# Synthetic Test Systems

The Future of Test – Available Today

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## Test Industry Challenges

Today's test and measurement suppliers face ever increasing pressure to deliver more cost effective solutions to customers that also support their dramatically increasing production rates. Some of the reasons for these pressures are: A) Total product life cycles and the cost of manufacturing products continue to decline while the cost of testing those products has not typically kept pace. B) Manufacturers continue to push for higher production throughput in their factories. C) Increased product complexity and rapid advances in technology and product integration continually force escalating requirements on production test equipment. Products also undergo more evolution during production than ever before, which in turn drive modifications to the test system during a production run. D) In situations where product life cycles are long there are significant issues with test asset obsolescence. E) Improved product performance drives the need for higher quality system level calibrations and self tests that execute faster and at run time.

Typically traditional test system providers take a combination of bench top instruments or instrument specific modules, and they rack them up with the appropriate interconnect cabling and connectors between the instruments and the product. They then add software that makes calls to the functional capabilities embedded in these instruments. This is better known as the "rack-and-stack" approach to test system development. Table 1 lists some examples of traditional instruments, and Figure 1 illustrates an example of a simple rack-and-stack Radio Frequency (RF) test system.

| Traditional Instruments |
|---|
| Oscilloscope |
| Digital Multimeter |
| Spectrum Analyzer |
| Frequency Counter |
| Function/Signal Generator |
| Network Analyzer |
| Power Meter |
| Logic Analyzer |

***Table 1:*** *Examples of traditional instruments. Most are also available as instrument modules.*

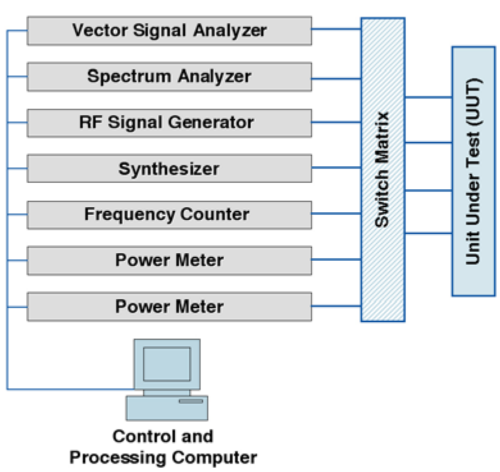


***Figure 1:*** *Block diagram example of a traditional RF test system based on bench top instruments.*

Bench top instruments are designed for use in a laboratory environment and provide stand alone capabilities, but suppliers have also included the option of a rack mount kit for integration into these test systems. Instrument modules include the same core hardware as bench top instruments, but they do not include the user interface, power supply, or other ancillary hardware elements. Instrument modules plug into a backplane and rely on a remote computer for user interface and control functions. Traditional test system implementations utilizing these elements are by far the most common, but they have a great deal of difficulty addressing the challenging problems facing the test and measurement industry today.

These rack-and-stack solutions are usually limited by their design. Rack-and-stack solutions typically test one component, module, or subsystem with limited ability to support the testing of a broad range of products. At best they can test a closely related family of products. As product life cycles and the cost to manufacture these products continues to shrink it becomes less and less cost effective to justify dedicated test systems. To keep the product test costs down a test system must now test many products in support of a reasonable Return on Investment (ROI) for each of the individual products .

Many of these bench top instrument based systems also rely on low speed communications buses like the General Purpose Instrument Bus (GPIB/IEEE-488) that significantly limits test throughput. However, this is only part of the problem. Significant problems also stem from the fact that the system integrator is generally limited to using the functionality and test algorithms built into the individual instruments at the time of manufacture. In many instances the configuration of the product slated for testing will only allow for optimizing the test algorithms for speed and performance, but with traditional instruments the system integrator does not have access at this level.

