STEVE GROSSMAN CONTRIBUTING EDITOR

Instruments Play New Roles On The Benchtop And The Desktop, Too

As boundaries blur between the real and virtual worlds, instruments enlarge their command in product design.

LIKE A FINE BOUILLABAISSE, INSTRUMENTS ARE BEING BLENDED WITH SOFTWARE, AND WHAT'S EMERGING FROM THE CALDRON IS BOTH EVOLUTIONARY AND revolutionary. The evolution is, as we would expect, driven by the continuing upward spiral of frequency and data rate. But the revolutionary capability stems from a most novel innovation in which signals and their software emulation become virtually interchangeable. This leads to an unusually powerful feature for those engaged in electronic design automation (EDA).

What's so astonishing about this event is how ingredients, both real and virtual (signals and software emulation), have been combined quite seamlessly to assist all who develop products to complete their designs more rapidly than ever. At the relatively humble beginnings of the oscilloscope and the logic analyzer, there was barely a hint of the powerful capabilities today's instruments provide routinely.

Though the oscilloscope predates World War II, it didn't begin to move into an aggressive development phase until the 1950s. One of the pioneers in oscilloscopes is Walter LeCroy Jr., the founder of LeCroy Corp. *(see "Oscilloscopes: From Simply Viewing To Complex Signal Analysis," p. 76).*

Another person who has both witnessed and participated in the oscilloscope's evolution is Ed Caryl, an oscilloscope applications engineer at Tektronix. He has been active in scope design for over 30 years. "There has been a four-order-of-magnitude progression over the past half century, with bandwidths at 5 MHz in the '50s climbing to over 50 GHz at present," he says.

"Back in the '50s, a user was lucky to get an oscilloscope to edge trigger," Caryl continues. Now, scope users can choose from a cafeteria of trigger sources, from very narrow pulses to very complex descriptions of parallel- and serial-bit streams. But according to Caryl, even these steps forward were wild dreams just a few years ago.

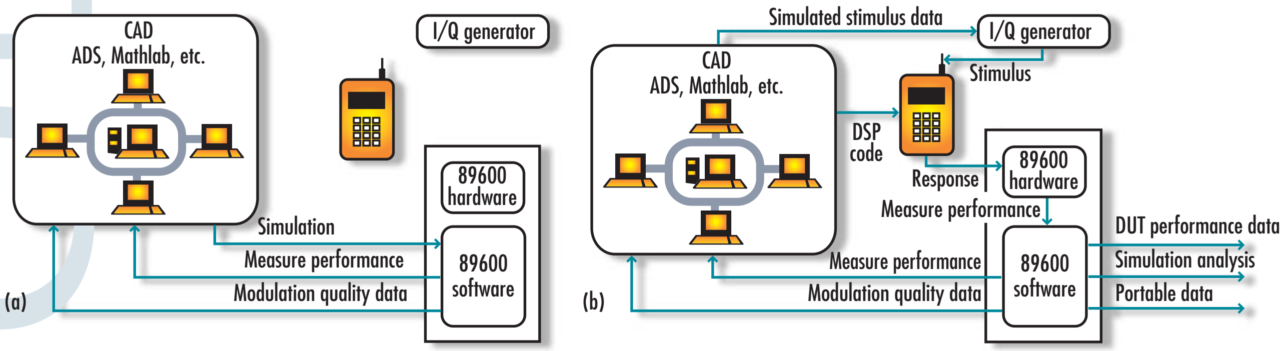
As the years passed, the kinds of measurements that oscilloscope users could perform on signals grew much more complex. Just 10 years ago, oscilloscopes were mostly analog in nature, only displaying a waveform. There was very little computation in the general-purpose oscilloscope, other than basic measurements.

1 Integrated tool sets like the Tektronix TLA715 8-GHz logic analyzer, TDS7404 oscilloscope, and P6860 analog/digital connectorless probe let designers probe, acquire, and display analog and digital time-correlated waveforms at high speeds with minimal impact on the signals.

Now oscilloscopes are actual PCs that do many complex computations on their own. Today, with the dramatic connectivity improvements to PCs, both internal and external, one can feed waveforms into multiple applications, such as Java and Windows. This has vastly expanded the designer's ability to analyze waveforms.

As for digital scopes, 10 years ago record lengths were 1000 to 2000 samples. Now 20 to 30 Msamples are commonplace. Also, 10 years ago the typical bench scope provided a bandwidth in the 400- to 500-MHz region.

