Tools, Test and Measurement | Volume 35

We get technical

The acute need for software automation in modern test labs

Debug with the confidence of 12-bit waveform visibility

Handheld digital multimeters for modern industrial troubleshooting

How to speed system design, validation, and production test using modular instruments and software

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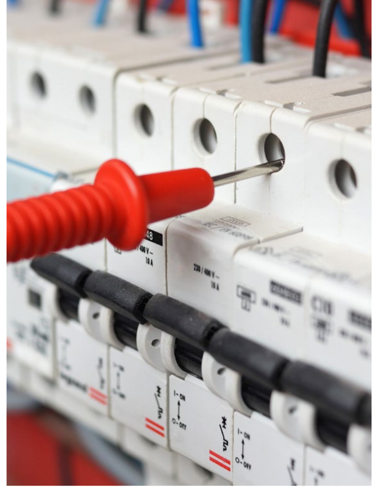

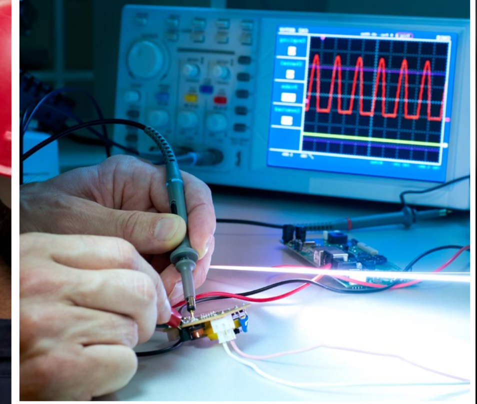

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Editor's note

Welcome to the DigiKey eMagazine Volume 35 – Tools, Test and Measurement.

In an era where precision, speed, and adaptability define success in engineering and test environments, this issue brings together insights that reflect the evolving demands of modern electronics development and infrastructure.

We begin with contributions from industry leaders who are shaping the tools and methodologies engineers rely on every day. B&K Precision explores the continued relevance and innovation in handheld digital multimeters—essential instruments that remain foundational even as systems grow more complex. Teledyne GmbH examines the advantages of 12-bit high-definition oscilloscopes over traditional 8-bit architectures, highlighting how increased resolution is enabling deeper visibility into signal behavior. Meanwhile, NI addresses a pressing industry shift: the acute need for software-driven automation in modern test labs, where efficiency and scalability are no longer optional.

Complementing these perspectives are a series of technical features that tackle both persistent challenges and emerging solutions. From the nuanced difficulties of detecting high-impedance ground faults and the limitations of conventional GFDI approaches, to safer and more efficient thermal inspection practices using IR windows, this issue underscores the importance of both innovation and safety. We also look at how modular instruments and software platforms are accelerating system design, validation, and production testing, offering pathways to reduced time-to-market. Finally, as edge computing continues to expand, we present a practical framework for wall-mount rack enclosures, addressing deployment realities in distributed environments.

Together, these articles provide a snapshot of an industry in transition—where hardware advancements, software integration, and system-level thinking are converging. We hope this collection not only informs but also inspires new ways of addressing the challenges you face.

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Source: NI

The acute need for software automation in modern test labs

It was not that long ago that a pair of headphones mainly consisted of two speakers and a wire. Then came the addition of a battery and wireless radio. Then microphones too, new controls, noise canceling, significant onboard processing and more... People now walk around with quite powerful computers in our ears, and consumers expect them to be lite-weight, reliable, powerful and affordable!

It's a tall order for any design engineering team to match the pace of innovation expected in a competitive market. But it's arguably tougher for the test engineer as these groups rarely get the same level of project time or resource investment as their Research and Development counterparts. Validation (and manufacturing) groups across industry are feeling increasingly stretched as the gap between their capacity and their project requirements is growing. This is forcing test leaders to accept they must change their methodology or risk product failure or market slowness.

One big change in methodology is the widespread adoption of greater software automation across validation labs in almost every test they do. This is for three main reasons.

