA^2s at the lower left side of the display:

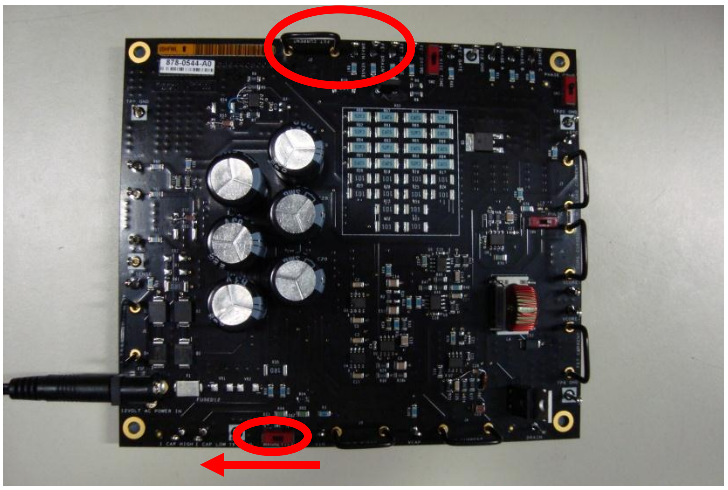
MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **Run/Stop** button to start acquisitions.
- ❑ Set the horizontal scale to **2 ms/div**.
- ❑ Select **Math -> Math Setup….**
- ❑ Press the **Editor** button to enter the equation.
- ❑ Press the Channels **2** button, the ***** multiply button, the Channels **2** button, and the **OK** button.
- ❑ Set the Math Vertical Scale to about **1.5 A^2**.
- ❑ Remove the power from the demo board.
- ❑ Press the front panel **Single** button.
- ❑ Apply power to the demo board.
- ❑ Select **Measure -> Measurement Setup….**
- ❑ Press the **More** tab at the left side of the control window.
- ❑ Press the **Area** button.
- ❑ Press the **Gating** button.
- ❑ Press the **Cursor** button.
- ❑ Using the Multipurpose **a** control, place the **a cursor** just to the left of the first major peak of the current.
- ❑ Using the Multipurpose **b** control, place the **b cursor 8 ms** to the right of the **a cursor**, approximately at the end of the first peak of the current. The cursor delta time readout should indicate a time delta of 8 **ms.**
- ❑ The resulting energy value should be compared to the rating of the fuse to be sure that the fuse rating is at least 5 times the measured I^2t value.

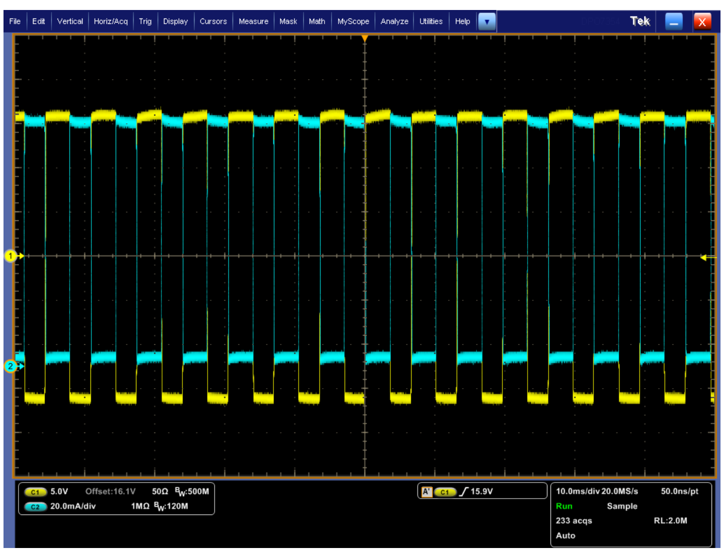
Switching Loss Measurements

Key Take Away Points

- Switching loss is one of the most critical measurements for optimizing the efficiency of a power supply. Although an ideal switching device is loss-less, a real switching device has losses, especially during the transitions from off to on and from on to off.
- To demonstrate switching loss measurements, this section of the lab measures the voltage across the switching device and current flowing through the switching device.



- Typical voltage and current switching waveforms look about like this:



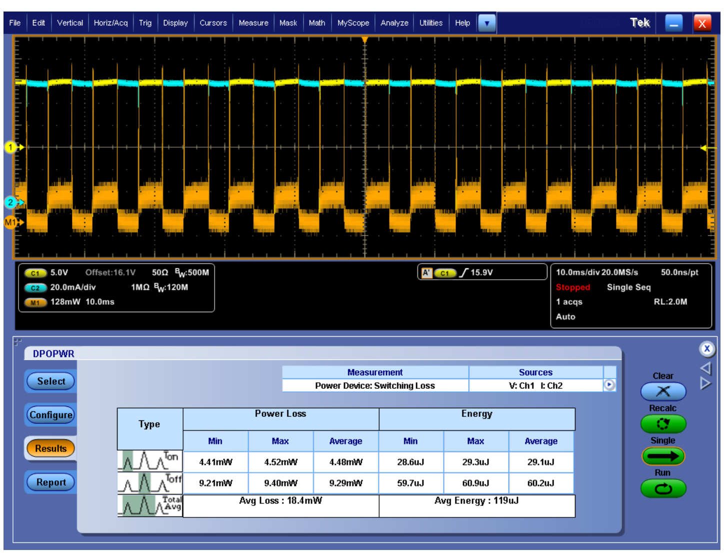
- When the switching device is off, there should be no current flowing through the device, so there should be no power dissipation. In practice, this is generally accurate.

MSO/DPO5000 Series Procedure:

- ❑ Press **Default Setup**.
- ❑ On the demo board, move **SW1** to the left position.
- ❑ Connect the **-** input of the differential probe to the **FET_SOURCE** test point.
- ❑ Connect the **+** input of the differential probe to the **FET_DRAIN** test point.
- ❑ Connect the current probe around the **FET_CURRENT** current loop and close the probe jaws.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Press **Autoset**.
- ❑ The voltage and current waveforms should be out of phase. If they are in phase, remove the current probe, turn it over, and re-connect it.
- ❑ Scale and position the signals as shown at the left.
- ❑ Select **Horiz/Acq -> Horizontal/Acquisition Setup….**
- ❑ Select **Automatic Mode**.
- ❑ Set the Horizontal **Scale** to **10 ms/div**.
- ❑ Adjust the **Sample Rate** to **20 MS/s** to achieve a record length of 2M.

Key Take Away Points

- When the switching device is conducting, there should only be a small voltage drop across the device. However, the current through the device can be large, so the “conduction loss” can be sizeable.
- The largest losses occur during the switching transitions, when there may be a considerable voltage drop across the device while there is considerable current flowing through the device. These “turn-on” and “turn-off” losses typically make up much of the total power dissipation in the switching device.
- One of the critical parameters for accurate switching loss measurements is the calculation of the switching device’s behavior during conduction. There are three ways to determine the correct values:
    - Provide the $R_{DS(on)}$ value (best model for MOSFETs) based on the device data sheet. This value is the expected on-resistance between the drain and source of the device when it is conducting.
    - Provide the $V_{CE(sat)}$ value (best model for BJTs and IGBTs) based on the device data sheet. This is the expected saturation voltage from the collector to the emitter of the device when it is saturated.
    - You can also measure the actual $R_{DS(on)}$ or $V_{CE(sat)}$ value for the switching device during conduction.
- With the Switching Loss measurements enabled, the display should look about like this:



- Notice that the switching loss measurements are made on each individual complete cycle within the selected region of the acquisition (the entire waveform, by default) and the statistics of those measurements are accumulated across the acquisition, but not between acquisitions.

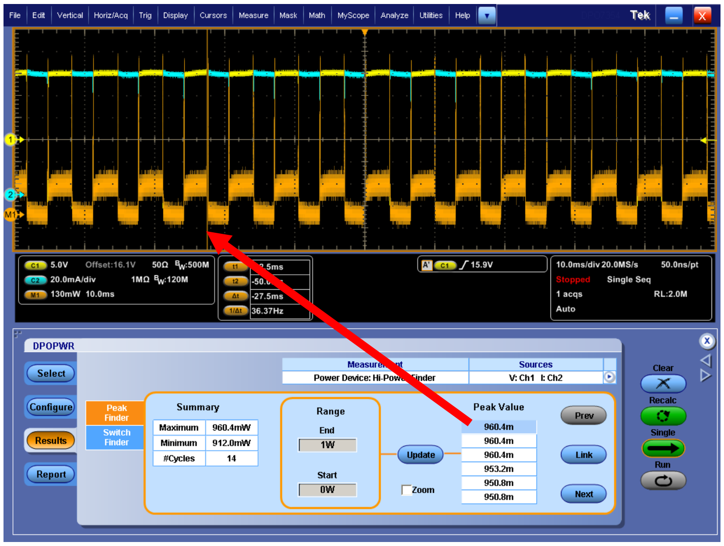
MSO/DPO5000 Series Procedure:

- ❑ Select **Analyze -> Power Analysis -> Select**.
- ❑ Press the **Switching Loss** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that the **Voltage** is on channel **1** and the **Current** is on Channel **2**.
- ❑ Verify that the **PWM Type** is set to **Fixed** and the **Cursor Gating** is **Off**.
- ❑ For simplicity in this demo, you may leave the **Device** set to **Auto**. This will select a MOSFET switching device with an RDS(ON) value of 20 mΩ. (You can also measure this actual value, or look it up on the component data sheet, and then select **User** and enter the value manually.)
- ❑ If you would like to make other manual adjustments to the setup, press the **On-Off** Level tab and make the changes in this control window.
- ❑ Verify that the **Math Destination** is set to **Math1**.
- ❑ Press the **Utility Deskew** button.
- ❑ Press the **Deskew** button.
- ❑ Press the **Static** tab. This will allow you to select the default static propagation delay values for the probes you are using.
- ❑ In the **From** section, select the appropriate differential probe from the drop-down menu.
- ❑ In the **To** section, select the appropriate current probe from the drop-down menu.
- ❑ Press the **Back** button.
- ❑ Press the **Single** button at the right side of the control window.

Hi-Power Finder

Key Take Away Points

- DPOPWR includes the Hi-Power Finder tool that automatically searches through and identifies the peaks in the switching loss power waveform. The Hi-Power Finder results display should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Hi-Power Finder** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that the **Voltage** is on channel **1** and the **Current** is on Channel **2**.
- ❑ Verify that the **PWM Type** is set to **Fixed**.
- ❑ Verify that the **Math Destination** is set to **Math1**.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ You can use the **Prev** and **Next** buttons to navigate between peak values listed in the table.

Safe Operating Area Analysis
The Safe Operating Area (SOA) display provides a very simple graphical method for monitoring the interactions between voltage and current. If you exceed the maximum limits (defined by maximum instantaneous current, maximum instantaneous voltage, and maximum instantaneous power) for the device, it will fail. Typically these specifications are provided in the component's data sheet. For example, the key maximum specifications for the MOSFET on the 878-0544-XX power demo board are: ○ V_{DSSmax} = 60 V ○ I_{Dmax} = 45 A, with peaks to 150A ○ P_{Dmax} = 125 W The resulting SOA graph from the MOSFET's data sheet is:

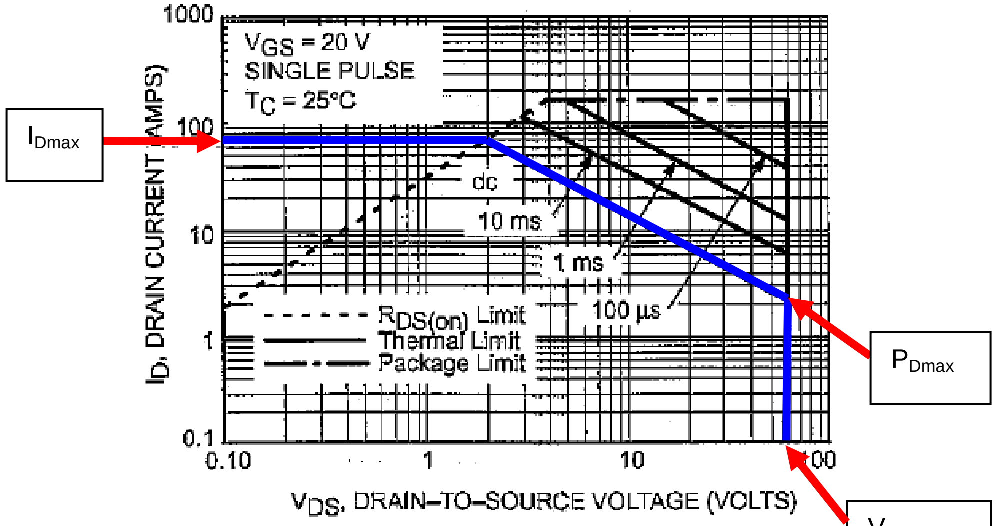
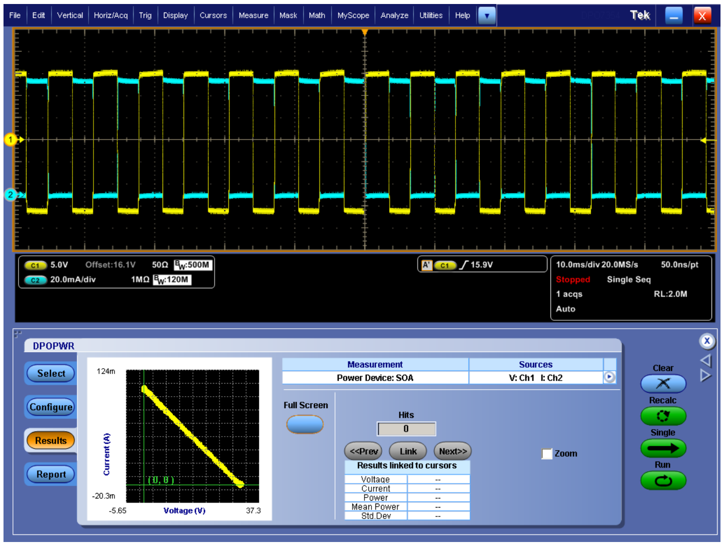


