The Future of Instrumentation: The Software Revolution

By Matthew Friedman

Engineers are becoming empowered to make measurements and create test systems specifically suited to their exact needs.

65 years ago Bell Labs forever changed technology with the invention of the transistor. Considered one of the greatest inventions of the twentieth century, it is hard to find an element of our life that has not been impacted by its existence. This of course has had a profound impact on instrumentation as well. Companies like Hewlett-Packard were born from this silicon revolution and their instruments replaced the vacuum tube instruments of General Radio before them. Like 45 years ago, we are now at another crossroads in instrumentation with the software revolution. Just as everyone expects their smartphone to have apps customized to their exact needs, engineers are struggling to make do with fixed functionality instruments. As we stand at the precipice of this new era, we are seeing a fundamental shift as engineers are becoming empowered to make measurements and create test systems specifically suited to their exact needs.

Test Complexity Drives Change in Instrumentation

With increased technological innovation comes the challenge of testing each new breakthrough. For example, as wireless standards become more complex, the number of operational modes for these devices increases exponentially. As we progress to the latest WiFi standards like 802.11ac, there are many new modulation schemes, additional channels, more bandwidth settings, and extra spatial streams that increase testing complexity. Additionally, characterizing WLAN transceivers is especially challenging when faced with thousands of independent operational gain settings (Figure 1).

With such complexity, manual testing techniques become infeasible and some level of automation is required. This is traditionally achieved by connecting box instruments over
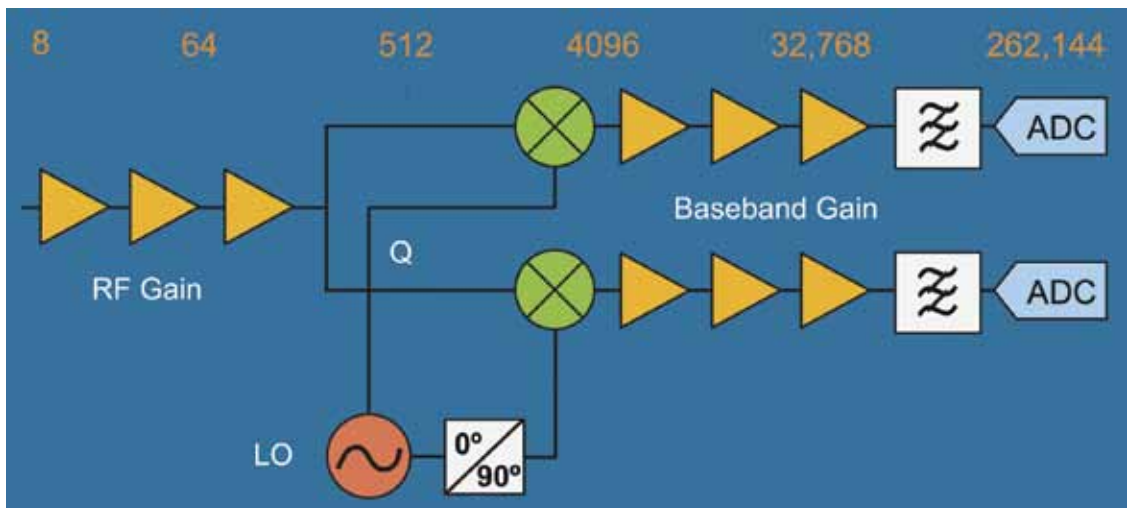

Figure 1 • An example block diagram of a typical WLAN receiver shows how each component has multiple gain stages, resulting in hundreds of thousands of different possible gain settings for a single receiver. (Courtesy of Qualcomm Atheros).

an instrument control interface to a computer, and then using a software application to automate the system. While these systems have been functional, they are often inefficient and do not apply the instrument as they are intended to be used.

Traditional box instruments are designed for when an engineer or technician wants to manually test or trouble-shoot a device. When automation is required, the instruments' screens, knobs, and buttons can often become a waste of space and money. Furthermore, these instruments are not typically designed to maximize measurement speed or data throughput.

The Move to PXI Modular Instruments

Over the last few years, the industry reached a tipping point and is making the switch to PXI. Optimized for automating measurements, PXI provides a solution that is often faster, smaller, and more cost-effective than traditional box instruments. For example, TriQuint Semiconductor saw their testing complexity massively increase as they had to characterize their latest generation RF power amplifiers over a wide range of frequencies, voltage supply levels, temperatures and power ranges. For the typical part, this requires 30,000 – 40,000 lines of data to completely test the design. Using traditional box instruments, a full characterization would take about two weeks to complete. By making the switch to PXI modular instruments for the bulk of their measurements, Triquint was able to significantly reduce testing times (Figure 2) and complete full characterization in about a day.

