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APPLICATION NOTE

High-Power DC-DC Converter Measurements Using the NI PXI System

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Introduction

Power management integrated circuits (PMICs) are used to manage or convert power within various systems, including mobile phones, tablets, and automotive applications like infotainment, advanced-driver assistance systems (ADAS), and electronic control units (ECUs).

PMICs, especially those used in compact handheld devices with limited space, are mounted directly on a printed circuit board (PCB), serving as a vital interface between the device's power supply or battery and its complex electronics. As semiconductors advance and integrate further, the use of PMICs in devices is rising, and the demand for power density and efficiency continues to grow. Fast charging has become a standard feature in the mobile devices we use every day, and as the automotive industry shifts toward electric vehicles (EVs), the efficiency of charging and discharging systems has become paramount.

A DC-DC power converter is a prime example of a widely available PMIC used in a diverse range of applications. It serves the purpose of upconverting or downconverting a direct current from one voltage level to another. When conducting design validation before manufacturing or evaluating a DC-DC converter for potential integration into a product, it's essential to employ a repeatable and precise test sequence.

Standard test sequences for DC-DC converters measure performance criteria, including voltage accuracy, efficiency, load and line regulation, load and line transient response, power supply rejection ratio (PSRR) analysis, shutdown and quiescent current, and noise.

The rapid expansion of the electronics industry, driven by the need for miniaturization in mobile devices and the increasing adoption of safe EVs, has created demand for a greater number of higher power DC-DC converter channels within a single PMIC. As a result, iterative and automatic control for a device under test (DUT) through digital communication has become imperative in test sequences. Additionally, there are further challenges related to effectively synchronizing instruments and scaling to measure multiple channels.

This application note explains how to conduct tests of DC-DC converters that require a power supply, Digital Pattern Instrument, frequency generator (FGEN), and oscilloscope within the NI PXI system, known for its power, precision, and speed.

PMIC Validation Challenges

Test engineers may encounter specific challenges when testing a PMIC, including:

- Debugging and automating various tests
- Synchronizing instruments
- Collecting a large amount of data
- Optimizing measurement efficiency and test time
- Improving data management

Test engineers may also confront additional challenges during PMIC verification, which encompass:

- Determining test plans to verify the functionality and performance of the PMIC
- Effectively correlating data with cross-functional teams, including design engineers, project managers, and other stakeholders
- Managing complex validation procedures

In particular, they may struggle to identify and diagnose issues and defects within the PMIC. Their ultimate responsibility is determining the root causes of all issues.

NI offers solutions to address all of these challenges that test engineers face.

PMIC Validation Solution

NI offers a range of instruments and software to address the challenges discussed above. Now let's look at how specific NI solutions solve each one.

Debugging and Automating Various Tests

NI software provides solutions for both interactive and automated tests. InstrumentStudio™ is an application software for interactive instrument control and lab measurements (see Figure 1) that enables test engineers to identify the root causes of issues, replicate test setups easily, and access instruments remotely.

LabVIEW is a graphical programming environment engineers use to develop automated research, validation, and production test systems (see Figure 2). Test engineers can also use pre-existing examples or software developed by LabVIEW for PMIC tests. These software solutions can also benefit design engineers by facilitating efficient debugging with test engineers.

The NI PXI system supports a robust array of AC (scope, FGEN), DC, and digital instrumentation. This single platform supports a wide range of tests, such as power provision and measurement, trace power acquisition, noise injection, and DUT control. Additionally, the PXI system simplifies the process of executing parallel multisite or multichannel tests at a reasonable cost per channel, with the flexibility to add instruments as needed (see Figure 3).

