Creating Arbitrary Waveforms in the U2300A Series and U2500A Series Data Acquisition Devices

Application Note

Introduction

The U2300A Series and U2500A Series data acquisition device (DAQ) families are equipped with two analog output channels capable of handling high sampling waveforms.

The DAQ devices can be used in numerous applications that do not need a current drive of more than 5 mA.

This application note covers the inner workings of how waveforms and arbitrary waveforms are formed. This note also aims to teach you the working aspects of the *DAQ Analog Output Application Program,* and what you should and should not do when configuring the DAQ analog output application program to generate waveforms.

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Working with Arbitrary Waveforms

What is an arbitrary waveform?
Generally, the answer to this, from a DAQ device's point of view, is that arbitrary waveforms are formed in accordance with how the digital-to-analog converter (DAC) respond to programming stimuli.

An arbitrary waveform can be any type of waveform, be it a wave that is square, triangle, sawtooth, or sinusoidal wave in nature; or a hand-drawn wave; or a combination of any other type of waveforms which one can think off. Arbitrary waveforms generally encompasses all of the above waveforms and more.

GETTING STARTED

Before you begin forming arbitrary waveforms, you will first need to understand the relationship between the waveform sampling rate and the number of waveform points shown below.

Equation 1

`Sampling rate = Desired frequency x Number of waveform points`

1. *Sampling rate is the frequency of sampling per unit time and the unit is expressed in Samples per second (Sa/s).*
2. *Desired frequency is the number of cycles per unit of time and the unit is expressed in Hertz (1/s).*
3. *Number of waveform points is represented by the unit Sample (Sa).*

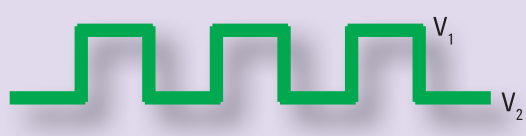
To fully understand the inner workings of how waveforms and arbitrary waveforms are formed, you will have to know the hardware specifications of your DAQ device to a certain level of detail.

To start forming arbitrary waveforms, you will first need to:
- Identify the sampling rate and the frequency of which you will want to form the waveform, and
- Set the number of points that is to dictate the accuracy of the waveform

As an example, the maximum sampling rate that a DAQ device can handle is 1 MSa/s. What this means is that this particular DAQ device can handle up to one million data in a second.

WHAT IS A SAMPLE?

The word "Sample" is indicated by its abbreviation "Sa". An example of a sample is usually derived from a voltage value. Let's say you want to form a square wave with a constant frequency and constant amplitude. As a square wave, your desired waveform should have two constant (repeating) voltage values. These two values are known as the sample points and the total number of sample points are dependent on the length of the square wave.



DAQ data receiving pattern

There are two analog output channels (CH201 and CH202) in the DAQ device of which waveforms can be generated. Data pattern is presented differently depending on whether both channels are active, or only one of the two channels are active.

For a single analog output active channel (CH201 or CH202):

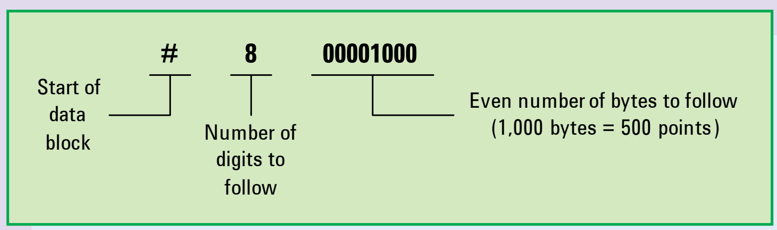
#8000010000	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	...
Data length indicator	1st data LSB	1st data MSB	2nd data LSB	2nd data MSB	3rd data LSB	3rd data MSB	4th data LSB	4th data MSB	...
	CH201 or CH202		CH201 or CH202		CH201 or CH202		CH201 or CH202		...

For dual analog output active channel (CH201 and CH202):

#8000010000	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	**<byte>**	...
Data length indicator	1st data LSB	1st data MSB	2nd data LSB	2nd data MSB	3rd data LSB	3rd data MSB	4th data LSB	4th data MSB	...
	CH201		CH202		CH201		CH202		...

