RFFE Validation Reference Architecture

Determine RFFE Design Performance Faster–from Interactive Bring-Up to Automated Validation
A More Streamlined Validation Workflow for RF Front Ends

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Trends in RFFE Validation

The number of supported frequency bands and test cases for new wideband wireless standards, such as 5G New Radio (NR) and Wi-Fi 7 (802.11be), continues to grow. Simultaneously, the need for power amplifier design tradeoffs between greater power efficiency and higher linearity keeps driving exploration of novel linearization and envelope tracking (ET) techniques.

NI’s RF Front-End Validation Reference Architecture simplifies the workflow of engineers responsible for validation of wideband RF power amplifiers (PAs) for demanding applications, like 5G NR and Wi-Fi 7. On the hardware side, NI’s portfolio of modular, lab-grade instrumentation and Focus Microwave wideband tuners deliver scalable, tailored, and tightly integrated validation test benches.

With NI RFIC Test Software, optimized for wideband wireless standards, engineers enjoy interactive control of validation benches and detailed results visualized in a streamlined workflow. The RFIC Test Software makes it easy to bring-up new DUTs, to interact manually to validate DUT performance, and to automate extensive device characterization routines.

RFFE Validation Reference Architecture Overview

Determine RFFE Design Performance Faster—from Interactive Bring-Up to Automated Validation

NI’s RFFE Validation Reference Architecture can help:
- Quickly bring up new designs of the latest 5G NR and Wi-Fi RF front ends
- Determine key RF performance metrics in 50 and non-50 Ω environments
- Explore best-in-class PA linearization with standard or custom DPD algorithms
- Configure extensive parameter sweeps with industry-leading speed
- Achieve accurate measurements with S-parameter calibration/de-embedding
- Lower the cost of test with integrated, modular, and scalable validation benches

**FIGURE 01**
Overview of RFFE Validation System Components

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Solution Details

RFFE Validation Reference Architecture: A More Streamlined Validation Workflow

1. Configure a cost-optimized, modular bench with a combination of DC, AWGs, analog, digital, and RF instruments. Expand your bench later or upgrade your VST for more bandwidth and frequency if needed.

2. Control your bench from the intuitive graphical user interface (GUI) in RFIC Test Software for fast and interactive bring-up of RF front ends. Configure frequency and power sweeps with no coding necessary.

3. Launch the Test Automation Wizard and instantly create easy-to-use code modules with NI's RF Reference Design Libraries in LabVIEW and .NET.

4. Transition to extensive automated characterization with TestStand sample sequences, looping over multiple parameters, and producing valuable results reports.

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System Architecture

NI’s RFFE Validation Reference Architecture gives engineers control of modular PXI test bench hardware through powerful and integrated software. At the top level, the RFIC Test Software acts as a visualization tool and intuitive graphical user interface (GUI) for fast bring-up and manual interaction with the RF DUT.

Working in conjunction with the soft front panel, the RFFE Validation Reference Architecture includes an Automation Wizard with easy-to-use reference design libraries (RDLs)—and an array of code examples in LabVIEW and .NET—to empower engineers to run quick, automated tests on their DUTs.

In addition, the Automation Wizard creates NI TestStand example sequences that use these code modules to automate extensive PA testing and results reporting, looping through multiple nested parameters without having to write complicated test software.

**FIGURE 02** RFFE Validation Reference Architecture Software and Hardware Interactions
Linearization and DPD Overview

Linearization of wideband RF power amplifiers with digital pre-distortion (DPD) is a popular technique to correct for higher-order non-linearities, minimizing spectral regrowth and improving EVM. The RFFE Validation Reference Architecture performs all four key DPD operations: characterizing device behavior, model extraction, model inversion, and application of predistortion to baseband IQ samples.

The RFIC Test Software allows you to apply DPD models and observe device behavior quickly and interactively. This solution supports both well-known DPD algorithms—lookup table (LUT), Memory Polynomial Model (MPM), and Generalized Memory Polynomial (GMP)—along with custom-implemented DPD models, such as custom MathWorks® MATLAB® software algorithms or dual-band algorithms from MaxLinear (NanoSemi). With the ability to save DPD coefficients, users can quickly switch between different models for easy comparison and visualization.

Also included is example code that empowers engineers with more control to automate device validation with DPD. Because these example programs use the same underlying measurement IP as the RFIC Test Software, users can more readily correlate results from the interactive and automated use cases.

