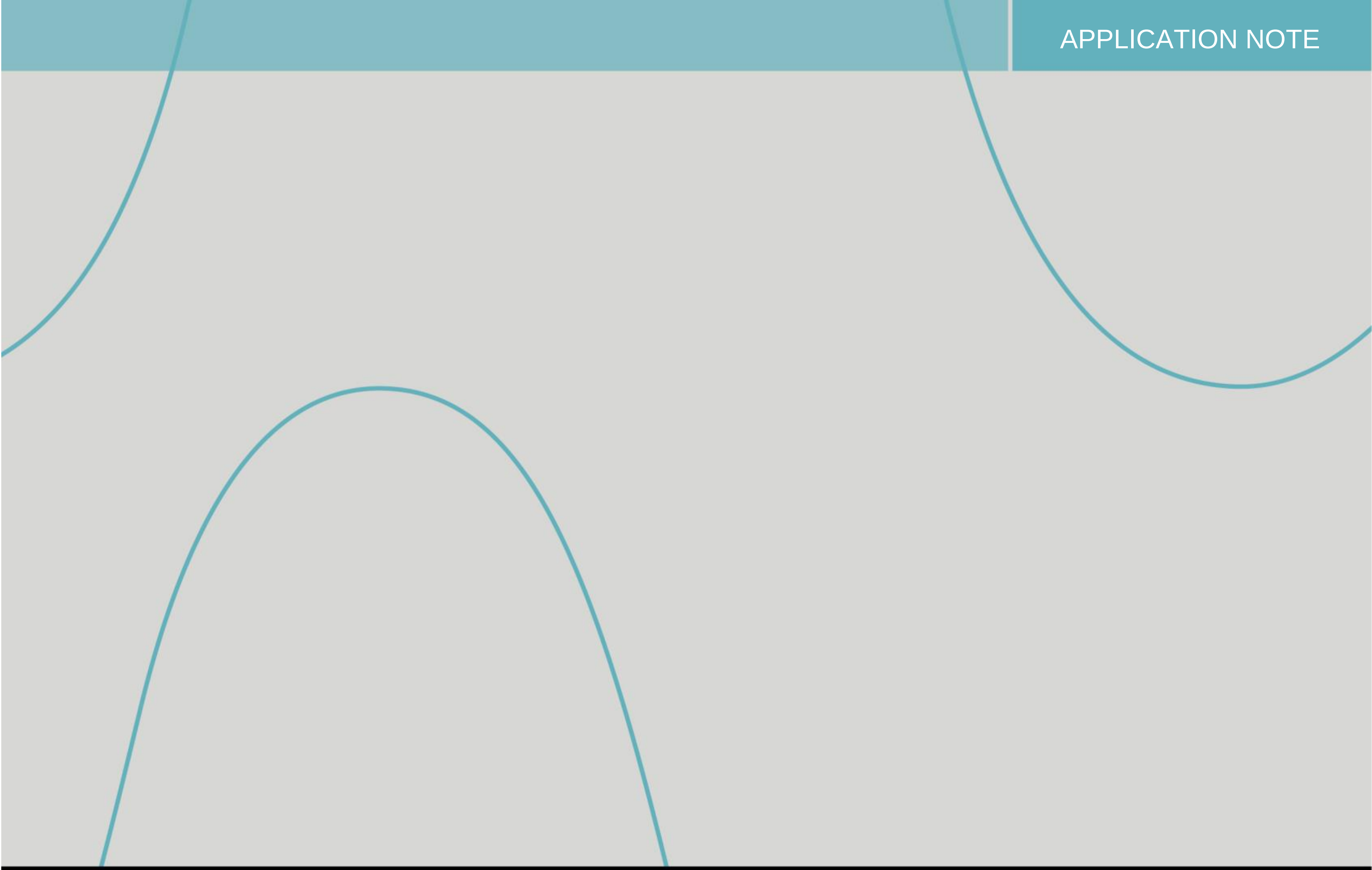
APPLICATION NOTE



Understanding Oscilloscope Probe Specifications

Voltage probes

KEYSIGHT

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Introduction

A “probe” can be thought of as any device used to transmit a voltage signal from a DUT (device under test) to an oscilloscope; this includes 50-ohm cables, active probes, passive probes, differential probes, wire leads, and ground extensions, etc. Probes are used to deliver signals to an oscilloscope from the device and are inherently lossy, plus their characteristics vary from probe to probe. Characteristics can depend on frequency, temperature, manufacturing variations, connection methods, and damage.

Your measurements are only as good as the probe that makes them. You can have the best, most advanced oscilloscope in your lab, but that does not matter if you choose the wrong probe. The probe is the critical link between the device under test (DUT) and the oscilloscope. It affects both your measurement results and the operation of the DUT.

Probing is a complex topic, often the subject of an afterthought in both design and testing. Since correct probing profoundly affects your ability to make accurate measurements, it is important to devote time to planning and preparing your probing techniques and requirements — which involves an in-depth review of probe data sheets.

Probe data sheets can be a tangled web of hard-to-understand specifications, lacking information on how those specifications affect your measurements. This application note aims to equip you with a better understanding of important probe specifications that can make or break your next breakthrough.

The specifications on a probe data sheet that most affect accurate measurement and visualization fall into three areas:

- The physical connection of the probe to the DUT.
- The electrical characteristics of the probe.
- The effects of the probe on the DUT.

This application note will highlight important specifications found in probe datasheets that give insight into options for connecting the probe to the DUT and the electrical ramifications of that connection on your measurements and DUT. This insight will help you better navigate probe datasheets, enabling you to make informed decisions for measurement accuracy and test optimization. The specifications are not listed in any specific order, but all should be considered when evaluating your next oscilloscope probe.

Connecting the Probe to the DUT

Choosing the correct probe for your application involves understanding what you want to measure and how you will physically connect the probe to the DUT to make those measurements. Important questions to ask yourself include, “What am I trying to measure?”, “Which points do I want to probe on my DUT, and what does the topology look like at those points?”, “What is the voltage and frequency at the test points?”, and “How can I design for probing test points to increase ease-of-access?” An important first step is determining the type of probe you need before exploring electrical characteristics and connector options.

Single-ended versus differential probes

For decades, single-ended probing has been the go-to for engineers. Single-ended probes measure single-ended signals relative to ground (voltage versus ground). One input connects to an active voltage test point and the other to a grounded test point on the DUT. This design requires the test point and ground lead to be easily accessible to the probe. The ground lead on the probe is also connected to the oscilloscope’s electrical ground, which is the same electrical ground of all the channels on the scope and within the lab.

This type of probe is still heavily used today and can meet the performance requirements of basic technologies. However, as technologies advance and circuit boards become more complex, the need to measure signals that are not ground-referenced increases. This need is apparent in technologies such as switch-mode power supplies (SMPS), inverters, motor drivers, USB, CAN, PCIe, and other signals where noise immunity is vital.

One way to measure ungrounded signals is to attach two identical single-ended probes to two different test points on a board and use the math function on the scope to measure the differential voltage between the two channels. This method is affordable but carries several drawbacks. It uses two channels on the oscilloscope to measure one differential signal, sacrificing valuable channel density. It also has poor measurement accuracy since single-ended probes typically cannot reject common mode noise very well. Additionally, if you use two probes to connect differential signals to two channels of the scope, the results are critically dependent on properly adjusting the skew between the two signals.

A better way to measure the differential voltage is by using a differential probe. Differential probes directly measure differential signals relative to each other (positive voltage versus negative voltage) and can measure voltages between any two test points. They do not require access to a ground lead on the circuit board and only use a single input on the oscilloscope.

