SOLUTION FLYER

RFIC Characterization
Automating Sub-mmWave Front-End Module, Transceiver, and Modem Test

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Test RF Components for Wireless Standards Including 5G New Radio

As development schedules shrink under time-to-market pressures and product complexity increases with every iteration of communications and cellular standards, test groups need a test solution that they can scale and adapt while keeping costs in check. The key to keeping pace in RFIC characterization and product test is a platform-based approach featuring software that defines the instrumentation. Built on the PXI platform for measurement and automation systems, the following reference solution provides R&D-grade instrumentation without sacrificing test time or the ability to cost-effectively adapt to changing test requirements as standards and designs evolve.

System Benefits
- Faster RFIC device characterization with high-throughput, modular PXI test systems
- Support for cellular technologies from 2G to 5G NR and LTE-A Pro and many variants of the 802.11 connectivity standard
- Frequency coverage of the latest unlicensed bands, including 7.125 GHz
- RF/wireless measurements including error vector magnitude (EVM), adjacent channel leakage ratio (ACLR), power, and harmonics to 26.5 GHz
- Up to 1 GHz instantaneous RF bandwidth to enable advanced digital predistortion (DPD) algorithms and future-proof against fast-changing wireless technologies
- Simplified system design with DC, digitizer, and pattern-based digital I/O for device under test (DUT) control; integrated on a shared timing, synchronization, and data bus
- Less lab space and multiple test benches with a small physical footprint

Figure 1. Typical Multiband RF Module
Reference Solution Architecture

You can configure a modular and flexible bench for your RFIC characterization and validation test in less time with less benchtop space using the NI reference solution for RFIC. Combining PXI modular instrumentation with powerful software and reference examples, this solution helps you get to measurements faster and shorten your overall test time. NI software provides example code and easy-to-use APIs for wireless standards from 2G to 5G New Radio (NR) and for connectivity standards including WLAN 6 and Bluetooth 5 in LabVIEW, C, and Visual Basic .NET. You can easily configure your measurements with intuitive soft front panels for all PXI modular instruments and transition to automation quickly by saving system configurations and expanding functionality with a high-level API.

The hardware architecture for the RFIC characterization reference solution includes a collection of standard PXI modular instrumentation:

The PXI Vector Signal Transceiver (VST) combines high-bandwidth vector signal generation and analysis in one instrument. It provides the stimulus signals to the DUT and analyzes the DUT’s spectral and modulation accuracy output while the synchronized baseband VST generates the envelope signal. Simultaneously, the scope captures fast voltage waveforms at various test points while the source measure units (SMUs) supply power and reliable DC readings to help you calculate DUT efficiency. You can further expand your RF measurement range with the PXI Vector Signal Analyzer to capture harmonic performance. Maintaining tight DUT timing and control is easy with NI’s high-speed digital instrument and pattern-based soft front panel interface.
RF and Baseband Instrumentation

VST
The VST combines an RF vector signal generator (VSG) and RF vector signal analyzer (VSA) in one instrument. The combination of wide bandwidth and high-quality RF measurement performance makes the NI VSTs ideal instruments for RF component test.

![Figure 3. PXIe-5840 RF VST](image)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>9 kHz to 6 GHz</td>
</tr>
<tr>
<td>Maximum Bandwidth</td>
<td>1 GHz</td>
</tr>
<tr>
<td>Nominal Output Power</td>
<td>+20 dBm</td>
</tr>
<tr>
<td>5G NR System EVM</td>
<td>0.32%</td>
</tr>
<tr>
<td>WLAN 6 System EVM</td>
<td>-50 dB</td>
</tr>
<tr>
<td>Input/Output Noise Density</td>
<td>&lt;-160 dBm/Hz</td>
</tr>
</tbody>
</table>

![Figure 4. PXIe-5820 Baseband VST](image)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseband I/Q Rate</td>
<td>1.25 GS/s</td>
</tr>
<tr>
<td>Maximum Complex Bandwidth</td>
<td>1 GHz</td>
</tr>
<tr>
<td>Peak-to-Peak Output Range</td>
<td>0.25 Vpp–3.0 Vpp</td>
</tr>
<tr>
<td>Input SFDR</td>
<td>78 dBC(^1)</td>
</tr>
</tbody>
</table>

