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# Vehicular Testing with Modular Instruments

## Introduction

Typical vehicles running on the roads today have dozens of electronics systems and subsystems comprised of microprocessors, transducers, actuators, and switches. These systems include essential engine controls, environmental controls, driver assistance systems, instrument clusters, and entertainment systems, among many others. The complexity of these interrelated systems requires very flexible test instruments that can be quickly reconfigured to handle multiple channels, varying bandwidth, increased resolution, and longer data records. Modular digitizers and modular signal sources are ideal instruments for the job.

Modular instruments reduce the size of traditional instruments so that they fit on a circuit card. Multiple cards can be inserted into a frame with a common computer interface, power, and interconnections. Modular instrument frames include computers, using the standard PCIe interface, PXI test frames, or LXI based boxes. Generally, multiple cards are used and configured by the engineer into a test system. The system may contain multiple instruments, single instrument types with multiple channels, or a combination of both.

Figure 1 shows a portable computer equipped with two PCIe modular digitizers. This compact, self-contained, setup can be used within a vehicle, allowing measurements while the vehicle is in motion. PXI based modular systems are not as autonomous but offer a greater number of modular instruments within a single crate. They require external monitors and keyboards. LXI based systems like Spectrum's digitizerNETBOX are well suited for laboratory installations and mobile usage, offering a large number of channels and connectivity via LAN for direct connection with the Laptop or remote control room monitoring and control.



Figure 1: A portable computer serves as the chassis for dual PCIe based digitizers creating a mobile test system.

## Vehicular Electronics

The basis for vehicular electronic subsystems is the microprocessor. Consider the generic automotive microprocessor shown in Figure 2.

These microprocessors differ from standard microprocessors in having higher environmental and reliability standards as well as the addition of specialized vehicular buses and interfaces such as CAN, LIN, and PSI5. These interfaces allow the microprocessor to communicate with other processors, transducers, and actuators.

The Controller Area Network or CANbus is the most

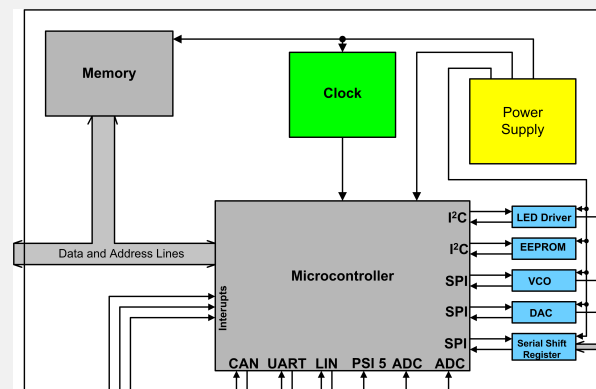


Figure 2: Generic vehicular microprocessor showing the microcontroller, memory and peripheral interfaces. Transducers and other controllers communicate using the various vehicular specific interfaces shown at the bottom of the microcontroller.

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sophisticated of the data buses shown here and is the backbone of many automotive data links. In its basic form it exchanges data at from 20 kb/s to 1 Mb/s over a two-wire bus using differential signaling with 8 byte data packets. A more recent version, CAN Flexible data rate (CAN FD) extends the data content to 64 byte packets exchanged at up to 12 Mb/s.

The Local Interconnect Network or LIN bus is a lower cost bus used to help reduce cost for non-critical applications. It operates over a single wire at up to 20 kb/s using two, four or eight byte data frames.

The PSI 5 interface is used to connect multiple sensors to electronic control units and has been used as the primary sensor communications bus for airbags and related restraint systems. It is a two wire bus operating at up to 189 kb/s using Manchester encoding.

## Applying Modular Digitizers

The most commonly used modular instruments are digitizers. A digitizer is an electronic acquisition device that acquires analog waveforms, samples and digitizes them through analog-to-digital converters (ADC's) and sends the digitized samples to a buffer, which allows them to be saved before being processed by a computer. Modular instrument suppliers, like Spectrum, offer digitizers with ADC resolutions of 8 to 16 bits with analog bandwidths to 1.5 GHz, and sample rates to 5 Giga sample per second (GS/s) with one through to 16 channels per card. Provision is made for synchronizing multiple cards allowing up to 16 cards per system (or up to 256 fully synchronized channels). These instrument systems are infinitely reconfigurable to acquire, store and measure signals in vehicular embedded systems.

Digitizers can be selected to match the data rates and bandwidth requirements of each of these interfaces as well and the more common processor and related operations.

Consider the task of monitoring the CANbus interface. The digitizer employed for this measurement has remotely configurable inputs allowing either single-ended or differential inputs for each channel. In this case the differential inputs were used. The results are shown in Figure 3. This acquisition is displayed using Spectrum's SBench 6 software which permits analysis of the physical layer of the interface. The amplitude and timing of the signal can be verified to assure compliance with the CANbus standards.