Differential probes can have very similar physical connection geometries to single-ended probes, so the main difference in performance between them is due to the differential versus single-ended topologies. Figure 1 compares Keysight’s 1134B single-ended and differential solder-in probe heads that look almost identical while Figure 2 shows the differences between the topologies.

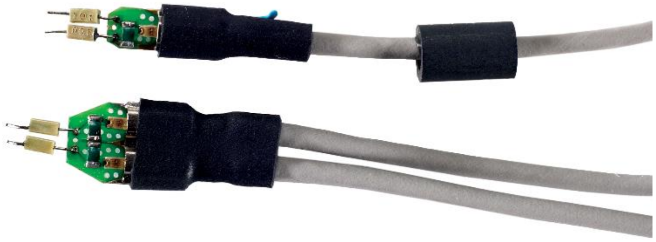


Figure 1. Close-up of Keysight 1134B single-ended (top) and differential (bottom) solder-in probe heads

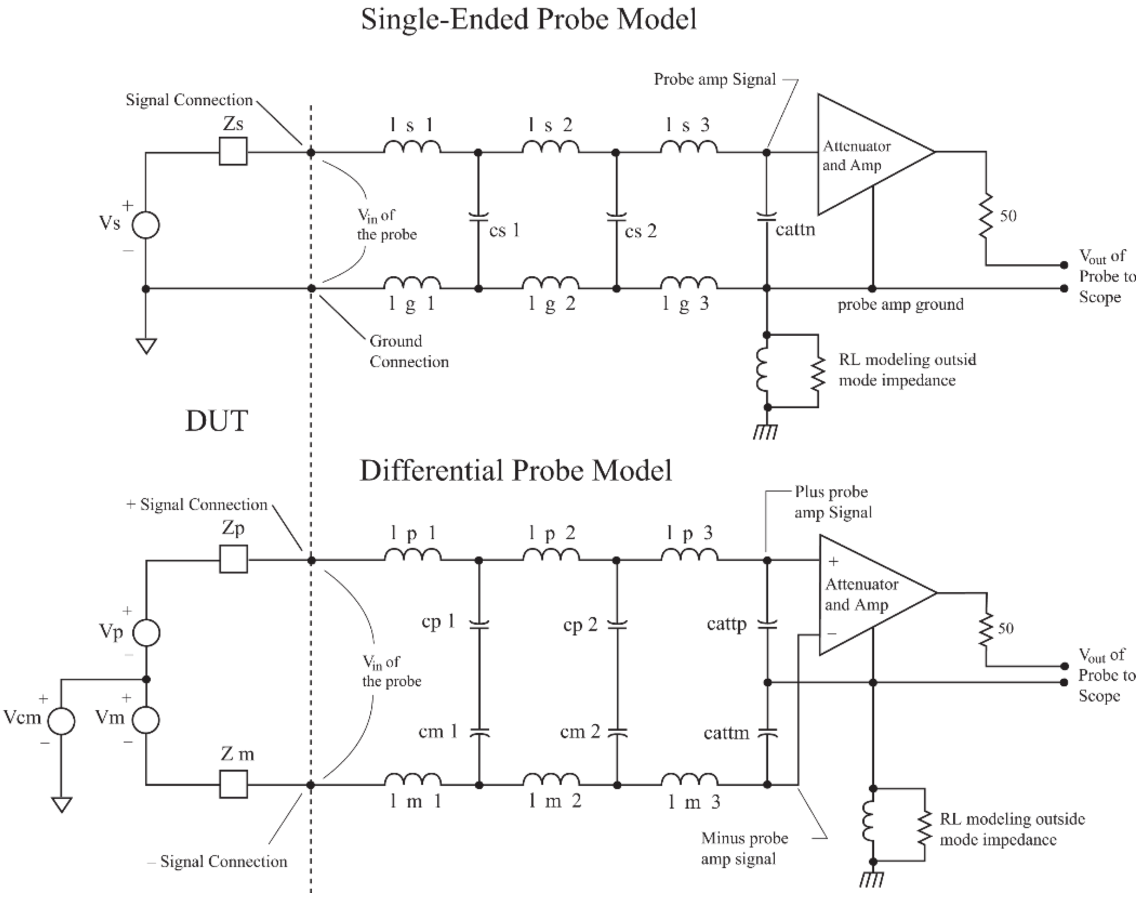


Figure 2. Simplified topology models of a single-ended probe (top) and a differential probe (bottom.)

Differential probes can also function as single-ended probes if the negative input connects to ground. Using a differential probe carries several performance advantages including higher bandwidth, faster rise times, higher common-mode rejection, and less probe loading. Common-mode rejection and probe loading will be discussed later in the paper. When determining which probe to use in your test flow, consider using a differential probe for differential and single-ended measurements so you are not limited to only ground-referenced test points on your DUT.

Probe accessories

Because of the challenges involved in probing circuits, it is not always feasible to directly attach the probe to the signal and ground. That is why it is common to see short lengths of wire soldered to points on a circuit to facilitate these connections. However, as shown in Figure 3, the increased parasitics from wires distort the measured waveform, introducing overshoot and ringing that otherwise does not exist. When V_{in} at the probe tip does not match that of Vout at the probe output to the scope, the oscilloscope will show an inaccurate representation of the signal under test. Wires that are used to extend the reach of a probe will introduce as much as 25 nH of inductive loading per inch into the probe circuit. Similarly, ground leads introduce inductance to the probe's return path that is not compensated for in the probe, creating an additional source of distortion in your measured waveform. These parasitics not only impact the measured waveform but also the circuit under test in the form of probe loading, a subject discussed later in the paper.

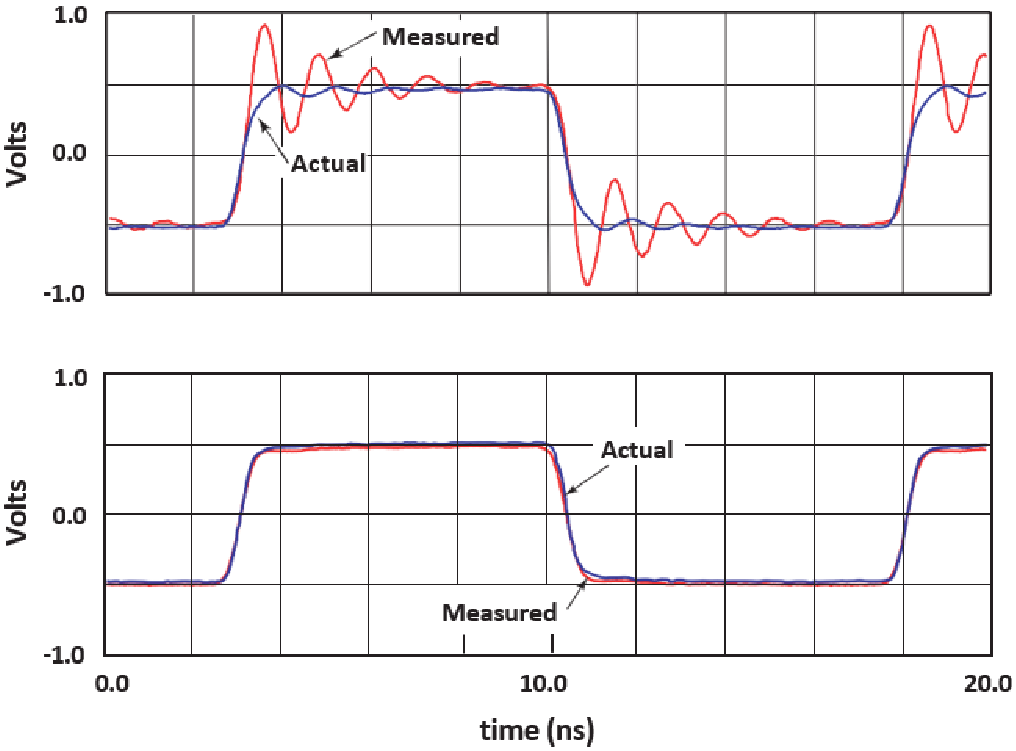


Figure 3. A 5-cm wire attached to the signal under test creates overshoot and ringing on the measured waveform (top). Properly damped 5-cm resistive probe tip lead extends the reach of the probe into tight spaces without adding distortion to the measured waveform (bottom).

