SOLUTION
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Electronically Scanned Array Characterization Reference Architecture

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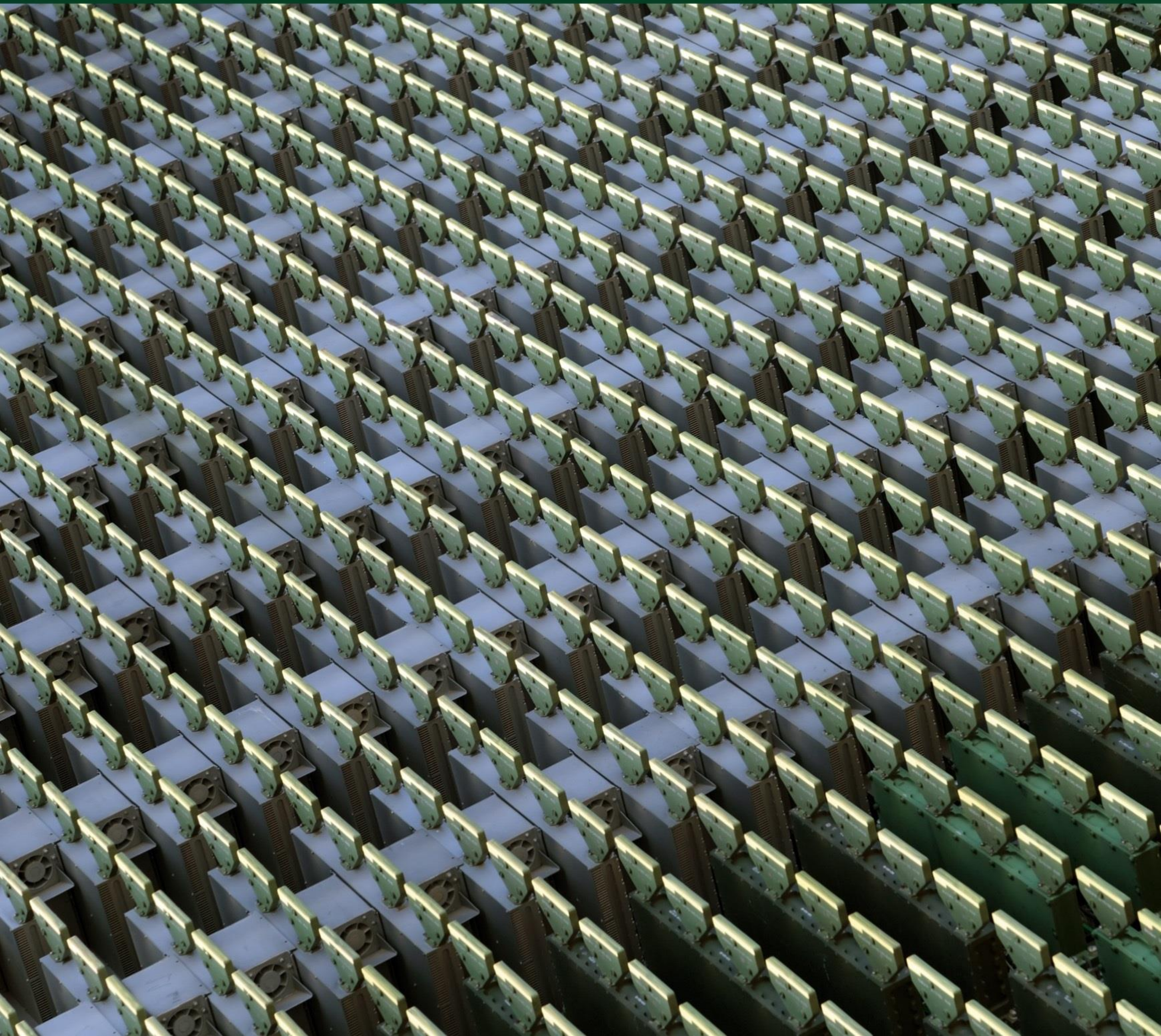
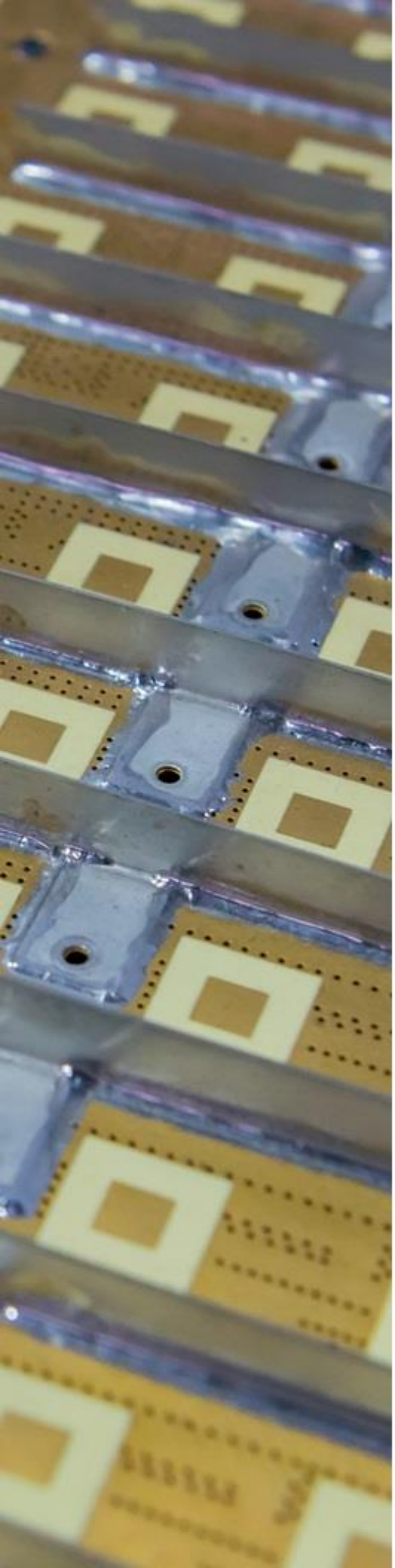




