

Instrument-grade Data Acquisition with Ethernet Brings Precision Measurement and Control to Networks

Amid the turmoil of evolving instrument capabilities, PCs losing expansion slots, and challenges to tried-and-true software and operating systems, users of computerized data acquisition (DAQ) systems are still searching for a solution to an old puzzle. In an industrial world that feels increasing pressure to operate as efficiently as possible, they seek ways to extend the reach and precision of their DAQ hardware, and to consolidate control to a single computer system.

Earlier approaches to distributed measurement and control had significant drawbacks. Historically, data acquisition cards, external DAQ systems, and instrument racks have been deployed relatively close to corresponding computer systems, as well as the sensors and signal sources to be monitored. Typical data acquisition solutions have offered limited measurement resolution (usually 12 to 16 bits), which could lead to expensive false failures and low production yields. While it's theoretically possible to locate a PC controller and higher resolution GPIB-equipped instrumentation at each required monitoring point, such distributed DAQ solutions are expensive and have been limited to dedicated PCs serving data on the network. GPIB is the most common bus architecture used in instrument-based test and measurement applications, but the prohibitive cost of this approach makes it impractical for large distributed DAQ systems. And, although bus standards such as RS-422 and RS-485 make it possible to operate DAQ hardware several hundred feet from a computer, the complete system frequently involves adapters, extenders, and other hardware that increase complexity and cost. Furthermore, other system requirements can collectively make it more desirable, or even necessary, to go with a bus standard that provides for less distance.

Factories, offices, and indeed, the whole world, have become more "connected" through use of local networks and the Internet, which promises virtually unlimited distance. Tying existing measurement instrumentation into a facility's existing network using Ethernet converters might seem like an obvious solution, but this approach also has drawbacks. The use of Ethernet

converters adds another layer of integration, maintenance, and troubleshooting complexity, and can cost up to \$1000 per converter for each GPIB instrument or test location. It should come as no surprise, then, that integrating an Ethernet interface directly into instrumentation is gaining ground as the next preferred data acquisition bus architecture.

Typical Application Requirements

Production and quality engineers in electronic manufacturing facilities rely on burn-in/stress testing (often referred to as HALT/HASS testing) to ensure long-term product reliability. Performing these tests efficiently demands the ability to make remote measurements in widely distributed burn-in chambers from a central location. These tests typically require repeatable, traceable measurements of parameters such as voltage, resistance, and temperature over multiple channels per monitoring site. Many burn-in test sequences require hours or days to complete, so long-term equipment reliability and data security are critical. In a typical industrial environment, process and field engineers always attempt to increase the efficiency and profitability of industrial equipment such as generators, engines, pumps, motors, and they run preventative maintenance tests constantly. Multiple channels must be monitored continuously for extended periods, often in noisy or hard-to-reach environments where PCs and operators are impractical. Control signals are necessary to support pass/fail alarms to alert supervisors of problems. In R&D/university labs, users need remote diagnostics, multiple channels of accurate measurements, and a modular, easily scalable form factor in order to validate and characterize system designs or monitor the lab environment (relative humidity, CO, O₂, and volatile gases).

When measurement points are widely scattered or difficult to reach, it becomes more difficult to monitor hardware or intervene if problems arise. Noisy or harsh industrial environments can interfere with measurement precision, requiring the use of expensive noise-rejection circuitry and specially hardened enclosures to withstand caustic, smoky, or otherwise hazardous conditions.

Who Moved My Slots?

Another incentive for the move to integrated Ethernet instrument solutions is being driven by developments in PCs. According to computer industry gurus, in the not-too-distant future, PCs will no longer contain expansion slots, and all communication with the system will take place over external buses. Older DAQ systems and PC architectures will persist, if for no other reason than industries are full of such systems that are still perfectly functional. However, new installations will require new PCs.

The leading contenders to replace current peripheral buses (GPIB, parallel, and RS-232 serial) are the Universal Serial Bus (USB) and FireWire (IEEE-1394). Both offer high speed, but are limited to a distance of approximately 50 feet (15 meters). Hubs are necessary to patch together individual cable drops in order to achieve longer distances. Total peripheral counts are 127 for USB, and 63 for FireWire. A more ideal bus solution would offer longer

distances, along with easy implementation and low cost. Ethernet satisfies these and several other related needs with the best of all worlds; it is common, extremely fast, inexpensive, and capable of long distance communication. Given that Ethernet is common now in business environments, it is almost assured that PCs will contain built-in Ethernet ports as well.