1. ***Test coverage:*** Conducting larger sweeps of test cases and vectors provide a more complete characterization and understating of a device under test (DUT). This leaves less room for errors in identifying potential faults. This level of testing would take forever with a manual or semi-automated set-up, software orchestration allows for much higher test coverage in much less time.

2. ***Repeatability:*** There is nothing more frustrating than repeating a test and finding a different result due to variances in test set-up rather than DUT behavior. Centralized software automation of the instrumentation provides the ability to save a complete lab set up, so that in the future there can be a toggle between complex test configurations involving multiple instruments at the click of a button.

3. ***Data access:*** Measurement data has been recognized as a new source of value for many product companies to derive wider product and operational performance trends – but it has no value if it never gets beyond the instrument. Software automation architectures that use modular instruments require the engineer to have immediate access to the measurements needed – while simultaneously streaming large contextual data sets into centralized storage for use by other people and artificial intelligence (AI) models.

New technology is democratizing software automation

The traditional challenge to software automation has been the high barrier to entry in writing the custom code required for each unique measurement that engineers may want. However, this is changing, first because of more complete application software that provides configuration-based workflows for complex measurements and second because generative AI mixed with graphical coding paradigms have lowered the barrier to entry for many engineers.

Application Software: What's faster than vibe-coding an application – using an application that already exists! Millions of hours of development have collectively been put into engineering tools for test and measurement applications. Take National Instruments (NI) InstrumentStudio the companion software to PXI that is used to configure and visualize measurements. When referencing multiple oscilloscopes such as the NI PXIe-5108 within a single chassis they automatically synchronize so they can be treated as though they were a single, high channel count instrument. The software infrastructure works in the driver to enable this is entirely abstracted from the user. To unnecessarily recreate this wheel every time degrades standardization benefits and introduces both time and risk.

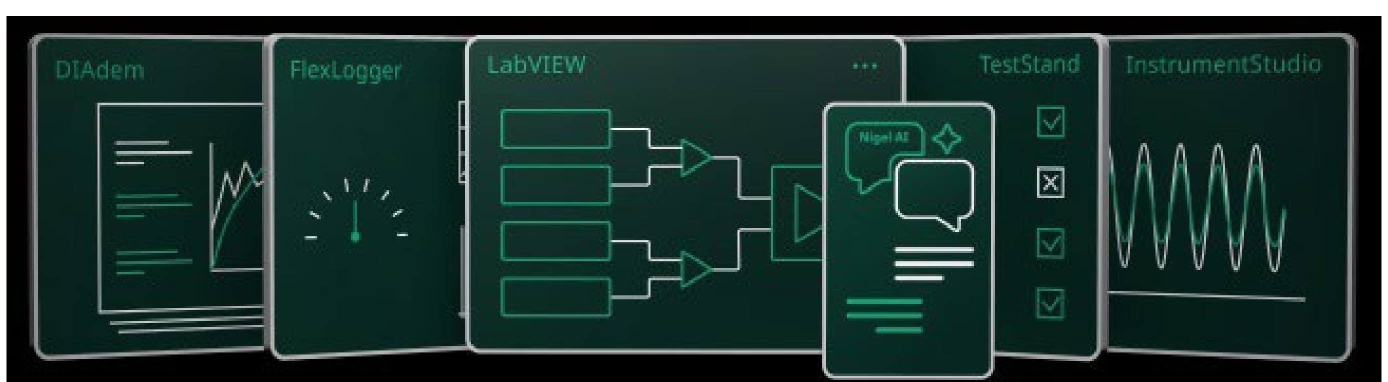
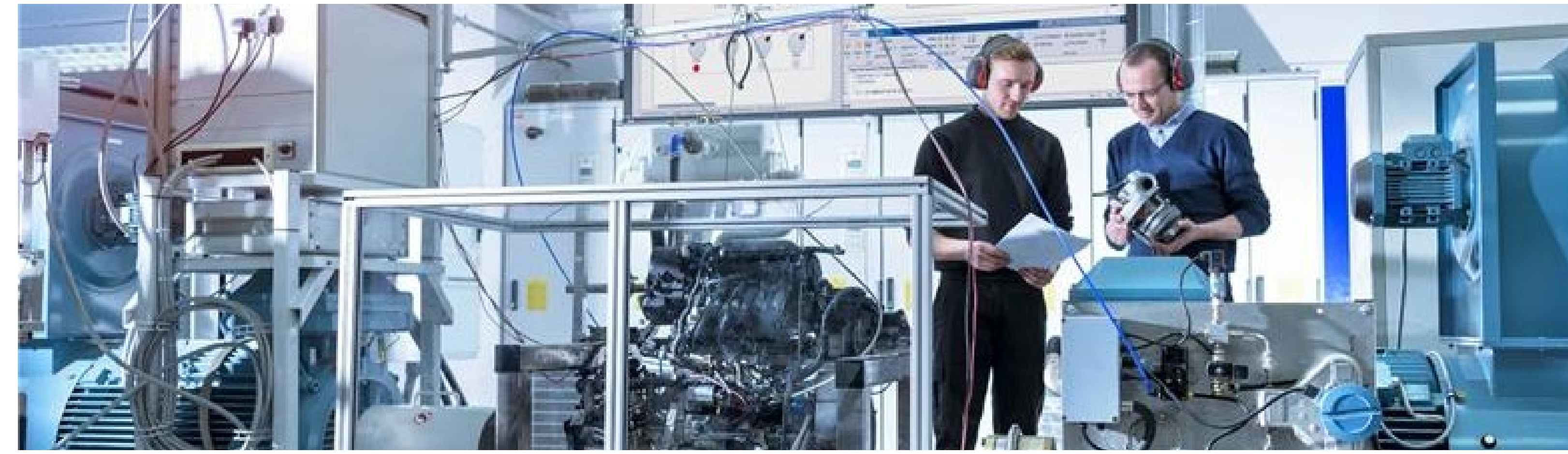