Electronically Scanned Array Characterization Reference Architecture

Solution Overview

The electronically scanned array (ESA) in its various forms, including the passive electronically scanned array (PESA) and active electronically scanned array (AESA), is the bedrock of modern RF systems in radar and communication applications. With the move towards ESA technology, the number of electronic components in a radar system has exponentially increased over time. Whether for radar or satellite communications, developing an ESA is a multi-step process ranging from the design or selection of fundamental components, integration, and validation of these components into functional modules and sub-assemblies, and finally system level verification once integrated into the final array. Each stage consists of key modeling, characterization, and ultimately production test with the importance of correlation across the lifecycle being a key requirement. Technical innovations in this area are created significant challenges across the product lifecycle from design, to characterization, to production including:

- More efficient high-power RF devices based on modern GaN process technologies
- Increasingly complex RF components and modules with progressively wider bandwidths
- Multichannel RF front ends to handle frequency agile and multiband applications
- More integration of high-speed digital I/O into the RF channel
- Software defined digital processing capabilities to meet multifunction application needs

To overcome these challenges a scalable and nimble test solution is required to handle and validate a multitude of scenarios, ranging from parametric test of components to validation of systems and be able to correlate the test data throughout the product lifecycle, NI offers the Electronically Scanned Array Characterization (ESA) Characterization Reference Architecture which provides a high-level hardware and software starting point for characterization and test engineers to perform pulsed RF measurements, and test the various components, modulus, and subassemblies that make up the modern ESA. The ESA Characterization Reference Architecture offers several advantages:

- Develop test systems to meet high mix, low volume needs
- Reduce capital costs substantially using high-performance modular test equipment vs. traditional single use instruments
- Capture better data faster and run multiple test cases simultaneously with industry-leading measurement speed and quality

ESA Characterization Reference Architecture

The ESA Characterization Reference Architecture from NI provides a high-level starting point for characterization and test engineers to perform pulsed RF measurements on the individual elements of an ESA system such as power amplifiers (PAs) and transmit receive modules (TRMs). The performance of these components in all environments ensures system performance, minimizes the likelihood of system downtime, and enables mission readiness. To test these components, the ESA Characterization Reference Architecture builds on the NI platform by providing recommended NI hardware with a dedicated software library called the Pulsed RF Measurements Library. This combination of hardware and software serves as the core for any test system used to test the elements of an ESA system and is fundamental in helping test teams meet their aggressive schedules.

ESA Characterization Hardware

The ESA Characterization Reference Architecture enables you to integrate both NI and third-party hardware to develop your test system. The key NI hardware required for testing ESA components, modules, and sub-assemblies include the Vector Signal Transceiver and Source Measure Unit.

Vector Signal Transceiver

The PXI Vector Signal Transceiver (VST) combines a vector signal analyzer and vector signal generator with a user-programmable FPGA and high-speed serial and parallel digital interfaces for real-time signal processing and control. With up to 2 GHz of instantaneous RF or complex I/Q bandwidth, the NI VST is ideally suited for a wide range of applications including RFIC validation and production testing, radar prototyping and system level validation, SATCOM Telemetry and data link validation, Satellite Link Emulation, and other RF wideband test scenarios. The VST product line provides the high performance necessary to support lab design and validation applications and incorporates the fast measurement speed and small form factor required to scale to production test applications. You can use VST instruments throughout the design cycle from design to validation to production test—minimizing measurement correlation errors and improving efficiency with test software reuse. The modular PXI platform allows users to configure systems with multiple VSTs to support multiple input, multiple output (MIMO) applications, and simplifies synchronization between instruments thanks to shared timing and synchronization resources in the PXI chassis.

Source Measure Unit

NI's source measure units (SMUs) are optimized for building automated test systems, with hardware features to reduce test execution time and tight software integration to reduce development effort. Built on the modular PXI platform, NI SMUs can be combined with other instruments such as oscilloscopes, Vector Signal Transceivers, and digital instruments to build mixed-signal test systems. Additionally, the modularity and channel density of these instruments allow you to build systems that test multiple devices in parallel and improve the throughput of each tester. NI SMUs combine power, precision, and speed into a single instrument allowing you to use the same instrument for both high-power sweeps and low-current measurements, while the addition of a high-speed update and sampling rate allows you to use the instrument in non-traditional ways, such as generating and measuring a waveform. These modules also include traditional SMU features such as output disconnect relays to isolate the instrument from your circuit, remote sense to compensate for lead drop, and guard to minimize leakage current in small signals.

Vector Signal Analyzer

PXI Vector Signal Analyzers (VSAs) feature a wide frequency range, real-time signal analysis, and advanced signal processing. These instruments can perform measurements for a broad range of wireless technologies with select models featuring a LabVIEW-programmable FPGA that you can customize for advanced measurement applications. PXI VSAs are ideal for microwave test, wireless test, radar test, spectral monitoring, software-defined radio (SDR), radio monitoring, interference detection, signals intelligence, and other applications. NI's VSA portfolio is highlighted by the PXIe-5668, which offers up to 765 MHz of instantaneous bandwidth up to 26.5 GHz with industry-leading dynamic range, and best-in-class measurement performance and speed.

RF Analog Signal Generator

PXI RF Analog Signal Generators deliver the functionality of RF signal generators to the modular, compact PXI form factor. These modules support frequency ranges from 250 kHz to 20 GHz. You can combine PXI RF Analog Signal Generators with other PXI modular instrumentation to design automated test systems for radar, and RF integrated circuits (RFICs).

High-Speed Serial Instrument

PXI High-Speed Serial Instruments are designed for engineers who need to validate, interface through, and test high-speed serial protocols. They consist of Xilinx Kintex-7 or Virtex-7 FPGAs and are programmable in LabVIEW FPGA for maximum application-specific customization and reuse. These instruments take advantage of FPGA multigigabit transceivers (MGTs) to support line rates up to 12.5 Gbps and up to 24 TX and RX lanes. As part of the PXI platform, they benefit from PXI clocking, triggering, and high-speed data movement capabilities, including streaming to and from disk, as well as peer-to-peer (P2P) streaming at rates up to 3.2 GB/s.

