NOTHING GOOD LASTS FOREVER, BUT IEEE 488'S SLOW DECLINE IS MAKING THE VENERABLE INSTRUMENT-INTERFACE STANDARD *SEEM* IMMORTAL.

IEEE 488: not dead yet?

L IKE THE CHARACTER in the famous Monty Python sketch, IEEE 488 is not dead yet. The decades-old standard's longevity is in question, however, and you probably have good reason to care about its fight for life. Whether you design test-and-measurement instruments, develop or implement systems that incorporate test-and-measurement products that others design, or simply use such products in your lab or test facility, the methods that instruments use to communicate with each other and with host computers matter a lot. The communications medium's physical implementation, protocol, and instrument-specific command sets strongly influence instruments' and systems' speed and cost and the time EEs must spend programming and debugging test applications.

In 1977, the IEEE adopted the bus structure and communication protocol that it named IEEE 488. Some others call it GPIB (general-purpose instrumentation bus). The bus's original name was HPIB (Hewlett-Packard instrumentation bus). HP, which, in 1999, spun off its electronic test-and-measurement business as Agilent Technologies, was the largest manufacturer of such equipment, a market position that Agilent still enjoys. Even before the early 1980s ushered in the widespread availability of PCs, large numbers of minicomputers (remember them?) were in use controlling instruments and processing the data they generated.

Until the advent of the HPIB, no standardized methods existed for interfacing instruments with computers. It's only a slight exaggeration to say that no two instruments interfaced in the same way.

The RS-232 serial-communication standard and the Centronics parallel-printer interface did a decent job of standardizing the computer side of the interface and even motivated some standardization on the instrument side. (RS-232 ports became popular on slower instruments.) Still, because it was rugged and relatively speedy, was designed for

instrument interfacing, and was backed by HP's clout, IEEE 488 remained for more than two decades the industry's primary standard for enabling instruments and computers to talk with one another.

Even so, IEEE 488's early era was no bed of roses. Although the standard did a good job of defining the communications hardware, it initially gave short shrift to interfacing's software aspects. More than a decade elapsed before the evolution of the necessary software standards, particularly SCPI (standard commands for programmable instruments). It took still longer to develop standard instrument drivers, whose existence relieved test-system designers of a great deal of application-specific programming.

SEEMINGLY TORPID PACE

The idea that the electronics industry includes a segment that marks its evolution in decades rather than months must seem bizarre—even unthinkable—to younger EEs whose experience stretches back only as far as the go-go days of the late 1990s. However, this seemingly torpid pace is keeping IEEE 488 alive, even if not in the most robust health, and will continue to do so for years to come.

To many observers, though, propelled by ubiquitous computer-interconnect standards, IEEE 488 appears to have entered the end game. It may not go quietly—powerful forces will keep it alive for years, but many in the industry see its demise as inevitable. A decade from now, on test floors and maybe even in some design labs, you'll still see instruments with IEEE 488 connectors and cables, but you'll probably have to look around for a while to find them.

The main reason that IEEE 488 will survive for so long is that, for years to come, many instruments with IEEE 488 ports will continue to perform useful work for their owners. Instruments such as benchtop DMMs measure quantities such as volts, amperes, and ohms, which will not change in 20 years—or ever. Sure, newer DMMs will be faster, more accurate, and less expensive and will measure lower currents and higher resistances, but if you own a DMM that meets your needs and still reliably meets its specifications, you require a strong incentive to replace it. On the other hand, some types of instruments, such as oscilloscopes, change more rapidly. Signal speeds continue to increase, making wider bandwidth scopes

AT A GLANCE

▷ Most test-and-measurement-industry observers believe that IEEE 488's days are numbered, but that the number will be well in excess of 3000 days.

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▷ The two top contenders for the instrument-interfacing standard of the future are Ethernet and USB. You can find one or both in many instruments.

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▷ The industry is hard at work to ensure that the switch to new communication protocols will be nearly painless. Existing instrument-control routines should work without modification with the computer-standard protocols.

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▷ Don't be fooled by the new protocols' high nominal bit rates; instrument interfacing usually involves short messages. In such service, IEEE 488 can be significantly faster than protocols that at first appear to be much faster than IEEE 488.

necessary. Scopes that offer communication ports other than IEEE 488 are becoming increasingly common. The result of the need to intermix old and new instruments will be increasing numbers of instrumentation setups that also intermix communication protocols (**Figure 1**).