DATA LENGTH INDICATOR

The length of the block header is fixed in the U2300A Series and U2500A Series DAQ devices — 10 characters (including the start data block character "#" and the 'number of digits to follow' character "8"), 20 bytes in size.



"#8" indicates that the following eight characters (0000 1000) is the actual data length, not the actual data. As an example, for the header "#800001000", the characters "00001000" is the data length translated to 1000 bytes of raw data, which is 500 points of output data.

The two tables above shows the pattern of which the DAQ device will accept its data. The data must be structured in such a way that the sending of data to DAQ device is of the pattern above in order to avoid distortion of the data output from the DAQ device.

There are two output resolutions to consider in a DAQ device: 12-bit and 16-bit. For 16-bit DAQ devices, the data will be read it as it is. For 12-bit DAQ devices however, the relationship below must be applied:

LSB	**MSB**
DDDD DDDD	XXXX DDDD

D: Data bits
X: Unused bits

Converting arbitrary inputs

You will need to know the basic steps to convert the data that is being sent into the DAQ device and to process it and output through the analog output port as an arbitrary waveform.

Parameters to consider in the conversion:

- Bit size of the DAQ that is used
- The input parameter type
- Bipolar or Unipolar
- Range of display

Bit size of the DAQ device that is used

Bits affect resolution. If the bit value is 16 bit, then the total resolution step is $2^{16} = 65536$. Let 65536 be known as bit steps. One bit step allocated for the position 0 V in the display range. The left over bit step for calculation consideration is thus $65536 – 1 = 65535$.

The input parameter type

It is recommended for you to understand the relationship between decimal, binary, hexadecimal, and American Standard Code for Information Interchange (ASCII) formats to help facilitate conversion between format values. We will discuss this in further details in the next section.

Bipolar or Unipolar

Typically, a DAQ device supports two types of polarity: Bipolar and Unipolar. Bipolar is a representation of voltage ranging from a negative region to a positive region of display (for example, –10 V to 10 V). Unipolar on the other hand signifies only positive regions of display (for example, 0 V to 10 V).

DAQ data receiving pattern *(continued)*

Typically, the DAQ device reads the data that it receives in a 16-bit format and outputs it accordingly in a 16-bit format. However, for 12-bit formats, the front portion of the MSB is filled in with "*don't care condition*" bits so that it fills up the 16-bit slot.

To justify the statement above, you can derive the relationship shown below:

For 12-bit formats, the number of bit steps is given as $2^{12} – 1 = 4095_{\text{(decimal)}}$

LSB = DDDD DDDD

Let us assume all bits are active high, therefore

$$\begin{aligned} \text{LSB} = 1111\ 1111_{\text{(binary)}} \quad &= (2^7 + 2^6 + 2^5 + 2^4 + 2^3 + 2^2 + 2^1 + 2^0)_{\text{(decimal)}} \\ &= (128 + 64 + 32 + 16 + 8 + 4 + 2 + 1)_{\text{(decimal)}} \\ &= 255_{\text{(decimal)}} \end{aligned}$$

MSB = XXXX DDDD

Let's assume all bits are active high and the "*don't care condition*" bits are active low, therefore

$$\begin{aligned} \text{MSB} = 0000\ 1111_{\text{(binary)}} \quad &= (2^{11} + 2^{10} + 2^9 + 2^8)_{\text{(decimal)}} \\ &= (2048 + 1024 + 512 + 256)_{\text{(decimal)}} \\ &= 3840_{\text{(decimal)}} \end{aligned}$$

$$\begin{aligned} \text{LSB + MSB} \quad &= (255 + 3840)_{\text{(decimal)}} \\ &= 4095_{\text{(decimal)}} \end{aligned}$$

As shown by the derivations above, a 12-bit format data can be converted to a 16-bit format data with the inclusion of four "don't care condition" bits in the front portion of the MSB.

Converting arbitrary inputs *(continued)*

Range of display

The range of display is closely related to the use of polarity. If Bipolar is used and the range varies from –10 V to 10 V, the effective range of display would be 2 × 10 V = 20 V.

The basic elements we considered above will fundamentally form a foundation to convert and produce arbitrary waveforms.

Input parameter type

There are four types of commonly used input parameters: decimal, binary, hexadecimal, and ASCII.

