Application Note/Product Note/Case Study

Pulse Burst RF Measurements for NMR, MRI and radar using modular digitizers

Many RF systems operate using burst modes where radio frequency (RF) signals are transmitted for a short period. Examples of this kind of operation include echo-ranging applications like radar, magnetic resonance imaging (MRI) and relaxation radiation detection in nuclear magnetic resonance (NMR). These applications transmit a burst of relatively high-power RF and then wait for a return echo or a relaxation radiation signal. Measurement of this type of signal requires instruments with wide bandwidth, high sampling rate, long acquisition memory, fast processing, and high-speed data streaming.

High Bandwidth Digitizers for RF Measurements

Spectrum Instrumentation has extended the M5i flagship series of high-speed PCIe digitizers, adding two new models with ultrawide bandwidths up to 4.7 GHz. M5i.3360-x16 and M5i.3367-x16 provide, respectively, one and two wide bandwidth channels (Figure 1).

Figure 1: New M5i.3360-x16 (1 channel) and M5i.3367-x16 (2 channel) leading bandwidth digitizers by Spectrum Instrumentation combine 10 GS/s sampling, 12-bit resolution, 4.7 GHz bandwidth, and 12.8 GB/s data streaming.

Each card can sample at rates of up to 10 GS/s, with 12-bit vertical resolution, specifically designed to deliver the most accurate acquisition and analysis of signals in the GHz range. The high bandwidth, supported by the fast sampling, makes them ideal for working with extremely high-frequency signals. The 10 GS/s sample rate results in a Nyquist frequency of 5 GHz, which is consistent with the 4.7 GHz bandwidth of the digitizer. Each card can acquire up to 8 Giga samples (GS) in internal acquisition memory. This onboard memory can be used as a ring buffer, like an oscilloscope, or as a FIFO buffer for continuous data streaming. The M5i series digitizers employ 16-lane, Gen 3 PCIe technology, which allows the acquired data to be streamed from the digitizer to a computer at an amazing 12.8 GB/s. The data can also be sent to a host computer memory for storage or directly to CPUs or compute unified device architecture (CUDA)--based graphical processing units (GPUs) for fast customized signal processing and analysis.

For applications requiring more than one or two channels up to eight M5i.33xx-x16 digitizers can be combined into a multichannel system using Spectrum's Star-Hub option (Figure 2).

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Star-Hub synchronizes data acquisition of the Individual cards by sharing common clock and trigger signals. A user programmable skew adjustment ensures minimal phase delay. The Star-Hub option is installed by mounting a single piggyback module onto any M5i series cards in the multi-channel system. Using accurately matched and shielded coax cabling, the board distributes the clock to each module and precisely synchronizes the trigger event with the system clock.

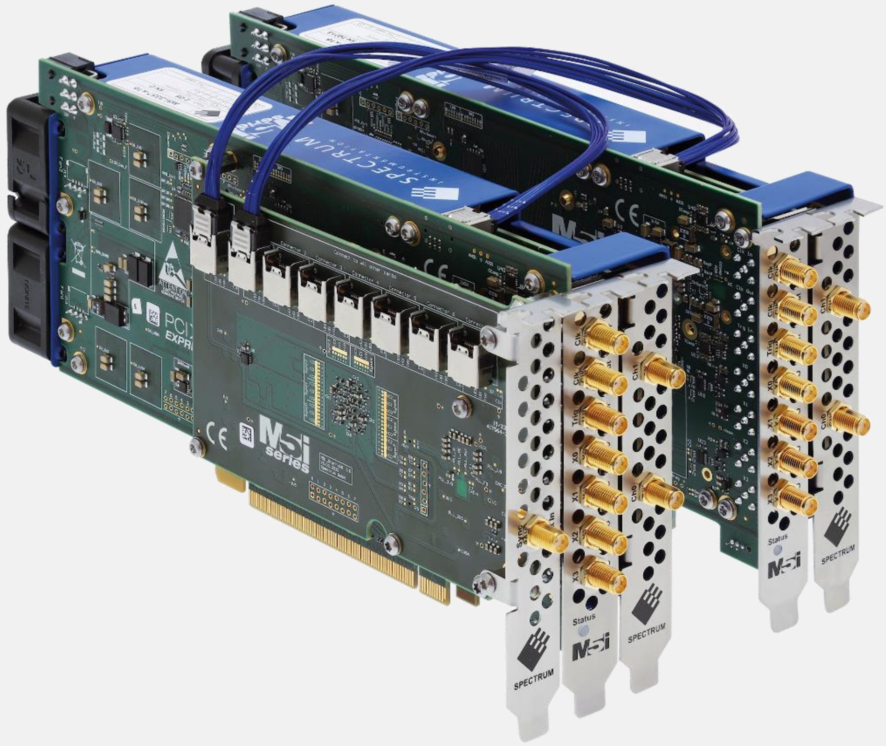

Figure 2: The Star-Hub option allows up to eight digitizers to be synchronized by sharing a common sampling clock and trigger source.

