Synthetic instruments in automatic test systems

This article will describe why there is a move toward synthetic instrument ATS architecture, how SI architecture will differ from that of a stand-alone instrument, and how it is possible to achieve high-performance measurements in a synthetic instrument framework.

By John Stratton

With the current trend to drive down the total cost of ownership of automatic test systems (ATS), industry-standard open architectures have been seen as a way of driving down the cost of tests (for design and manufacturing) and of reducing the size of the ATS platforms (by eliminating redundant hardware). Since these open architectures have been based on rapidly changing commercial computer standards, a large investment in hardware is quickly becoming a support problem—the problem that an open architecture was supposed to fix. Additionally, these architectures have been optimized for digital or low-frequency analog signals making it a technical challenge to implement high-performance microwave tests. One proposed solution is to extend the frequency range using general-purpose frequency converters allowing microwave signal generation and analysis in a modular architecture. This proposed solution is currently being driven by the defense electronics market where long support life (e.g., 20+ years) is essential. To achieve a high reuse of synthetic instrument (SI) hardware assets, a tremendous additional burden is placed on the software architecture. The SI software must be flexible enough to accommodate many different types of hardware transducers while maintaining National Institute of Standards and Technology (NIST) traceability of the final measurement.

This article will describe why there is a move toward synthetic instrument ATS architecture, how SI architecture will differ from that of a stand-alone instrument, and how it is possible to achieve high-performance measurements in a synthetic instrument framework.

What is a synthetic instrument?

A synthetic instrument is a concatenation of hardware and software modules used in combination to emulate a traditional piece of electronic instrumentation. The key objectives of automatic test systems based on synthetic instruments are to allow insertion of technology when higher performance measurements are required and lower cost, promoting competition (e.g., multiple instrument vendors supplying a similar product). These goals must be accomplished while minimizing or eliminating the need to re-write test application software. According to the Synthetic Instrument Working Group[1] there are four major components in the SI architecture, as seen in Figure 1.

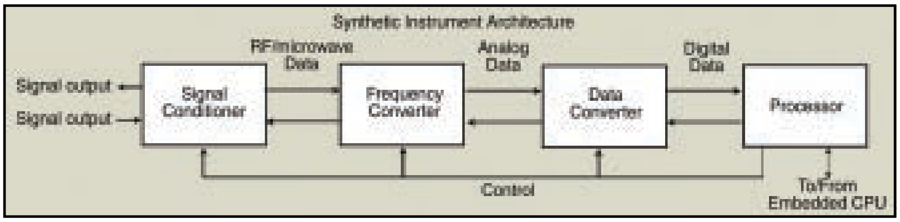

Figure 1. Synthetic instrument architecture.

This simplified architectural block diagram can describe most microwave instruments, like signal generators, spectrum analyzers, frequency counters and network analyzers. However, the implementation with SI modules of these microwave instruments may require multiple signal conditioners, frequency converters and data converters to emulate the function of its original instrument (i.e., vector network analyzer). First we will examine these functional blocks to better understand how they are to be used and what requirements will be needed to develop such a product.

The most important functional block in the synthetic instrument architecture is the data converter (analog-to-digital converter (ADC) and digital-to-analog converter (DAC)). Data converters have two main drawbacks to them: limited bandwidth (sample rate) and distortion-free dynamic range (effective bits). While this may seem obvious, there continue to be great advances in data converter technology, bringing us closer to an ideal software-defined instrument. The reason that data converters are the most important module is that if the digitizer (ADC module) or the arbitrary waveform generator (AWG with DAC module) has enough dynamic range and bandwidth to capture or generate the entire signal(s) of interest, one needs only apply software algorithms to convert the voltage, current or power data to the desired measurement or signal. In other words, multiple measurements can be performed from a single time-data capture. You can achieve this today for some low-frequency, narrow-bandwidth applications.