**FIGURE 03**
RFIC Test Soft Front Panel
DPD Screenshot

**Linearization Algorithms**
Select from traditional or custom linearization implementations.

**Performance Visualization**
Observe single- and dual-band DPD improvements in ACP and modulation quality in real time.

**Sweep Results**
Configure frequency, power, and load sweeps to characterize DPD performance as conditions change.

**PA Linearity Measurements**
Observe Gain, AM-AM and AM-PM response of the PA easily visualized both with and without DPD.

**PA Performance Metrics**
Obtain measurement results such as ACP, EVM, power, and RMS memory to characterize PA performance.
Hardware Configuration

For DPD testing, the RFFE Validation Reference Architecture combines multiple instruments into a unified measurement experience that controls PXI Vector Signal Transceivers (VSTs), precision Source Measure Units (SMUs), and high-speed digital I/O for DUT control. The VST is a key element of the measurement configuration and combines a wideband RF signal generator and RF signal analyzer into one module. Tight synchronization between RF generator and analyzer enables accurate measurements of gain and AM-AM/PM using modulated waveforms.

The PXI platform takes advantage of the latest multicore processors to speed up processing of mathematically complex DPD algorithms. With bandwidth requirements often three to five times higher than the signal bandwidth for DPD, this can mean anywhere from 1600 to 2000 MHz bandwidth is required for the latest Wi-Fi 7 and 6G NR standards. With up to 2 GHz of instantaneous bandwidth, PXI Vector Signal Transceivers in combination with PXI Controllers can easily handle these high demand applications.

![FIGURE 04](image)

RFFE Validation System Diagram

DPD Solution Features and Specifications

**DPD Models**
- NanoSemi single- and dual-band DPD
- Custom MathWorks MATLAB® software algorithms
- Memoryless AM-AM/PM LUT
- Memory Polynomial Model (MPM)
- Generalized Memory Polynomial (GMP)

**Supported Signal Types**
- 5G NR: single carrier and carrier-aggregated
- 2G to 4G
- Wi-Fi(802.11a/b/g/n/ac/ax/be)

**Measurements**
- AM-AM/PM
- RF power and gain
- EVM per symbol/subcarrier
- ACP
- SEM
- RMS memory (phase)
- Harmonics
- Power-added efficiency
Load-Pull Overview

NI has partnered with Focus Microwaves to integrate control of their passive load tuners as part of the RFFE Validation Reference Architecture. All Focus tuners use extremely efficient calibration and tuning algorithms to produce consistent measurement results sweep after sweep.

Users can interactively adjust and sweep the reflection factor (complex gamma) of their tuner directly from the RFIC Test Software, as they visualize the performance of the amplifier with the changing impedance. Additionally, users can automate their impedance sweeps and measurements from the code and test sequence examples included with the Automation Wizard.

**Sweep Impedance**
Configure detailed impedance sweeps to characterize power amplifier performance as conditions change, with and without DPD.

**Performance Visualization**
Observe RF power amplifier performance in real time using CW and wideband signals.

![Load-Pull Example Code Screenshot](image)

**FIGURE 05**
Load-Pull Example Code Screenshot

Load-Pull Solution Features and Specifications
- Scalar, pre-calibrated load pulling for highly repeatable generation of complex reflection factors
- Integrated control of various Focus Microwaves wideband, fundamental, passive tuners via Ethernet (TCP/IP) connection
- Multiple tuner impedance setting modes: motor position, gamma, VSWR
- Smith chart and numerical visualization, and results logging
- Integration of bench calibration S-parameters
Envelope Tracking Overview

Envelope tracking (ET) for wideband power amplifiers relies on an ET Power Supply (ETPS) to vary the DC power supply dynamically in conjunction with the amplitude of a modulated wireless signal. Envelope tracking keeps a PA near compression as often as possible, thus improving overall efficiency.

For ET testing, the NI RFFE Validation Reference Architecture transforms multiple instruments into an easy-to-configure, unified measurement experience that simplifies control and synchronization of the VST, a high-bandwidth arbitrary waveform generator (AWG), and high-speed digitizer. Utilized in conjunction with InstrumentStudio, all instruments work together cohesively in an integrated ET test system.

The RFFE Validation Reference Architecture also features LabVIEW and .NET example code and ready-to-run automated test sequences that can be customized for extensive automated validation applications.

**FIGURE 06**
RFIC Test Soft Front Panel and InstrumentStudio Envelope Tracking Screenshot

- **Integrated Bench Control**
  Simplify configuration of SMUs, AWGs, oscilloscopes, and RF instrumentation.

