WHITE PAPER

Introduction to the NI 5840 Second-Generation PXI Vector Signal Transceiver

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Introduction

The requirements of tomorrow's RF and wireless technologies are changing the methodology and equipment that engineers use to design and test mobile devices. For example, wider bandwidth signals in future standards such as 5G require wider bandwidth RF instruments. In addition, multi-antenna technologies like multiple input, multiple output (MIMO) and beamforming produce a need for modular and flexible instrumentation that can scale from testing single-antenna devices to 8x8 MIMO devices and beyond. Finally, lower cost radios also require lower cost approaches to wireless test. NI's second-generation vector signal transceiver (VST) is designed to address today's and tomorrow's RF design and test challenges through a unique approach that combines excellent RF performance with a flexible software-designed architecture.

What Is a VST?

NI introduced the concept of a VST in 2012. A VST combines an RF signal generator, an RF signal analyzer, a high-speed digital interface, and a user-programmable FPGA onto a single PXI module. NI's VSTs feature an FPGA that users can program in LabVIEW software – a feature that allows engineers to modify the instrument's firmware. The NI 5840 VST provides an upgrade to the first-generation VST in nearly every aspect, from supporting a wider frequency range to higher output power to a larger FPGA, in fewer slots and with a wider instantaneous bandwidth of 1 GHz.

Spec	PXIe-5840 Performance*
Frequency Range	9 kHz to 6.5 GHz (band edge)
Max. Output Power	+20 dBm
Bandwidth	Up to 1 GHz
EVM	-50 dB (802.11ax, loopback, external LO)
Tx/Rx Amp. Accuracy	± 0.5 dB
Tuning Time	300 us
Slots	2
FPGA	Xilinx Virtex X690T
Digital I/O	60 MHz, 8-port parallel DIO 12 Gb/s, 4-port high-speed serial

Table 1. Specifications of PXIe-5840

NI's VST combines high-performance RF front ends with a flexible and powerful LabVIEW-based software experience. As a result, engineers benefit from the RF generation and measurement quality of a lab-grade instrument along with the customizability of a software-defined radio. With the VST's LabVIEW-programmable FPGA, engineers can customize the instrument's LabVIEW-based firmware to control a device under test (DUT) in real time, dynamically control/sequence the vector signal generator (VSG) or vector signal analyzer (VSA), or add real-time signal processing to the instrument.

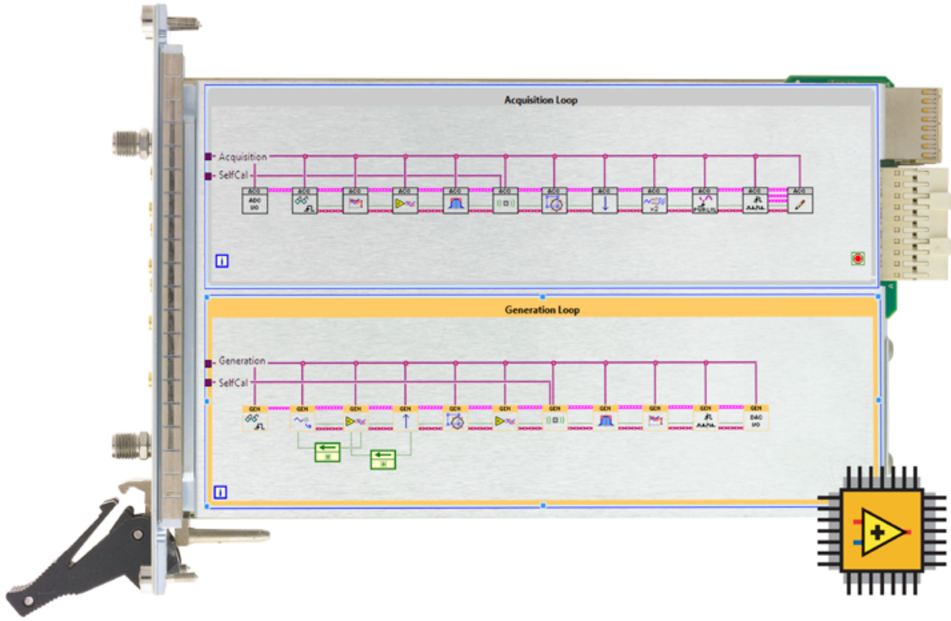

Figure 1. The VST's firmware is designed in LabVIEW for easy customization.

As a result, VSTs serve a wide range of RF design and test applications and are ideally suited for applications that require an RF stimulus and RF response. Example applications include wireless production test, RFIC characterization, channel sounding, radar prototyping, signal intelligence, and software-defined radio.

High-Performance RF Front End

The PXIe-5840 features a high-performance RF signal generator and RF signal analyzer. Both instruments use direct conversion from IQ to RF and are optimized for excellent measurement quality. Key technical features of the VST include:

- Wide instantaneous bandwidth
- Excellent EVM performance
- Modular architecture
- Flexible digital interface
- Wide frequency range

Wide Instantaneous Bandwidth

Over the past decade, wireless standards have evolved to use significantly wider bandwidth channels to achieve higher peak data rates. For example, since 2003, Wi-Fi has evolved from 20 MHz channels to 160 MHz channels in today's 802.11ac and 802.11ax standards. Mobile communication channels have evolved from 200 kHz in GSM to 100 MHz in today's LTE-Advanced technology. In the future, technologies such as LTE-Advanced Pro and 5G will use 1 GHz of bandwidth or more.