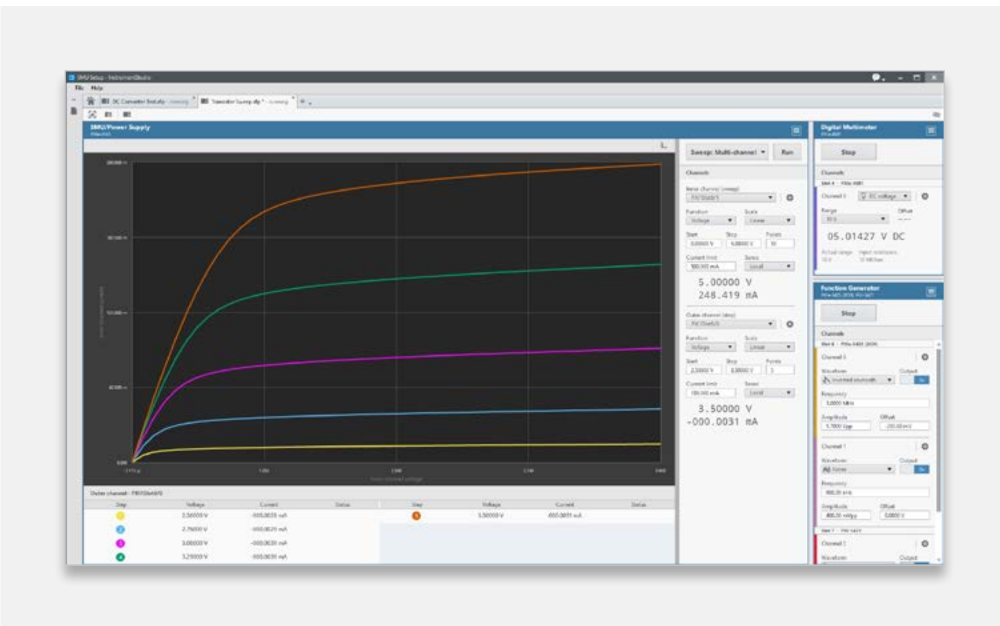

FIGURE 1
Plot of I/V Curve Measured Using NI SMUs with InstrumentStudio

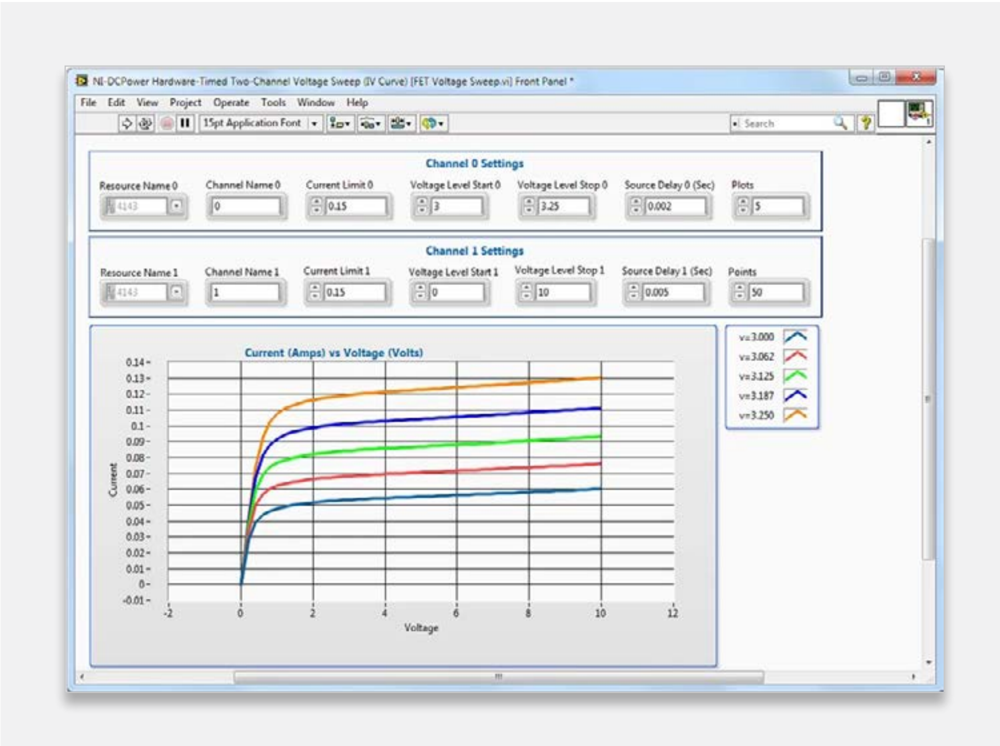

FIGURE 2

Plots of I/V Curve Measured Using NI SMUs with LabVIEW

FIGURE 3

NI offers PXI modules for generating and measuring signals, with chassis options featuring up to 18 slots.

Synchronizing Instruments

PXI and PXI Express chassis provide an internal timing and synchronization feature, so test engineers don't have to worry about connecting external devices or external cables to synchronize instruments. These chassis maintain a 10 MHz backplane clock, a PXI trigger bus, and a PXI star trigger signal (see Figure 4). PXI Express chassis also add a 100 MHz differential clock and differential star triggers to the backplane, enhancing noise immunity and delivering industry-leading synchronization accuracy, with module-to-module skew of 250 ps and 500 ps respectively. The timing and synchronization feature proves invaluable when synchronizing measurements, especially in scenarios like PMIC validation systems that require measurements between multiple instruments, including power supplies, e-loads, source measurement units (SMUs), oscilloscopes, and FGENs.