Many times a signal waveform or data protocol used in the product will change over time. These changes can result in the need to change one or even all of the instruments in the test system. The traditional RF test system shown in Figure 1 illustrates this point. If the original product, otherwise known as the Unit Under Test (UUT), operated below 3GHz the test system integrator would typically select spectrum analyzers, synthesizers, signal generators or vector signal analyzers covering this frequency range to reduce initial procurement costs – especially in a competitive bid for the test system. If the next generation of the product moved into the 6GHz range or higher it would require reprocuring and reintegrating all of the instruments with the limited 3GHz frequency coverage despite the fact that the processing power and instantaneous bandwidths of the 3GHz elements may still prove adequate for testing the upgraded product. This process results in significant non-recurring costs, and it contributes to the proliferation of test systems specific to individual products.

All of these issues effect military, aerospace and commercial test system applications. However, the problems associated with instrument obsolescence challenges military applications to the highest extent due to their long operational life cycles. Military test systems typically remain in service for more than 20 years. Obsolescence issues in these systems arise largely because the test software is written around instrument specific hardware capabilities, and the software drivers are correspondingly specific making evolutionary enhancements more like revolutionary re-designs. Replacing obsolete devices can also result in a situation where no functionally equivalent device exists. In some circumstances the system integrator must replace one instrument with several to achieve equivalent functionality, and traditionally architected test software makes this task even more difficult.

Last but not least, system calibration and self test are becoming more important in terms of total cost of ownership of a test system. The instruments used in the rack-and-stack approach are designed primarily for stand alone operations and calibration. In many cases when these instruments are integrated into a system the calibration and functional test requirements become difficult to perform, and in some cases impossible. The performance levels of today's products require the execution of calibration routines at the integrated system level. This approach is necessary in order to have any chance of meeting the standard 4:1 or 10:1 performance requirements typically levied on the test system.

As an industry, the test and measurement suppliers are being challenged to supply flexible, scalable and efficient test system solutions that solve these problems. The challenge has been the development of an approach that cost effectively meets the demands of today while preserving the investments of the future.

## Synthetic Meets the Challenges

Progressive companies in the industry are working to meet these challenges today, and synthetic instrumentation has emerged as the solution of choice for many. Synthetic instruments “synthesize” the stimulus or measurement capabilities found in traditional instruments through a combination of software algorithms and hardware modules that are based on core instrumentation circuit building blocks. The concept of synthetic instrumentation finds its roots in the well accepted technologies and techniques behind software defined radios, mobile phones and other communications systems designed and fielded today. To better describe and define the concept of synthetic instrumentation a brief overview of Software Defined Radio (SDR) may help.

A software defined radio, as shown in Figure 2, simply consists of a Digital Signal Processing (DSP) engine, a generic transmitter and receiver front end, and some form of transmission antenna. The generic transmitter and receiver front end converts digital data to and from modulated radio waves for wireless communications. Behind these components sits a high speed Digital Signal Processing (DSP) unit that provides most of the radio functionality. In essence this combination provides a “generic” radio. The radio designer programs the functionality of the radio into the DSP through software. The designer writes software algorithm and control modules that generate or process digitally represented signals at the inputs and outputs of the DSP. If the communication protocols or the processing algorithms need modification, or if the radio must now communicate as a different radio type, the designer needs only to modify the software and download it to the radio. The SDR approach removes much of the necessity for redesigning and manufacturing new hardware as traditionally dedicated radio designs required. The processing speed and power available in small packages today makes software defined radio implementations possible with relative ease.

