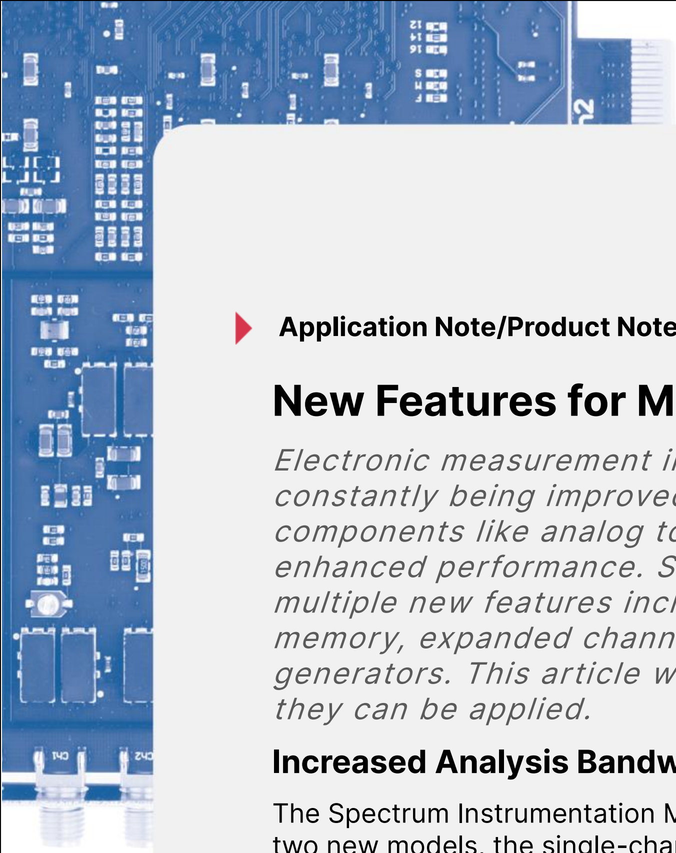

Application Note/Product Note/Case Study

New Features for Modular High-Speed Digitizers

Electronic measurement instruments, like modular digitizers, are constantly being improved and updated. Market needs and improved components like analog to digital converters drive this movement to enhanced performance. Spectrum Instrumentation has just added multiple new features including higher bandwidth, longer acquisition memory, expanded channel count, faster data transfer, and built-in pulse generators. This article will review these new features and show how they can be applied.

Increased Analysis Bandwidth

The Spectrum Instrumentation M5i series of high-speed modular digitizers recently added two new models, the single-channel M5i.3360-x16 and dual-channel M5i.3367-x16, which have improved analog bandwidths of 4.7 GHz. This is supported by a maximum single channel sampling rate of 10 Gigasamples per second (GS/s) with 12-bit amplitude resolution. The combination provides the most accurate acquisition and analysis of signals in the GHz range. M5i series digitizers also have full-scale input voltage ranges from ±200 millivolts to ± 2.5 volts. Standard acquisition memory is 2 Gigasamples (GS), with an option to increase it to 8 GS. The 8 GS memory at the maximum 10 GS/s sampling rate provides an 800 ms record length. These digitizers all carry Spectrum Instrumentation's standard five-year product warranty.

The two new digitizers bring the total number of available M5i.33xx modules to seven. Models offer maximum sample rates of 3.2, 6.4, and 10 GS/s and bandwidths of 1, 2, 3, and 4.7 GHz. This range of bandwidths and sampling rates allows users to select the most cost-effective digitizer that matches their specific needs.

