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Future military test systems hinge on synthetic instrumentation



Synthetic Instrumentation: contemporary architectures and applications (Part II)

Part I of this two-part series provided an overview of an emerging technology called Synthetic Instrumentation (SI) and discussed key issues and considerations that a user or developer should be aware of before embracing this technology.^[1] Part II discusses the concept of SI in more detail in terms of how stimulus and measurement functions can be implemented employing “core” SI hardware and software components.

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Synthetic instrument implementations often come in a variety of flavors; there are many ways to build an SI mousetrap. Current industry implementations center on three distinct types: generic /loosely coupled component SI, integrated commercial off-the-shelf (COTS) SI, and Department of Defense (DOD) or military application-specific SI. The ensuing sections will provide a brief overview of typical characteristics, test and measurement capabilities, and customer needs satisfied by these three SI instantiations.

Before we launch into the specifics of each SI implementation type it’s important for the reader to understand some key concepts and issues from a hardware and software perspective, pertaining to the range of alternatives available to a developer when considering the implementation of an SI solution.

SI is substantially different from a virtual instrument (VI) in that stimulus and measurement functions can be synthesized from a limited set of “generic” SI components as opposed to discrete instrument types such as a spectrum analyzer (Figure 1). However, an SI is similar to its VI cousins in that it is optimized for computer control and does not have physical interfaces, such as knobs or buttons. The users typically interact with a SI via a software-defined graphical user interface. A graphical user interface can simulate a front panel for an entire SI, or its constituent components, by providing software “widgets” that represent physical knobs, buttons and displays^[2].

From strictly a test and measurement hardware perspective, most all current instantiations of SI are being implemented in Versa Module Europa (VMEbus) extensions for instrumentation (VXI), and to a lesser extent in peripheral components interface (PCI) extensions for instrumentation (PXI). The reasons for this are quite pragmatic: key SI architectural components such as analog to digital converters (ADCs), digital to analog converters (DACs), upconverters and downconverters are commercially available in the modular VXI and PXI commercial formats and afford substantial space saving over conventional rack and stack automatic test system (ATS) implementations. Emerging small form factor-based modular technologies such as local area network (LAN) extensions for instrumentation (LXI)

are also entering the scene and viable commercial off-the-shelf (COTS) SI solutions are projected to be available within the next year.

From a hardware and software processing perspective the implementation choices are a bit more varied and complex. The SI paradigm is predicated on the ready availability of computational hardware and application-specific software modules, which in essence, allows a SI to emulate classical discrete instruments and their associated stimulus/measurement functions. The SI developer has a range of implementation alternatives available in this regard: personal computers (PCs), embedded PXI/VXI Slot 0 controllers, commercially available digital signal processors (DSPs) or field-programmable gate arrays (FPGAs). Each

