LXI: A SHIFT IN THE FUNCTIONAL TEST PARADIGM

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Abstract- LAN-based instrumentation, leveraging the advantages that LXI (LAN eXtensions for Instrumentation) has to offer, has resulted in a paradigm shift in functional test methodology. The early days of test program design involved utilizing test instrumentation with parallel interfaces such as IEEE-488. These interfaces were slow and had limited bandwidth, but the response to individual message queries was relatively quick and ideal for multiple command-response sessions used for setup, control, and data gathering purposes.

The very nature of LAN-based instrumentation requires a re-evaluation of this approach and with it the classis test paradigm. The TCP/IP protocol stack, triggering, synchronization, security, and inter-device interaction are fundamental areas of LAN-based test that provide tremendous opportunity, but also involve understanding any subtle differences that may exist.

Other parallel advances in instrumentation such as powerful inexpensive digital signal processors, FPGA devices, and large onboard memory also has changed the way particular test sequences are implemented. The need to rely on the host computer for processor intensive operations is no longer needed, and therefore reduces the burden on both the communications interface and the host.

This paper will address how the adoption of LAN-based instrumentation changes the way test engineers approach test program set (TPS) design. It will also provide recommendations to leverage the strengths that LAN-based test has to offer.

A NEW INTERFACE EMERGES

Faced with the growing need for a replacement for an aging IEEE-488 (commonly known as GPIB), the instrumentation community established the LXI Standard. It provides the flexibility and performance common on backplane-based implementations, such as VXIbus, to the next generation of small to medium sized systems. (See Figure 1). LXI-based instrumentation also provides an ideal distributed measurement architecture.

The LXI Consortium was co-founded in the fall of 2004 by VXI Technology, Inc. to address this need. Membership has since grown to nearly 50 leading test and measurement companies from around the globe, making LXI the fastest growing programmable instrumentation bus standard in the history of the industry.

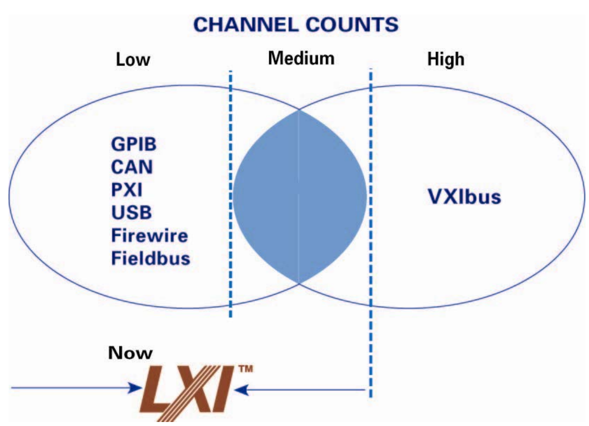

Figure1.

Ethernet has emerged as the choice for this next generation standard based upon technical merit and wide general industry acceptance of the interface by computer manufacturers and users. Technical advantages such as TCP/IP error checking, fault detection, long inter-device connectivity, ease of cable routing, and inexpensive networking hardware clearly make Ethernet an attractive alternative to current parallel bus and other serial-based interfaces. Many of the attributes that have made Ethernet so popular to the computer industry are also attractive to the instrumentation community; however, instrumentation manufacturers and users alike demand key functionality not typically associated with this vanilla flavor Ethernet.

Determinism, synchronization, triggering, device discovery, and predictable software driver interoperability are all essential functional requirements that extend beyond standard Ethernet. Different application areas will also drive other functional requirements, and these requirements can vary tremendously with applications ranging from bench top to functional test to distributed data acquisition. Concrete functional requirements are not the only aspect that must be considered, and this has been clearly demonstrated to many engineers as test system methodologies have evolved.

CROSS-PLATFORM FUNCTIONALITY

Test engineers are commonly tasked with integrating hardware utilizing different physical interfaces such as RS232, GPIB, MXI-2, and IEEE-1394. This combination of interfaces is inevitable because the best solution may not be available in a designated package, resulting in added complexity and integration time. Even though LXI-based instruments reside on a common inexpensive bus, and provide many attractive features, the need for cross platform integration will continue throughout the industry adoption cycle.

The Ethernet interface is platform and operating system independent, and is integrated into nearly every computer available on the market ensuring long-term stability. Even with this stability, it is still critical to characterize real-world use-case scenarios in order to determine if LXI can address all applications and, if not, what the alternatives are.

