Using an MSO to Debug a PIC18-Based Mixed-Signal Design

Application Note 1564

Introduction

Design engineers have traditionally used both oscilloscopes and logic analyzers to test and debug mixed-signal embedded designs based on microcontrollers (MCUs). But a new class of measurement tools called Mixed Signal Oscilloscopes (MSOs) offers many advantages for debugging your embedded designs.

To illustrate the unique advantages of an MSO, this paper shows a typical turn-on and debugging methodology for a mixed-signal embedded design based on a Microchip PIC18 microcontroller.

The MSO is used to verify proper signal quality of a pulsed analog "chirp" output signal generated by the MCU and its associated peripheral hardware based on a variety of analog, digital, and serial I/O (I^2C) input conditions. But before exploring this particular embedded design and explaining how it was turned-on and debugged with an MSO, let's define what we mean by "MSO."

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What is an MSO?

An MSO is a hybrid test instrument that combines *all* of the measurement capabilities of a Digital Storage Oscilloscope (DSO) with *some* of the measurement capabilities of a logic analyzer – into a single, synergistic instrument. With an MSO, you are able to see multiple time-aligned analog and digital waveforms on the same display, as shown in Figure 1.

MSOs typically lack the advanced digital measurement capabilities and the large number of digital acquisition channels of full-fledged logic analyzers; the relative simplicity of MSOs allows them to avoid the complex use model associated with operating full-fledged logic analyzers. In fact, one of the primary advantages of an MSO is its use model. You use an MSO in much the same way you use an oscilloscope. And because MSOs are highly integrated, they are much easier to use than loosely tethered two-box mixed-signal measurement solutions. A good MSO should be user-friendly, provide fast waveform update rates, and operate much like an oscilloscope – not like a logic analyzer.

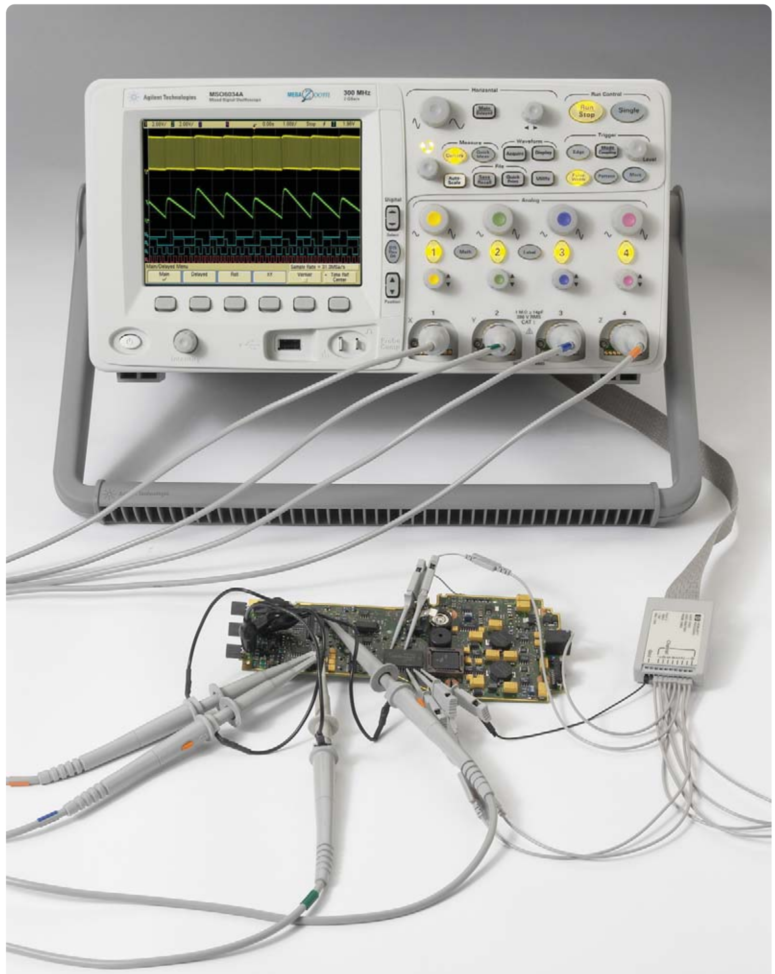

Figure 1. Agilent's 6000 Series Mixed Signal Oscilloscope (MSO)