The current and most likely future leader in replacing IEEE 488 is Ethernet. USB will also play a major role; indeed,

several of Agilent's latest instruments support USB 2.0 and, because USB 2.0 is backward-compatible, they support USB 1.1 as well. Another external serial bus, FireWire, also known as IEEE 1394, no longer appears to figure significantly in the future of instrument interfacing, even though it is technically superior to USB, including USB 2.0. The reasons are primarily political.

Thanks to a more efficient protocol and in spite of a raw bit rate 20% lower than USB 2.0's, FireWire—even in its initial implementation—is faster than USB 2.0. Subsequent versions of FireWire will be still faster. Moreover, unlike the host-centric USB, FireWire, with its peer-to-peer topology, seems tailor-made for test-and-measurement systems that include both a host computer and instruments such as modern oscilloscopes and logic analyzers, which contain their own computers. (By enabling several computers to share control of the bus, the new OTG (On The Go) extension of USB 2.0 should at least partially overcome FireWire's advantages in applications that embody multiple computers that can act as hosts.) But, whereas manufacturers need not pay royalties to use USB in their products, using the patented FireWire technology requires royalty payments. The royalty situation together with the influence of a few large companies that back it has enabled USB to leap ahead of FireWire in test-and-measurement applications.

Figure 1
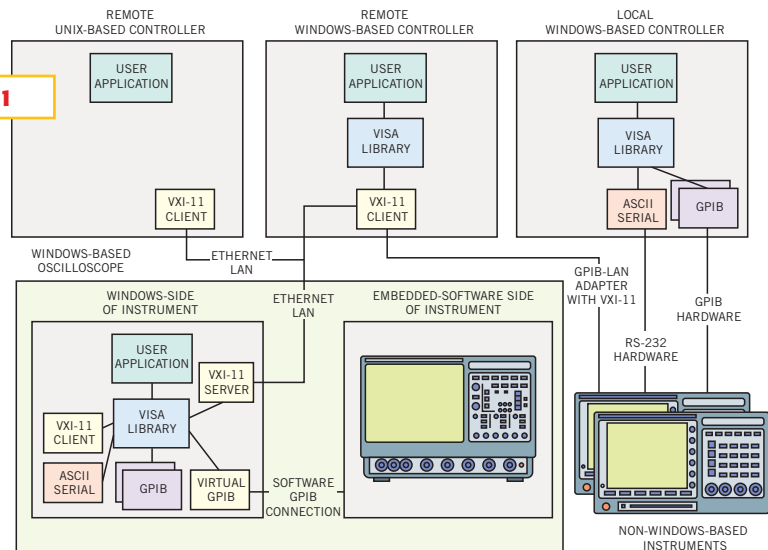
The software architecture of a system that incorporates IEEE 488 and RS-232 interfaces can appear daunting, but, with modern development tools and instrument drivers, application development is generally less difficult than this diagram suggests (courtesy Tektronix).

The most obvious reasons for turning to computer-standard interfaces in place of IEEE 488 for instruments are cost, size, cable length of instrument networks, and increasing difficulty of installing specialized peripheral controllers in newer PCs. Here, "PCs" refer not just to laptops, but also to the new breed of small desktop machines in "sealed" enclosures. Greater speed, an apparent advantage of the newer interfaces, is often an illusion, however (see **sidebar**, "Un-

derstanding instrument I/O: performance and protocols"). In fact, in typical instrumentation applications, which involve short messages, IEEE 488, rather like the tortoise that won the race with the hare, can prove faster than protocols that are nominally hundreds of times as fast. Besides speed, the most important reasons for staying with IEEE 488 are the existence of such a large infrastructure supporting it, instruments' long service lives, and the physical ruggedness of

IEEE 488 connectors and cables.

Industry groups and software vendors are hard at work on the infrastructure problem. They aim to make customers' libraries of control routines work without modification through the PC's USB or Ethernet port and the corresponding ports of instruments that lack IEEE 488 interfaces. Moreover, several companies now offer external adapters, which let PCs that provide only USB or Ethernet ports and lack IEEE 488 ports control in-

UNDERSTANDING INSTRUMENT I/O: PERFORMANCE AND PROTOCOLS

By Joe Mueller, Agilent Technologies

With alternatives to IEEE 488 becoming available for instrumentation, understanding the impact of selecting new I/O approaches is sometimes difficult. Although most engineers are aware of the convenience and cost benefits of computer-standard I/O, it is also important to understand how an I/O approach will affect system throughput and the impact of various protocols on a system.

Formally, protocols are the conventions that you establish on both ends of the interface to accomplish a task. For these purposes, the most important issues are the types of tasks the system performs. Today, the major protocols for instrumentation are those that transmit ASCII strings, or SCPI (standard commands for programmable instruments).