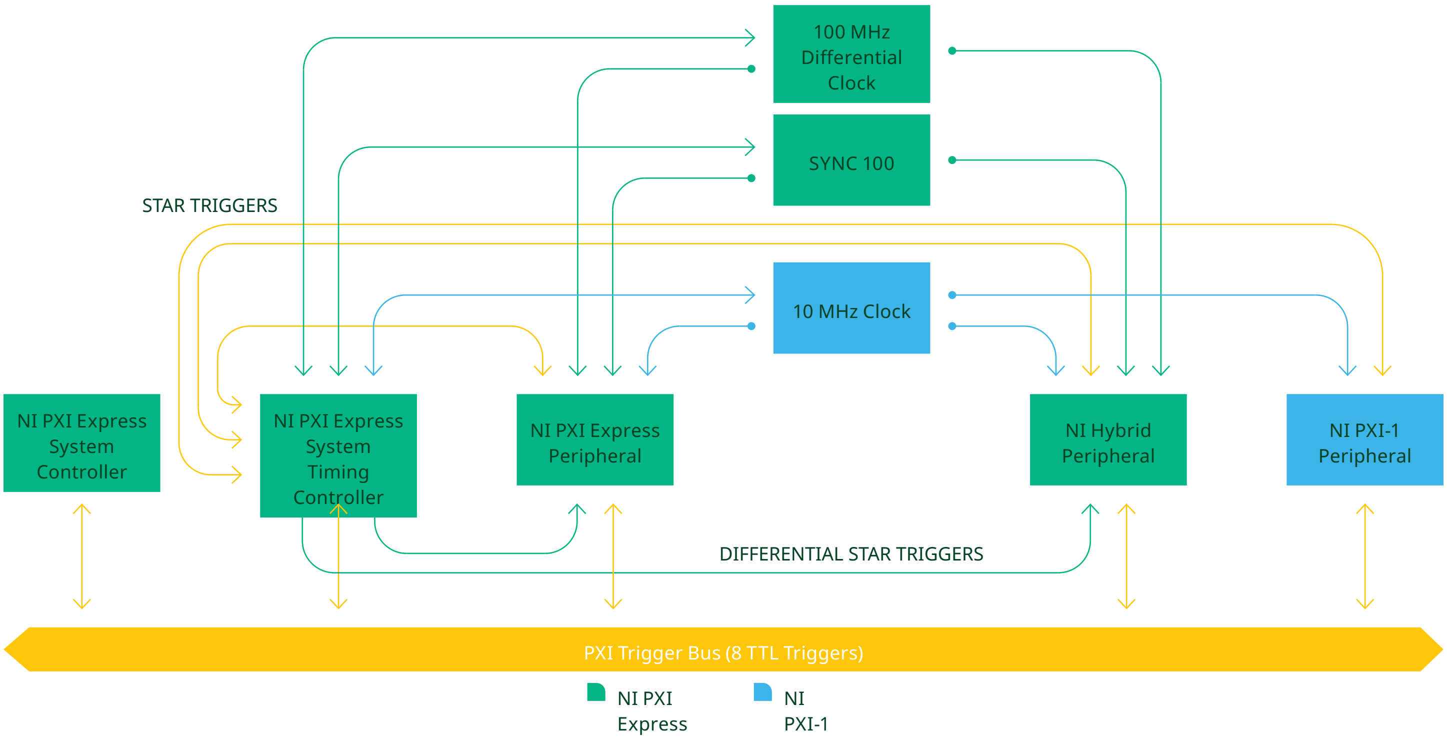

FIGURE 4

PXI Chassis Timing and Synchronization Features

Collecting a Large Amount of Data and Optimizing Measurement Efficiency and Test Time

Recently released NI PXI products incorporate PCI Gen3 technology, giving the NI PXI system the advantage of the largest data bandwidth, supporting speeds up to 24 GB/s and offering faster data latency compared to other communication protocols. This enables the rapid transmission of large data sets, such as oscilloscope raw data or screen captures. Not only can data be transmitted quickly, but the reduced data latency also enhances test efficiency in scenarios where repeated command execution is essential, like automated test or a mass production test.

Improving Data Management

New functionality within SystemLink provides a web-based tool designed for managing data ingestion and engineering analysis, ensuring specification compliance, and enhancing cross-team collaboration. Test engineers and design engineers can efficiently oversee and compare data from design tools, simulation tools, and measurement systems using SystemLink. Additionally, it can generate compliance reports, drawing attention to measurements that fall outside the specified parameters.

Next, we'll explore an example of a PMIC test setup that incorporates the NI PXI system and software features mentioned above.

PMIC Test Setup

Device under Test (DUT)

The device under test (DUT) used in this example is an evaluation board (EVB) DC1811B-B that features the LTM4676A buck-type regulator. It accepts a wide input voltage range of 4.5 V to 26.5 V and can provide a broad output voltage range from 0.5 V to 5.5 V at 13 A or single 26 A (see Figure 5A).

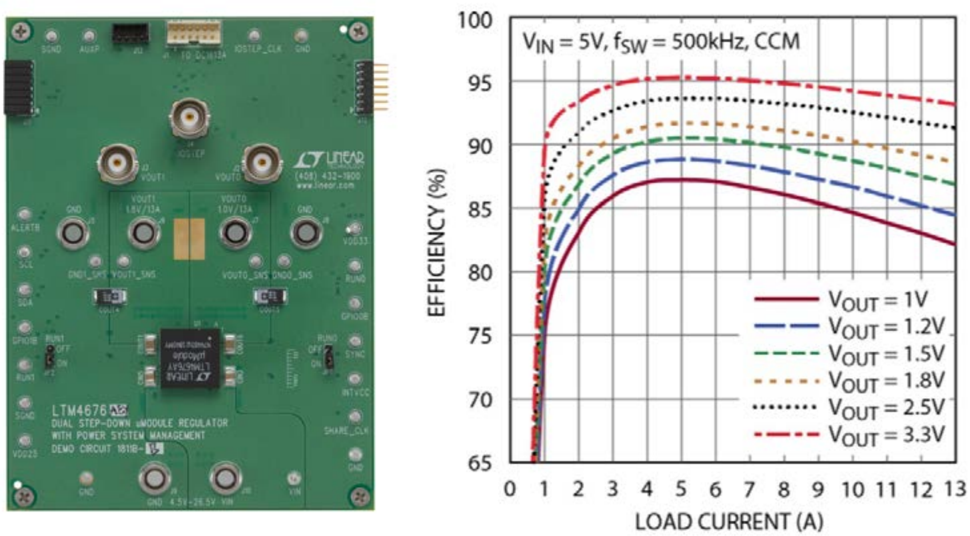

FIGURE 5

A) EVB (DC1811B-B) using LINEAR LTM4676A IC. B) Efficiency versus load current at V_{IN} = 5 V (DC1811B-B specification).

Connecting the DUT with Instruments

Figure 6 serves as an example demonstrating the measurement of the DUT's characteristics and illustrates the cable connections between the DUT and NI instruments. These instruments are used for supplying power to the DUT, controlling it with I2C, and sinking the current.