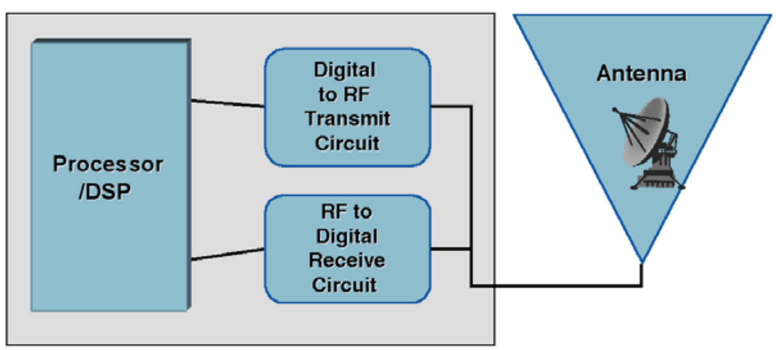


***Figure 2:*** *Bock diagram of a software defined radio*

The block diagram of a synthetic instrument shown in Figure 3 looks very similar to that of a software defined radio. The main differences are the replacement of the antenna with interfaces to the product that will be tested, the addition of multiple levels of circuitry to support even more flexible signal conditioning, and signal paths that allow for the reconfiguration or bypassing of circuit elements as desired. These simple modifications enable the real power behind synthetic instrumentation.

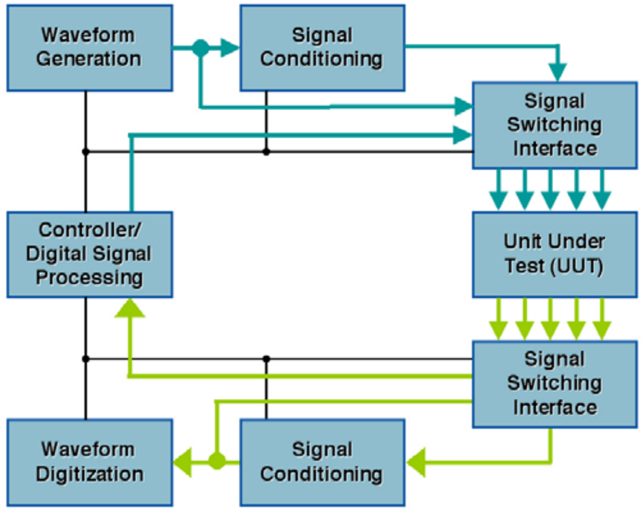


***Figure 3:*** *Block diagram of a synthetic test system.*

To walk through the fundamentals of synthetic instrumentation we will look at just the stimulus path as shown in Figure 4. If the test system is modularized around the "functional building block" circuits commonly found in many signal generating instruments, one will generally find some type of digital signal processing engine to create the signal waveform followed by a Digital to Analog (D/A) converter. In the case of RF signal generation an upconversion block will be found for the primary purpose of getting the signal from baseband to RF. In an integrated system, the RF output will then connect to the UUT through some cabling and switch matrix. In a traditional instrument these circuit elements are internalized and locked up inside a box with no possible way to access intermediate circuit capabilities without significantly compromising the integrity of the actual fixed instrument. In a synthetic instrument these functional blocks represent separate modules with access to the inputs and outputs.

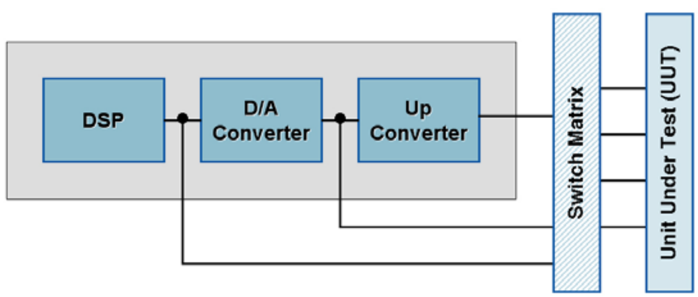


***Figure 4:*** *Synthetic instrument signal stimulus path.*

This "functional partitioning" allows the user to put signal switching between the functional blocks and exploit the fundamental capabilities of the individual circuits as well. For example, if we connect all of the blocks serially we have an RF and microwave signal generator. If we tap off the signal between the D/A converter and the upconversion module we have an analog signal generator or function generator. If we take the output directly from the DSP we have a digital pattern generator. By combining various signal generation, capture, and signal conditioning modules a synthetic test system may include the synthesis of digital, analog, power, RF, microwave or many other signal types.