IEEE 488 intrinsically supports ASCII communication. The two primary protocols for network-based instruments are VXI-11, which provides thorough emulation of such IEEE 488 capabilities as device clear and serial poll; and TCP/IP (Transfer Control Protocol/Internet Protocol), or "sockets," which provides only ASCII communication.

The USB implementers' forum has recently completed defining the USBTMC (USB Test and Measurement Committee) instrument protocol. When you use it with the USB488 protocol, USBTMC provides comprehensive IEEE 488 emulation.

Table A shows typical performance of several interfaces implemented in typical instruments communicating with a high-speed computer. Hardware limits the IEEE 488 values, which will not improve significantly over time. On the other hand, the Ethernet values scale with the processor speed, so new high-speed devices will be a factor of five to 10 times as fast on both the transfer-rate and 10-byte-turnaround benchmarks. The USB performance will also scale, but less dramatically than Ethernet.

TRANSFER RATE CAN MISLEAD

Many I/O-performance evaluations focus on the maximum transfer rate. Transfer rate is obviously important when you try to estimate how long it takes to transfer large blocks of data, such as an oscilloscope trace. However, in many applications,

the system sends more short transactions than long ones. In these cases, the time to do a short transaction is a better predictor of the I/O performance.

The 10-byte-turnaround test measures how long it takes to send a 10-byte query and then read a 10-byte response. This test shows the software and protocol overhead to set up a transaction. Even when the messages are hundreds of bytes, the time to set up the transfer is usually greater than the actual data-transfer time. The total time to query a large block is roughly the turnaround time plus the number of bytes transferred divided by the transfer rate.

In spite of the cost and speed benefits of computer-standard I/O, the availability of additional protocols provides another compelling reason for engineers to move away from IEEE 488. Some protocols of particular interest to test and measurement are:

Browser interface (http): At first, you may not understand why you might want an instrument to produce a Web page. However, a couple of exciting applications are copying an image of the instrument's front panel directly into a report, or being able—from home or from around the world—to check the status of an experiment running in a lab.

RPCs (remote-procedure calls): These calls enable functions called in one computer to execute in a remote computer. Computer systems commonly use RPCs as building blocks for high-level protocols and distributed systems. For test and measurement, RPCs relieve you of dealing with the complexity of SCPI or creating external instrument drivers. With RPCs, your program calls a high-level function that executes in the instrument, eliminating the need to create a driver to translate function calls into SCPI commands.

File-system protocols: These protocols provide a way for an instrument to present its internal data as files on your computer. When you use this technique, measurement data and screen images from the instrument are simply files that you can copy from the instrument to the your computer.

Although all of these protocols are available, many instruments still lack them. As these and other protocols become more common and I/O performance increases, instruments will increasingly move to computer-standard I/O.

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TABLE A—TYPICAL TRANSFER RATES OF SEVERAL I/O APPROACHES WITH TYPICAL INSTRUMENTS

Interface	Transfer rate	10-byte turnaround time
IEEE 488	500 kbytes/sec	600 msec
USB (USBTMC-USB488)	10 Mbytes/sec	700 msec
100-Mbps Ethernet (VXI-11)	1 Mbyte/sec	2 msec
100 Mbps Ethernet (TCP/IP)	4 Mbytes/sec	600 msec

struments whose only interface is an IEEE 488 port. The compatibility that the software libraries and port adapters make possible is exactly what you need to economically and quickly build instrumentation systems that mix communication protocols.

Using an instrument as a Web server is one aspect of 21st-century instrument interfacing that nobody could have envisioned when HPIB's developers invented the bus. Web-server technology is particularly well-suited to instruments that connect to Ethernet networks and that use TCP/IP (Transfer Control Protocol/Internet Protocol).

In one sense, some proponents of Web-based test and measurement have made more of this technology than is justified. It's true that Web-server technology has become so compact and inexpensive that individual sensors costing no more than a few hundred dollars each can transmit Web pages that users can view via the browser software of any Web-enabled PC. Still, the approach quickly becomes unmanageable in applications that involve more than a few sensors.

Applications involving hundreds and even thousands of sensors are common. To aggregate the multiple device outputs into a Web page that portrays the data in a form that users can understand, these applications need software that can't reside within individual sensors. If more than a few users are to view the data, the best arrangement is to let the computer that controls the test setup aggregate the data and serve the Web page. Thus, though inexpensive, servers embedded in

The 33220A function/waveform generator is one of the first instruments from Agilent Technologies to incorporate a USB 2.0 interface.

the sensors still constitute overkill.

