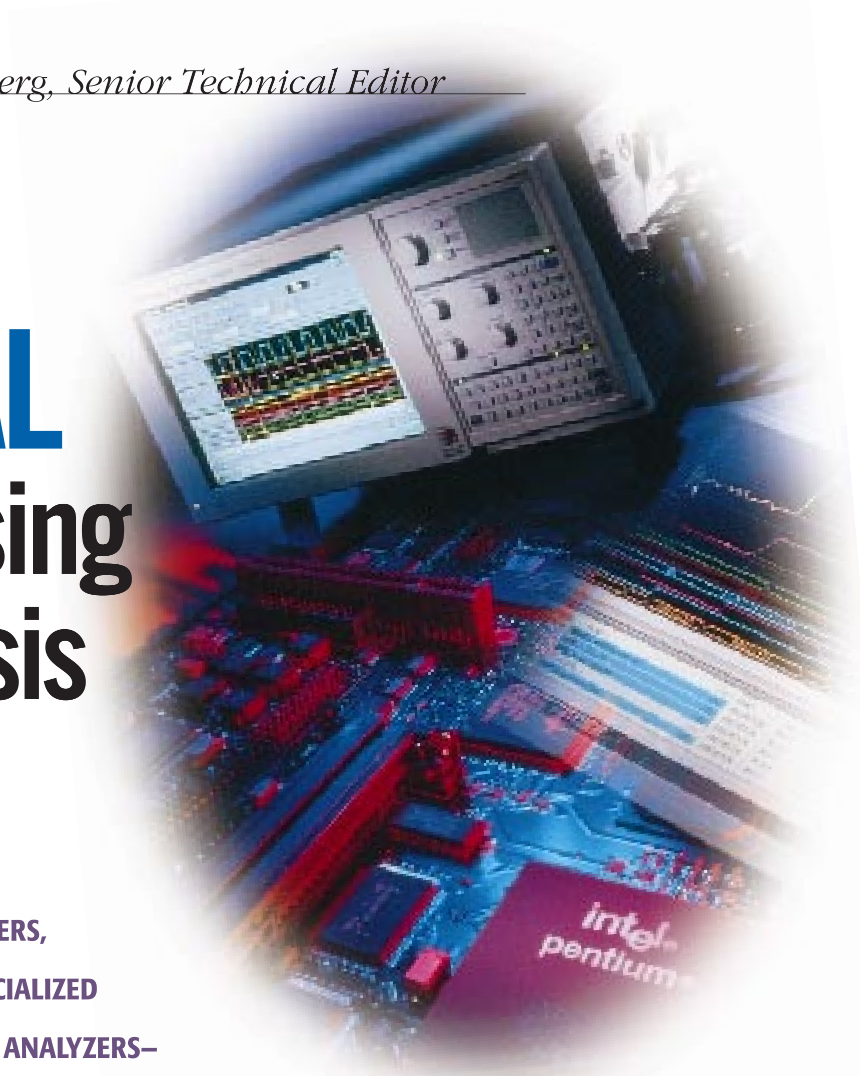
 By Dan Strassberg, Senior Technical Editor

DON'T BE ILLOGICAL when choosing logic-analysis tools



Tektronix's TLA 700-series analyzers contain a standard PC that runs most PC-based software-development and debugging tools. The logic analyzers also simultaneously perform state and timing analysis through the same probes and provide 500-psec timing resolution.

BESIDES CONVENTIONAL LOGIC ANALYZERS, INSTRUMENT MAKERS NOW OFFER SPECIALIZED TOOLS THAT—THOUGH NOT TRUE LOGIC ANALYZERS—PERFORM RELATED AND OFTEN COMPLEMENTARY FUNCTIONS. YOU HAVE AN EXPANDING TOOLBOX AT YOUR DISPOSAL, BUT YOU MUST CHOOSE WISELY.

Like so much of electronics, logic analysis is changing profoundly. Microprocessors with complex architectures and clock speeds that already top 0.5 GHz present incredible challenges. Ever-faster buses that depend on intricate communication protocols now pervade electronic systems. Circuitry that once resided in multiple ICs whose pins afforded ample opportunities for probing now resides deep within ASICs, where many layers of logic separate it from probe points.