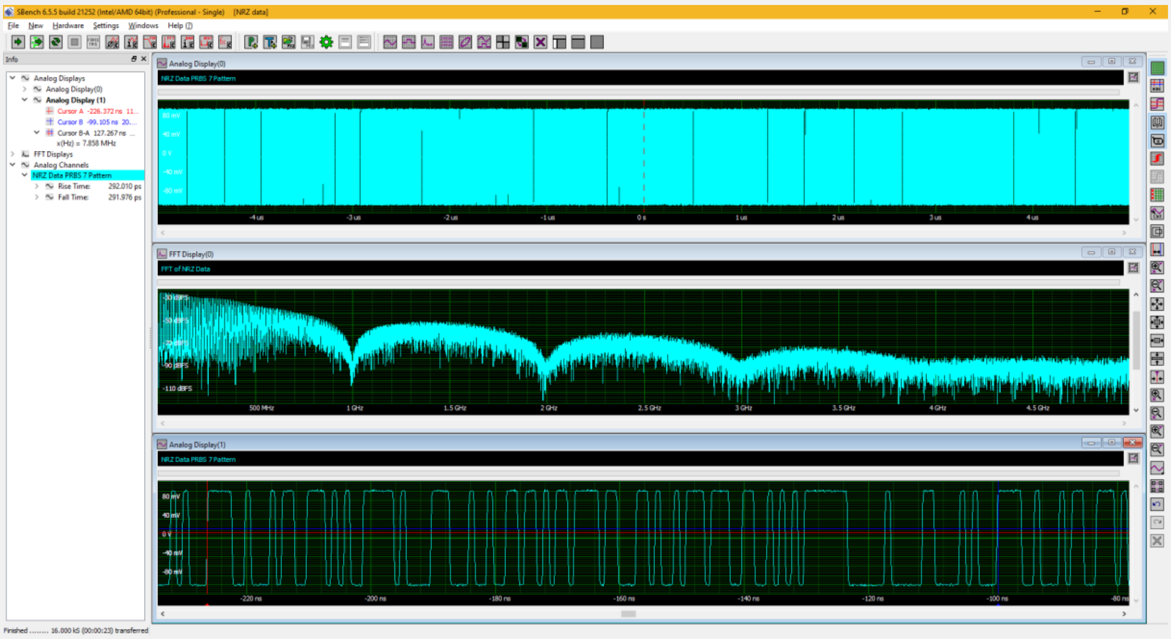

Figure 1: The acquisition of a 10 us duration NRZ serial data stream clocked at 1 GHz. A zoom trace shows the details of the data pattern while the Fast Fourier Transform shows the signal's frequency response.

Bandwidth is a key specification that defines the range of frequencies that the digitizer can acquire without significant attenuation. Bandwidth is the frequency of an input signal where the amplitude falls to the half power point -3 decibels (dB), or a gain of 0.707 of the amplitude, at low frequency.

As an example, wide-band digitizers can be used to acquire and analyze high-speed serial data streams. A general rule of thumb is that the bandwidth required for a given high-speed serial data stream should be three to five times the data stream's clock rate. Figure 1 shows the acquisition of a non-return to zero (NRZ) data stream clocked at 1 GHz using Spectrum Instrumentation's M5i.3360-x16 digitizer and displayed with their SBench6 acquisition and analysis software.

The data consists of a pseudo-random binary stream, commonly used in serial data testing, with a 27 data pattern (PRBS 7). The upper trace in the figure shows the entire 10 us acquisition acquired at 10 GS/s. The bottom trace contains a horizontally expanded zoom view showing a segment of about a 160 ns. The zoom trace shows the details of the PRBS 7 data pattern, which repeats every 128 ns for the 1 GHz clock. Cursors in the expanded trace mark a full data cycle. The SBench6 software measures the signal's rise and fall time at just over 290 ps. SBench6 also calculates the fast Fourier transform (FFT) of the acquired signal, as shown in the middle trace. This is the frequency domain view or spectrum of the data signal covering the span of 5 GHz. This is the Nyquist frequency of the 10 GS/s sampling rate. The FFT exhibits the expected Sin(x)/x frequency spectrum of the digital data stream with nulls at multiples of the clock frequency, 1 GHz in this case. Note that the FFT amplitude falls to the baseline beyond 4 GHz. This shows that the 4.7 GHz bandwidth of the Spectrum instrumentation M5i.3360-x16, or M5i.3367-x16, digitizers are a good match to the signal's frequency content.

Software Support

In addition to a base version of SBench6, the M5i series digitizers are delivered with a software development kit (SDK) and drivers for Windows and Linux operating systems. The SDK includes detailed documentation and working programming examples using most popular programming languages, such as, Visual C++, Delphi, Visual Basic, VB.NET, C#, Python, Java, Julia, and IVI. Spectrum also supports third-party system software products like LabVIEW and MATLAB.

Multichannel Acquisitions

The acquisition of more than one or two channels of high-speed data is enabled by the Spectrum Instrumentation Star-Hub option which allows up to eight modular digitizers to be connected. Minimal phase delay and timing skew are assured by sharing common clock and trigger signals among the connected cards. The Star-Hub option is installed as a piggy-back module on any of the M5i series digitizers, which are then connected by accurately matched and shielded coaxial cables, as shown in Figure 2.