Pulsed RF Measurements Library

A unified software experience across the design cycle

With easy to use, interactive interface panels for developing and debugging systems, to automatable APIs for deploying both characterization as well as production test systems, the Pulsed RF Measurements Library provides a unified software experience for testing ESA components and modules across the design cycle. In addition to easy-to-use panels, the library also includes support for several development environments including LabVIEW, C, C#, and .NET, as well as for FPGA programming.

Key Measurement Capabilities:

- Power and phase stability
- Network analysis and S-parameters
- Pulse profile and stability
- Power added efficiency
- Spectral analysis
- Phase noise

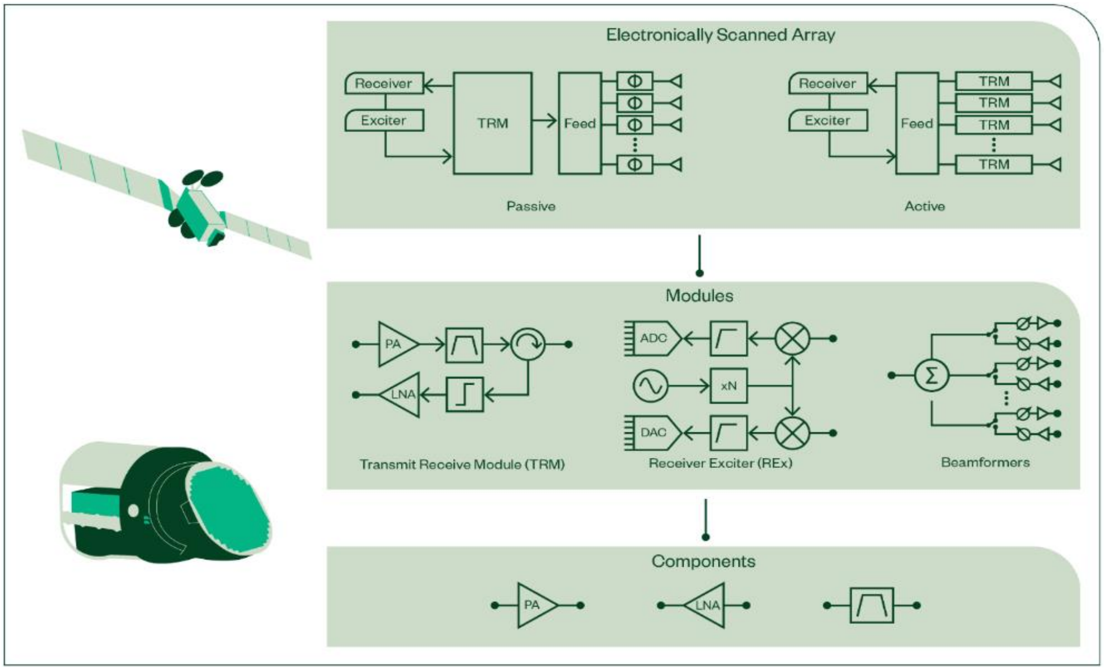


FIGURE 01
Components And Modules Used in the Latest Electronically Scanned Arrays for Radar and Satellite Communication Applications

"Teams working on the next generations of phased array technology face intense market pressures. Technology advancements create new testing scenarios that must be addressed in less time than previous generations, and traditional approaches have lacked the scalability to meet this challenge while adding risk. The Electronically Scanned Array Reference Architecture allows teams to validate and test the next generation of phased arrays and their components confidently and in a more scalable fashion than traditional solutions on the market."

Luke Schreier
Senior VP and General Manager, Aerospace Defense & Government
NI

Pulse Profile and Pulse Stability

Pulse Profile and Pulse Stability Measurements

The designs of the active components within an ESA are highly impacted by heating effects, and nonlinear distortions due to the evolving complexity, denser architectures, and the introduction of the GaN technology. These designs are also subject to trapping and memory effect when used with pulsed signals and the integration of gate pulsing circuitry. When operating in these conditions, components might become unstable and cause the output pulse to vary in phase and amplitude from one pulse to another, causing transient distortions such as overshooting, undershooting, drooping and in certain cases a variation in the pulse repetition interval (PRI) with respect to input stimulus. For radar systems specifically, this results in a drop in signal-to-noise ratio (SNR), incorrect parameter estimation, false target detection, or limitations in the smallest cross section the radar can detect along with many other degradations in radar performance.

COMMON TEST CHALLENGES

- SYNCHRONIZING RF PULSED STIMULUS WITH DUT CONTROL TO ACCURATELY CHARACTERIZE COMPONENT STABILITY
- INSTRUMENTATION PHASE NOISE NEGATIVELY AFFECTS MEASUREMENT ACCURACY
- LIMITED RF INSTRUMENTATION BANDWIDTH REDUCES TEST COVERAGE

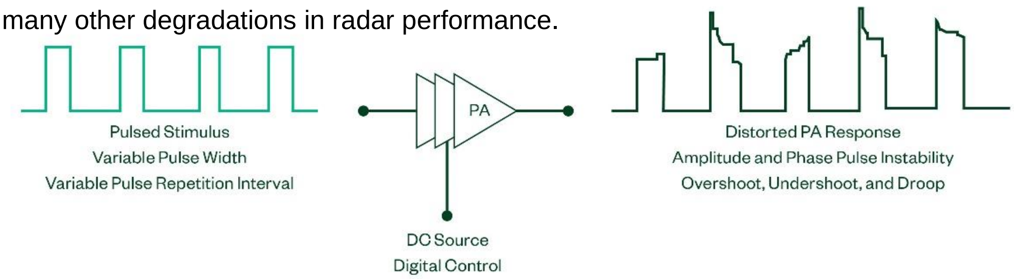


FIGURE 02
Example Distortions Due to the Non-linear Properties of the Active Components Used in ESAs.