Product-development teams, which once focused on hardware, now usually include more software engineers than hardware designers. To hardware designers, general-purpose logic analyzers are important allies. Software engineers, on the other hand, either avoid using the instruments or maintain a strained, arm's-length relationship with them.

Logic analysis must adapt to this new landscape or risk irrelevance. Instrument makers have responded by introducing new species of logic-analysis tools (**Tables 1** and **2**) and collaborating more closely with suppliers of other types of tools, especially software-based tools. The new products include accessories for general-purpose instruments as well as specialized stand-alone units. Though not true logic analyzers, these units perform related functions. Many of the new tools come from companies that don't produce general-purpose logic analyzers (see **sidebar** "For more information... ") To ensure that you make logical decisions about logic analysis, you need a clear understanding of these new tools—what they're good for and what they're not.

AT A GLANCE

- Logic analysis is evolving to address changes in electronic-product design and the makeup of design teams.
- Logic-analyzer manufacturers are collaborating closely with makers of other types of development tools.
- Vendors are introducing new types of products that complement (and perhaps compete with) general-purpose logic analyzers.
- Bus analyzers ease bus debugging by triggering on protocol violations and presenting complex data in an easy-to-digest format.
- Products that resemble logic analyzers are displacing traditional in-circuit emulators in both hardware and software debugging of µP-based systems.

THE END OF THE ICE AGE?

For nearly two decades, the logic analyzer has been a vital tool for debugging µP-based system hardware. For debugging µP code, however, software engineers have relied more heavily on another hardware-based tool—the classical in-circuit emulator (ICE). Now, however, advanced processors are confounding these ICEs. Although traditional ICEs are holding their own with 8- and 16-bit processors of older architecture, in systems based on newer µPs, the ice man cometh for the classical ICE.

Hardware-based debugging tools for newer processors bear a faint resemblance to traditional ICEs and a stronger resemblance to logic analyzers. Gone are most of the classical-ICE features that provided real-time control of processor operation and some of the features that allowed real-time observation of processor activity. In their place, you now find run-control via µP serial ports—background-debugging mode (BDM) on Motorola (www.motorola.com) devices and IEEE 1149.1 (JTAG) on other manufacturers' chips.

In the realm of debugging tools for newer buses, at least a dozen manufacturers offer hardware-based products aimed at filling software engineers' needs. Many of the new buses are serial and even more of them depend on complex communication protocols. The new bus-analysis tools aim to display bus traffic in a way that makes apparent the significance of the bus activity. They also strive to detect and trigger on protocol violations in real time. For most modern buses, this task requires fast, complex hardware.

THE MULTITALENTED INSTRUMENT

A logic analyzer provides two views of digital-circuit activity. In the timing-analysis or asynchronous mode, the analyzer acts like an oscilloscope, though

BUS MONITORS VERSUS BUS ANALYZERS: THERE IS A DIFFERENCE

Bob Garrett, Boulder Creek Corp

Instruments that most vendors call protocol analyzers are actually protocol monitors. The distinction is subtle yet significant. To properly identify a device as an analyzer or a monitor, you need to consider whether the instrument:

- relies on a hardware front-end device to translate raw data into protocol information and
- actively participates in the bus or communications link.

Controller-area-network (CAN) analyzers provide a good example. Many of these instruments rely on hardware translation in a CAN-controller chip to convert the asynchronous data stream into CAN messages. This method precludes the possibility of accessing raw data for analysis and relies instead on the controller IC to properly translate the data. Although the instrument may flag as an error incorrect communication traffic, the message content (the raw data) is unavailable because it doesn't get past the CAN chip.

Nevertheless, monitors that rely on controller chips for translation aren't necessarily less useful than analyzers. A monitor may be ideal if the network is functioning properly and if the goal is to view communication traffic. A monitor is also appropriate for debugging system-level problems. Many monitors also generate bus traffic.

In contrast, a true analyzer does not rely on a separate translation device to translate the raw data into messages; it provides the raw data for examination. Most true analyzers are based on general-purpose data-acquisition engines. Therefore, you can use such instruments to troubleshoot hardware-timing and system-level problems.

Another difference is that true analyzers do not participate in communication on the bus. Observing a misbehaving system shouldn't disturb the system's operation. Monitors insert themselves into the communications link at the outset, performing arbitration, acknowledging messages, and changing the overall topology of the system. For example, if a device won't acknowledge traffic on the bus, adding an active node in the link can generate an acknowledgement and cause the problem to mysteriously vanish. What has really happened, however, is that the monitor has masked the problem.

