

Using the Arbitrary Waveform Generator CAM

Introduction:

The Arbitrary Waveform Generator CAM (Configurable Analog Module) is an extremely useful device for creating periodic waves. The waves created are based on samples made in time and are not limited to linear or sine functions. This CAM is called Periodic Wave or Arbitrary Periodic Wave Generator in the AnadigmDesigner2 Library window. The generator can create simple waves such as triangle, a sawtooth, or a square wave. It could be set up to show the details of a complex wave such as preshoot, overshoot, ringing, or reflections in addition to the typical rise times and fall times: also sums of harmonically related sines, sine times sine, or other modulated waves.

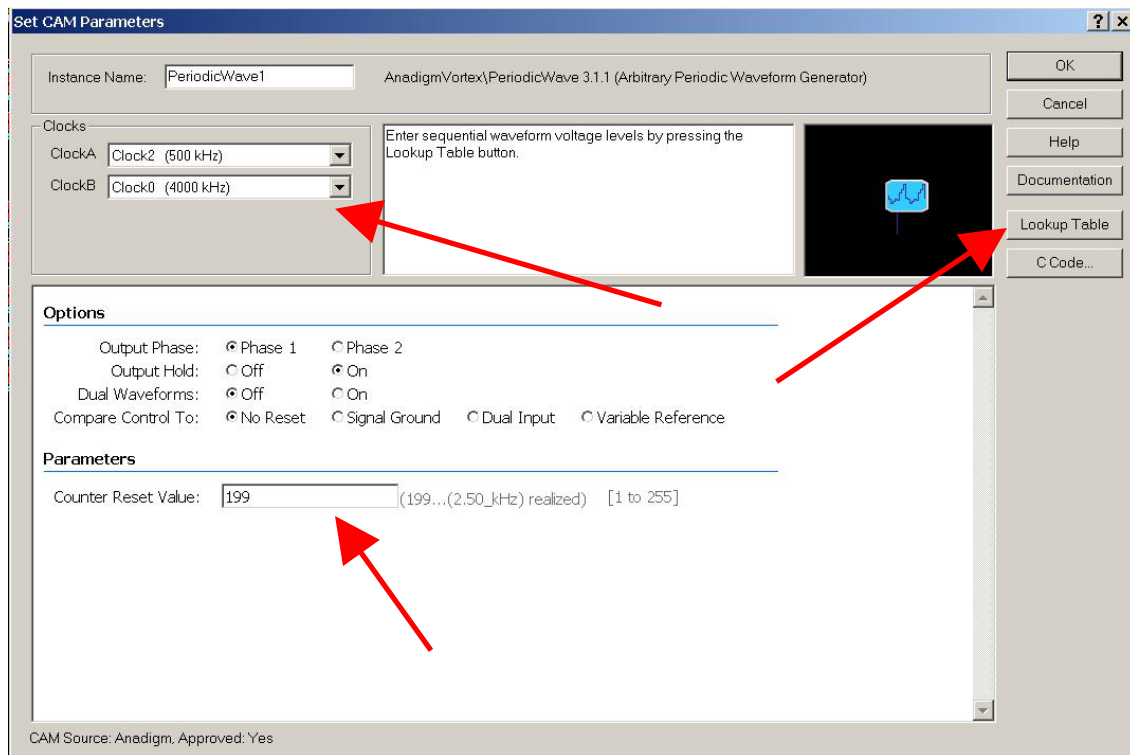
The essential the waveform is created with sampled amplitude values evenly spaced in time. The Arbitrary Waveform Generator CM uses an internal clock to step through a Lookup Table (LUT) of voltage values to create the waveform. The Lookup Table contains up to 256 voltage values equally spaced in time. The clock used to step through the Lookup Table is called Clock B on the Set CAM Parameters window and is derived from the Master clock.

This paper describes how to use the Arbitrary Waveform Generator Configurable Analog Module (CAM) by using frequency, amplitude, and other waveform parameters to establish a set of values to be put into the Lookup Table.

