Application Note

Easy creation of customized multi-channel, multi-functional test and measurement systems

Electronic test and measurement, driven by necessity, continues to move in the direction of multi-channel and multi-functional instruments. Electronic devices under test continue to increase in complexity using parallel and array topologies that require more measurements to be made at higher speed while maintaining time coherence.

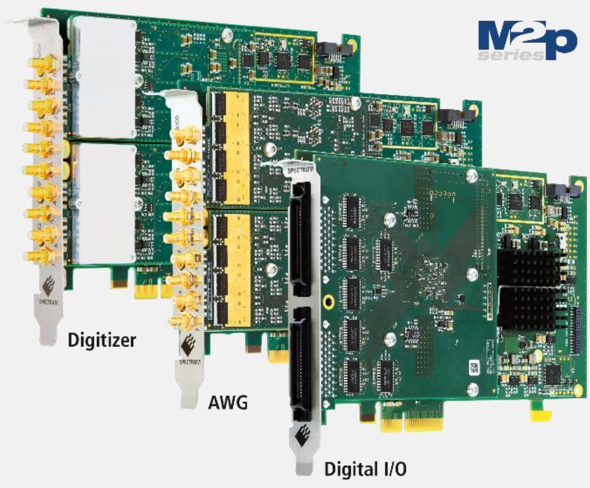

Figure 1: The M2p series modular instruments includes digitizer, arbitrary waveform generator, and digital I/O cards.

Spectrum Instrumentation, a leading supplier of PC-based test and measurement products, now has a complete line-up of PCIe cards, the M2p series shown in Figure 1, that allows economical multi-channel test systems to be created.

The M2p series offers 39 different products in three separate instrumentation classes: digitizers, for analog signal acquisition, Arbitrary Waveform Generators (AWGs), for analog signal generation, and a Digital I/O cards that can both acquire or generate high-speed digital signals.

This article will investigate how the products can be used in multichannel/multifunction test systems for several testing applications.

Industrial motor control

Electric motors are a good example of how modern electronics has changed. Since the 1990's motors, especially industrial motors, have transitioned from power line driven to electronic based motor drives. Even small motors, like those under 750 Watts which make up 90% of the motors in use, now use electronic motor drives. Let's look at a typical motor controller (Figure 2).

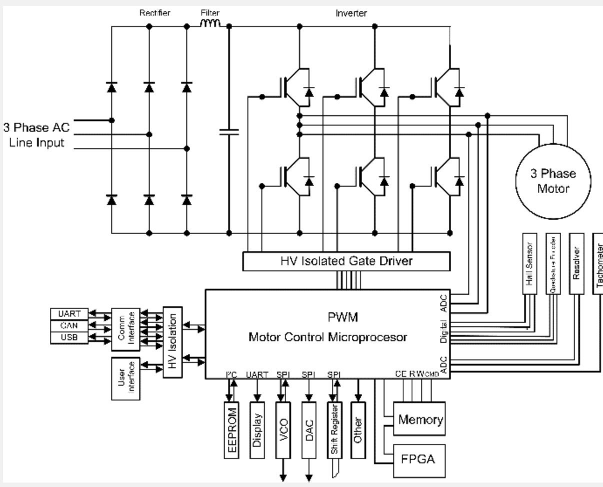

Figure 2: A typical motor control system uses pulse width modulation to control a three-phase motor. The control system is a mixed signal device using analog and digital signals.

Motor controllers operate like a switched mode power supply. They rectify and filter the mains to convert the mains AC into a DC bus. Portable device motors use batteries to supply the DC bus. This DC bus powers a switching inverter which drives the motor using pulse width modulated (PWM) signals. In the case of DC motors, the inverter is also used to commutate the motor. Speed and angular position sensors then feedback the motor speed and torque to complete feedback control loops. The controller microprocessor is a mixed signal device having both analog and digital signals. Serial interfaces communicate between the microprocessor and auxiliary devices such as the controller display, EEPROM, VCO, and DAC's.

This environment is ideal for the M2p series modular instruments. Digitizers can acquire, display, and analyze analog signals. While Digital I/O modules can do the same for digital signals, like those used in address and data buses. AWG's can simulate sensor signals based either on acquired signals or those created mathematically.