True analysis becomes critical for verifying system operation at the lowest levels. For this purpose, you need to closely examine the raw data and its timing to obtain the most detailed information possible. True analysis is also critical when tracking down so-called benign bugs—incorrect operations that don't cause system failures and can therefore go undetected through several design iterations. Benign bugs are dangerous because they can become malignant when an unusual event occurs or when any part of the system changes. Verifying systems in detail gives you the opportunity to eradicate such bugs before you ship your product.

FOR MORE INFORMATION...

For information on logic analyzers, bus/protocol analyzers, and related hardware-based debugging products such as those discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or use *EDN*'s InfoAccess service. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

Ancot Corp
Bus/protocol analyzers, especially for SCSI and Fibre Channel.
Menlo Park, CA
1-650-322-5322
fax 1-650-322-0455
www.ancot.com
Circle No. 311

Boulder Creek Corp
PC-based logic analyzers (serial- and Universal Serial Bus (USB)-port plug-ins), controller-area-network bus analyzers, and embedded logic-analysis cores for ASICs.
Santa Cruz, CA
1-831-460-3710
fax 1-831-460-3715
www.bcreek.com
Circle No. 312

Computer Access Technology Corp (CATC)
Bus/protocol analyzers, especially for IEEE 1394 and USB.
Santa Clara, CA
1-800-909-2282, 1-408-727-6600
fax 1-408-727-6622
www.catc.com
Circle No. 313

Data Transit
Bus/protocol analyzers for many buses, such as EIDE, SCSI, Ultra-2 and Ultra-3 SCSI, low-voltage differential SCSI, UDMA-33, UDMA-66, USB, IEEE 1394, PCMCIA, and Compact flash.
San Jose, CA
1-408-264-4300
fax 1-408-365-1444
www.data-transit.com
Circle No. 314

Embedded Support Tools Corp (EST)
In-circuit emulators that use serial ports such as background debugging mode (BDM) for µP control. Extensive support for Motorola processors, especially the PowerPC family.
Canton, MA
1-781-828-5588
fax 1-781-821-2268
www.estc.com
Circle No. 315

Finisar Corp
Bus/protocol analyzers for high-performance buses, such as Fibre Channel.
Mountain View CA
1-650-691-4000
fax 1-650-691-4010
www.finisar.com
Circle No. 316

FuturePlus Systems
Tools that work with HP logic analyzers to support specific processors and buses: PCI, CompactPCI, USB, and Rambus, for example.
Colorado Springs, CO
1-719-380-7321
fax 1-719-380-7362
www.futureplus.com
Circle No. 317

Genoa Technology
Bus/protocol analyzers, for example for USB.
Moorpark, CA
1-805-531-9030
fax 1-805-531-9045
www.gentech.com
Circle No. 318

Hewlett-Packard Co
Logic-analysis and in-circuit-emulation products, including optional support for µP control via BDM and IEEE 1149.1 serial ports in 16600 and 16700 families.
Santa Clara CA
1-800-452-4844
www.hp.com/go/logicanalyzer
Circle No. 319

Hitex GmbH
Emulators for CompactPCI, USB, and others.
Karlsruhe, Germany
011-49-721-9628-0
fax 011-49-721-9628-189
www.hitex.de
Circle No. 320

Intellitech Corp
Scan-based debugging tools, including ASIC-embeddable debugging tools.
Durham, NH
1-603-868-7116
fax 1-603-868-7119
www.idft.com
Circle No. 321

Ixia Communications
Traffic generators and emulators for high-speed communications protocols, such as fast Ethernet.
Calabasas, CA
1-818-871-1800
fax 1-818-871-1805
www.ixiacom.com
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Link Instruments Corp
PC-based logic analyzers.
Fairfield, NJ
1-973-808-8990
fax 1-973-808-8766
www.linkinstruments.com
Circle No. 323

Micro Computer Control Corp
Bus monitors, for example, for the I_2C bus.
Hopewell, NJ
1-609-466-1751
fax 1-609-466-4116
www.mcc-us.com
Circle No. 324

NCI
PC-based logic analyzers and PCI-bus analyzers.
Huntsville, AL
1-256-837-6667
fax 1-256-837-5221
Circle No. 325