How much is enough when determining bits and bandwidth requirements? When try-

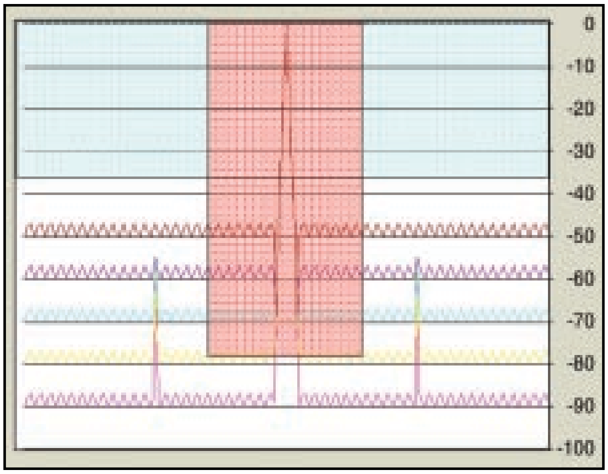

Figure 2. 100 MHz CW tone with Fs/4 spurs.

ing to understand this question I like to think of data converters in the frequency domain (amplitude vs. frequency), like a spectrum analyzer. Imagine the data converter as a window of available signal. This window has only a finite amount of width (sample rate bandwidth) and height (dynamic range or effective bits). If you can view or generate your signal within the confines of the window, no signal conditioning or frequency translation will be required. Let's take a simple example of generating a 100 MHz continuous wave (CW) tone using an AWG (Figure 2). When analyzing this CW tone with a wide bandwidth digitizer, such as one used in an oscilloscope (7+ effective bits), one can see the 100 MHz signal but the digitizer doesn't have enough dynamic range to measure the Fs/4 spurs created by the DAC in the AWG. The logical choice would be to choose a digitizer with higher dynamic range, like a spectrum analyzer (11 to 13+ effective bits), if such analysis is required. However, with the increased dynamic range there is a corresponding decrease in bandwidth, now requiring some frequency conversion along with multiple acquisitions to capture and "stitch" together the entire signal of interest. When covering multiple gigahertz of analysis bandwidth, as when searching for unknown spurs, many hundreds or even thousands of acquisitions may be required to cover the frequency span of interest.

The frequency converter block is a concept easy to understand, but difficult to implement when low spurious or low noise performance is required, such as in a microwave signal generator or microwave signal analyzer. This SI module does just what you would think, converting a signal from one frequency to another. A signal generator may take the in-phase and quadrature (I/Q) output of the AWG and translate it to 10 GHz, thereby generating a radar signal. Conversely, to perform some modulation analysis of a communication signal by downconverting the signal from a 43 GHz local multipoint distribution services (LMDS) transmission to an intermediate frequency (IF) that fits within the bandwidth of your digitizer, one can analyze the output of the digitizer. Since most frequency converters are based on a superheterodyne architecture, the internal mixers create images and spurs. The challenge in designing frequency converters is to minimize unwanted signals during the conversion process.

The signal conditioner's main function is to translate the signal level to within the range acceptable to the frequency converter. In the above example the signal conditioner might be a high-power amplifier and a bandpass filter to supply the required clean microwave signal for a radar receiver test. Once the signal is properly conditioned, by amplification or attenuation, it can be sent on to the frequency converter, if required.

Software implementation of synthetic instruments is critical to long-term support life. With traditional ATS development the test system (TS) programmer will take advantage of all the built-in measurements of any particular instrument included in the rack. For measurements that are not included, the programmer/engineer will collect the required data and create an algorithm to support the needed measurement. This process is the most efficient way to produce an ATS. However, this same effort is difficult to support over the life of the program.

All measurement software and algorithms must be separated from the measurement hardware. Let's take a simple example like the peak search function in a signal analyzer. There is a single command in most signal analyzers that support this function. However, each manufacturer implements this function differently, which may yield different results. If, on the other hand, the algorithm resides in the TS software (whether purchased or written) the results would yield the same answer no matter which hardware was used (assuming the same hardware performance specifications). This would virtually eliminate the hardware obsolescence problem, thus highlighting the need for common hardware interfaces and software interfaces.