As a practical example consider measuring the voltages and currents in a three phase, brushless DC (BLDC) motor used in a portable hand tool. The phase voltages and current were obtained using a 16 bit, eight channel M2p.5968-x4 digitizer that samples at up to 125 MS/s. The digitizer was controlled by Spectrum Instrumentations SBench6 software which is also used to display and analyze the data from the measurement, as shown in Figure 3.

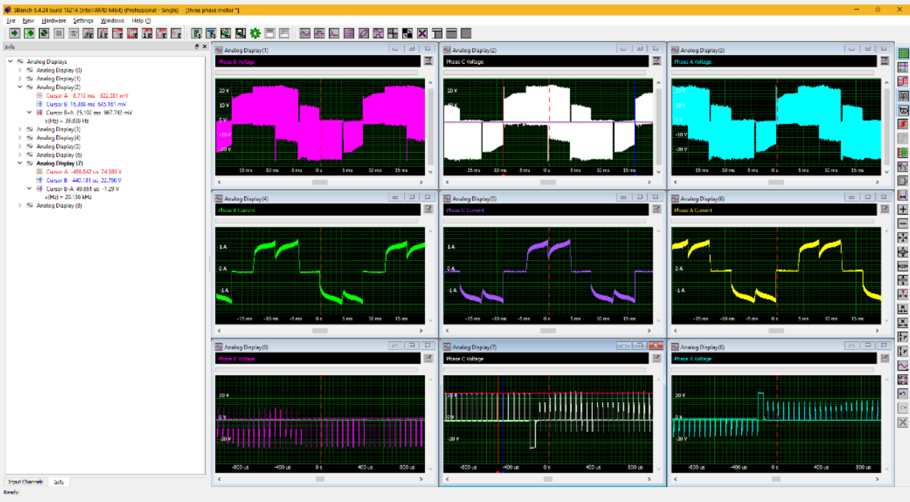

Figure 3: The three phase voltages and currents from a BLDC motor. The voltage waveforms are shown in the top row, currents in the middle row, and a zoom view of the voltage waveforms in the bottom row.

The acquisition duration of 40 ms at a sampling rate of 10 MS/s captures about 1.6 periods of the motor rotation. Cursors in the analog display 2 (top center) measure the rotational period of 25 ms as readout in the info panel to the left. This translates into a rotational frequency of 40 Hz or 2400 revolutions per minute. The voltage waveforms show the characteristics of the 6-step commutation, sometimes called trapezoidal control. The commutation is also observed in the current waveforms as six ‘pulse-like’ waveform segments per rotation. The voltage waveform shows the switched nature of the PWM voltage waveforms. The horizontally expanded view in the bottom row shows the individual pulse waveforms. Cursors in the analog display 7 (bottom center) measure the switching frequency as 20 kHz. The inverter section is floating and not ground (earth) referenced and three-phase delta connection uses six differential channels, that is twelve single ended channels requiring 2 digitizer cards in the system.

The motor controller uses the outputs of the Hall effect sensors to determine the motor speed and shaft angular position. The sensor consists of three Hall effect transducers spaced at 120° intervals inside the motor housing. The sensor has three digital outputs one from each Hall effect transducer.

Figure 4: The three phases of the hall effect sensor allow the controller to determine the motor rotational speed as well as the shaft’s angular position.

The three phases of the hall effect sensor can be acquired by using the M2p.7515-x4 Digital I/O card, as seen in Figure 4. The M2p7515-x4 can acquire or source up to 32 digital channels at sample rates as high as 125 MS/s. The M2p series also has an option, the M2p-Star-Hub that allows up to 16 different cards (digitizers, AWGs, and digital I/O modules) to be mixed and synchronized (sharing common clock and trigger signals) forming a time correlated measurement system.

The three Hall effect senor digital outputs break the rotation period into six sub-periods, each subtending 60° of rotation. The colored box overlays at the bottom of the figure show the six sensor output states that occur during a single rotation of the motor armature. The Hall effect sensor allows the motor controller to determine the motor speed and angular position. It uses the six sensor states to commutate the motor windings to maintain rotation.

The 32-bit wide Digital I/O module can also investigate the parallel digital buses as shown in figure 5.