New Wave
PCI bus support for Tektronix logic analyzers.
Norwood, MA
1-603-595-8116
fax 1-781-762-9445
www.busboards.com
Circle No. 326

Tektronix Inc
Logic analyzers, partnership program with other vendors of embedded-system debugging tools.
Portland, OR
1-800-426-2200
fax 1-503-222-1542
www.tek.com/Measurement
Circle No. 327

Verisys Inc
Bus/protocol analyzers, especially for versions of SCSI.
Aptos, CA
1-831-662-7900, ext 224
fax 1-831-662-7910
www.verisys.com
Circle No. 328

VMEtro Inc
Bus/protocol analyzers, especially for VME, VXI, PCI, CompactPCI, and Futurebus+.
Houston, TX
1-281-584-0728
fax 1-281-584-9034
www.vmetro.com
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For more information on the products available from all of the vendors listed in this box, circle one number on the reader service card. *Circle No. 330*

usually with many more channels than you find in scopes. In the timing mode, the logic analyzer's internal clock provides the timebase. However, unlike a scope display, the waveform presentation shows only two levels (1 and 0) in any clock period.

In the state-analysis, or synchronous, mode, the target system's clock acts as the instrument clock. In the state view, time usually runs from the top of the screen to the bottom, and the analyzer usually presents the data as meaningful mnemonics, such as processor op codes and high-level-language instructions.

Recently, logic analyzers have expanded their capabilities to include performance analysis, which often involves statistical analysis of measurements. Once the exclusive domain of the traditional ICE, performance analysis helps software engineers determine how efficiently the target-system software is running. For example, performance analysis can indicate the amount of time (typical and worst case) that a target system spends executing subroutines.

MARRIED TO THE BUS

A few bus-analyzer manufacturers proclaim that their instruments make general-purpose logic analyzers obsolete and that only a timid engineer would purchase a logic analyzer for bus analysis. According to these manufacturers, such engineers hesitate to invest in an instrument that is married to only one bus, because next year's project might use a different bus.

Bus-analyzer manufacturers insist that you can buy two bus analyzers for less than the cost of one general-purpose logic analyzer and its associated preprocessors. Thus, if next year's project *does* use a different bus, you can buy a new bus analyzer and still spend less than the cost of a general-purpose logic analyzer. These manufacturers also assert that the bus an-

THE WEB BECOMES A LOGIC-ANALYSIS TOOL

Hewlett-Packard has turned to the World Wide Web to ease collaboration among members of large embedded-system-development teams. If the team members are dispersed across the globe, as is often the case today, the advantages can be particularly dramatic. But even if your lab and your workstation are only a few feet apart, you can enjoy the advantages of HP's approach.

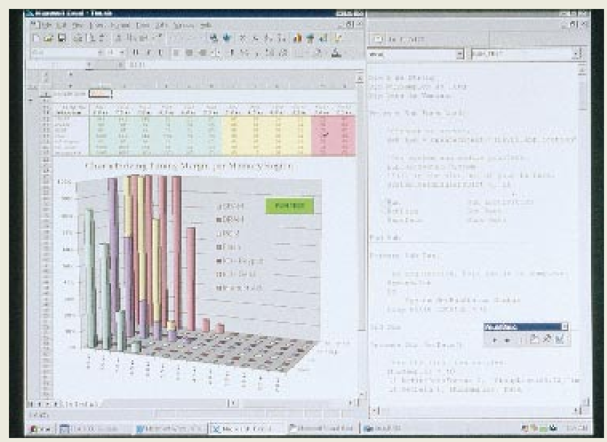
Tools that have been available for the last five years use wide-area networks, networkable instruments, and specialized software to facilitate cooperation among team members. For example, a software engineer in India can download code to a prototype system in a lab in Silicon Valley. Then, from the console of a workstation in India, the engineer can debug the code just as if he were seated next to the prototype.

With HP's Web-enabled logic-analysis tools (the 16600A, 16700A, and 16702A logic-analysis mainframes—$25,740, including 204 channels; $10,040; and $11,500 respectively), you no longer need specialized software on the workstation to monitor the prototype. A standard Web browser (version 4.0 or higher of Microsoft (www.microsoft.com) Internet Explorer or Netscape (www.netscape.com) Communicator does the job. With the browser, you simply log into the Web page that the logic analyzer automatically creates when you connect it to the corporate intranet.

