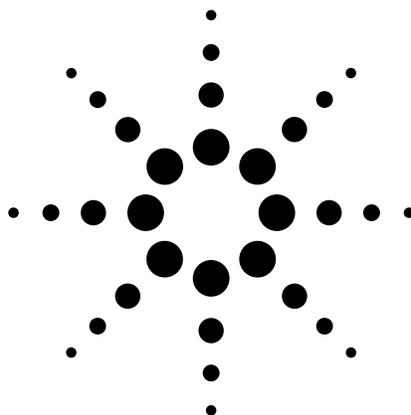


Using Synthetic Instruments in Your Test System

Assessing the benefits and tradeoffs

Application Note 1465-24



For decades, automated test systems (ATS) built around benchtop instruments have been the dominant architecture used in aerospace and defense applications. In the late 1980s, modular VXI-based systems addressed several shortcomings of the rack-and-stack approach. In particular, card-based instruments mounted in a multi-slot mainframe reduced the size and weight of systems. The speed and capabilities of the VXI backplane also enabled enhanced triggering and faster data transfers. However, all such commercial technologies tend to have lifecycles that are much shorter than a typical aerospace or defense system, possibly affecting long-term maintenance and support of an ATS.

These issues are the driving force behind an approach called synthetic instrumentation (SI). The concept is simple: SIs let you configure and reconfigure modular hardware and software elements to create the

functionality of multiple measurement devices. This building-block approach makes it possible to update or upgrade an ATS or a Test Program Set (TPS) by simply replacing a single module such as a digitizer or down-converter. It can also reduce the burden of software updates over the lifetime of an ATS.

Using Synthetic Instruments in Your Test System is the fifth in a series of application notes that will help you manage the shift to LAN eXtensions for Instrumentation (LXI) from GPIB, VXI or PXI. The purpose of this note is to help you assess the potential value of SI to your present or future requirements. To create context for the discussion, this note presents a brief history of SI, compares a rack-and-stack system to an SI-based system, describes the initial applications of SIs, and illustrates the emulation of conventional instruments with SIs. This note also includes a glossary of terms related to synthetic instrumentation.

Table of contents

Reviewing the roots of SI	2
Putting SIs in perspective	3
Assessing the situation	3
Weighing commercial applications	3
Overview: LXI	3
Comparing present and future solutions	4
Reviewing purpose and usage	4
Looking at current solutions	4
Understanding the SI approach	5
Deciding if SIs are right for you	6
Exploring the initial applications	6
Utilizing current SI devices	7
Recapping present and future value	8
Glossary/Acronym guide	9
Related literature	9



Agilent Technologies

Reviewing the roots of SI

In the mid 1990s, the U.S. Department of Defense (DoD) assigned the U.S. Navy the task of developing new types of ATS for the testing of avionics and weapons systems. This ongoing project has six driving goals:

- Reduce the total cost of ownership of ATS
- Reduce the time to develop and deploy new or upgraded ATS
- Reduce the physical footprint of each system
- Reduce the logistics footprint via decreased spares, support systems and training
- Provide greater flexibility through systems that are interoperable among U.S. and allied services
- Improve the overall quality of testing

These are ambitious goals but the DoD, defense contractors and equipment manufacturers believe they can be achieved over time by applying advances in commercial technologies. (LXI is one recent example.)

The greatest progress toward these goals is coming from the use of SIs. According to the Synthetic Instruments Working Group (SIWG)¹ a synthetic instrument is a reconfigurable system that links a series of elemental hardware and software components via standardized interfaces to generate signals or make measurements using numeric processing techniques. The key word is reconfigurable: the elemental blocks can be arranged and rearranged via software commands—and the signals rerouted via switching—to emulate one or more types of traditional test equipment.

To make it work, an SI will contain as many as four major components: signal conditioners, frequency converters, data converters and numeric processors. The basic block diagram shown in Figure 1 describes most microwave instruments, including spectrum analyzers, frequency counters, network analyzers and signal generators.

Unlike general purpose instruments, which are optimized to perform one task (e.g., spectrum analysis or signal generation), the synthetic instrument architecture is optimized to provide greater efficiency in an ATS by reducing redundant elements such as the digitizers and downconverters found in multiple instruments used within current systems.