For test instruments, an advantage of an Ethernet connection over a USB or IEEE 488 connection is Ethernet's much greater allowable cable length. Ethernet LANs—even using gigabit-per-second Ethernet technology—can span thousands of feet. USB and IEEE 488 are limited to tens of feet. Although the shorter cables are usually adequate for linking units mounted in several adjacent equipment racks, the IEEE 488 and USB approaches can fail if the computer that controls the test setup is not adjacent to the instrument racks.
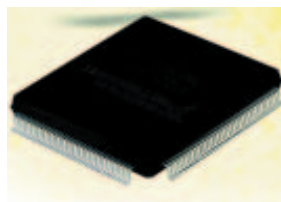
Engineers have often solved this problem by assigning the instrument-control functions to a computer near the test equipment and using Ethernet to link this control computer to the

The National Instruments TNT5002 combines IEEE 488 control with a PCI interface.

more distant host, which might perform data reduction and provide the user interface. Now, however, you can often eliminate the separate control computer. To do without it, the instruments must

include their own Ethernet interfaces, or the system must include an adapter that communicates with the host via Ethernet and with the instruments via IEEE 488 or USB. This adapter can be small and is usually less expensive than a PC.

Bear in mind, though, that if your test equipment generates a lot of network traffic by sending large amounts of data to the host, it may be inappropriate to share the Ethernet LAN with other users. Despite the seemingly huge bandwidth of 100-Mbps and 1-Gbps Ethernet LANs, you may find that your test setup must have a control computer close to the instruments, and, to keep traffic on the shared network manageable, the control computer must reduce the data before transmitting it to the host.

TURNABOUT ISN'T ALWAYS FAIR PLAY

When you use USB as your instrumentation bus, a feature that at first appears to be a USB advantage can turn into a complication if you configure your system differently from the way USB's system architects envisioned. In the absence of not yet widely available OTG capabilities, USB is a host-centric bus. If one of your instruments is built on a PC, as are today's highest performance digital oscilloscopes and logic analyzers, the instrument can act as the host PC for your computer-controlled test setup. But, if you want to use a separate computer as the host, the host can't use USB to communicate with the computer-based instrument, because such an instrument's USB port is the wrong type. The developers of USB, including USB 2.0, intended it to have one computer per bus, and that computer had to be the host.

To make the PC-based instrument act as a USB peripheral and not a host, you need hardware that isn't commonly available—an I/O adapter card that contains a USB-peripheral connector and peripheral controller—and you need to modify the BIOS firmware on the computer-based instrument's PC motherboard. For many PC-based instruments, a more convenient approach exists, however. If the instrument's PC motherboard contains an Ethernet port, as many do, you can use that port for communication with the host and you can use the PC-

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FOR MORE INFORMATION...

For more information on Ethernet, USB, or IEEE 488 hardware or software products for instrument interfacing, go to www.edn.com/info and enter the reader service number. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

Adept Scientific Inc
www.adeptscience.co.uk
Enter No. 301

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Agilent Technologies
www.agilent.com
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Capital Equipment Corp
www.cec488.com
Enter No. 303

Dataq Instruments
www.dataq.com
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Data Translation
www.datx.com
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Dewetron Inc
www.dewamerica.com
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Fluke Corp
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ICS Electronics
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IOtech Inc
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based instrument as the test setup's control computer. You can't, however, use this elegant approach if the manufacturer designed the PC-based instrument's embedded software to make the instrument a closed system, which performs only the primary instrument functions. One vendor designed its older PC-based scopes in exactly this way.

National Instruments' business started with IEEE 488 interfaces and grew to include what is probably the industry's widest array of data-acquisition and modular-instrumentation hardware as well as a broad assortment of data-acquisition and test-and-measurement software. LabView is the company's best-known software package and probably its best-known product. Nevertheless, despite all of the other businesses it has entered, NI continues to supply IEEE 488 interfaces and gives no indication that it will curtail its efforts in this area any time soon. In fact, it has just introduced an IEEE 488-interface IC, which it will use in its own hardware products and will resell to companies that continue to design IEEE 488 interfaces into test-and-measurement products. By combining IEEE 488 and PCI connectivity as well IEEE 488 transceivers in one chip, the TNT-5002 helps instrument manufacturers simplify instrument design. On a pc board, the chip occupies less room than do the traditional three or four chips, thus making instruments easier and less expensive to manufacture. The chip uses a 3.3V PCI core, supports both 3.3 and 5V signaling, and complies fully with revision 2.2 of the PCI local-bus specification. A development kit containing 24 chips costs $600.□

Author's biography
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Reference
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