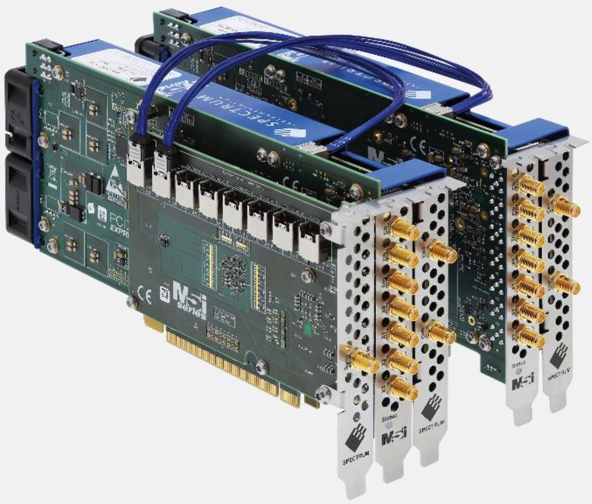

Figure 2: A typical Star-Hub pairing of two M5i series digitizers showing the piggy-backed Star-Hub board and the coaxial cable sets interfacing the trigger and clock signals.

Star-Hub allows data acquisition systems from 2 to 16 channels. By using dual-channel digitizers, a 16-channel system with a maximum sampling rate of 5 GS/s can be created. For faster sampling, single-channel digitizers can be used to configure an 8-channel system with a maximum sampling rate of 10 GS/s. Once Star-Hub is installed the timing for all the cards in the system is driven by the internal clock, which has an accuracy of ±1 ppm. Alternatively, the user can supply their own clock via a front panel SMA connector.

Timing skew between the digitizer cards is addressed using a programable skew adjustment which allows users to compensate for timing mismatches in a specific setup.

One example of applying the M5i series digitizers with a Star-Hub option is in the measurement of DDR memory timing. DDR memory devices use three data and timing signals: clock, data strobe, and the data signal itself. Figure 3 shows the acquisition of these timing signals using three Star-Hub linked M5i.3360-x16 single-channel digitizers, each sampling at 10 GS/s.

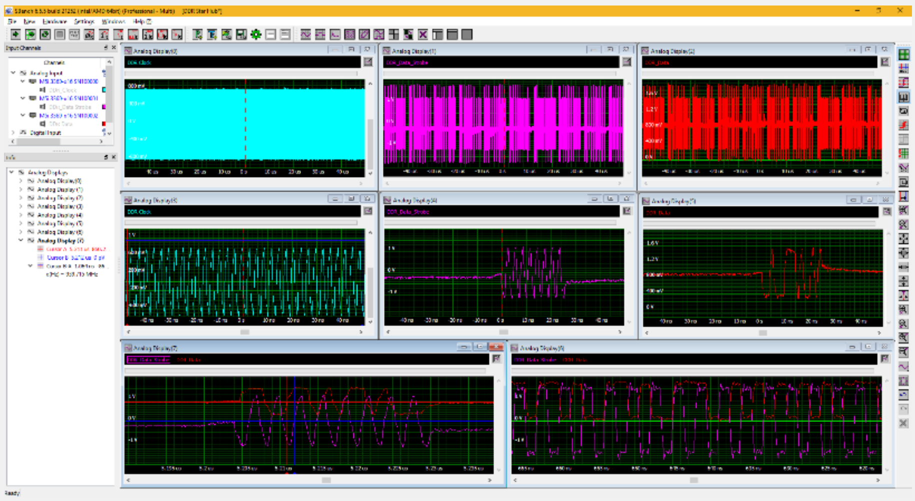

Figure 3: A three-channel acquisition of the DDR clock, data strobe, and data signals Shown in SBench6 along with zoom views of the signals.

The acquisitions have a duration of 100 us, which at 10 GS/s uses one million samples of the on-board acquisition memory. Zoom traces under each signal expand each of the signals horizontally to show the details of the signals over an interval of 100 ns. The phase relationship between the Data (DQ) signal and the Data Strobe (DQS) signal indicates the type of operation being performed in the memory. The DQ and DQS signals are in phase during a read operation. The DQ and DQS signals are out of phase during a write operation. The two bottom grids show the phase relationships between the data strobe (violet trace) and data

(Red trace) signals. The lower left grid (Analog Display 7) shows a write operation while Analog Display 6 shows a read operation. The time skew between the DQ and DQS signals in the write operation is measured using cursors at 1.064 ns.

Transferring Data to the Computer

A powerful feature of the Spectrum Instrumentation M5i digitizer series is their ability to stream data from the digitizer to a computer at extraordinary transfer rates. Streaming enables the digitizers to be used with commercial off-the-shelf (COTS) PC technology, like graphical processing units (GPUs) for limitless signal processing, and solid-state data (SSD) arrays to form streaming systems that can store hours of acquired data.