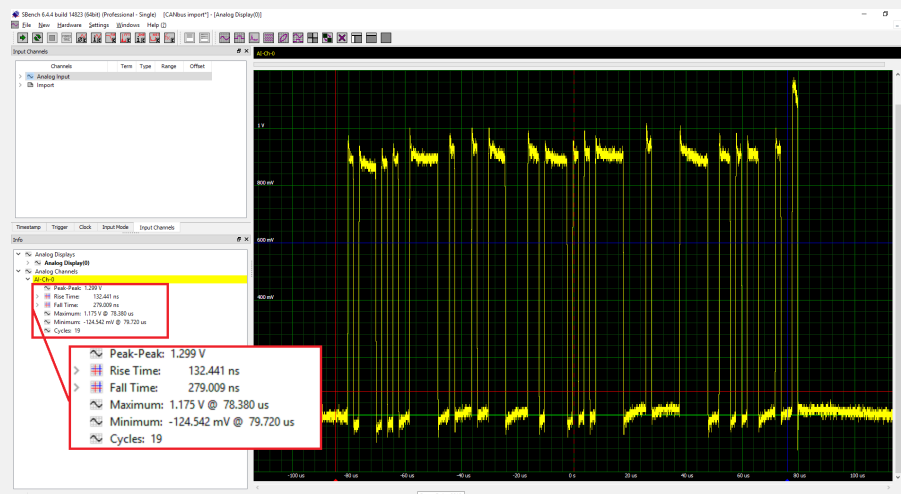


Figure 3: A CANbus packet from a steering angle sensor is acquired and measurements of the physical layer attributes of the signal are made using a Spectrum M2p.5946-X4 4 channel, 80 MS/s, 16 bit digitizer and SBench 6 software.

Basic measurements of signal amplitude including peak-to-peak, maximum, and minimum characterize the packets. Additional timing measurements of the rise and fall times are made to assure bus signal integrity.

Going beyond the physical layer the Spectrum digitizer can interface with third party

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programs like LabVIEW and MATLAB where the waveform data can be decoded and the protocol layer can be explored. Experienced programmers can use the Windows and Linux drivers to create custom programs in C, C++, Python or similar languages to develop custom decode operations.

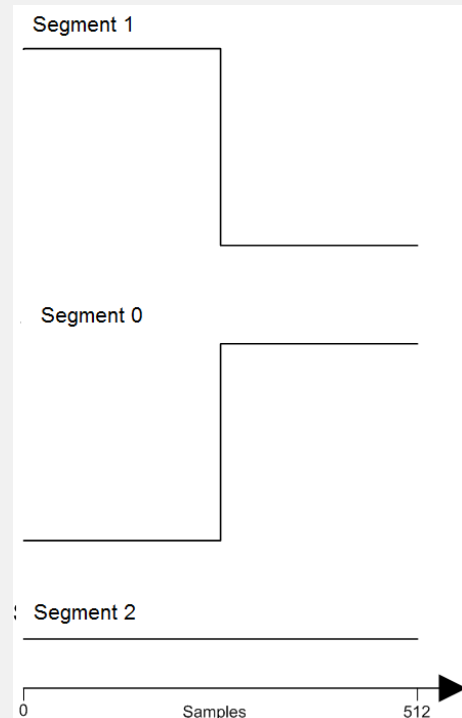
## Using signal sources for simulation

In many engineering projects testing can be held up because you are missing a critical component or it is too expensive to conduct a physical test. An arbitrary function generator (AWG) can be used to create almost any waveform and simulate the missing component. Arbitrary waveform generators are digital signal sources that operate very much like a digitizer in reverse. Where a digitizer samples an analog waveform, digitizes it and then stores it in its acquisition memory, the AWG has a numeric description of the waveform stored in waveform memory. Selected samples of the waveform are sent to a digital to analog converter (DAC) and then, with appropriate filtering and signal conditioning, are output as an analog waveform.

For simulation, if you have access to the response waveform of the missing part acquired by a digitizer, or it can be created analytically, you can use the AWG as a replacement. One of the common problems is to be able to output a series of waveforms each representing a different state of the system being tested. While this might be done with multiple generators and some sort of switching there is a more efficient method.

AWG's with a fully featured sequence mode, such as the Spectrum M4i.66xx-x8 series, offer the ability to switch between waveforms in real time eliminating even the time to reload different waveforms. The AWG's waveform memory is segmented and every waveform needed for a test can be stored, each in its own segment. The AWG steps through the waveforms, under computer control, based on the instructions stored in a separate sequence memory. The contents of the sequence memory can be updated or changed without affecting the output state of the AWG. This sequence mode operation allows adaptive changes in the test sequence based on a test result. This capability greatly reduces test times and improves the thoroughness of the test.