Once the browser has imported the data from the Web page, you can easily transfer the data for further analysis to such familiar applications as Microsoft Excel. To further simplify the job, HP offers BenchLink XL, a PC-based Excel add-in software package that automatically imports data directly from the logic analyzer into the spreadsheet.

HP's logic analyzers use Motorola (www.motorola.com) processors. Many third-party software-development tools run only on PCs, which, of course, use Intel (www.intel.com) processors. Mindful of this situation, Tektronix used a PC as the heart of its TLA 700 logic-analyzer family. You can run most PC-based development and debugging tools directly on the TLA 700. With an HP logic analyzer, on the other hand, you need a separate PC; for Unix-based tools, you need a separate workstation.

Although HP has the largest share of the logic-analysis market, Tek's use of an Intel-architecture processor would seem to



Both Hewlett-Packard and Tektronix offer swift and painless ways of getting logic-analyzer data into analysis applications. A Tek logic analyzer gathered this Microsoft Excel presentation of performance-analysis data.

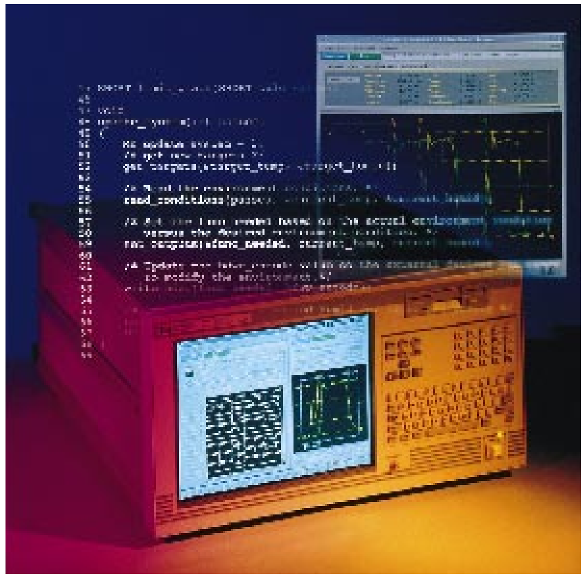
be a major advantage for the TLA 700. However, HP Product Manager Greg Peters strongly disagrees. He says that in most large companies, the Information Technology (IT) department strictly limits the number of types of PCs it allows on the corporate network. A logic analyzer with a PC inside isn't a mainstream PC and won't get IT approval.

"If you think you can simply ignore IT and connect the logic analyzer anyhow, you're wrong," Peters says. IT has to supply a node address for each PC you connect. "You'll never get an address for a device that IT hasn't approved," he says.

Nevertheless, Tek hardly believes that HP's Web-enabled logic analyzers leave the TLA 700 in the dust. The Tek unit not only can locally run PC-based development software, but also acts as a server, sending information to client programs running on remote workstations or PCs. Each TLA 700 has a programmatic interface that is based on Microsoft's Component-Object-Model technology. According to Tek, this interface makes it easy for remote applications to control the TLA 700 and use data that the logic analyzer provides.

alyzer is more compact and easier to use.

Still, most bus-analyzer vendors don't see their products competing with general-purpose logic analyzers. Instead, they see the products as complementary. The logic analyzer, together with a good oscilloscope, excels at hardware debugging. The bus analyzer's forté is debugging bus-related software problems—of course, only on the bus for which the instrument was designed. Many systems have multiple buses, and not all development teams have a bus analyzer for each of those buses. If no bus analyzer is available for one or more of the system's buses, a general-purpose logic analyzer can come to the rescue. The logic analyzer is also the tool of choice for problems unrelated to buses.



The flagship of HP's extensive logic-analyzer line, the 16702A replaces the well-known 16500 series. Besides logic analysis, this unit can host two emulation modules that communicate with the μP under test via the chip's IEEE 1149.1 or BDM port.

REALLY, IT'S STATE ANALYSIS

Bus analysis with a logic analyzer is really a special case of state analysis. Although a logic analyzer may not always be the most efficient bus analyzer, the substitution is often quite effective. Moreover, employing a general-purpose logic analyzer for bus analysis may help you get to the root of hardware problems that confound many dedicated bus analyzers. Logic analyzers excel at finding such problems because they perform timing analysis, a function that few dedicated bus analyzers are capable of (see **sidebar** "Bus monitors versus bus analyzers: There is a difference.")