Burst Mode Measurements

NMR is a common application where burst mode RF signals are encountered. NMR spectroscopy is an analytical technique used to reveal the chemical composition and molecular structure of a sample. It studies the interaction of RF radiation at selected frequencies with the nuclei of molecules placed in a strong magnetic field. The external magnetic field causes certain nuclei in a molecule to absorb select radio frequencies. The absorbed energy is re-emitted at the substance’s resonant frequency, which reveals the identity and intramolecular relationships within the sample. A conceptual block diagram of an NMR spectrometer is shown in Figure 3.

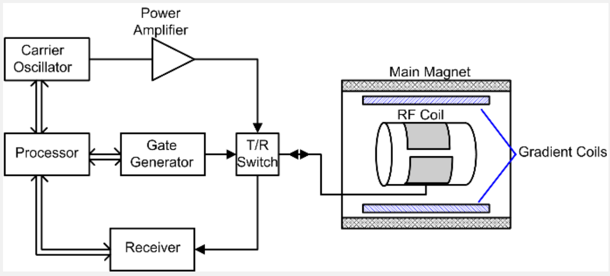

Figure 3: A conceptual block diagram of an NMR spectrometer where an RF pulse stimulates a sample inside the RF coil to emit an RF signal related to the element and molecular structure of the sample.

The transmit/receive (T/R) switch controls the function of the RF coil. In the transmit state, a gated RF burst from the power amplifier excites the sample. In the receive state the RF coil picks up the sample’s RF response and feeds it to the receiver. High bandwidth digitizers can be used to study the T/R switch operation, monitoring the RF signal from the power amplifier, the gate signal, which determines the state of the T/R switch, and the output of the T/R switch. Figure 4 shows a simulated measurement of the T/R switch operation using three M5i.3360-x16 4.7 GHz bandwidth single-channel digitizers, each with a 10 GS/s sampling rate. The units are linked using Star-Hub and Spectrum Instrumentation’s SBench6 acquisition and analysis software is used for control and display.

Figure 4: Analysis of a T/R switch RF input (upper left grid), gate signal (upper center grid), and the T/R switch output (upper right).

The input to the T/R switch is a 350 MHz continuous sine wave, shown in the upper left grid. The Fast Fourier Transform (FFT) of the input signal, in the lower left grid, shows a single spectral line at 350 MHz. The FFT, filtering, and basic measurements are included in the SBench6 software. The RF excitation frequencies commonly used in NMR range from 10s of MHz to 1 GHz. This is well within the bandwidth of the Spectrum digitizers. Other related applications like radar use higher frequencies. For example, the M5i.33xx-x16 digitizers can be used up to their -3dB bandwidth of 4.7 GHz, which would accept S-band radar signals in the 3 to 4 GHz range.

The gate signal, shown in the upper center grid, is a pulse waveform that controls the state of the T/R switch. SBench 6 includes measurement capabilities, shown in the Info panel to the left of the traces, that show the gate pulse train has a frequency of 2.5 kHz (400 us period) and a pulse width of 81.9 us (duty cycle of 20.5%). The digitizer has acquired a 2 ms record length at 10 GS/s. This record includes 20 MS of data for each channel. The digitizer has a standard acquisition memory of 2 GS and an optional memory of 8 GS. The 8 GS memory can record 800 ms at the 10 GS/s sampling rate. Long acquisition records allow multiple cycles to be studied to follow changes in response over time. Even with these long records, there is no loss in time resolution. A horizontally expanded zoom trace compares the details of the gate signal pulse edge with the gated carrier showing the time response of the T/R switch. Additionally, the rise time of the gate signal is measured as 2.5 ns.

The T/R switch output in the upper right grid shows the gated waveform as an RF burst. This pulse modulation changes the RF spectrum as seen in the lower right grid, adding a sin x/x modulation envelope due to the pulse modulation, and decreasing the peak spectral amplitude by about 14 dB, as read by the absolute maximum measurements in the Info panel.

In addition to SBench6, the M5i.33xx-x16 series digitizers include a software development kit (SDK) and drivers for Windows and Linux operating systems offering the tools for custom software. The SDK includes detailed documentation and working program examples using the 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.

Another digitizer option that may be of value in this type of application is the digital pulse generator (DPG). The DPG option enables the digitizer to output up to four rectangular pulses with user-set periods, phases, and widths. The timing resolution of the pulses is based on the sampling clock. For instance, a DPG option installed in an M5i.33xx-x16 digitizer can output up to four pulse streams with a timing resolution of just 3.2 ns. The pulse generator operates in conjunction with the digitizer so that both operate simultaneously.

One concern in handling long acquisition records is streaming this data to a host computer for further analysis and archiving. The M5i digitizers utilize a 16-lane Gen3 PCIe bus 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 to be streamed, in a FIFO process, directly to the computer with no data loss. Even faster sampling rates can be streamed without data loss 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.

This example looked at a single T/R switch operation. Some NMRs use multiple RF coils arranged in phase arrays, and measurements on these systems may require more channels. This, again, can be addressed using the Star-Hub option.

Conclusion

The Spectrum Instrumentation M5i.33xx-x16 digitizer family is well-matched to pulsed RF applications found in NMR, MRI and radar. They offer GHz bandwidths supported by up to 10 GS/s sampling rates with long acquisition record lengths. Optional capabilities include synchronizing multiple channels and even generating programmable pulse outputs.