Platform Independence

Ethernet also increases the options users have for controller platforms and operating systems. Microsoft Windows® running on a PC currently reigns as the platform of choice for DAQ, but it is not preferred by everyone, and also is not the most compatible solution for all enterprises and applications. Other computing platforms and operating systems exist; notably, Apple machines, workstations, mainframes, Unix, Linux, DOS, etc. In the past, making DAQ technically and economically feasible meant limiting such products to a few, most prevalent computing environments. At the present time, attempting to mate data acquisition with alternative platforms almost universally means the use of an external DAQ instrument, for which hardware interfacing and software are still required. By having DAQ communicate using Ethernet, half of the problem is eliminated. If the user can connect the DAQ hardware to a system with an Ethernet port, completing the system becomes an exercise in developing programs that can send commands and retrieve data.

Timing and Control

One aspect of DAQ that is closely tied to the operating system is the response to external triggers and other types of stimuli. Systems in which a certain maximum response time can be guaranteed are said to be “deterministic.” By knowing this maximum response time, programmers can design programs to operate predictably, and also avoid applications in which the system is incapable of providing the required timing and control precision.

Microsoft Windows is a message-driven, event-polling system with non-preemptive scheduling, which means that it can't guarantee interrupt response times, and thus, does not have deterministic performance. For those applications requiring a response in minutes or even seconds, Windows might work fine, but a time-critical application that encounters long or unpredictable delays might fail.

Classically, the solution to real-time control with Windows has been to equip internal DAQ cards or external DAQ systems with self-contained microprocessor and timing hardware that can operate independently of the PC. This arrangement becomes even more necessary with Ethernet-based DAQ, because networks themselves are typically non-deterministic as well. Ethernet can transfer large blocks of data more efficient than small blocks. For that reason, a large memory buffer is highly desirable with network instruments so the data logger can autonomously buffer data without the need for frequent PC intervention or tying up the network.

On-board timing and processing is also necessary because, without full-time reliance on the controlling PC, the DAQ system must take a more active role in supplying conditional logic, triggering, and other supporting control functions. Many applications depend on pre-programmed alarm limits and analog triggers to allow automatic notification when critical events occur. In Ethernet-based systems, instruments must assume more of the burden for these services.

Advantages of Ethernet

Current generation Ethernet protocols transfer data at 10Mbits and 100Mbits per second. A speed of 100Mbits per second is approximately 10Mbytes per second, which is ten times faster than GPIB. More exotic Ethernet standards are being developed that provide 1Gbit and 10Gbits per second. Thus, there is some promise of even faster protocols with Ethernet, although new interfacing hardware may be needed. Conversely, the maximum speed for GPIB will probably never exceed 1Mbyte per second. An attempt to adopt a faster version GPIB a few years ago was largely unsuccessful, as manufacturers and users seemed unwilling to trade the robustness of the proven GPIB bus standard for a modest speed increase.

Ethernet also provides for simple, convenient connectivity. Cabling, connectors, hubs, and tools are readily available to permit wiring cable drops or whole facilities relatively quickly. Many enterprises are already wired with LANs, so large networks of distributed DAQ instruments can be set up without requiring the construction of a completely new network infrastructure. See *Table 1* for an overview of the differences between traditional data acquisition and ethernet-based solutions.

Recent Trends in Data Acquisition Hardware

Computerized DAQ systems have come a long way in terms of speed, resolution, accuracy, and overall performance in the two decades since they were introduced. Initially, the measurement world was split into two camps, and each made certain concessions to get what it wanted. Those who needed high resolution and accuracy of instruments gave up the speed, versatility, and economy of computerized data acquisition systems. Those who needed high channel counts, mixed signals, high speed, and relatively low cost-per-channel went with computerized DAQ, but usually resigned themselves to 3½- or 4½-digit resolution and proprietary bus architectures. Today, these seemingly conflicting sets of capabilities are converging in the form of multi-channel DAQ systems designed to operate on standardized buses such as GPIB, RS-232, and, most recently, Ethernet. Such systems vary in their operating convenience, channel counts, performance, and capacity to deal with mixed signal types. However, all of them embrace standardized communication interfaces. At the cutting edge of this trend is the DMM-based data acquisition system, which typically offers all the operating conveniences and display of a high resolution DMM that give such instruments their versatility and measurement integrity:

- 6½-digit (or better) resolution—The equivalent of 22-bit A/D conversion provides more sensitive measurements than 12-, 14-, and 16-bit A/D converters used in DAQ cards and many external systems.
- Integrating A/D conversion—Inherently superior at rejecting noise than successive approximation A/Ds used in most DAQ boards and in some external DAQ systems.
- Signal conditioning—Built-in excitation and filtering for various types of sensors simplify test setups.
- Built-in math functions—Automate the process of converting voltages and currents to engineering units and physical measurement parameters.
- Additional test capabilities—In addition to basic DC voltage and digital I/O, typical DMM-based data acquisition systems include measurement/control functions not found in conventional boards and systems, such as sophisticated DC current measurement, AC volts and current, two- and four-wire resistance, temperature (thermocouples, RTDs, or thermistors), frequency/period, event counter, totalizing, and continuity.

Unlike a typical desktop DMM, a hybrid DMM/DAQ system can include expansion slots to accept additional signal conditioning or switching modules that increase the number of available input channels.

The addition of a built-in Ethernet interface provides transmitter/receive capability and the ability for the system to be assigned an IP address. Once this is accomplished, an Ethernet-equipped computer or controller can talk directly to the instrument via Ethernet. The package can be fine-tuned with features such as expanded data memory, automatic setting of IP address, and an alternate interface (e.g., RS-232).

System Topologies

There are a number of network topologies for communicating an Ethernet-based data acquisition system, as shown in *Figures 1–4*. All of them can reduce networking costs because they use only one computer, as compared to traditional systems, where a separate computer/controller may be needed with each instrument or DAQ system.

Table 1. Traditional vs. Ethernet-based instruments

CRITERIA	TRADITIONAL SOLUTIONS	FUTURE WITH ETHERNET
Resolution	DAQ cards & data loggers with 10, 12, 14, or 16 bits of resolution (3½ to 4½ digits)	DMM-like DAQ systems with up to 22 bits (6½ digits) or more of resolution.
Storage capacity	DAQ cards—used PC memory or on-card FIFO. Data capacity depended on RAM.	Data loggers—onboard memory—Typical capacity for tens of thousands of readings. Stand-alone instruments with extra data memory to hold hundreds of thousands of readings.
Processing	PC processor and software, or self-contained processor and firmware	On-board processing, timing, signal conditioning, math functions, autonomous control operation.
Timing	Traditionally non-deterministic bus—Boards and external DAQ systems have relied on internal clocks for sample timing	Ethernet is also non-deterministic bus, but instruments control their own sample rates and timing.
Computer/controller requirements	DAQ cards—generally, one PC per card or group of cards. Data loggers and instruments—varies from one to several instruments per PC.	One PC per tens of instruments. Less PC, less cost, less maintenance. More productivity
Interfaces	DAQ Cards—straight to PC bus. Data loggers and instruments—proprietary interface cards, GPIB, RS-232, parallel.	Ethernet—simple connection via standardized networking connectors.
Transfer Speed	Sustained rates via GPIB of 1 Megabyte per second.	10 and 100 Megabits per second.

Direct Connection PC to Ethernet Instrument

A direct connection of computer to DAQ system is the simplest of all Ethernet-based schemes, and resembles the usual GPIB or RS-232 topology. Distances of up to 100 meters are possible.

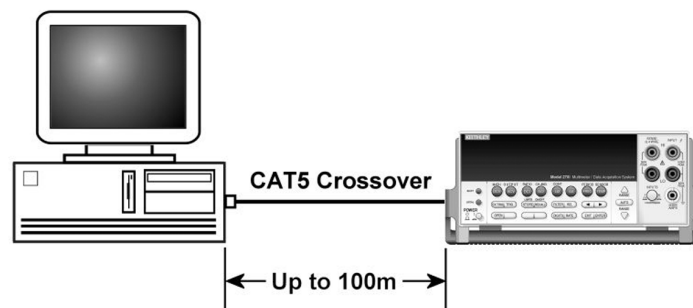


Figure 1. PC direct to Ethernet instrument – Straight-through connection provides ease and convenience

PC to Hub to Ethernet Instrument

The addition of a hub to the topology (Figure 2) allows the controlling computer to access other Ethernet resources in addition to DAQ system(s). Maximum distance is increased to 200 meters from the computer to the DAQ system (100m to and from the hub).