- Decimal is a numeral system with a base of 10. It uses the symbols 0 to 9 to represent values zero to nine.
- Binary is a numeral system with a base of 2. It represents numeric values using two symbols, usually 0 and 1.
- Hexadecimal is a numeral system with a base of 16. It uses sixteen distinct symbols, most often the symbols 0 to 9 to represent values zero to nine, and A, B, C, D, E, F (or a to f) to represent values ten to fifteen.
- ASCII code can be simply defined as the code used to recognize which key is entered from a computer keyboard. Each key has a predefined binary, hexadecimal, or decimal values assigned to it. If multiple keys are pressed, the resulting binary, hexadecimal, or decimal values will be different. You can search for a list of tables relating each ASCII code with its respective binary, hexadecimal, and decimal values online.

Table 1. Decimal, binary, and hexadecimal relationships

Relationship between decimal and binary systems		Relationship between decimal and hexadecimal systems	
Decimal	Binary	Decimal	Hexadecimal
0	0	0	0
1	1	1	1
2	10	2	2
3	11	3	3
4	100	4	4
5	101	5	5
6	110	6	6
7	111	7	7
8	1000	8	8
9	1001	9	9
10	1010	10	A
11	1011	11	B
12	1100	12	C
13	1101	13	D
14	1110	14	E
15	1111	15	F
and so on...			

Table 1 shows a simple relationship between decimal values with binary and hexadecimal values. Converting such values for test and programming purposes take little effort with the vast amount of information and conversion tools available on the World Wide Web today.

Bipolar and Unipolar equations

With the following arbitrary waveform equations, you will be able to form and easily perform the conversions.

BIPOLAR

Equation 2

For 12 bit:

$$\text{DAQ input code}_{(decimal)} = \frac{\text{Desired output voltage } (V_0) + 10}{\frac{(2 \times 10)}{(2^{12} - 1)}}$$

For 16 bit:

$$\text{DAQ input code}_{(decimal)} = \frac{\text{Desired output voltage } (V_0) + 10}{\frac{(2 \times 10)}{(2^{16} - 1)}}$$

Equation 3

UNIPOLAR

Equation 4

For 12 bit:

$$\text{DAQ input code}_{(decimal)} = \frac{\text{Desired output voltage } (V_0)}{\frac{(2 \times 10)}{(2^{12} - 1)}}$$

For 16 bit:

$$\text{DAQ input code}_{(decimal)} = \frac{\text{Desired output voltage } (V_0)}{\frac{(2 \times 10)}{(2^{16} - 1)}}$$

Equation 5

The formulas above (Equations 2, 3, 4, and 5) are the first block towards polarity conversion. Notice the decimal formatted values for the DAQ input code; these values are the ratios telling the DAQ device which bit step is the desired output voltage pointing to.

For example, if you need to know which bit step the DAQ should give to 1 V as the desired output voltage for a 16-bit DAQ device in Bipolar mode:

DAQ input code $_{(decimal)}$ = (1 + 10) / (20 / 65535) = 36044.25 ≈ 36044
Therefore, 1 V takes the 36044th bit step out of 65536 bit steps.

Notice that 2^{16} represent 65536 bit steps and for calculation wise, 65535 is used to allocate a bit step for 0 V.

****Rule of thumb**: For Bipolar mode, 0 V sits at the center of the total bit steps of 65536. Therefore, 0 V is found at the 32768th bit step. It is safe to say that 1 V, which is larger in value than 0 V, should have a higher bit step value. Our calculated bit step value of 36044 for 1 V earlier lies in the correct region as it is a higher bit step value than 0 V.**

DAQ Analog Output Application Program

The runtime interface of the DAQ Analog Output application program is shown below:

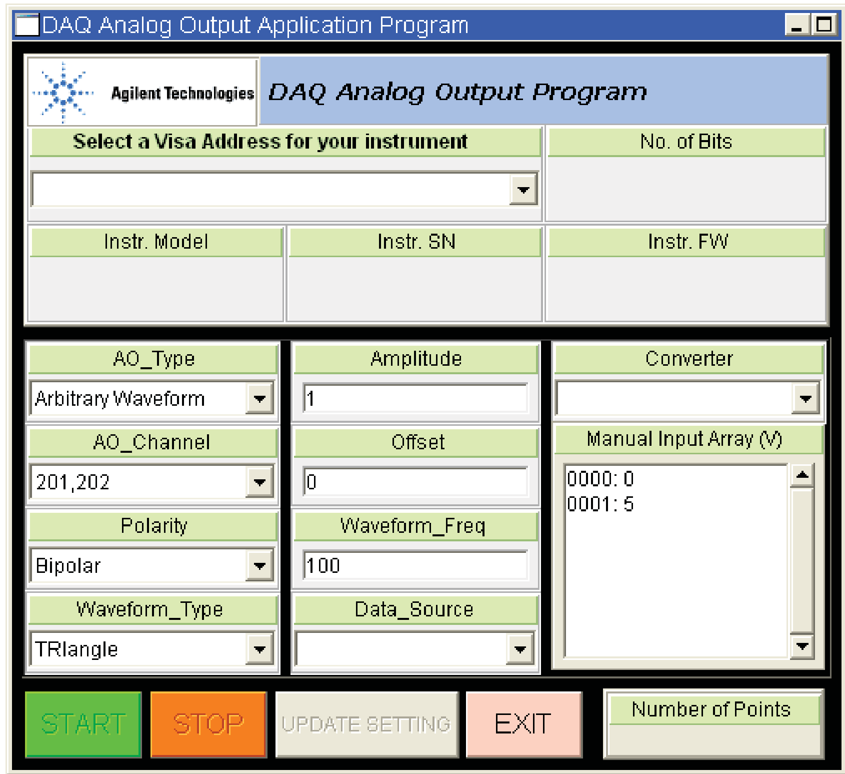


Figure 1. User interface of the DAQ Analog Output Application Program

As seen above, the upper portion of this program is used to detect the Virtual Instrument Software Architecture (VISA) address. Select a DAQ device connected to your PC (via its VISA address), and the number of bits supported, instrument model, instrument serial number, and instrument firmware version will be displayed accordingly.

The correct practice when using this program is to select the desired VISA address of your instrument first before proceeding further

Do bear in mind that the VISA address will be retained in the list even though the respective DAQ device has been disconnected. To clear the list and start afresh, you must close the runtime program and execute it again.

DAQ Analog Output application program parameters

There are nine important parameters to consider when working with the DAQ Analog Output application program:

1. Analog output type (AO_Type)
2. Analog output channel (AO_Channel)
3. Waveform polarity (Polarity)
4. Waveform type (Waveform_Type)
5. Waveform amplitude (Amplitude)
6. Waveform offset (Offset)
7. Waveform frequency (Waveform_Freq)
8. Data source (Data_Source)
9. File converter (Converter)

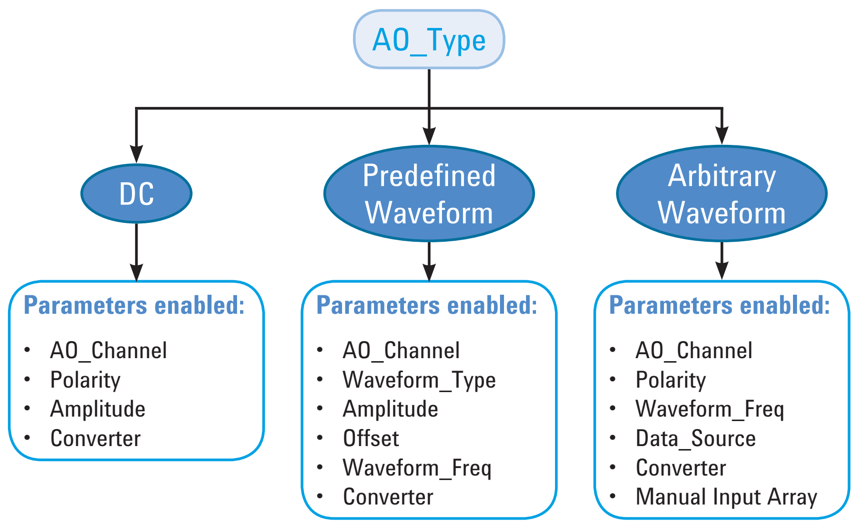
Remember to click **UPDATE SETTING whenever you select another AO_Type so that the list of enabled options will be refreshed**

1. Analog output type (AO_Type)

The DAQ Analog Output application program is made to enable only the functions that are related — and disable the functions that are not related — to the given task.