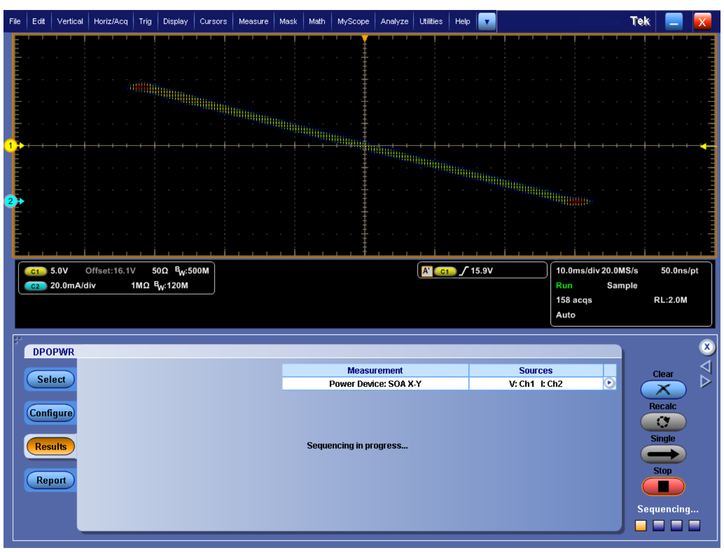
Figure 11. Maximum Rated Forward Biased Safe Operating Area

Key Take Away Points

- To demonstrate Safe Operating Area (SOA) measurements, this section of the lab displays the voltage across the MOSFET versus the current flowing through the MOSFET.
- The SOA display should look about like this:



- NOTE: Especially for this complex display, the demo may be more effective if you increase the waveform intensity.
- X-Y cursors can be used to identify specific points in the waveform, such as those that violate the SOA mask.
- There is also an XY display mode for SOA. The SOA XY display looks like this:



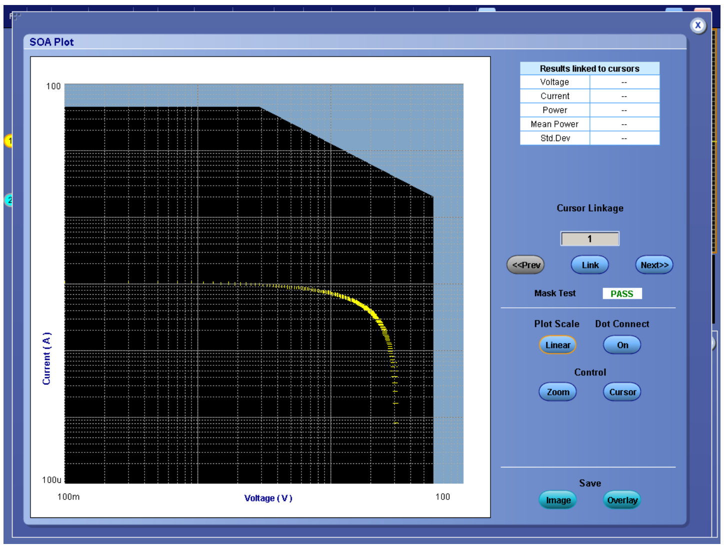
- Although both of these display modes for SOA can be useful for visual analysis, the real power in the SOA XY display is with mask testing.

MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **SOA** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that the **Voltage** is on channel **1** and the **Current** is on Channel **2**.
- ❑ Verify that the **Cursor Gating** is set to **Off**.
- ❑ Notice that you can also specify an SOA mask from this control window.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **SOA XY** button.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ When you are done, press the **Stop** button at the right side of the control window.

Key Take Away Points

- Based on the component specifications, the horizontal top of the SOA mask is set at the I_{Dmax} value of 45 A, from 10 mV to about 3V (where the power hits the P_{Dmax} value of 125 W).
- The vertical side of the SOA mask is set at the V_{DSSmax} value of 60 V, from 10 mA to about 2A (where the power hits the P_{Dmax} value of 125 W).
- The angled side of the SOA mask is drawn where the power equals the P_{Dmax} value of 125 W.
- The SOA mask test log display should look about like this:



- Clearly in this case, as in many cases in embedded system power applications, the design is not pushing the limits of the device. As long as the maximum voltage and current do not exceed half of the maximum values, a careful analysis of the SOA display is probably not necessary.

MSO/DPO5000 Series Procedure:

- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **SOA** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ In the **Mask** section, click the **Enable** check box.
- ❑ Press the **Mask Editor** button.
- ❑ In the **Mask Grid Scale** section, press the **Log** button.
- ❑ First, set the outer dimensions of the display:
  - ❑ Double-click on the **X-Max** text box and enter **100** V.
  - ❑ Double-click on the **Y-Max** text box and enter **50** A.
- ❑ Then, define the mask area:
  - ❑ Click on the **Y axis** at the I_{Dmax} point of **45 A**. (You can see the coordinates in the readout in the upper right corner.)
  - ❑ Click at the point of **45A** and **3V**.
  - ❑ Click at the point of **2A** and **60V**.
  - ❑ Click at the V_{DSSmax} point of **60V** on the **X axis**.
  - ❑ Press the **Apply** button.
- ❑ Press the **Save Mask** button, enter a filename, and press the **Save** button.
- ❑ Press the **X** in the upper right corner of the control window.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ Press the **Full Screen** button.
- ❑ Press the **Log Plot Scale** button.
- ❑ When you are done, press the **X** in the upper right corner of the control window.

dv/dt and di/dt Measurements

Key Take Away Points

- This section of the lab demonstrates dv/dt and di/dt measurements, also known as voltage and current slew rate measurements, on the switching loss waveforms from the previous lab.
- These measurements indicate how quickly the switching device is turning on and off.
- The dv/dt display should look about like this:

- The di/dt display should look about like this:

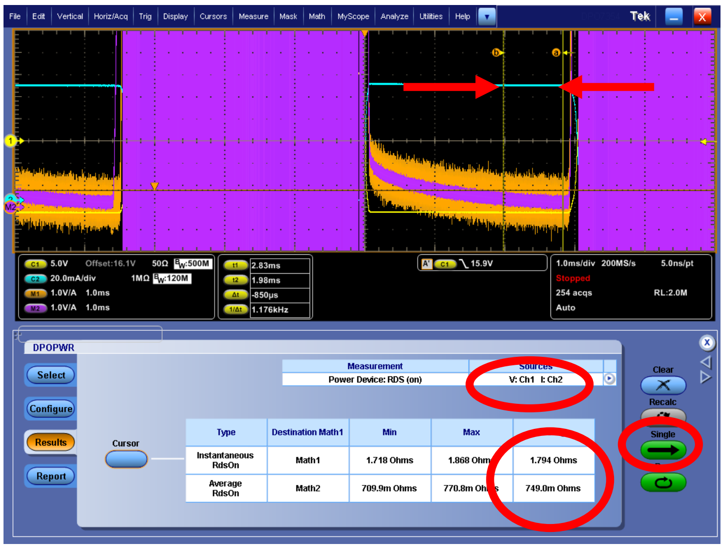
MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **dv/dt** button.
- ❑ Notice that the channel 1 voltage waveform has been selected as the source.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **di/dt** button.
- ❑ Notice that the channel 2 current waveform has been selected as the source.
- ❑ Press the **Single** button at the right side of the control window.

R_{DSon} Measurements

Key Take Away Points

- This section of the lab demonstrates the measurement of the dynamic on-resistance or R_{DSon} of a MOSFET switching device. This is the effective resistance of the MOSFET during the conduction cycle. Because the value changes with the current flowing through the device, this measurement is made at the actual drain current (unlike the data sheet spec, which is only valid at one specific current level). The RDS(on) display should look about like this:



MSO/DPO5000 Series Procedure:

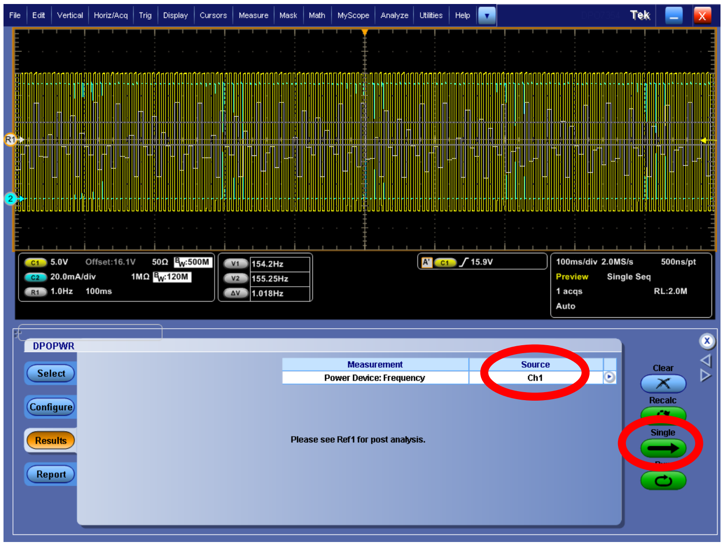
- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Select **Horiz/Acq -> Horizontal/Acquisition Setup….**
- ❑ Select **Automatic Mode**.
- ❑ Set the Horizontal **Scale** to **1 ms/div**.
- ❑ Adjust the **Sample Rate** to **20 MS/s** to achieve a record length of 2M.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **RDS(on)** button.
- ❑ Notice that the **Voltage** is on channel **1** and the **Current** is on Channel **2**.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ With the mouse, drag the cursors over to the conduction region (where the cyan drain current is high and the yellow voltage drop is low) to define the measurement region.
- ❑ Press the **Cursor** button and press **Yes** in the popup message dialog.

Tektronix

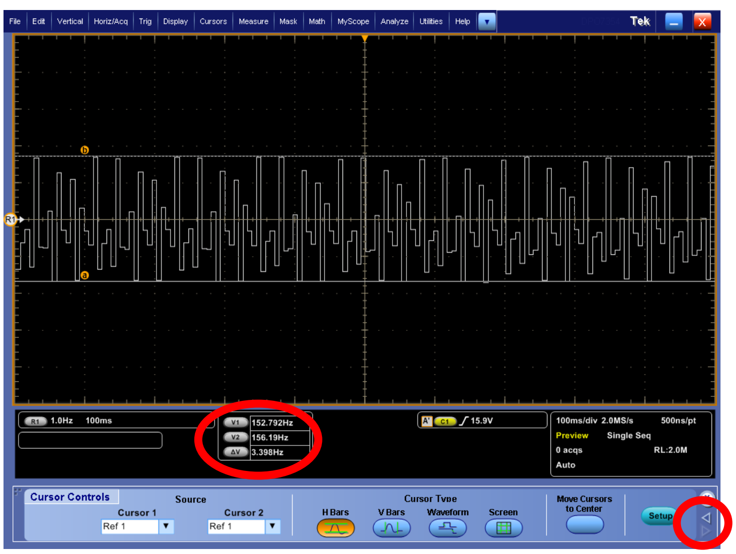
Modulation Analysis with Measurement Trends

Key Take Away Points

- To demonstrate modulation measurements, this section of the lab characterizes the switching frequency of the MOSFET. The frequency modulation analysis display should look about like this:



- The remaining reference waveform on the display is the trend of the frequency measurement. Because it is a waveform, you can make automatic and cursor measurements on it. Notice that the readouts indicate the proper units:

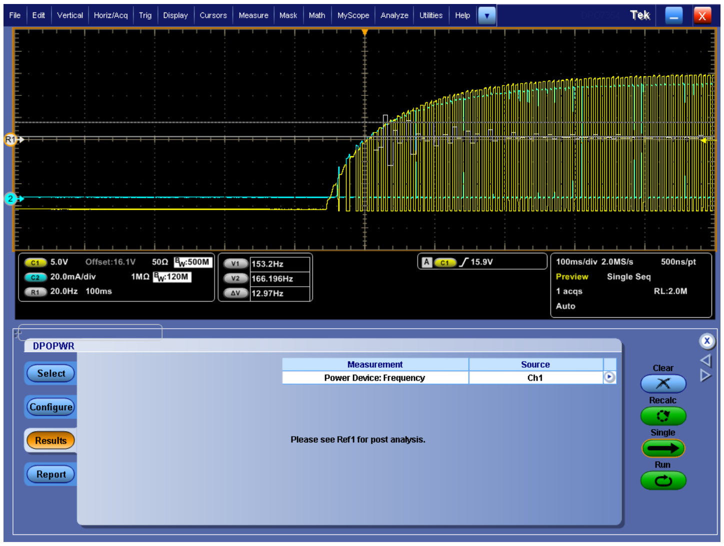


MSO/DPO5000 Series Procedure:

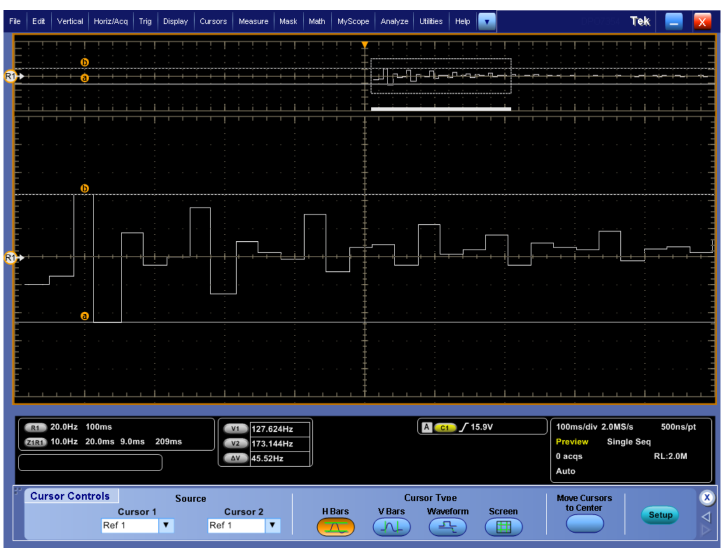
- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ Set the Horizontal **Scale** to **100 ms/div**.
- ❑ Adjust the **Sample Rate** to **2 MS/s** to achieve a record length of 2M.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ In the **Modulation Analysis** section, press the **Frequency** button.
- ❑ Notice that the **Voltage** is on channel **1**.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ Press the channel **1** and **2** buttons to turn off the display of channels 1 and 2.
- ❑ Press the front panel **Cursor** button twice to re-attach the Multipurpose controls to the cursors.
- ❑ Using the Multipurpose controls, measure the peak-to-peak variation in frequency.
- ❑ When you are done, press the channel **1** and **2** buttons to turn on the display of channels 1 and 2.
- ❑ Click on the white arrow to return to the power application.