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

- **Sweep and Adjust Delays**
  Take advantage of sub-nanosecond synchronization between instruments to sweep the envelope delay and find the best timing settings.
Envelope Tracking Hardware Configuration

A critical challenge for ET PA testing is synchronization and stable alignment of RF and Vcc signals supplied by a vector signal generator (VSG) and arbitrary waveform generator (AWG). The RFFE Validation Reference Architecture is based on NI PXI instrumentation and features shared trigger and timing bus resources. This implementation minimizes synchronization jitter between RF and Vcc signals to less than 20 ps. In addition, by routing timing signals on the PXI backplane, these results are stable and repeatable. The software includes the NI Fast ET Align measurement which rapidly estimates RF and Vcc alignment. Finally, the envelope tracking software can simultaneously apply DPD to the stimulus signal.

FIGURE 07 PXIe Power Level Servo Loop Diagram

Envelope Tracking Solution Features and Specifications

Synchronization
- AWG-to-VSG jitter: < 20 ps
- AWG-to-VSG skew resolution: 1 ns

Supported Signal Types
- 5G NR
- 2G to 4G
- Wi-Fi (802.11a/b/g/n/ac/ax/be)
Accelerated Test Times
The evolution of wideband wireless technologies and multi-mode power amplifiers is increasing the demands on automated validation and characterization of power amplifiers. Combining high-performance modular instruments with fast and reliable measurement software, the RFIC Validation Reference Architecture delivers accurate RF results with test times that are typically 5 to 10 times faster than traditional instruments.

Reliable Path Loss and Fixture Calibration with S-Parameters
The RFIC Test Software includes support for S-parameter calibration files, extracting magnitude and phase information to correct for path losses through every cable, fixture, and other signal paths.

From Mobile to Infrastructure RF Front Ends
The versatility of the RFIC Test Software means that base station infrastructure PAs, that often require external amplifiers and attenuators, are easily configurable. The RFIC Test Soft Front Panel comes with a built-in System Compensation Panel that intuitively lays out the gain/attenuation at each stage in the signal chain. This ensures no component is subject to higher power levels than it can handle, and that every component is tested under the correct conditions.

Fast Power Level Servo Technology
A unique benefit of the NI RFIC approach is the super-fast FPGA-based power level servo using NI VSTs. By performing the control loop entirely on the instrument FPGA, engineers can achieve very fast power level convergence. By decoupling the power level servo algorithm from the embedded controller and performing it on an FPGA, engineers can achieve significant reductions in validation time and cost. The RFIC Test Software also supports output power servo routines using USB power sensors coupled to the output load. The software automatically reads the power sensor and adjusts the level of the generated waveform to achieve the desired output power set point.

FIGURE 08
PXIe Power Level Servo Loop Diagram
From Characterization to Production Test

The openness and flexibility of the NI RFFE Validation Reference Architecture empowers engineering teams to transition test systems from the R&D lab to the manufacturing floor. This can be done by leveraging the initial engineering investment early in development, using the same type of instrumentation and measurement science for production test, and reducing the correlation efforts between the two. NI’s combination of fast measurement speed and small physical footprint make it an ideal test solution for high-volume, high-throughput environments.

Additionally, NI PXI instruments will use similar software tools to ensure a quick transition whenever a change needs to be made. The PXIe-5842 is integrated into the RFIC Test Software in a similar way as the PXIe-5841 and PXIe-5830/1—requiring no change to software and ensuring users with familiarity have a seamless experience using any vector signal transceiver.

**Interactive Bring-Up**
- Quickly validate PA behavior using instrument soft front panels or reference examples.

**Automated Characterization**
- Automate PA/FEM characterization through easy-to-use example code and sequences.

**Production Test**
- Reuse test equipment and characterization software in manufacturing test.

Deploying PXI in Manufacturing Test

You can deploy PXI for manufacturing test either as a stand-alone system or as part of the NI Semiconductor Test System (STS). The STS combines the NI PXI platform with NI’s speed-optimized test software for high test throughput inside a fully enclosed test head suited for production environments.

**PXI Chassis and Controller**

**PXI RF and Modular Instrumentation**

**NIRFmx Measurement Science and NI TestStand (Test Management)**

**STS Standardized Docking and Cabling Interface**

**FIGURE 09** PXI Platform Across the Product Development Lifecycle
The STS enclosure houses all the key components of a production tester including test instruments, device under test (DUT) interfacing, and device handler/prober docking mechanics. With the open, modular STS design, you can take advantage of the latest industry standard PXI modules for more instrumentation and computing power to lower the overall cost of RFFE production test.