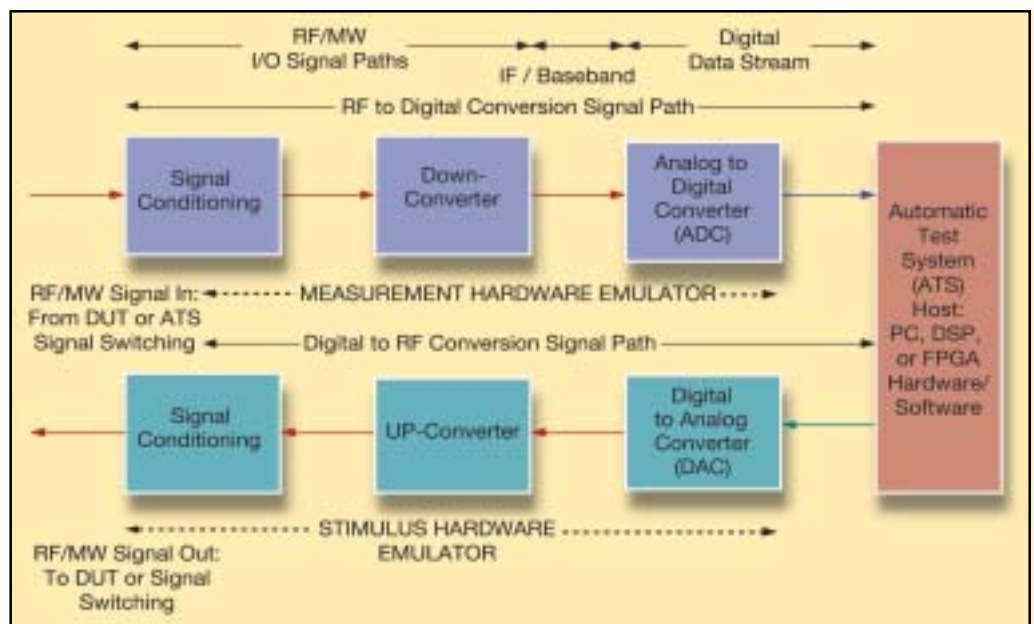


Figure 1. Synthetic instrument-based ATS architecture.

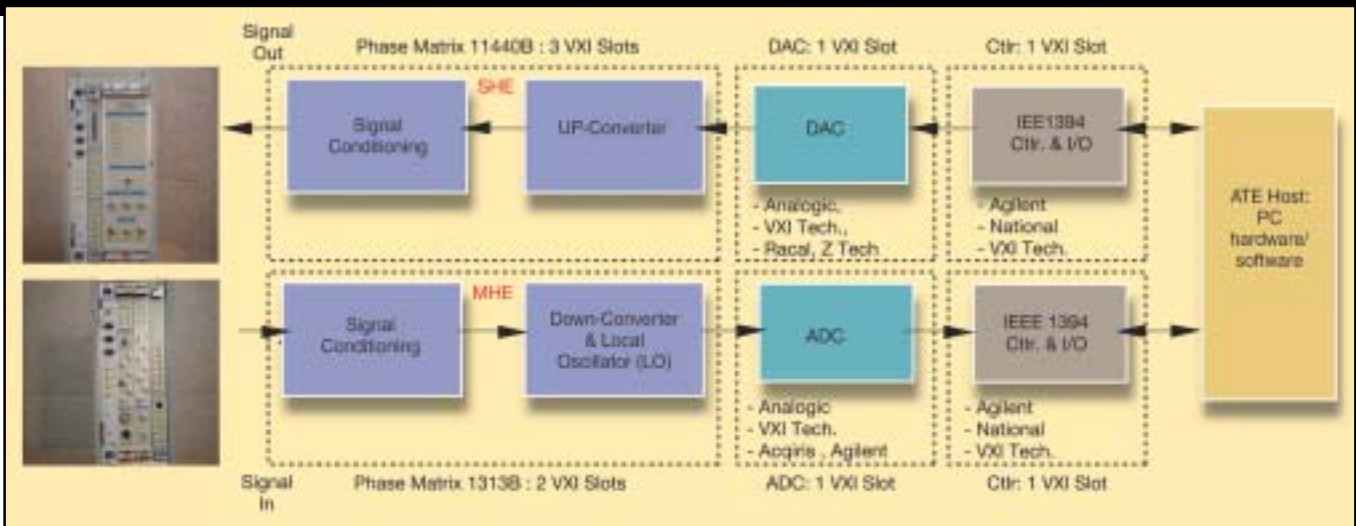


Figure 2. Generic/loosely coupled component SI.

of these implementations has pros and cons associated with them.

A PC-based system will invariably be the lowest cost, most flexible and lowest risk alternative in that it can host a number of mainstream test and measurement software engines, such as LabVIEW and Agilent VEE, which can be adapted to perform a myriad of SI functions. If the application demands speed a DSP card may be the optimum choice but will require somewhat more time, money and intellectual capital to implement [3]. If you're a system integrator and have a particular application that warrants you to provide substantial value added in terms of control and processing capability, as well as speed for your targeted measurement functions, perhaps an FPGA implementation is the way to go. Early adopters of SI may have to initially develop their own measurement-unique software test routines by employing assembly language or a high level programming language such as C or C++. They may choose to use DSP or FPGA technology if the required SI routines are not readily available or the

user prefers text-based software as opposed to using mainstream test and measurement graphical programming tools. Over time, it is anticipated that the more pervasive SI functions and synthesis tools will become commercially available in text-based and graphical programming environments such as LabVIEW, MathCAD, VEE, Visual Basic, and C/C++[4].