"Of course, there were scan converters up to 5 GHz, but there was no vertical amplifier. You simply directly connected the scan con-



2 Agilent Technologies' ADS design automation software and 89600 Vector Signal Analyzer join simulation analysis (a) and actual DUT performance (b). They do so with a single set of tools, so designers can compare the measured signal directly against the simulated signal

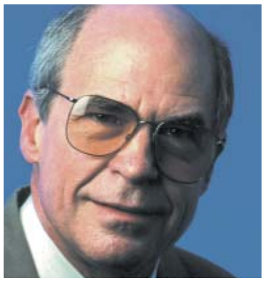
verter tube or a CRT, with no attenuators, no amplifiers, and no ability to modify the signal. You scanned the signal, digitized it, and thus captured it in some crude form," says Caryl. Now real-time scopes offer designers 6-GHz bandwidths with 100,000-point record lengths, plus the ability to respond to complex triggering and perform sophisticated analysis.

Will sampling and real-time scopes merge in the next 10 years? Caryl thinks that's not very likely. The gap is wide: 6 GHz for real-time scopes and 55 GHz for sampling versions. It will be very hard to reach the higher levels in real time due to the front-end circuitry in a real-time scope. The attenuators and amplifiers limit the bandwidth before you get to the analog-to-digital con-

Oscilloscopes: From Simply Viewing To Complex Signal Analysis

Innovators

WALTER O. LeCROY JR.



Much has changed since LeCroy Corp. introduced its first digital oscilloscope (DSO) in 1970. Thirty-two years ago, we used our experience in designing time digitizers and integrating ADCs for particle physics to develop a 1-Gsample/s, 8-bit DSO that had a record length of 20 samples. Since then, DSOs have come a long way, mostly to keep pace with the high-speed, complex electronic signals that must be viewed and analyzed.

Recently, analysis has become increasingly important. A relatively short time ago, viewing signals on an analog oscilloscope was acceptable. Trained engineers could "eyeball" a signal on an oscilloscope screen and determine if a glitch or other anomaly was present. "Viewing technologies" were developed for digital oscilloscopes designed to replicate the look and feel of analog oscilloscopes.

As signals grew faster and more complex in shape, the need for higher-precision measurements became crucial. Very recent advances in DSOs have created a new way to handle current and future generations of product design. More types of measurements can be made, calculations can be performed faster, and the deadtime between triggers when taking measurements and conducting analysis is much shorter.

Older oscilloscope technology used mature Windows operating systems and a processor to handle the user interface, but data handling was done with a slower embedded processor. Even just calculating a few pulse parameters required large amounts of processing resources, slowing down acquisition rates and causing a substantial increase in deadtime between triggers.

New technology allows for real-time data flow at 10 Gbytes/s from the ADC to a high-speed acquisition memory. In the memory, data is converted into packets and sent through multigigabit Ethernet links, and eventually into cache memory. This technique from LeCroy is optimized for making calculations on long data arrays, and lets signals be processed between 10 to 100 times faster than previous oscilloscope technologies.

To achieve this processing speed, DSOs have had to integrate modular software architecture and advanced chip design. The architecture enables Windows 2000 to be completely integrated with the DSO data handling, measurement calculations, analysis routines, display algorithms, and I/O functions. Advanced chip designs, like SiGe amplifiers/attenuators and ADCs, and DRAM ASICs, create the environment for streaming data to be processed through the fastest PCI bus available today.

Not only does this new technology let engineers view today's high-speed complex signals in a manner unattainable with older technologies, it expands as signal speed increases. DSOs now have the flexible platform necessary to keep pace with testing needs, allowing increasingly sophisticated measurements on ever-faster signals.

Walter O. LeCroy Jr. founded LeCroy Corp. in 1964. Prior to that, he was chief electronics engineer at Nevis Laboratories. LeCroy earned a BS in physics from Columbia University.

verter. In a sampling scope, these circuits aren't an issue because the sampling bridge captures the signal. It's right out in front, immediately behind the 50-W connector.

The logic analyzer, on the other hand, began in the early 1970s. One of its pioneers was Chuck Small of Agilent Technologies, then Hewlett-Packard *(see "How Microprocessor Systems Defined The Logic Analyzer," right)*. Another major innovator of the logic analyzer is Chuck House *(see Logic Analyzers, Then And Now," p. 80)*.

In the case of Tektronix, some early logic analyzers were spinoffs from scopes. "The first logic analyzers were actually scope plug-ins," remembers Dave Holaday, an electrical engineer with Tektronix's logic-analyzer hardware engineering group.

Originally, memory depths were very shallow. One early logic analyzer had an 18-channel card with a memory depth of no more than 1 kbit per channel. "Since the depth was so shallow, you could actually take an acquisition and scroll through the data without taking very long to go through the entire data stream," says Holaday.