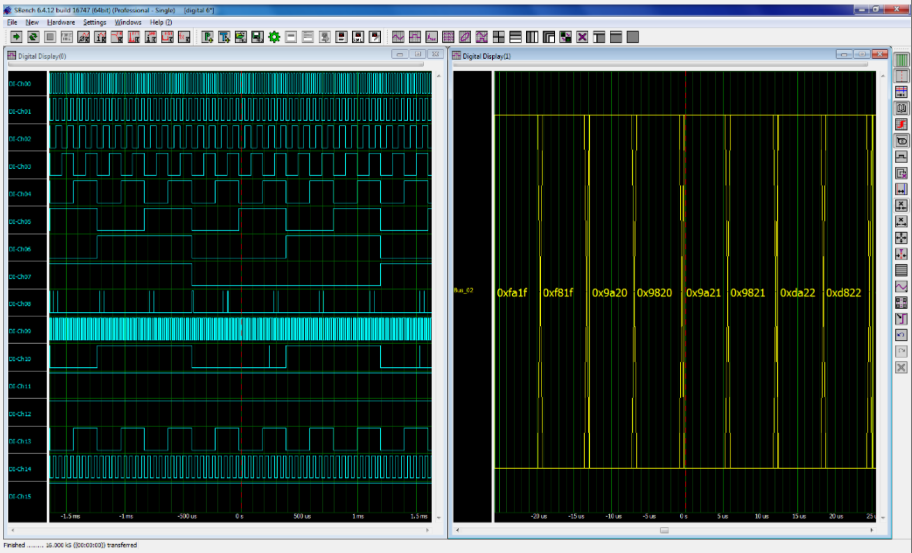

Figure 5: A 16-bit parallel digital bus shown in both the bitwise and bus view.

The digital signals can be displayed in either a bitwise or a bus view. Bus view annotation can be displayed in hex, octal, binary, or signed or unsigned decimal format.

Source-response testing

Some electronic devices like amplifiers, filters, receivers, and digital interfaces, must be externally excited for testing, they require a signal source as well as a measuring instrument. Modular digitizers and modular arbitrary waveform generators (AWGs) are available with multiple source and measurement channels that can be configured in bandwidth, sample rate, and memory. Combining the two products in one system provides a very cost effective and efficient way to meet an extensive range of test requirements. This example uses a stimulus–response test system composed of a Spectrum M2p.5968-x4 16-bit digitizer and an M2p.6568-x4, 8 channel 125 MHz, 16-bit, arbitrary waveform generator.

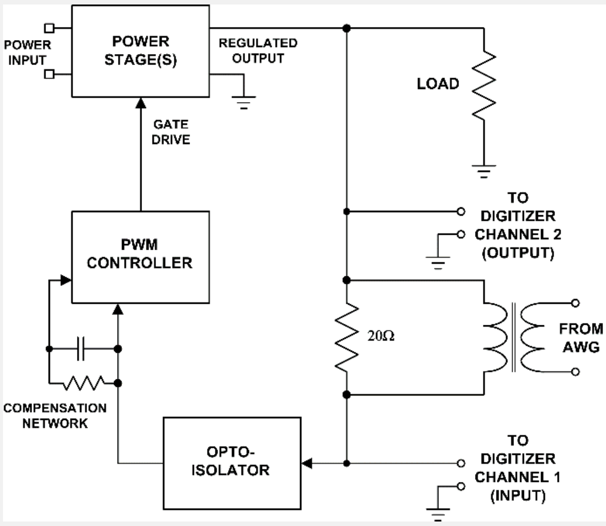

Figure 6: The functional block diagram of a switched mode power supply showing the introduction of a small perturbing signal to measure the phase margin of the power supply control loop.

Phase margin is a critical figure of merit, which serves to indicate the stability of a closed loop control system. It is one of the most common design verification measurements made in power supplies during development and debugging. Measuring phase margin is an example of a source-response measurement that requires both a digitizer and a signal source.

Phase margin is the phase difference between the input and output of the open circuit control loop at a frequency where the loop has unity gain. Unity gain with a 360° phase shift is an unstable, oscillatory condition. While this measurement characterizes the open loop characteristics of the feedback control loop, it is most often measured in a closed loop configuration. The block diagram in figure 6 shows a common technique for measuring open loop characteristics, such as phase and gain margin, while maintaining a closed loop configuration.