The PIC® microcontroller-based "chirp" design

Figure 2 shows a block diagram of an embedded "chirp" product developed by Solutions Cubed of Chico, California, USA, for an embedded industrial application. At the core of this mixed-signal embedded product is a Microchip PIC18F452-I/PT microcontroller that operates on an internal 16-bit instruction set. Since this particular MCU has an internal bus structure and includes an embedded Analog-to-Digital Converter (ADC), this mixed-signal device and its associated external circuitry is a perfect candidate for turning on and then debugging with an MSO. Although understanding the operation of this specific design may not be very relevant to your particular design applications, we will provide an overview of this system's operation so that you can see how an MSO is used for this type of mixed-signal measurement application.

The ultimate goal of this design was to generate analog "chirp" output signals with various lengths, shapes, and amplitudes that are based on a variety of analog, digital, and serial I/O input conditions. (A "chirp" is an RF-pulsed analog signal consisting of a specific number of cycles often found in aerospace/defense and automotive applications.) The MCU simultaneously monitors the following three analog and digital inputs to determine the analog characteristics of the output chirp signal that it needs to generate:

1. The status of the user control panel is monitored with one of the PIC microcontroller's available parallel digital I/O ports to determine the shape of the output-generated chirp signal (sine, triangular, or square wave).

2. The output level of an acceleration analog input sensor is monitored via one of the PIC microcontroller's available ADC inputs to determine the amplitude of the output-generated chirp signal.

3. The status of the serial I^2C communication link is monitored with the MCU's dedicated I^2C serial I/O port to determine the number of pulses to be generated in the output chirp. This I^2C communication input signal is generated from another intelligent sub-system component from within this embedded design.

Depending on the status of these three analog, digital, and serial inputs, the PIC MCU generates a series of parallel output signals to an external 8-bit DAC to create an analog chirp signal of various amplitudes, shapes, and lengths. The unfiltered stair-step output of the DAC is then fed through an analog low-pass filter to smooth the output signal and reduce noise. This analog filter also induces a predetermined amount of phase shift to the output signal. Finally, the MCU generates a parallel digital output via another available digital I/O port to drive an LCD display that provides system status information.