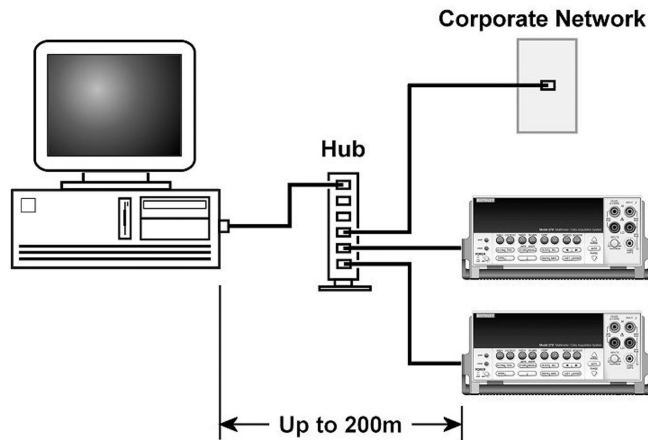


Figure 2. PC to Hub to Ethernet – connect or change data acquisition without affecting connection to Internet or corporate network

PC to LAN to Ethernet Instruments

A topology ideally suited to an installed, enterprise-wide DAQ network is shown in **Figure 3**. Multiple DAQ systems can be distributed about a plant to gather data and send them back over the network to a centralized computer. Distance is limited only by the size of the network.

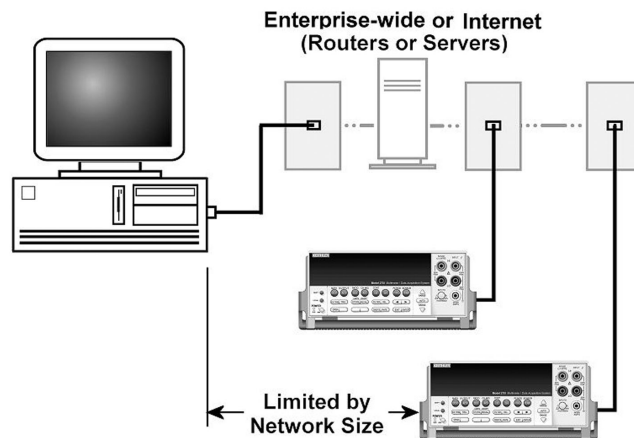


Figure 3. PC to LAN/Internet to Ethernet instruments

PC to Internet to Ethernet Instruments

Virtually unlimited distance for distributed data acquisition is possible by using the Internet in place of the LAN shown in **Figure 3**. Ethernet instruments can be set up anywhere in the world where Internet access is available. However, firewalls would have to be managed to allow access to IP addresses outside of corporate networks.

PC with Multiple NICs

The final example of Ethernet topology is the use of two or more network interface cards in the PC. This arrangement (*Figure 4*) creates a separate instrumentation sub-network that isolates data acquisition results from other information on the corporate network. In this way, users who don't need to access instrumentation data can't inadvertently communicate with the instruments.

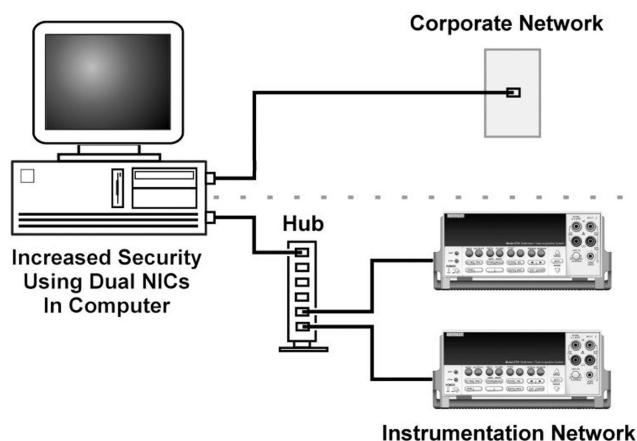


Figure 4. PC with dual Network Interface Cards

Conclusion

The combination of instrument-grade, DMM-based data acquisition hardware and Ethernet interfacing opens exciting possibilities for constructing cost-effective DAQ systems that can gather data from all over the world, and report results back to a central controlling computer. Additional benefits, such as measurement integrity, versatility, simplified programming, and true computer platform independence can also result from this combination. Perhaps more important, DAQ with Ethernet eliminates many of the mutual compromises that are imposed by other DAQ architectures. Now, engineers and researchers can enjoy the best of all worlds, with high measurement resolution, high channel counts, expandability, and intelligence in the DAQ system that can be distributed over long distances.

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