At that time, processors were typically Zilog Z80s that only ran at 4 MHz. In the early days, designers dealt with 5-V CMOS and TTL logic with some ECL support. As speeds were far slower than they are today, you could pretty much ignore signal integrity matters. You really didn't have transmission line issues and ringing problems.

But higher speeds have driven devices to lower voltages. So, we have smaller margins around the transition when determining whether the signal is high or low. Now there are 400-mV logic families. Moreover, edge rates that were 5 to10 ns have shrunk to the 100- to 200-ps range, placing all of the analog issues upon us—noise, ringing, overshoot, crosstalk, and the like.

As Holaday recalls, "We moved to the 300-MHz versions in the late '80s." He notes that Tektronix announced an 8-GHz analyzer in April *(Fig. 1)*. Looking ahead, Holaday sees the data package becoming larger and the memory getting deeper. He expects logic analyzers to look more and more like a software tool.

Poised to revolutionize RF circuit design is the recently introduced ability to link test

How Microprocessor Systems Defined Logic Analyzers

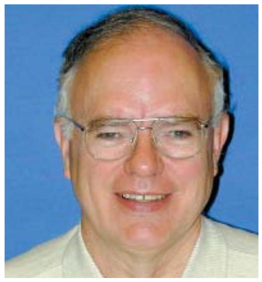
When the microprocessor and inexpensive ROM memory arrived in the early 1970s, building small, stored-program computing systems became practical. System designers learned that with the rapidly growing applications of microprocessors, a conventional oscilloscope-centric debug approach was no longer effective. They needed a new tool that would let them view the simultaneous operations of increasingly parallel systems.

In 1973, the introduction of the logic-state analyzer by Agilent Technologies, then Hewlett-Packard, and the logic-timing analyzer from Biomation immediately satisfied the debugging requirements of systems designers applying the first microprocessors. Logic-state analyzers synchronously capture the state of the system to the clock, while logic-timing analyzers use an asynchronous (internal) clock to sample the system.

The first logic analyzers let system designers trigger on a 12-bit address and data pair from a processor like the Intel 4004. Once the trigger event had been detected, the analyzer would capture and display the contents of its 16-state-deep memory. As microprocessors advanced and system debug requirements grew in complexity, new logic analysis enhancements emerged. Later in the '70s, Agilent introduced logic analyzers that featured multiple trigger-event sequencing, microprocessor-specific instruction inverse assembly, and a combination of state and timing analysis.

Innovators

CHUCK SMALL



By the mid '80s, microprocessor-based systems were capturing analog signals, performing digital signal processing, and outputting analog signals. Agilent integrated digital oscilloscope channels into the logic analyzer. For the first time, digital designers had a comprehensive view of system operation that showed critical insights into hardware and software interaction.

Microprocessor packaging and bus structures have advanced dramatically over the last three decades, driven by the need for higher performance systems. In the early '70s, logic analyzer probing consisted of wire leads with simple pin grabbers, called flying leads. Although it worked, this approach was cumbersome and time consuming to connect to dual-inline packages. To simplify connection of the logic analyzer to the system under test, microprocessor-specific probing was introduced for the Intel and Motorola processors in the late '70s.

Today's logic analyzers offer a wide array of high-signal-integrity alternatives to the flying lead probe. High-density pin grid array (PGA) and standard bus interposer probing solutions simplify the connection of the analyzer to popular microprocessors and buses—such as PCI and DDR.

Digital system performance demands have steadily increased, driving microprocessor and I/O buses to higher operating rates. Logic analyzer performance has increased in speed, width, and memory depth to meet the needs of today's system designers debugging multiple, gigabyte-transfer-rate buses. Equally important, today's logic analyzers enable the capturing of multiple time-correlated snapshots of traffic on the buses that make up a system.

These rapid changes in microprocessor system architecture and performance have shaped the logic analyzer. Over time, it has evolved from a tool that presents a view into the system under test as ones and zeros, or a binary waveform display, into a tool that provides a processor/bus-specific time-correlated view into increasingly complex digital systems. Logic analyzers will continue to change to meet new system debug requirements of the digital designer.

Chuck Small is an R&D project manager, developing computer bus probing for logic analyzers at Agilent Technologies. He was a member of the team that designed the first logic-state analyzer. He received his BSEE/CS from the University of Colorado.

equipment with a design automation tool. This link enables an interchange between the real and virtual worlds—that is, the ability to correlate simulated and measured performance data for a design and verify performance.