At least one company supports using a general-purpose logic analyzer for bus analysis. FuturePlus Systems has built one of its core businesses by providing hardware and software that adapt HP logic analyzers to bus analysis.

Perhaps because you can often use a logic analyzer for bus analysis, some in the industry have begun interchanging the terms "bus analyzer" and "logic analyzer." Such reckless terminology is unfortunate because you usually can't make the opposite substitution—that is, you generally can't substitute a bus analyzer for a logic analyzer.

MORE MEMORY PLEASE

As systems become more complex, it is not surprising that users are demanding logic analyzers with greater memory depth. Engineers commonly use a logic analyzer to obtain a record (trace) of the target-system activity preceding a malfunction to find and fix the problem. The

TABLE 1–DIGITAL TEST TOOLS

		Scopes		Logic analyzer	Emulation			Pulse pattern generator	Data generator/analyzer
Measurement abstraction		Logic scope	High-performance DSO		Emulation probe	Emulation+ debugger	Traditional ICE		
High	Debugger			Links to debugger	Links to debugger	X	X		
	Source			X		X	X		
	Symbolic			X		X	X		
	Assembly			X			X		
	Distribution			X					
	Chart			X					
	State			X			X		
	Digital stimulus			X				X	X
	Digital response			X					X
	μP control			X	X	X	X		
	Logic waveform (16 channels)	X		X					
	Pulse/data generator			X				X	X
Low	Analog	X	X	X					

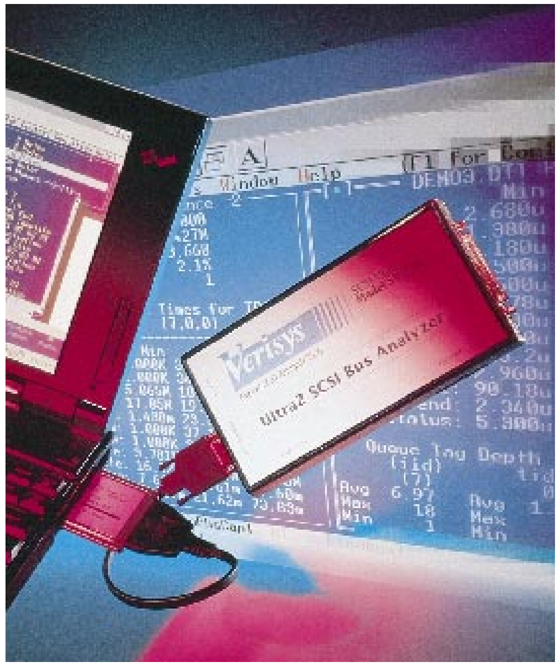
Note:
Does not include bus-analysis tools.
(courtesy Hewlett-Packard)

chain of events that culminates in a malfunction often begins many clock cycles before the first aberrant behavior is noticeable. The deeper the buffer, the better the chance it will capture the offending event.

Although all logic-analyzer manufacturers are committed to producing instruments with memory depth as great as the technology permits, Hewlett-Packard derides the practice of gathering ever-increasing amounts of data. In fact, HP engineers have named the technique "swallow (lots of data) and wallow (in all of the data)." HP already supplies logic analyzers with 4-Mbit/channel trace memories, but the company's application engineers argue that you are usually better off refining the criteria that trigger a trace and capturing less data. Of course, this practice presupposes that you can determine exactly how to refine the trigger criteria.

One bus-analyzer manufacturer talks about developing an analyzer with a memory depth of 1 Gbit. The analyzer would capture 128-bit-wide traces, so it would fill its memory in 8 million clock periods. The bus's clock speed is 100 MHz, so the trace buffer would fill in just 80 msec. Without an automated searching method, you might spend days scrutinizing that 80-msec record for the event that precipitated the failure. On the other hand, for automated searching to work, you must be able to define what you are searching for. And if you can define what you are searching for, why not trigger on it instead of searching after you've captured the data?

One reason is that the malfunction may occur so infrequently that, even if you know what to search for, it may be days before the condition arises. In such situations, the deep trace may be extremely valuable, notwithstanding the difficulty in extracting the secrets it contains.