Mixing these various interface types requires an understanding of how each one operates, and how this inherent operation will affect the overall test sequence and performance for different applications. Several scenarios are easy to imagine:

- Slow cycle tests with long measurement aperture times
- High channel count tests with short aperture times
- Complicated instrumentation requiring extensive setup
- Large block data transfer requirements
- Tightly integrated instrumentation handshaking

The evolution of communication interfaces continues to drive the need to understand these types of issues, a task that test engineers are not unfamiliar with.

HISTORICAL TEST PERSPECTIVE

The introduction of the personal computer (PC), accompanied by GPIB instrumentation, resulted in a production test revolution. Smaller, inexpensive test stations were configured and maintained at a fraction of the cost of larger proprietary test behemoths. These new stations started to move towards open standards using the SCPI command language and were programmed with Basic or Quick Basic.

Both the PC and programming languages continued to evolve with processing speeds eclipsing many megaflops, and languages expanding to include C/C++, Visual Basic, and graphical environments such as HP VEE and LabVIEW. The increased program execution speeds were welcomed by all, but resulted in unforeseen troubles to the test engineer. Suddenly, stable proven test programs were failing when ported over to new computers with expanded RAM and faster processors.

It soon became apparent that timing was everything; typical functional test timing sequences that had executed flawlessly in the past now failed. The increased program execution speeds did not compensate for delays and settling times that were inherent in the older systems. As a result it became necessary to modify test sequences or insert delay loops to slow program execution. A typical sequence that encountered such difficulties was as follows:

- Close Measurement Path
- Configure Instrument
- Take Measurement
- Open Measurement Path
- Repeat

These problems can be attributed to a number of different issues such as program execution exceeding settling times, measurements beginning before instrument aperture times have been met, or streaming commands beyond the buffering capabilities of the device. Architectural changes, even as simple as improving PC speed, can have an observable impact on test execution. Even the most innocuous enhancements, such as adopting the most widely used open-architecture communications platform in the world, can have unforeseen consequences within the test community.

OPEN ARCHITECTURE

The advantages of adopting an open architecture test platform spans both hardware and software, providing a wide range of choices not available to those locked into proprietary designs. An open-hardware approach guarantees that a well-defined set of signal and interface characteristics have been adopted, and that multiple vendors will provide support and products. All of this results in reduced cost, extended test system life cycles, and commercial-off-the-shelf (COTS) product availability. The VXIbus is a prime example of the features that can be realized through open architecture designs; this platform continues to evolve providing viable high-density modular solutions utilizing other open-platform interfaces such as LXI.

The LXI Standard was designed with hardware independence in mind and this is largely accomplished by leveraging well established industry standards. The LAN interface for LXI devices is based upon IEEE 802.3 standards and it is intended to support current and future networks with 10/100baseT or faster connections. Utilizing this standard greatly reduces entry obstacles for instrumentation manufacturers primarily due to implementations that have been driven by the PC market. The very nature of this interface also makes it ideal for many distributed applications; standard CAT-5 copper connections can reach 100 meters point-to-point and fiber optic implementations can span several kilometers without additional switches or routers.

Open software support also plays an important role in reducing development costs and ensuring life cycle management. Software independence is built upon well-defined standards such as the familiar plug&play and IVI driver sets. This is further extended into the application development environment providing the freedom of choice to select software environments best suited to meet specific needs.

Even with all of the benefits of the LXI platform listed above, there are inherent differences between this TCP/IP Ethernet-based interface and other serial and parallel interfaces currently in use. Understanding these differences will simplify the integration task greatly.

INTERFACE PROTOCOLS

The LXI Standard is based on TCP/IP, a set of protocols, notably UDP and TCP, which were defined for the ARPAnet and now form the basics of Internet communication. Briefly, the protocols specify how hosts are addressed, how messages find their way between hosts (i.e., routing), and the general formats for those messages. The IP protocols form the Network Layer, Layer 3 of the ISO OSI Model, and TCP and UDP form Transport Layer 4.

ISO OSI Network Model
Layer 7 - Application
Layer 6 - Presentation
Layer 5 - Session
Layer 4 -Transport
Layer 3 - Network
Layer 2 -Data Link
Layer 1 - Physical

TABLE 1.