Most Keysight probe comes standard with various tip and ground connectors that extend probe reach and meet a variety of geometric needs, so soldered wires decrease in necessity. These tips and connectors are specially designed to isolate the probe parasitics from the test circuit and display the signal with minimal distortion, but each component carries its own specifications to consider.

Some probes only meet the maximum specified bandwidth and support using certain probe tips, like the Keysight N275xA InfiniiMode probes. These probes have different measurement modes — single-ended, differential, and common mode — and can measure signals up to 6 GHz, but it depends on which tip you use. The probe can only measure 6 GHz when using the browser tip, and this tip only supports differential measurements. The solder-in tip can measure up to 2.5 GHz, and the socketed tip can measure up to 3 GHz in all measurement modes. Examples like the InfiniiMode probe exemplify the importance of thoroughly reading the data sheet before purchasing to ensure the probe meets your testing requirements.

Evaluating Probe Electrical Characteristics

Like oscilloscopes, probes have electrical characteristics that greatly affect signal integrity. Your oscilloscope has documented specifications that collectively impact the accuracy of the signal on the screen — noise, input voltage, and bandwidth, to name a few. Your probe also has independent specifications that affect how well your signal is replicated on the oscilloscope screen and how the probe impacts your DUT. When choosing test equipment, consider the specifications of both the oscilloscope and probe and the impact those specifications will have on your test results. This will enable you to get a realistic idea of the whole test system, and not just the individual pieces of the system.

Frequency response and bandwidth

One of the most important probe electrical characteristics is bandwidth. If you don’t have a fast enough probe to measure your signal speeds or capture accompanying harmonics, you cannot accurately visualize the signal and make correct measurements. The datasheet of each probe you evaluate contains frequency response plots, bandwidth ratings, and rise time specifications. All three are related to one another. The frequency response of an instrument is defined as the ratio of the voltage at the probe output divided by the voltage at the probe input (V_{out}/V_{in}). This is usually shown on a graph with amplitude, expressed in dB, versus frequency.

The probe bandwidth is the continuous band of frequencies up to the point where the frequency response drops to -3 dB, or where the amplitude has fallen to 70.7%, as depicted in Figure 4. Beyond the bandwidth of the probe, signal amplitudes become overly attenuated, and measurements become unpredictable.

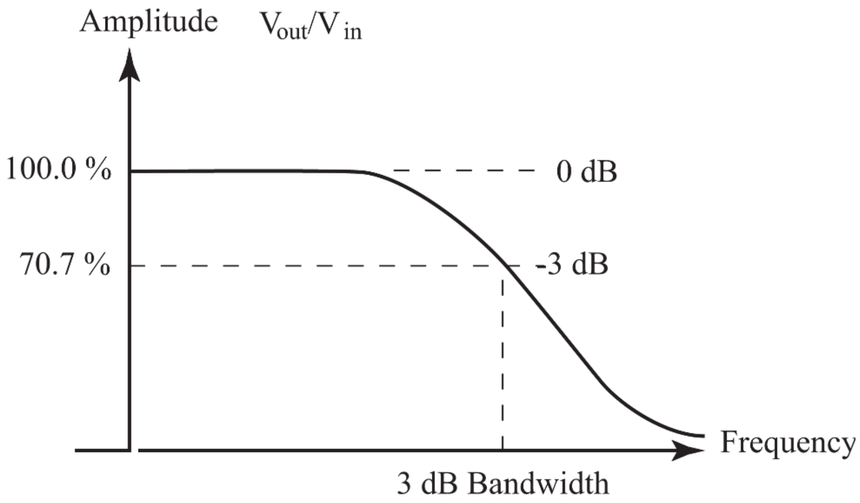


Figure 4. Bandwidth is defined as the continuous band of frequencies up to the point where the instrument's transmitted response decreases by 3 dB.

To see exactly what the signal looks like at the probe tip and to get accurate measurements, the signal at the probe's output must match the signal at the probe tip within the probe bandwidth and with minimal degradation. In the frequency domain, when the probe transmits the signal from input to output with minimal degradation, a flat frequency response (0 dB) appears throughout the bandwidth of the probe. In practice, it is very difficult to achieve 0 dB due to the inherent noise of the system and the added circuitry of the probe.

The parasitics generated by the physical connection of the probe to the DUT in conjunction with the internal components of the probe can form a resonant circuit with a lower frequency than the bandwidth of the probe. This in-band resonance will cause the output of the probe to differ from the input and can show up as overshoot and ringing on your measured waveform. With this in mind, it is important to consider the frequency responses of probes you intend to purchase.

For reference, Figure 5 shows the frequency responses found in the data sheet of Keysight's DP001xA High-Voltage Differential Probes at low attenuation settings. DP0010A has a specified bandwidth of 250 MHz, DP0011A is 500 MHz, DP0012A is 1 GHz, and DP0013A is 1.7 GHz. You can see in Figure 5 that the traces begin to degrade significantly around the maximum bandwidth of each probe model.

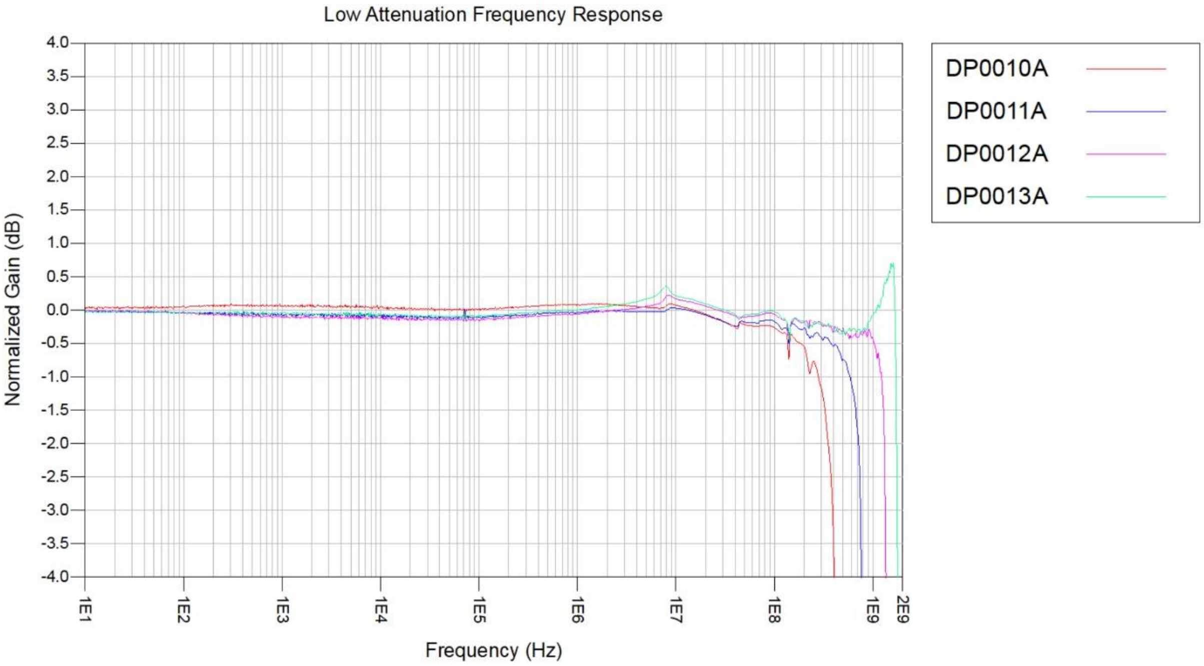


Figure 5. Frequency response plots of Keysight's DP001xA High-Voltage Differential Probes.