The AO_Type parameter is the next most important option that you should select after selecting the desired instrument from the "Select a Visa Address for your instrument" panel. Select an AO_Type parameter that is appropriate for your test environment: DC (Direct Current), Predefined Waveform, or Arbitrary Waveform.

Selecting an AO_Type parameter will affect the other parameters by enabling or disabling their options. The chart below will show you the list of options that are enabled when the respective AO_Type is selected.



Notice that throughout all the AO_Type, converter is always selected. The function of this converter will be discussed later.

2. Analog output channel (AO_Channel)

Use the AO_Channel parameter to select the desired output channel to output your waveform from.

There are only two analog output channels in the entire DAQ device family and it is labeled as CH201 and CH202. The following options are available from the AO_Channel parameter:

- 201 (Channel 201 only)
- 202 (Channel 202 only)
- 201, 202 (Channel 201 and Channel 202)

DAQ Analog Output application program parameters *(continued)*

3. Waveform polarity (Polarity)

There are two types of polarities that you should consider: Bipolar or Unipolar.

Bipolar is used if the output waveform consists of negative and positive values or consists entirely of positive values.

Setting this parameter to Unipolar will limit the output waveform to positive values only.

Take note that if you accidentally set this parameter to Unipolar but the waveform actually has negative values, a runtime error will occur.

4. Waveform type (Waveform_Type)

There are five waveform types to select in this parameter: SINusoid, SQUare, SAWTooth, TRIangle, and NOISe.

5. Waveform amplitude (Amplitude)

Amplitude is defined as the height in voltage that a waveform is able to achieve.

6. Waveform offset (Offset)

Offset can be set to negative or positive values. When offset is a positive value, the waveform will be shifted upward within the –10 V to 10 V region that the DAQ device is working in. Likewise, the waveform will be shifted downward within the –10 V to 10 V region if offset is set to negative value.

The waveform will maintain its center at x-axis within a Cartesian plot if the offset value is at 0.

7. Waveform frequency (Waveform_Freq)

Set the frequency of the waveform that is released from the analog output channels. Frequency is defined as the number of cycles that the waveform is created in one second.

8. Data source (Data_Source)

The Data_Source parameter allows you to generate arbitrary waveforms in two ways.

Select **Manual** to manually enter the points in voltage values within the range of –10 V to 10 V for bipolar and 0 V to 10 V for unipolar mode. Type the values (in voltage) in the "Manual Input Array" text box and click **Update Setting** before running the program with the **Start** button.

Select **From text file** if you choose to select your arbitrary points source from a text file. See the Converter parameter below to learn more about converting your arbitrary points from a text file source.

9. File converter (Converter)

This portion is tightly linked with the Data_Source parameter. As the Data_Source parameter has the option to receive points from a text file, it is therefore important to note where the text file comes from.

Intuilink and the Agilent Measurement Manager (AMM) can be used to our advantage to create arbitrary points but such applications only generate its file in **.csv* format and other file types. The file converter utilizes such applications to its advantage as it allows **.csv* files to be converted to **.txt* files, depending on whether you are converting from an AMM-based or an Intuilink-based **.csv* file.

To do this, select **Convert Intuilink csv to txt** to convert Intuilink-based **.csv* files, or select **Convert AMM csv to txt** to convert AMM-based **.csv* files and click **Update Setting** and then **Start**.

A series of dialog boxes will appear to assist you in converting your data. It is recommended for you to open up the **.csv* file first to know its range of data prior to a successful conversion.

Configuration Do's and Don'ts

Divide-by-two rule

The implicit rule of divide-by-two is driven by the output buffer arrangement when the two output channels are involved.

Picture the output sequence as below:

CH201_point1, CH202_point1,
CH201_point2, CH202_point2,
CH201_point3, CH202_point3,
...,
CH201_pointN, CH202_pointN
CH201_pointN+, CH202_pointN+

The whole output sequence is repeated again and again until the DAQ device is instructed to stop.