In addition, the bandwidth requirements of the instrument often exceed the bandwidth of the wireless communications channel. For example, when testing RF power amplifiers (PAs) under digital predistortion (DPD) conditions, the test equipment itself must extract a PA model,

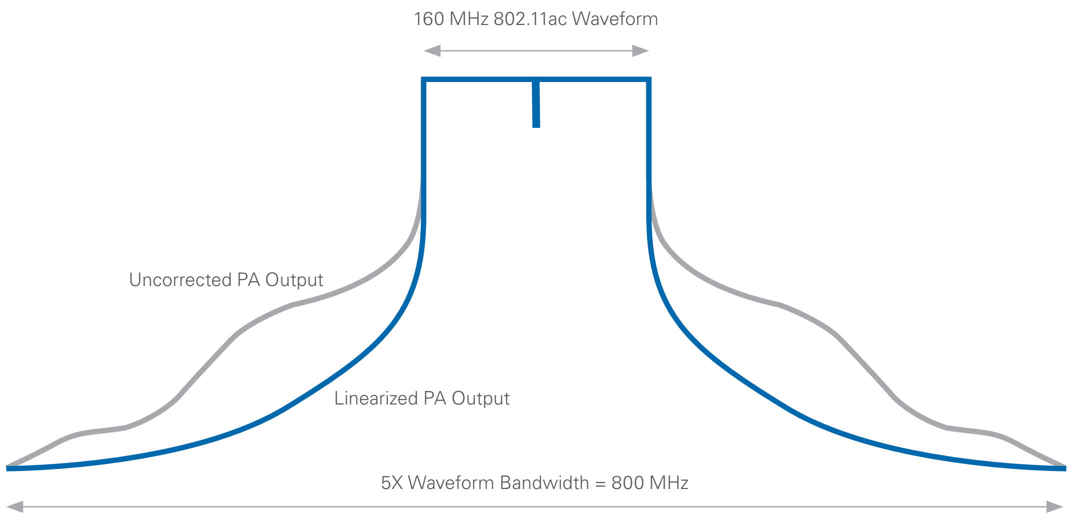

Figure 2. DPD Algorithm Using 5X Signal Bandwidth

correct for nonlinear behavior, and then generate a corrected waveform. Advanced DPD algorithms often require 3X to 5X the RF signal bandwidth. As a result, instrument bandwidth requirements can be up to 500 MHz for LTE-Advanced (100 MHz signal) and 800 MHz for 802.11ac/ax (160 MHz signal).

A significant enhancement of the second-generation VST is its wider instantaneous bandwidth of 1 GHz. Because of this wider bandwidth, engineers can use the second-generation VST to solve application challenges that currently can't be met using existing instrumentation. For example, in tests for LTE-A Pro devices, many of the LTE carriers are separated by several hundred megahertz. With the VST's wide bandwidth, engineers can use a single instrument to generate or analyze multiple LTE carriers instead of using multiple instruments.

In addition, wideband radar systems often require up to 1 GHz of signal bandwidth to better capture pulsed signals. Also, in spectrum monitoring systems, the bandwidth of the instrument can dramatically improve the scan rate. Finally, wide signal bandwidth is an essential requirement for many advanced research applications.

> *"The combination of the industry's widest bandwidth and low latency software-designed instrument allowed us to discover our automotive radar sensors as never before, and even allowed us to identify problems very early in the design phase that were previously impossible to catch. With the VST and FPGA programmable by LabVIEW, we were able to rapidly emulate a wide range of diverse scenarios, thus influencing safety and reliability aspects in autonomous driving."*
>
> —Niels Koch, Component Owner Radar Systems, Audi AG

