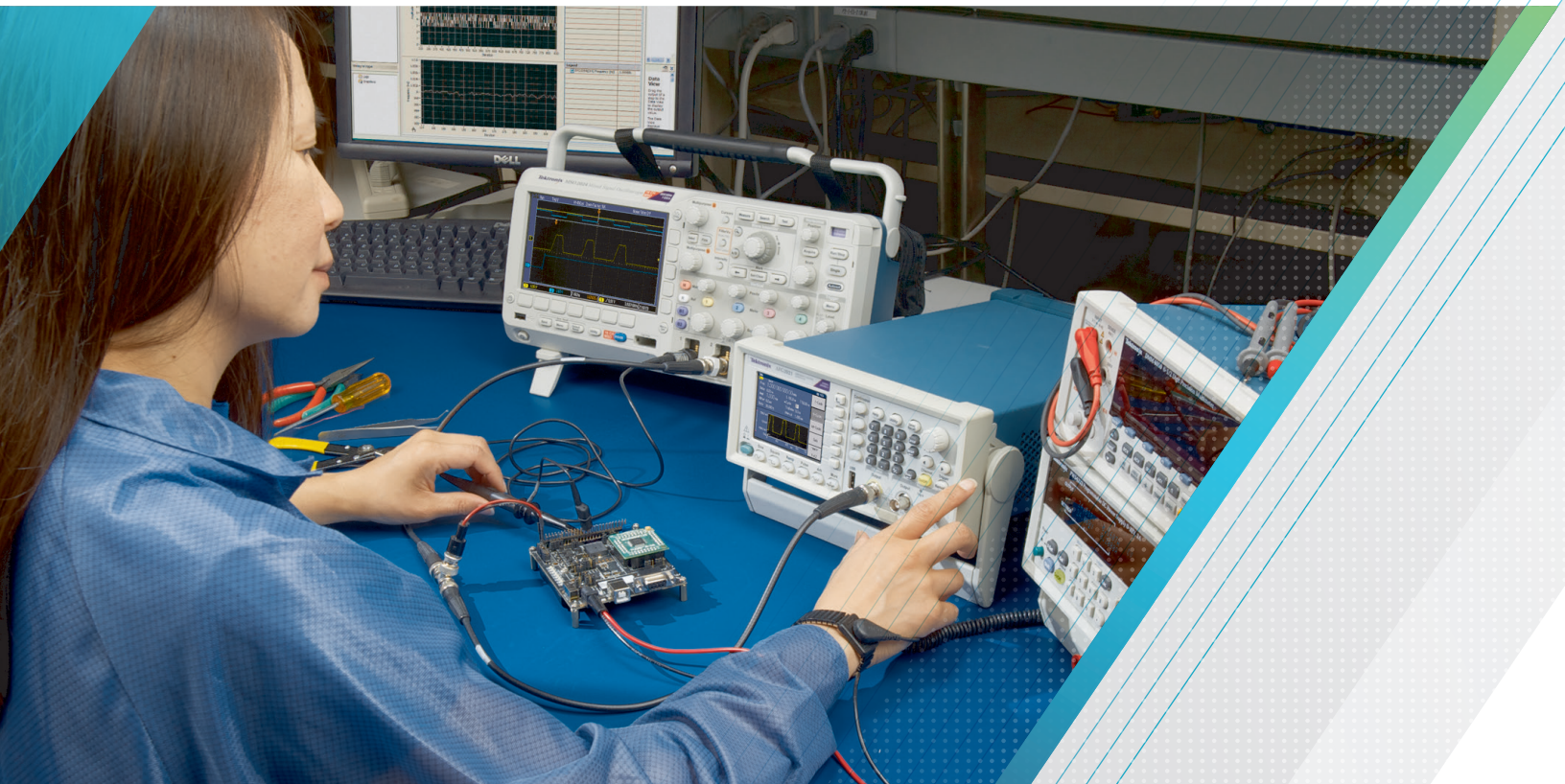


Replicating Real World Signals with an Arbitrary/Function Generator

APPLICATION NOTE



Introduction

Nearly all consumer products today have circuits or devices that require the input of specific electronic signals in order for the product to perform correctly. This input could be as simple as the signal from an automotive knock sensor, or as complex as a serial data communication bus signal such as Controller Area Network (CAN) or Inter IC Bus (I²C) signal. When designing and testing these devices, a mechanism is required to replicate the input signals. In many cases it may also be useful to add noise or other anomalies to the signals to test the devices under real world and stress conditions. A common approach is to create these signals using software applications or just capture a live signal using an oscilloscope. This created or captured waveform is then loaded in an Arbitrary/Function Generator (AFG) such as the AFG3000 Series and AFG2000 Series from Tektronix. The AFG can replicate this signal repeatedly to test the final circuit design in a controlled environment such as a temperature chamber or EMC testing room. Since replicated signals can be easily modified, they allow control over the testing to verify full reliability of the device being tested. Some oscilloscopes, like the MDO3000 and MDO4000C Series MDOs and the 5 Series MSO, include an optional, integrated AFG and can capture, modify and replicate the signal all in one instrument.

This application note will guide you through the steps required to replicate real world signals using the Tektronix AFG product and ArbExpress software.

AFG Basics

First, let's discuss what an Arbitrary/Function Generator is. Fundamentally, the Arbitrary Waveform Generator part of the AFG is a sophisticated playback system that produces waveforms based on stored digital data that describes the constantly changing voltage levels of an AC signal. To put the arbitrary concept in familiar terms, it is much like a CD player that reads out a digitally encoded analog audio signal from a disk in real time. The Arbitrary Waveform capability of the AFG offers a degree of versatility that few instruments can match. With its ability to produce almost any waveform imaginable, the AFG embraces applications ranging from automotive sensor simulation to wireless network stress testing.

The Function Generator part of the AFG produces stable as well as accurate and agile waveforms in standard shapes – particularly the all-important sine and square waves. Agility is the ability to change quickly and cleanly from one frequency to another. Most AFGs offer some subset of the following familiar wave shapes:

- Sine
- Square
- Triangle
- Sweep
- Pulse
- Ramp
- Modulation
- Haversine

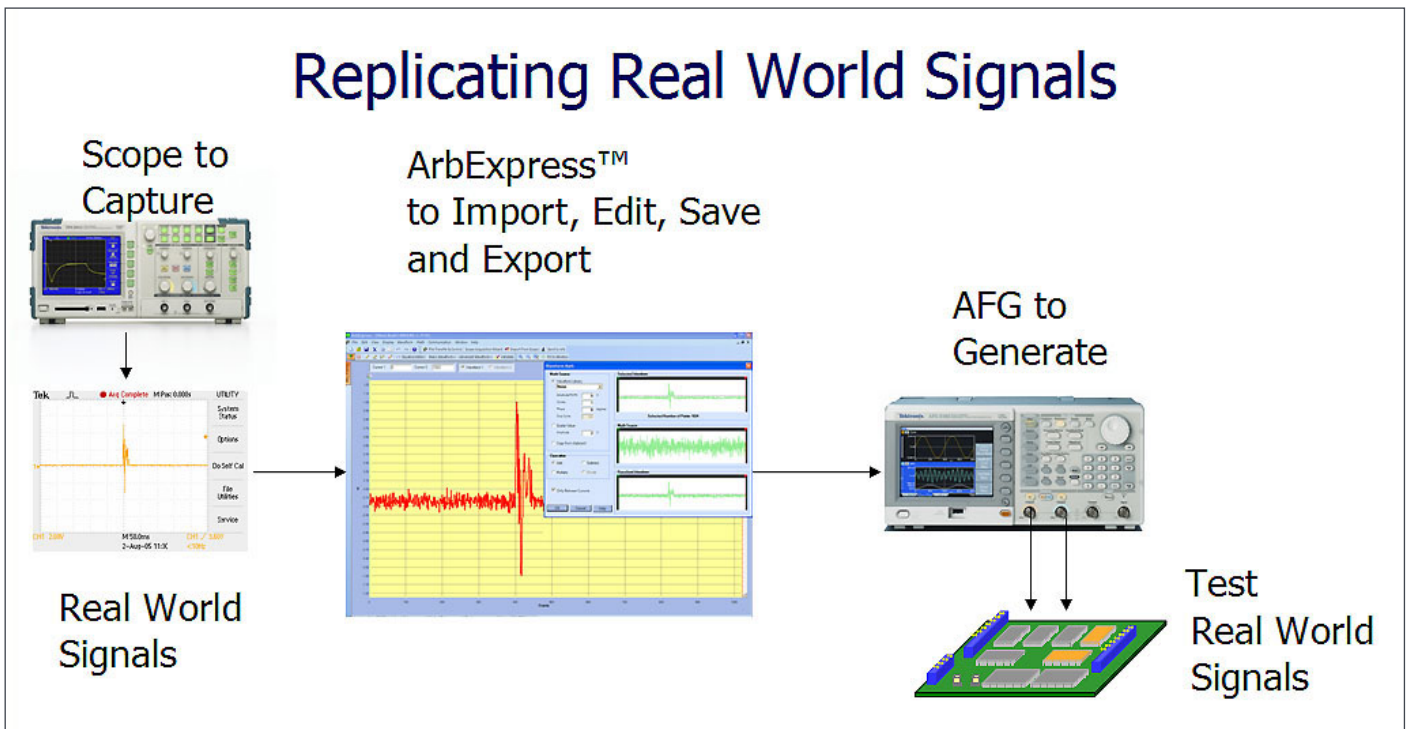


Figure 1. Flow chart of signal replication process.

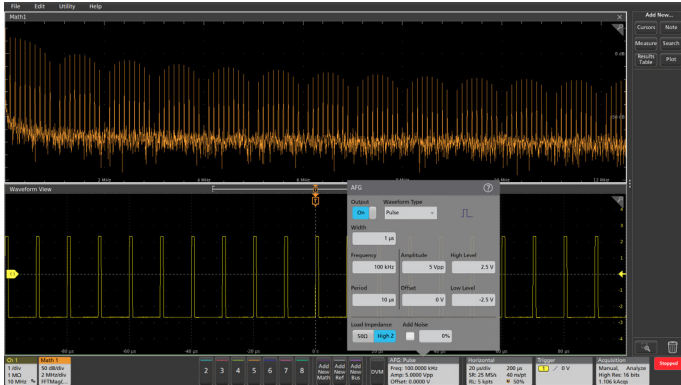


Figure 2. 5 Series MSO time- and frequency-domain displays of the built-in AFG's pulse waveform.

Today's AFGs are designed to provide improved phase, frequency, and amplitude control of the output signal. Moreover, many AFGs offer a way to modulate the signal from internal or external sources, which is essential for some types of standards compliance testing.

Engineering Education Applications

AFGs provide an easy-to-use educational tool, allowing engineering students to visualize common electrical signals, experience the effects of the signal generator's controls, and compare real-world measurements to theory. Used with an oscilloscope, a student can examine the characteristics of standard signals in the time and frequency domains, and easily verify their understanding of the coursework.