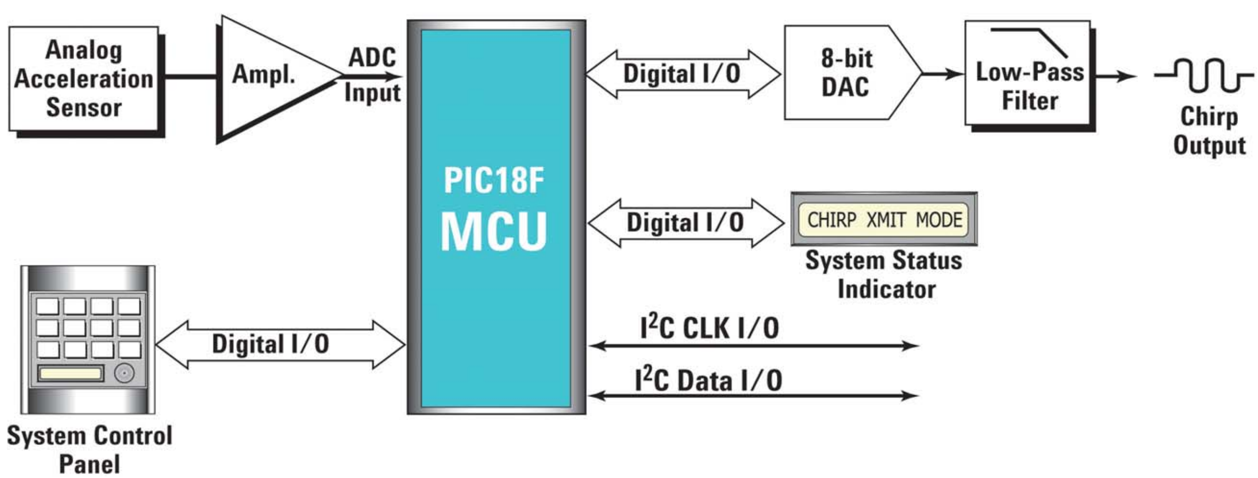

Figure 2. Mixed-signal embedded design that generates analog "chirp" outputs based on analog, digital, and serial I/O

Turning on and debugging an embedded "chirp" design with an MSO

The first step in designing/programming the MCU in this design was to configure the MCU's I/O for the appropriate number of analog and digital I/O ports. You can trade-off the number of analog I/O ports for digital I/O ports and vice versa in this particular microcontroller from Microchip.

Before attempting to code the MCU to monitor various inputs and generate the final specified output signals, we decided to first develop test code to turn on one section/function of this embedded design at a time and verify proper operation and signal integrity before adding interactive complexity. The first section/function we turned on and debugged was the external output DAC and analog filter. To verify proper operation of this circuitry and internal firmware, we initially coded the PIC MCU to generate a continuous/repetitive sine wave of fixed amplitude, regardless of the input control/status signal conditions.

Figure 3 shows a screen-image from an MSO that captured the continuous digital outputs of the MCU's digital I/O port (blue/bottom traces) that drives the digital inputs of the external DAC. In addition, we can see the time-aligned stair-step output of the converter (yellow/top trace) and the analog-filtered output signal (green/middle trace). Since this particular signal was a relatively low-level output signal utilizing just 16 levels of the 8-bit DAC (256 levels max), we can easily view the unfiltered/stair-step output characteristics of this converter on the oscilloscope's display.

We set up this particular acquisition to trigger when the DAC's output reached its highest output level (center-screen). Triggering at this particular point using conventional oscilloscope triggering would be impossible, since scope triggering requires edge transitions – it is impossible to trigger at the "top" of a signal with a conventional oscilloscope. To trigger at this point/phase of the output signal, we established a simple one-level pattern trigger condition based on the digital input signals of the DAC (outputs of the PIC MCU I/O port) that were coincident with the highest output analog level of the external converter. To trigger at this precise point in the waveform, we entered a parallel binary pattern of "HHHL LHHL" for triggering. Since this MSO employs "qualified" pattern triggering, the scope always triggered at the beginning of the specified pattern and never triggered on unstable/transitional conditions because this scope requires that the logic levels be stable for a minimum of 2 ns, and then triggers only when a stable pattern is *entered*. Note that some mixed-signal measurement solutions/options will trigger *whenever* a specified pattern trigger condition is present. This means that they might trigger during the middle of a pattern, or possibly during a transitional/switching state. Without "qualified" pattern triggering, the result will be unstable triggering.

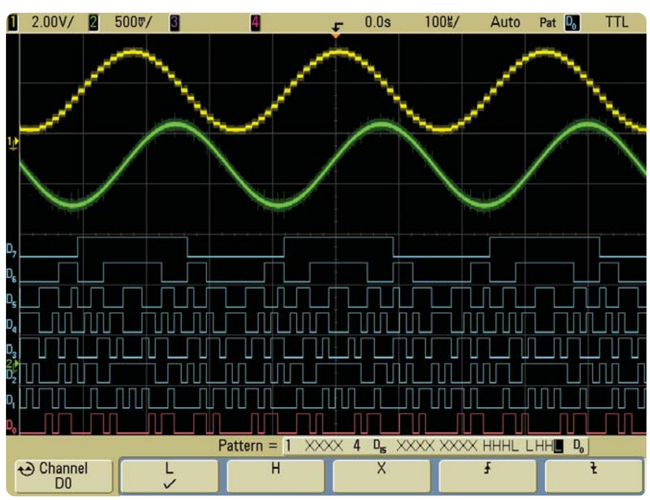

Figure 3. The MSO captures parallel digital input and analog output of a PIC MCU controlled DAC.