The DoD expects these SI modules to come from a variety of vendors, enabling easy mixing and matching as requirements change or modules become obsolete. What's more, any substitution of modules—replacement or “technology insertion”—should require only minimal changes to the core system software.

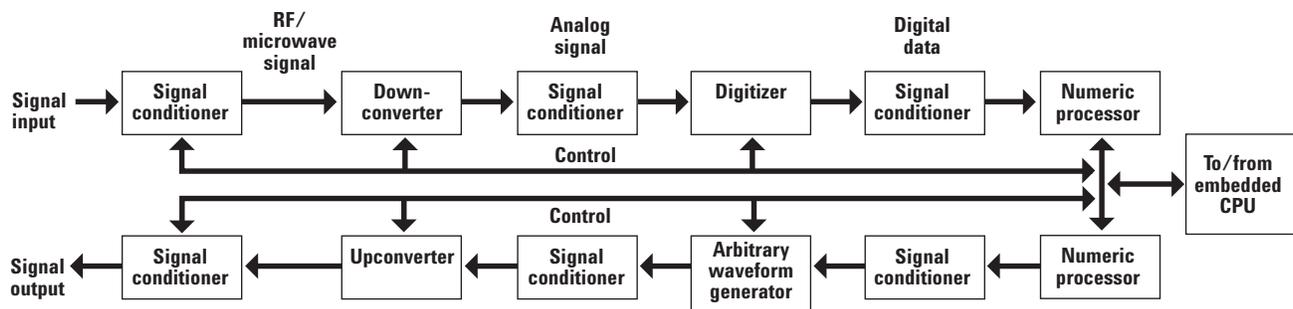


Figure 1: Basic architecture of an RF/microwave synthetic instrument

¹ Includes joint participation of the DoD, prime contractors and suppliers.

Putting SIs in perspective

SIs are clearly intended to address a specific set of needs that are especially important to the military—but may also be relevant to some commercial organizations. For example, if your company is bidding on a contract that requires or gives preference to the NxTest concept, then SI will be required. Longer term, commercial organizations that utilize outsourcing and offshore manufacturing may benefit from the use of SIs in test systems they define or provide.

Assessing the situation

Today, two gating items are modulating near-term adoption of SIs: hardware availability and software effort. Gradually, a wider variety of hardware is becoming available, and Agilent is in the vanguard of both SI and LXI. The LXI standard, which addresses the needs of synthetic instrumentation, is perhaps the most promising platform for SI due to the potential longevity of the LAN interface.

Software is another matter. Currently, substantial effort is required to create the software modules that provide essential functionality such as the measurements and calibration routines needed to replace a stand-alone instrument. There is also the time and effort required to support software written in-house. If you add to that the typical effort required to create the mainline test program or suite of TPS, then the total up-front development cost is acceptable only if SIs are required.

Looking ahead, SI vendors recognize the need for software tools that will reduce effort, accelerate development and ensure accurate, repeatable results. As these tools become readily available—and reuse of software modules more commonplace—the development costs for SI-based systems should decrease. However, vendors need to address one key issue: the interchangeability of software components. If vendor substitution is equally viable with both the hardware and software elements of SIs, then the major benefits of the NxTest vision will be within reach.

Weighing commercial applications

If you develop systems within a commercial organization, the business model for most automated test applications probably can't support the higher initial costs of developing SI-based solutions. Of course, this requires a case-by-case assessment—and only you can decide if the potential benefits outweigh the current tradeoffs. Some early adopters may find SI to be very useful in a specific application.

For many commercial organizations, the long-term promise of SI means it will be worth watching in the future. As more hardware and software modules become available, the economic benefits will increase for commercial applications.

Overview: LXI

LXI is the architecture for test systems that's based on proven, widely used standards such as Ethernet. By clearly defining the interaction of those standards, LXI enables fast, efficient and cost-effective creation—and reconfiguration—of test systems.

In addition to the reach of LAN, LXI makes it possible to control and monitor system hardware through a built-in browser interface—across the hall or, with commercial security tools, around the world. Advanced triggering and synchronization is enabled by LAN-based capabilities, a hardware trigger bus and the IEEE 1588 precision time protocol.

More information is available at www.lxistandard.org.