\(^1\) Nominal for 10 MHz signal
VSA
PXI VSAs feature a wide frequency range up to 26.5 GHz, real-time signal analysis, and advanced signal processing. Besides traditional spectral measurements, these instruments can test a broad range of signals from 2G to 5G NR, WLAN, and Bluetooth. Select models also feature a LabVIEW-programmable FPGA that you can customize for advanced measurement applications. PXI VSAs are ideal for spectrum analysis, spur hunting, harmonic measurements, phase noise, and high-dynamic-range, low-noise measurements.

NI's VSA portfolio features the PXIe-5668, which offers up to 765 MHz of instantaneous bandwidth with best-in-class dynamic range, measurement performance, and speed.
Figure 5. PXIe-5668 VSA

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>20 Hz to 26.5 GHz</td>
</tr>
<tr>
<td>Maximum Bandwidth</td>
<td>Up to 765 MHz</td>
</tr>
<tr>
<td>Phase Noise</td>
<td>-129 dBc/Hz at 1 GHz (10 kHz offset)</td>
</tr>
<tr>
<td>Average Noise Floor</td>
<td>-167 dBm/Hz at 1 GHz</td>
</tr>
<tr>
<td>Amplitude Accuracy</td>
<td>±0.25 dB</td>
</tr>
<tr>
<td>Tuning Speed</td>
<td>3 ms (1 GHz step)</td>
</tr>
<tr>
<td>Third-Order Intercept</td>
<td>+25 dBm at 1 GHz</td>
</tr>
</tbody>
</table>

1 Preampflifier present and enabled

Typical Software Architecture

Reference solutions for RFIC characterization include a combination of PXI modular instruments and test, measurement, and automation software that provides a balance of customization and short time to measurement. The TestStand test executive is an off-the-shelf solution for automating code modules from many languages into an efficient, repeatable test plan. Measurement examples in LabVIEW provide prebuilt access to common measurements using the NI-RFmx API and act as a starting point for developing customized measurement applications that can parallelize multiple instruments at once. The NI-RFmx API simplifies common spectral measurements and offers personalities for all relevant communications and wireless standards. The foundation of all measurement software solutions is the instrument-specific drivers and APIs that provide direct access to every PXI instrument’s measurement and generation capabilities, cross-module synchronization, and fully customizable instrument automation solutions.
Front-End Component Test

The emergence of new, higher bandwidth wireless technologies and multimode power amplifiers (PAs) increases the demands on automated PA test in characterization, validation, and high-volume manufacturing test.

The NI approach to front-end component test combines high-performance modular instruments in an integrated and tightly synchronized platform with optimized, faster measurement software to test front-end modules for 802.11a/b/g/h/n/ac/ax, GSM/EDGE+, UMTS (W-CDMA/HSPA/HSPA+), cdma2000, EV-DO, LTE/LTE-A Pro, and 5G NR.

NI PXI automated test systems deliver best-in-class RF measurement performance with test times that are typically 5X to 10X faster than traditional instruments.
Solution Features

- Ability to test RF PAs and integrated front-end modules for handset/user equipment (UE) and base station/small-cell devices
- Advanced DPD test capabilities including AM-AM/AM-PM measurements and multiple algorithms
- Industry-leading baseband-to-RF synchronization for envelope tracking applications
- Advanced digital synchronization with MIPI RFFE DUT control
- Integrated power efficiency measurements with accurate DC measurements

Hardware Configuration

The following reference hardware configuration provides a complete characterization and validation bench setup with subnanosecond timing and triggering for fast and reliable results.

Figure 7. Reference Architecture Test Configuration
Fast Power Level Servo Technology

Power level servo is traditionally a time-consuming process. You can cut test time significantly by performing the control loop entirely on the instrument FPGA. This unique feature of the FPGA-based VST decouples the power level servo algorithm from the embedded controller and helps the system exploit dramatic measurement parallelism. This reduces test time and test cost significantly.