The software to calibrate the measurement signal path becomes more complex than it previously was. Most instrument manufacturers achieve their high-performance specifications by employing internal correction algorithms that remove amplitude, phase and frequency-dependant non-linearities. These NIST traceable, high-accuracy measurements are also dependant on the components within the instrument. For example, a signal analyzer will be disaggregated into a downconverter, a digitizer and measurement software. If, as expected, one or more of these modules could be substituted with another vendor's module, how will traceability be guaranteed? A sophisticated software application will be required to solve this instrument agnostic problem.

Computer industry driving change in the test equipment market

Since the development of the personal computer there is a trend away from expensive proprietary computers and computer operating systems toward an open "Wintel" platform. These computers are embedded (traditional rack & stack instrumentation, VME bus extension for instrumentation (VXI), and PCI extensions for instrumentations (PXI)) or external as a test system controller.

Instrument manufacturers and systems integrators have found that using external personal computers (PCs) gives the best price-vs. performance profile that the market offers. However, most instruments still have an embedded controller. The customers who demand lower cost and higher-performance test systems are driving the demand for external PC usage. This trend will continue as long as Moore's Law holds true (performance doubling every 18 months). PC manufacturers are introducing new models approximately every six months and are driving down the cost of computer components due to their high volume purchase commitments. However, off-the-shelf PCs don't always meet the environmental and EMI resistance for industrial and field applications. Hence, we see the continued use of embedded controllers in instrumentation.

Where test systems are today

The computer industry is changing the way test instruments are being developed. The partially adopted VME/VXI architectural design reduced the cost and increases the reliability of sophisticated ATSs as requested by customers. Most VXI implementations were a redesign of currently shipping test instruments into the VXI form factor. Some of the key design advantages of the VXI are the large amount of board space in which to lay out instrument-grade hardware and the well-defined backplane and communication bus. However, due to the small sales volume of the VXI hardware and the additional expense of redesign, manufacturers were forced to charge more than their fully integrated instruments to meet their profit targets even though there was no display, computer or power supply. This apparent disconnect met with moderate success in the A/D and automotive industries where longer ATS life cycle support and smaller form factor is a requirement.

VME (computer backplane) lost support from the mainstream computer industry, replaced by the next best technology, Peripheral Component Interconnect (PCI). The results are a move away from VXI, for the instrumentation manufacturers, now tied to the computer industry. While VXI addressed the size and cost of new instrument development it failed to adequately address production cost, product availability, and long-term support. Unfortunately, there is a steady decrease of available VXI products resulting from product obsolescence. Since many of these products have no available replacement, test systems further reduce how many VXI card slots are occupied in a given ATS. This spiraling down of sales—forcing further obsolescence—is starting to accelerate.

During the early 1990s, Intel proposed new bus architecture for PCs. PCI promised to provide significant benefits over its predecessors, and it did. This was followed by Compact PCI (cPCI), and led to its instrument counter part (PXI), which was introduced by National Instruments in 1998.

Is PXI a logical replacement for VXI in defense ATSs?

PXI is picking up where VXI is leaving off but with an even smaller form factor (3U or 5.25 inches of rack space), higher speed backplane and somewhat reduced cost. With its roots in the PC, rugged Euro-Card, and the now legacy VXI markets, PXI is vying to be next instrument platform of choice.

Technology advances have given the PXI/Euro-Card form factor large support. For products that are comprised of semiconductor components, such as digital I/O and low-frequency analog, one can design the functionality of an older C-Sized VXI card onto a significantly smaller PXI/cPCI card. This new smaller card can be designed with a lower manufacturing cost and with increased reliability. However, this smaller form factor, while good for the digital designer, produces limitations for the RF/microwave engineer when components don't change at Moore's Law frequency and are physically larger than their low-frequency and digital counterparts. For high-performance microwave measurements or devices requiring high sensitivity measurements, which are common in most Aerospace/Defense applications, PXI doesn't provide the electromagnetic interference and compatibility (EMI/EMC) shielding or quiet power supply necessary. Some of these issues could be resolved over time with increased attention and development.

To address the issue of available board space there have been more recent introductions of a 6U PXI card providing more than twice the available design landscape. However, while this is an advantage for a more complex design, the 6U card cage takes up the same rack space as a VXI chassis yet provides less than half the landscape area of the C-Sized VXI card.