Comparing present and future approaches

Whether you view SIs as a near-term requirement, a long-term curiosity or something in between, a comparison with traditional approaches reveals some interesting highlights. Within the context of the DoD's driving goals, it is easy to illustrate the advantages of synthetic instruments versus GPIB, VXI or PXI solutions.

Reviewing purpose and usage

The main purpose for a military-related system is to test devices or assemblies in locations such as the flight line, an aircraft hangar or a repair depot. The same system may also be used in the original manufacturer's facility.

When the test system is fielded for military use, the top priority is to identify and replace defective electronic systems or assemblies as quickly as possible to return an aircraft or vehicle to operational service. The second priority is to repair the defective system or assembly and put it into the inventory of spares.

The usage model for such test systems involves rapid deployment, perhaps into areas of conflict. Putting the systems closer to the aircraft or vehicles they support translates into higher levels of operational readiness—and reduced downtime—for those aircraft or vehicles. In this scenario, flexibility and easy maintenance are more important than absolute measurement throughput.

Looking at current solutions

In this context, systems built around benchtop GPIB instruments, modular architectures such as VXI and PXI, or a combination, have noteworthy advantages and disadvantages.

GPIB instruments: The foremost advantage of these devices is the combination of measurement capabilities, performance, accuracy and repeatability contained in one unit. Essentially every type of measurement from DC to low frequency to RF is available in this format. What's more, the cumulative expertise of the vendor—the "science" behind an accurate measurement—is built into the firmware of each instrument. For system integration, GPIB is well established as the dominant architecture for automated testing.

On the downside, a system built with just GPIB instruments can be so large and heavy that it is difficult to move frequently or across long distances. One obvious reason for this is the number of front-panel displays and

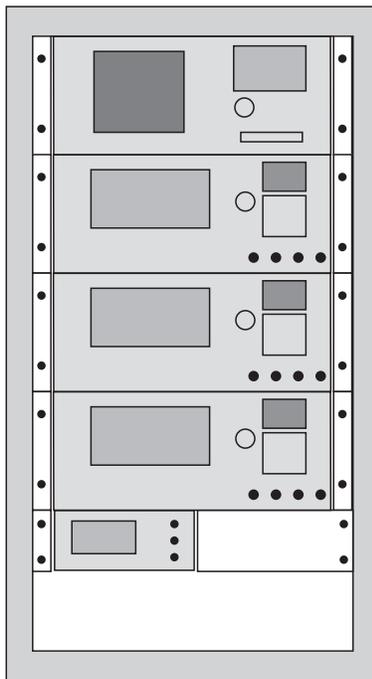


Figure 2. Redundant or unneeded hardware such as instrument displays, keypads and digitizers add extra space and weight to rack-and-stack systems.

keypads that go unused in a computer-controlled system (Figure 2). Less obvious in a large test system is the number of redundant digitizers, frequency converters and other block-diagram elements within many of the instruments.

It is also costly to upgrade such a system. For example, when a faster, wider-bandwidth digitizer becomes available, it may take several months before it is available in a GPIB instrument—and it may be necessary to replace the existing instrument to get the benefits of the new digitizer. What's worse, changing an instrument probably means software modifications, which entail additional time and expense to make the system software work with the new device.

VXI and PXI: With these modular architectures, the key advantage is the combination of measurement performance and triggering capabilities available in a compact form factor. Also, there is only one display, which is connected to either an external or embedded controller. The ability to embed the controller in the VXI or PXI mainframe also saves space and simplifies system transport.

Because VXI and PXI are based on flexible, reconfigurable modules, the SIWG accepts them as SIs within the DoD NxTest vision. However, some functions or measurements—high frequency RF, high-wattage power supplies—are not available in VXI or PXI. The cost of a VXI- or PXI-based solution is also generally higher than an equivalent rack-and-stack system.

With regard to system longevity, both modular architectures fall short because they are based on computer backplanes that tend to evolve rapidly then become obsolete. For example, VXI is based on the 1980s-vintage VMEbus, which is gradually disappearing from the computer world. Similarly, PXI is based on the PCI bus, which is being replaced by PCI Express. As time passes, it will become more expensive to support and sustain VXI- and PXI-based systems.