When considering a probe for your application, Keysight recommends a bandwidth of at least five times the signal frequency to visualize the fifth harmonic. Many oscilloscope and probe manufacturers market the maximum bandwidth of their instruments, but that bandwidth may only be accessible in certain circumstances like when fewer channels or a certain probe tip are used, as mentioned before. To verify the flat frequency response of probes before purchase, be sure to analyze the frequency response plots in the data sheets or user guides. If you cannot find the frequency response plots readily available on the Keysight website, please engage a Keysight representative to obtain that information.

Rise time

Rise time is the time it takes for a signal to move between the specified thresholds of a rising edge, as shown in Figure 6. The most common rise time thresholds in the industry are 10% to 90% and 20% to 80%. These thresholds are typically used when data sheets report probe rise times.

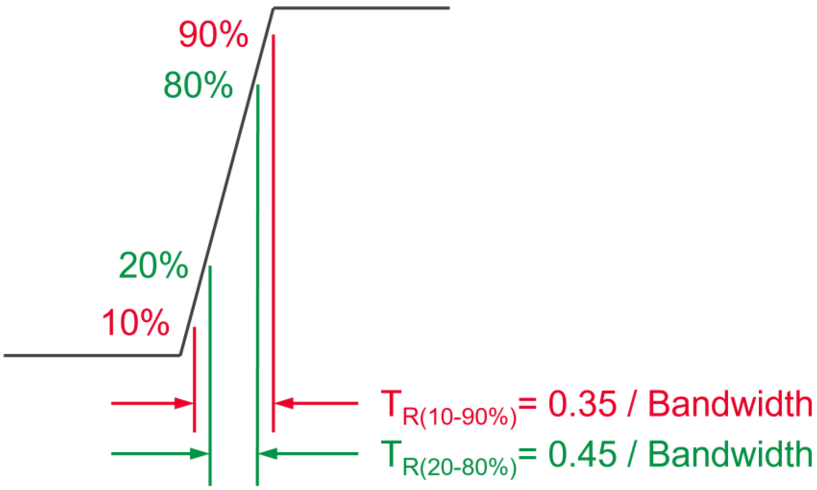


Figure 6. Probe rise time specifications for different thresholds and the relationship between rise time and bandwidth.

The rise time of a probe is related to its bandwidth, meaning you can estimate the minimum probe bandwidth required to measure the signal’s rise time, or you can estimate the fastest rise time the probe can measure based on its bandwidth. The following equation describes the rise time and bandwidth relationship based on 10% - 90% thresholds:

$$T_R = \frac{0.35}{BW}$$

The following equation describes the rise time and bandwidth relationship based on 20% - 80% thresholds.

$$T_R = \frac{0.45}{BW}$$

Within this relationship, you can see that as rise time gets faster (T_R gets smaller), bandwidth increases.

Probe datasheets document the rise times and bandwidths of probes so you do not have to do the math to find the fastest rise time the probe can measure. Be sure to review this specification when probe shopping to ensure the probe rise time is sufficient enough to capture your signal.

Input voltage

Like oscilloscopes, probes contain input voltage ranges. These ranges can be tricky to understand on a probe data sheet as not all input ranges are the same. Voltage ranges you might find on a probe data sheet include maximum (non-destructive) input voltage, transient range, offset range, dynamic range, and active signal range — all specifications you should pay attention to when choosing the best probe for your application.

The maximum (non-destructive) input voltage is the same as the transient range and refers to the absolute max transient peak that the probe can withstand without causing damage. This is not a voltage at which you want to continuously use your probe since measurement results will be nonlinear and the probe may become damaged. The appropriate input voltage levels for accurate measurements and continuous signals include the active signal range (also called dynamic range), and the offset range.

The dynamic range of a probe is the acceptable range of voltages in which the probe can make measurements. The offset range is the amount of offset the probe can apply to bring the signal within the dynamic range, so the signal is visible on the oscilloscope. If the probe offset or probe dynamic range is too small for your peak-to-peak voltages, then you cannot accurately capture and measure your signal, so pay attention to these specs in the data sheet. Typically, probes have higher offsets at the probe tip than oscilloscopes have at the input, and there is an advantage to this. The probe can apply a large offset, bring the signal into the dynamic range, and then send the signal to the probe amplifier for attenuation. This gives you more of a voltage range to work with and maximizes the signal-to-noise ratio of the measurement.

The table below shows a snippet from Keysight’s N7020A Power Rail Probe data sheet including different voltage ranges.

	With N7022A main cable	**N7021A pigtail & N7022A**	**N7023A browser**
Probe bandwidth (-3 dB)	2 GHz	2 GHz	350 MHz (with ground spring)
Maximum input voltage (non-destructive)	± 30 V peak input		
Attenuation ratio	1.1:1		
Offset range	± 24 V		
Input impedance at DC1	50 kΩ ± 2%		
Active signal range	± 850 mV (about offset voltage)		

In this example, the maximum input voltage of the probe is ± 30 V, the offset range is very large at ± 24 V, and the active signal range (dynamic range) is small at ± 850 mV. Figure 7 shows an example of how these voltage ranges work together on the N7020A. Given the signal in Figure 7, 23.150 to 24.850 V is the only range in which the probe can make accurate measurements.

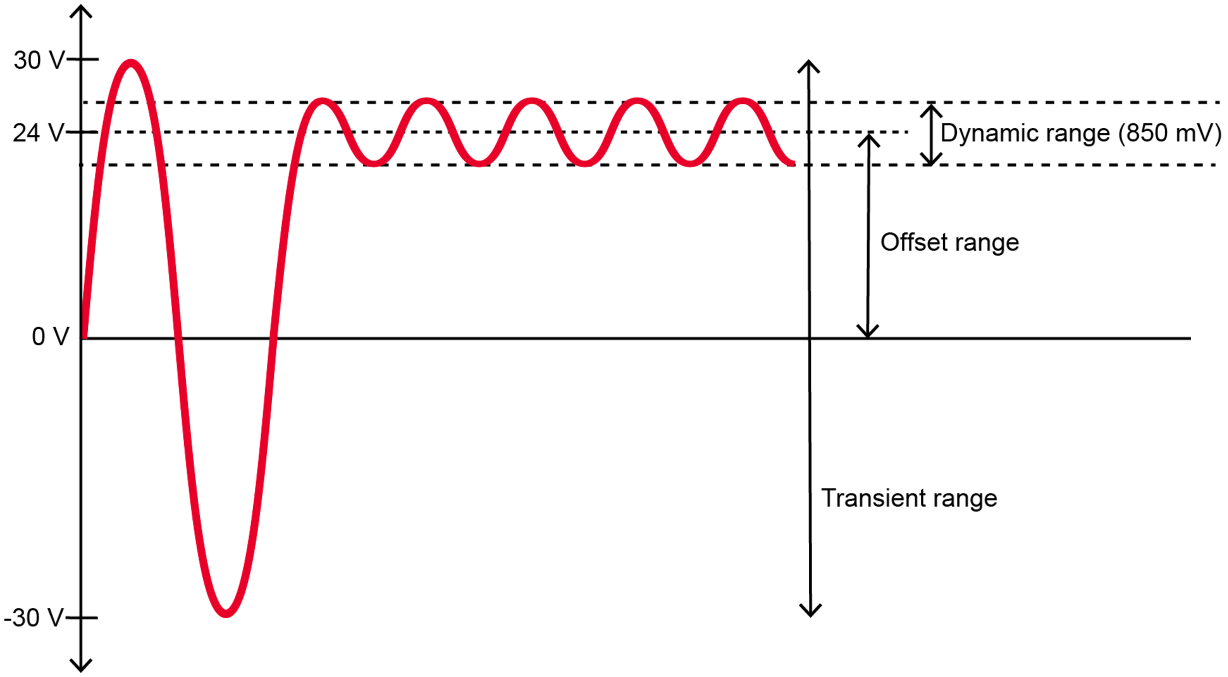


Figure 7. Depiction of the maximum input voltage, offset range, and active signal range of the Keysight N7020A Power Rail Probe.