Tying together EDA software with measurement and analysis instrumentation generates new ways to accelerate the design process. The components are Agilent's Advanced Design System (ADS), an EDA software tool, and an instrument like Agilent's 89600 Vector Signal Analyzer (VSA).

ADS harnesses a variety of automation tools that can fulfill the design requirements of the coming generations of wireless systems. The VSA is a spectrum analyzer that employs vector properties to preserve the phase and magnitude of signals that it analyzes.

A typical flow starts in the design environment, where modeling occurs. It enables designers to develop transmitters, receivers, virtually any set of RF components, and subsystems. Once initial modeling has been completed, data from the design simulation can be streamed to a signal analyzer, like the 89600 *(Fig. 2a)*.

The 89600 software takes that data and puts a number of built-in tools to work—such as DSP analysis, fast Fourier transforms, and error vector magnitudes. After the 89600 analyzes the signal, the results are streamed back to the CAD tool to tweak, correct, and enhance the simulation *(Fig. 2b)*.

The ideal signal is streamed into the I/Q generator, which can output the signal to the real world, upconverting it to whatever frequency is required. Then that signal is applied to actual hardware, the device under test (DUT) *(Fig. 2b, again)*.

Next, the 89600 hardware measures what's arriving from the DUT, and the results are fed to the 89600 software. Now the "measured response" going back to the design environment is from real hardware.

"DSP code" consists of equalization algorithms intended to reside in the receiver. These parameters are fed directly to the DUT, in effect programming the chips within the DUT. Designers can port this data to any destination, as denoted by the three arrows exiting from the 89600 software. PT

Logic Analyzers, Then And Now

When ICs first became available to electronics engineers 30 years ago, oscilloscopes could no longer do the job. Asynchronous logic designs with multiple pins gave rise to multipath race conditions. On the other hand, synchronous algorithmic state designs were register-based, with the binary combinations of data representing the real signal of interest.

To meet designers' needs, two separate classes of test equipment emerged. Logic timing analyzers deal with asynchronous issues, using sampled data and displays of pseudovoltage versus time. Today, we call them digital oscilloscopes. Logic-state analyzers handle the second set of issues. They provided binary-, octal-, or hex-number displays of data registers. These quickly evolved to show assembly-level instruction sets, ASCII character sets, and compiled statements.

Since then, many variants have appeared. Most logic analyzers offer both logic timing and state displays. Network bus analyzers and microprocessor emulators fall into the second category. Yet the test equipment industry has ultimately failed our field. No major test equipment or emulator vendors have dealt with the obvious fact that software has replaced hardware as the quality variable. The result is a shocking lack of appropriate and analogous tools for software developers and testers.

This curious lack is excused on the grounds that it's a different business, one that we don't understand, or one that doesn't have a sizable market. This is merely self-serving. The same statements applied to logic analysis during its infancy. Emulator companies were trying to sell chips, not development systems. But test companies were dedicated to testing the most difficult and important scientific and engineering problems that existed. Logic analyzers are sold to hardware developers on these same projects, and they're taught in the electronic engineering curricula.

Innovators
CHARLES H. HOUSE

How did this happen, and why hasn't it happened in software? Well, several vendors spent 10 years and $200 million dollars educating and equipping universities to teach logic analysis. But no company invested one-twentieth of that for the analogous software measurement problem—a problem that's 10 times larger. Moreover, major software vendors have assiduously avoided dealing with the quality issue. Users are the test beds, and they're losers in such scenarios because the vendors have devoted their resources to getting code developed and sold, rather than validated and verified.

Why haven't the major test equipment companies dealt with this opportunity? It may have mostly to do with maturation and consequent sclerosis of innovative activity, an endemic problem in most corporations as they grow and age. Unfortunately, it's nearly impossible for small startups to change a collective paradigm of design if the large test corporations, users, and software vendors are happy with the status quo.

Software errors have been responsible for numerous major failures, from banking and stock market exchange shutdowns to telecommunications failures, elevator malfunctions resulting in deaths, automobile "seizures" and collisions, and industrial plant explosions. Legislation, already prominent in health-care systems and avionics, trails major catastrophic events. Still, the eventual result will be a major burden on tools vendors to deal with these regulations by designing adapted tools per industry. In the long run, this will be much more expensive than putting the emphasis on the design process in general, and testing for and verifying safety-critical capabilities up front. Where is the software logic analyzer, and the test industry leadership to define, design, and establish it?

Charles H. (Chuck) House is director, societal impact of technology, for Intel Corp. He's an IEEE Fellow for his role in the creation of the logic analysis instrumentation field and chairman of the board for Applied Microsystems.