The M5i digitizers utilize a 16-lane Gen3 PCIe bus that is capable of transferring data at rates up to 12.8 GB/s. This exceptional speed allows single-channel data acquired at a sampling rate of 6.4 GS/s, or dual-channel data acquired at 3.2 GS/s, to be streamed, in a FIFO process, directly to the PC with no data loss. Even faster sampling rates can be streamed, without data loss, by using a new 8-bit transfer mode. The mode supports data streaming at acquisition rates of up to 10 GS/s from a single channel, or up to 5 GS/s on two channels.

To stream data directly to off-the-shelf graphical processing units (GPUs), the M5i digitizers use Spectrum CUDA Access for Parallel Processing (SCAPP) software. SCAPP allows the transfer of acquired data, via remote direct memory access (RDMA) to GPU's using Nvidia's Compute Unified Device Architecture (CUDA) standard. Once there, users can exploit the GPU's extremely high processing power. The SCAPP software includes all the routines necessary for controlling the interactions between the digitizers and the GPU. It also includes example routines for complex processing functions like digital down conversion, filtering, averaging, FFT, data demultiplexing, and data conversion. The SCAPP software is also based on C/C++ and Python for easy implementation and customization using normal coding skills.

An example of a SCAPP application is the creation of a digital down converter (DDC). In this case a 702 MHz input signal was acquired using an M5i.3337-x16 digitizer card sampling at a rate of 6.4 GS/s. The acquired data was continuously streamed directly to an Nvidia RTX A4000 GPU at the maximum transfer speed of 12.8 GB/s. The SCAPP software uses a series of processing blocks to implement the DDC function. These include a direct digital synthesizer (DDS), lowpass filtering, and down sampling. All the processing blocks are performed in the GPU. The down-conversion process mixes the data with a complex sinusoid that is generated by the DDS, then applies a moving average,

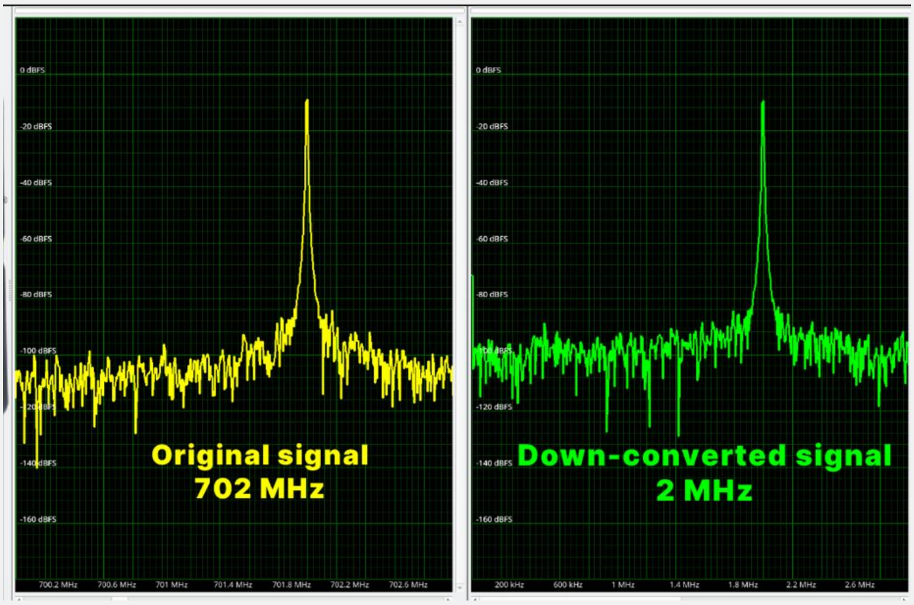

Figure 4: The original signal spectrum and the spectrum of the down-converted version after processing in a SCAPP-implemented digital down converter.

decimates the result (in this case by a factor of 512), passes the decimated data through a Finite Impulse Response (FIR) filter, rescales it and then transfers the processed data to the PC memory for storage or additional processing. Figure 4 shows two frequency domain screenshots of the original signal's spectrum and the spectrum of the processed down-converted signal.

In addition to down-converting the signal from 702MHz to 2 MHz, the filtering has improved the signal-to-noise ratio by averaging and filtering, and the decimation process has shortened the record length for more convenient storage and processing on a PC.