How to Configure:

Once the Arbitrary Waveform Generator is placed into the circuit design in the AnadigmDesigner2 design space you can point to the CAM and right click to see the **Set CAM Parameters** window. This window has three major areas of interest and two minor questions to answer. The first area is the Clock Frequencies in the upper left corner. (Setting the system clocks is covered in the next section and in another window.) In this window you can select from the 4 system clocks to supply Clock A and Clock B. The next area is the CAM Parameters section at the bottom of the window shown below. In this section the Counter Reset Value is set. The Counter Reset Value is the number of samples in your waveform and is also calculated in the next section. The third important part is the Lookup Table button which opens another window specific to the Lookup Table. Defining the Lookup Table describes the waveform that the Arbitrary Waveform Generator will create. Creating the data for the Lookup Table is covered in a section below.

The two minor questions are at the center of the window and are called CAM options. These have important effects on the wave but are easily understood and quickly set.



Now to the design equations. If the **Set CAM Parameters** window above is open it needs to be closed to continue to the next step.

Design Equations for Frequency:

To reiterate the initial statement, the essential idea for creating the waveform is that one entire period of the wave needs to be created with a sampled amplitude values evenly spaced in time. The Arbitrary Waveform Generator CAM creates a waveform by repeatedly stepping through the voltage values in the Lookup Table (LUT). To generate the Lookup Table you need to know how many individual points will make up one complete cycle of your desired wave. The timing of each of these individual points or samples is controlled by Clock B, a divided version of the Master Clock. Clock B is set in the upper left corner of the Set CAM Parameters window.

For example, Clock B shown in the previous figure is set to 4000 kHz (4MHz) thus each step is 250 nanoseconds long. If the lookup table contains 200 samples, the total wave period is 50 microseconds ($250 \times 200 = 50,000$ ns or $50 \mu\text{s}$). Thus the contents of the LUT are read over and over again 20,000 times a second. Simply put, a 20kHz wave. Fortunately there is an equation that relates the period of your desired wave to both the Master Clock divider number (M) and the number of samples (N).

In this section you will calculate the Master Clock divider, M and learn where and how to use this value. You will also calculate the number of samples (N, also called the "Counter Reset Value" in the Set CAM Parameters window) but this will be used in the next section. Because M and N are related and the equations are design equations there may be a range of possible solutions to the design equation below.

To calculate the values of the clock divider (M) and the number of samples (N) the design equation is:

$$M * N = T_p / (8 * T_{\text{master}})$$

Where:

T_p is the desired period = $1/f_p$, where f_p is the desired frequency

T_{master} is period of the Master Clock or $=1/f_{\text{master}}$, where f_{master} is the Master Clock frequency

N is selected based on the value of M.

In general N is 256 or less and is an integer value but needs to be maximized for the smoothest possible wave.

The value of M can only be 1 or an even integer less than or equal to 62.

In some cases there is an easy answer, as in the first example. In other cases the best procedure is to use a spreadsheet program, such as Microsoft Excel, to calculate the ratio of periods and then calculate M for different values of N. This allows you to look down the list of calculated M's to see if there is a right value or a value close enough for practical purposes. And if you use a spreadsheet put these calculations as far right as possible. This leaves the left most columns to create the data for the Lookup Table, which is discussed in the following section.

Once you have chosen the values of M and N you then adjust the clock dividers to set M for the Clock B division used in the Arbitrary Waveform Generator CAM. Then adjust a clock divider to set $8 * M$ for the Clock A. The reason for two clocks is that Clock B drives the Lookup Table (LUT) while Clock A drives the switched capacitor circuitry eight times slower than the Clock B rate. (Clock B is always faster than Clock A.)

Now consider an example:

Assume you want to create a 2.5kHz triangle wave. The first step is to find T_p , in this case:

$$T_p = 1/(2.5\text{kHz}) = 400\mu\text{s}$$

Now calculate the Master Clock Period:

$$T_{\text{MASTER}} = 1/(16 \text{ MHz}) = 62.5 \text{ ns}$$

Now the equation for N and M is :

$$\begin{aligned} M * N &= T_p / (8 * T_{\text{MASTER}}) \\ &= 400 \mu\text{s} / (8 * 62.5\text{ns}) = 400\mu\text{s} / 0.5 \mu\text{s} \\ &= 800 \end{aligned}$$

Now try some values for M: (remember M must be 1 or *an even integer* less than 62)

First if M = 1 that would make N 800 which is too big (is greater than the 256 maximum)