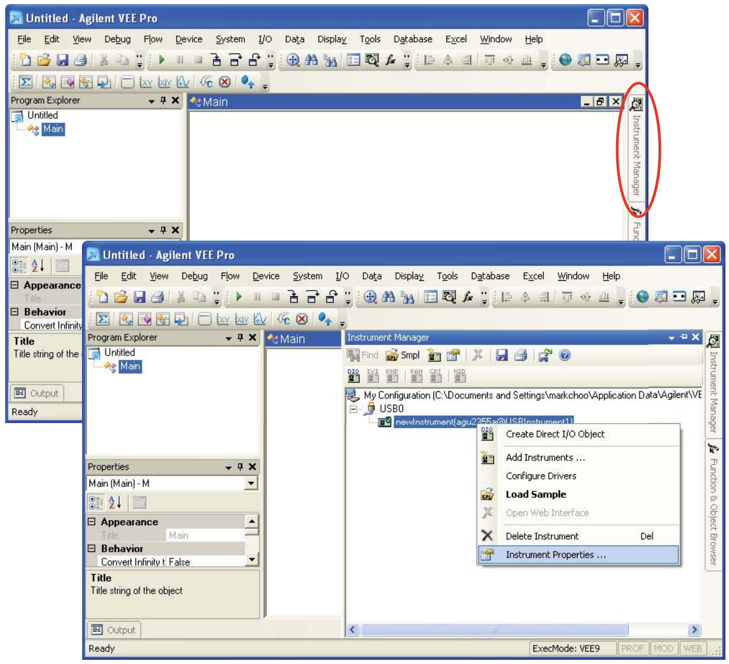
There is only one DAC in the DAQ device, and to generate two waveforms simultaneously, the DAC multiplexes the output points between channel 201 and 202. This is done in an interlacing manner.

If the numbers of points specified for both channels are not even (not divisible by two), this output scheme breaks. In other words, if one channel had one more data point than the other, the DAQ device design is made such that this extra point will be ignored.

Little-Endian (little end first)

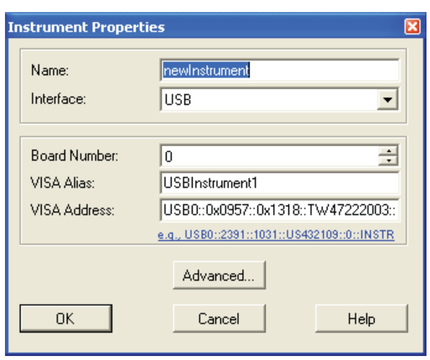
It is always a good practice to set your DAQ instrument to little-endian mode first before starting your program as this is a common mistake done by many Agilent VEE programmers.

To do this, follow the steps below:



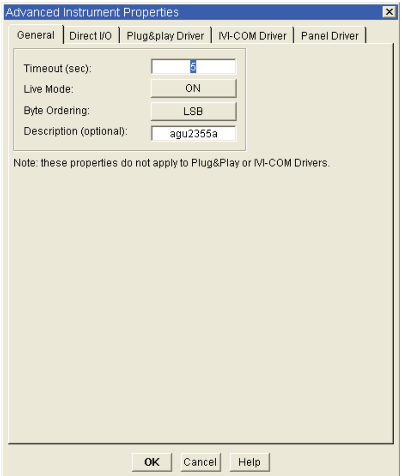
Select your connected DAQ device in the Instrument Manager panel. The Instrument Manager panel can be expanded by clicking the Instrument Manager tab located at the right side of the Agilent VEE user interface.

Right click on your DAQ device and select **Instrument Properties...**.



Little-Endian (little end first) *(continued)*

Click **Advanced...** and select **LSB** in the Byte Ordering selection.



The reason to set it so is because the data streaming back from DAQ is arranged in a little-endian manner. The data sent to DAQ is also expected to be in this little-endian manner.

General comparison between the U2761A and the U2300A and U2500A Series DAQ Devices

Description	U2761A USB Modular Function Generator	U2300A and U2500A Series USB DAQ Devices
Sampling rate	50 MSa/s	1 MSa/s
Frequency sweep (linear or logarithmic)	Yes	No
Modulating waveform (AM, FM, PM, ASK, FSK, PSK)	Yes	No
Arbitrary waveform drawing tools in AMM	Yes	No
Output connection	BNC	Screw terminal

Conclusion

This application note has covered the fundamentals of how to successfully create an arbitrary waveform using the DAQ device analog output ports.

The *DAQ Analog Output Application Program* provides an alternative mean for you to make use of the arbitrary waveform generation feature. If you are interested in making your own programs for this purpose, the formulas and concepts in this application note should be sufficient to kick start your program.

This application note has also covered the basic comparison table of the commonly used U2761A and the U2300A and U2500A Series DAQ devices.

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