Key Take Away Points

- Modulation analysis is most useful when analyzing the power supply's control loop during power-up, the response to a change in input voltage ("line regulation"), or the response to a change in load ("load regulation").
- To view the variations in the frequency during power-up, start the measurement and then power up the demo board:



- If you zoom in on the startup transient, you can see that the peak-to-peak variations in frequency are much higher during startup than during stead-state operation. The display should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ Disconnect the power from the demo board.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ Re-connect the power to the demo board.
- ❑ Press the channel **1** and **2** buttons to turn off the display of channels 1 and 2.
- ❑ Draw a box around the start-up transient and select **Zoom 1 On**.
- ❑ Press the front panel **Cursor** button twice to re-attach the Multipurpose controls to the cursors.
- ❑ Using the Multipurpose controls, measure the peak-to-peak variation in frequency.
- ❑ When you are done, press the channel **1** and **2** buttons to turn on the display of channels 1 and 2.
- ❑ Click on the white arrow to return to the power application.

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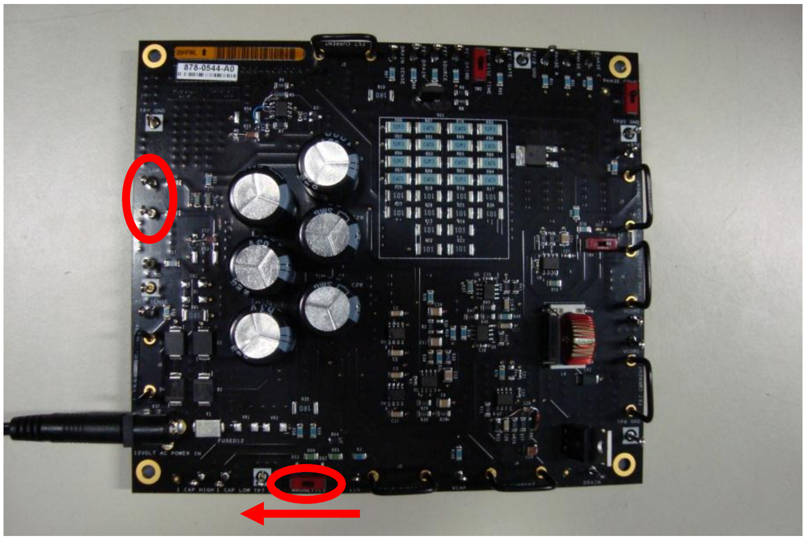
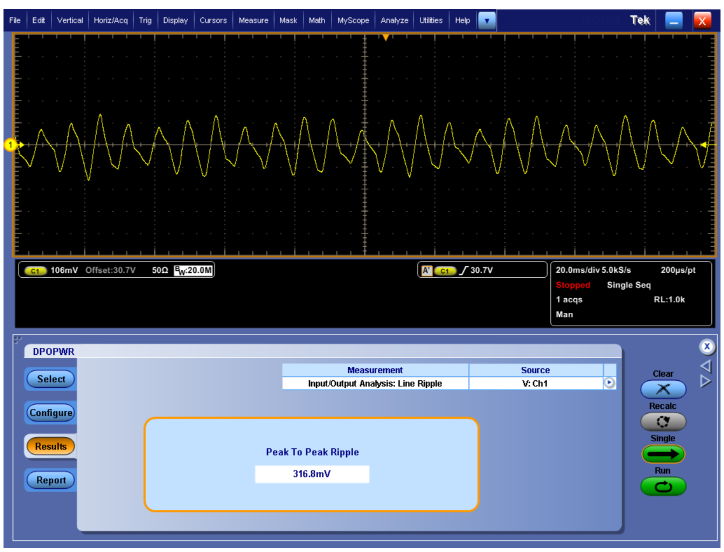
Line and Switching Ripple Measurements

Key Take Away Points

- To demonstrate ripple measurements, this section of the lab measures the voltage across the DC output section of the demo board.



- The line ripple measurement display should look about like this:

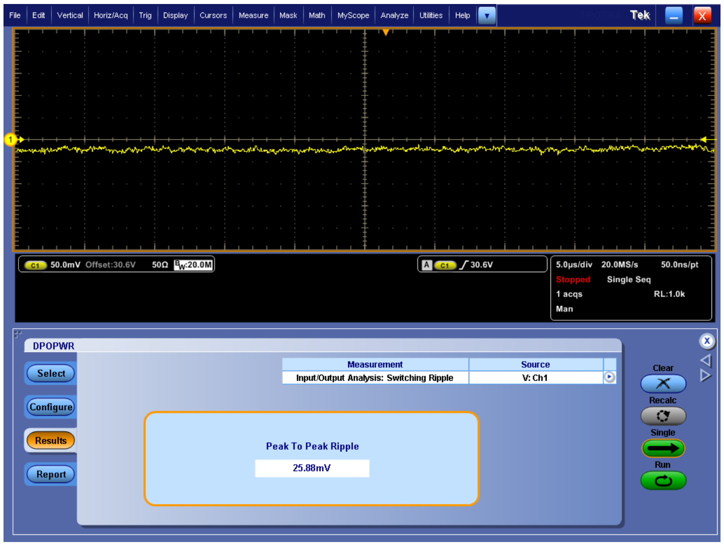


MSO/DPO5000 Series Procedure:

- ❑ NOTE: This section of the lab continues with the oscilloscope setup from the previous section.
- ❑ On the demo board, move **SW1** to the left position.
- ❑ Connect the **-** input of the differential probe to the **DC LOW** test point.
- ❑ Connect **+** input of the differential probe on channel 1 to the **DC HIGH** test point.
- ❑ Press the front panel **2** button to turn off channel **2**.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Input/Output Analysis** tab near the left side of the control window.
- ❑ Press the **Line Ripple** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that **AC Coupling**, **20 MHz Bandwidth**, and **HiRes Acquisition Mode** are selected.
- ❑ In the **Ripple Frequency** section, press the appropriate button for the local AC power.
- ❑ Press the **Single** button on the right side of the control window.

Key Take Away Points

- If, instead, we measure the Switching Ripple, we see the ripple on the output that is related to the switching frequency (of about 150 kHz, in this case):



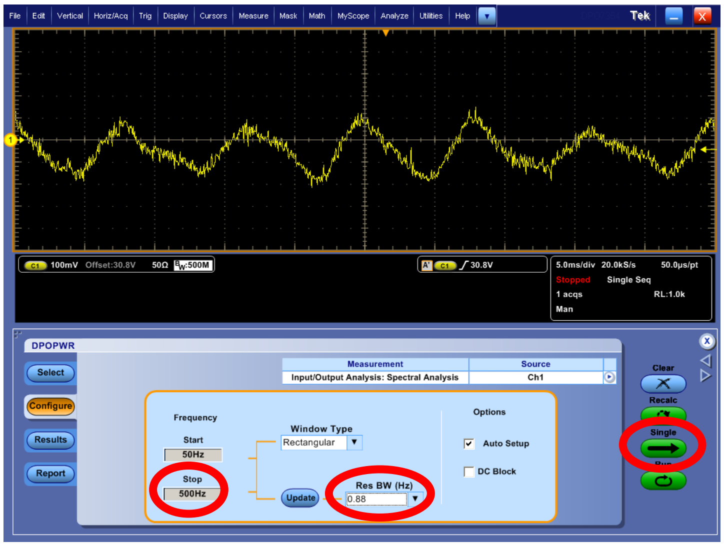
MSO/DPO5000 Series Procedure:

- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Switching Ripple** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that **AC Coupling**, **20 MHz Bandwidth**, and **HiRes Acquisition Mode** are selected.
- ❑ In the **Switching Frequency** text box, press the appropriate switching frequency.
- ❑ Press the **Single** button on the right side of the control window.

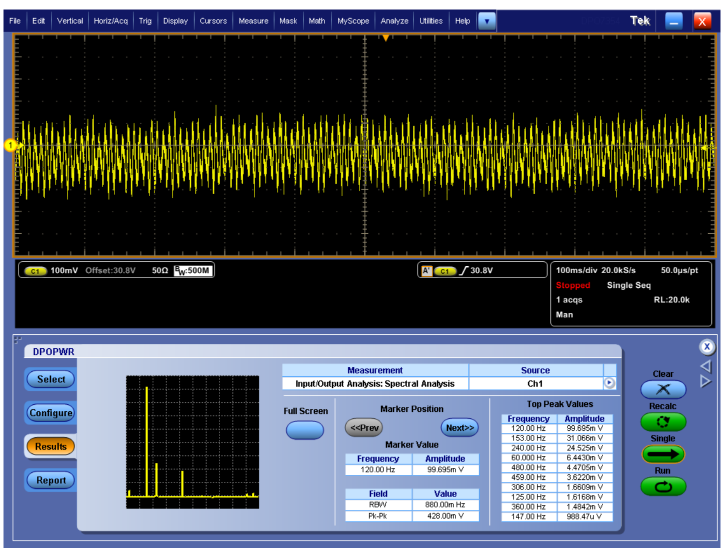
Output Spectral Analysis

Key Take Away Points

- To demonstrate the spectral measurement on the output signal, set up the span and resolution to cover the spectrum of the frequencies of interest. In this case, we're going to look at the harmonics of the line frequency on the output signal:



- The output spectral analysis display should look about like this:

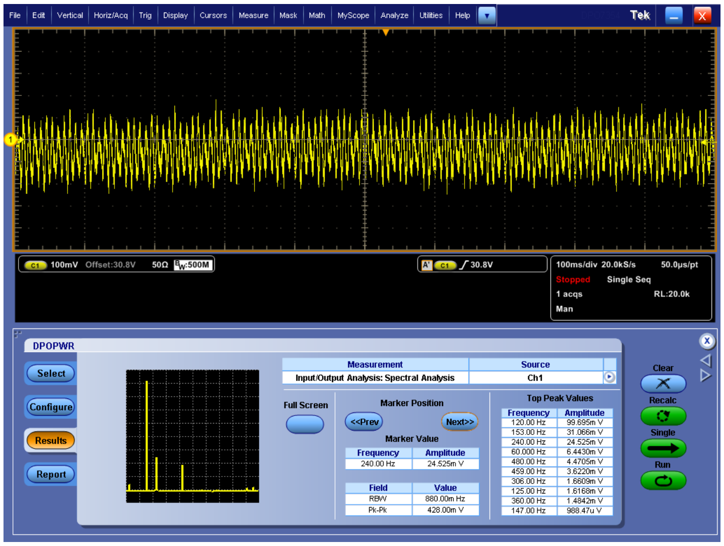


MSO/DPO5000 Series Procedure:

- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Select** tab near the left side of the control window.
- ❑ Press the **Spectral Analysis** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Verify that **50 Hz Start Frequency**, **Rectangular Window Type**, and **Auto Setup** are selected.
- ❑ Set the **Stop Frequency** to **500 Hz**.
- ❑ Select a **Res BW (Hz)** value of about **1 Hz**.
- ❑ In the **Ripple Frequency** section, press the appropriate button for the local AC power.
- ❑ Press the **Single** button on the right side of the control window.
- ❑ If you see the message "RBW not updated, set maximum available RBW and continue measurement?", press the **Yes** button.

Key Take Away Points

- You can use the Peak Find feature to automatically jump between peaks in the spectral display:



MSO/DPO5000 Series Procedure:

- ❑ Press the **Next>>** button twice to jump the little red marker to the fifth harmonic Notice that the readout in the Marker Position section shows the Frequency and Amplitude at the marker.

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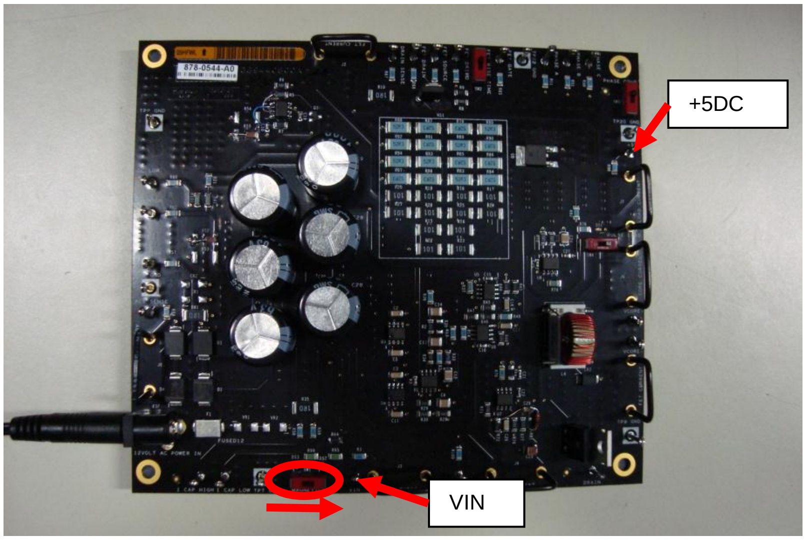
Turn On Time Measurement

Key Take Away Points

- To demonstrate DC-DC turn-on time measurements, this section of the lab measures the voltage across the DC input and DC output sections of the demo board:



- The turn-on time setup control window for the input section should look about like this:

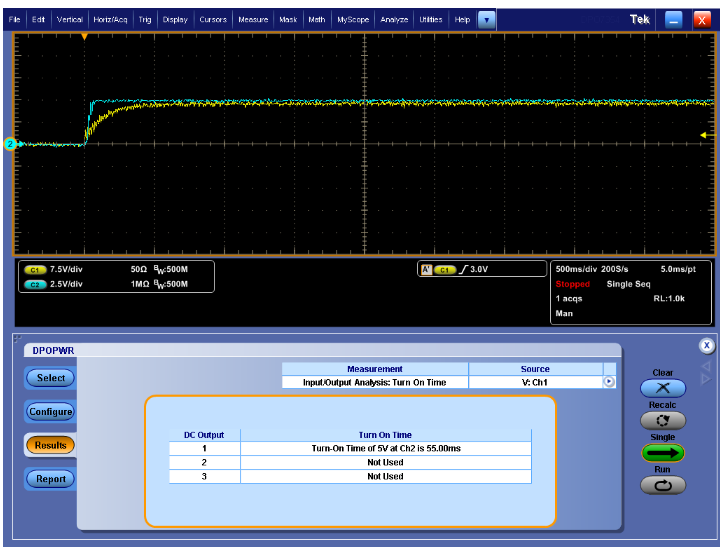
MSO/DPO5000 Series Procedure:

- ❑ On the demo board, move **SW1** to the right position.
- ❑ Press **Default Setup**.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 1 of the oscilloscope.
- ❑ Set the channel 1 Vertical **Scale** to **5 V/div**.
- ❑ Connect a TPP0500 or TPP1000 passive probe to the channel 2 input.
- ❑ Press the channel **2** button to turn on the display of channel 2.
- ❑ Set the channel 2 Vertical **Scale** to **5 V/div**.
- ❑ Select **Horiz/Acq -> Roll Mode Auto** to deselect it.
- ❑ Disconnect the power from the demo board.
- ❑ Press the front panel **Clear** button.
- ❑ Select **Analyze -> Power Analysis**.
- ❑ Press the **Input/Output Analysis** tab near the left side of the control window.
- ❑ Press the **Turn On Time** button.
- ❑ Press the **Configure** tab on the left side of the control window.
- ❑ Make sure the **Input** tab is selected.
- ❑ Press the **DC-DC Convertor** button.
- ❑ Double-click on the **Max Voltage** text box and enter the AC voltage of about **15V**.
- ❑ Double-click on the **Trigger Level** text box and enter the trigger level value of about **7V**.
- ❑ Double-click on the **Max Turn On Time** text box and enter a value of about **2s**.