Note that a synthetic instrument may also include redundant or parallel paths as shown in Figure 5. For instance, a system can have a high resolution and narrow bandwidth D/A converter module as well as a low resolution and high bandwidth module. The synthetic instrument architecture focuses on partitioning the system by the fundamental circuit building blocks necessary to construct the required stimulus signals and measurement analysis. The design can include as many different signal conditioning modules as required. For situations where multiple simultaneous signals are required the digital processing modules are just duplicated as well. This allows the system designer to provide as many parallel stimulus or measurement paths as required. However, since the architecture supports such high levels of reuse it also minimizes the redundant elements to only those required.

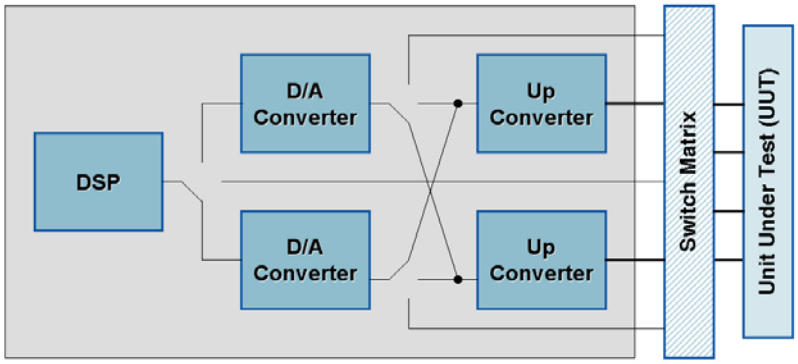


***Figure 5:*** *Synthetic instrument signal stimulus path with the addition of some parallel paths.*

By maximizing the use of individual modules and reducing redundancy the synthetic instrument supplier can procure higher performance elements to satisfy tougher requirements. Since the user is not paying for unnecessary duplicate copies of many functional elements it is possible to reduce the cost of the overall system while still increasing system performance. For example, if three different instruments include a DSP, D/A converter, filter and attenuator circuit block it is possible to apply a portion of the money saved toward the purchase of one higher performance set. These factors are highlighted in Figure 6. These reductions in test assets have the added benefit of reducing the size of the test system as well as reducing the number of hardware spares required to support the test system.

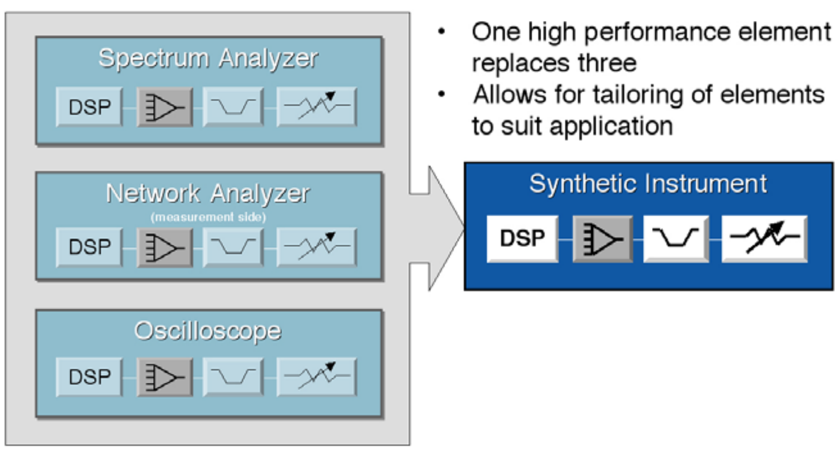


***Figure 6:*** *Synthetic instrumentation reduces the need to procure redundant hardware and allows the insertion of higher performance circuit elements.*

This access to low level circuit building blocks greatly aids the calibration process. Figure 7 shows the basic synthetic instrument block diagram with the addition of calibration and System Functional Test (SFT) loop back circuitry. This circuitry can include simple loopback switch paths, along with calibrated sensors and other related hardware. It is not possible to break into the middle of the circuitry chain of a traditional instrument. This makes traditional instruments more difficult to calibrate. More importantly it makes traditional instruments difficult, if not impossible, to calibrate effectively at run time. The synthetic system approach provides the ability to calibrate each functional element and allows for the tailoring of calibration routines for varying types of measurements. In most cases this results in greatly improved system performance.