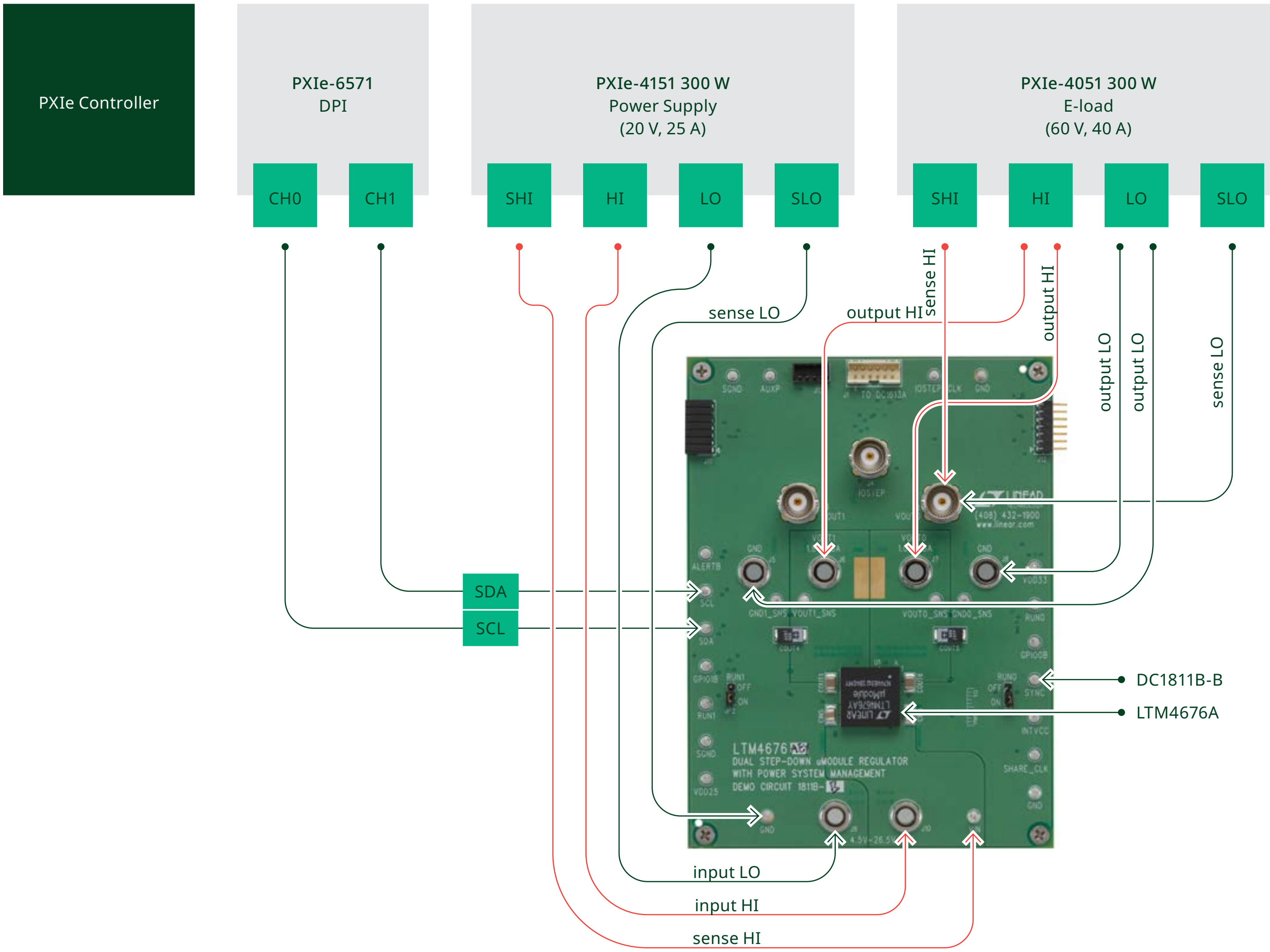

FIGURE 6

Wiring Diagram for Connecting Digital Pattern Instrument, Power Supply, and E-Load on DC1811B-B

Figure 7 illustrates an example of testing the DUT using the NI PXI system. In this scenario, the NI high-power supply (PXIe-4151) and a high-power e-load (PXIe-4051) are used to test the LTM4676A regulator. This regulator offers a broad input voltage range (4.5 V to 26.5 V) and a wide output voltage range (0.5 V to 5.5 V) with a maximum current capacity of 26 A. To establish communication with the regulator via I2C, the NI Digital Pattern Instrument (PXIe-6751) is used.