Hardware Specifications

Engineers can specify a modular combination of PXI instruments to complete their NI RFFE Validation Reference Architecture, going from the most basic, to more comprehensive setups with multiple, synchronized instruments. Simpler measurements of the most basic RF parameters might require only a PXI chassis, controller, and VST, while other configurations for envelope tracking call for additional instruments like arbitrary waveform generators, scopes, and SMUs.

The RFFE Validation Reference Architecture is scalable to meet the exact needs of your application.

PXI Vector Signal Transceivers

NI’s VSTs combine an RF vector signal generator (VSG) and RF vector signal analyzer (VSA) with a powerful FPGA into a single PXIe instrument. The combination of wide bandwidth and high-quality RF measurement performance makes the NI VSTs an ideal solution for RF power amplifier testing of sub-6 GHz and mmWave front-end modules.

The third generation VST, the PXIe-5842, brings much improved measurement capabilities and new features applicable in a wide range of RF applications. Among the new capabilities are best-in-class EVM performance (802.11be, <50 dB), enhanced LO Offset mode with improved average noise density, continuous frequency coverage up to 23 GHz, and up to 2 GHz of instantaneous RF bandwidth.

<table>
<thead>
<tr>
<th>PXIe-5842 Vector Signal Transceiver</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency Range</strong></td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
</tr>
<tr>
<td><strong>Channels</strong></td>
</tr>
<tr>
<td><strong>Maximum Power Output @ 5 GHz</strong></td>
</tr>
<tr>
<td><strong>Tuning Time</strong></td>
</tr>
<tr>
<td><strong>Tx/Rx Amplitude Accuracy</strong></td>
</tr>
<tr>
<td><strong>Wi-Fi 6 EVM (MCS 11) @ 80 MHz</strong></td>
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### PXIe-5831 mmWave VST

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Frequency Range</td>
<td>24 GHz – 44 GHz</td>
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<tr>
<td>Bandwidth</td>
<td>1 GHz</td>
</tr>
<tr>
<td>Maximum Power Output</td>
<td>+17 dBm</td>
</tr>
<tr>
<td>5G NR EVM, 100 MHz BW @ 28 GHz</td>
<td>-46 dB</td>
</tr>
<tr>
<td>Direct Ports</td>
<td>2</td>
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<tr>
<td>Amplitude Accuracy</td>
<td>+/- 0.25 dB</td>
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### PXIe-5820 Baseband VST

<table>
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<tr>
<th>Specification</th>
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<tbody>
<tr>
<td>Frequency Range</td>
<td>0 – 500 MHz</td>
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<tr>
<td>I/Q Bandwidth</td>
<td>1 GHz</td>
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<tr>
<td>Max Sample Rate</td>
<td>1.25 GS/s</td>
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<tr>
<td>Common-Mode Accuracy</td>
<td>± 2 mV</td>
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### PXIe-4147 Precision SMU

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<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Channels</td>
<td>4</td>
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<tr>
<td>Maximum Continuous Power</td>
<td>±8 V, 3 A, 24 W</td>
</tr>
<tr>
<td>Transient Response</td>
<td>&lt; 50 µs</td>
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### PXIe-6570/1 High Speed Digital

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<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Data Rate</td>
<td>200 Mb/s</td>
</tr>
<tr>
<td>Pattern Timing</td>
<td>39.0625 ps placement</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>-2 V to 7 V</td>
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</table>

### PXIe-8881 Embedded Controller

<table>
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<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Processor Core</td>
<td>Xeon 18-core</td>
</tr>
<tr>
<td>Controller Bandwidth</td>
<td>24 GB/s</td>
</tr>
<tr>
<td>Hard Drive Memory</td>
<td>512 GB</td>
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### PXIe-1095 Chassis

<table>
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<th>Feature</th>
<th>Specification</th>
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<tr>
<td>PXI Express Slots</td>
<td>18</td>
</tr>
<tr>
<td>Total System Bandwidth</td>
<td>24 GB/s</td>
</tr>
<tr>
<td>Total Power Rating</td>
<td>1644 W (dual supply)</td>
</tr>
</tbody>
</table>
System Integration on Your Terms

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.

To learn how you can streamline validation workflows, increase product quality, and shorten test timelines, contact your account manager or NI at (888) 280-7645 or info@ni.com.

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