Figure 4 shows a trigger set up condition of the MSO that provided triggering precisely at the DAC’s 50% output level. We achieved this by using pattern triggering on the parallel digital input signals *in addition to* an analog trigger condition. Keep in mind that not all MSOs/mixed-signal measurement solutions permit combined mixed-signal triggering on both analog *and* digital conditions. But with two analog output conditions at the same level (50% rising level and 50% falling level), triggering coincident with either the rising or falling point required more than just pattern triggering on the 8-bit input pattern. With the addition of qualifying on a “low” level on analog channel 2, the scope was able to trigger at the desired phase using a combination of analog *and* digital pattern triggering. (Note that analog signals are considered “high” when they are above the analog trigger level, and “low” when they are below the trigger level.)

Also shown in Figure 4 are automatic parametric measurements including amplitude, frequency, as well as the phase shift of the filtered output signal relative to the stair-step output of the DAC.

After turning on and verifying proper operation of the external DAC and analog filtering circuitry, the next step in this design/turn-on process was to generate a specific number of non-repetitive sine wave pulses (chirps) based on a serial I^2C input. Figure 5 shows an overlay (infinite-persistence) of various length chirps using standard oscilloscope edge triggering. With conventional oscilloscope edge triggering, it is impossible to qualify triggering on specific-length chirps.

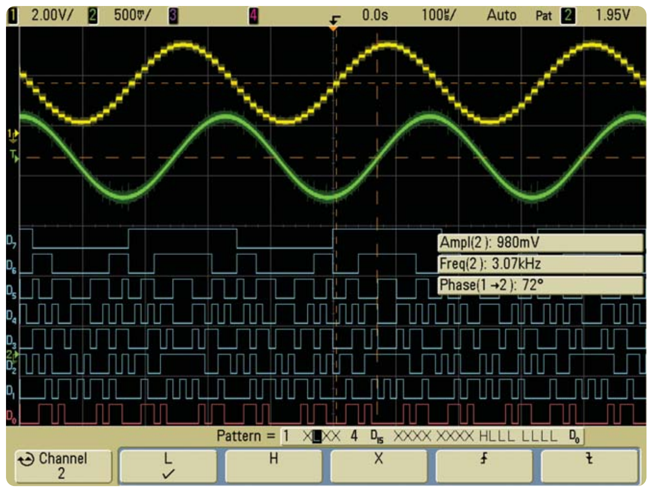

Figure 4. The MSO triggers at the 50% crossing point using a combination of analog and digital pattern triggering.

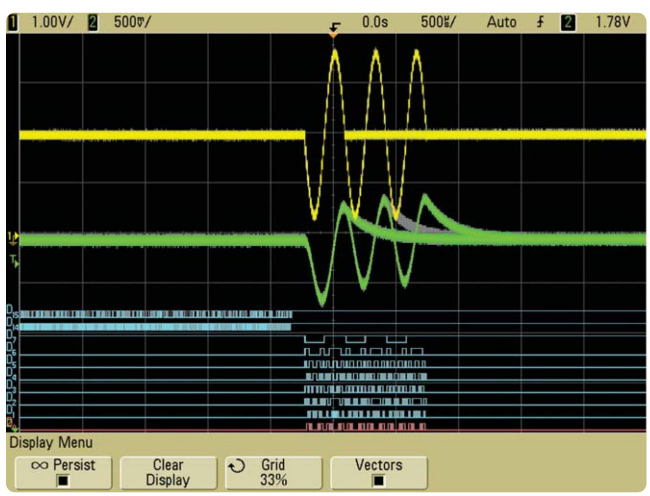

Figure 5. Conventional oscilloscope edge triggering fails to synchronize on specific-length chirps.