The oscilloscope display in Figure 2 shows the internal AFG generating a pulse waveform. The time-domain display of the pulse signal is shown in yellow in the lower graticule, and the frequency-domain (FFT) display of the signal is shown in orange in the upper graticule.

With the arbitrary waveform generation capabilities, students and researchers can also experiment with the theoretical and practical effects of subtle signal changes.

Creating Arbitrary Waveforms

Throughout most of this note, we will be discussing the Arbitrary Waveform capability of the AFG. In order to use it, you must first create the signal to be generated. Several methods are available for this. The more common approaches are to use software to draw the waveform from specifications or to capture the waveform using an oscilloscope and then send this to the AFG for generation. We will explore both of these methods.

Capture Engine Knock Sensor Signal

For our first example we will capture an automotive knock sensor output using an oscilloscope, send this to the

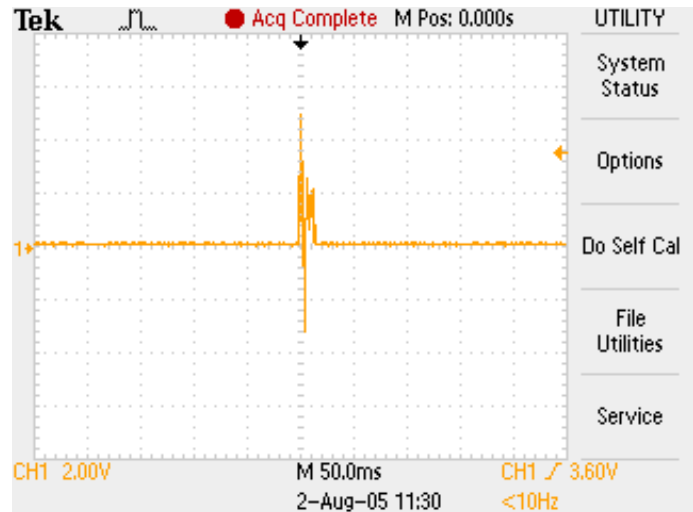


Figure 3. Knock sensor captured on oscilloscope.