TCP is connection-oriented, setting up a persistent connection between two hosts, and it is reliable. Reliable in this case means that an application that sends a message via TCP will know if that message is received at the other end. TCP uses a number of techniques to guarantee delivery: requiring messages to be acknowledged, automatic retransmission of missed messages, and timeouts to detect missed messages and hosts that are unavailable. With all of these features it should not be surprising that TCP has a larger message overhead when compared to other interfaces; this is commonly referred to as first-byte latency.

The robustness and high data transfer rates of TCP/IP communications is clearly ideal for instrumentation interfaces, but what affect will the overhead of communication transactions have on a typical test sequence? Furthermore, are there instances where such an interface will greatly outperform current systems or not offer any relative advantage?

LXI TEST METHODOLOGY

Instrument Drivers

The very nature of TCP/IP communication favors large block data transfers that can leverage Ethernet's high data transfer rates, while minimizing the affects of first byte latency. A clear understanding of the measurement cycle, along with the capabilities of today's modern instrumentation, will identify where performance concerns may arise.

Legacy parallel instrumentation bus architectures, some based on ever-changing PC bus structures, favored programming techniques that maximized individual transfers. In some instances instrument configuration literally utilized millions of single byte data transfers. This programming approach was fairly inefficient, but performed well at the time. Adopting this approach for LXI-based instrument control would require significant overhead due to the first-byte latency associated with each setup message transfer.

Resolving this issue can be as simple as re-evaluating the instrument programming paradigm. Modern instrumentation is designed with significant on-board memory and processing capabilities unavailable in the past. Combining this enhanced processing capacity with improved instrument driver design will negate the impact of first-byte latency in this case; many small setup peak and poke commands are replaced with a single more comprehensive setup function call.

Table 2 identifies data transfer rates for various packet sizes and clearly the larger packet size transfers leverage Ethernet's throughput strength, while the effect of any first byte latency becomes negligible. The third column illustrates the transfer times involved if multiple 1 kByte transfers were used instead of single larger block transfers.

Packet Size (Byte)	Transfer Time (Sec)	Equivalent 1kByte Transfer Time (Sec)
1k	400 E-6	400 E-6
32k	6.5 E-3	12.8 E-3
4M	200 E-3	1.60

Table 2.

Test Program Sequencing

Another fundamental aspect of test system operation that must be understood is related to the actual time that is required to set up specific test sequences. A typical test sequence includes defining the signal path through a number of relays, configuring an instrument with the required aperture and settling times, initiating the measurement cycle, and returning the resultant value (See Table 3).

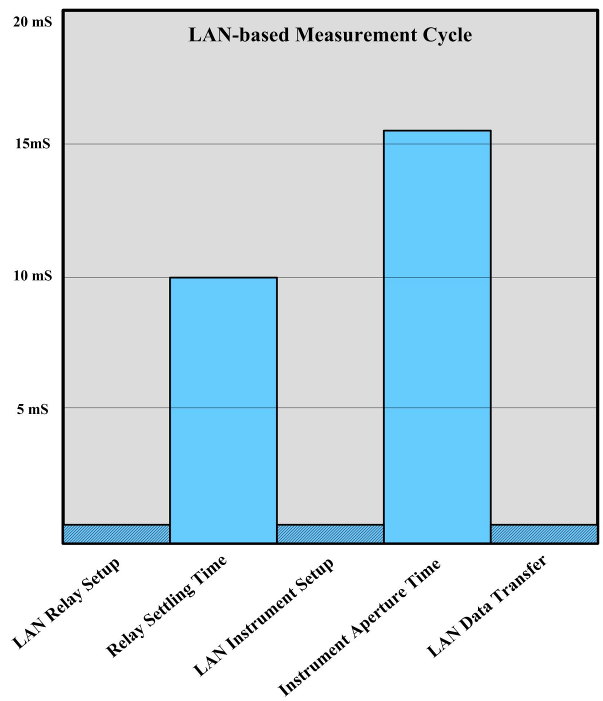

Table 3.

Actual results utilizing this type of comparison will undoubtedly vary relative to the types of instrumentation and switching utilized. Realistic comparisons relative to interface access times must include references to the overall test sequence if the results are to be meaningful. Table 4 illustrates a simple measurement sequence with sample comparisons of instrument and switching specific delays compared with communication access times. The results indicate that a common test sequence will have far greater instrument and switch settling latencies than any observed due to the communication protocol.