System software: With any of the three major test-hardware architectures, an essential key to success is the ability to reduce the time, effort and expense of software development and support. This depends heavily on development tools and environments that enable greater reuse of software in system creation or modification. Today, text-based programming with the variants of C is most commonly used for high-performance test systems. Other solutions such as Agilent VEE Pro and NI LabVIEW provide graphical tools for system creation.

Whichever tools you prefer, the use of device drivers can simplify the programming task. This is especially true with register-based VXI and PXI

devices: drivers allow programming at a higher level by handling low-level operations such as reading and setting card attributes, initiating measurements, and loading or unloading data. Although programming at the register level enables detailed computer control of each module, it can be quite complicated and time consuming.

Understanding the SI approach

With SI, the fundamental elements of multiple instruments are realized through functional modules such as digitizers, upconverters, downconverters and arbitrary waveform generators. By arranging and rearranging the interconnection of these building blocks and the associated software modules, it's possible to emulate the functionality of an oscilloscope, a spectrum analyzer, a power meter, and other instruments in much less physical space. Operationally, this is a software-intensive process in which the system could perform a series of tests by configuring the hardware, any needed switching, and the associated software module for one type of measurement and then reconfiguring the hardware, switching and software modules for the next type of measurement.

System hardware: As a comparison, a rack-and-stack system containing a spectrum analyzer, three microwave sources and a power meter might occupy 18U of rack space. Using a variety of half-rack SI modules that don't have displays or keypads, the same functionality occupies 11U of rack space, as shown in Figure 3. This type of system is smaller, lighter and easier to transport. It also simplifies support by making it easier to replace or upgrade individual instrument modules as needed.

A rear-panel view of the SI system would reveal LAN ports on each module. By creating LXI-compliant SIs, Agilent is providing a PC-to-instrument interface that delivers the stability, longevity and performance of LAN. This simplifies PC connectivity and also helps lower the total cost of ownership for the ATS.

The rear view would also show a hardware trigger bus cable that complements a variety of LAN-based triggering capabilities. In combination, these triggering capabilities equal or surpass the capabilities VXI and PXI.

System software: The points mentioned earlier still apply. Today, it requires a significant development effort to create the needed measurement and calibration functionality. However, any software modules designed for transportability can be reused with other SI-based systems, and potentially with other hardware modules.

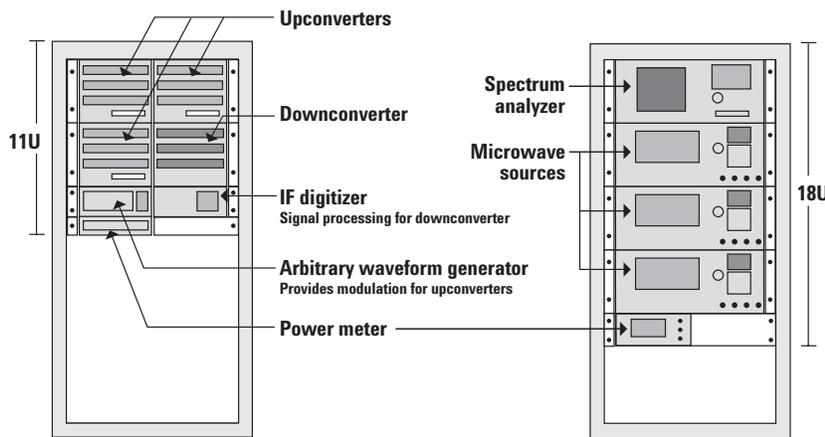


Figure 3. An SI-based system can provide equivalent (or greater) functionality in less rack space.

Deciding if SIs are right for you

In the near term, SIs offer useful benefits that must be weighed against the tradeoffs. The main overall benefit of the modular, building-block approach is greater flexibility in less space. This approach will also make it easier to replace individual modules—or achieve “technology insertion”—when new, updated capabilities are available. Longer term, this should also make it easier to replace any modules that go obsolete.