As an example an AWG can be used to replace a PS15 transducer producing a programmable series of output codes. PS15 use Manchester encoding. Manchester code always places a transition at the middle of each bit period. It may (depending on the information to be transmitted) have a transition at the start of the period as well. The direction of the mid-bit transition indicates the data. Transitions at the period boundaries do not carry information. They exist only to place the signal in the correct state to allow the mid-bit transition. The guaranteed transitions permit the signal to be self-clocking. To generate a PS15 packet there are three waveform segments required as shown in Figure 4. A logical "1" (segment 1) is indicated by a high to low transition. A logical "0" (Segment 0) is indicated by a low to high transition. Finally, a baseline level (Segment 2) of 0 volt DC level.



**Figure 4: The three waveform segments are required to create a Manchester encoded data packet.**



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By defining three waveform segments using these components any combination of data patterns can be synthesized. This means that by rearranging the order of these three segments the content of the packet can be changed. Figure 5 shows four examples of PS15 packets each composed of the three segments but each having a different data content.

In this example the segments are set to a length of 512 samples with a clock rate of 50 MS/s so that the duration of each component (TBIT) will be 10.24  $\mu$ s. Packets are separated by a baseline signal lasting more than two bit clock periods. The AWG was controlled using a MATLAB script which assembled four different data patterns for the purposes of this test from the three bus segments. Switching between the packets occurs seamlessly with no discontinuities.

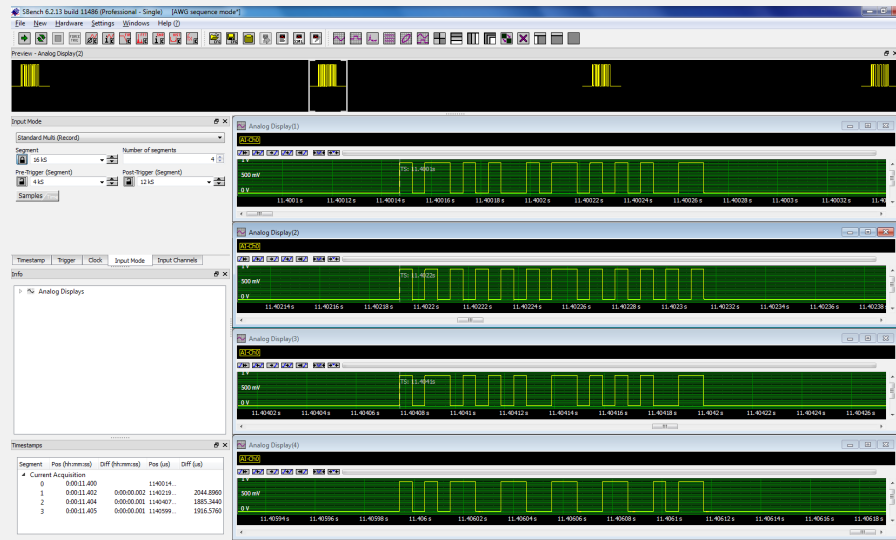


Figure 5: The four different data patterns resulting from reordering the sequence memory contents. Keep in mind that this can be done dynamically while the AWG is running.

## Power sequencing

Another area of concern is for the proper sequencing of power rails when powering up or down. Embedded computing systems generally require multiple supply voltages to deliver power to the microprocessor, memory, and other on-board devices. Most microcontrollers have a prescribed order in which the voltages must be applied to prevent problems like lockups. Power management IC's (PMIC) or power sequencers perform many of the sequencing tasks. Since most processors use multiple voltages a digitizer with up to 8 inputs is an ideal instrument for this type of measurement. Additionally, since power up/down sequences take on the order of milliseconds, large acquisition memories are also needed.

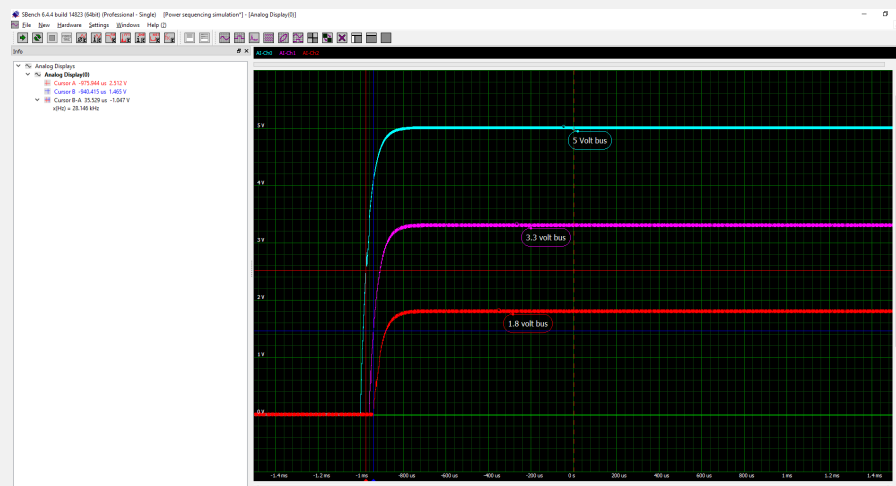


Figure 6: Monitoring 5, 3.3, and 1.8 volt power rails to determine the correct power-on sequence

