The right dynamic

Could an Abacus be the ultimate in auto dynamic signal analysis?

by Dr Sri Welaratna

FFT-based signal analyzers for automotive use are a challenge for designers of data acquisition and analysis instruments. The frequency bandwidth for most applications is low – usually less than 2kHz – but it can be necessary to cover the complete audio range up to 20kHz.

Designers have long aimed to meet all requirements in a single platform and while the original FFT analyzers built on visible minicomputers achieved this, they weren't portable, often occupying one or two 5ft (1.5m), 19in (48cm) racks.

The newly evolving PXI bus is a repackaging of VXI bus concepts into a smaller footprint, with the higher-speed backbone provided by compact PCI. Until now, PXI data acquisition modules have not solved the computational bottleneck caused by bringing all data to a central processor attached to the bus. While there is a continuing debate – VXI versus PXI – most users of signal analysis instrumentation would agree that neither provides a total solution for automotive applications. Everyone does agree that there is a trend towards simpler standard interfaces such as USB and Ethernet for interconnections.

A new signal analysis system from Data Physics uses Ethernet to interface multiple chassis and the host computer. This system, sold under the tradename Abacus, is an architectural advance that overcomes the limitations of VXI and PXI for scalability of real-time measurements. Ethernet as an interfacing system offers several significant advantages: 1Gbyte/s communication speed; up to 100m distance between the host computer and the measurement chassis; and simplicity and connectivity with multiple users via local area networks.

A single Abacus chassis is a portable instrument that connects to the host computer via Ethernet. The chassis may contain from one to four modules, each consisting of eight input channels, two output channels and two tachometer channels. Each module contains a megaflop digital signal processor to provide the computational power. The input and output channels use 24-bit ADCs and DACs. The chassis uses a Pentium processor to supervise traffic and supports streaming data to a 100Gbyte local disk at an aggregate rate of 20Mbyte/s.

When more than 32 input channels are required, multiple Abacus chassis are connected in a star configuration to the host. Ethernet provides a convenient solution to the connectivity problem. A network switch acts as the hub for the network. Each chassis is connected to the network switch at 100Mbit/s and the switch connects to the host computer at 1Gbit/s. To enable all channels in the multiple chassis to be simultaneously sampled, a clock signal is distributed via a synchronizing cable. By using the same technology as Ethernet, the synch cable is able to distribute the sampling clock

Abacus featuring embedded PC, local disk, up to 32 inputs, eight outputs and eight tacho channels

at speeds of up to 50MHz chassis-to-chassis. The synch cables come in calibrated lengths of 2.6m to 31m and a compensation circuit in each Abacus chassis applies the precise delay to align the samples within the specification for channel-to-channel match.

When one considers that a 1,024 measurement channel Abacus system provides a match between channels of better than 0.5º even at the maximum useful frequency of 49kHz, one begins to see the benefits of the distributed architecture. Electrons travel in cables at 5ns/m, so transducers distributed over a large structure such as the Airbus A380 would have a variability between channels of up to 4µs due to the differing transducer cable lengths. This is equivalent to as much as 6º phase error at 49kHz. Compare that with the Abacus solution, which distributes the digitizers (with up to 30m between adjacent chassis) allowing transducer cables to be of the same nominal length.

Abacus is a significant architectural advance. Scalability is at the heart of its design. Each module contains its own signal processor. The DSP-centric design is essential to the high real-time analysis bandwidth of the system. Each chassis contains its own disk storage. The local bus disk is essential to the high real-time recording rate of the system. The system uses the 132MHz PCI bus within each chassis for optimum performance and availability of off-the-shelf components. Ethernet provides system connectivity within the system and to the wide area networks. Whether one uses a mere eight channels of data acquisition in a single chassis or 1,000 channels distributed over 32 chassis, the system retains the same high specifications.

The solution to the problem of a simultaneously sampled really large system has not been obtained by relaxing requirements of accuracy. When one looks closely at the specifications for dynamic range, signal:noise ratio, total harmonic distortion, alias rejection and channel-to-channel match, one can see that Abacus has an analog front end that does justice to the 24-bit digitizers. It is the first time that a dynamic signal analyzer has been able to deliver a 150dB dynamic range in a spectrum – the entire potential of the 24-bit ADC. At its full bandwidth, the input dynamic range is 120dB, a testament to the analog design and the 24-bit delta sigma technology. At smaller bandwidths, the dynamic range increases, reaching 150dB at bandwidths below 1,000Hz, often the analysis range for automotive vibration studies. The answer lies in signal processing; onboard DSP is used for decimation filtering with selective noise rejection. Even after decimation filtering, the 1Gbit DSP has plenty of spare capacity with which to maintain real-time measurements. Whether operating at its maximum bandwidth of 49kHz or a low 1kHz, one can measure the tri-spectrum average in real-time and with selectable overlap.

Vibration studies for automotive design include: modal analysis of structures for dynamic behavior; order analysis of engines, gearboxes and turbochargers for rotational effects; and acoustics analysis for noise and sound quality. Abacus provides measurements for all three fields of study: frequency response functions for modal analysis; order tracking for rotational vibration analysis; third octave, acoustic intensity; and sound quality measurements for noise analysis.

Environmental vibration effects on an automobile and its components are studied by reproducing such vibrations in the laboratory using one or more shakers and a vibration controller. Abacus is both a single-shaker vibration controller and a system for controlling multiple shakers, whether arranged to share the load in a single axis or used to drive multiple shakers in six degrees of freedom for authentic real-world simulation. A variety of techniques exists to model the environment as random, sinusoidal, shock, or combinations of these. Sophisticated measurement methods are used to analyze the behavior of vehicles while being vibrated in their true environment. Yet another technique uses recordings of road vibration to simulate the exact time history of travel on a particular road in the laboratory. By eliminating benign sections and selectively synthesizing sections of road, one can accelerate the testing of a vehicle or its components for durability studies. In such applications, the vibration control system is a feedback controller that needs high real-time computational ability. With its DSP-centric design, the Abacus is perfectly suited to the task.

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Architectural advances in technology are not everyday occurrences. Abacus, therefore, is a serious contender to qualify as a rare but significant advance in signal analysis. Emerging out of the existing technologies of PCI bus and Ethernet, Abacus delivers a powerful solution that makes use of off-the-shelf components for a low-cost solution to a sticky problem. Abacus also benefits from the combined research and development inherent in a technology as ubiquitous as Ethernet.

Portable system for field or in-vehicle measurement

Networked Abacus chassis for high channel counts

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