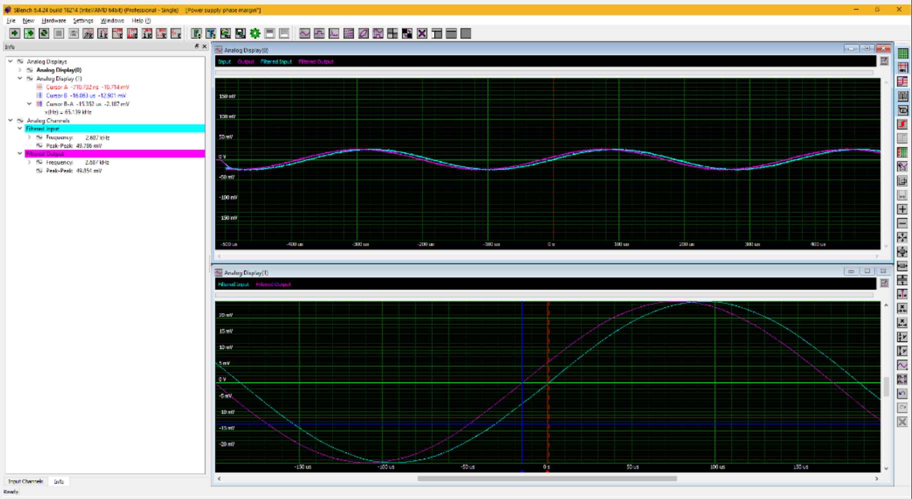

Figure 7: Measuring the phase margin in a power supply using a small perturbing sine wave. Unity gain occurred at a frequency of 2.687 kHz. The time difference between the waveforms is -15.352 µs (-14.85°).

A small spreading resistor, 20 Ohms in this example, is inserted into the control loop at a point where it will not disturb the normal operation of the circuit. A small sinusoidal signal from the AWG is injected via a transformer and as the frequency is varied, the gain and phase difference around the loop can be determined by measuring the voltages with the digitizer. The loop gain is the ratio of the loop output measured on channel 2 divided by the loop input measured on channel 1. The phase difference is also measured between the loop input and output directly. The frequency of the sine wave is varied until the input and output waveforms are equal (unity gain, 0dB). The phase difference at this frequency is the loop's phase margin. Note that the greatest difficulty encountered with this measurement is the accurate determination of the small voltages encountered in the presence of the switching noise of the power supply. The effect of the noise can be reduced significantly by averaging, synchronous with the sine wave excitation, or by filtering the signal. In this example, Spectrums SBench6 software applies a 20 kHz low pass filter to both the signals before measurement, as shown in Figure 7.

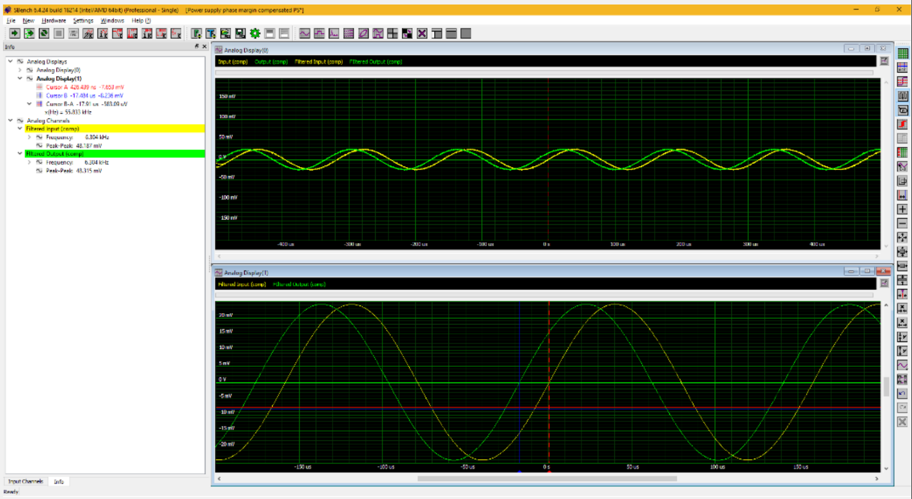

Figure 8: The improvement in phase margin because of a change the compensation network values. The delay is -17.91 µs and the unity gain frequency has shifted to 6.304 kHz and the phase margin is now a more stable -40.6°.

The phase difference is computed as the delay multiplied by the unity gain frequency times 360°.

Note also that the shape of the input and output waveforms is a good indication that the loop is not being overdriven by the sine excitation. Overdrive would show as a non-sinusoidal waveshape.