Based on commercial, off-the-shelf technology, PXI provides a solution that is faster, smaller and more cost effective than traditional solutions. Some of the key features include (Figure 3):

Small, modular architecture: PXI modules are available from DC to 26.5 GHz and can be mixed and matched to create a full test system in a small benchtop footprint or 3U of rack space.

High throughput data transfer: Based on the PCI Express bus, PXI is able to achieve data transfers more than 20 times faster with 100 times less latency than traditional instrument control interface like Ethernet and GPIB.

	Traditional Bench Test Time (s)	PXI Test Time (s)	Speedup
GSM Test	6	1.1	6X
EDGE Test	14	1.1	14X
WCDMA Test	9	1.1	9X

Figure 2 • Triquint Semiconductor realizes test speeds 6 to 14 times faster using PXI modular instruments over traditional instruments.
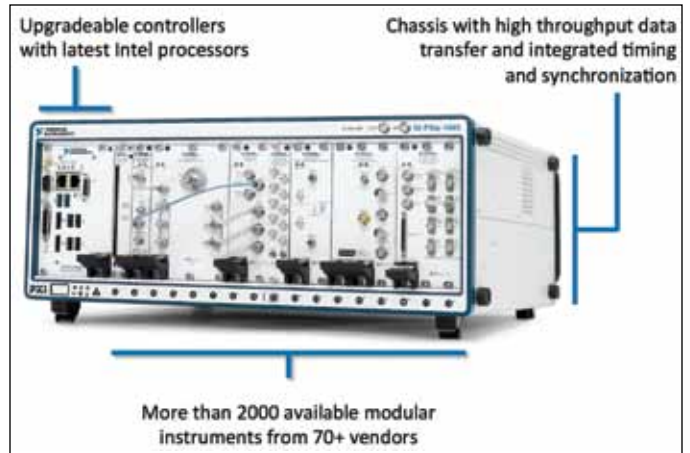

Figure 3 • The PXI platform is ideally suited to meet today's and tomorrow's testing needs.

Upgradeable, modular controllers: Engineers can add extra processing capabilities by simply swapping the controller while keeping the same chassis and instrumentation. For example, to improve performance, they can easily switch a system built in 2001 operating at 2.5 GFLOPS with a controller running the latest Intel core i7 processor at over 35 GFLOPS.

Integrated timing and synchronization: PXI chassis incorporate dedicated 10 and 100 MHz reference clock and trigger lines to every slot to address the needs of synchronizing multichannel and MIMO test systems.

The PXI market has grown immensely since its introduction 15 years ago. According to Frost and Sullivan, it is expected to be over billion-dollar market by 2017. Already today there are more than 70 companies with more than 2,000 different products.

The Revolution of Software

While PXI provides a faster, smaller, and more cost-effective option, its real power lies in allowing the user to create test systems better suited to their exact needs. For example, ST Ericsson had the challenge of the increasing complexity of testing their latest RF platforms for mobile phones and tablets. These platforms containing multiple radios, such as GPS, Bluetooth, WCDMA, and LTE, require approximately 800,000 measurements to fully test. Further complicating the tests is that they must work with multiple standards and custom digital protocols to properly interface their chips. When traditional box instruments proved not to be flexible enough to meet their needs, ST Ericsson turned to NI LabVIEW system design software and NI PXI hardware to perform the needed DUT interfacing, RF measurements and analysis. Not only was the system much more flexible, ST Ericsson was able to reduce test time by a factor of 10, from 3 days to 8 hours.

Figure 4 • The NI PXIe-5644R is the world's first software-designed instrument.

However, even with all this flexibility, there is often a need for more. For example, many new tests require capabilities like frequency domain triggering, real-time spectral masks and embedded control algorithms. These tasks can be difficult to execute as they are required to be directly executed within the instrument's embedded firmware and typically must be implemented by the vendor. Fortunately, there is a new paradigm in instrumentation called software-designed instruments that opens up the instrument's firmware and allows the engineer complete access to add their required functionality.

The first instrument to support this paradigm is the NI PXIe-5644R vector signal transceiver (Figure 4). Combining a vector signal analyzer, a vector signal gen-erator and high-speed digital I/O in one three-slot PXI module, the NI PXIe-5644R vector signal transceiver is a fraction of the size and cost of traditional solutions while maintaining industry-leading measurement performance. What makes it a software-designed instrument is that is has an open, user-programmable FPGA at its core. Users can modify its software and firmware, which is based on LabVIEW, to create an instrument specific to their needs.