The Pulsed RF Measurements Library provides the ability to characterize the two main attributes identified in the IEEE Std 181™-2011 including:

- **Pulse Stability** including pulse-to-pulse and intra-pulse stability measurements.
- **Pulse Profile** including state levels, transition duration, overshoot/undershoot, droop, and pulse ripple/ringing.

The NI Advantage:

01
Wide frequency coverage from sub-L to Ka band and flexible bandwidth configuration up to 1 GHz to tailor the test system to the design.

02
Tight sub-nanosecond synchronization between PXI modules for synchronous RF pulsing and flexible trigger routing for DUT control.

03
Phase stability up to -90 dB with low phase noise impact due to shareable LO between transmit and receive.

FIGURE 03
Measurement Panel for Taking Pulse Profile and Stability Measurements Included with the Pulsed RF Measurements Library.

Pulse Profile and Pulse Stability Sample Specifications

Pulse Profile for PXIe-5842

MEASUREMENT BANDWIDTH	MINIMUM PULSE WIDTH	STANDARD DEVIATION
2 GHz	6.43 ns	0.00017 ns

TABLE 01
Typical Pulse Width Specifications.

MEASUREMENT BANDWIDTH	RISE TIME DETECTED	STANDARD DEVIATION
2 GHz	585 ps ns	70.9 ps

TABLE 02
Typical Rise Time Specifications.

Pulse Stability – S Band

PULSE WIDTH (SECONDS)	PRI (SECONDS)	AMPLITUDE PULSE STABILITY (DB)	AMPLITUDE STABILITY STANDARD DEVIATION (DB)	PHASE PULSE STABILITY (DB)	PHASE STABILITY STANDARD DEVIATION (DB)	TOTAL PULSE STABILITY (DB)	TOTAL STABILITY STANDARD DEVIATION (DB)
2µ	10m	-85	0.4	-77	0.6	-77	0.5
5µ	10m	-86	0.7	-81	0.5	-80	0.4
10µ	10m	-86	0.5	-81	0.4	-80	0.3
20µ	10m	-86	0.5	-81	0.7	-80	0.6
50µ	10m	-86	0.4	-81	0.4	-80-	0.3

TABLE 03
PXIe-5842 (Center Frequency = 2.0 GHz)

Pulse Stability – X Band

PULSE WIDTH (SECONDS)	PRI (SECONDS)	AMPLITUDE PULSE STABILITY (DB)	AMPLITUDE STABILITY STANDARD DEVIATION (DB)	PHASE PULSE STABILITY (DB)	PHASE STABILITY STANDARD DEVIATION (DB)	TOTAL PULSE STABILITY (DB)	TOTAL STABILITY STANDARD DEVIATION (DB)
2µ	10m	-84	0.4	-76	0.6	-76	0.6
5µ	10m	-85	0.5	-79	0.4	-78	0.3
10µ	10m	-86	0.6	-79	0.4	-78	0.4
20µ	10m	-86	0.5	-79	0.5	-78	0.4
50µ	10m	-85	0.4	-79	0.4	-78	0.4

TABLE 04
PXIe-5842 (Center Frequency = 10.0 GHz)

*Additional specifications provided for S through Ku bands at center frequencies 2, 4, 5.5, 6, 10, 14 and 18 GHz
**Additional specifications provided for PXIe-5831 & PXIe-5841 with PXIe-5655

S-Parameters

S-Parameter Measurements

The interaction between front-end components (typically power amplifiers, duplexers, and phase shifters) needs to be accurately predicted and controlled with special focus on input/output port impedance mismatch and antennas mutual coupling. This can be achieved by characterizing the reflections and transmissions of a stimulated device connected to a load, also called scattering parameters or S-parameters. The S-parameter measurement can be leveraged for calibration purposes or contribute to application-specific processing such as radar cross section and spectrum flatness.

COMMON TEST CHALLENGES

- CORRELATION OF SMALL SIGNAL AND LARGE SIGNAL ANALYSIS DUE TO MULTIPLE INSTRUMENTS
- COMPLEXITY OF DUT INTERFACES DISTORTS BUILT IN REFLECTOMETRY OF VNAS
- PERFORMING FUNDAMENTAL RF MEASUREMENTS UNDER UNIQUE APPLICATION-SPECIFIC STIMULI

○ Good ◒ Better ● Best

	MEASUREMENT QUALITY	TEST TIME	COST
1 COUPLER/PORT, 1 VST	○	◒	●
2 COUPLERS/PORT, 1 VST	◒	○	◒
1 COUPLER/PORT, 2 VSTs	◒	◒	○

TABLE 05
Decision Matrix for Choosing the Hardware Configuration Best Suited for Your Application.

The Pulsed RF Measurements Library provides several suggested hardware configuration options to accomplish S-parameter measurements. The configuration you choose depends on your measurement accuracy, cost, and sweep speed requirements.

The NI Pulse Measurement Library also includes a calibration utility to perform system calibration prior to taking your S-Parameter measurements. The library includes options for SOLT, QSOLT, or SOLR calibration depending on the hardware configuration you’ve chosen for your application.

The NI Advantage:

01
Perform flexible S-parameter measurements using CW and pulsed waveforms on the same HW as large signal analysis

02
Combine S-parameters with other parametric tests and simplified integration using a single reconfigurable and modular system.