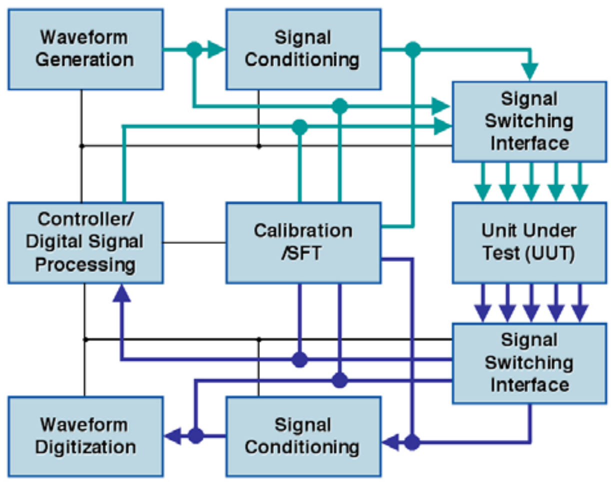


***Figure 7:*** *Basis synthetic instrument block diagram with the addition of calibration and system functional test loops.*

The synthetic architecture also enhances the ability to upgrade the test system as well as the systematic handling of obsolescence issues. When an upgrade or obsolescence situation arises, it is only necessary to add or replace the functional blocks directly impacted — not the entire instrument suite. This reduces the cost of handling obsolete instruments, in addition to reducing the technical risks associated with the effort.

The concept of synthetic instrumentation treats the hardware in the same ways that object oriented programming treats software "modules". Consequently, object oriented software matches perfectly with the synthetic instrumentation approach. Advanced synthetic implementations utilize software objects that correlate one-to-one with the functional hardware modules, and they also implement stimulus and measurement algorithms as software objects. This encapsulation of all required information about a functional hardware module makes it easy for intelligent software to combine modules in different configurations and determine the final stimulus or measurement capability. Simply put, if you know the transfer function for each of the modules then you can combine them to create complex stimuli or measurements. Since the modules are treated as objects then one or more sets of calibration coefficients can also reside in the object. This allows the combining of modules in many different ways while still maintaining the high fidelity system level calibrations all the way out to the interfaces for the unit under test.

Significant side benefits to this object oriented approach are the ability to provide integrated diagnostics and fault prediction for the test system and the UUT. Integrated diagnostics are very difficult to perform in traditional test systems that use sequential programming techniques. With the object oriented synthetic system approach, intelligent software can easily monitor the operational state and status of the hardware and software objects to provide real time diagnostics. The addition of trending to the system can also provide fault prediction capabilities.

In the synthetic environment the choice of interfaces does not matter. The solution provider can mix PXI, VXI, GPIB, Ethernet, USB, PCI, PCI-X, or any other communications bus in the solution including switch fabric architectures since the interfaces between hardware and software modules are also treated as plug in objects. The hardware configuration is abstracted from the software components and modules. This provides an extremely powerful systems architecture.

One of the greatest benefits that synthetic instrumentation provides is the ability to perform tests that are not limited by the characteristics of the test instruments, but instead represent the operational characteristics of the UUT. A simple example of this is the characterization of an attenuator bank. A conventional approach might be an output level test using a power meter followed by a frequency response using a spectrum analyzer, with the tests being carried out at operational reference settings.

The results of a single sweep with each instrument will appear as shown in Figure 8 (Gain) and Figure 9 (Frequency Response). The performance in Figure 8 appears linear, and there are no obvious problems. The performance in Figure 9 still appears fairly linear. However, since two instruments are employed it is not easy to investigate all areas of operation. Any attempt to cover the whole operational range will require executing the tests multiple times at different power levels, frequencies and attenuator settings while inevitably repeating many data points numerous times. Single-domain tests often hide poor non-linear characteristics in some areas of operation, and although traditional instrumentation can be configured and utilized to cover the entire range of tests it is not particularly efficient. What must be taken into consideration is the extensive amount of engineering and test time overhead that is involved with the deployment of traditional instrumentation.