AFG, and use the replicated signal to evaluate the engine computer control system.

A knock sensor is a small piezo-electrical device that is found on any newer automobile. When coupled with the Electronic Control Modules (ECM), it can identify when knock occurs and retard the ignition timing accordingly. Generating different amplitudes and timing of this knock sensor signal can greatly speed up overall testing of the ECM design and eliminate the requirement to wait for the engine to knock in order to accurately test the ECM device. Without the use of a signal source to generate this signal, evaluation of the design would be a much harder task.

To capture a real life knock signal including all overlaid distortions and anomalies, one needs to probe the output signal of the piezo-sensor and capture the signal while the engine is running. The sensor signal should represent the signal and timing produced by all cylinders of that particular engine. The next step is to extract one knock of one cylinder and replicate this signal with the AFG.

In our case, we first capture a non-distorted signal and potentially add anomalies throughout the test procedure. Waiting for the engine to knock can be a tedious task. Therefore, to capture the signal we will use a known good sensor, remove the sensor from the engine and tap it with a small wrench to simulate an engine knock. This approach works very well to simulate how the sensor reacts to a true engine knock. The resultant waveform is then captured on a Tektronix portable TPS2000 Series oscilloscope. It represents the ideal signal of one knock and one cylinder of the Engine. See Figure 3.

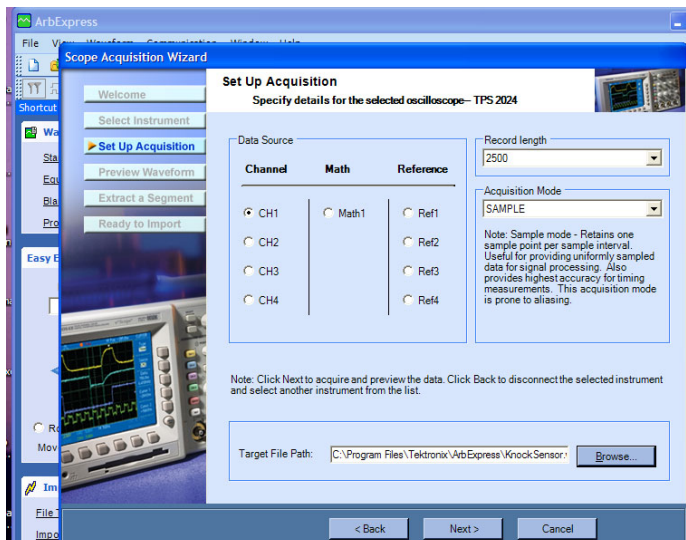


Figure 4. ArbExpress Scope Acquisition Wizard.

Using ArbExpress™ Software Scope Acquisition Wizard

Once the signal has been captured on the oscilloscope, we can use Tektronix' AFG's free companion software, "ArbExpress" and its Scope Acquisition Wizard to grab the waveform from the oscilloscope. This is done via the oscilloscope's supported TekVisa connections such as LAN, GPIB or RS-232. The acquisition wizard takes you through the required steps which ensure you grab just the portion of the waveform you are interested in. If you want the complete waveform, ArbExpress™ software can also import it directly or open .CSV file formats that many oscilloscopes support.

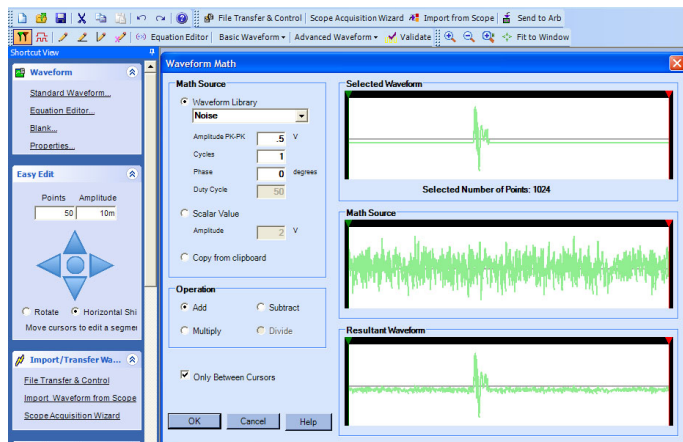


Figure 5. ArbExpress Math Function to add Noise.