03
Reduced overall test time and cost with unified software experience and increased hardware reuse.

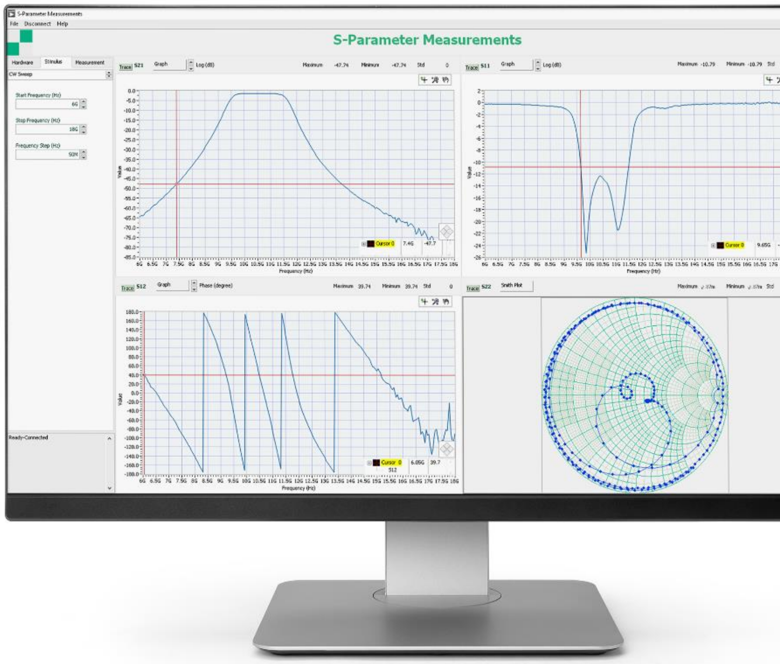


FIGURE 04
Measurement Panel for Taking S-parameter Measurements Included with the Pulsed RF Measurements Library.

S-Parameters Sample Specifications

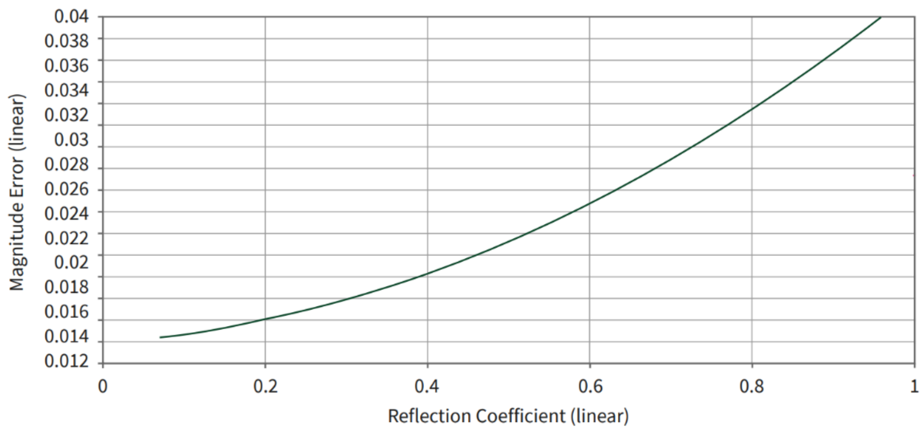


FIGURE 05
Reflection Magnitude Error with PXIe-5831 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

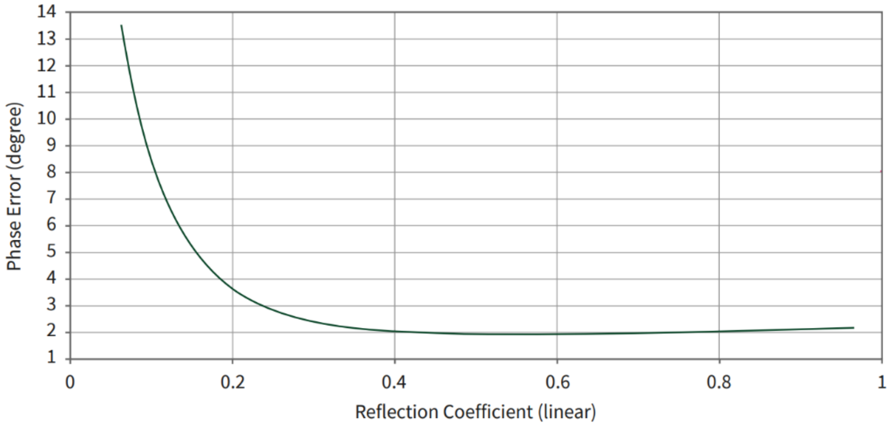


FIGURE 06
Reflection Phase Error with PXIe-5831 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

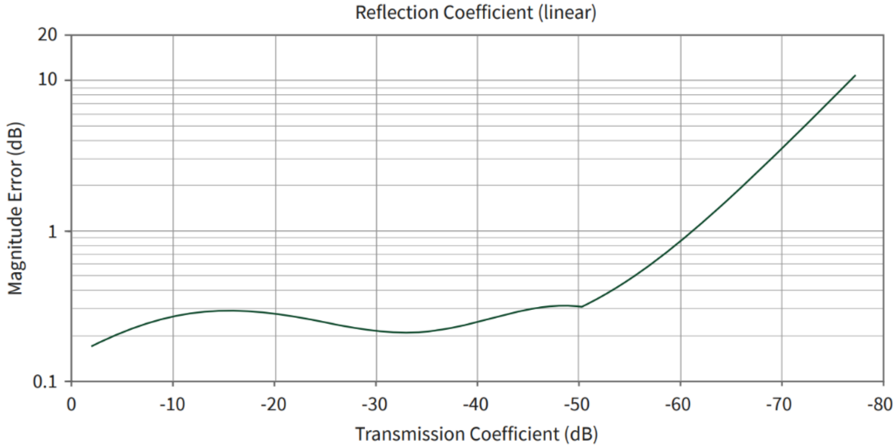


FIGURE 07
Transmission Magnitude Error with PXIe-5831 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

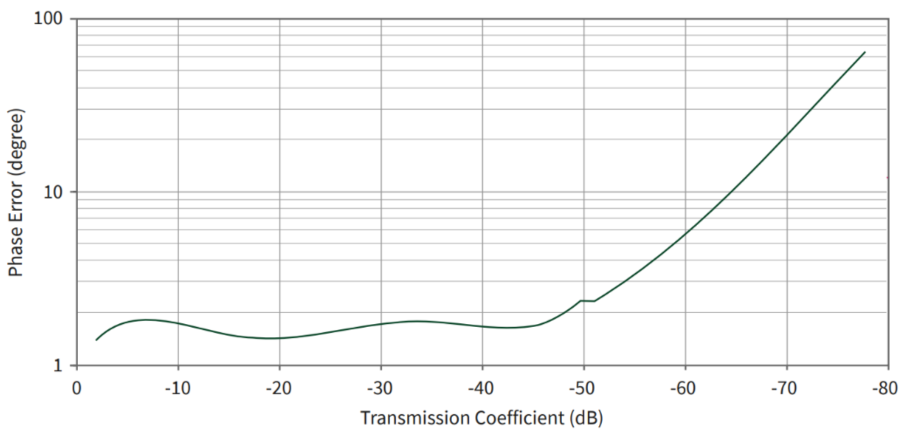


FIGURE 08
Transmission Phase Error with PXIe-5831 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