Is PXI a logical replacement for VXI in defense ATSs? Defense test systems require long support life and continuously go through upgrades and modernization, while supporting new weapon systems as well as replacement of obsolete equipment (COTS or custom). To replace an obsolete VXI card, for example, when an acceptable VXI alternative is not available, a new PXI chassis, taking up additional rack space, will be required. Alternatively, the complete replacement of the VXI functionality forces significant re-works and expense. In either case, choosing the VXI architecture, while initially a good idea, has turned into a larger long-term support burden.

Even as PXI is enjoying industry growth and acceptance, Intel has decided PCI has run out of life. While PCI has been the dominant bus standard for the past 10 years, Moore's Law has made it inadequate for newer, more powerful applications and designs. PCI Express is the future, according to Intel. So where does PCI/PXI go from here? Since the physical hardware backplanes are not compatible (PCI is parallel, PCI Express serial) Intel has developed a bridging strategy while the industry converts. Some logical questions might be, how long will PCI Express be around? And will we make the same mistake again?

LAN-based synthetic instrument modules

For synthetic instrument's concept to be successful (with reusable hardware and open software) industry must agree upon a few standards.

Common hardware interfaces. Earlier it was discussed how using the internal PC interfaces could cause churn in your ATS hardware modules dependant on whatever bus interface is employed. While no interface standard lasts forever there are a couple that could be considered to meet the 20+ years support life demanded by the A/D industry. Let's consider alternating current (AC) and LAN power as those standards.

Common ac receptacle power has been around for quite a while, and I'm unaware of any proposed standard to replace it. Since most digital and analog circuits require a variety of dc voltage choices a common dc power supply is not practical. Additionally, card-cage-based platforms (VXI/PXI) with built-in power supplies are never optimized for the instrument cards installed. There is either not enough power (too many power hungry modules are installed, leaving open slots) or one overpaid for excess available power (all card slots are full).

Local area network (LAN) as a communication medium may be the standard that will be around the longest. It was introduced in 1985 (Institute of Electrical and Electronic Engineers (IEEE) 802.3a) operating at 10 Mbits per second and has increased in bandwidth to support 10 Gbits per second by 2002 (IEEE 802.3ae), thus progressing in speed, three orders of magnitude in the span of 17 years. LAN is one of the lowest-cost interfaces to implement in computers (included in most PCs) or instruments (based on computer standard interfaces). The largest detraction of LAN, however, is the non-deterministic nature and intermodule synchronization required by some test applications. Most of these issues could be addressed with the IEEE 1588 (Precision Clock Synchronization Protocol for Networked Measurement and Control Systems) standard introduced in 2002. John Eidson of Agilent Labs originally developed this technique, which became IEEE 1588, for distributed instrumentation and control tasks.

Conclusion

Driving down the cost of ownership of ATSs will require careful consideration of what role the functional elements should take. Ideally, one would use as many commercial industry standards as possible (like IVI-COM) without locking into a standard that is likely to change through technology advancement. With this in mind, LAN-based synthetic instruments offer the best compromise between cost, performance, size and—most important—long life. DE

References

1. Synthetic Instrument Working Group—Joint participation between the Department of Defense, defense prime contractors and suppliers.

ABOUT THE AUTHOR

John Stratton started his engineering career as an advanced development engineer for Texas Instruments in Richardson, Tx. He worked on projects in the Defense Systems and Electronics Group including: S3B FLIR and ISAR, Mark XV IFF, and F15/F16 LANTIRN programs. In 1990, Stratton joined Agilent Technologies Inc. (then Hewlett-Packard) as a field sales engineer where he managed various accounts including A/D customers in Southern California. Since 1997 he has held various product marketing and product-planning positions focused on RF and microwave products and solutions. Stratton manages the product marketing and planning staff for the Systems Product Operation in Santa Rosa, Calif. He has published articles optimizing test processes using RF and microwave test equipment. He graduated from Lawrence Institute of Technology with a BSEE in 1984.