Setup Measurement Path (6 Relays, 1 Call)	Relay Closure / Settling Time	Configure Instrument & Initiate Measurement (1 Call)	Measurement Aperture Time (1PLC)	Return Measured Value (1 Call)
400 E-6	10 E-3	400 E-6	16.67 E-3	400 E-6
Complete Measurement Cycle Statistics				
Instrument Aperture Switch Settling Time			= 93.6%	
Ethernet Communication			= 4.4%	

Table 4.

There are other methods available to combine hundreds or thousands of test cycles, and the VXIbus platform is an ideal solution for this type of application. Instrumentation and switching devices each contain the intelligence to provide very deterministic synchronization between subsystems utilizing backplane trigger lines. Several function calls set up the instrument and switching path information, along with details regarding which trigger lines will be utilized for handshaking. A single command then begins the sequence and no further program intervention is required until the sequence is complete and data is read from the instrument.

Utilizing sequences such as these, referred to as scan lists, completely eliminates all test program intervention and leverages stored values relative to relay settling time, instrument aperture settings, and relay closure paths. A test sequence measuring hundreds of voltages routed through various multiplexers could be streamlined and effectively eliminate all interface overhead.

This functionality is easily integrated into the LXI environment utilizing a bridge device such as VXI Technology's EX2500 Gigabit Ethernet Slot-0 Interface. The EX2500 is a Class A certified interface providing all of the synchronization and triggering inherent in LXI devices, in addition to providing access to the highly integrated features available with VXIbus instrumentation.

Access to the VXI trigger subsystem, through the LXI TriggerBus hardware trigger interface, also simplifies integrating other LXI devices, as well as legacy instrumentation, into the VXIbus environment. This inherent instrument-switch interaction is also enhanced by on-board VXIbus measurement intelligence, thus changing the way classic test sequences are viewed.

Enhanced Instrumentation

Advances in on-board processing power and large inexpensive memory resources have changed the way data is accessed and processed, further driving the need for a high-speed communication interface capable of performing large block data transfers. Many data acquisition applications are pushing the limits of measurement instrumentation, requiring multi-channel parallel ADC architectures to acquire data at hundreds of thousand of samples per second per channel. The functional test arena is experiencing this trend as well with the move to synthetic instrumentation, especially in RF and microwave applications.

For example, raw data transfers from a 24-bit, 16-channel digitizer operating at 100 kSa/sec/channel would result in 6.4 Mbytes of available data per second. If such an instrument is deployed in a VXIbus form factor there could be several additional cards operating concurrently. This type of scenario can leverage deep on-board memory resources capable of temporarily storing the acquired data, and then efficiently transferring it to the host computer utilizing large-block transfers over the local LXI-VXI bridge interface.

Expanded onboard processing capabilities have also changed the way that data is manipulated locally, prior to initiating a transfer operation. Local hardware processing, utilizing an on-board user-programmable digital signal processor (DSP), can improve total system performance when used for data reduction and mathematical manipulations (See Figure 1). Data manipulation, such as Fast Fourier Transforms (FFT), when performed on-board the digitizer can reduce raw data transfer requirements by orders of magnitude.

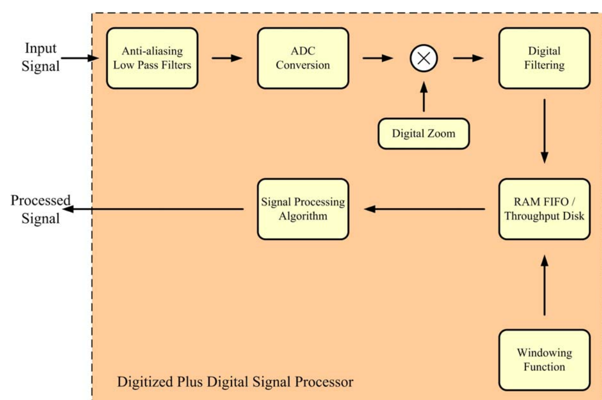

Figure 1.

Complicated mathematical operations across multiple channels can also be performed returning only the resultant values. This approach not only reduces overall data transfer requirements, but simplifies user application program development and maintenance.

CONCLUSION

LXI is the ideal replacement for GPIB-based instrumentation, and recognizing that subtle differences exist between parallel and serial interfaces will not only simplify the integration task but maximize the instrument's performance.

The LXI-based instrumentation interface provides many advantages over its predecessors, but it also presents the test engineer with new performance characteristics that must be considered and evaluated. Characteristics such as distributed connectivity, high bandwidth and data rates, and simplified cabling can be leveraged for many applications, but care must be taken to understand any inherent differences that may exist.