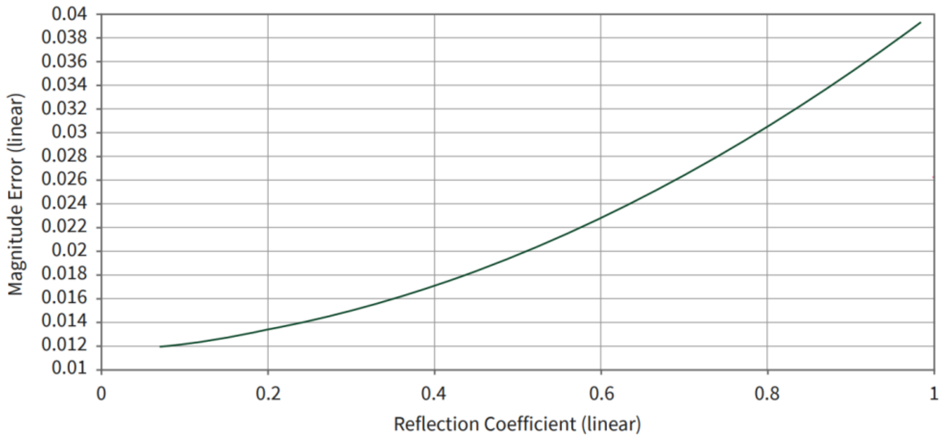


FIGURE 09
Reflection Magnitude Error with PXIe-5841 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

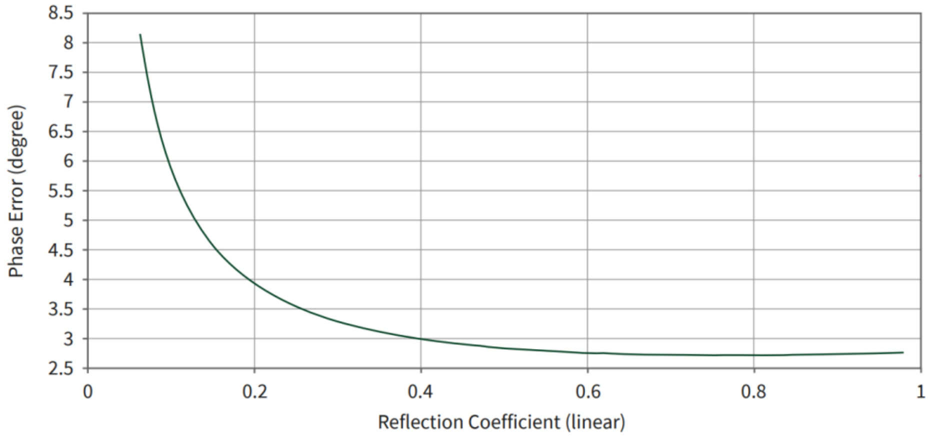


FIGURE 10
Reflection Phase Error with PXIe-5841 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

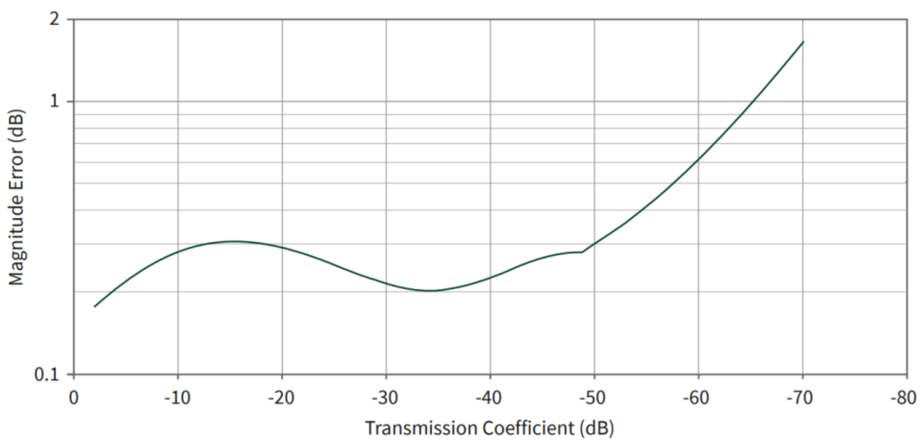


FIGURE 11
Transmission Magnitude Error with PXIe-5841 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

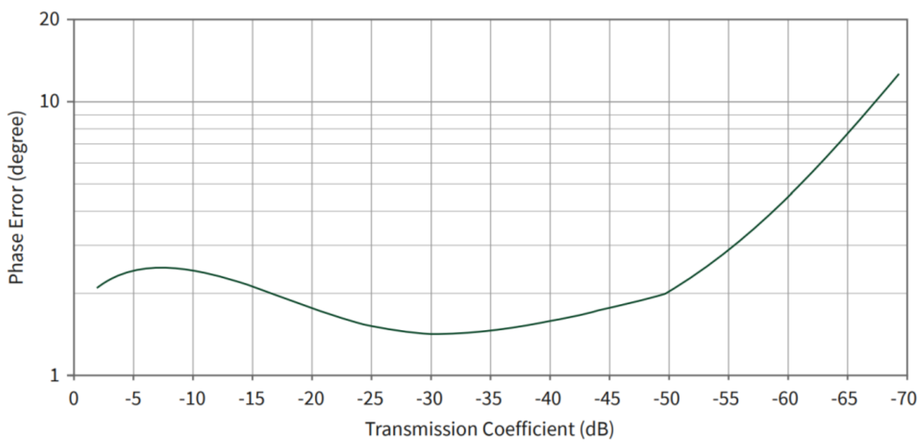


FIGURE 12
Transmission Phase Error with PXIe-5841 at 0 dBm power level and 1 kHz IFBW with no averaging and two couplers per port