Figure 6 is a simple example of a power sequence measurement. Three power rails are monitored (5, 3.3 and 1.8 Volts). What is expected is that the voltage levels should rise monotonically and in the desired order. In this example the 5 Volt supply turns on before the

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others, followed by the 3.3 Volt and 1.8 Volt lines.

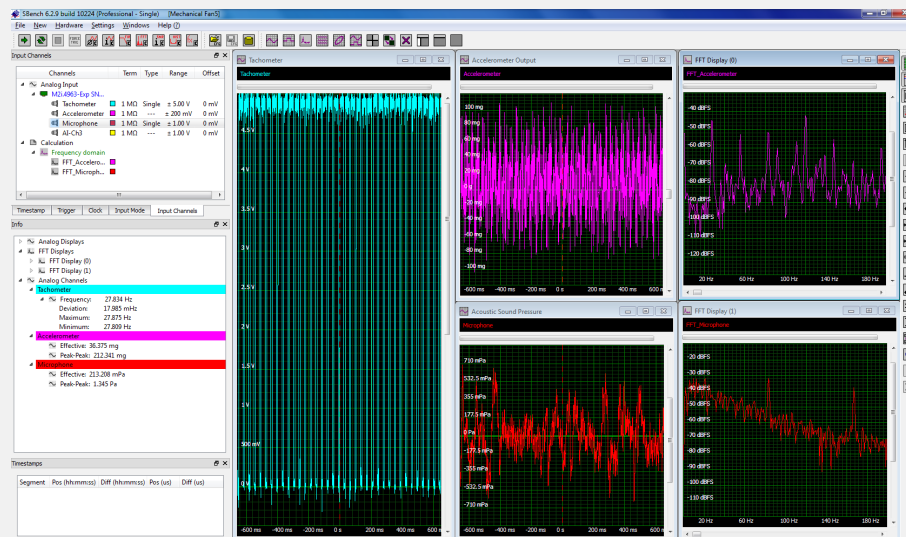
Time delay can be measured with cursors as shown in the figure where the time delay between the 5 volt and 3.3 volt bus is measured as 35.5  $\mu$ s.

Power measurements of this type can extend to measuring ripple, regulation and response to transients.

## Mechanical measurements

Modular instruments can also make mechanical measurements using suitable transducers. Figure 7 shows a series of mechanical measurements performed on a fan.

This SBench 6 screen image shows the tachometer output in the left-most grid. This waveform consists of one pulse per revolution of the fan. The fan speed is read by measuring the frequency of this signal. The Frequency readout in the Info pane on the left center of the figure reads this frequency as 27.8 Hz (revolutions per second). Multiplying this frequency readout by 60 gives the rotational speed of the fan as 1668 revolutions per minute (RPM). Statistical readouts showing the minimum, maximum, and deviation of the frequency appear below the frequency readout.



**Figure 7: The measurement of the vibration and acoustic properties of a fan instrumented with a tachometer, accelerometer and microphone.**

The accelerometer output appears in the upper center grid labeled 'Accelerometer Output'. A custom vertical scale has been setup using the analog channel settings to read directly in g's. Measurements of the signals peak to peak and effective (rms) amplitudes appear in the Info pane. This time domain view of the signal is somewhat difficult to interpret so the Fast Fourier Transform (FFT) of this signal is computed and shown in the upper right hand display grid.

The FFT shows the frequency components that make up the acceleration signal. The frequency domain or spectrum view of the FFT provides easier physical interpretation because it separates the various frequency components. The left most peak occurs at 27.8 Hz, the rotational frequency of the fan motor. Other spectral components correspond to physical attributes of the fan.

The microphone output is shown in the center bottom grid scaled to read Acoustic Sound Pressure. This data has been rescaled also so as to read in units of pressure, namely Pascals. Measurements in the Info pane show the peak to peak and effective amplitudes of this signal. As in the case with the vibration signal the FFT of the acoustic provides a good deal of physical insight.



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### Conclusion

Modular instruments are well matched to vehicular test and measurement applications. They offer a large number of channels with resolutions from 8 to 16 bits. Digitizing rates up to 5 GS/s permit selection of fast or slow sampling matched to the application. Arbitrary waveform generators enable simulation scenarios. They allow testing even with missing components. The choice of PCIe, PXI, or LXI configurations matches the needs for portable or laboratory testing.

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