Out of the box, the vector signal transceiver provides a software experience similar to other instruments with a quick time to first measurement/generation and a pro-gramming interface for the most common functions. However, the true power comes from the fact that all LabVIEW software and firmware source code is provided to enable users to modify their instruments to their spe-cific needs. System design software like LabVIEW is well suited to software designed-instruments because it is capable of abstracting the processing implemented on an FPGA and the microprocessor on the PXI controller in a way that does not require extensive knowledge of comput-ing architectures and data manipulation. This frees the user to focus on the functionality of algorithms and instru-ment control to meet their specific application needs.

Qualcomm Atheros is one of the initial users of the software-designed vector signal transceiver in the testing of their latest 802.11ac WLAN transceiver. They were faced with the challenge of their latest designs having multiple gain settings at each stage of the radio structure. This resulted in hundreds of thousands of data points that needed to be acquired for a single operational mode. Using traditional instruments it was not feasible to perform all these measurement and instead used a best estimate gain table that would only produce approximately 40 meaning-ful data points per iteration. However, after making the switch to the vector signal transceiver, they were able to
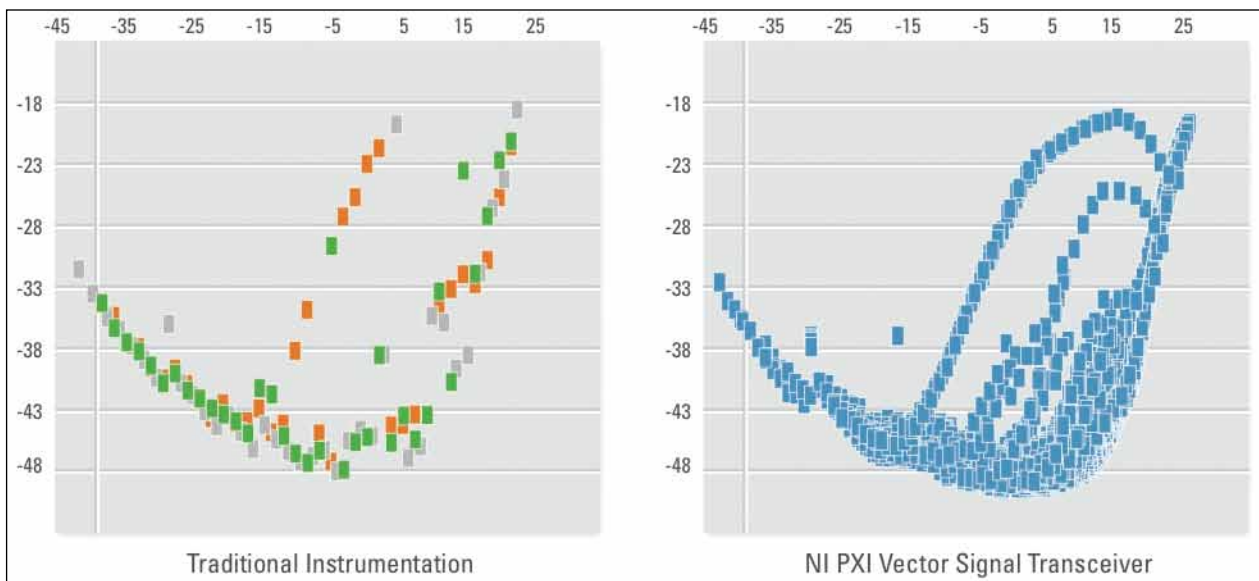

Figure 5 • Qualcomm Atheros realized a 200 times improvement in measurement speed and a better understanding of their devices after making the switch to the vector signal transceiver.
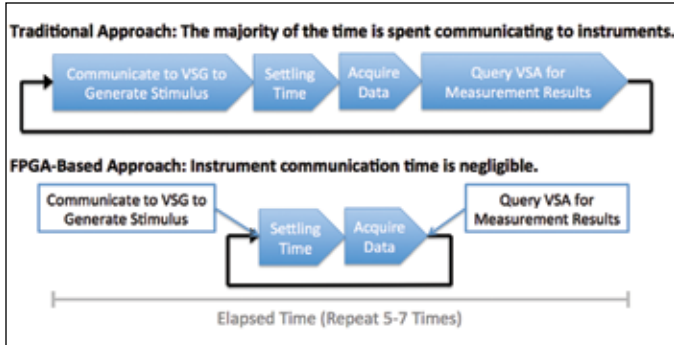
Figure 6 • Embedding power amplifier servoing control algorithms directly in the instrument can provide over an 800 times reduction in test time.

perform DUT control and data processing directly within the instrument. This resulted in 200 times improvement in measurement speed and also allowed a test sweep to acquire all 300,000 data points for a better determination of optimal operational settings (Figure 5).