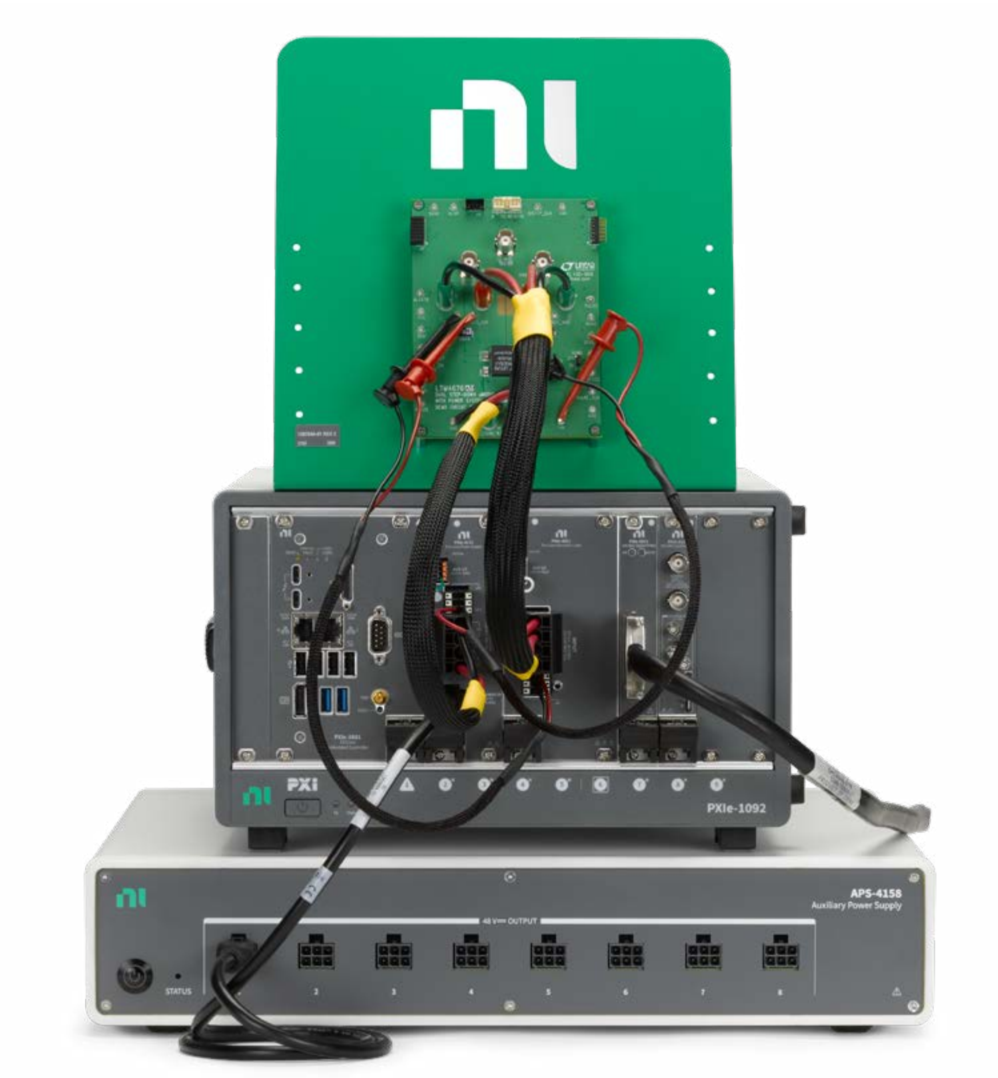

FIGURE 7

NI PXI system setup for testing the LTM4676A regulator. Includes PXIe-6571 Digital Pattern Instrument, PXIe-4151 300 W power supply, and PXIe-4051 300 W e-load with DC1811B-B.

Choosing the Test Equipment

Power Supply

NI offers several power supplies, including the PXIe-4151. This instrument is capable of responding to power density and efficiency improvements, such as those required for mobile fast charging and automotive vehicle electrification. It provides 300 W power output, with options like 20 V, 15 A, or 12 V, 25 A, all with DMM-like measurement accuracy. One of its notable features is the SourceAdapt function, which enables transient response tuning. This advantage is a key aspect of the NI SMU/Power Supply, as it can increase measurement speed and validation efficiency. This power supply can be seamlessly integrated with other NI modules using the PXI timing and synchronization technology and APIs or InstrumentStudio.

FIGURE 8

A) NI PXIe-4151 300 W power supply with auxiliary power supply. B) Quadrant diagram for PXIe-4151.

Electronic Load

The NI PXIe-4051 e-load is the first electronic load designed specifically for the PXI platform. It can sink up to 60 V and up to 40 A, offering 300 W of available load power capability with DMM-like measurement accuracy. This instrument also includes features like SourceAdapt and PXI timing and synchronization, as it shares the same underlying hardware and software technology with the NI SMU/Power Supply.

FIGURE 9

A) NI PXIe-4051 300 W e-load. B) Quadrant diagram for PXIe-4051.

SourceAdapt Technology

Using SourceAdapt technology, you can optimize the SMU, power supply, and e-load response for various loads, including those that are highly inductive or highly capacitive. This technology employs a digital control loop instead of a traditional analog control loop, so you can completely customize the transient response of the hardware. To learn more about SourceAdapt technology, follow this link.

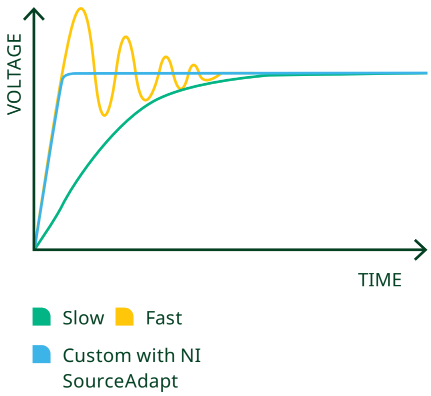

FIGURE 10

SourceAdapt technology enables customized responses for maximum stability and minimum rise times.

Digital Pattern Instrument

The PXIe-6571, a Digital Pattern Instrument with 100 MVector/s and 32 channels, is a versatile tool suitable for digital communication and protocol verification. It serves to automate efficient and repetitive testing, thus alleviating challenges for the test engineers.

Scope/FGEN

To characterize the AC parameters in PMIC tests, the NI PXI system can include both a scope and FGEN.

Instrument	Description
PXIe-4151	300 W power supply, 150 V CAT I isolation, 1.8 MS/s sample rate, and 100 kS/s update rate. Transient response tuning (SourceAdapt). Requires auxiliary power (via 2U box or power “brick”).
PXIe-4051	300 W electronic load, 150 V CAT I isolation, 1.8 MS/s sample rate, and 100 kS/s update rate. Transient response tuning (SourceAdapt). Programmable slew rate (CV, CC modes).
PXIe-6571	100 MVector/s 32 channels PXI Digital Pattern Instrument, 128 M vectors memory. Active Load (16 mA), PPMU (-2 V to 6 V, up to 32 mA).
PXIe-5433	2 channels, 800 MS/s, 80 MHz BW, 24 Vpk-pk arbitrary waveform generator (generating user-defined, arbitrary waveforms and standard functions including sine, square, triangle, and ramp).
PXIe-5162	4 channels 1.5 GHz bandwidth oscilloscope that samples at up to 5 GS/s with flexible settings for coupling, voltage range (up to 50 Vpk-pk), and filtering (20 MHz, 175 MHz, or full BW).

Measurement Parameters

When testing the PMIC, typical parameters of interest involve sourcing and measuring input voltage (V_{in}), measuring input current (I_{in}), measuring the output voltage (V_{out}), and sinking a load current (I_{out}). From these measured values, power efficiency can be determined. Other parameters include accuracy, line/load regulation, line/load transient, AC ripple voltage, PSRR, shutdown/quiescent/inrush current, Over Voltage Protection (OVP), and Over Current Protection (OCP).