Generic/loosely coupled component SI architecture

Figure 2 depicts a typical generic/loosely coupled commercial SI test system employing commercial off-the-shelf stimulus and measurement hardware/software components employing two VXI enclosures: one for stimulus generation and the other for measurement. The stimulus subsystem or stimulus hardware emulator (SHE) is composed of a three-slot PMI VXI 1140B microwave synthesizer (10 MHz-20 GHz), a single slot VXI Technology VME 3640A DAC/arbitrary function generator and an Agilent E8491B IEEE-1394 VXI single slot 0 controller and associated I/O. Conversely, the measure-

ment subsystem or measurement hardware emulator (MHE) consists of a single slot PMI VXI 1313B signal conditioning unit and downconverter and associated local oscillator, a single slot VXI Technology VN2601 14-bit digitizer, as well as the same IEEE-1394 VXI slot 0 controller and I/O as employed in the SHE VXI chassis.

The SI architecture depicted in Figure 2 is an ideal replacement for numerous legacy general-purpose RF/microwave and baseband stimulus/measurement systems that are fast approaching obsolescence. The system architecture can be employed in numerous applications including spectrum analysis, surveillance applications such as communication intelligence (COMINT), satellite monitoring, radar/electronic warfare characterization, frequency management, NIST traceable calibration (microwave power measurement calibration, microwave signal generator calibration, microwave power calibration). The signal analysis portion of the system is capable of synthesizing via software any number of stand-alone instruments such as a:

- spectrum analyzer;
- wide bandwidth receiver;
- modulation analyzer;



Figure 3. 5 GHz CW signal observed via a spectrum analyzer synthetic instrument.

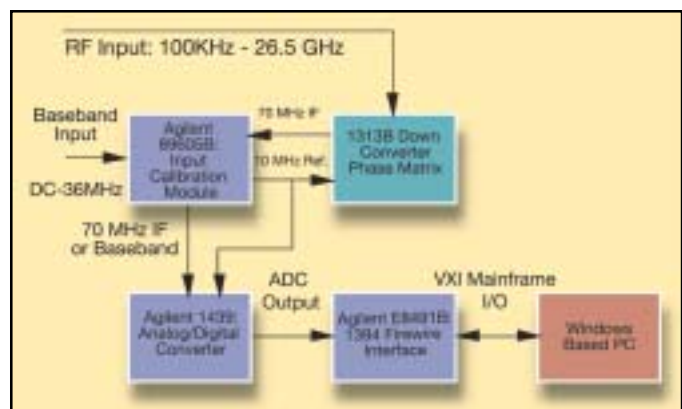


Figure 4. Agilent SI vector signal analyzer system employing an external 70 MHz IF downconverter.