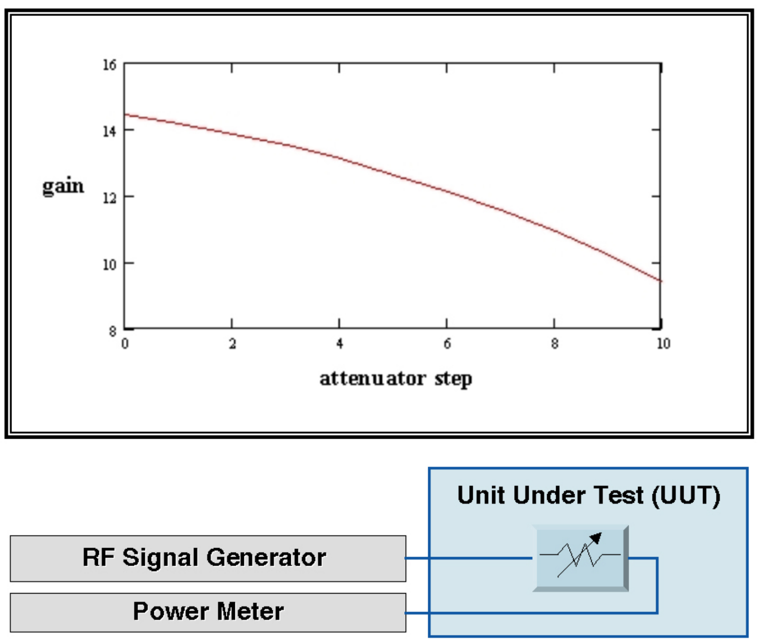


***Figure 8:*** *The results of a traditional power measurement test on an attenuator bank.*

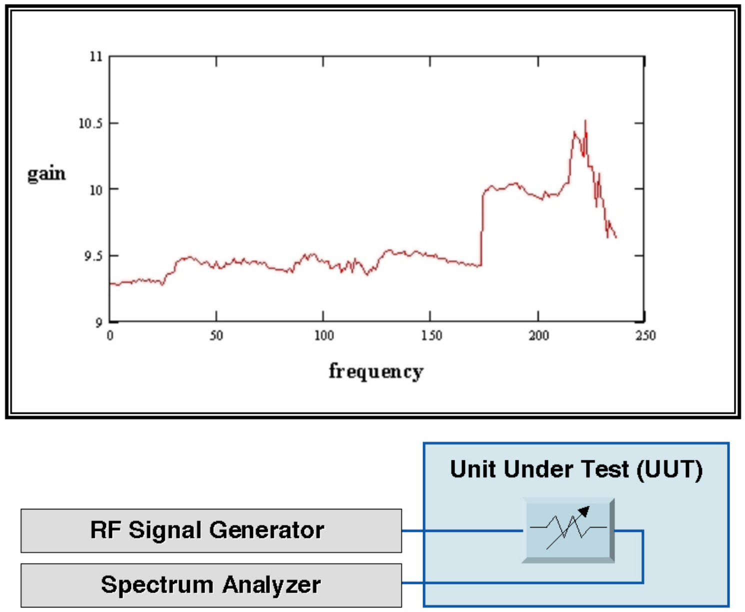


***Figure 9:*** *The results of a traditional frequency response test on the same attenuator bank.*

A single synthetic instrument will, instead, perform a more complex test that will characterize the amplitude and frequency response as a three dimensional surface. The results of this test are shown in Figure 10. This plot shows that the attenuator bank has some poor non-linear characteristics in certain areas of operation, most likely involving some specific attenuators in the bank. After correction, the tests can easily be repeated in just the relevant areas, and if necessary additional pass/fail criteria can be defined as slopes of the response surface. Test dimensionality can also be increased to include phase response or other elements. These complex test scenarios are easily handled by the synthetic instrumentation approach, and the benefits toward decreased test times and increased UUT test coverage are limited only by the creativity of the test designer.