Key Take Away Points

- The turn-on time setup control window for the output section should look about like this:

- The turn-on time measurement results control window should look about like this:



MSO/DPO5000 Series Procedure:

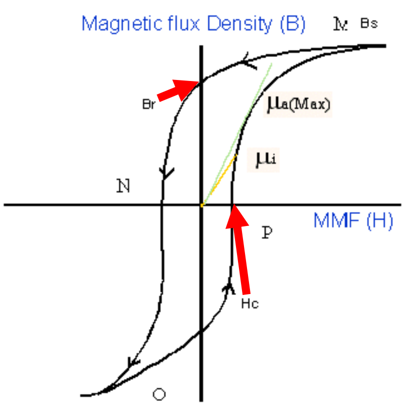
- ❑ Press the **Output** tab.
- ❑ Press the **Single** button at the right side of the control window.
- ❑ Wait for the **Arm** light and then the **Ready** light on the front panel to light.
- ❑ Re-connect the power to the demo board.
- ❑ At the selected Horizontal Scale setting, it will take a few seconds from the time the green **Trig'd** light is lit until the waveform is completely acquired.
- ❑ Press the **Yes** button in the popup dialog.

Magnetics Measurements

As with the dynamic on-resistance of the MOSFET, the characteristics of the magnetic components in a power supply are different in the circuit and may not match the specifications in the component data sheet.

The magnetic measurements are based on an XY display of the current through the inductor and the integral of the voltage across the inductor. This curve typically shows hysteresis or "path dependence" where a point on the curve is dependent upon the location of the previous point.

In this figure:



H is the Magnetic Field Strength, measured in Amperes / meter.

H_c is the Coercive Force, or the magnetic field that must be applied to reduce the magnetization to zero after the magnetization has been driven into saturation.

B is the Magnetic Flux Density, measured in Teslas.

B_s is the Saturation Flux Density, or the maximum magnetic flux density induced in the material regardless of the applied field H.

B_r is the Remanence Flux Density, or the magnetization remaining in a magnetic device after an external magnetic field is removed. (Only ferromagnetic materials such as iron have remanence.)

μ_i is the Initial Permeability, and **μ_a** is the Maximum Amplitude Permeability.

Inductance is the electromagnetic property where a change in the current through a device induces an opposing voltage. The electrical current i produces a magnetic field, where the magnetic flux Φ is measured in webers. The self-inductance of the device is the ratio of the magnetic flux times turns of wire to the current, or L = N*Φ/L, which is measured in Henrys. The current through an inductor and the voltage across the inductor are related as di/dt = v/L, or L= ∫v / I, so the inductance can be directly calculated from the XY display.

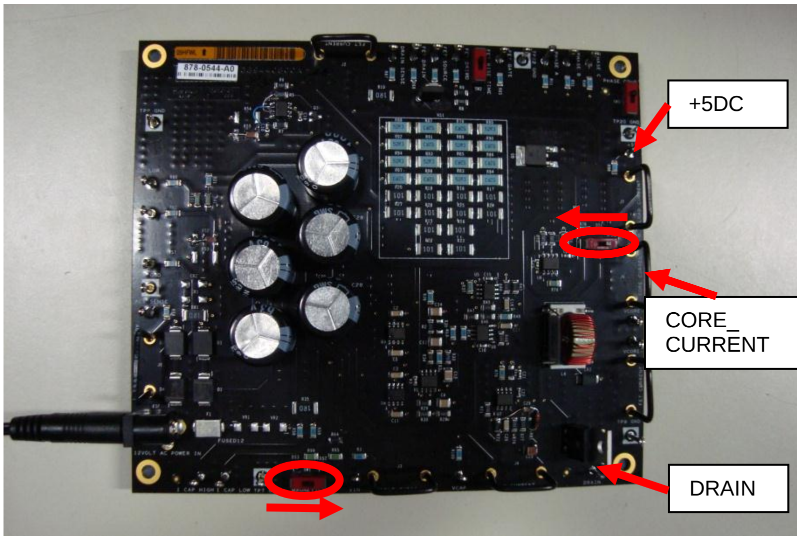
Transformers and coupled inductors can also be measured with DPOPWR. Inductance measurements on one winding is similar to an inductor, but the other windings must not be loaded.

Magnetic Loss is a composite measurement of the losses within the magnetic device. There are three components to this loss.

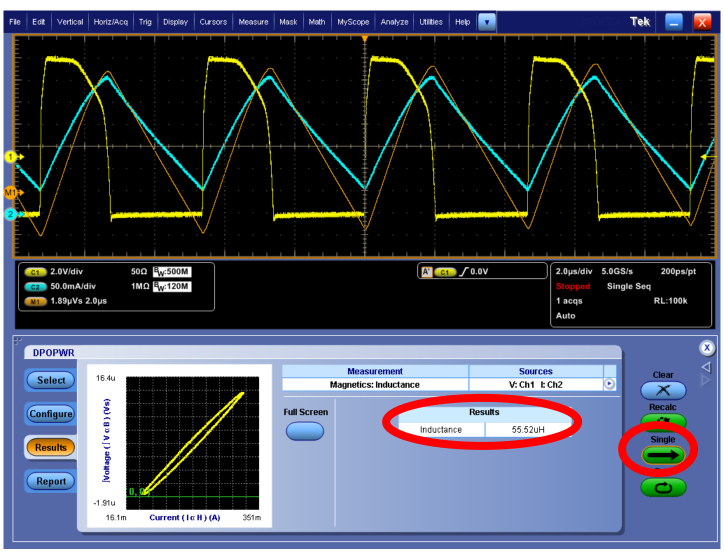
- **Copper Loss** is the loss due to the resistance in the wire used in the inductor or transformer. This power loss is proportional to the resistance of the wire and the square of the current through the device, just like a resistor.
- **Hysteresis** Loss occurs when the magnetization of the core material changes and the magnetic domains expand and contract within the imperfect crystal structure. The energy loss is proportional to the area inside the B-H curve's hysteresis loop and increases with frequency.
- **Eddy Current Loss** is due to eddy currents flowing within the core material. Eddy currents and the resulting losses are minimized by increasing the resistance of the core material, with techniques such as laminating the materials or using the core of a non-conductive magnetic material like ferrite.

Key Take Away Points

- To demonstrate magnetics measurements, this section of the lab measures the voltage across and current through the inductor on the right side of the demo board.



- Inductance is the most basic specification for a magnetic device such as an inductor or transformer. Although the nominal inductance value may be specified in the component data sheet, the effective inductance value depends upon the actual signal characteristics in the circuit.
- The inductance measurement display should look about like this:

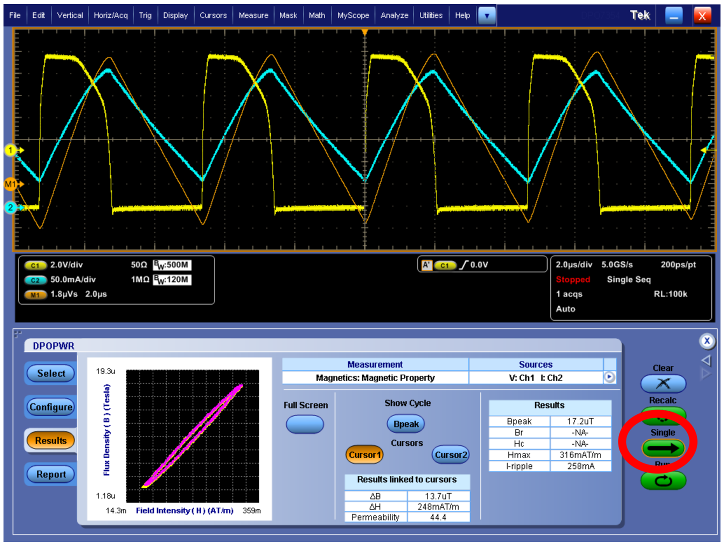


MSO/DPO5000 Series Procedure:

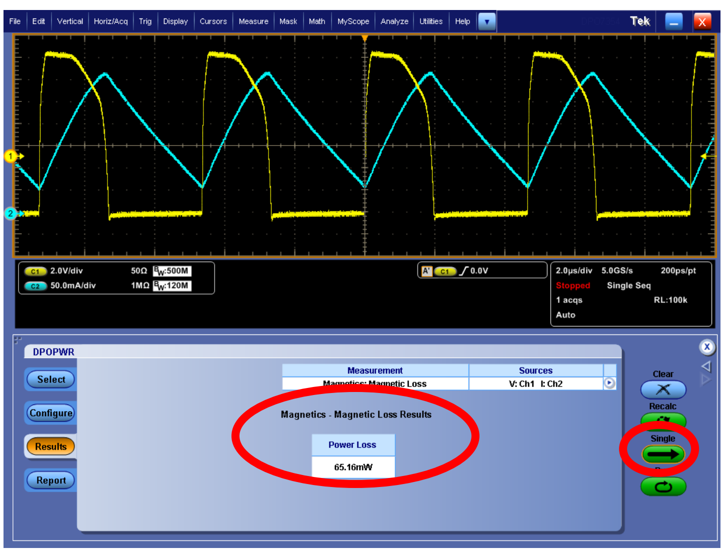
- ❑ On the demo board, move **SW1** to the right position to enable the magnetics measurements.
- ❑ On the demo board, move **SW2** to the left position to turn off the varying load and flashing LED.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 1 of the oscilloscope.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ Connect the **+** and **–** inputs.
- ❑ Press the **AutoZero** button.
- ❑ Connect the **-** probe input to the **+5DC t**est point.
- ❑ Connect **+** probe input on channel 1 to the **DRAIN** test point.
- ❑ Connect a TCP0030 current probe to channel 2.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ In the **Range** section of the control window, select **Manual**.
- ❑ Set the **Range** to **5A**.
- ❑ Make sure that the current probe's jaw is closed. Press the **Degauss AutoZero** button on the probe.
- ❑ Connect the current probe around the **CORE_CURRENT** current loop and close the probe jaws.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Magnetics** tab near the left side of the control window.
- ❑ Press the **Inductance** button.
- ❑ Press the **Single** button on the right side of the control window.

Key Take Away Points

- To measure the magnetic properties of the inductor, the control window should look about like this:



- In most power supply designs, the dominant losses (which limit the power supply's efficiency) are switching loss and magnetic loss. Magnetic power loss is a composite value which includes core losses, eddy current loss, hysteresis and copper losses in the inductor or transformer.
- The magnetic power loss measurement display should look about like this:



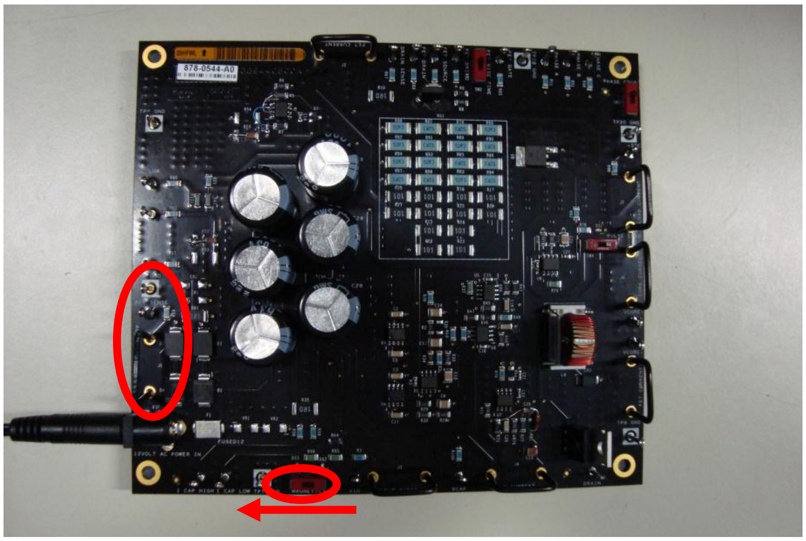
MSO/DPO5000 Series Procedure:

- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Magnetic Property** button.
- ❑ Press the **Single** button on the right side of the control window.
- ❑ Press the **Select** tab on the left side of the control window.
- ❑ Press the **Magnetic Loss** button.
- ❑ Press the **Single** button on the right side of the control window.

Optional Power Efficiency Measurement

Key Take Away Points

- This optional lab requires the use of two differential probes and two current probes. Because these four probes draw more power from the oscilloscope than it can supply alone, the external probe power adapter must be used.
- To demonstrate power efficiency measurements, this section of the lab measures the AC input power to the demo board.