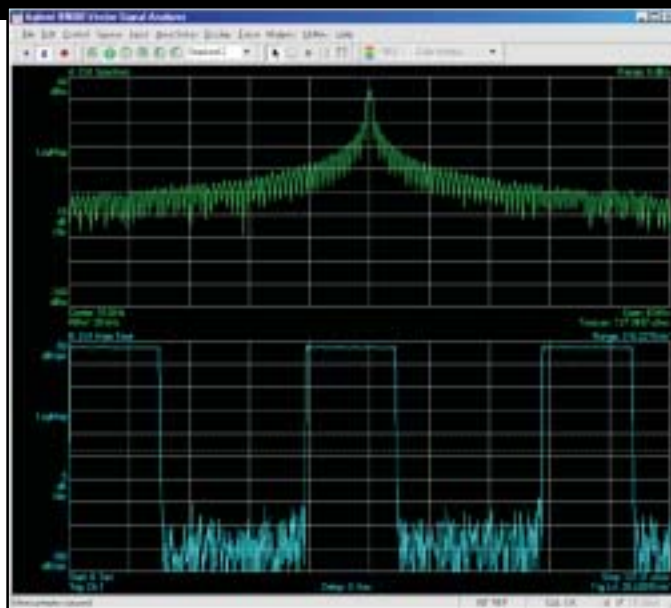
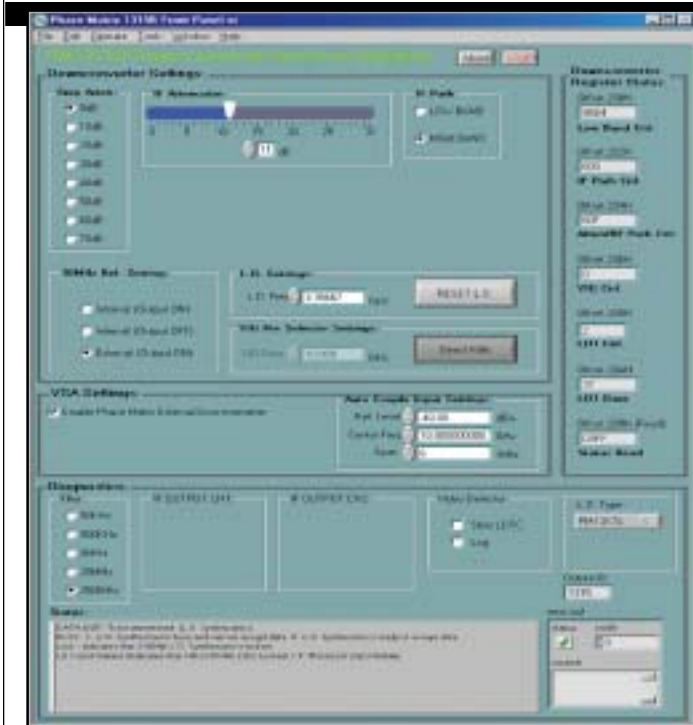


Figure 6. Agilent VSA pulsed CW SI application.



Figure 7. BAE's SI-based IAIS.

Figure 5. Combined Phase Matrix 1313B/Agilent VSA GUI.

- microwave frequency counter;
- power meter;
- power calibrator; and
- digital oscilloscope.

The subject SI type is termed “loosely coupled” in that the system is constructed using COTS components from a broad cross section of manufacturers and the user must provide both the hardware and software glue to make the component parts function as a system, especially from a system calibration perspective. For example, the SI developer must ensure that signal input and output (I/O) and behavioral compatibility exists between hardware components, from a component connectivity and signal specification point of view. A case in point is the signal interface between the measurement system’s downconverter and its ADC. This design detail is made somewhat less problematic when employing downconverters that possess a flexible intermediate frequency (IF) output that can accommodate a wide range of digitizer inputs^[5]. Although this architectural implementation employs proprietary COTS components and places a demand on the user to system engineer an SI solution from the requisite component parts, the relatively straightforward and simple nature of commonly used SI I/O interconnects and graphical signal analysis software such as LabVIEW, with its signal processing package, makes this type of SI instantiation, for all practical purposes, a de-facto open architecture implementation. The functional separation of microwave downconversion, digitization and signal processing enables an all-digital IF section to be implemented. The digitized signal

data is subsequently passed on to the computer for fast Fourier transform (FFT) or other similar signal analysis operations. The system designer is no longer tied down to slow, proprietary, internal microcontroller technology but is empowered by fast moving “Wintel”-based technology. Since FFT, as well as any additional post-signal processing is accomplished within a PC, the system can leverage the ever more powerful computing power associated with this commercially available technology.

For the system depicted in Figure 2, a software-defined spectrum analyzer (SA) is depicted in Figure 3. As can be inferred from the tabs on the referenced figures, virtual front panel controls for each primary SI component can similarly be constructed.