Two more voltage ranges to be aware of relate only to differential probes — common mode dynamic range and differential dynamic range. Common mode dynamic range is the maximum voltage range a differential probe can measure when making single-ended measurements referenced to ground. Differential dynamic range is the maximum voltage range a differential probe can measure when making differential measurements not referenced to ground. Sometimes these ranges are referred to as common mode and differential measurement ranges. When shopping for differential probes, review these two different dynamic ranges on the data sheet and verify that they meet your measurement needs. These dynamic ranges are usually the same or almost equal, but you might find some probes where they differ.

Attenuation and gain

Most oscilloscopes have relatively low voltage input ratings and cannot directly measure voltages above this range without risking damage. To prevent damage and work with voltages higher than the scope rating, you need a probe that attenuates the signal. The probe attenuation ratio, also known as the divider ratio or attenuation factor, is the ratio by which a probe reduces the input voltage before it reaches the oscilloscope's front end. These ratios can span from 1:1, meaning no attenuation, to over 1000:1, and some probes support more than one user-selectable attenuation ratio. Keep in mind that as you increase attenuation, you amplify the oscilloscope noise relative to the signal measured. The signal is divided down by the attenuation ratio while scope noise increases by the same amount. This may not matter if the probe noise spec is very low to begin with.

When selecting a probe, you typically only have to pay attention to the attenuation ratio of passive probes and not of active probes. This difference is due to the architecture of a passive probe — each passive probe with an attenuation ratio contains an impedance divider. For example, in a 10:1 passive probe, the probe tip has a 9 MΩ resistor, so the divider has a 9:1 resistance ratio between the probe tip and the input of the oscilloscope (1 MΩ), as shown in Figure 8. Conversely, the divider has a 1:9 ratio between the probe capacitance and the combined capacitance of the cable, compensation box, and oscilloscope. This leads to higher capacitance in passive probes versus active probes and therefore, more loading. The effects of probe loading will be discussed in the next section. Active probes, on the other hand, have probe amplifiers that form a buffer, so active probes can adjust their attenuation automatically without user input.

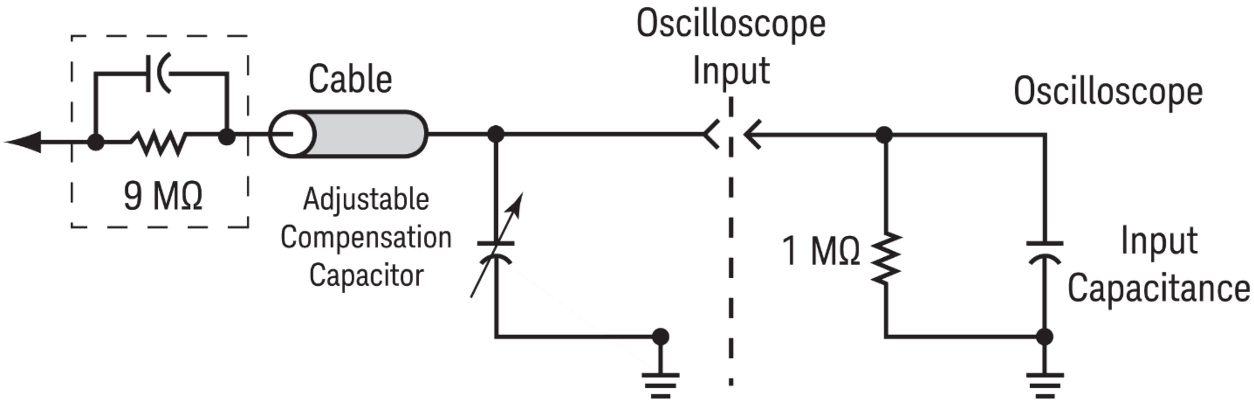


Figure 8. Architecture of a high-impedance passive probe with a 10:1 attenuation ratio.

It is important to scan the data sheet of the probe to ensure that the probe supports the attenuation ratio that you need while also delivering the performance you expect. Different attenuation ratios carry different advantages and disadvantages. For example, using a probe with a 1:1 attenuation ratio is great for making highly sensitive, low-voltage measurements. However, 1:1 Passive probes have limited bandwidth and can only support low-frequency signals. The table below describes the advantages and disadvantages of various probe attenuation ratios.

Probe attenuation	1:1	10:1	1000:1
Advantages	Low-voltage, low-frequency measurements	Mid-voltage measurements	High-voltage measurements
	More sensitive	Less probe loading	Less probe loading
Disadvantages	Limited bandwidth and dynamic range	Increases scope and probe noise by 10x	Increases scope and probe noise by 1000x

It is fairly common to hear the words attenuation and gain used interchangeably when describing how a probe alters a signal's voltage or current level. This dual nomenclature is incorrect, and it is important to emphasize that probe attenuation always involves making the signal smaller by dividing the incoming signal by the attenuation ratio. Attenuation is not to be confused with gain which involves multiplying the input signal to make it bigger, which is the same as dividing the input signal by a number less than 1. Attenuation ratios will always be ≥ 1, like 10:1, whereas gain ratios will always be < 1, like 0.5:1. Probes that introduce gain to a signal are designed to be very sensitive and offer extreme detail. Keysight currently only offers gain on current probes.

Noise

Oscilloscopes are not the only pieces of equipment that have noise that degrades resolution and masks small signals. Probes also add noise to the system in addition to the noise of the oscilloscope. When shopping for probes, it is important to consider the combined system noise of the probe and oscilloscope to verify that the noise level is low enough to accurately make measurements. In most cases, the oscilloscope will have much less noise than the probe, which means that probe noise is of utmost importance to maintain signal integrity.

You will find noise specifications reported in two different ways in probe data sheets — probe noise and noise spectral density — and some data sheets include both. Typically, all noise specs are input-referred unless stated otherwise. Probe noise is the noise floor of the probe, sometimes reported as a standalone spec, or as a function of the oscilloscope noise floor, in V_{rms}, measured with nothing connected to the probe inputs. For example, the Keysight 2 GHz Power Rail Probe data sheet specs the probe noise as a "10% increase in the noise of the connected oscilloscope." Be aware that some probe data sheets will spec noise at super-low, unrealistic bandwidths, so dig more into user manuals to verify noise specs at the probe bandwidth and at different attenuation ratios.

Noise spectral density is a specification that describes the spectral density of the noise of the probe as a function of frequency, or noise spectral density divided by the probe bandwidth. It is defined as voltage per square root Hertz and has units of V_{rms}/rt Hz. For example, the Keysight DP0001A Differential Probe data sheet specs the probe noise and noise spectral density as 180 mV and 9 µV/rt Hz, respectively, at an attenuation ratio of 50:1 and bandwidth of 400 MHz. The Keysight InfiniiMax RCRC Probes data sheet only specs noise in terms of noise spectral density, as depicted in the table below.