By plugging this small unit from Verisys into a notebook PC's PC-Card slot, you turn the PC into an Ultra-2-SCSI bus analyzer.

IN BED WITH ASICs

Just as high-speed buses that use complex communication protocols are a fact of life in modern electronic systems, so are complex ICs—even so-called system-on-chip ASICs. Consequently, the idea of embedding logic analyzers or portions of logic analyzers within ASICs seems destined to garner increasing interest.

More and more, complex ASICs hide the points that you need to connect to a logic analyzer to verify the ASIC design. In response, companies, such as Boulder Creek and Intellitech, are developing technologies that make the logic analyzer part of the IC. A serial interface provides access to the instrumentation functions. However, if the vendor produces the IC in significant quantities, the area that the instrumentation functions occupy can raise the IC cost to an unacceptable level. Therefore, to save area after verifying the design, ASIC designers must often remove the instrumentation functions from the chip layout.

AN ANALYZER FOR EVERY BENCH

Conventional logic analyzers come in a range of prices and capabilities. Market leader Hewlett-Packard's pricing begins at $4995 for the 54645D mixed-signal oscilloscope. This instrument has 16 logic-timing-analysis channels that acquire 200M samples/sec (or 400M samples/sec if you use only eight logic inputs). The 54645D also has two 100-MHz-bandwidth analog channels that acquire a maximum of 200M sam-

TABLE 2A—DIGITAL-BUS ATTRIBUTES

	µPs and internal buses	Peripheral buses	LAN/WAN
Examples	Pentium II, PowerPC, PCI, VME, Rambus	RS-232C, Universal Serial Bus, Firewire	Ethernet, ATM, ISDN, Fibre-Channel
Bus length	6 to 12 in.	10 ft	100 ft to miles
Configuration	Circuit design, system integration	Simple/self-configuring	Managed networks
Adoption/deployment cycle	1 to 3 years	3 to 5 years	5 to 10+ years

TABLE 2B—INSTRUMENTS FOR DIGITAL BUSES

	Logic analyzers	Bus analyzers	Protocol analyzers
Characteristics/abilities	General-purpose	Dedicated	Dedicated
	Physical-layer-oriented	Protocol-focused	Protocol-focused
	Extrapolation to high-level language	PC+adapter	Stand-alone
	Stand-alone	Localized ports	Great distance between ports
	Monitoring	Monitoring	Monitoring
	Real-time trace of multiple buses	Emulation	Emulation
		Traffic generation	Traffic generation
		Single-bus	Single-bus

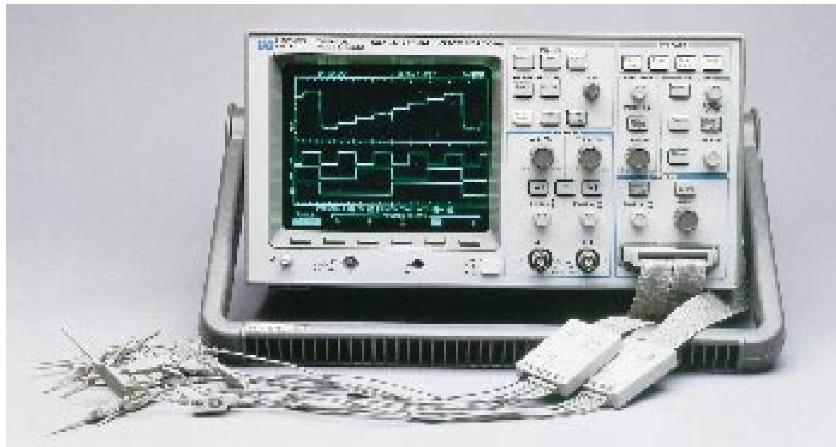
Courtesy of Tektronix

ples/sec to a depth of 1M sample. Just $5 more buys the 34-channel 1664A, which does 500-MHz timing and 50-MHz state analysis. This unit has a monochrome CRT display. All other HP logic analyzers now sport color flat-panel displays with resolutions of 640×480 pixels or more.