The spectrum analyzer SI depicted in Figure 3 does not represent the full functional capabilities of a generic SA, but instead a subset of SA functions such as marker delta frequency, next peak and peak search. This reflects the inherent power and utility of the virtual instrument SI paradigm: the capability to hide instrument complexity and employ only those software-defined functions that are pertinent to the targeted application. The sample screen shot depicts a 5 GHz continuous wave (CW) signal from an Agilent 83650 signal generator applied to the spectrum analyzer SI programmed to a 5 MHz span and a digital

resolution bandwidth of 1000 Hz. The displayed signal reflects an 80 dB spurious free dynamic range (SFDR) for the VXI Technology 14-bit digitizer employed in the SI measurement channel.

Integrated COTS SI

For those users who do not have the time or inclination to design and develop their own SI-based systems from scratch, a number of integrated/proprietary systems are available in the marketplace. For example, the Agilent 89600 series VXI-based vector signal analyzers (VSAs) are noted for their cutting-edge DSP features, particularly for emerging communications standards^[6]. The 89600 is capable of performing signal analysis in the time, frequency and modulation domains. The user can take advantage of these features and its open architecture analog front end by using their own or another third party’s VXIbus downconverter (Figure 4) to provide an IF signal at a nominal 70 MHz to the 89600 measurement system for analysis. The 89600 VSA will then

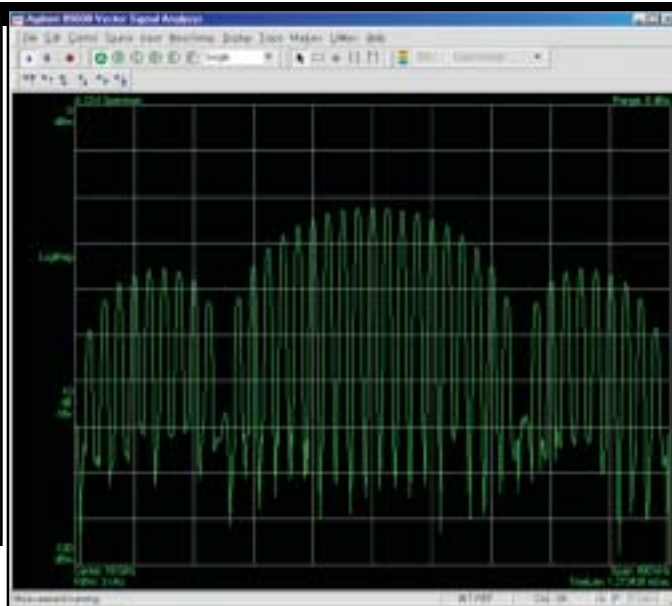
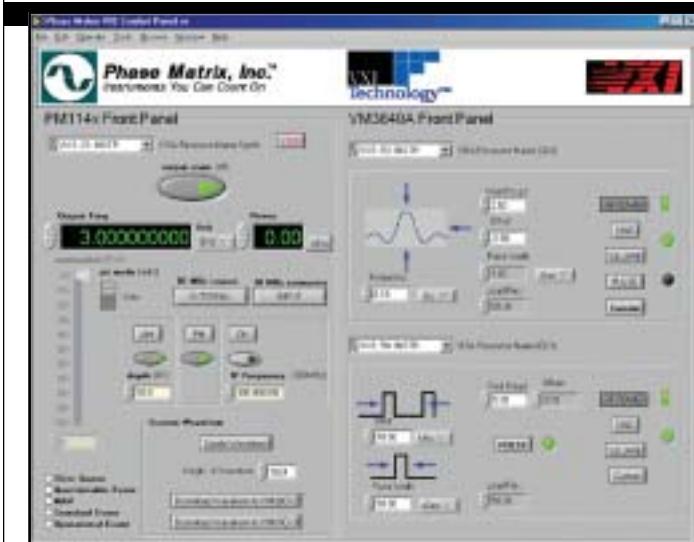


Figure 8. Complex Stimulus Soft Panel: PMI 114x & VXIT 3640A.

Figure 9. Complex pulsed RF stimulus.

perform digitization of the IF signal and signal recording. Its DSP-based software gives the user full access to a wide range of vector signal analysis tools. Along with wide IF bandwidths (36 MHz), this family of VSAs offers signal capture memory, IF triggering, a wide variety of analog and digital demodulators, in-situ calibration and an extensive set of analysis tools.