	N280XA InfiniiMax III			N283XA InfiniiMax III+		MX003XA InfiniiMax 4	
Probe head	450 Ω	200 Ω	N5444A 2.92 mm	450 Ω	N5444A 2.92 mm	450 Ω	N5444A 2.92 mm
Input referred noise spectral density	23.9 nV/rt (Hz)	12.0 nV/rt (Hz)	23.9 nV/rt (Hz)	Diff 5:1 atten 33.5 nV/rt (Hz) Diff 10:1 atten 53.9 nV/rt (Hz) SE A or B 5:1 atten 27.8 nV/rt (Hz) SE A or B 10:1 atten 47.7 nV/rt (Hz) CM 5:1 atten 21.8 nV/rt (Hz) CM 10:1 atten 38.4 nV/rt (Hz)		23.9 nV/rt (Hz)	23.9 nV/rt (Hz)

Common mode rejection

To reiterate, the noise of the entire system is an essential specification to consider when outfitting your lab bench. Probe noise can significantly impact your measurements and your ability to see small signals, which oscilloscope noise further exacerbates. While your probe and system noise should be low, your probe also needs the ability to reject common-mode noise that may mask signals of interest. To cover this topic, we will revisit the differences between single-ended and differential probes.

Unwanted common mode signals can affect the signal you see on screen. Electromagnetic interference, cross talk, and other noise characteristics on or around your DUT can create common mode noise. Your probe needs to be able to reject common mode noise to give you the most accurate signal. When using a single-ended probe, the ground lead is not a part of the probe coaxial assembly that enables current to run through the shield without affecting the signal. Current flows through the ground lead and creates a circuit that couples the common mode noise onto the measured signal, and common mode noise is not rejected.

To precisely measure signals and maintain signal integrity, you need to be able to reject common mode noise from reaching your oscilloscope inputs. Differential probes connect to two test points that are not ground-referenced and therefore have no ground lead issues. Instead, they contain differential amplifiers that amplify the difference voltage. The amplifier’s ability to reject common mode voltages is reported as the common mode rejection ratio (CMRR), a specification found on all differential probe data sheets.

Figure 9 shows the common-mode rejection superiority of the Keysight 1134B single-ended and differential solder-in probe heads. The single-ended probe (green line) has less rejection over the frequency band measured than the differential probe (dotted red line). Around 1.5 GHz, the difference is close to 20 dB. This is significant since the common mode (noise) will be amplified by the single-ended probe, causing considerably more noise on its output relative to the differential probe.

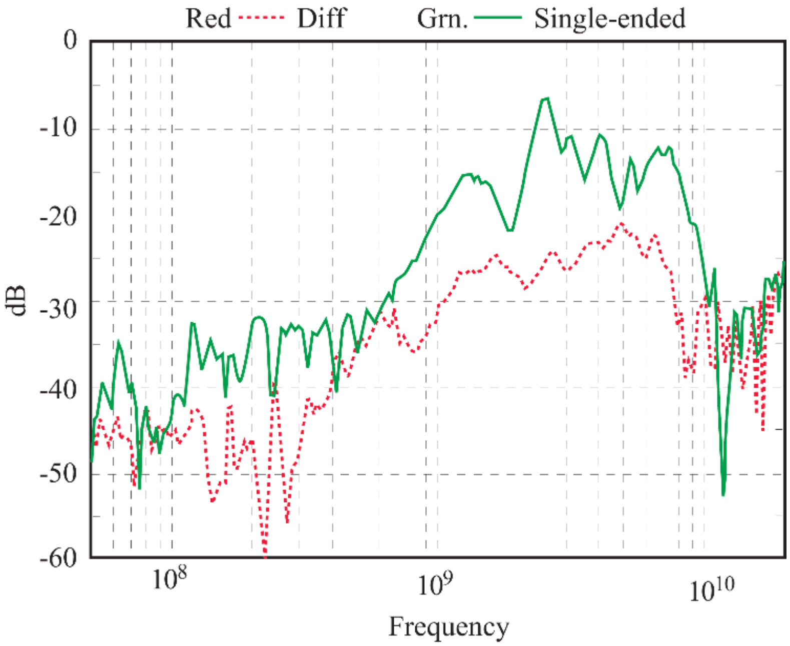


Figure 9. Common mode response of Keysight 1134B differential (red) and single-ended (green) probe heads.

Assessing How the Probe Affects the DUT

When you attach a probe to a circuit, you add a load to the circuit. This probe loading draws additional current from the source and changes the operation of the circuitry behind the test point, thereby changing the measured signal. Probe loading is an unfortunate side effect that all probe users must deal with when connecting a probe to a DUT. It is inevitable and unpreventable, but you can choose the best probe to minimize it.

Probe loading

To attain an accurate measurement, the probe needs to acquire the signal and provide the truest representation of it without excessively loading or otherwise changing the signal source over the entire frequency range of the probe. All probes introduce a complex load to the circuit under test. The goal is to ensure that the effects of this load are kept within acceptable limits.

Probe data sheets list input resistance and capacitance, which combine to alter and load a circuit under test, and it is important to review both of these specifications prior to purchasing a probe. Assuming the signal source impedance is resistive, the probe’s resistive component creates a voltage divider that consists of the circuit’s output resistance and the probe's input resistance. The voltage divider reduces the voltage amplitude of the measured signal without altering its shape, as shown in Figure 10. The lower the probe resistance relative to the source resistance, the more the probe loading reduces the voltage amplitude of the measured waveform. Additionally, the lower the probe resistance is relative to the circuit, the more current must flow into the probe, increasing the chance that your circuit will be adversely affected.

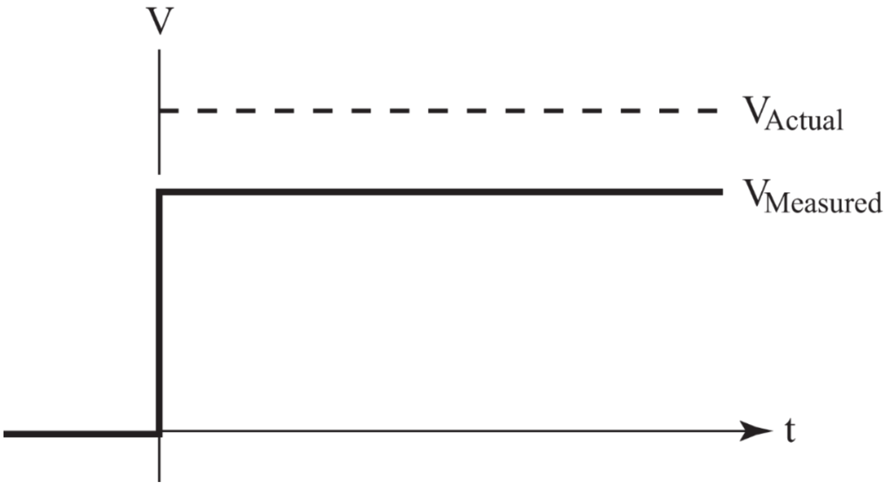


Figure 10. Resistive loading reduces the amplitude of the measured signal without altering the shape.

As signal frequencies increase or edge speeds decrease, probe capacitance behaves like a short circuit, allowing current to flow through the probe with low impedance. At high frequencies, this capacitive reactance becomes a significant factor in circuit loading and may cause your circuit to fault because it cannot drive adequate voltage margins. This means that probes with large input capacitances will significantly load the DUT as frequencies increase, so do not ignore this specification on a probe.

Capacitive loading is a major source of probe-related measurement errors because it affects rise and fall time, bandwidth, and edge-to-edge timing measurements. Capacitive loading alters the shape of the measured waveform by introducing an exponential response as shown in Figure 11, which can attenuate glitches, reduce ringing and overshoot, or slow the measured edge just enough to create setup or hold time violations in your circuit. To choose the probe with the lowest probe loading, we start by discussing passive versus active probes.