Using the MSO's I^{2}C triggering capability, the scope was able to synchronize acquisitions on specific serial input conditions that instructed the PIC MCU to generate specific-length (number of pulses) output chirps. This is shown in Figures 6 and 7.

Figure 6 shows the MSO's ability to trigger on a 3-cycle chirp with I^{2}C triggering on specific serial address and data content, and Figure 7 shows the scope's ability to trigger on a 1-cycle chirp. Digital channels D14 and D15 (top two blue digital traces) were defined as the I^{2}C clock and data input triggering signals respectively. Actually, we could have defined any of the sixteen digital or 2 to 4 analog scope channels to serially trigger on these two serial input signals.

While monitoring the serial input and analog output signals, D0 through D7 were set up to monitor the DAC input (MCU output) signals (bottom eight blue and read digital traces) as shown in Figures 6 and 7.

Although not shown, we could have set up another analog channel of the oscilloscope to simultaneously probe, acquire, and trigger the MSO based on the additional analog input signal from the input analog acceleration sensor, which determines the output signal amplitude. In addition, we could have utilized unused MSO digital channels to monitor and/or further qualify triggering on the digital control panel inputs or the LCD output driver signals.

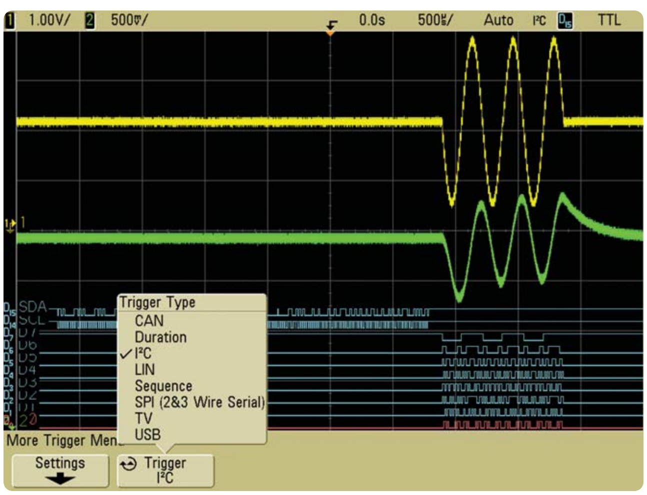

Figure 6. Triggering on a 3-cycle chirp with I^{2}C triggering in an MSO.

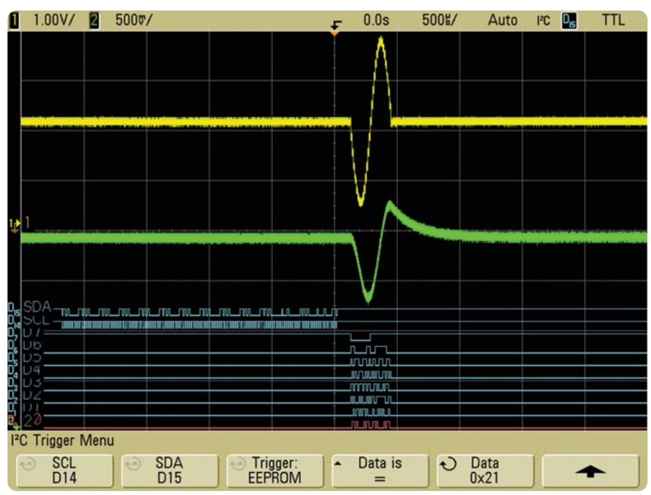

Figure 7. Triggering on a 1-cycle chirp with I^{2}C triggering in an MSO.