Figure 5 depicts a phase matrix graphical user interface (GUI) for a 1313B external

downconverter working within the context of a 70 MHz IF VSA system that is depicted in Figure 4. As can be seen from the subject figure, the user can affect control using this GUI of essential downconverter and VSA settings such as input signal step attenuation, IF attenuator/level setting, IF path selection (low/high band), VSA ref level, VSA center frequency, and frequency span of interest.

Once these control parameters are set, the user can then make the appropriate measurement manually, using frequency markers provided by the VSA display or automatically via employing Visual Basic scripts.

Figure 6 depicts a screen shot of an Agilent VSA SI measurement, being controlled by the GUI in Figure 5, in a classical radar

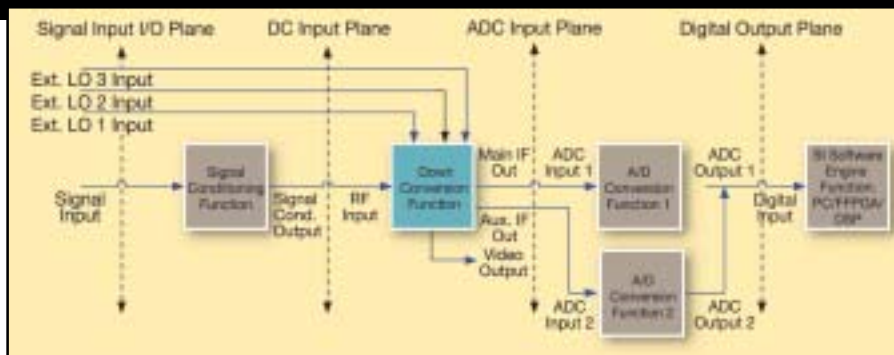


Figure 10. One of 16 variations possible in SI component partitioning/interconnects.

measurement application. In the subject screen shot, a 10 GHz, -40 dBm, 20 μ sec pulsed CW signal is observed and selected parameters are measured by the VSA. The bottom window depicts a simultaneous time domain measurement of the same signal's pulse parameters as well as the VSA's IF level triggering level. A programmable VSA IF triggering level enables a stable IF signal to be observed and measured.

The employment of integrated COTS SI solutions such as Agilent's SI VSA can assist the user in deploying flexible test and measurement solutions to the factory and the field in a timely manner as long as the appropriate hardware (standard IF I/O) and software (Active X/COM) hooks/access are provided to the user, as in

the Agilent 89600 series of SI VSAs. These "hooks" enable the user to employ their own custom signal conditioning/tuner hardware and software control in order to adapt the COTS solution to the user's specific SI application.

DOD/military application-specific SI

The main impetus for SI at this time is being primarily spearheaded in the DOD ATS community^[7]. The emphasis on high mobility/down-sized testers and combating ATS obsolescence in field and depot applications is driving contractors to roll out various SI instantiations in response to DOD's desire for SI. Major DOD Test and Measurement (T&M) programs such as the

Advanced Virtual Instrument Test System (AVITS), Third Echelon Test Set (TETS), Agile Rapid Global Combat Support System (ARGCS), and the Air Force's Improved Avionics Intermediate Shop program (IAIS) are in the midst of either planning, developing or evaluating SI solutions in direct response to DOD's testing needs.

Figure 7 depicts a typical DOD SI solution: a high mobility version of an RF stimulus and measurement subsystem (SIMSS-RF) for an IAIS system. The SI was designed, developed and manufactured by BAE Systems^[8]. The SI-based system is currently under development and is comprised of commercial off-the-shelf (COTS) and custom modules that provide common hardware modular components needed for the signal conditioning, frequency translation, sampling and processing of signals required to affect the IAIS stimulus and measurement functions via DSP-based software. BAE's SI is being used to test a wide cross-section of avionics components such as computers, radars, EW systems, flight control systems, displays, store management, communications, navigation and low altitude navigation and targeting infrared for night (LANTIRN)

targeting pod line replaceable units.