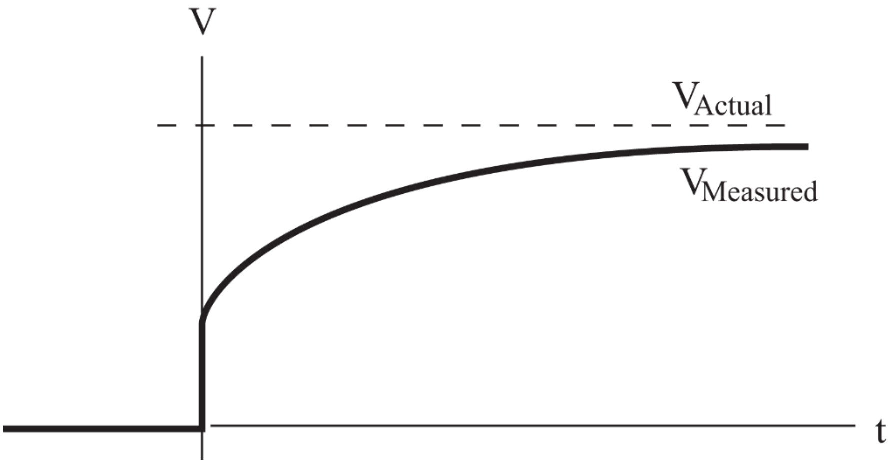


Figure 11. Capacitive loading alters the shape of the waveform by introducing an exponential response.

Passive versus active probes

Passive probes

Compared to active probes, passive probes are more rugged and less expensive. They offer a wide dynamic range and high input resistance to match a scope’s input impedance. However, 1 MΩ-input probes impose heavier capacitive loading and have lower bandwidths than active probes and low-impedance (z0) resistor-divider passive probes. Passive probes also require manually adjusting the input impedance to match that of the scope.

The low-impedance resistor-divider probe has either 450 Ω or 950 Ω input resistance to give 10:1 or 20:1 attenuation with the 50 Ω input of the scope. The input resistor is followed by a 50 Ω cable that is terminated in the 50 Ω input of the scope. The key benefits of this probe include low capacitive loading and very high bandwidth —in the range of a couple of GHz — which helps to make high-accuracy timing measurements. In addition, this is a low-cost probe compared to active probes in similar bandwidth ranges. The one critical trade-off is that this probe has relatively heavy resistive loading, which can affect the measured amplitude of the signal, depicted in Figure 10.

Active probes

If your scope has more than 500 MHz of bandwidth, consider using an active probe. Despite being higher priced than passive probes, active probes are the tool of choice when you need high-bandwidth performance. Because of their significantly lower capacitive loading, active probes give you more accurate insight into fast signals.

Active probes contain active components and therefore require probe power. Many modern active probes rely on intelligent probe interfaces that provide power and serve as communication links between the probe and the scope. Typically, the probe interface identifies the type of probe attached and sets up the proper input impedance, attenuation ratio, probe power, and offset range.

When it comes down to it, the real driving factor of whether you need an active or a passive probe is the degree of signal integrity you want to maintain. In this case, an active probe will always win. Why? It has everything to do with input impedance and probe loading.

Input impedance

The input impedance of a probe is one of the most important specifications on a probe data sheet. It is a complex number that contains resistive and capacitive components and refers to the probe's ability to oppose current. Input impedance is reported in Ohms and the data sheet will typically also include a plot of the probe's input impedance over frequency. Figure 12 shows the input impedance curves found in the data sheet of Keysight's N287xA passive probes.

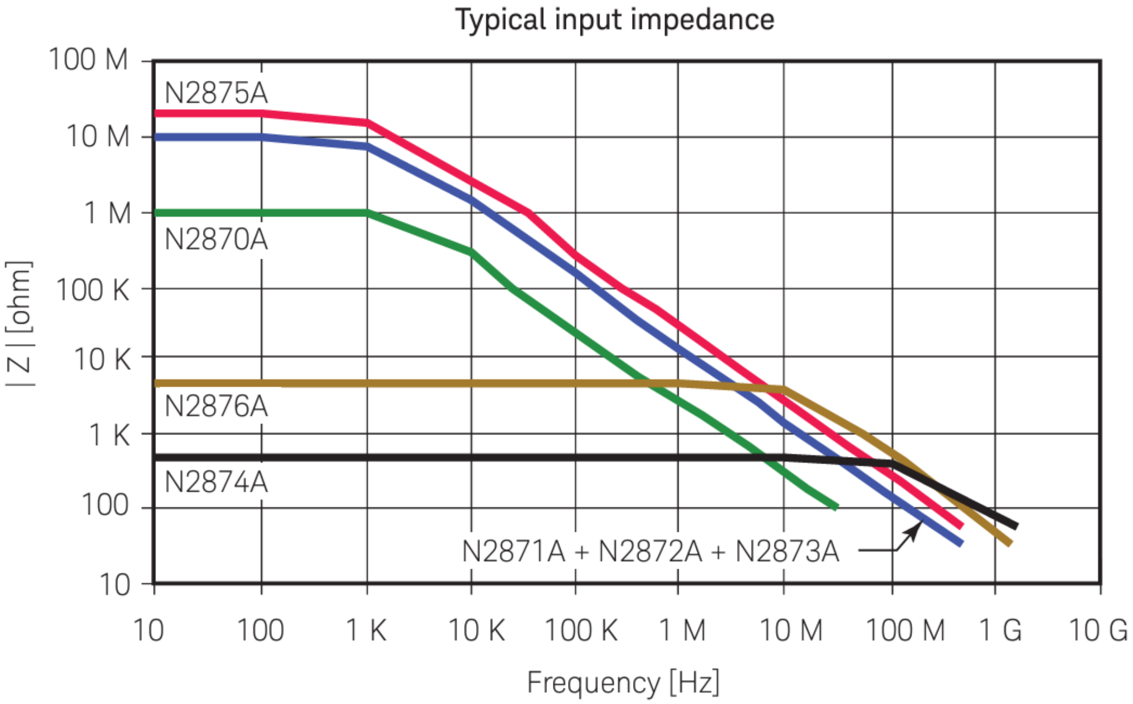


Figure 12. N2870A Series input impedance vs. frequency characteristics.

Many people think that a probe's input impedance is a constant number. You might hear that the probe has a kΩ, MΩ, or even a 10 MΩ input impedance, but that is just the maximum value that is not constant over frequencies. Input impedance decreases over frequency, so it is imperative to review the input impedance plot in the data sheet. At DC and low-frequency ranges, the probe's input impedance starts at the rated input resistance, say 10 MΩ for a 10:1 passive probe, but as the frequency goes up, the input capacitance of the probe behaves like a short circuit, and the impedance of the probe starts to drop.

The higher the input capacitance, the faster the impedance slope drops. Figure 13 shows a comparison between a 500 MHz passive probe and a 2 GHz active probe. You'll see that at a crossover point of ~10 kHz and beyond, the input impedance of the active probe is higher than that of the passive probe. Higher input impedance means less loading on the DUT signal, and less loading means greater signal integrity.