Adding Noise to the Imported Waveform

After importing the waveform, ArbExpress software allows for editing of the waveform. Various tools such as free hand drawing, point draw and waveform math give the user ample freedom and flexibility to modify the waveform. To test the final device under real world or extreme conditions one can easily add noise or anomalies to the waveform. This eliminates the effort of capturing a "distorted" signal with an oscilloscope. One can simply add the distortions with ArbExpress.

Transfer Edited Waveform to AFG

Once the waveform looks exactly how you want it, you can easily transfer it using ArbExpress software directly to an AFG, an MDO3000 with option MDO3AFG, or an MDO4000C with option MDO4AFG, through a USB, LAN or GPIB interface. If desired, the waveform can also be saved on a USB memory device and opened directly on the AFG instrument using its USB port on the front panel. Via the USB memory device, libraries of waveforms can be saved and opened effortlessly.

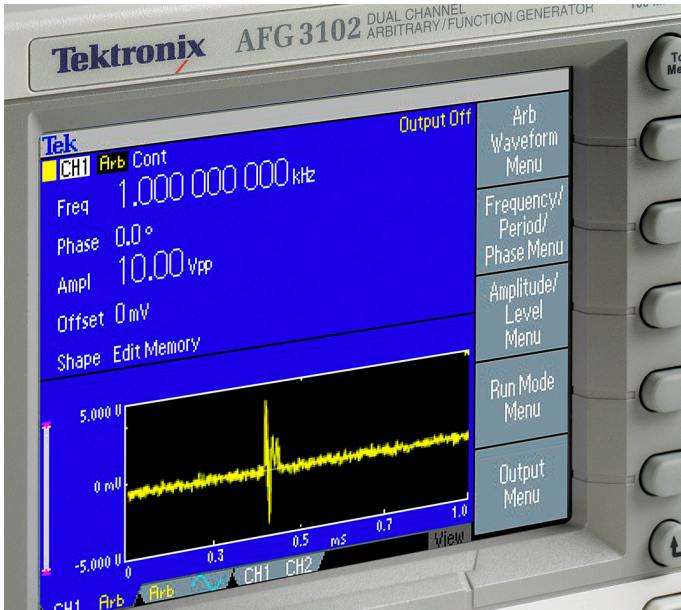


Figure 6. AFG3000 Series front panel user interface.

Once the waveform is transferred or loaded into the arbitrary waveform memory of the AFG, the large display shows the waveform that will be generated. This takes the guesswork out of knowing whether you have loaded the correct waveform. The final steps are to set the desired amplitude and frequency (repetition rate of the waveform memory used), and to turn on the output. This allows for easy testing of the ECM device with different amplitudes of the sensor pulse. One can also activate a variable noise source in the signal generator output path to test for the amount of noise the ECM can tolerate.

Synchronizing Multiple Instruments

Since automobiles have multi-cylinder engines, two or more dual-channel AFGs need to be synchronized in order to provide the required number of inputs to the ECM. To synchronize multiple single or dual channel AFGs, designate one as master and connect its external reference output to the external reference inputs of the other instruments. To gain even more precise timing synchronization, connect the master's TTL trigger output with the trigger input of the connected slaves. Additional timing control is available through an easily adjustable phase offset between the two channels within an instrument.

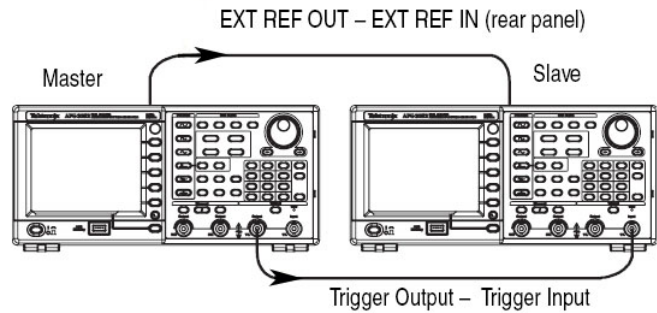


Figure 7. Synchronizing 2 AFG3000 Series instruments.