Currently, the major tradeoff is the intensity of the software effort but, as mentioned earlier, this is likely to change as hardware vendors begin to provide the necessary software tools. Looking at the whole system, another possible tradeoff is in the ability of SI-based systems to scale gracefully: larger systems will tend to put greater demands on the host PC. A higher-performance PC may be able to handle the demands of a complex system, but a faster processor (or multiple processors) and more memory also means a higher price for the PC and therefore a higher total cost for the system. The use of intelligent, LXI-based instruments—which can offload many computing tasks from the PC—is another way to head off this potential issue.

Exploring the initial applications

Today, SIs are a good fit with certain problems but are not quite ready for others. For example, SIs are not optimized for single-purpose applications (e.g., just spectrum analysis), one-box testers on the production line, bench-top applications in R&D, or short-lived test systems. As more software tools become available, the situation will become more favorable for these scenarios.

In contrast, SIs are well suited to situations that require multiple identical ATSS or when a system will be in service for many years. The flexibility of SI is also a good match when you need to test a wide variety of similar devices with a limited set of measurement hardware. These are clearly the major issues facing the DoD and its prime contractors when creating, supporting and preserving a TPS.

Sketching the DoD scenarios

As mentioned on page 4, SIs must address four present and future scenarios: flight-line test; intermediate-level (I-level) test; depot test; and at-manufacturer or OEM test. These represent a continuum of testing that includes conscious tradeoffs between size, cost, speed and performance.

The vision is to use a common, scalable hardware platform complemented by common test software and database management software that will be networked across all levels of service and support, and across all branches of the military. In practice, the flow of information starts in the field when an aircraft or vehicle detects an anomaly in one of its electronic systems. From that, the hardware and the information flows from one stage to the next:

- **Flight-line test:** In this operational, front-line application, the test system receives a message from the aircraft or vehicle and flags it for attention. When it returns to base, the critical need is to quickly identify and swap out the correct *subsystem*. The defective unit is recorded in the central database so it can be tracked through the rest of the process.
- **I-level test:** The key need is to identify the defective *module* within the subsystem. If it can be removed, it is recorded in the central database and then sent to the next stage.
- **Depot test:** At centralized repair centers, the module is tested with the intent of identifying defective *components* at the card level. The repaired unit will be placed into the inventory of spares where it will eventually return to service—and enable the increased availability of aircraft or vehicles.

Typically, OEM testing occurs before the card, module or subsystem is delivered to the military and put into service. If the same test system—hardware and software—is used by both the manufacturer and the military, there can be greater confidence in the results and potentially lower costs in system development, deployment and support.

Utilizing current SI devices

In May 2006, Agilent's initial offering of six synthetic instruments became the first Class A LXI products to achieve certification from the LXI Consortium. These SIs demonstrate Agilent's ability to leverage proven RF technologies into innovative LXI-based solutions that serve the needs of the DoD, its prime contractors and others who can benefit from the flexibility of modular instrumentation.

Reviewing the original six

N8201A: This high performance 26.5 GHz downconverter provides IF output frequencies of 7.5, 21.4 and 321.4 MHz, enabling three different signal bandwidth capabilities. External mixing can be utilized to downconvert microwave signals as high as 110 GHz. The N8201A is leveraged from the Agilent PSA Series spectrum analyzers.

N8211A: This high performance 20/40 GHz analog upconverter generates a stimulus signal with superior AM, FM and pulse modulation capabilities via external or internal modulation. The N8211A leverages the Agilent PSG analog signal generator's high output power, low phase noise and excellent level accuracy. This module is available with a variety of options, including output power and modulation type.

N8212A: This high performance 20 GHz vector upconverter functions as a microwave source with greater than 2 GHz I/Q modulation bandwidth. It features AM, FM and pulse modulation (via external or internal modulation) and multisource coherent carrier capability. The N8212A is based on the Agilent PSG vector signal generator and includes options for greater spectral purity and enhanced phase noise.

N8221A: This 30 MSa/s IF digitizer has a 7.5 MHz IF input and provides 80-dB dynamic range, 14-bit resolution, and 8-MHz modulation bandwidth. This module was also leveraged from the PSA Series spectrum analyzers.

N8241A: This arbitrary waveform generator (AWG) features 1.25-GSa/s output with 15-bit resolution—simultaneously—and is based on the Agilent N6030A AWG. The N8241A offers dual-channel, single-ended and differential outputs, with 500 MHz of instantaneous analog bandwidth per channel.