If M equals 2, N is 400 which is still too big

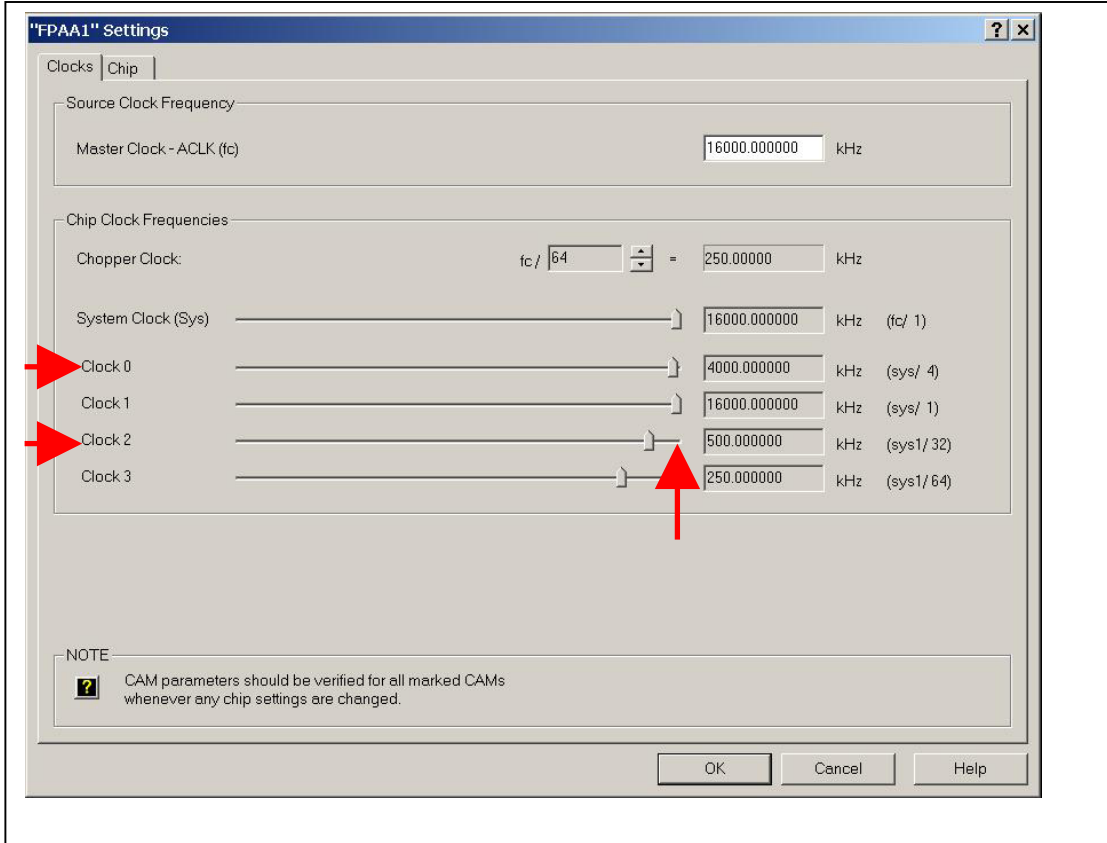
If M equals 4, N is 200 which is in the acceptable range

If M equals 6, N is 133.333 which is not an integer, but 133 could be used in a pinch

If M equals 8, N is 100 which is also in range.

You could continue this analysis further but remember that larger values of N gives a smoother wave and there are already two viable values of N. Thus in this case an M = 4 and N = 200 is the best choice. Also notice that a spreadsheet would be helpful for trying a lot of values.

Once you have M for Clock B, calculating $8 * M$ for Clock A is easy. In this case $8 * M$ is 32. The last step is to set the physical clocks. The physical clocks are developed internal to the Anadigm FPAA IC from the supplied Master Clock frequency (typically 16.00 MHz). At the tip of the AnadigmDesigner2 design space in the banner menu find the **Settings > Active Chip Settings** selection. This opens the following window:



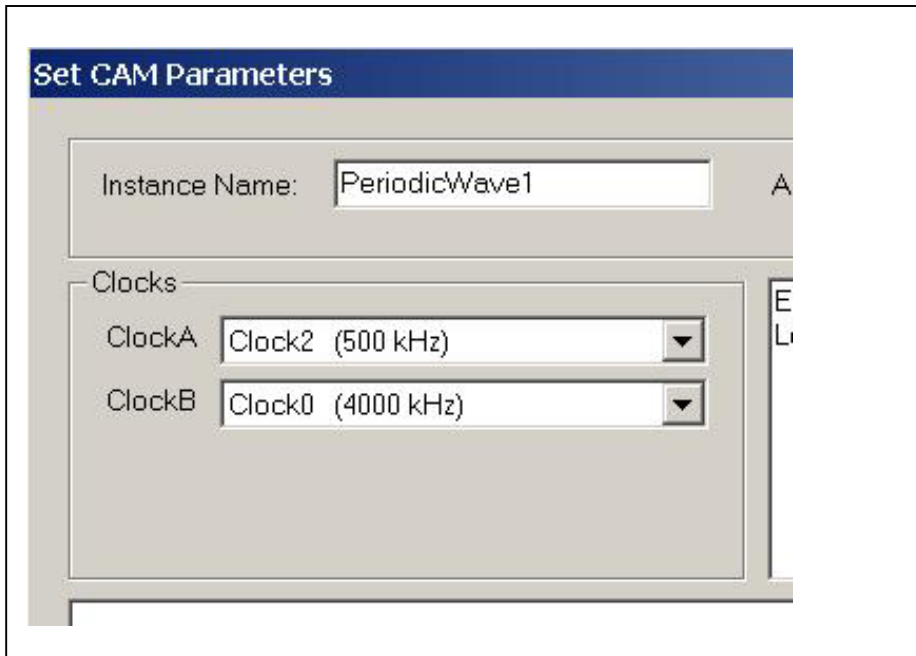
Observe the 16.00 MHz (listed as 16000 kHz) Master Clock Frequency that is fixed external to the IC. Notice the four different physical clocks named Clock 0, Clock 1, Clock 2, and Clock 3 that can be changed. We will use Clock 0 and Clock 2 for our example.

In the Clocks tab of the window above use the slider to set the desired physical clock frequencies

- Clock 0 is divided down by 4 to be 4000 kHz to be used as Clock B
- Clock 2 is divided down by 32 to be 500 kHz to be used as Clock A
- Clocks 1 and 3 are not changed and are available for other CAMs to use as needed.

When this is done clock **OK** to close this window

Next point to the Arbitrary Waveform Generator icon and right click to select the “**CAM Settings**”.



In the upper left corner of the Set CAM Parameters window is where the logical Clock A and Clock B are assigned to the physical system clocks. In this window you use the selection arrow to pick between the physical clocks: Clock 0, Clock 1, Clock 2, or Clock 3. You will see the resultant clock frequency in parenthesis. In this example Clock 0 has a frequency of 4000kHz which is now assigned to ClockB and Clock 2 has a frequency of 500 kHz which is assigned to ClockA.

The next step is to use the value of N to generate the data for the Lookup Table(LUT).

Design Equations for Amplitude:

To create the output waveform from the Arbitrary Waveform Generator the Anadigm FPAA IC steps through a Lookup Table (LUT) at regularly spaced time intervals defined by the logic clock, Clock B. The table itself appears as three columns. The first column is the index, which is the order where that particular point appears within the sequence of points. The index column is numbered from 0 to the “Counter Reset Value” that is specified on the lower left of the Set CAM Parameters window. The number N that was calculated in the previous section is used to calculate the Counter Reset Value and to create the data. The Counter Reset Value ranges from 1 to 255 (thus 2 to 256 samples) and is equal to N-1. The third and final column is the value that the CAM is actually going to put out of the chip. You can see in the example LUT below that sometimes the CAM can't quite give what you ask for, although it is close.

Index ▲	Requested (-4 to 4)	Realized ▲
0	0.000	0.000
1	0.040	0.000
2	0.080	0.000
3	0.120	0.000
4	0.160	0.000
5	0.200	0.000
6	0.240	0.000
7	0.280	0.000
8	0.320	0.000
9	0.360	0.000
10	0.400	0.000
11	0.440	0.000
12	0.480	0.000
13	0.520	0.000
14	0.560	0.000

It is possible to enter each value by hand, but that is a lot of tedious work. A quicker method is to use the spreadsheet, such as Microsoft Excel, to generate the data. A useful fact is that the Lookup Table itself only uses the leftmost column of the spreadsheet for the requested value. This leaves the remaining spreadsheet columns open to things like calculating the interval between values, or harmonics or other things to create a complex waveform.