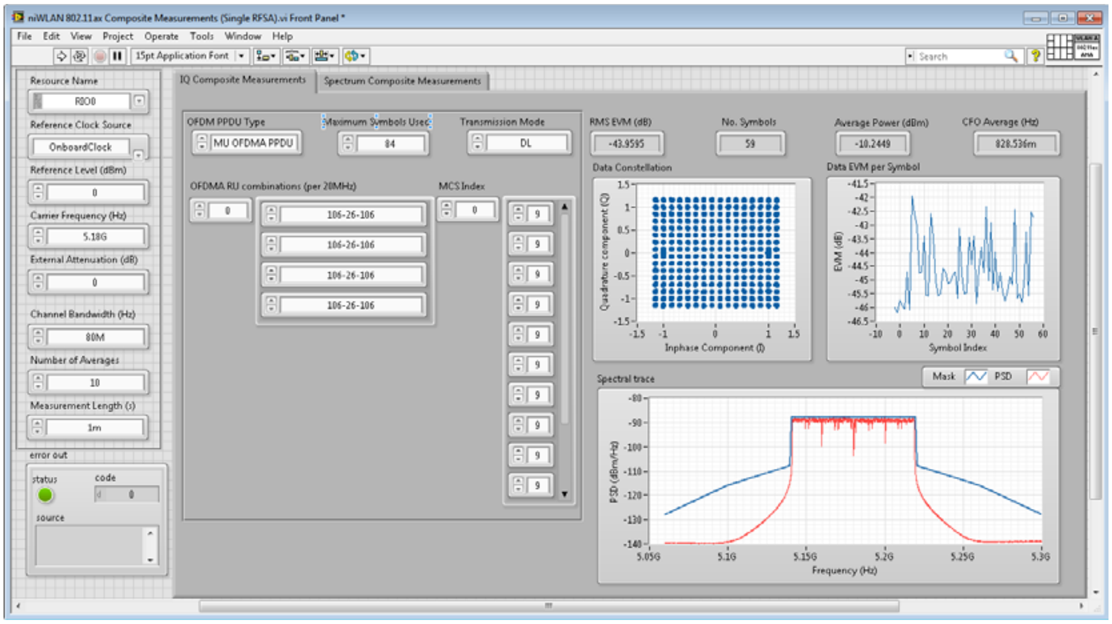

Figure 3. 1024-QAM Constellation in 802.11ax Using the WLAN Toolkit

EVM Measurement Performance

A second critical requirement of next-generation wireless devices is even more stringent EVM performance requirements. With higher order modulation schemes and wideband multicarrier signal configurations, the RF front ends of today's wireless devices require better linearity and phase noise to deliver the required modulation performance. Because of these requirements, tomorrow's RF test instrumentation must deliver even more accurate RF performance.

For example, when measuring EVM performance on a wireless device, the RF signal analyzer should typically deliver EVM performance that is 10 dB better than that of the device it is testing. For example, the 802.11ax 1024-QAM modulation scheme will likely push EVM limits of the access points to -35 dB and push EVM limits of the transceivers and PAs to -40 dB or better. As a result, instruments require EVM performance of -50 dB or better to accurately characterize the DUT.

The second-generation VST uses advanced, patented IQ calibration techniques to deliver best-in-class EVM performance for wideband signals. In addition, the modular design of PXI instruments provides engineers with the most demanding EVM performance requirements the ability to improve on the VST's native performance even further. Using a PXI external local oscillator (LO), systems based on the second-generation VST achieve EVM performance of better than -50 dB.

Figure 5. Typical 8x8 MIMO System With Eight PXIe-5840 VSTs

Modular and Easily Synchronized

Modern communications standards use sophisticated multi-antenna technology. In these systems, MIMO configurations provide a combination of either higher data rates through more spatial streams or more robust communications through beamforming. Because of these MIMO benefits, next-generation wireless technologies, such as 802.11ax, LTE-Advanced Pro, and 5G, will use more complex MIMO schemes with up to 128 antennas on a single device.

Not surprisingly, MIMO technology adds significant design and test complexity. It not only increases the number of ports on a device but also introduces multichannel synchronization requirements. To test a MIMO device, RF test equipment must be able to synchronize multiple RF signal generators and analyzers. In these configurations, the instrument's form factor and the synchronization mechanism are critical.

With the compact footprint of the second-generation VST, engineers can synchronize up to eight VSTs in a single 18-slot PXI chassis. In addition, each of the VSTs can be synchronized in a completely phase-coherent manner. In hardware, each VST features the ability to import or export the LO so that all modules can share a common LO. In software, engineers can use NI's patented T-Clock technology to easily synchronize multiple instruments using the NI T-Clk API. Using this API, engineers can synchronize multiple VSTs or even synchronize VSTs with other modular instruments, either in LabVIEW, C/C++, or .NET.

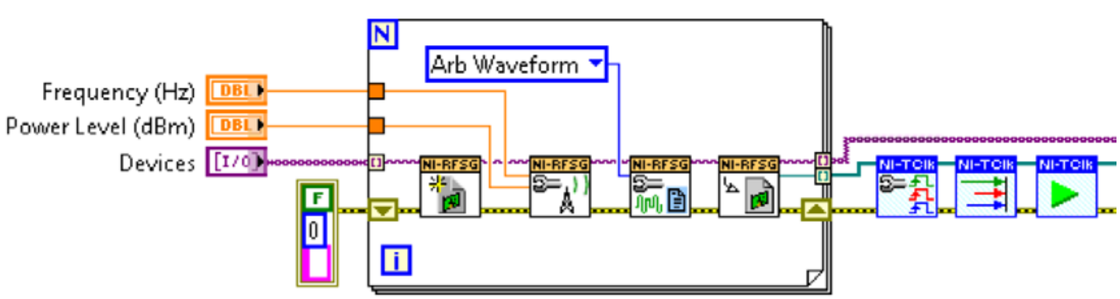

Figure 6. With the NI T-Clk API, engineers can synchronize the VST with other PXI instruments.