**Figure 8. Output Power Servo RFIC Soft Front Panel**

**Table 1. Benchmarking PC Processing Against FPGA Processing**

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Servo Processing in PC</th>
<th>Servo Processing in FPGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTE FDD 10 MHz 12 RB</td>
<td>25 ms</td>
<td>&lt;2 ms</td>
</tr>
</tbody>
</table>
DPD
You can quickly test your PA designs under DPD conditions with NI’s RFIC test software. DPD, an advanced linearization technique, corrects for signal distortion and improves PA metrics such as ACLR and EVM. Testing a PA under DPD conditions involves four key operations: device behavior characterization, model extraction, model inversion, and the application of predistortion to baseband I/Q samples.

NI’s RFIC test software supports several DPD models, including the memoryless AM-AM/PM lookup table (LUT), the memory polynomial (MP) model, and the generalized memory polynomial (GMP) model for higher bandwidth signals with memory effects. In addition, the RFIC reference solution includes example programs you can use to automate device test. Because these example programs use the same underlying measurement IP as the soft front panel, you can more easily correlate results from the interactive and automated use cases.

**DPD Algorithm**
Apply DPD algorithms to ET PAs to correct for AM-AM and AM-PM distortion.

**Envelope Control**
Applies envelope shaping and real-time control of VSG-to-AWG delay.

**PA Performance**
Observe AM-AM and AM-PM behavior of PA under envelope tracking conditions.

**PA Performance Metrics**
Use metrics such as ACLR, EVM, power, and RMS memory to characterize PA performance.

*Figure 9. Quickly test your PA designs under DPD conditions with NI’s RFIC test software.*
Envelope Tracking

Envelope tracking (ET) improves the efficiency of PAs for modern, high-bandwidth OFDM signals with a high peak to average power ratio (PAPR). An ET power supply (ETPS) dynamically modulates the DC power it supplies to the PA by following the amplitude of the envelope of high PAPR modulated wireless signals. ET keeps a PA near compression as often as possible, thus improving overall efficiency.

For ET test, the NI RFIC Test Soft Front Panel transforms multiple instruments into a single measurement experience. It combines the VST for signal generation and analysis; a synchronized, high-bandwidth arbitrary waveform generator (AWG) to generate the envelope waveform; and a high-speed digitizer for finding optimum delays for the highest efficiency. The RFIC Test Soft Front Panel controls and synchronizes the instruments so you can focus on your DUT’s performance. You can also easily switch to full automation with the included sample test applications and a large collection of diverse, license-free waveforms.

**Figure 10.** For ET test, the RFIC Test Soft Front Panel transforms multiple instruments into a single measurement experience.
Transceiver and Modem Test

You can also take advantage of the NI platform to test the baseband and transceiver performance of your designs. Using the RF and baseband VSTs, you can convert RF to baseband and baseband to RF to check for I and Q impairments and fine-tune your design for the best modulation accuracy. Furthermore, with the NI platform, you can characterize and validate your design’s digital baseband stage early in the design cycle by generating and analyzing standard-compliant baseband I/Q signals going to and coming from your device’s baseband processor.

Transceiver and Modem Solution
- Test transceivers and modems for handset/UE and base station/small-cell devices
- Test digital, baseband, and RF capabilities of mobile transceivers
- Test modems and transceivers under carrier aggregation conditions using the modular PXI architecture
- Validate modem firmware under a wide range of conditions using flexible waveform configurations

Hardware Configuration

The following hardware reference configuration shows common insertion points to quickly and accurately characterize and validate your modem digital and firmware designs as well as your transceiver conversion and I/Q modulation performance.

Figure 11. Test Insertion Points for Modem and Transceiver Characterization
Software for RFIC Characterization Test

You can achieve extremely fast and high-quality measurements with minimal software development using NI-RFmx, which is a set of interoperable measurement toolkits with easy-to-use APIs in LabVIEW, C, and C#. It features soft front panels to help you get the most from your NI PXI RF VST and VSA instruments right out of the box. NI-RFmx includes the most advanced optimization techniques such as multiple measurement parallelism and high-dynamic-range noise correction for industry-leading measurement speeds.