The essential idea for creating the data is that the entire period of the complete cycle of the wave needs to be created with N sample values evenly spaced in time. The wave can be between +4 Volts and -4 Volts but for best accuracy it is wise to keep the wave less than +3 Volts to -3 Volts. Also be aware that this is the differential voltage output. Thus each output pin of the Anadigm FPAA IC will be half of the specified voltage and have opposite polarity.

For a sinusoid (Sine, Cosine, etc) this simply means that each sample is calculated at 360 degrees divided by N. For example if there are 200 sample points (N=200) the angle interval would be 360 divided by 200 or 1.8 degrees per point. For a triangle wave you need to determine how many points are allotted to rise from zero to the peak, then fall from the positive peak to the negative peak, and finally rise back from the negative peak to zero. This is a good time to continue the preceding example.

Example of creating a triangle wave repeated at 2.5kHz

In the previous section we calculated the N and M for a 2.5kHz wave. In this case the M was 4 which gave an N of 200. Now we need to calculate the value of each point in the wave.

First make an assumption that the wave will start at zero, rise to a peak, then decline to a negative peak before rising again back to zero. You could make other assumptions about the start of the wave that are equally valid, such starting at the positive peak or the negative peak. The point is that whatever assumption you choose effects the rest of the setup and calculations. Next assume that the wave will exist between maximum values of +2 Volts and -2 Volts.

Based on the given assumption of starting at zero and climbing to the peak, divide the wave into 4 sections that cover the complete cycle of the wave. The first section is the rise from zero to positive peak. The second section is the fall from the positive peak to zero. The third section is the fall from zero to the negative peak. And the fourth and final section is the rise of the negative peak to zero. Knowing this I need to allot my 200 samples evenly between the four sections; in other words 50 samples per section.

The essence of the previous paragraph is how and why to calculate the voltage interval between the values. The wave is going from 0 Volts to 2 Volts in 50 equally spaced points. That means that each space is 2 divided by 50 vertical intervals of 0.04 Volts. This is easily done in the spreadsheet by doing the calculation of the interval somewhere to the right of the page then using this relation in each cell:

$$\text{Present cell} = \text{previous cell} + \text{interval}$$

Or as is done in Excel:

$$A2 = A1 + \$C\$1$$

	A	B	C	D	E	F	G	H	I	J	K	L
1	0.00		0.04				TP=	1/2.5kHz	0.0004			
2	0.04						Tmaster=	1/16MHz	6.25E-08			
3	0.08											
4	0.12						N*M = Tp/(8*Tmaster)					
5	0.16						N * M =		800			
6	0.20						Possible Values					
7	0.24							M	N			
8	0.28							1	800	too big		
9	0.32							2	400	still to big		
10	0.36							4	200	in range		
11	0.40							6	133.3333	not integer		
12	0.44							8	100	in range		
13	0.48			Positive Peak =		2.00	(Wave goes 0 to +2 to 0 to -2 and back to 0)					
14	0.52			Negative Peak =		-2.00	Thus 4 sections, 50 points per section					
15	0.56											
16	0.60			Interval =	Distance / number of points							
17	0.64				0.04							

With the above formulation it is easy to copy and paste to fill out the samples from 1 to 51. Did I just say 51? Yes, there is a difference that you can see when you compare the figures. The Lookup Table uses an index starting at zero while Excel starts the index at 1. I find this a little disconcerting, but that leads me to double-check my calculations. It also explains why the actual value of the Counter Reset Value in the **Set CAM Parameters** window is not N but N-1.

Now beyond the waveform peak the expression for the first 50 samples would continue above the desired peak value. So the algorithm needs to be modified to track the negative going part of the waveform. Since the same interval is used all that is required is to change the plus sign to a minus sign giving the expression:

Present Cell = Previous Cell – interval

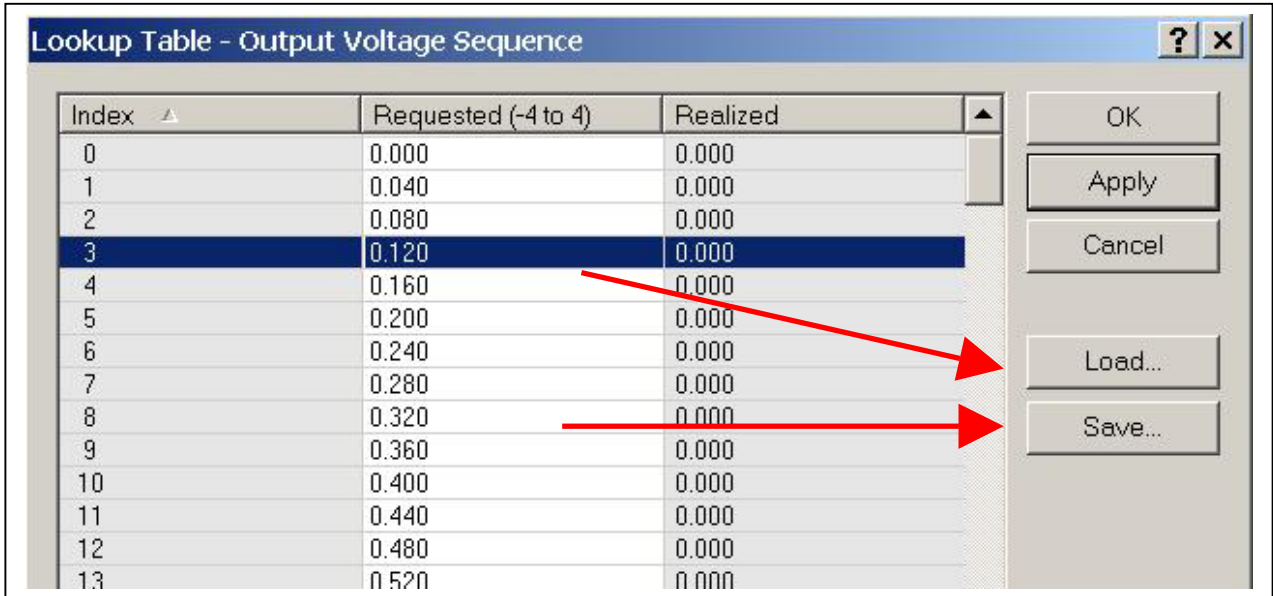
Or as is done in Excel:

A52=A51-\$C\$1

This expression is used until the negative peak is reached. Then, since the signal is rising again we can go back to the original algorithm.

Once the data is created it is time to put it all together.

Going back to the Lookup Table window notice the buttons on the right edge.



The first step is to use the **SAVE** button to create a file in a convenient directory with a meaningful name. The **SAVE** button opens a typical Windows save window that allows you to browse into or create the proper directory and select the meaningful name of your choice. For this example the meaningful name is **Try2pk** as in triangle, two point five kilohertz. This file has an extension of .csv and is easily opened and edited in Excel. Once you have the file and open it in Excel you can copy the entire design spreadsheet into the new .CSV file. Remember that the Arbitrary Waveform Generator CAM only looks at the left most column of data values from your spreadsheet. This means that you can see all the other parts of the file in Excel and AnadigmDesigner2 only uses what it needs from column A of the spreadsheet. Once you have saved the final .CSV file use the **LOAD** command to bring that file into the Lookup Table.

With the clocks set and the Lookup Table in place there are only two minor things remaining to do.

The Two Minor Things

At the start of all this I mentioned that there were two minor things to be done. These are in the CAM options section of the Set CAM Parameters windos.

Options			
→	Output Phase:	<input checked="" type="radio"/> Phase 1	<input type="radio"/> Phase 2
→	Output Hold:	<input type="radio"/> Off	<input checked="" type="radio"/> On
	Dual Waveforms:	<input checked="" type="radio"/> Off	<input type="radio"/> On
	Compare Control To:	<input checked="" type="radio"/> No Reset	<input type="radio"/> Signal Ground <input type="radio"/> Dual Input

The **Output Phase** selection simply tells the CAM when this waveform starts, on the rising clock edge or the falling clock edge. This is an immense issue at the start of the wave but after the first few cycles is a moot point.

The **Output Hold** option does make a huge difference in the output. With the Hold **OFF** the output waveform returns to zero between each point. This makes the output look like the back of a porcupine, very spiky. With the Hold **ON** the voltage stays at the level until the next sample is output. This makes the output look much smoother.

Once the CAM is wired to the outputs, the PAM will start singing as soon as the configuration is downloaded.

Conclusion:

This is only the introduction to the Arbitrary Waveform Generator CAM. There are many other things you can do with it. There will be other notes on some of the more advanced things possible. Your imagination can probably create many more.