For applications where signals need to be acquired over extended time periods Spectrum Instrumentation also offers streaming systems based on a Supermicro server, with an AMD EPYC processor, and RAID storage using U.2 SSDs with up to 240 terabytes of storage. This system can stream over six hours of continuous gap-free data at the 10 GS/s sampling rate for post-acquisition analysis. Longer time periods can be achieved by running at lower sampling rates or, if the data storage does not need to be gap-free, using the digitizers multiple recoding mode. Multiple recording allows the acquisition and transfer of numerous trigger events, even if they have an extremely short re-arming time.

Built-in Pulse Generator

Automated test and measurement processes often require a signal source. Spectrum Instrumentation offers arbitrary waveform generators (AWGs) and digital input-output instrument models for the more sophisticated test requirements. In addition, they have just introduced a digital pulse generator (DPG) option for their digitizers and AWGs, including the M5i series high-speed digitizers. The DPG option adds the ability to generate four digital pulses or pulse streams and output them through the modular instrument's multi-purpose input/output connectors on the front panel. These pulses are synchronous with the digitizer clock. The DPG can output single pulses, pulse bursts, or continuous pulse streams. The pulse timing can be free running, gated, or triggered using all the instrument's internal and external trigger sources. The basic pulse setup parameters including frequency, duty cycle, and delay are easily programmable as are the trigger modes and trigger source. The pulse amplitude is a fixed 3.3-volt low voltage TTL output level compatible with high impedance loads.

The DPG option allows instruments like the M5i series of digitizers to output pulse signals for automated test equipment triggering and synchronization, control lines for experiments, and gating signals for keying RF sources. Gated RF sources are used in a wide range of RF devices, from radar to keyless entry systems. Consider the need for a pulse source to gate an RF carrier for a radar under test. The DPG is an ideal source and, being integral to the digitizer, it does not require an additional instrument. Figure 5 shows an example of

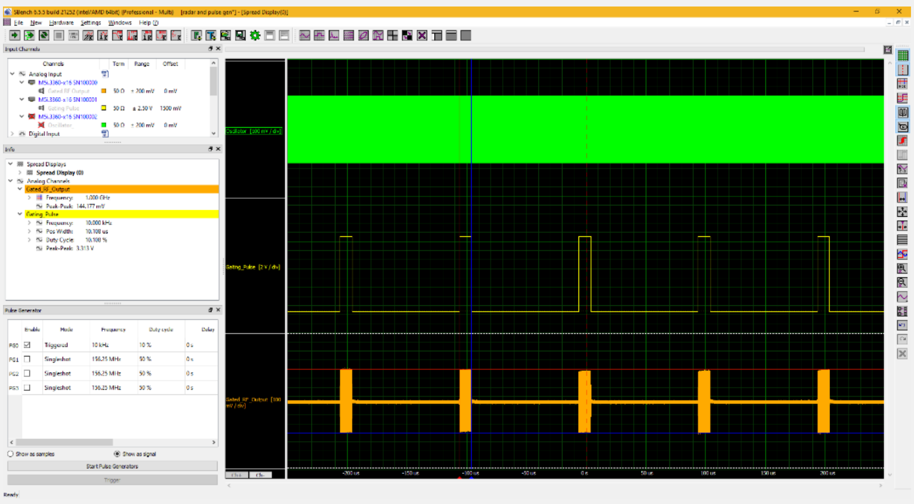

Figure 5: Using the DPG option as a gating source to generate a pulsed radar signal from a 1 GHz oscillator output using an external RF switch.

using the DPG as a gating signal source for a 1 GHz continuous wave source for a radar test.

The DPG pulse is used as a gate signal (center trace) to on and off key a 1 GHz RF carrier (top trace) with an external RF switch circuit to generate a pulsed radar signal (bottom trace). This produces a pulse repetition frequency of 10 kHz and a 10% duty cycle. The pulse generator setup in SBench6 for this gating signal is shown in the Pulse Generator window in the bottom left of the display. Settings for frequency, duty cycle, delay, trigger mode, and loop count define the generated pulse. Measurements of both the DPG output and the gated RF pulse are displayed in the Info window (above the Pulse Generator window). The pulse peak-to-peak amplitude, frequency, width, and duty cycle are shown along with the amplitude of the gated pulse output and the frequency of the RF carrier. The signals are displayed in a common grid of the spread display type for visual comparison.

The DPG option is a useful tool that increases the value of the digitizer and in many cases reduces system costs by eliminating the need for a separate signal generator.

Conclusion

Spectrum Instrumentation now offers new digitizers with wider bandwidth, faster data streaming with real-time processing, multi-channel capability, and even quad built-in pulse generators. All these improvements are intended to make automated testing easier, more accurate, and faster than ever before.