The measured phase margin, -14.85° is critically low. The phase margin was increased by adjusting the compensation network on the PWM controller. The result is shown in figure 8. The phase margin has been increased to –40.6°. This provides much greater stability in the system.

SPECTRUM

Application Note

Simulation

Some development situations require system elements that are not currently on hand. Rather than stopping work until the missing parts are available, it is possible to simulate the missing elements using an AWG. The AWG can produce an extremely wide variety of waveforms both analytically or by importing the waveforms from a digitizer or oscilloscope. An example is the electrocardiogram (ECG) signal shown in Figure 9.

Figure 9: A thirty-second-long ECG waveform captured by a digitizer; the waveform was transferred to the SBench6 Function trace where it can be imported into the AWG. The lower zoom trace shows the more familiar sinus rhythm.

Once the waveform is acquired, it can be modified by changing its amplitude and offset. Other waveforms can be combined with the waveform arithmetically. The waveform can also be filtered. After any of these modifications, the resulting output can be imported into the AWG.

The AWG also can produce real-time changes in the waveform being output. All the waveforms required for a test procedure can be loaded immediately and then selected as needed using the AWG's sequence mode. This greatly increases testing speeds as it eliminates the need to switch between multiple generators, or the time it takes to load new waveforms.

The real-time control of waveform segments makes it easy to provide adaptive response to varying test needs. Measured test results can change the sequence order and this can occur without stopping the test procedure. This is the most powerful benefit because it enables adaptive testing where test conditions can be changed based on measured performance.

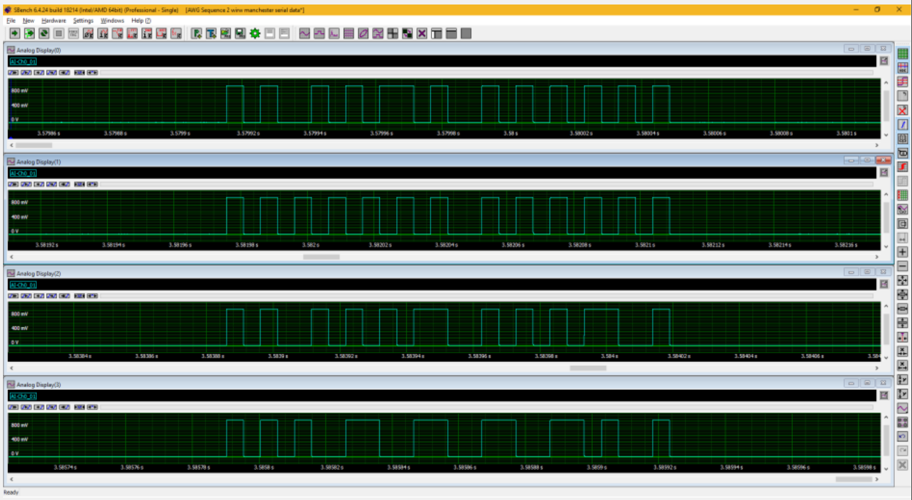

Figure 10: Any of these four different Manchester encoded serial data packets stored in the AWG waveform memory can be selected for output under computer control while the previous packets is being output. The selected packet is output as soon as the current pack

Consider outputting a Manchester encoded serial data stream that might be encountered in an RFID, ethernet, or automotive type application. The message content can be altered on the fly using the AWGs sequence mode as illustrated in Figure 10.

There are four packets with different data content in this example, the number of waveforms is limited only by the available waveform memory in the AWG. As one packet is being output the next packet to be output is selected by computer control. The selected packet is queued and is output seamlessly after the current packet is finished. So, in this example any of the four packets can be output on demand during the test.

Conclusion

Multiple M2p series modular instruments, digitizers, AWGs, or digital I/O cards can be used in a test system where they work interactively to provide mixed mode signal acquisition and sourcing. All three modular instrument classes can be linked together using a Star-Hub module to achieve phase stable synchronization. Being half size PCI Express x4 modules, the M2p cards can be installed directly into a PC system. The PCIe bus allows data transfer, to and from CPUs and GPUs at rates up to 700 MBytes per second. The combination of modular design, fast data transfer and access to advanced processing technology makes it easy to create very powerful multi-channel, multi-functional test and measurement systems. The M2p series products are supported by Spectrum Instrumentation's SBench 6 software or can be programmed using a wide variety of third-party software packages and programming languages.

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