Waveform Creator

You need to work with the latest high-bandwidth, complex waveforms and move them from bench to bench and system to system while keeping equipment costs low. The NI-RFmx Waveform Creator helps you create and generate unencrypted wireless waveforms from 2G to 5G, WLAN, and Bluetooth. It also features generation capabilities for analog (FM-RDS), FSK, PSK, and QAM signals. You can use it to create, download, and play back standard-compliant signals without paying additional licensing costs to move from one system to the next. You can also include filter configurations and I/Q impairments in your waveform configuration while performing basic measurements. Licensed with NI-RFmx, the NI-RFmx Waveform Creator improves the wireless generation interactive panel experience.

Figure 12. NI-RFmx Waveform Creator
NI-RFmx Soft Front Panel

NI-RFmx includes soft front panels featuring a modern, unified, and accessible UI/UX design with a familiar feel. They offer both spectral analysis and cellular personalities. You can use them to control instrument sessions for debugging tests, take composite and overlapped measurements, share saved settings and recall them from other benches to guarantee results correlation, and debug and monitor the soft front panels from their automated measurement application.

![Figure 13. NI-RFmx Soft Front Panel](image)

NI-RFmx Programming API

As a measurement-oriented API, NI-RFmx reduces the time and effort it takes to automate with reliable results. In as few as four software calls, you can automate many fundamental measurements such as spectral traces and transmitted channel power. These measurements include a complete set of thoroughly documented functions for customizing parameters such as sweep time or integration bandwidth.

NI-RFmx features examples for programming each measurement. These examples include both basic and advanced functionality to give you the appropriate starting point depending on your application goal. In addition to measurement examples, NI-RFmx offers advanced examples that show you how to easily use multimeasurement parallelism with results naming, composite measurements, and advanced automation with signal naming.

Programming in LabVIEW

With constrained timetables, you need an intuitive way to build powerful applications. The many advantages of programming in the LabVIEW graphical environment include tight integration with measurement hardware from any vendor, simple representation of complex logic on the diagram, and custom engineering user interfaces. You can perform standards-based measurements quickly with dedicated palettes per standard for standards such as GSM, WCDMA, LTE, and NR. Implement power servo and DPD easily with dedicated API functions.
Programming in C/C#

You can build robust RF applications in the most common text languages such as C and Visual Basic .NET. Like LabVIEW, NI-RFmx has basic and advanced examples for programming in these text-based languages to help you get results quickly.

```csharp
try
{
    /* Create a new RFmx session */
    instrSession = new RFmxInstrMX(resourceName, "");

    /* Get SpecAn signal */
    specAn = instrSession.GetSpecAnSignalConfiguration();

    /* Configure measurement */
    specAn.Chp.ConfigureRF("", centerFrequency, referenceLevel, externalAttenuation);
    specAn.Chp.ConfigureRFChannelPeakAndAvg("", integrationAndBandwidth, integrationAndBandwidth);
    specAn.Chp.ConfigureRFChannelPeakAndAvgAveraging("", averagingEnabled, averagingCount, RFmxSpecAnWMCapAveragingType.Rms);

    /* Retrieve results */
    specAn.Chp.Results.Read("", timeout, out absolutePower, out psd);
    Console.WriteLine("Absolute Power (dBm) [0]n", absolutePower);
    Console.WriteLine("PSD (dBm/Hz) [0]n", psd);
}

catch (Exception ex)
{
    DisplayError(ex);
}

finally
{
    /* Close session */
    CloseSession();
    Console.WriteLine("Press any key to exit....");
    Console.ReadKey();
}
```

Figure 14. NI-RFmx Spectral Analysis Basic Example in LabVIEW

Figure 15. NI-RFmx Spectral Analysis Basic Example in C#
TestStand With the TestStand Semiconductor Module

Once you establish and validate a test plan, you can reduce overall test time by creating an automated test sequence using a test executive. With TestStand industry-standard test management software, you can build and deploy automated test systems faster. It includes a ready-to-run test sequence engine that supports multiple test code languages, flexible result reporting, and parallel/multithreaded test.