N8242A: This AWG features a choice of either 1.25 GSa/s or 625 MSa/s with 10-bit resolution. It offers dual-channel, single-ended and differential outputs, with 500 MHz or 250 MHz of instantaneous analog bandwidth per channel.

Others: For signal routing, the L4445A microwave switch/attenuator driver module allows control of a broad range of microwave switches and attenuators. These LXI-based modules provide switching bandwidth up to 50 GHz. Agilent also offers the N8262A, a 40-GHz wideband peak and average power meter with 100 MSa/s continuous sampling rate and 30 MHz video bandwidth. This LXI device is based on the Agilent P-Series power meters.



Figure 4. Agilent N8211A 20/40 GHz performance analog upconverter



Figure 5. Agilent N8241A arbitrary waveform generator

Emulating RF instruments

This versatile set of modules can be quickly and easily reconfigured to make a host of measurements that would ordinarily require a vector signal analyzer, spectrum analyzer and oscilloscope. They can also be used to emulate the capabilities of an obsolete instrument such as the HP 8902A measuring receiver. Two brief examples will illustrate some of the possibilities.

SI stimulus unit: This requires signal generation hardware and software modules to create the required signals and perform scalar or vector signal analysis. Signal generation might utilize the N8241A AWG module (for maximum signal bandwidth and accuracy), the associated signal-creation software, and the N8211A or N8212A upconverter, depending on requirements for modulation, output power and signal purity (Figure 6).

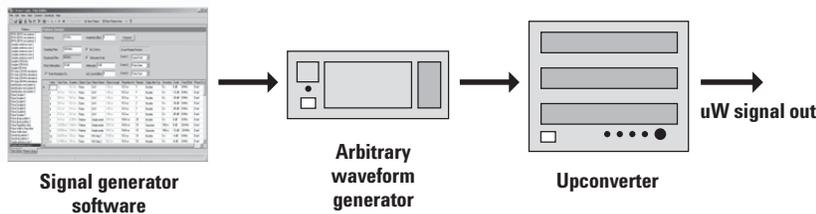


Figure 6. For signal generation, the SI chain includes numeric processing, data conversion and frequency conversion.

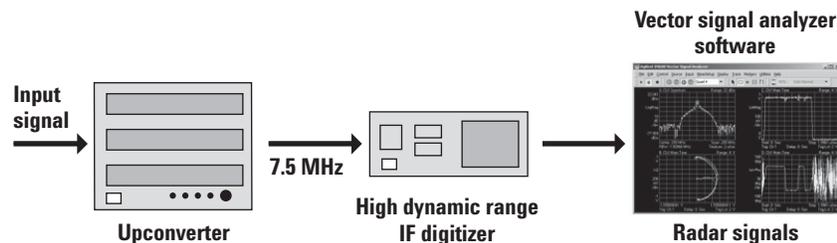


Figure 7. Agilent N8241A arbitrary waveform generator

SI measurement unit: The input signal would be routed to the N8201A down-converter, which would provide a 7.5-MHz signal to the N8221A digitizer. Through its LAN connection, the host PC would acquire one or more data blocks and apply the appropriate software modules for vector signal analysis or spectrum analysis of signals from devices such as radar systems, cell phones and wireless networking equipment (Figure 7).

A caveat: You can use SIs to emulate a legacy instrument up to the point where the SI hardware is too different. For example, software can emulate a legacy instrument that has poor noise floor; however, it can't emulate a legacy instrument that has a better noise floor than the SI hardware. Also, most GPIB instruments have a unique set of timing, network and bus issues that are very difficult to reproduce. In other words, SIs can emulate legacy instruments, but no emulation will be a perfect duplication of the original.

Recapping present and future value

The basic premise of synthetic instruments is very appealing: they let you configure and reconfigure building-block modules to create the functionality of multiple measurement devices. With benefits such as smaller test systems, easier transport, single-module updates or upgrades, long-lived I/O and simpler software updates, LXI-based SIs readily support the DoD's vision for NxTest.

As SI vendors address the need for software tools that reduce effort, accelerate development, ensure accurate, repeatable results, and enable interchangeability of software components, then the development costs of SI-based systems will fall and these solutions will become more viable for commercial applications. Over the long-term, it will be worth watching the growth and development of SIs—and worth monitoring their progress toward a new era of greater flexibility in automated test systems.