Power Added Efficiency

Power Added Efficiency Measurements

Monolithic microwave-integrated circuit (MMIC) designs demand more efficiency and higher performance while reducing the component's footprint, maintaining reliability, and reducing test cost. With the move towards integrated antenna arrays and the introduction of 5G in radar systems, satellites, and wireless connectivity applications, new MMIC designs and solid-state devices are expected to deliver higher RF power and wider operational bandwidth while lowering power consumption and limiting heat dissipation. Power added efficiency (PAE) is one of the most common figures of merit to characterize and validate power amplifiers and integrated circuits. The newest MMIC designs impose a real challenge to the component's characterization and validation process, due to the need for higher signal integrity and lower cost modular test systems capable of measuring all component-specific performance indicators.

COMMON TEST CHALLENGES

- SYNCHRONIZATION OF RF AND DC INSTRUMENTATION FOR ACCURATE MEASUREMENT RESULTS
- TRADITIONAL MEASUREMENT SETUPS ARE CHALLENGING AND DIFFICULT TO USE
- AUTOMATING SWEEP MEASUREMENTS

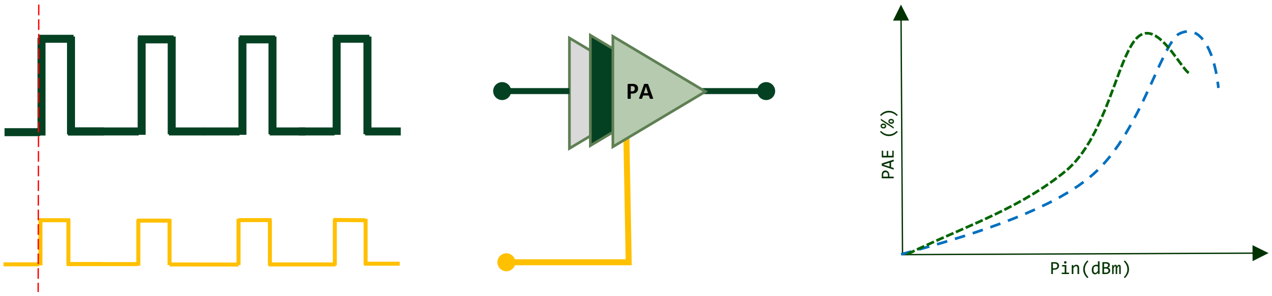


FIGURE 13
Combine a Source Measurement Unit with a Vector Signal Transceiver in a Synchronous PXI System to Accurately Measure PAE.

The same data set that is used for PAE can also be used to calculate the compression points of your DUT. The Pulsed RF Measurements Library includes the calculations for the P1dB, P2dB, and P3dB compression points.

The NI Advantage:

01
Easy-to-use integration of DC and RF measurements in both interactive examples and programmatic APIs

02
Tight sub-nanosecond synchronization between PXI modules for synchronous RF pulsing, DC triggering, and DUT control.

03
High-precision DC and RF instrumentation and scalable measurement capabilities with reduced test time for performing frequency

FIGURE 14
Measurement Panel for Taking Power Added Efficiency and Compression Point Measurements Included with the Pulsed RF Measurements Library.

Power Added Efficiency Sample Specifications

The power-added efficiency measurement relies on the combined used of a Source Measure Unit (SMU) and Vector Signal Transceiver to meaure the RF input and out power of the DUT with respect to the DC supply.

Source Measure Unit

IV Boundary	60 V 3 A DC (10 A Pulsed) 40 W (500 W Pulsed
Sensitivity / Resolution	100 fA 100 nV
Max Speed	Sampling 1.8 MS/s Update 100 kS/s

TABLE 06
PXIe-4139 High-Current SMU Specifications

Vector Signal Transceiver

Frequency Range	9 kHz to 6.5 GHz
Instantaneous Bandwidth	Up to 1 GHz
Phase Noise	-127dBc/Hz @ 2.4 GHz (Typ, @ 10 kHz offset) -120 dBc/Hz @ 5.8 GHz (Typ, @ 10 kHz offset)
Tuning Time	< 175 usec
Transmit P_{OUT}	> +20 dBm (< 4 GHz) > +15 dBm (4 to 6 GHz)
Receive Noise Floor	< -164 dBm/Hz (< 4 GHz), -50 dBm Ref Level < -162 dBm/Hz (4 to 6 GHz), - 50 dBm Ref Level
Channels & Slots	1 TX & 1 Rx, 3 Slots (2 slots per additional channel)

TABLE 07
PXIe-5841 with PXIe-5655 Specifications

Frequency Range	5-21 GHz, 22 to 44 GHz (mmWave)
Instantaneous Bandwidth	Up to 1 GHz
Phase Noise	-101 dBc/Hz @ 10 GHz (Typ, @ 10 kHz offset)
Tuning Time	< 500 usec
Transmit P_{OUT}	> +15 dBm (< 18 GHz) > 0 dBm (22-44 GHz)
Receive Noise Floor	< -162 dBm/Hz (< 12 GHz), -30 dBm Ref Level < -160 dBm/Hz (22 to 44 GHz), - 30 dBm Ref Level
Channels & Slots	1 TX & 1 Rx, 3 Slots (2 slots per additional channel) *mmWave Frequency Range is external to Chassis

TABLE 08
PXIe-5832 Specifications

RFmx

RFmx is a set of interoperable software applications that optimize NI RF instrumentation for general-purpose, cellular, connectivity, and aerospace/defense test applications. RFmx streamlines test system development by accelerating setup, measurement, and performance. Soft front panels provide an intuitive interface for connecting to hardware, enabling users to efficiently perform measurements and debug automated tests. Composite measurement functionality and parallelized execution ensure maximum instrument utilization for test time reduction. You also can perform and debug measurements with interactive software front panels, create and playback open, unlocked waveforms with the included RFmx Waveform Creator, and speed up automated testing with the performance-optimized API. And with dedicated personalities for conventional spectrum analysis, modulated signals, and standard defined signals, RFmx is tailored to your application.