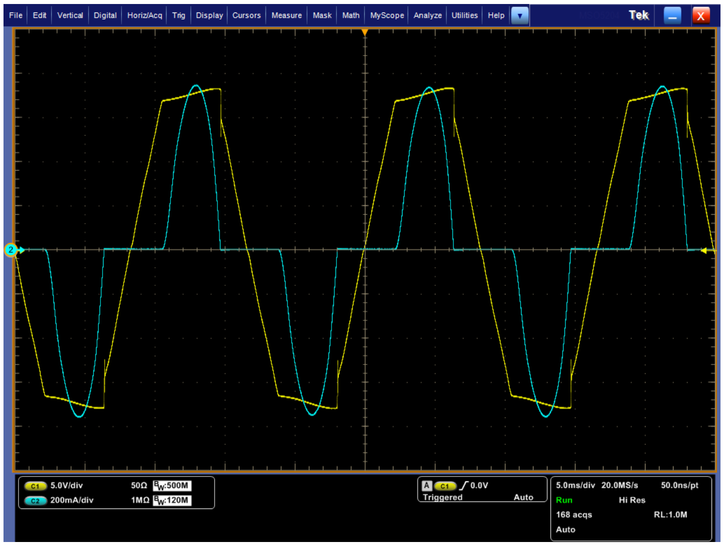
- The display should look about like this, with the input voltage on yellow channel 1 and the input current on cyan channel 2:

MSO/DPO5000 Series Procedure:

- ❑ Connect the external probe power adapter (119-7465-xx) to the rear of the oscilloscope and connect it to line power.
- ❑ On the demo board, move **SW1** to the left position.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 1 of the oscilloscope.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ In the **Range** section of the control window, select **Manual**.
- ❑ Make sure that the **Range** is set to **42V**.
- ❑ Connect the **+** and **–** inputs.
- ❑ Press the **AutoZero** button.
- ❑ Connect the **-** input of the differential probe to the **GND** test point.
- ❑ Connect the **+** input of the differential probe to the **AC High** test point.
- ❑ Set the Horizontal **Scale** to **5ms/div**.
- ❑ Press the front panel **2** button to turn on channel **2**.
- ❑ Connect a TCP0030 current probe to channel 2 on the oscilloscope.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ In the **Range** section of the control window, select **Manual**.
- ❑ Set the **Range** to **5A**.
- ❑ Make sure that the current probe's jaw is closed. Press the **Degauss AutoZero** button on the probe.

Key Take Away Points

- The display should look about like this:



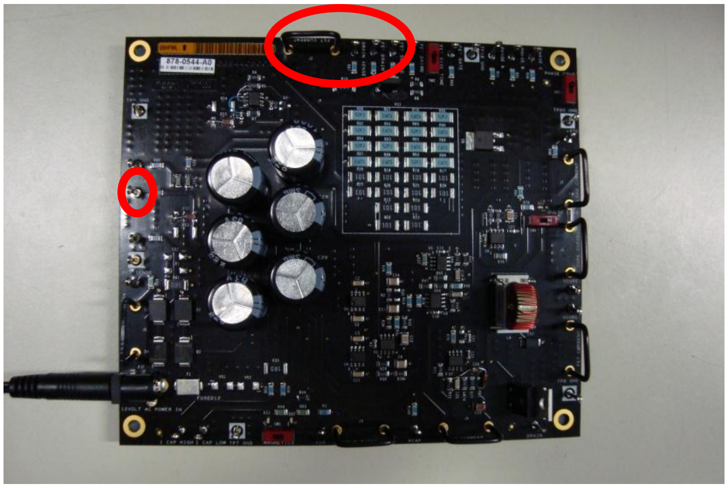
MSO/DPO5000 Series Procedure:

- ❑ Connect the current probe around the **AC_CURRENT** current loop and close the probe jaws.
- ❑ Scale and position the signals as shown at the left.
- ❑ In this case, the voltage and current waveforms are <u>in</u> phase. If the phase of channel 2 signal is opposite of the channel 1 signal, remove the current probe, turn it over, and reconnect it.
- ❑ Select **Horiz/Acq->Acquisition Mode->HiRes**.
- ❑ Select **Horiz/Acq->Resolution…** or **Horiz/Acq->Horizontal/Acquisition Setup….**
- ❑ Set the **Sample Rate** to **20 MS/s**. This will set the record length to **1M points**.
- ❑ To simplify the next part of the lab setup, press the front panel **1** and **2** buttons to temporarily turn off the display of channels 1 and 2.

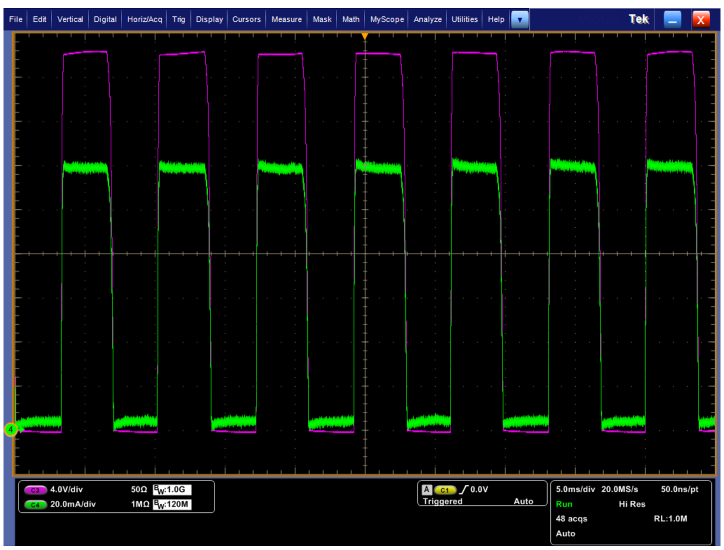
Key Take Away Points	**MSO/DPO5000 Series Procedure:**

Key Take Away Points

- To demonstrate power efficiency measurements, this section of the lab measures the AC output power delivered to the resistive load on the demo board.



- The display should now look about like this, with the voltage across the load on purple channel 3 and the load current on green channel 4:

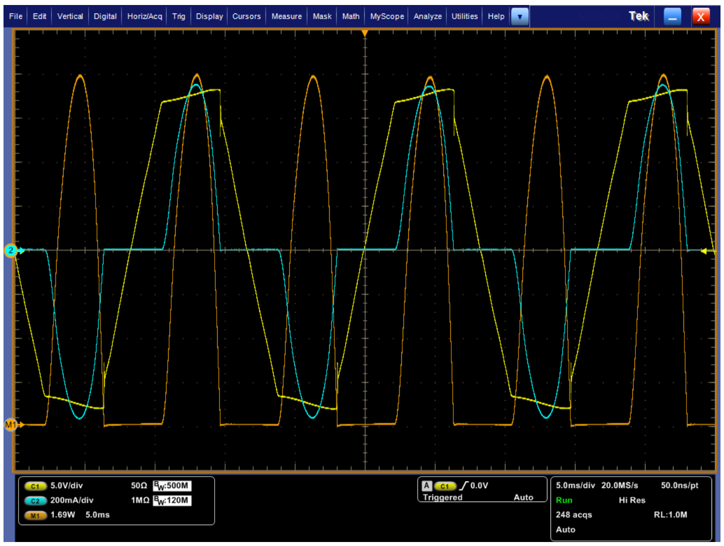


MSO/DPO5000 Series Procedure:

- ❑ Press the front panel **3** button to turn on channel **3**.
- ❑ Connect a TDP0500 or TDP1000 differential probe to channel 3 of the oscilloscope.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ In the **Range** section of the control window, select **Manual**.
- ❑ Make sure that the **Range** is set to **42V**.
- ❑ Connect the **+** and **–** inputs.
- ❑ Press the **AutoZero** button.
- ❑ Connect the **-** input of the differential probe to the **FET DRAIN** test point at the top of the board.
- ❑ Connect the **+** input of the differential probe to the **DC High** test point on the left side of the board.
- ❑ Press the front panel **4** button to turn on channel **4**.
- ❑ Connect a TCP0030 current probe to channel 4 on the oscilloscope.
- ❑ Press the **Menu** button on the probe's comp box.
- ❑ In the **Range** section of the control window, select **Manual**.
- ❑ Set the **Range** to **5A**.
- ❑ Make sure that the current probe's jaw is closed. Press the **Degauss AutoZero** button on the probe.
- ❑ Connect the current probe around the **FET_CURRENT** current loop at the top of the board and close the probe jaws.
- ❑ Scale and position the signals as shown at the left.
- ❑ The voltage and current should be in phase. If they are out of phase, remove the current probe, turn it over, and re-connect it.

Key Take Away Points

- Now that the oscilloscope is acquiring the input and output voltages and currents, we need to measure the instantaneous input and output power. Instantaneous power is simply the product of the voltage and the current, so we use the multiplication function in math to generate the instantaneous power waveform.
- The instantaneous input power waveform should look about like the orange waveform below. Notice that the power is 0 when the current is 0, and a positive value whenever the voltage*current product is positive.



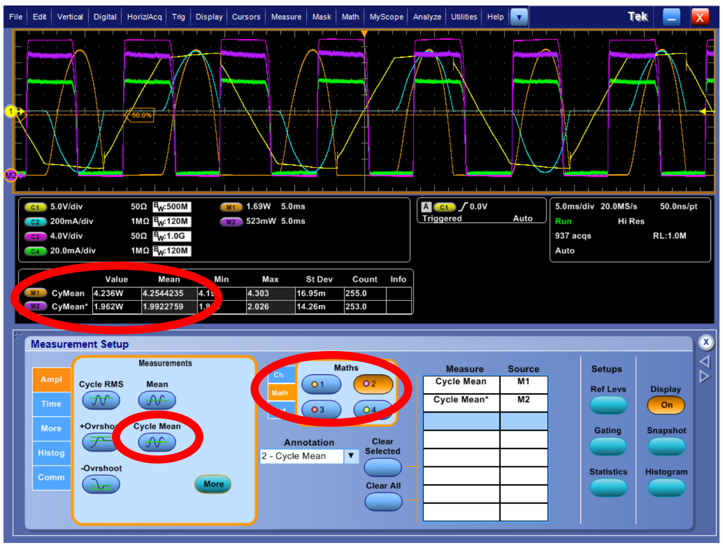
- To measure the average input power, we can use the automatic mean measurement. However, we want to measure the average across an integer number of cycles to get a correct and stable value, so we will use the special cycle mean measurement. With the measurement enabled, the display should look about like this:

MSO/DPO5000 Series Procedure:

- ❑ Scale and position all of the signals so each vertically fills most of the graticule without going outside the graticule.
- ❑ Turn on the display of channels 1 and 2 by pressing the front panel **1** and **2** buttons.
- ❑ To simplify the next part of the lab setup, press the front panel **3** and **4** buttons to temporarily turn off the display of channels 3 and 4.
- ❑ Select **Math -> Ch1*Ch2**.
- ❑ Select **Measure -> Measurement Setup…**.
- ❑ In the center of the control window, press the **Math** tab and press the Maths **1** button.
- ❑ At the left side of the control window, press the **Ampl** tab.
- ❑ In the Measurements window, press the **More** button to display the next page of measurements.
- ❑ Press the **Cycle Mean** button.
- ❑ Notice the measurement annotations on the display, showing where the cycle mean measurement is being made.

Key Take Away Points

- The instantaneous output power waveform should look about like the purple waveform below. Notice that the power is 0 when the voltage and current are 0, and a positive value whenever the voltage*current product is positive.
- To measure the average output power, we can use the automatic mean measurement. Again, we want to measure the average across an integer number of cycles to get a correct and stable value, so we will use the special cycle mean measurement. With the measurement enabled, the display should look about like this:



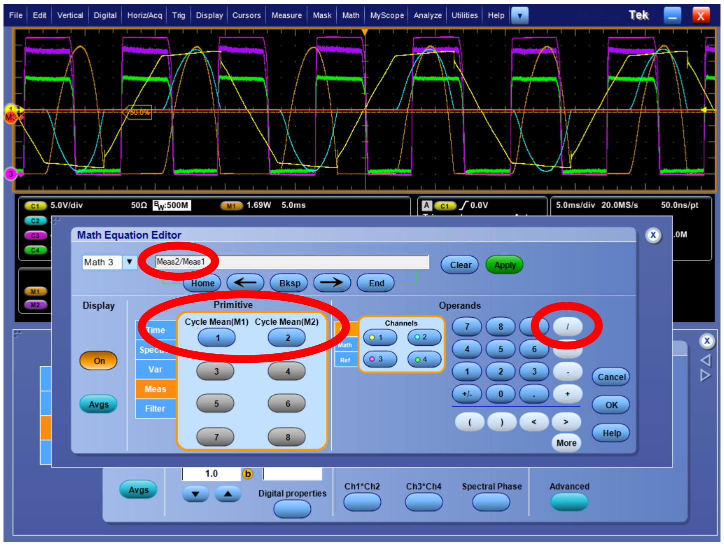
- NOTE: All of the voltage, current, and instantaneous power waveforms in this lab have a dominant fundamental component and have duty cycles near 50%. In these cases, the automatic cycle measurements work very well. In some power supplies, the waveforms have very high or low duty cycles and may exhibit high noise or ringing on the signal. In these cases, you may need to use cursor gating on the measurements to get accurate and repeatable results.
- So far in this lab, we have set up the oscilloscope to measure the average input power and the average output power. Now we can calculate the input-to-output efficiency.

MSO/DPO5000 Series Procedure:

- ❑ Turn on the display of channels 3 and 4 by pressing the front panel **3** and **4** buttons.
- ❑ Select **Math -> Ch3*Ch4**.
- ❑ In the center of the control window, press the Maths **2** button.
- ❑ Press the **Cycle Mean** button.
- ❑ Again, notice the measurement annotations on the display, showing where the cycle mean measurement is being made.

Key Take Away Points

- To calculate the efficiency, we need to divide the average output power by the average input power, so we use the division function in math to generate the value.



- The output of the efficiency calculation is a math waveform. To provide a numerical readout, we can use the automatic measurement system again. The measurement below indicates an efficiency of about 47%:

- Clearly, this demo board circuit is a very inefficient supply, but this measurement technique is valid and can be very useful.

MSO/DPO5000 Series Procedure:

❑ Select **Math -> Math Setup….**

❑ Press the **Math3** tab at the left side of the control window.

❑ Press the **Editor** button.

❑ Press the **Meas** tab near the left side of the control window.

❑ Press the **Cycle Mean (M2) 2** button.

❑ Press the **/** division button.

❑ Press the **Cycle Mean (M1) 1** button.

❑ Press the **OK** button. This will display a red math waveform which represents the ratio of average output power to average input power.

❑ Select **Measure -> Measurement Setup….**

❑ In the center of the control window, press the **Math** tab and press the Maths **3** button.

❑ At the left side of the control window, press the **Ampl** tab.

❑ In the Measurements window, press the **More** button to display the next page of measurements.

❑ Press the **Mean** button.