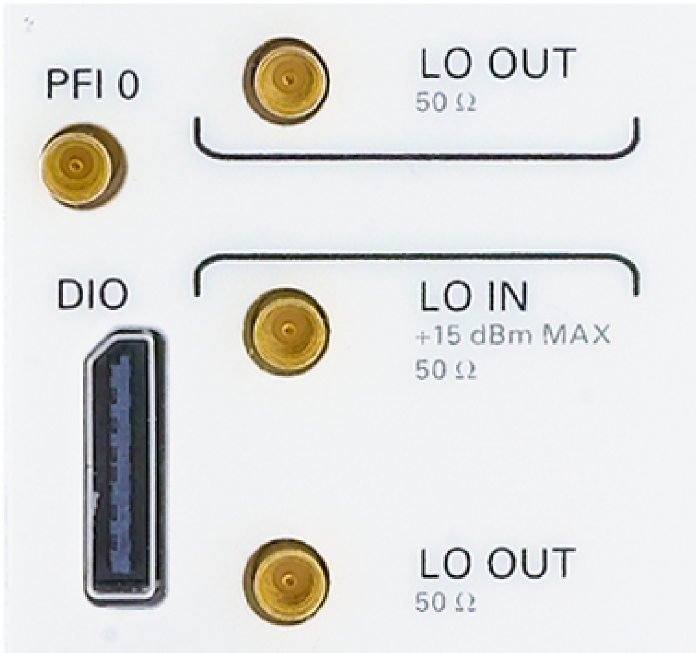

Figure 7. Digital Interfacing Ports on VST Front Panel

In addition, in MIMO test applications for wireless technologies such as WLAN, the WLAN toolkit natively handles synchronization of multiple VST's. For example, using the WLAN soft front panel, engineers can dynamically choose the number of VSTs present in a PXI system to configure it for MIMO test.

Flexible Digital Interface

In addition to the onboard VSG and VSA, the VST features a flexible digital interface capable of both high-speed parallel and high-speed serial interfacing. The VST's digital lines are directly connected to a user-programmable FPGA through level shifting buffers. As a result, the digital lines support 1.2, 1.5, 1.8, 2.5, and 3.3 V voltage levels and are exposed on the instrument front panel using a 42-pin Nano-Pitch connector. Using this connector, eight digital lines are dedicated to high-speed parallel interfacing. The parallel interface operates at up to 60 MHz clock rates, and this interface can be controlled in real-time using the instrument's onboard FPGA.

A new addition to the VST is the high-speed serial interface, which features four multi-gigabit transceivers (MGTs) that operate at data rates of up to 12 Gb/s per lane. Given this performance, the serial interface is capable of supporting high-speed serial standards such as Xilinx Aurora and Serial RapidIO. A benefit of the high-speed serial interface is that it gives users the ability to stream the full instruments bandwidth out the front panel to third-party signal processing modules such as the ATCA-3671. As a result, engineers have two data streaming options and can stream data either out the front panel connector or through the PCI Express backplane.

Wide Frequency Range

Finally, the second-generation VST features a broad and contiguous frequency range from 9 kHz to 6.5 GHz (band edge). With the combination of contiguous frequency coverage and full suite of software for wireless standards measurements, engineers can use a single instrument to test a wide range of wireless technologies.

Modern electronic systems are increasingly using a blend of multiple wireless technologies. Prevalent examples of this are integrated chipsets that combine AM/FM, Bluetooth, GNSS, and Wi-Fi technologies on the same chipset. Many of these wireless technologies operate below 6 GHz, and Table 2 lists some of the most common examples.

With the growing prevalence of combining wireless technologies within the same device, it is increasingly important that test equipment have contiguous frequency coverage from near-DC to greater than 6 GHz. Although both the first- and second-generation VSTs provide contiguous frequency coverage to 6 GHz, the second-generation VST expands the VST frequency at both the low end to 9 kHz and the high end to 6.5 GHz. As a result of the wide frequency range, engineers can not only test the latest wireless technologies for avionics, Wi-Fi, and mobile communications but can also future-proof their test system for new emerging wireless technologies that are not present in today's electronics.

Technology	Band or Frequency Range
LORAN-C (Navigation Signal)	100 kHz
AM Radio	635 kHz to 1,605 kHz
FM Radio	88 MHz to 108 MHz
VOR/ILS (Avionics)	108 MHz to 118 MHz
Satellite Weather Radio	136 MHz to 138 MHz
Remote Keyless Entry Systems	315 MHz or 434 MHz
Wireless Medical Telemetry Service (WMTS)	608 MHz to 614 MHz; 1,395 MHz to 1,400 MHz; and 1,427 MHz to 1,432 MHz
2G/3G/4G Mobile Communications	800 MHz to 1 GHz and 1,800 MHz to 2 GHz
ZigBee	868 GHz, 915 GHz, and 2.4 GHz ISM Bands
GNSS (GPS, Glonass, Galileo, and so on)	L1 (1.58 GHz), L2 (1.28 GHz), L3 (1.38 GHz), L5 (1.18 GHz)
Sirius Satellite Radio (SDARS)	2.315 GHz
Bluetooth	2.4 GHz ISM Band
Wi-Fi (802.11a/b/g/n/ac/ax)	2.4 GHz and 5.8 GHz ISM Bands

Table 2. Carrier Frequency of Various Wireless Technologies

Software-Designed Architecture

One of the most unique attributes of the VST is its highly scalable software architecture. The VST is designed with multiple use models that range from a getting-started experience with the soft front panels to a high-level programming API to a fully customizable FPGA programming experience.