Glossary/Acronym guide

- ATE** – Automated test equipment
- ATS** – Automated test system
- AWG** – Arbitrary waveform generator
- CASS** – Consolidated Automatic Support System
- COTS** – Commercial off-the-shelf
- DoD** – United States Department of Defense
- eCASS** – The modernized version of CASS
- GPIB** – General Purpose Interface Bus; also known as IEEE-488 and HP-IB.
- IF** – Intermediate frequency
- LAN** – Local area network
- LXI** – LAN eXtensions for Instrumentation
- Morphable** – Able to emulate the functionality of various traditional instruments by reconfiguring hardware and software SI modules
- NxTest** – Next-generation Automatic Test Systems
- OEM** – Original equipment manufacturer
- PCI** – Peripheral Component Interconnect
- PXI** – PCI eXtensions for Instrumentation
- RF** – Radio frequency
- SI** – Synthetic instrumentation
- SIWG** – Synthetic Instruments Working Group
- Technology insertion** – The introduction of new or improved hardware or software capabilities into an existing system
- TPS** – Test Program Set
- VME or VMEbus** – Versa Module Eurocard
- VXI** – VME eXtensions for Instrumentation

Related literature

The 1465 series of application notes provides a wealth of information about the creation of test systems, the successful use of LAN, WLAN and USB in those systems, and the optimization and enhancement of RF/microwave test systems:

Test System Development

- *Test System Development Guide: Application Notes 1465-1 through 1465-8* (pub no. 5989-2178EN)
<http://cp.literature.agilent.com/litweb/pdf/5989-2178EN.pdf>
- *Using LAN in Test Systems: The Basics*, AN 1465-9 (pub no. 5989-1412EN)
<http://cp.literature.agilent.com/litweb/pdf/5989-1412EN.pdf>
- *Using LAN in Test Systems: Network Configuration*, AN 1465-10 (pub no. 5989-1413EN)
<http://cp.literature.agilent.com/litweb/pdf/5989-1413EN.pdf>
- *Using LAN in Test Systems: PC Configuration*, AN 1465-11 (pub no. 5989-1415EN)
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- *Using USB in the Test and Measurement Environment*, AN 1465-12 (pub no. 5989-1417EN)
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- *Using LAN in Test Systems: Applications*, AN 1465-14 (pub no. 5989-1416EN)
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- *Using LAN in Test Systems: Setting Up System I/O*, AN 1465-15 (pub no. 5989-2409)
<http://cp.literature.agilent.com/litweb/pdf/5989-2409EN.pdf>

- *Next-Generation Test Systems: Advancing the Vision with LXI*, AN 1465-16 (pub no. 5989-2802)
<http://cp.literature.agilent.com/litweb/pdf/5989-2802EN.pdf>

RF and Microwave Test Systems

- *Optimizing the Elements of an RF/Microwave Test System*, AN 1465-17 (pub no. 5989-3321)
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- *6 Hints for Enhancing Measurement Integrity in RF/Microwave Test Systems*, AN 1465-18 (pub no. 5989-3322)
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- *Calibrating Signal Paths in RF/Microwave Test Systems*, AN 1465-19 (pub no. 5989-3323)
<http://cp.literature.agilent.com/litweb/pdf/5989-3323EN.pdf>

LAN eXtensions for Instrumentation (LXI)

- *LXI: Going Beyond GPIB, PXI and VXI*, AN 1465-20 (pub no. 5989-4371)
<http://cp.literature.agilent.com/litweb/pdf/5989-4371EN.pdf>
- *10 Good Reasons to Switch to LXI*, AN 1465-21 (pub no. 5989-4372)
<http://cp.literature.agilent.com/litweb/pdf/5989-4372EN.pdf>
- *Transitioning from GPIB to LXI*, AN 1465-22 (pub no. 5989-4373)
<http://cp.literature.agilent.com/litweb/pdf/5989-4373EN.pdf>
- *Creating hybrid systems with PXI, VXI and LXI*, AN 1465-23 (pub no. 5989-4374)
<http://cp.literature.agilent.com/litweb/pdf/5989-4374EN.pdf>

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