Tektronix

Understanding the TekVPI Interface

Introduction

The **TekVPI** (**Tek**tronix **V**ersatile **P**robe **I**nterface) architecture is the new-generation probe interface architecture for the MSO/DPO5000 Series oscilloscopes. TekVPI probes combine excellent electrical probe performance with advanced, bidirectional serial interface communications with the oscilloscope. The design architecture of TekVPI provides users improved ease-of-use in probe setup, easy selection of displayed probe status and setup information, as well as accurate probe measurement performance results all intended to simplify and improve the performance of the user's test and measurement experience.

In 1969, Tektronix introduced a probe interface which used a BNC type connector for passing the acquired analog signal and added an analog-encoded scale factor detection pin, which enabled the compatible oscilloscope to automatically detect and scale the displayed vertical attenuation range appropriately. Today, we refer to this interface as TekProbe™ Level 1. A P6139A or P6139B passive probe is a common example.

In 1986, probe usability was further enhanced with the introduction of the TekProbe-BNC Level 2 probe interface architecture which supports the required operating power requirements for "active" probe types which contained transistors, IC's, or other active components as part of the probe's signal conditioning network design. TekProbe-BNC Level 2 further extended the capabilities of Level 1 designs by adding probe communications with the oscilloscope to improve the usability of increasingly sophisticated probe types and to accomplish calibrated offset at the probe tip.

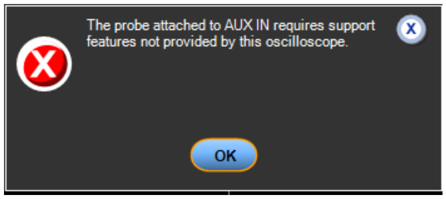
In early 2006, Tektronix introduced the next generation of probe interface, the TekVPI architecture. Each TekVPI probe features controls and indicators right on the probe for quick and easy access to the probe's most commonly required setup controls and operating status. TekVPI probes also have a Menu button that enables users to quickly and easily access a probe setup menu on the oscilloscope. The instrument provides comprehensive probe information including: probe model type, probe serial number, probe operating status and warnings. Additionally, all probe setup controls can be changed and monitored from the instrument display. Because of the probe communications, the oscilloscope can save the probe setup and provide remote control of the probes through the programmable interfaces (USB, GPIB, and Ethernet).

SCOPE PAD ASSIGNMENTS

Traditionally, the precisely-regulated power resources for the active probes were provided by the host oscilloscope. Therefore, every oscilloscope was burdened with the cost and weight of the power conditioning circuits. Sometimes, instrument constraints limited the number or type of probes which were supported. The TekVPI architecture moves the complexity of the power conditioning into the probe itself, where the design can be optimized for that specific probe. The TekVPI host oscilloscope distributes a +12 V_{DC} bulk power supply which each probe or adapter regulates to meet its own needs, providing more flexibility in probe support. An example of this benefit is found with the TCP0030, 30 Ampere AC/DC current probe. Previous current probes of this measurement range required external power supplies to provide the necessary resources required for "bucking currents" and to perform degaussing operations necessary to maintain accurate measurement capability. The TCP0030 and TCP0150 TekVPI current probes now eliminate this need for an external power supply when used with the MSO/DPO5000 series. The MSO/DPO5000 series oscilloscopes can provide up to 10W of probe power (supporting two of these current probes) as described in more detail at the end of this section. An external power adapter is also available to support those applications requiring more power.

The TekVPI design also simplifies the attachment of the probe or adapter, allowing the user to simply insert the probe connector into the oscilloscope's TekVPI input channel connector. The probe is locked in place until the user presses the push-button lock release. To assure electrical signal integrity of the probe interface connections gold-plated spring contacts are used. In addition to TekVPI probes, the interface is directly compatible with BNC cables and TekProbe level 1 probes such as the P6139A and P6139B.

Note: On the MSO/DPO5000 Series, the front panel Aux In connector provides full power and communication capabilities, but only offers 1 MΩ termination. Therefore, when probes which expect 50Ω termination (such as TekVPI active and differential probes) are connected, you will see an error message pop up and the probes are <u>not</u> powered up:



Lab Objectives

For this lab, if you have the optional probes and the time, go through the procedure on the right side of each page. If not, simply follow the pictures and text on the left side of each page.

- Obtain a basic understanding of the TekVPI interconnect.
- Learn how to control the TekVPI probes with the MSO/DPO5000 Series oscilloscope.
- Learn about some basic applications of the new TekVPI probes.

Coaxial Cable

Key Take Away Points

- Coaxial cables with BNC connections are directly compatible with the TekVPI interface on the MSO/DPO5000 Series oscilloscope.
- When a coax cable is connected to an analog channel on an MSO/DPO5000 Series oscilloscope, the relevant readouts for the probe appear in the Probe Controls control window.
- Advanced probes can be individually calibrated. Since this is not relevant for cables, the Calibration should be cleared or “initialized”.
- The probe controls such as Deskew Time and External Attenuation for the probe appear in that channel’s Probe Setup menu.
- The Attenuation control allows you to specify the amount of external attenuation that has been applied to the signal. Notice that the displayed waveform amplitude and/or the units/div value on the channel 1 readout reflect this selection.

- Notice the vertical readout. Since the Termination is set to 1MΩ, the channel’s bandwidth is at the maximum 500 MHz. If the Termination is set to 50Ω and the bandwidth is set to full, the channel bandwidth would be the instrument’s maximum bandwidth.

MSO/DPO5000 Series Procedure:

- ❑ Power up the oscilloscope.
- ❑ Press the front panel **Default Setup** button to set the oscilloscope into a known state.
- ❑ Connect a coax cable to the Channel 1 input. (Since there is no communication from the cable, it doesn’t really matter if you do this step or not.)
- ❑ Select **Vertical->Probe Controls**.
- ❑ Using the Source drop down menu, select **Ch 1**.
- ❑ Press the **Setup** button.
- ❑ If the **Calibration Probe Status** is not already “Initialized”, press the **Clear ProbeCal** button.
- ❑ Touch the **External Atten** text box to attach the Multipurpose controls to the Attenuation controls.
- ❑ Using the Multipurpose **a** control, adjust the **External Atten**.

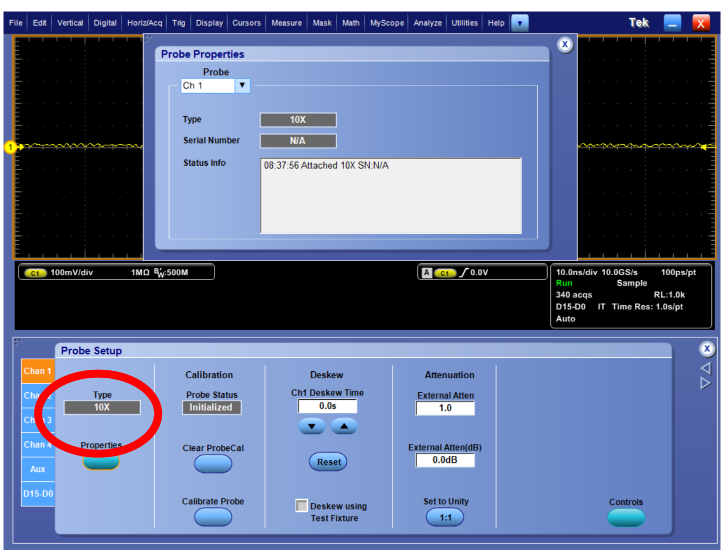
P6139A and P6139B Passive Probes

Key Take Away Points

- The P6139A andP6139B are examples of TekProbe level 1 probes. It uses a BNC connector to transmit the analog signal, and transmits the probe's voltage scale factor data via a spring-loaded pin. (See picture at right.)
- The P6139A and P6139B 10X passive voltage probes are directly compatible with the TekVPI interface on the MSO/DPO5000 Series oscilloscope.

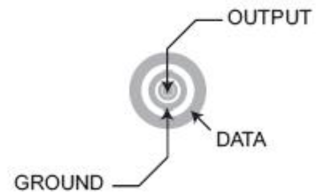
P6139B passive probe

- When a probe is connected to an analog channel on an MSO/DPO5000 Series oscilloscope, the relevant readout and controls for the probe appear in that channel's Probe Setup menu.
- In the case of a P6139A and P6139B, there are no controls, and the menu displays that the probe is a 10X voltage probe.
- Notice that the units on the channel 1 readout are Volts.



- Note that the P6139A and P6139B expect 1MΩ termination to work correctly. On an MSO/DPO5000, if the termination is set to 50Ω, the probe will not work as expected.

MSO/DPO5000 Series Procedure:



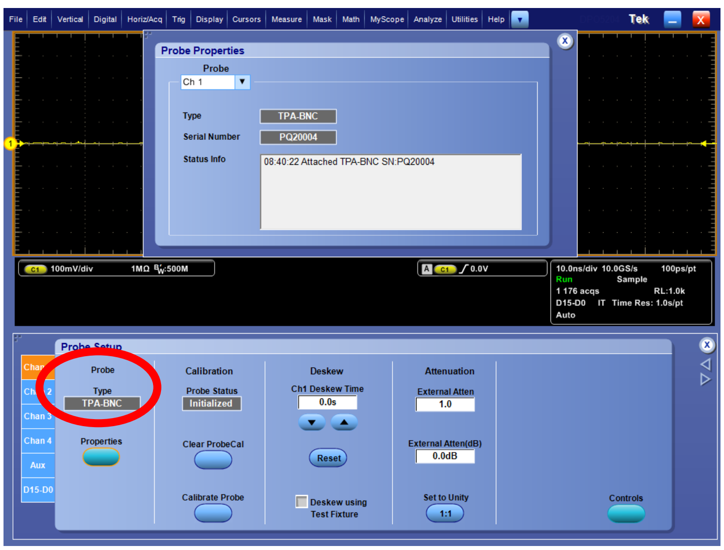
TekProbe level 1 probe

- ❑ Connect the P6139A or P6139B 10X passive voltage probe to the Channel 1 input.
- ❑ Select **Vertical->Probe Controls**.
- ❑ Press the **Setup** button to display the available Probe Setup controls such as Deskew Time and External Atten.
- ❑ And, again, if the **Calibration Probe Status** is not already "Initialized", press the **Clear ProbeCal** button.
- ❑ Press the Probe **Properties** button to display the available information about the probe.
- ❑ When you are done, click the **X** in the upper right corner of the Probe Properties control window to close it.
- ❑ Look at the probe accessories that come with the P6139B. The probe accessories, including the hook tip, ground leads, ground spring, and colored bands are now common across the general-purpose passive probe portfolio (P6139B, P5050B, and the new TPP Series).

TPA-BNC Adapter

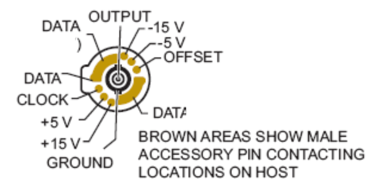
Key Take Away Points

- TekProbe level 2 probes include power connections for active probes and increased data communications with the scope. However, they are not mechanically compatible with the TekVPI connector.
- The data and clock signals are I^2C serial bus connections.
- The TPA-BNC adapter is designed to allow the user to connect legacy TekProbe level 2 probes, such as the P624X series active and differential probes and the TCP202 current probes, to the MSO/DPO5000 Series.
- When the TPA-BNC by itself is attached to channel 1 and the channel's Probe Setup menu is selected, the display should look about like this:



- When a TekProbe level 1 probe (such as the P6139A or P6139B) or a TekProbe BNC level 2 probe (such as the P6243) is attached to the TPA-BNC, the probe information is displayed in the Probe Properties control window.

MSO/DPO5000 Series Procedure:



TekProbe level 2 probe

- ❑ Connect the TPA-BNC adapter to the Channel 1 input.
- ❑ Select **Vertical->Probe Controls**.
- ❑ Press the **Setup** button to display the available Probe Setup controls such as Deskew Time and External Atten.
- ❑ Press the **Properties** button and notice that the TPA-BNC status information such as serial number is displayed. Close the Probe Properties control window.
- ❑ Connect the P6139A or P6139B to the input of the TPA-BNC.
- ❑ Notice that the 10X attenuation of the probe appears in the Probe Type readout in the control window.
- ❑ If you connect a supported TekProbe level 2 probe such as a TCP202, you will see the probe name appear in the Probe Type readout.
- ❑ Press the **Properties** button and notice that the probe status information such as serial number is displayed.

TPA-BNC – Just A Mechanical Adapter?

There is more under the cover than meets the eye! Although described as an adapter, the TPA-BNC is *much more* than a passive signal path, mechanical adapter. It contains sophisticated circuit boards, ICs, connectors and shielding.

It is a mechanical adapter (TEKPROBE BNC to TekVPI), but it also is a power converter and a TEKPROBE Level 2 to TekVPI control signal converter allowing the use of existing TEKPROBE Level 2 interface active voltage probes, high and low voltage differential probes, micro-volt pre-amplifier probe, and current probes to name a few with the Tektronix oscilloscope products that use the TekVPI probe interface.

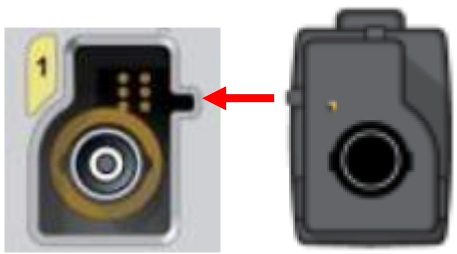
- Power Conversion – requires circuitry to convert the TekVPI voltage levels (12V, 5V) and provide the voltage levels (+15V, -15V, +5V, -5V) required for TEKPROBE interface probing solutions to function.
- Control Signal Conversion – requires circuitry to convert TEKPROBE control signaling; such as attenuation factor, range, product serial number, and product type into TekVPI control signaling formats.
- Backward Compatibility – allows moving into the next generation of test and measurement tools while maintaining compatibility to use existing TEKPROBE interface tools without losing your present DUT test fixtures and testing setups.

TPA-BNC – NOT JUST ANOTHER ADAPTER!