Creating Serial Data Signals

In automotive applications, other sensors and communication circuits also require replication and testing. To mention only some, Antilock Brake Systems and Transmission Control Systems often use elaborate control communication such as serial data buses like CAN. A simple example of the utility of an AFG is shown in Figure 8. A CAN signal was captured with the oscilloscope and the signal was loaded into the AWG memory. Then the AFG added random noise to the output signal. Finally, the oscilloscope decodes the resulting CAN bus signal and demonstrates the effects of noise on the received payload at the receiver. Display and control devices may use I2C devices. All these signals can easily be captured with an oscilloscope and replicated using an arbitrary/function generator. However, for serial data buses it may be more useful to create the clock and data signals directly as logic signals. Then, noise and other anomalies can be added to verify the DUT's operation, just as described in our previous example.

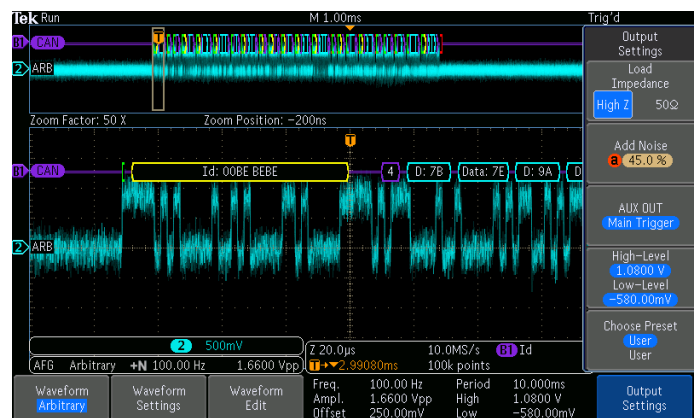
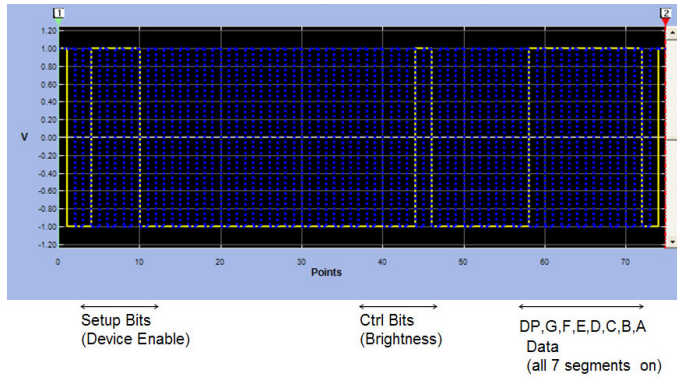


Figure 8. MDO3000 Series oscilloscope with built-in AFG adding noise to a captured CAN signal and then decoding the resulting serial bus traffic.



I²C Clk & Data Timing Diagram

Figure 9. I²C clock and data requirements.

Creating I²C Clocks and Data with ArbExpress™ Software

In the following case, we will use ArbExpress to create the serial clock and data required to drive an I²C LED driver circuit. We will then send these waveforms to a two-channel AFG for generation. This same technique can be used for other communication buses such as CAN.

Identifying Timing Requirements

Before creating the logic messages to drive the I²C device, one needs to understand the timing diagrams of the device specifications. For this example, we have determined that the device needs 76 clock cycles to send one message that defines the LED device, the brightness and the segments to be illuminated. The clock and data waveforms are overlaid in Figure 9.

Using ArbExpress™ Software Standard DC Waveform to Define Waveform Length

To create these waveforms using ArbExpress we begin with a standard DC waveform and define a waveform length of 76 points (creating a DC waveform will just be used as a way of defining how many points we want in our waveform).

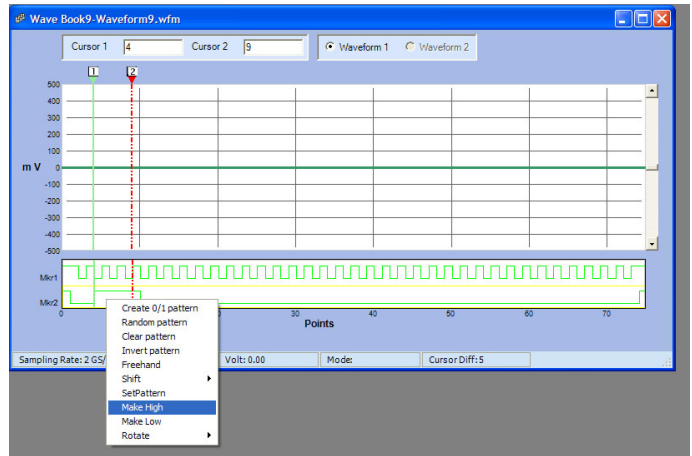


Figure 10. ArbExpress Markers “Make High” function.