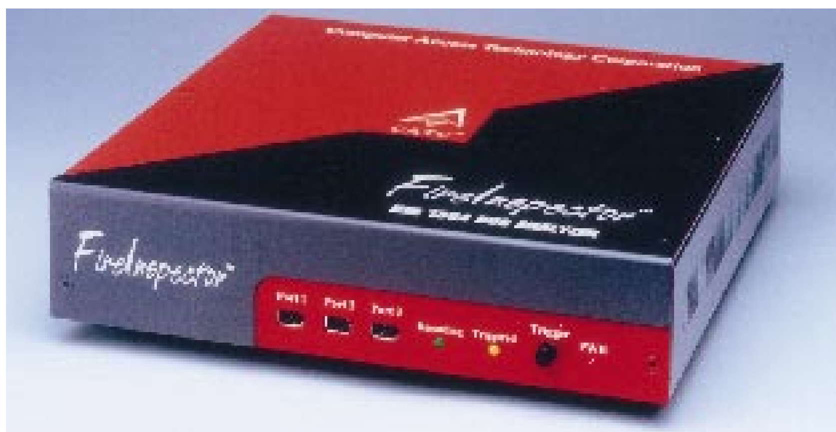
The top of HP's benchtop-analyzer line is the $20,000 1660ES, with 136 logic channels that perform 500-MHz timing and 100-MHz state analysis. This instrument also includes two 500-MHz-bandwidth, 2G-sample/sec scope channels. The $16,300 1660EP substitutes a 32-channel digital-pattern generator for the scope channels.

HP's modular systems, the $25,740, 204-channel 16600A; the $10,040 16700A; and the $11,500 16702A are now Web-enabled (see **sidebar** "The Web becomes a logic-analysis tool"). Your choice of plug-in modules determines the 16700A's and 16702A's logic-analysis characteristics. HP supplies modules that perform state analysis to 1 GHz and timing analysis to 4 GHz. The 16600A accommodates one emulation module; the 16700A and 16702A each accommodate two emulation modules. These modules communicate with a variety of µPs via the chips' serial ports (IEEE 1149.1 or BDM, for example). Thus, these systems incorporate both logic analysis and a nontraditional form of in-circuit emulation.

Tektronix's TLA 700 family includes both portable ($9500) and system-level ($14,750) logic-analysis mainframes. The units provide 500-psec timing resolution (equal to 2 GHz), 200-MHz state-analysis speed, and 512-kbit/channel maximum memory depth. They can simultaneously perform state and timing analysis through the same probes. Portable mainframes accommodate 272 channels. System-level mainframes accommodate 680 channels. The required 34- to 136-channel plug-in modules cost $8400 to $27,300 each.



For hardware debugging, a scope is almost indispensable, but using a separate scope and logic analyzer can become messy. However, a few low-cost instruments combine the two functions. HP's $4995 54645D combines two 100-MHz scope channels with 16 logic-timing-analysis channels.



The FireInspector PC-based bus/protocol analyzer from CATC scrutinizes the IEEE 1394 high-speed serial bus.

DON'T BREAK THE BANK

Many vendors offer lower cost logic analyzers. Link Instruments' PC-based instruments come in enclosures external to the host PC. The company offers units with speeds to 500 MHz and with as many as 160 channels. Prices range from $1350 to $7000. The company also makes PC-based digital scope units that are good companions to the logic analyzers.

Boulder Creek's Pod-A-Lyzer PC-based logic analyzers are unusual for several reasons. The most noticeable reason is their size: The units are no larger than the pods that interface between conventional logic analyzers and the target system. The devices also need no dedicated interface card within the PC; they connect to standard serial (RS-232C) or Universal Serial Bus ports. An 18-channel unit with memory of 64 kbits/channel does timing analysis at 100 MHz and state analysis at 66 MHz and costs $1295.

NCI offers two PC-based logic-analyzer lines. The 400-MHz Mobilogic line comes in a 3×6×15-in. external enclosure. Prices range from $3995 for 48 channels with memory of 64 kbits/channel to $8990 for 96 channels with memory of 256 kbits/channel. The company also makes logic analyzers on PC plug-in cards. These units offer as many as 96 channels (two boards), timing-analysis speeds as high as 400 MHz, and state-analysis speeds of 50 MHz. Memory depths reach 1 Mbit/channel. Prices range from $2425 to $3995.

Bus-analyzer prices are at least as varied as the buses themselves—ranging from $295 for a controller-area-network bus analyzer that you must use with a low-cost logic analyzer to $30,000 for a Fibre Channel analyzer. Options can even further raise the price of the Fibre Channel analyzer. □

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