The TestStand Semiconductor Module adds features specifically designed to address semiconductor test challenges, so you can:

- Reduce development time with built-in step templates for continuity, leakage, and digital pattern bursts
- Easily generate test reports in standardized reporting formats including STDF and ASCII text
- Maximize throughput and scale using integrated pin mapping and multisite abstraction
- Simplify test sequence development using interactive debugging with NI-RFmx soft front panels

Although TestStand includes many features out of the box, it is designed to be highly extensible. As a result, tens of thousands of users worldwide have chosen it to build and deploy custom automated test systems. The TestStand Semiconductor Module extends the TestStand development environment to help you develop, debug, optimize, deploy, and maintain semiconductor test systems. With this add-on module to industry-standard TestStand, you gain a world-class test program development and debugging environment.

TestStand supports code modules from integrated development environments (IDEs) such as LabVIEW and Microsoft Visual Studio so you can easily author, automate, and debug instrument control, measurement, and analysis code written in both LabVIEW and Visual Basic .NET. You can take full advantage of the NI-RFmx API to create RFIC characterization test suites.
With a DUT-centric, dynamic multisite programming paradigm, you can write instrument control, measurement, and analysis code that scales from one to 32 or more sites. You can disable one or more specific sites dynamically in response to poor yield of one or more faulty tester sockets. The included Pin Map Editor helps you define the relationship between DUT pins and instrument channels.
Correlate Measurements From Characterization to Production Test

As characterization and production development efforts evolve, you may find correlating measurements between the lab and production floor challenging. You can simplify the correlation process by using the same hardware and software configuration in both the lab and on the production floor. The PXI platform’s small form factor makes it ideal for benchtop use in the lab, and its ruggedness and modularity make it a compelling solution for production.

You can use the PXI platform for RFIC manufacturing test as either a stand-alone system or part of the NI Semiconductor Test System (STS). STS combines the NI PXI platform, test management software such as TestStand, and LabVIEW graphical programming inside a fully enclosed, standardized test head.

Characterization System

- PXI Chassis and Controller
- PXI Modular Instrumentation
- NI-RFmx Measurement Software
- NI TestStand Test Executive

Production System

- NI STS Docking and Cabling Interface
- T4, T2 (pictured), and T1 Sizes Available
- PXI Chassis and Controller
- PXI Modular Instrumentation
- NI-RFmx Measurement Software
- NI TestStand Test Executive

Figure 17. Semiconductor Test System

The STS enclosure houses all the key components of a production tester including test instruments, DUT interfacing, and device handler/prober docking. With the open, modular STS design, you can use the latest industry-standard PXI modules for more instrumentation and computing power, increase the return on the development investments you make in characterization, and lower your overall cost and development time for RFIC production test.

Learn more at ni.com/sts
Platform-Based Approach to Test and Measurement

What Is PXI?
Powered by software, PXI is a rugged PC-based platform for measurement and automation systems. It combines PCI electrical-bus features with the modular, Eurocard packaging of CompactPCI and then adds specialized synchronization buses and key software features. PXI is both a high-performance and low-cost deployment platform for applications such as manufacturing test, military and aerospace, machine monitoring, automotive, and industrial test. Developed in 1997 and launched in 1998, PXI is an open industry standard governed by the PXI Systems Alliance (PXISA), a group of more than 70 companies chartered to promote the PXI standard, ensure interoperability, and maintain the PXI specification.

![Figure 18. PXI Platform](image)

Integrating the Latest Commercial Technology
By leveraging the latest commercial technology for its products, NI can continually deliver high-performance and high-quality products to you at a competitive price. The latest PCI Express Gen 3 switches deliver higher data throughput, the latest Intel multicore processors facilitate faster and more efficient parallel (multisite) test, the latest FPGAs from Xilinx help push signal processing algorithms to the edge to accelerate measurements, and the latest data converters from TI and ADI continually increase the measurement range and performance of NI instrumentation.

![Figure 19. NI products feature the latest commercial technology to accelerate your measurements.](image)
NI offers more than 600 different PXI modules ranging from DC to mmWave. Because PXI is an open industry standard, nearly 1,500 products are available from more than 70 different instrument vendors. With standard processing and control functions designated to a controller, PXI instruments need to contain only the actual instrumentation circuitry, which provides effective performance in a small footprint. Combined with a chassis and controller, PXI systems feature high-throughput data movement using PCI Express bus interfaces and subnanosecond synchronization with integrated timing and triggering.