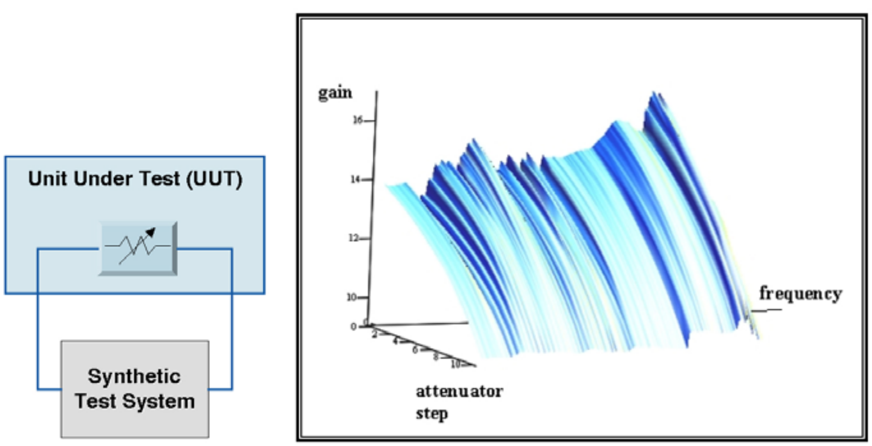


***Figure 10:*** *The combined amplitude/frequency tests on the same attenuator bank carried out by a synthetic instrument capable of performing multi-dimensional tests.*

## Synthetic Solutions

Due to the broad range of benefits enabled by the synthetic instrumentation approach, a great variety of test and measurement applications can be supported. Synthetic solutions, in use or under development today, include applications in the diverse military, aerospace and commercial test markets.

Today the Department of Defense (DOD) is aggressively pursuing the procurement of new test systems as well as upgrades to legacy systems based on the synthetic architecture. This should come as no surprise since many of the technology advances in the test and measurement industry were born out of military and aerospace test applications. Synthetic test systems will provide the DOD with the flexibility it needs, as well as more portable, cost effective, and obsolete immune solutions that allow for multi-service support in the battle field.

During the recent war with Iraq we saw many instances where the war fighters dramatically outpaced their logistics support. The flexibility and smaller size of synthetic test systems will provide the military more test capability with less assets along with the ability to test assets from multiple services. The ability to run many different test algorithms and provide multiple interfaces supports the multi-service test capability, and the enhanced portability will benefit the war fighters in the battle field.

The most exciting potential for synthetic instrumentation in military and aerospace testing resides in the ability to run legacy test programs without modification. The Navy CASS test system runs over 3000 Test Program Sets (TPSs), but it faces serious instrument obsolescence problems. At Autotestcon 2002 Aeroflex and Lockheed Martin performed a joint demonstration that replaced a suite of traditional RF instruments with a synthetic RF subsystem. The demonstration system executed unmodified representative CASS test programs. This included both the software and hardware interfaces to the UUT. With over 600 CASS system in the field and billions of dollars invested in TPSs the synthetic instrumentation approach can dramatically decrease the cost and complexity of dealing with large scale obsolescence problems.

Recently a top manufacturer of commercial satellites wanted to dramatically decrease the time it spent testing satellite communications payloads from unit level through fully integrated satellites. The group tested payloads from the initial step of installing individual units on panels up through complete integrated payloads and then finally at the fully integrated satellite level. Figure 11 shows a block diagram of their instrument based legacy system, and Figure 12 shows the block diagram of the synthetic test system that replaced it. This situation provided an excellent way of evaluating the performance and ROI potential associated with a synthetic test system since the end user had a legacy system available for direct comparison.