Examples of Software-Designed Instrument Applications

With software designed-instruments, engineers are empowered to create the instrument specifically suited to their exact needs. Early users of the vector signal transceiver are already customizing it in many different ways; two recent examples are those of power amplifier servoing and channel emulation.

Example: Power-Level Servoing for Power Amplifier Test

It is important for power amplifiers (PAs) to have an expected output power, even outside their linear operating modes. To accurately calibrate a PA, a power-level servo feedback loop is used to determine the final gain. Power-level servoing captures the current output power with an analyzer and controls the generator power level until desired power is achieved, which can be a time-consuming process. In simplest terms, it uses a proportional control loop to swing back and forth in power levels until the output power-level converges with the desired power. The vector signal transceiver is ideal for power-level servoing because the process can be implemented directly on the user-programmable FPGA, resulting in a much faster convergence on the desired output power value (Figure 6).

Example: Radio Channel Emulation

As RF modulation schemes are growing in complexity, bandwidth increases and radio spectrums are becoming more crowded, it becomes important to not only test wireless devices in a static environment, but to understand how these devices behave in a dynamic real-world environment. A radio channel emulator is a tool for emulating wireless communication in a real-world environment. Fading models are used to simulate air interference, reflections, moving users, and other naturally occurring phenomenon that can hamper an RF signal in a physical radio environment. By programming these mathematical fading models onto the FPGA of the vector signal transceiver, the module can be reconfigured to go beyond a traditional VSA/VSG paradigm and become an embedded device providing real-time impairments of your RF signals (Figure 7).

With software-designed instruments, the user is truly able to create the instrument specifically designed to their exact needs. Already, we are seeing unique and novel ways to apply this concept and overcome the challenges of instrumentation defined by the vendor. The future will always hold new testing challenges but we can be confident that a user empowered with software-designed instruments will be able to rise to the occasion.

About the Author:

Matthew Friedman is the Senior Product Manager for the RF and Microwave platform at National Instruments. Prior to his current position, Matthew was the product manager for instrument control software. Along with his work at National Instruments, he is active in test & measurement standards bodies. He serves as a director and marketing co-chairman in the PXI Systems Alliance and was previously the marketing chairman of the IVI Foundation.
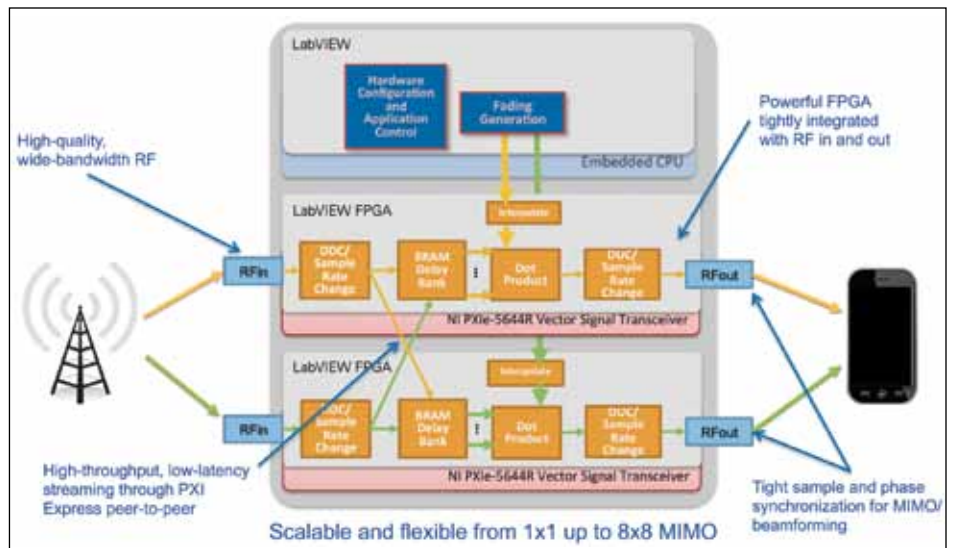

Figure 7 • Software-designed instruments can be reconfigured into embedded devices like channel emulators to aid in the understanding of how devices will work in real-world environments.