The simplest software use model for the VST is the soft front panel experience. With the soft front panel, users can quickly and easily configure the RF signal generator or analyzer to debug fixtures and get fast measurement results. For example, in Figure 8, the soft front panel gives engineers the ability to configure the VST for an adjacent channel power (ACP) measurement.

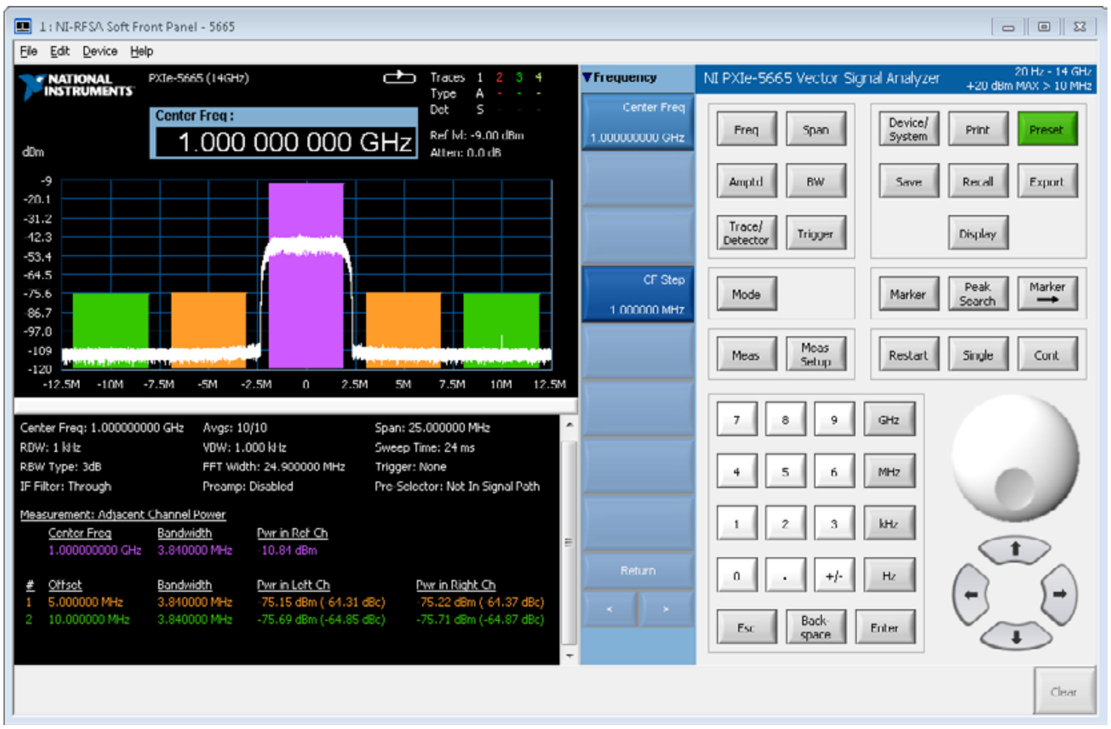

Figure 8. Users can configure the VST for quick measurements using the RFSA and RFSG soft front panels.

> *"We selected the VST because of its versatility and proven testing speed. We can use the VST to test a variety of cellular and wireless standards from 65 MHz to 6 GHz. Within a single PXI rack, we could integrate five VSTs and test five UUTs in parallel, guaranteeing maximum system production capability."*
>
> —Paolo Bertoldo, Business Development, SEICA