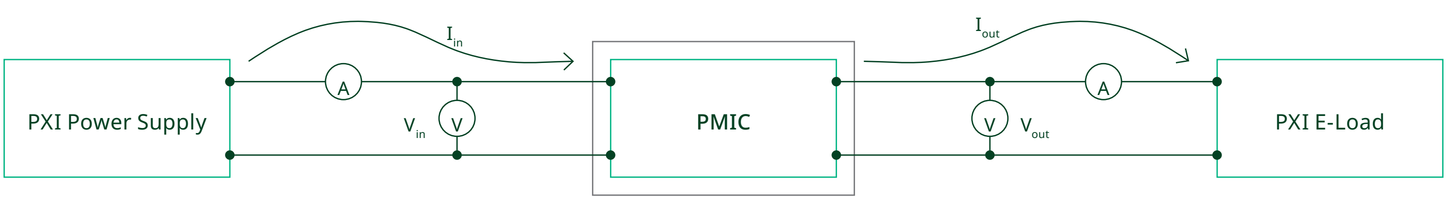

FIGURE 11

Simplified Diagram of the PMIC Test Setup

Power Efficiency

In most cases, a test setup for calculating power efficiency is connected between a power supply and an e-load in order to sink the PMIC's current. The setup then measures the voltage and current across the input (V_{in} and I_{in}) provided by the power supply and the output (V_{out} and I_{out}) measured by the e-load (see Figure 6/Figure 11).

Power efficiency represents the ratio of power consumed to power delivered and is typically expressed as a percentage: ($[V_{out} * I_{out}]/[V_{in} * I_{in}] * 100$). This metric holds significant importance in battery-powered products, particularly in cases such as mobile devices and EVs, where it directly affects the available execution time of the products.

Figure 6 depicts the wiring diagram using a channel of the PXIe-4151 (power supply)/PXIe-4051 (e-load) and using channels of the PXIe-6571. To test the typical parameters (power efficiency, load regulation, and load transient), the PXIe-4151 (power supply) is used to provide the input voltage and measure the input current, while the PXIe-4051 (e-load) functions as a load to sink output current and measure the current/voltage at the PMIC (LTM4676A) output. The channels of the PXI-6571 serve as clock and data channels for I2C communication, connected to pins on the EVB (DC1811B-B) to modify the configuration status of the PMIC.

A power efficiency versus load current curve illustrates how the efficiency of the PMIC varies as the load increases. A set of efficiency versus load curves can be displayed, with one curve for each input voltage. In the results graph in Figure 12, the PMIC was configured to generate a constant 3.3 V. The power efficiency was measured at four different input voltage values: 9 V, 12 V, 18 V, and 20 V. The PXIe-4051 was configured to sweep a load current from 0.1 to 24 A in 25 steps and measure the output voltage from the PMIC.

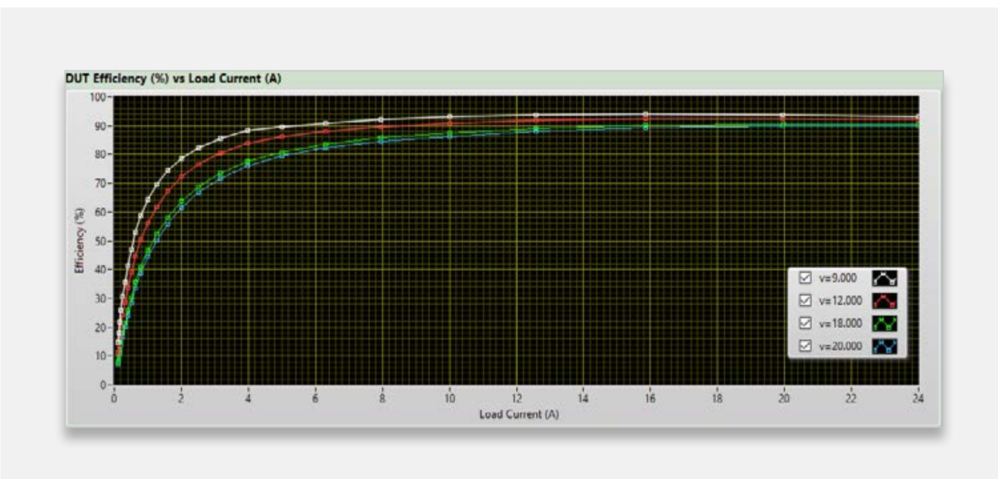

FIGURE 12

Results Graph of Power Efficiency at a Constant 3.3 V Output Voltage from the PMIC (LTM4676A)

Example: Test Procedure in NI Hardware

1. Set V_{in} at the specified level (9 V) from the PXIe-4151.
2. Set I_{out} at the desired starting level (0.1 A) from the PXIe-4051.
3. Sweep I_{out} to the desired ending level (24 A), recording V and I levels for the PMIC input and output with the PXIe-4051.
4. Repeat steps 1–3 for all desired V_{in} levels (9 V, 12 V, 18 V, and 20 V).

Load Regulation

A load regulation test measures a PMIC's ability to maintain an output voltage when the load current is swept from its minimum and maximum rated values. During this test, the input voltage (V_{in}) from the PXIe-4151 remains steady, typically at its nominal voltage. The results of the load regulation are expressed in terms of mV/A or as a percentage. The measured output voltage changes should be within the range specified in the product's technical specification. It's important to note that the load regulation test requires the same connections as in the wiring diagram (Figure 6) used for the power efficiency test.

In Figure 6, the PXIe-4151 and PXIe-4051 are configured using a remote sense, or four-wire, connection (port name: Sense HI and Sense LO). This setup eliminates lead resistance that would otherwise affect measurement accuracy. The remote sense connection method works like so: one pair of test leads connects the source outputs (load inputs) between Input (Output) HI and Input (Output) LO, while a second set of leads measures the voltage drop across Sense HI and Sense LO. To ensure accurate measurements, the sense leads should be connected as close to the PMIC as possible to prevent lead resistance from affecting readings.

Figure 13 illustrates load regulation plots. Note that the output voltage of the PMIC was configured to a constant 3.3 V, and the channel of the PXIe-4051 was configured to sweep the load current from 0.1 mA to 24 A. This test was performed with four different input voltage conditions (9 V, 12 V, 18 V, and 20 V) using the PXIe-4151.