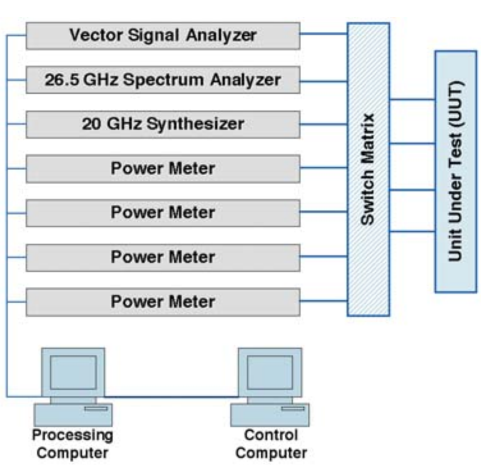


***Figure 11:*** *Block diagram example of a traditional legacy RF satellite payload test system.*

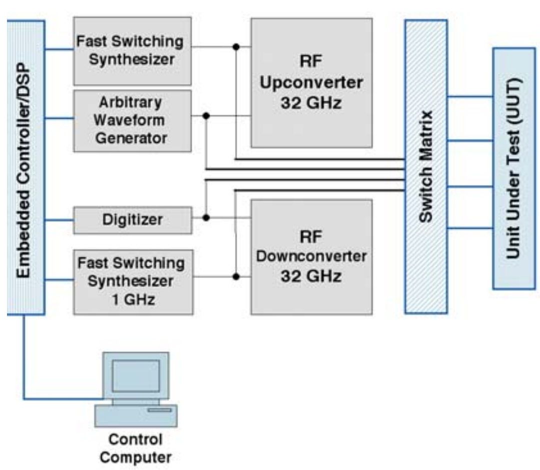


***Figure 12:*** *Block diagram example of a synthetic test system that replaces the system in Figure 11.*

In conducting the comparison the end user executed the same test procedures on both systems using the same test sequencer software. The resulting benchmark data shows an impressive performance advantage for the synthetic system. Table 2 highlights the results and shows an average speed increase of almost 2-1/2 times. The almost 10 times speed increase for the Linear Frequency Response Versus Drive test really stands out since they run this test thousands of times on each satellite. These results are only part of the savings. System setup and calibration times also exhibit similar reductions leading to significant end-to-end test cycle time and cost savings.

| Test Description | Speed Improvement |
|---|---|
| Fixed Mode Gain Step / Deltas | 1.16 |
| ALC Mode Gain Step / Deltas | 1.27 |
| Linear Frequency Response Versus Drive | 9.09 |
| Saturated Frequency Response Versus Drive | 3.45 |
| Group Delay | 3.13 |
| Out-of-Band Attenuation | 4.35 |
| Gain Transfer – OBO | 3.03 |
| Spurious Outputs (In-Band) | 4.17 |
| Translation Frequency | 1.39 |
| Two Carrier C/IMD | 3.45 |
| Noise Figure | 2.27 |
| AM / PM Conversion | 4.55 |
| ALC Characteristics | 1.92 |
| Average Speed Increase | 2.38 |

***Table 2:*** *Test execution speed improvement of Synthetic Test System vs. Legacy Rack-and-stack Test System.*

For commercial radio and communications testing the synthetic approach yields similar results. Today, analog to digital and digital to analog conversion blocks capable of hundreds of megahertz of instantaneous bandwidth are readily available. These elements coupled with receiver front ends and high performance RF up and down conversion blocks allow for the implementation of software defined test systems. In essence these test systems make up an instrumentation quality SDR capable of testing both legacy and software defined radios. The software defined flexibility allows the resulting system to test multiple radio types with different frequencies, modulation schemes, data protocols, and even frequency hopping capabilities.

As can be seen, the benefits to procuring a synthetic instrument based test system can be quite compelling. If you or your company are in need of a new or upgraded test system you should seriously consider a synthetic test system solution. At Aeroflex we have been fielding synthetic test systems to satisfied customers for several years, and our passion for performance continually drives us to push these systems to new heights. Please give us a call to see how a synthetic test solution can work for you.