TPP0500 and TPP1000 Passive Probes

Key Take Away Points

- For high-fidelity acquisition of high-speed ground-referenced voltage signals, the TPP0500 / TPP1000 is an excellent choice:
    - 500 MHz / 1 GHz probe bandwidth provides wide-bandwidth general-purpose probing for any of the MSO/DPO5000 Series scopes.
    - ≤4 pF input capacitance minimizes probe AC loading on the circuit.
    - 10 MΩ input resistance at the probe tip minimizes probe DC loading on the circuit.
    - 300 V CAT II Maximum Input Voltage provides wide dynamic range while minimizing AC (capacitive) loading.
- The TekVPI connector on the TPP0500 / TPP1000 has a mechanical key which corresponds to the TekVPI connector on the front of the MSO/DPO5000 Series. This mechanical lockout prevent attachment of the probe to oscilloscopes which do not support these probes:



- Notice that the vertical readout indicates that the TPP1000 provides 1 GHz bandwidth! The display should look about like this:

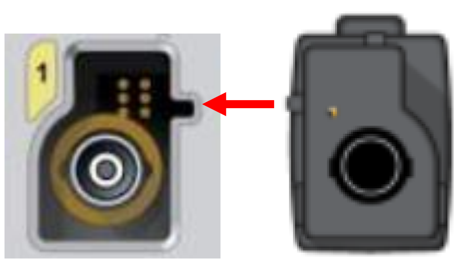
MSO/DPO5000 Series Procedure:

- ❑ Connect a TPP0500 or TPP1000 probe to channel 1.
- ❑ Press the front panel Vertical **Menu** button.
- ❑ Select **Vertical->Probe Controls**.
- ❑ Press the **Setup** button to display the available Probe Setup controls such as Deskew Time and External Atten.
- ❑ The TPP probes have an automated AC calibration capability.
- ❑ Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- ❑ Connect the probe ground to the ground connection just above the PROBE COMP signal.
- ❑ Press the **Calibrate Probe** button.

TPP0502 and TPP0850 Passive Probes

Key Take Away Points

- For high-fidelity acquisition of low-amplitude, high-speed ground-referenced voltage signals, the TPP0502 is an excellent choice:
    - 500 MHz probe bandwidth and only 2X attenuation provides low-noise, wide-bandwidth probing for small signals with any of the MSO/DPO5000 Series scopes.
    - 2 MΩ input resistance and ≤12.7 pF input capacitance minimizes probe loading on the circuit.
    - 300 V CAT II Maximum Input Voltage provides wide dynamic range while minimizing AC (capacitive) loading.
- For high-fidelity acquisition of high-voltage, high-speed ground-referenced voltage signals, the TPP0850 is an excellent choice:
    - 800 MHz probe bandwidth and 50X attenuation provides wide-bandwidth general-purpose probing for high-voltage signals with any of the MSO/DPO5000 Series scopes.
    - ≤1.8 pF input capacitance minimizes probe AC loading on the circuit.
    - 40 MΩ input resistance at the probe tip minimizes probe DC loading on the circuit.
    - 2.5 kV_{Peak}, 1000 V_{RMS} CAT II Maximum Input Voltage provides wide dynamic range while minimizing AC (capacitive) loading.
- Like the TPP0500 / TPP1000, the TekVPI connector on the TPP0502 and TPP0850 probes have a mechanical key which corresponds to the TekVPI connector on the front of the MSO/DPO5000 Series. This mechanical lockout prevent attachment of the probe to oscilloscopes which do not support these probes:



MSO/DPO5000 Series Procedure:

- ❑ Connect a TPP0502 or TPP0850 probe to channel 1.
- ❑ Press the front panel Vertical **Menu** button.
- ❑ Select **Vertical->Probe Controls**.
- ❑ Press the **Properties** button to display probe information and connection status.
- ❑ Click the white **X** in the upper right corner to close the pop-up window.
- ❑ Press the **Setup** button to display the available Probe Setup controls such as Deskew Time and External Atten.
- ❑ The TPP probes have an automated AC calibration capability.
- ❑ Connect the probe tip to the PROBE COMP signal on the lower right corner of the oscilloscope.
- ❑ Connect the probe ground to the ground connection just above the PROBE COMP signal.
- ❑ Press the **Calibrate Probe** button.

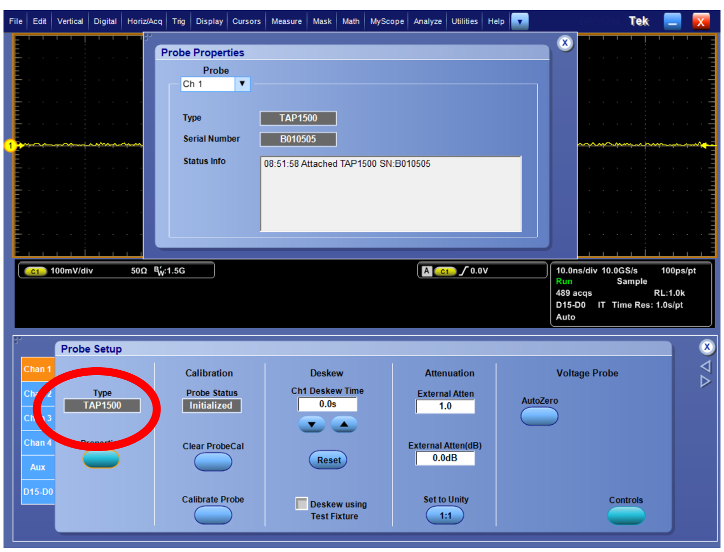
TAP1500, TAP2500, and TAP3500 Active Probes

Key Take Away Points

- For highest-fidelity acquisition of high-speed ground-referenced voltage signals, the TAP series active probes are an excellent choice:

	TAP1500	TAP2500	TAP3500
Bandwidth	≥1.5 GHz	≥2.5 GHz	≥3.5 GHz
Attenuation	10:1	10:1	10:1
Input Impedance	1 MΩ || ≤ 1 pF	40 kΩ || ≤ 0.8 pF	40 kΩ || ≤ 0.8 pF
Input Dynamic Range	-8 V to +8 V	-4 V to +4 V	-4 V to +4 V
Input Offset Range	-10 V to +10 VDC	-10 V to +10 VDC	-10 V to +10 VDC
Max Input Voltage (nond struct)	±15 V (DC + peak AC)	±30 V (DC + peak AC)	±30 V (DC + peak AC)

- Notice that you can call up the MSO/DPO5000 Series Probe Controls control window simply by pressing the Menu button on the probe. The display should look about like this:



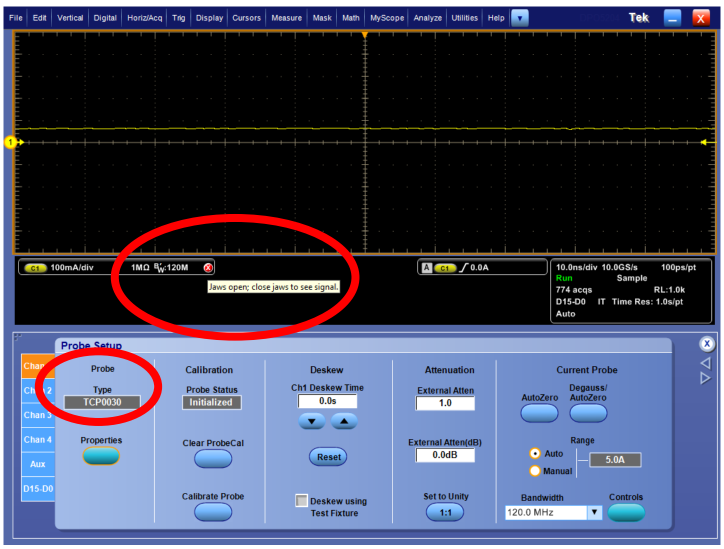
MSO/DPO5000 Series Procedure:

- ❑ Connect a TAP Series active probe to channel 1. Make sure the green Status LED on the probe is lit.
- ❑ Press the **Menu** button on the probe. Notice that the probe is identified in the Probe Type readout.
- ❑ To offset the input signal in the probe, use the Multipurpose **a** control.
- ❑ Press the **Setup** button to display the available Probe Setup controls such as Deskew Time and External Atten.
- ❑ Press the **Properties** button and notice that the probe status information such as serial number is displayed. Close the Probe Properties control window.
- ❑ To minimize any DC offsets in the probe, after the probe and oscilloscope have warmed up for at least 20 minutes, short the probe input to ground and press the **AutoZero** button on the oscilloscope.

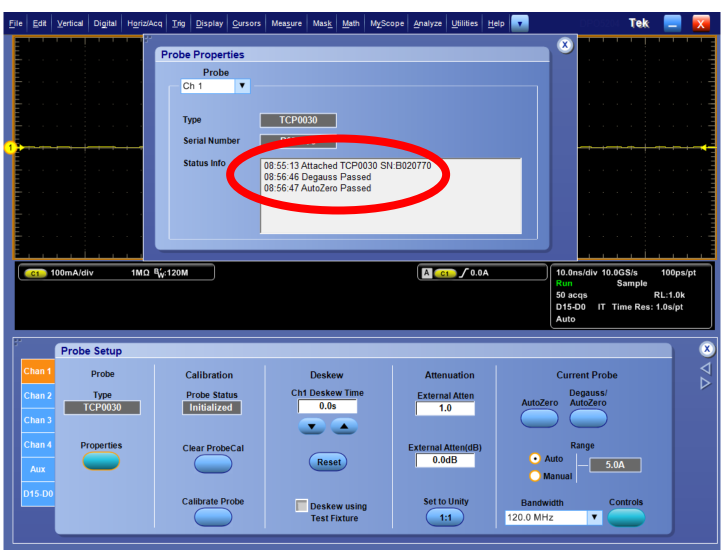
TCP0020 and TCP0030 Current Probes

Key Take Away Points

- For high-fidelity acquisition of high-speed current signals, the TCP0020 or TCP0030 are excellent choices:
    - DC to >50 MHz or 120 MHz bandwidth.
    - 20 A_{RMS} or 30 A_{RMS} current capability.
    - Provides automatic units scaling and readout on the oscilloscope display.
- When you first connect the current probe, you will see a pop-up notifier in the middle of the display if the probe needs to be degaussed and the offsets zeroed out. Also, notice the red error icon and the mouse-over message which appears when the probe jaws are open:



- You can call up the MSO/DPO5000 Series Probe Controls control window simply by pressing the Menu button on the probe. The display should look about like this:



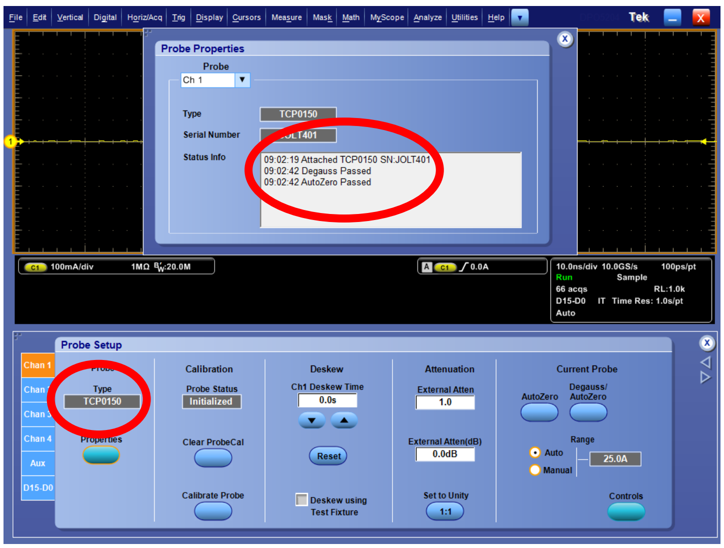
MSO/DPO5000 Series Procedure:

- ❑ Connect a TCP0020 or TCP0030 current probe to channel 1.
- ❑ To remove any residual magnetic fields and DC offsets in the current probe, press the **Degauss / AutoZero** button, either on the probe or in the control window on the oscilloscope.
- ❑ Press the **Menu** button on the probe. Notice that the probe is identified in the Probe Type readout.
- ❑ To manually match the vertical sensitivity of the probe to the signal, press the **Range** button, either on the probe or in the control window on the oscilloscope. However, automatic scaling is the default, so you may not ever need to use this control.
- ❑ Press the **Setup** button to display the available Probe Setup controls such as Deskew Time and External Atten.
- ❑ Notice that the units on the vertical and trigger readouts change to units of current (mA and A).

TCP0150 Current Probe

Key Take Away Points

- For high-fidelity acquisition of large current signals, the TCP0150 is an excellent choice:
  - DC to 20 MHz bandwidth.
  - Provides automatic units scaling and readout on the oscilloscope display.
  - 150 A_{RMS} / 500 A_{peak} pulse current capability.
- You can call up the MSO/DPO5000 Series Probe Controls menu simply by pressing the Menu button on the probe. The display should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ Connect a TCP0150 probe to channel 1.
- ❑ To remove any residual magnetic fields and DC offsets in the current probe, press the **Degauss / AutoZero** button, either on the probe or in the control window on the oscilloscope.
- ❑ Press the **Menu** button on the probe. Notice that the probe is identified in the Probe Type readout.
- ❑ To manually match the vertical sensitivity of the probe to the signal, press the **Range** button, either on the probe or in the control window on the oscilloscope. However, automatic scaling is the default, so you may not ever need to use this control.
- ❑ Press the **Setup** button to display the available Probe Setup controls such as Deskew Time and External Atten.
- ❑ Notice that the units on the vertical and trigger readouts change to units of current (mA and A).