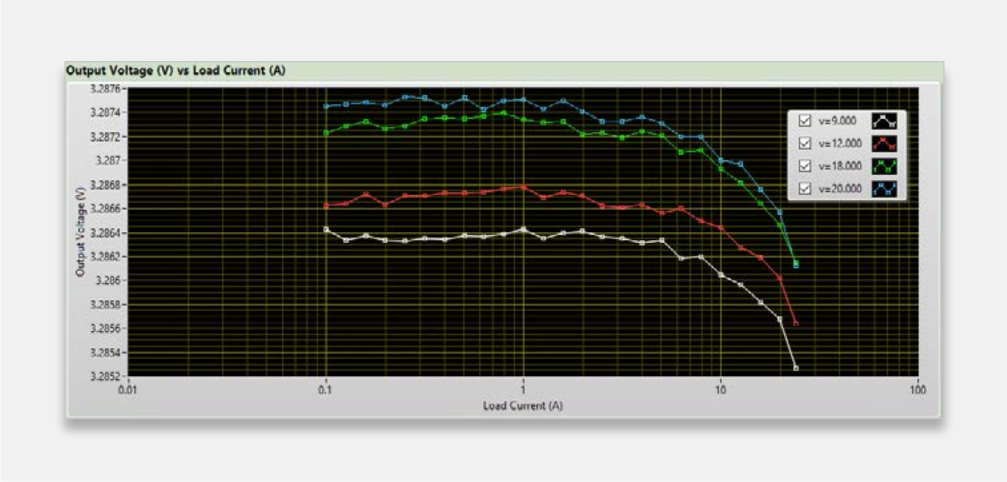

FIGURE 13

Results Graph of Output Voltage versus Load Current at a Constant 3.3 V Output Voltage from the PMIC (LTM4676A)

Example: Test Procedure in NI Hardware

1. Set V_{in} at the desired level (9 V) from the PXIe-4151.
2. Set I_{out} at the minimum level (0.1 A) from the PXIe-4051.
3. Sweep I_{out} to the maximum level (24 A), recording V and I levels for the PMIC output with the PXIe-4051.
4. Repeat steps 1–3 for all desired V_{in} levels (9 V, 12 V, 18 V, and 20 V).

Load Transient

A load transient test measures the time it takes for the output voltage of the PMIC to settle to the specified accuracy range after the output current load changes. This test may be the simplest diagnostic tool available for accessing the performance of a voltage regulator on the PMIC.

Although it's easy to hold the output voltage constant while the load current changes slowly, sudden leaps in load current can force the output voltage to fluctuate. To analyze this rapid change in current and voltage, an external oscilloscope is used. However, the fast sampling rate of the PXIe-4051 allows you to capture load transients without an oscilloscope. Traditional SMUs cannot capture these transient responses, but the PXIe-4051 (e-load) and PXIe-4151 (power supply) can capture responses at a maximum rate of 1.8 MS/s for voltage and current simultaneously, with a maximum update rate of 100 kS/s.

Figure 14 depicts the output voltage of the PMIC and the load current from the PXIe-4051 when the load current leaps from 1 A to 20 A and from 20 A to 1 A. These measurements were conducted by the PXIe-4051.