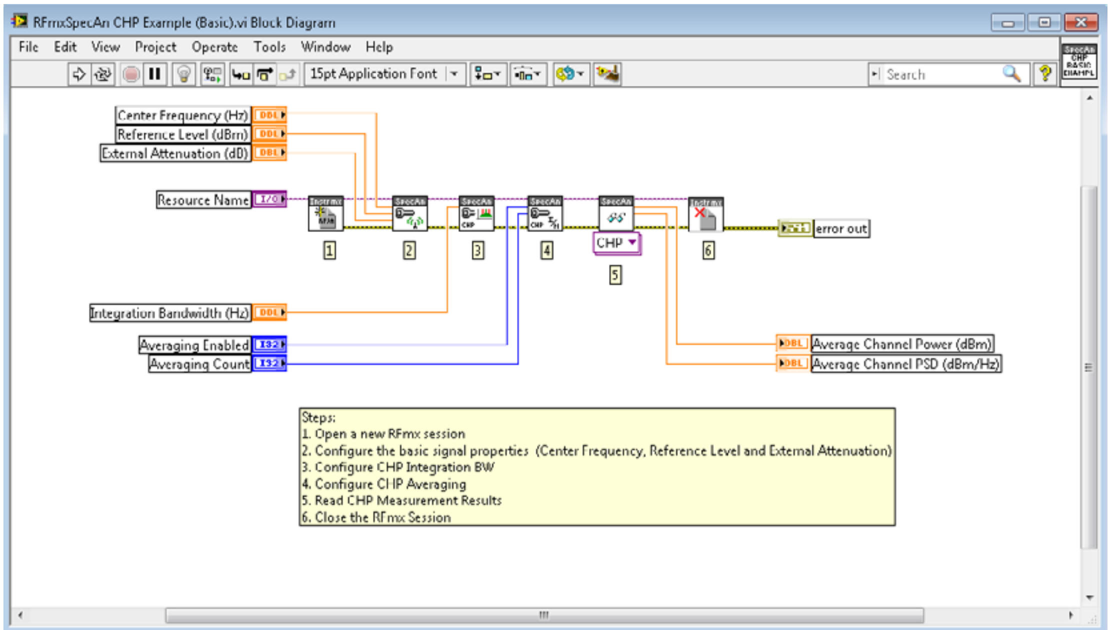

Figure 9. Channel Power Measurement in RFmx

The second use model uses NI RFmx, which provides an intuitive programming API that offers both ease of use and advanced measurement configuration. Engineers can get started with one of more than 100 example programs in C, .NET, and LabVIEW that are designed to make instrument automation straightforward. For example, Figure 9 illustrates a channel power measurement using an RFmx LabVIEW example that uses six function calls.

The most innovative and powerful aspect of the VST's software experience is its LabVIEW-programmable FPGA. Under this design paradigm, the firmware onboard the instrument is written in LabVIEW, and engineers can customize to address a particular application need. The core firmware is divided into an acquisition loop, a generation loop, and an example user loop as Figure 10 illustrates.

> *"We were able to reduce manufacturing test time of power amp (PA) by five times compared to our existing test system by using the NI VST to implement power servoing on the FPGA level."*
>
> —Roy Yoon, Product and Test Engineer of NPI, Broadcom, Korea

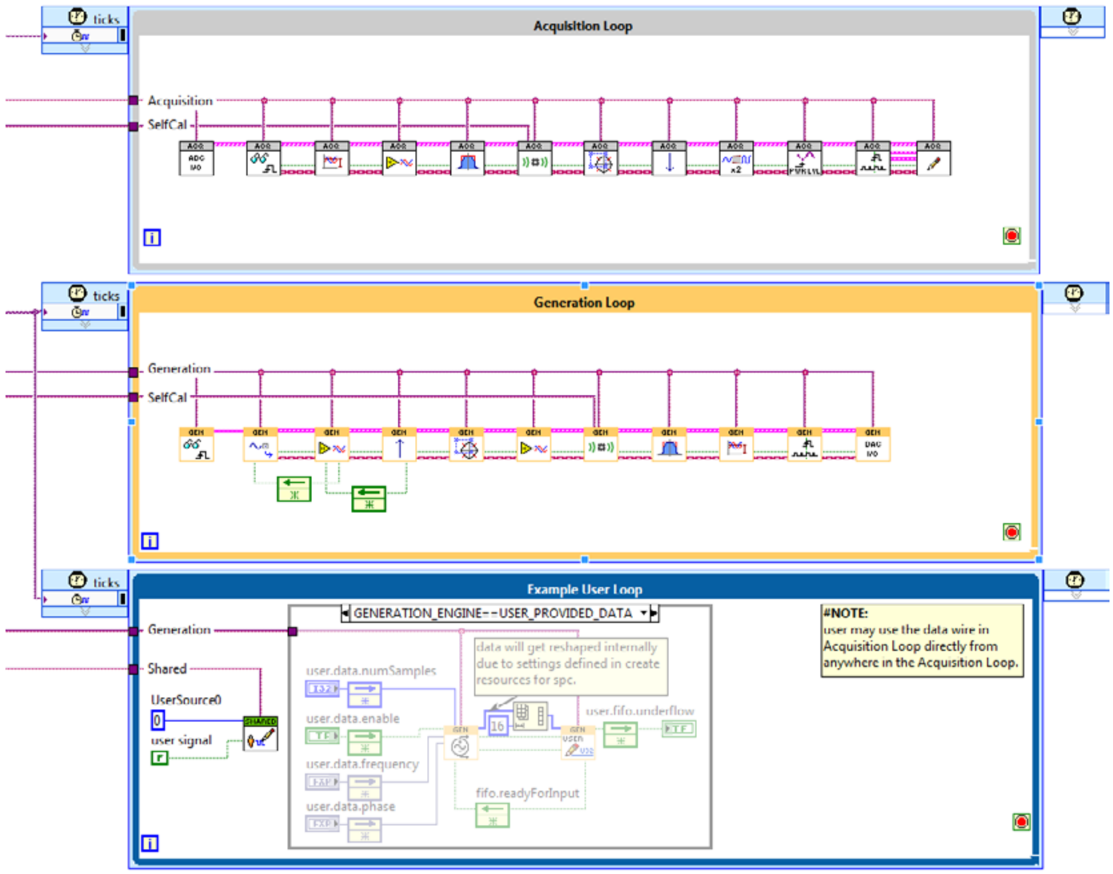

Figure 10. Channel Power Measurement in RFmx

In Figure 10, the LabVIEW FPGA diagram is divided into three Timed Loops. The first Timed Loop, the acquisition loop, handles IQ input records, timing/triggering, IQ calibration, and storage to memory. The second loop handles the VSG operation and performs a similar triggering, calibration, and waveform sequencing for signal generation. The third loop is referred to as the "example user loop" and it is explicitly designed for user customization. Typical IP for the user loop could be digital control, input-to-output signal processing, or closed-loop control.