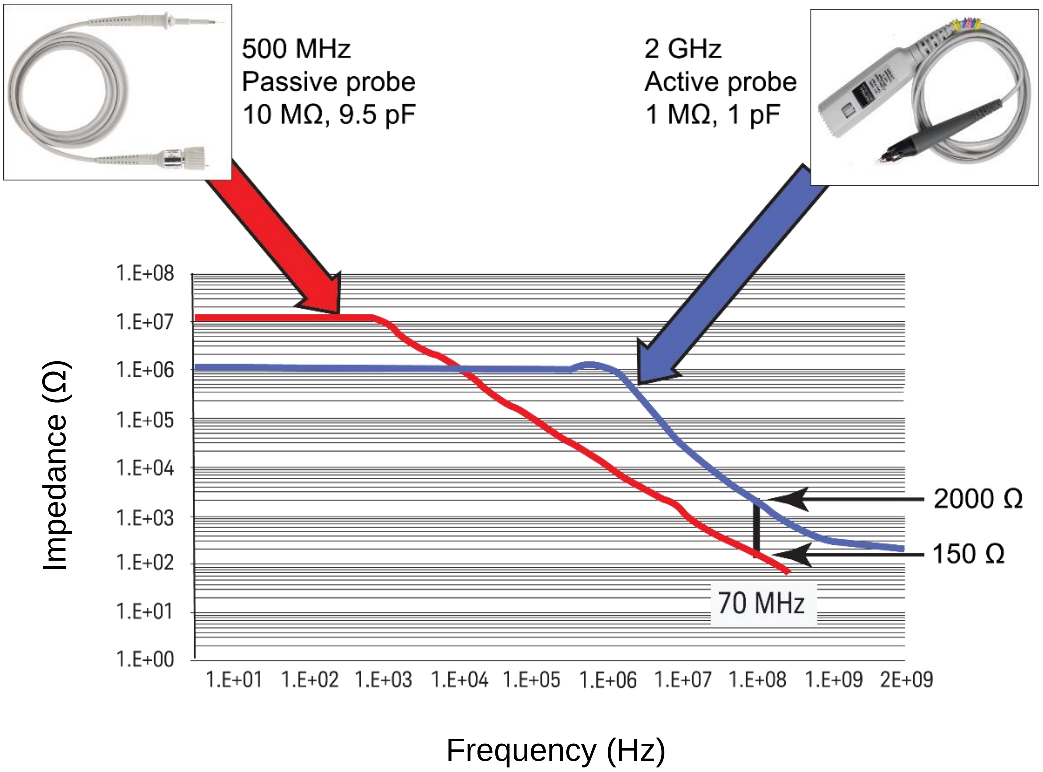
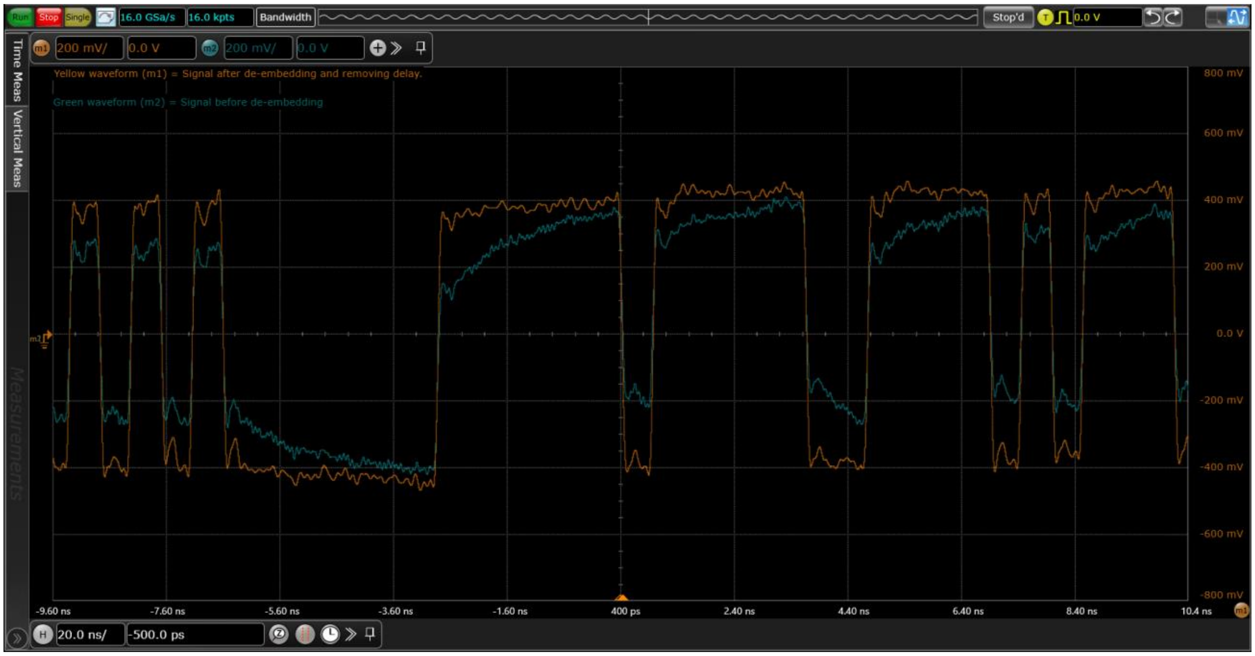


Figure 13. At a crossover point of ~10 kHz and beyond, the input impedance of the active probe is higher than that of the passive probe.

At about 70 MHz bandwidth, the input impedance of the passive probe decreases to ~150 Ω, while the input impedance of the active probe is about 2.5 kΩ. The difference between them is significant. If, for example, you had a system that had 50 Ω or 100 Ω source impedance, the passive probe would have a significantly higher effect on the signal due to probe loading. In that frequency range, connecting the passive probe is like hanging a 150 Ω resistor on your circuit. If you can tolerate that, the passive probe will be fine. If you cannot tolerate that, then this probe will be an issue, and you are better off choosing a probe with a higher impedance at high frequencies, like an active probe.

Custom Probing Solutions

Finally, if probes on the market do not meet your needs and you prefer to design your probe or tip, Keysight offers De-Embedding Software (D9010DMBA) on Infiniium Oscilloscopes. This software package includes PrecisionProbe and InfiniiSim Basic, two tools designed to de-embed the effect of cables and fixtures from measurements, including probe loading. PrecisionProbe enables you to characterize the frequency response of a probe or cable. InfiniiSim aids you in modeling out probes or cables from a measurement, as shown in Figure 14. It's important to note that these tools can remove the effects of the probe loading from the measurement, but the loading of a probe and its effects on a DUT are physical phenomena that cannot ever be removed.


Yellow waveform (m1) = Signal after de-embedding and removing delay.

Green waveform (m2) = Signal before de-embedding

Figure 14. Results from InfiniiSim show what a signal would look like with no cable between the DUT and the oscilloscope.

Conclusion

This paper provided a ton of information, and yet it only grazed the top surface of each topic. Choosing the right probe for your application is as important as choosing an oscilloscope. Hopefully, this paper has clued you in on the different specifications found on a probe data sheet and which are more important to review than others.

The order of the specifications presented in this paper does not matter — you could start with any of them when reviewing data sheets. However, when searching for your next probing solution, keep in mind the three areas of consideration that will drive the accuracy and precision of your next test:

1. How the probe will physically connect to the DUT.
2. How the probe's electrical characteristics will affect your measurements.
3. How the probe will load your DUT and alter signal content.

To explore the topics discussed in this paper in greater depth, and to learn more about the Keysight probe models mentioned, check out the content listed below:

- What's That You Were Asking About Oscilloscope Probing? – Webinar
- 7 Common Oscilloscope Probing Pitfalls to Avoid – eBook
- Becoming Familiar with Your Standard Oscilloscope Probe – Application Note
- Demystifying RCRC and RC Probes – Application Note
- Optimizing Oscilloscope Measurement Accuracy on High-Performance Systems – Application Note
- Differential Probe vs Single-Ended Probe Comparison – Application Note
- Improving Measurement Accuracy with Oscilloscope Probes – Application Note
- Practical Application of the InfiniiSim Waveform Transformation Toolset – Application Note

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