DOD systems such as the BAE SI IAIS often differentiate themselves from commercial SI systems by employing custom FPGA DSP software for application-specific measurements and application-specific instrumentation to supplement generic SI-based instrumentation components. In addition, due to the operational environments in which they operate, there is a strong emphasis on in-situ diagnostics and self-calibration. Historically, DOD test systems require test equipment calibration and alignment procedures that are arduous and time-consuming. SI-based systems can eliminate many of these procedures by incorporating calibration and alignment into the SI as a real-time background task. For example, the BAE SI-based system is capable of self-monitoring and automatic adjustment of internal alignment factors within the SI that change over time due to hardware imperfections, temperature drift, component aging, etc.

Figures 8 and 9 are representative of complex signal synthesis and signal generation capability that can be accomplished using COTS SI stimulus hardware and software in support of DOD test applications. In Figure 8, an integrated soft panel is provided to affect complex signal generation control for both a Phase Matrix 1140 B synthesizer and a VXI Technology 3640A arbitrary waveform generator (AWG) working in unison to generate a pulsed RF signal simulating a rotating radar antenna application. The left side controls the RF generator functions (frequency, power, modulation) of the Model 1140B⁹. The right side controls the 3640 AWG. One channel of the AWG drives the pulse input (simulating the radar parameters pulse width and pulse repetition frequency) and the second channel drives the AM input (simulating antenna rotation time and lobe leakage level) via a pseudo sin x/x function. Figure 9 represents the subject pulsed RF stimulus signal as observed in the frequency domain via an Agilent VSA generated spectrum analysis plot.

One of the major challenges in implementing an SI-based solution in DOD ATS systems is that there are many ways to architect an SI solution based upon form factor, component topology and the behavioral specifications of a solution's component parts. If SI is to live up to its potential as a multifunction test and measurement space saver and a mitigating solution for instrument/ATS obsolescence—some attempt at standardization is inevitable. Otherwise, system design, technology upgrades and replacement of aging SI systems may lead to untenable situations.

Figure 10 illustrates the challenge at hand and depicts one of 16 variations in SI component partitioning and I/O interconnects that are possible when architecting an SI solution. User connectivity needs in implementing the downconverter function is a key driver in determining a standard set of SI I/O interconnects required to support a broad cross-section of DOD ATS applications.

The DOD has come to recognize this issue and is soliciting help to standardize I/O topology interconnects as applied to SI¹⁰. This standardization effort is to be affected at the SI component I/O level of system indenture. The results of the standardization effort will serve as a starting point for component interoperability for SI-based DOD ATS interfaces. The goal of this standardization effort will be a joint SI I/O standard specified and supported by government and industry.

Conclusion

An overview and introduction of SI technology was provided that included discussions of the various hardware and software choices that are available to the user and developer alike. Three various flavors or instantiations of contemporary architectures

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were described and discussed: generic/loosely coupled component SI architecture, integrated COTS SI architecture and DOD application-specific SI architecture. All of these contemporary architectures are extremely similar from a block diagram point of view and primarily differentiate themselves on development strategies employed, reduction to implementation and applications.

The generic/loosely coupled architecture is targeted and applicable to those developers who want to “spin” their own SI ATE using SI COTS hardware and software components and add significant value in terms of developing SI Virtual instrument soft panels, application software and choose, from a topology and performance specification perspective, best of class SI hardware components.

The integrated COTS SI architecture is targeted to the developer who wants to field test applications quickly, minimize non-recurring engineering (NRE) charges and adapt existing hardware and canned software in order to affect a timely and cost-effective solution to a target application.

Finally, DOD/application-specific SI architectures are “tuned” to the specific target application/applications and operational environment for which the SI-based ATS is to be employed.

SI technology will set forth a new ATS/instrumentation technology paradigm in which various hybrid architectures/applications will emerge that will appear to be similar in nature to the casual observer, but upon careful scrutiny may differ significantly in their various implementations/reduction to practice, performance and use models. DE

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