Create Clock and Data Logic with the Marker Editor

We then use the Marker display and edit features to create the logic waveforms. Markers are defined as digital outputs and available on many high performance Arbitrary Waveform Generators (AWGs). As the AFG supports analog waveforms, we will convert these marker waveforms to analog waveforms. Creating the clock waveform only takes a right mouse click on the Mrk1 display and selecting “Create 0/1 pattern”. Once the clock waveform is created we can create the data waveform. For that, we use the cursors to define an area and then a mouse click on the Mrk2 display to select “Make High”, see Figure 10.

This operation sets the area between the two cursors to “1” or “high”. In this fashion, we define all high bits needed for this message. You may also notice in Figure 11 that the first and last bit of the clock (Mrk1) and Data (Mrk2) are set to high. This is used to identify the beginning and ending of the I²C message being sent and used for synchronization, see Figure 11.

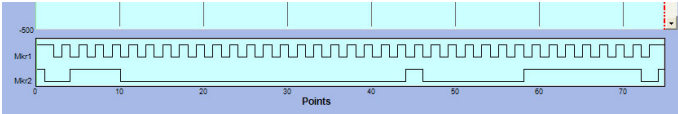


Figure 11. I²C clock and data requirements edited using ArbExpress Marker editor.

The analog data required for the AFG is created by simply saving the waveform and markers as a single ASCII (.CSV) file. Once saved, the marker data will be found in column 2 and 3. Just copy and paste these individual columns into separate csv files and then open them using ArbExpress. The marker information will now be opened as Analog Data (see Figure 12). If required, noise or other anomalies can be added using ArbExpress, and then the final signals sent directly to the AFG using the Send to ARB function, or save them to a USB memory device.

Generating the Final Output

The clock waveform is loaded to one channel of the AFG and the data waveform to the other channel. The dual channel models of the AFG enable you to lock the amplitude and frequency of the independent channels together. When adjusting these parameters on one channel the other channel will then automatically follow suit. This enables quick testing where two synchronous channels are needed. Note that when adjusting the frequency of an arbitrary waveform you are adjusting the repetition rate of the window of data being generated. So in this example you will be adjusting how fast these 76 clock cycles will be repeated.

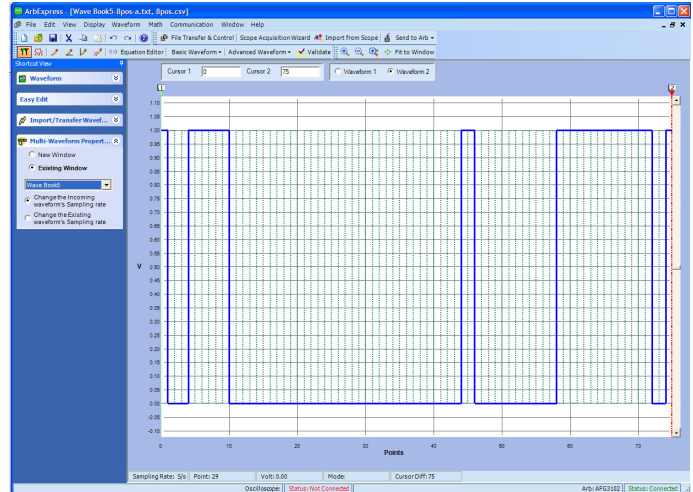


Figure 12. I²C clock and data displayed as overlaid analog waveforms.

Conclusion

As we have seen with these examples, replicating automotive knock sensor signals and serial data buses such as I²C become simple tasks when using an AFG and ArbExpress™ software. Beyond that, the described technique can be used for many different applications. With the AFG instruments capability of 128K points of arbitrary waveform memory, most data messages required for automotive communication can easily be achieved.

In these examples we have used automotive applications, but most electronic applications also require the ability to replicate and generate real world signals. With an AFG, an MDO3000 with option MDO3AFG, an MDO4000C with option MDO4AFG, or a 5 Series MSO with option 5-AFG, and ArbExpress™ software, replicating real world signals is a simple task. With its unprecedented ease of use, dual channel capability and companion ArbExpress software, the AFG reduces the time required for many operational and stress tests during component and device design qualifications. Also with features such as burst, sweep and modulation control on the AFG, many other applications can use this single instrument that technicians and engineers can easily become familiar with.

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