Summary

This paper showed how a mixed signal oscilloscope (MSO) can be used to more effectively and efficiently turn on and debug embedded mixed-signal designs based on a Microchip PIC18 microcontroller. The next time you need to turn on and debug your PIC MCU-based mixed-signal design, you might consider using an MSO in place of your current DSO and/or logic analyzer measurement solution. For more detailed information on debugging embedded designs, download Agilent's Application Note 1562, "Debugging Embedded Mixed-Signal Designs Using Mixed Signal Oscilloscopes" at **http://cp.literature.agilent.com/litweb/pdf/5989-3702EN.pdf**.

Glossary

ADC Analog-to-digital converter, sometimes referred to as an A-to-D

Analog I/O Real-time analog input and output signals of a microcontroller (MCU) or digital signal processor (DSP)

Chirp An RF-pulsed analog signal consisting of a specific number of pulses

DAC Digital-to-analog converter, sometimes referred to as a D-to-A

Digital I/O Latched input and output signals of a microcontroller (MCU) or digital signal processor (DSP)

DSO Digital storage oscilloscope that acquires and displays analog characteristics of input signals using either real-time or equivalent-time sampling techniques

I^{2}C Inter-integrated circuit bus, which is a common 2-wire serial bus that utilizes a self-arbitration protocol

LCD Liquid crystal display

MSO Mixed signal oscilloscope that synergistically combines *all* of the measurement capabilities of an oscilloscope with *some* of the measurement capabilities of a logic analyzer and includes a time-correlated display of both analog and digital waveforms

MCU Microcontroller unit

Qualified pattern triggering Triggering at a specific location within a digital parallel pattern (usually entry or exit points) and ensuring that an input pattern has stabilized with a minimum time qualification (present for >x time) before generating a trigger event so that the scope or logic analyzer does not trigger on unstable/transitional input switching conditions

RF Radio Frequency

Solutions Cubed, LLC

Agilent Technologies would like to thank Solutions Cubed, LLC of Chico, California, for providing the block diagram and measurement example of the mixed-signal MCU-based "chirp" design discussed in this paper. Agilent Technologies has worked closely with Solutions Cubed on various mixed-signal embedded design projects. Agilent currently offers an MSO training board based on the embedded chirp design developed by Solutions Cubed and documented in this application note. The MSO training board (N2918A), which can be purchased directly from Agilent Technologies, not only provides signals to train you on how to use an MSO, but also includes a variety of signals that demonstrate other important characteristics of oscilloscopes including glitch capture, waveform update, and display quality. Using this new MSO training board along with the easy-to-follow user's guide, you can quickly become familiar with how to effectively use an MSO in about one to two hours.

Solutions Cubed can provide mixed-signal hardware and software embedded design services/consulting according to your specified requirements. Contact Solutions-Cubed directly:

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Related Literature

Publication Title	Publication Type	Publication Number
Agilent 6000 Series Oscilloscopes	Data sheet	5989-2000EN/ENUS
Agilent 6000 Series Oscilloscope Probes and Accessories	Data sheet	5968-8153EN/EUS
Agilent 54830 Series Infiniium Oscilloscopes	Data sheet	5988-3788EN/ENUS
Agilent 54830 Series Infiniium Oscilloscopes Probes and Accessories	Data sheet	5968-7141EN/EUS
Debugging Embedded Mixed-Signal Designs Using Mixed Signal Oscilloscopes	Application Note	5989-3702EN
Why Oscilloscope Waveform Update Rates are Important	Application note	5989-2002EN
Oscilloscope Display Quality Impacts Ability to Uncover Signal Anomalies - Agilent 6000 Series Scope versus Tek TDS3000B Series Scope	Application note	5989-2003EN
Oscilloscope Display Quality Impacts Ability to Uncover Signal Anomalies - Agilent 6000 Series Scope versus LeCroy WaveSurfer 400 Series Scope	Application note	5989-2004EN
Deep Memory Oscilloscopes: The New Tools of Choice	Application note	5988-9106EN
Evaluating Oscilloscope Vertical Noise Characteristics	Application note	5989-3020EN
Ten Things to Considers When Selecting Your Next Oscilloscope	Application note	5989-0552EN

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