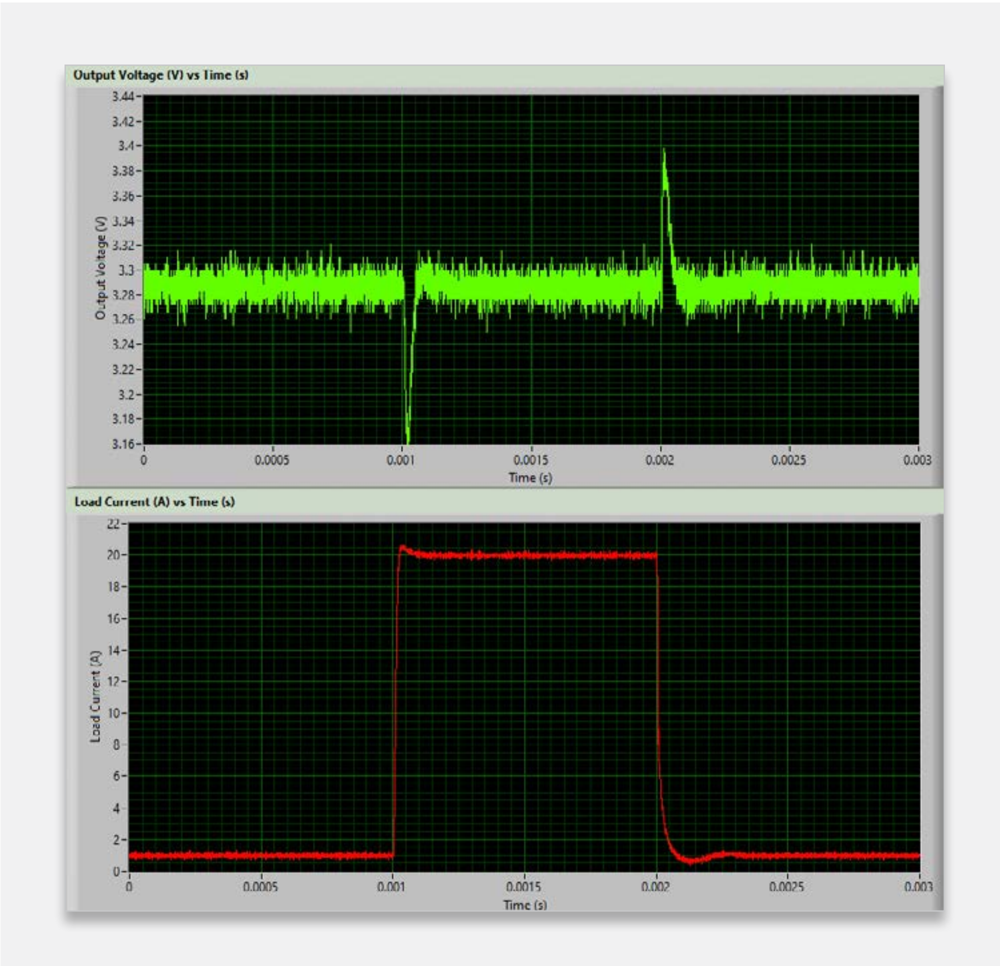

FIGURE 14

Response Graphs of Output Voltage and Load Current Measured by the PXIe-4051

Example Test Procedure in NI Hardware

1. Set V_{in} to the desired level (12 V) from the PXIe-4151.
2. Set I_{out} to the desired level (1 A) from the PXIe-4051.
3. Change I_{out} to a new level (20 A), recording the response on V_{out} and I_{out} with the PXIe-4051.

Example PXI Configuration for Multichannel PMIC

To characterize the performance of a multichannel PMIC, a test engineer can connect the NI PXI SMU/Power Supply(s) and NI PXI SMU/E-Load(s) as the same power source(s) and e-load(s) used in the one-channel PMIC discussed earlier. Additionally, the PXIe-6571 serves as an essential piece of digital communication hardware for repetitive configuration changes in multichannel PMICs.

Similar to the previous example, this setup uses NI hardware (NI SMU/Power Supply/E-Load/6571) to source and measure input voltage (V_{in}), measure input current (I_{in}), measure output voltage (V_{out}), and sink a load current (I_{out}). These measurements are crucial for calculating values related to line/load regulation, efficiency, accuracy, and quiescent/shutdown current.

In addition to characterizing the performance of the multichannel PMIC with this hardware, test engineers can assess AC parameters required of the PMIC using the NI FGEN/Oscilloscope. Tests incorporating the NI FGEN/Oscilloscope and this hardware, which are used to evaluate AC parameters, include line/load transient, PSRR, noise, OVP, OCP, and startup/shutdown sequence.

Figure 15 illustrates a typical test configuration. It shows how the NI instruments are connected to the DUT for measuring multichannel PMIC performance.

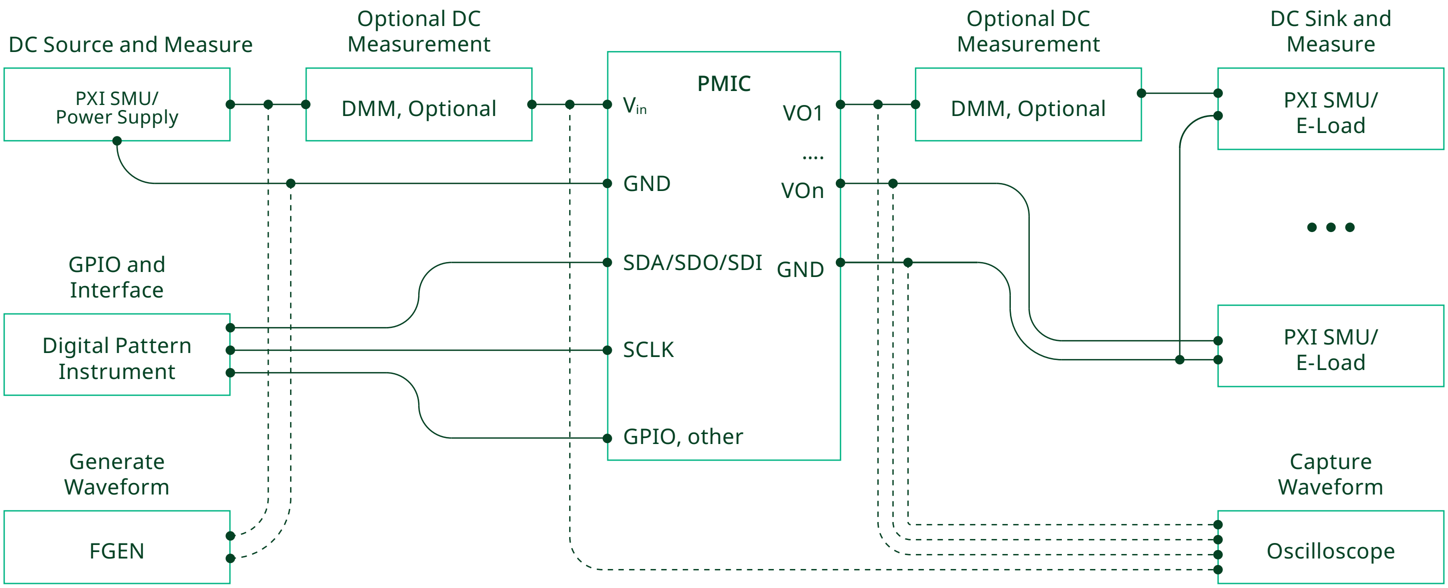

FIGURE 15

Example PXI Configuration for Multichannel PMIC

Conclusion

When testing PMICs, the NI PXI system helps test engineers easily collect a large amount of data, synchronize instruments, automate thousands of tests, optimize test time, and reduce the capital costs associated with validation systems. The NI PXI system can encompass power supply (for example, the PXIe-4151 300 W power supply), e-load (for example, the PXIe-4051 300 W e-load), digital communication hardware (for example, the PXIe-6571 100 MVector/s Digital Pattern Instrument), oscilloscope (for example, the PXIe-5162 5 GS/s Scope), FGEN (PXIe-5433 800 MS/s), and more instruments.

The NI hardware presented in this application note is characterized by its flexibility in power management, load handling, measurement accuracy, precise timing and synchronization, large data bandwidth, low data latency, and various digital communication capabilities. This complete setup for testing PMICs equips test engineers with what they need to address a wide variety of conditions with LabVIEW examples or InstrumentStudio and solve their specific measurement challenges.