> *"The VST and FPGA programmable by LabVIEW enabled the development of a radar simulator with performance and sampling times that not only suit the design requirements but also allow further developments and improvements."*
>
> —Mauro Cortese, Head of R&D and Test Solutions, MPG Instruments

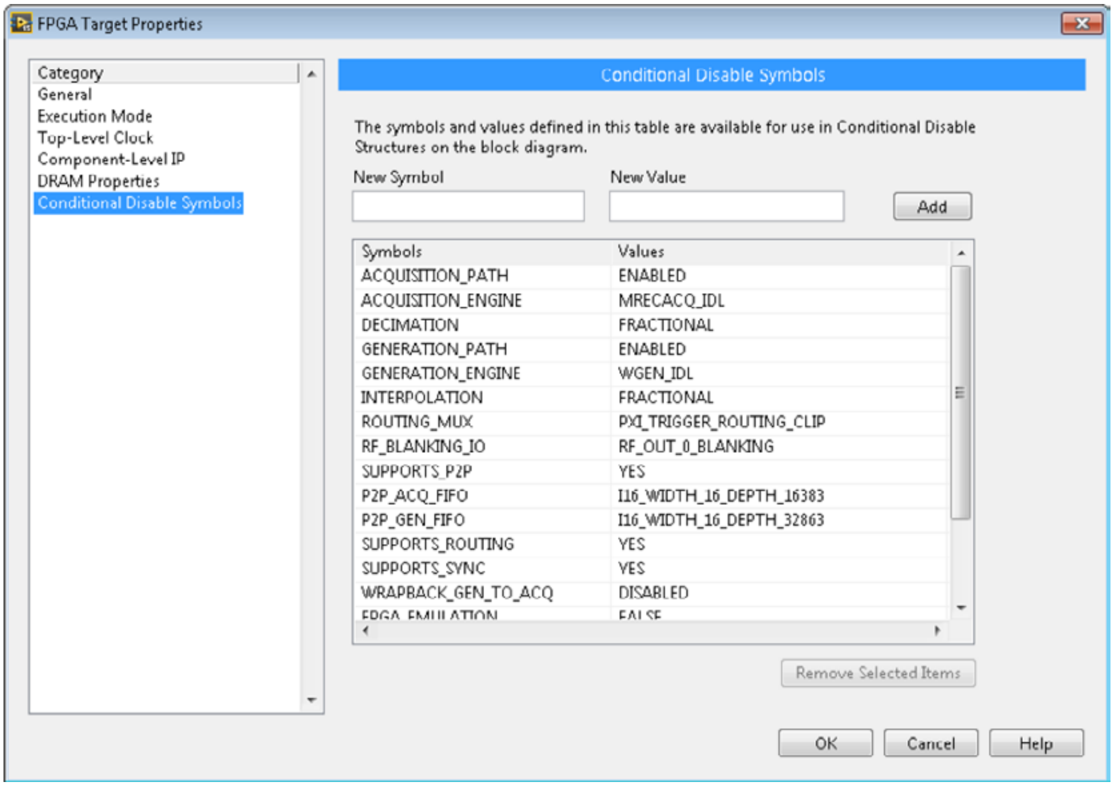

Figure 11. Subtractive FPGA extensions can help to free up FGPA space.

With the second-generation VST, users can quickly and easily enable/disable default IP to optimize space on the FPGA. This feature, is called subtractive FPGA extensions. Using subtractive FPGA extensions, engineers can disable a particular IP block that is not required for their application. In doing so, they free up FPGA slices that they can use for other programming. Figure 11 illustrates the configuration-based wizard that engineers can drive from the LabVIEW project window.

A common IP block to disable using FPGA extensions is the logic-intensive fractional resampler. Although disabling the resampler requires applications to use the VST at the maximum IQ rate of 1.25 GS/s, disabling this block can also free up substantial space on the FPGA. The fractional resampler IP block consumes approximately 30 percent of the FPGA's digital signal processor (DSP) slices. Thus, by disabling the fractional resampled using subtractive FPGA extensions, engineers can easily increase the available programming slices on the FPGA.