**Oscilloscopes**
Sample at speeds up to 12.5 GS/s with 5 GHz of analog bandwidth and leverage numerous triggering modes and deep onboard memory.

**Digital Multimeters**
Perform voltage (up to 1000 V), current (up to 3 A), resistance, inductance, capacitance, and frequency/period measurements as well as diode tests.

**Digital Instruments**
Perform characterization and production test of semiconductor devices with timing sets and a per channel pin parametric measurement unit (PPMU).

**Waveform Generators**
Generate standard functions including sine, square, triangle, and ramp as well as user-defined, arbitrary waveforms.

**Frequency Counters**
Perform counter/timer tasks such as event counting and encoder position, period, pulse, and frequency measurements.

**Source Measure Units**
Combine high-precision source and measure capability with high-channel density, deterministic hardware sequencing, and SourceAdapt transient optimization.

**Power Supplies and Loads**
Supply programmable DC power, with some modules including isolated channels, output disconnect functionality, and remote sense.

**Source Measure Units**
Combine high-precision source and measure capability with high-channel density, deterministic hardware sequencing, and SourceAdapt transient optimization.

**Switches (Matrix and MUX)**
Feature a variety of relay types and row/column configurations to simplify wiring in automated test systems.

**FlexRIO Custom Instruments and Processing**
Provide high-performance I/O and powerful FPGAs for applications that require more than standard instruments can offer.

**Vector Signal Transceivers**
Combine a vector signal generator and vector signal analyzer with FPGA-based, real-time signal processing and control.

**GPIB, Serial, and Ethernet**
Integrate non-PXI instruments into a PXI system through various instrument control interfaces.

**Data Acquisition Modules**
Provide a mix of analog I/O, digital I/O, counter/timer, and trigger functionality for measuring electrical or physical phenomena.
Hardware Services

All NI hardware includes a one-year warranty for basic repair coverage, and calibration in adherence to NI specifications prior to shipment. PXI systems also include basic assembly and a functional test. NI offers additional entitlements to improve uptime and lower maintenance costs with service programs for hardware. Learn more at ni.com/services/hardware.

<table>
<thead>
<tr>
<th>Program Duration</th>
<th>Standard</th>
<th>Premium</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1, 3, or 5 years</td>
<td>1, 3, or 5 years</td>
<td>Length of service program</td>
</tr>
<tr>
<td>Extended Repair Coverage</td>
<td>●</td>
<td>●</td>
<td>NI restores your device’s functionality and includes firmware updates and factory calibration.</td>
</tr>
<tr>
<td>System Configuration, Assembly, and Test¹</td>
<td>●</td>
<td>●</td>
<td>NI technicians assemble, install software in, and test your system per your custom configuration prior to shipment.</td>
</tr>
<tr>
<td>Advanced Replacement²</td>
<td></td>
<td>●</td>
<td>NI stocks replacement hardware that can be shipped immediately if a repair is needed.</td>
</tr>
<tr>
<td>System Return Material Authorization (RMA)³</td>
<td></td>
<td>●</td>
<td>NI accepts the delivery of fully assembled systems when performing repair services.</td>
</tr>
<tr>
<td>Calibration Plan (Optional)</td>
<td>Standard</td>
<td>Expedited³</td>
<td>NI performs the requested level of calibration at the specified calibration interval for the duration of the service program.</td>
</tr>
</tbody>
</table>

¹This option is available only for PXI, CompactRIO, and CompactDAQ systems.
²This option is not available for all products in all countries. Contact your local NI sales representative to confirm availability.
³Expedited calibration includes only traceable levels.

PremiumPlus Service Program

NI can customize the offerings listed above or offer additional entitlements such as on-site calibration, custom sparing, and life-cycle services through a PremiumPlus Service Program. Contact your NI sales representative to learn more.

Technical Support

Every NI system includes a 30-day trial of phone and email support from NI engineers, which can be extended through a Standard Service Program (SSP) membership. NI has over 400 engineers around the globe to provide local support in more than 30 languages. Additionally, you can take advantage of NI’s award-winning online resources and communities.