TDP0500, TDP1000, TDP1500, and TDP3500 Differential Probes

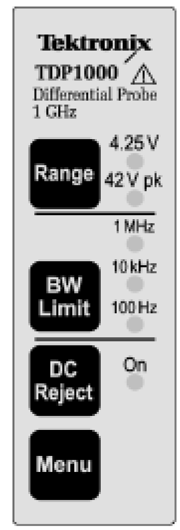
Key Take Away Points

- For high-fidelity acquisition of high-speed differential voltage signals, the TDP Series differential probes are excellent choices:

	TDP0500 / TDP1000	TDP1500	TDP3500
Bandwidth	500 MHz / 1 GHz	1.5 GHz	3.5 GHz
Attenuation	5:1 and 50:1	1:1 and 10:1	5:1
Differential Input Impedance	1 MΩ || < 1 pF	200 kΩ || < 1 pF	100 kΩ || ≤ 0.3 pF
Differential Mode Input Voltage Range	±42 V (DC + peak AC)	±8.5 V (10X) ±0.85 V (1X)	±2 V
Common Mode Input Voltage Range	±35 V (DC + peak AC)	7 V	-4 V to +5 V
Input Offset Range	±42 V	±7 V	±1 V
Max Input Voltage (nondestruct)	±100 V (DC + peak AC)	±25 V (DC + peak AC)	±25 V (DC + peak AC)

MSO/DPO5000 Series Procedure:

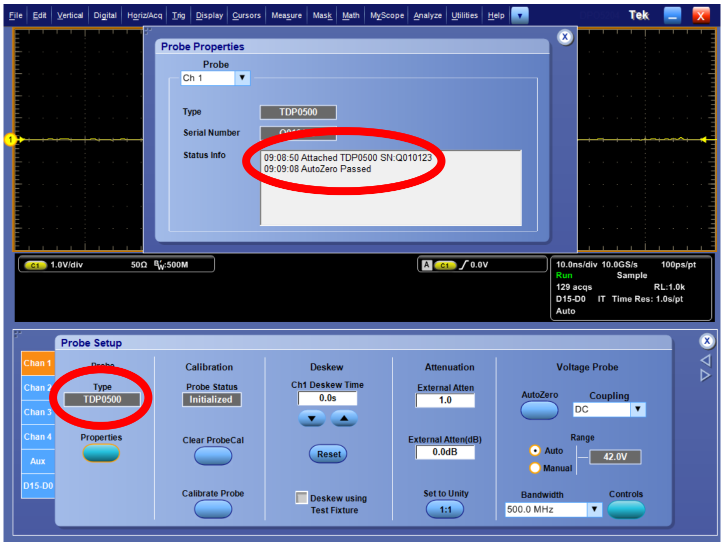
- ❑ Connect a TDP Series differential probe to channel 1.



TDP1000 Controls

Key Take Away Points

- You can call up the MSO/DPO5000 Series Probe Controls control window simply by pressing the Menu button on the probe. The display should look about like this:

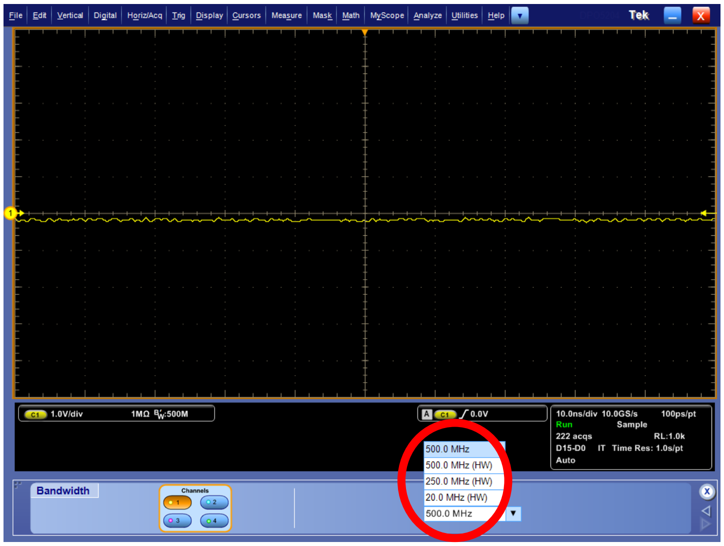


MSO/DPO5000 Series Procedure:

- ❑ Select **Vertical->Deskew…** to display the available Probe Deskew Time and External Atten controls.
- ❑ Press the **Menu** button on the probe. Notice that the probe is identified in the Probe Type readout.
- ❑ To manually match the vertical sensitivity of the probe to the signal, press the **Range** button, either on the probe or in the control window on the oscilloscope. However, automatic scaling is the default, so you may not ever need to use this control.
- ❑ To offset the input signal in the probe, touch the **Offset** text box and use the Multipurpose **a** control to adjust the DC offset.
- ❑ To minimize any DC offsets in the probe, after the probe and oscilloscope have warmed up for at least 20 minutes, set the range to the desired setting, short both probe inputs to ground and press the **AutoZero** button in the control window.

Key Take Away Points

- The TDP Series probe adds new bandwidth and coupling capabilities. Before you connect the probe, the channel's menu looks something like this:



- After connecting the TDP Series probe, the menu changes to look something like this:

- Notice that additional bandwidth selections have been added.

MSO/DPO5000 Series Procedure:

- ❑ Remove the probe from channel 1.
- ❑ Select **Vertical->Bandwidth Limit….**
- ❑ Press the down arrow on the **Bandwidth** text box to display the available bandwidth settings.
- ❑ Connect the TDP series probe to channel 1.
- ❑ Press the probe **Menu** button to display the full Probe Controls control window.
- ❑ Press the down arrow on the **Bandwidth** text box and notice the additional bandwidth selections have been added.
- ❑ To minimize noise on the display, select the lowest bandwidth setting that does not distort the signal.

Key Take Away Points

- Notice that the DC Reject ("Rej") capability of the probe has replaced the channel's AC coupling selection in the menu.
- DC Reject is useful when you are measuring small amplitude signals superimposed on a large differential offset component. DC Reject generates an internal offset that cancels the DC component of the signal.
- Because the input is always directly coupled, the DC reject mode does not increase the common and differential mode dynamic ranges for DC components. The DC reject mode also disables any capability of external offset adjustment.
- In the screen shot below, the probe is connected between the CAN_H and GND signals. With the probe and oscilloscope DC-coupled, the signal appears as a $1V_{pp}$ AC signal riding on a 2.5V DC baseline, as shown in the white reference trace below. (The CAN_H signal is positive relative to the baseline, and the CAN_L signal is negative relative to the baseline.) When the probe's DC Reject enabled, you'll notice that most of the DC offset has been removed, similar to AC coupling.

- Finally, notice the variety of probing accessories for the TDP series for versatile connectivity to the device under test: point probing, variable spacing, square pin connection, KlipChip connection, and a new solder-down connection that incorporates damping networks for improved signal fidelity.

MSO/DPO5000 Series Procedure:

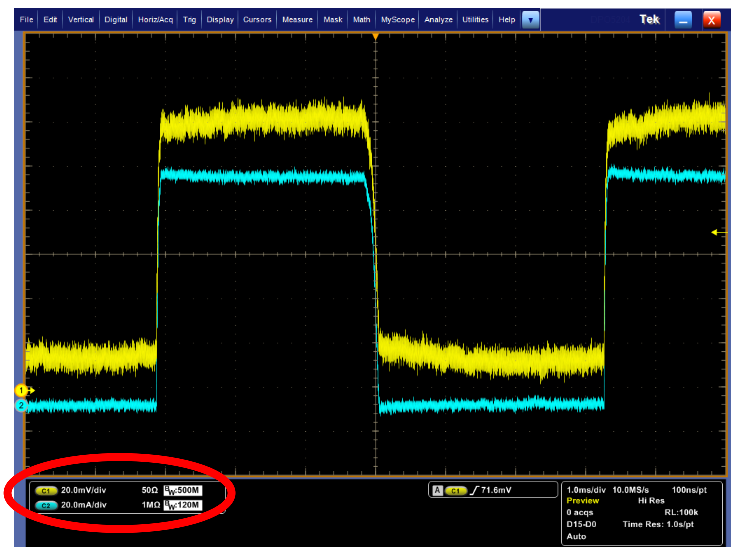
- ❑ Connect the probe to a signal with significant DC offset, such as **CAN_H** on the demo board.
- ❑ Make sure that the probe **Offset** is set to **0 V**.
- ❑ Press the **DC Reject** button on the TDP probe, or select **Vertical->Coupling…** and press the **DC rej** Coupling button, and notice the effect on the display.
- ❑ Look at the box of probing accessories provided with the TDP Series of probes.

Key Take Away Points

(optional) Measuring Current with Differential Probes

- Differential probes can also provide wideband current measurements by measuring the voltage drop across a known impedance. For example, the 3PQS power demo board has a 1Ω resistor in series with the load, as shown below:

- For comparison purposes, the screen shot below shows the TCP0030 current measurement on channel 2. The display of the current waveform should look about like this:



MSO/DPO5000 Series Procedure:

- ❑ Connect the 12VAC power adapter to the power demo board and plug it in.
- ❑ On the 878-0544-XX demo board, connect the differential probe to the DRAIN_SENSE and FET_DRAIN test points.
- ❑ On the 3PQS board, connect the differential probe across the large 1Ω resistor which is in series with the load.
- ❑ Select **Vertical->Vertical Setup…**.
- ❑ Double-click on the **Units** text box, enter **A**, and press **Enter** to set the units to Amperes to display the signal (and automatic measurements) in Amps.
- ❑ Press the front panel **Autoset** button.
- ❑ If the signal looks too noisy, you can filter the display with HiRes. Press the front panel **Acquire** button, press **Acquisition** tab, and press the **Hi Res** Acquisition Mode button.

TxDP0x00 and P52xxA Series High-Voltage Differential Probes

Key Take Away Points

- For high-fidelity acquisition of high-voltage differential voltage signals, the TxDP0x00 and P52xxA Series differential probes are excellent choices.
- The TxDP0x00 TekVPI probes are similar to the existing P52xxA probes, but they have double the bandwidth of the P52xxA probes and do not require the TPA-BNC adapter for use on TekVPI® scopes.

  For reference, the nomenclature acronyms have the following definitions:
  TMDP0200: **T**ektronix **M**edium-Voltage **D**ifferential **P**robe with **200** MHz bandwidth
  THDP0200: **T**ektronix **H**igh-Voltage **D**ifferential **P**robe with **200** MHz bandwidth
  THDP0100: **T**ektronix **H**igh-Voltage **D**ifferential **P**robe with **100** MHz bandwidth

Characteristic	TMDP0200	THDP0200	THDP0100
Attenuation	25X/250X	50X/500X	100X/1000X
Dynamic Range	250X: +/- 750V 25X: +/- 75V	500X: +/- 1500 V 50X: +/- 150V	1000X: +/- 6000V 100X: +/- 600V
Common Mode Voltage	250X: +/- 750V 25X: +/- 75V	500X: +/- 1500V 50X: +/- 150V	1000X: +/- 6000V 100X: +/- 600V
Bandwidth	200 MHz	200 MHz	100 MHz
Rise Time	< 1.8 ns	< 1.8 ns	< 3.5 ns
Slew Rate	< 275 V/ns @ 1/250 gain	< 650 V/ns @ 1/500 gain	< 2500 V/ns @ 1/1000 gain
Input Impedance at the Probe Tip	5 MΩ || < 2 pF	10 MΩ || < 2 pF	40 MΩ || < 2.5 pF

- For comparison, these are the basic specifications for the P52xxA Series differential probes:

Characteristic	P5200A	P5202A	P5205A	P5210A
Attenuation	50X / 500X	20X / 200X	50X / 500X	100X / 1000X
Differential Input Voltage	500X: ±1300V 50X: ±130V	200X: ±640V 20X: ±64V	500X: ±1300V 50X: ±130V	1000X: ±5600V 100X: ±560V
Common Mode Voltage	500X: ±1300V 50X: ±130V	200X: ±640V 20X: ±64V	500X: ±1300V 50X: ±130V	1000X: ±5600V 100X: ±560V
Bandwidth	50 MHz	100 MHz	100 MHz	50 MHz

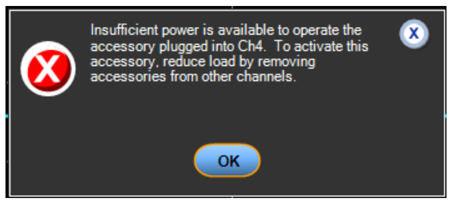
Note: P5202A, P5205A, and P5210A require the use of the TPA-BNC adapter with the MSO/DPO5000 Series.

THDP0200 Probe and Accessories

MSO/DPO5000 Probe Power

Key Take Away Points

- The MSO/DPO5000 oscilloscopes contain the TekVPI probe interface that provides power to qualifying TekVPI voltage and current probes. The oscilloscopes internal power supply can provide up to about 15W (12W with software versions ≤6.2.0) of power to all the TekVPI probe inputs located on the front of the oscilloscope (Channels 1, 2, 3, 4, and the Aux In).
- Because some of the available TekVPI probes can draw a significant amount of power, possibly collectively exceeding the 15W of integrated power the MSO/DPO5000 oscilloscope can provide, Tektronix offers an external power supply accessory (Tek Part Number 119-7465-xx). The TekVPI external power supply can provide up to 50W of power through the rear panel connector to the TekVPI front panel probe inputs, enabling the usage of any combination of qualifying probes without exceeding power requirements.
- The oscilloscope will display this message when the power draw has been exceeded, indicating the need for a TekVPI external power supply:



- The table below lists the maximum power draw[1] associated with each type of TekVPI probe or accessory that can be used with the MSO/DPO5000 Series oscilloscopes. This table can help you determine if you potentially need the external power supply for your application.

TekVPI Probe/Accessory	Description	Max Power Draw
TAP1500	1.5 GHz Single-ended Active FET Voltage Probe	1.5W
TAP2500	2.5 GHz Single-ended Active FET Voltage Probe	1.5W
TAP3500	3.5 GHz Single-ended Active FET Voltage Probe	1.5W
TDP0500	500 MHz Differential High Voltage Probe (± 42 V)	1.5W
TDP1000	1 GHz Differential High Voltage Probe (± 42 V)	1.5W
TDP1500	1.5 GHz Differential Voltage Probe (± 8.5 V)	1.9W
TDP3500	3.5 GHz Differential Voltage Probe (± 2 V)	1.5W
TCP0020	15 A, 50MHz, AC/DC Current Probe	4.0W
TCP0030	30 A, 120MHz, AC/DC Current Probe	8.4W
TCP0150	150 A, 20 MHz, AC/DC Current Probe	9.2W
TMDP0200	200 MHz High Voltage Differential Probe	2.7W
THDP0100	100 MHz High Voltage Differential Probe	2.7W
THDP0200	200 MHz High Voltage Differential Probe	2.7W
TPA-BNC[2]	TekVPI Interface Adapter	2.5W
TEK-DPG	TekVPI Deskew Pulse Generator	1.5W

Note1: The power numbers listed in the table are theoretical maximum values. The actual power draw from the probe depends on several factors, including the parameters of the circuit being measured (especially for current probes) and the type of probe connected to the TPA-BNC adapter.

Note 2: The TPA-BNC will only draw a maximum of 2.5W of power from the oscilloscope no matter which TekProbe Level 2 interface probe is used with it.