> *"The NI VST gives us incredible flexibility that allows a more focused test solution in a smaller footprint than traditional benchtop instruments. The reprogrammable FPGA allows us the ability to quickly tailor the system to meet specific test objectives while maintaining a common architecture across many test platforms."*
>
> —Don Miller, Senior Staff Engineer, Lockheed Martin Space Systems

Applications for User-Programmable FPGA

The ability to use LabVIEW to program an instrument's FPGA is unique to NI software-designed instrumentation. By programming the FPGA, engineers can solve some of the most advanced test and measurement challenges, from designing a fully customized instrument to delivering the absolute fastest test time.

RFIC Testing

An application that is distinctively solved through software-designed instruments such as the VST is PA testing in conjunction with a real-time DPD implementation. In RF power amplifier (PA) tests, many measurements such as EVM and ACP must be made under DPD conditions to better understand how the PA will perform in context of a complete mobile device. Figure 12 illustrates a typical test configuration for an RF PA.

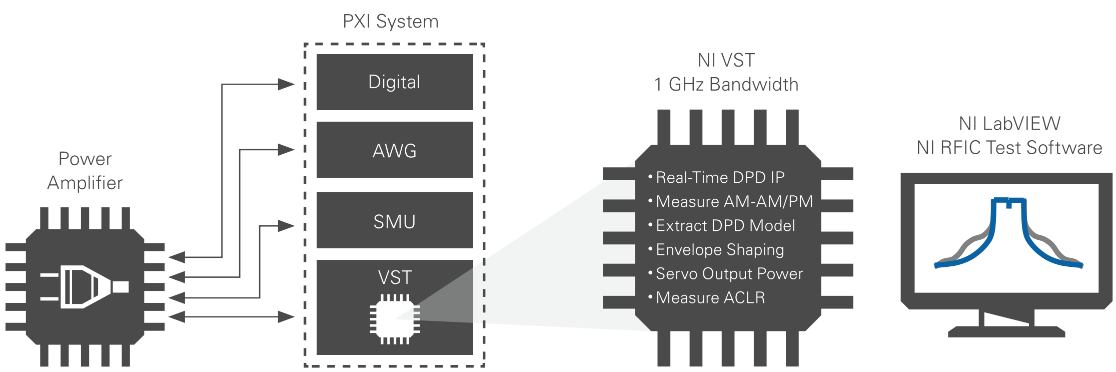

Figure 12. Typical Configuration for PA Testing Under DPD Conditions

In these cases, engineers can also use the FPGA to develop their own custom, real-time DPD algorithm. The faster FPGA-based DPD implementation not only saves critical test time but also allows engineers to embed highly protected algorithms in the FPGA. By delivering an FPGA bitfile to prospective customers instead of source code, organizations can better protect their DPD IP.

Radar Prototyping

A second application that software-designed instrumentation can uniquely solve is radar prototyping. In this application, customers can use the FPGA as a complete target simulator. In radar applications, a radar system detects a "target," such as an automobile, airplane, or other object, by sending a stimulus signal and then waiting for the response. Attributes of the stimulus' reflection off the target such as the delay and frequency shift indicate both the distance and velocity of the target. The combination of the VST's wide bandwidth and user-programmable FPGA makes it ideal for target emulation. In addition, engineers can easily customize the FPGA to modify the types of targets they need to simulate.

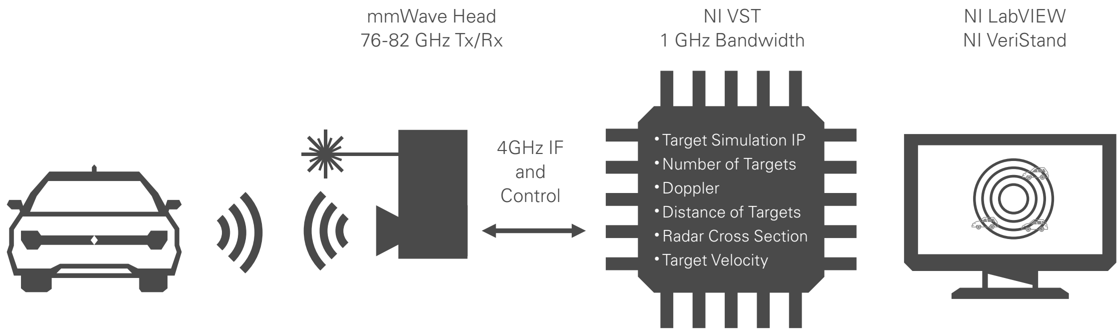

Figure 13. Radar System Block Diagram With milimeterWave Head

In Figure 13, the VST has been combined with block upcoverter/dowconverter for signal generation and analysis in the automotive radar band at 76 GHz to 82 GHz. In addition to frequency translation, this module also uses laser technology to measure the distance to a radar sensor.

Conclusion

Although requirements of tomorrow's RF and wireless technologies are constantly changing, NI's software-centric approach to instrumentation scales the biggest test challenges of today and tomorrow. And the second-generation VST offers the analog performance to address some of the most difficult measurement challenges, but with the software flexibility to adapt to future test needs.

NI's VST technology delivers a unique and innovate approach to RF test and measurement that is already solving a wide range of advanced measurement challenges. As a result, the VST is the instrument of choice to reduce the cost of RF design and test.