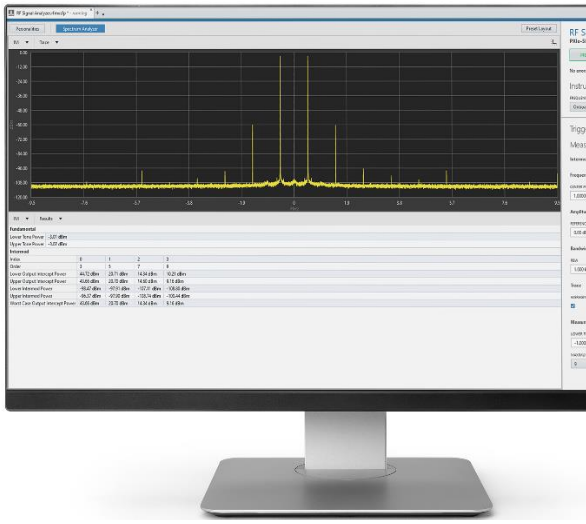


FIGURE 15
Use RFmx Soft Front Panels for Interactive Measurement and Debugging of Complex RF Signals.

RFmx SpecAn

RFmx SpecAn is a measurement personality that extends the capability of NI RF instrumentation for spectrum analysis and device-specific characterization. This software enables you to analyze signals in the time, frequency, and power domains with measurements such as transmit power (TXP), adjacent channel power (ACP), and CCDF. You can characterize and correct for amplitude-amplitude/amplitude-phase distortion (AM-AM/PM) using built-in digital predistortion (DPD) models, or you can validate beamformer performance by capturing phase and amplitude versus time (PAvT).

RFmx Noise Figure

RFmx Noise Figure is application software that runs inside RFmx SpecAn. This software extends the capability of NI RF instrumentation and helps you measure noise figure, gain, and effective temperatures using the Y-factor and Cold Source methods. Additionally, you can use RFmx Noise Figure improve measurement accuracy with built-in calibration procedures and decrease test time with integrated noise source control and multifrequency measurement optimization.

RFmx Phase Noise

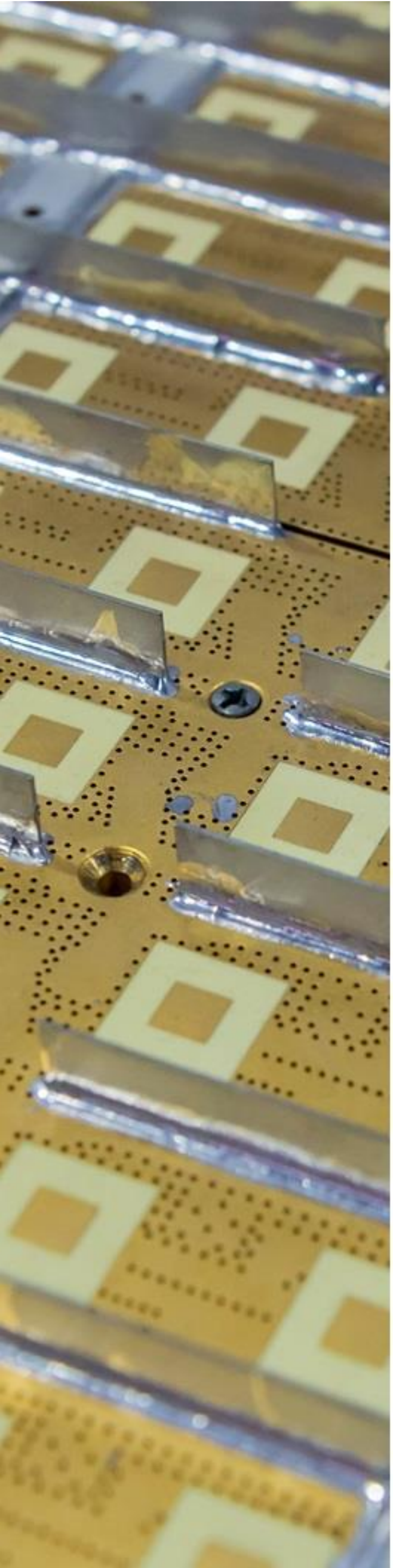
RFmx Phase Noise is application software that runs inside RFmx SpecAn. This software extends the capability of NI RF instrumentation for phase noise analysis and helps you measure log plot, spot, and integrated phase noise with intelligent automatic range settings or manual configuration. You can enhance measurement performance with advanced techniques such as trace smoothing, spur removal, and instrument phase noise cancellation.

RFmx Demod

RFmx Demod is a measurement personality that extends the capability of NI RF instrumentation for analog and digital modulated signal analysis. This software enables you to analyze signals with a variety of modulation schemes including AM, FM, PM, ASK, FSK, MSK, PSK, and QAM with measurements such as analog distortion, frequency error, error vector magnitude (EVM), and demodulated bits. You can apply advanced signal processing to acquired signals with pulse shape filtering, equalization, synchronization, and impairment compensation.

> "With the increased emphasis on digital active electronically scanned arrays, systems are becoming more capable and multi-functional than ever before. For test engineers, this creates the technical challenge of validating fundamental component and system level RF parameters over a wide variety of test cases and applications. The Electronically Scanned Array Characterization Reference Architecture allows test engineers to validate high mix test plans more efficiently than traditional single function test equipment by combining modular, software connected RF instrumentation with trusted measurement science with a validated system configuration."

Abhay Samant
Chief Software Engineer, Aerospace Defense & Government
NI



NI Services and Support

NI offers a variety of solution integration options customized to your application-specific requirements. You can use your own internal integration teams for full system control or leverage the expertise of our worldwide network of Alliance Partners to obtain a turnkey system.

Contact your account manager or call or email us to learn more about how NI can help you increase product quality and accelerate test timelines at (888) 280-7645 or info@ni.com.

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