Figure 1: NI LabVIEW+ Suite: 788509-35
Source: NI

Source: NI



As the user considers the workflow of tasks that together represent the role of a test engineer, more and more of them have application software targeted specifically to solve each problem (Figure 1). NI TestStand is the world's leading test management and sequencing tool. NI DIAdem has established itself as the go-to for data analysis and report generation for large data-sets. While NI SystemLink delivers remote management capabilities, saving teams from writing and maintaining web-based monitoring tools. Every time engineers opt for a test optimized tool rather than creating something new, or compromising with a generic alternative, they squeeze a little more productivity out of their already packed schedule.

Generative AI and Graphical Coding Paradigms: What's faster than writing an application: writing an application with the assistance of generative AI. However, as far as this technology promises a lot, it also should be used with caution due to the risk and quality issues it can introduce.

When code is generated (human or AI), the designer is still accountable for the correct operation and stability of it. That includes verifying measurements, identifying edge cases, and ensuring that results can be trusted. If an issue is missed, the consequences are tied to the outcome of the test, not the tool used to create it.

Measurement applications contain some unique properties that differentiate them from software development in other industries such as web, database or financial applications. The big difference is that they interact with the real world – streaming large quantities of mixed signal data into a program creates needs for parallelism, time domain knowledge and often varied hardware target deployment, event interruptions and an operator UI.

Tools that make behavior visible—showing how data flows, how processes interact, and how code is deployed—make it easier to understand and validate those systems.

Graphical code is not inherently easier to understand for every type of application – but it does make measurement application development more straightforward, as it represents the operation of these systems really well.

The distinction is similar to how circuits are approached. A circuit can be represented as a netlist, a complete description of components and connections, but when diagnosing behavior, engineers rely on schematics because they make relationships and dependencies visible. The choice of a development environment is not just for accurate representation, but for effective understanding too.

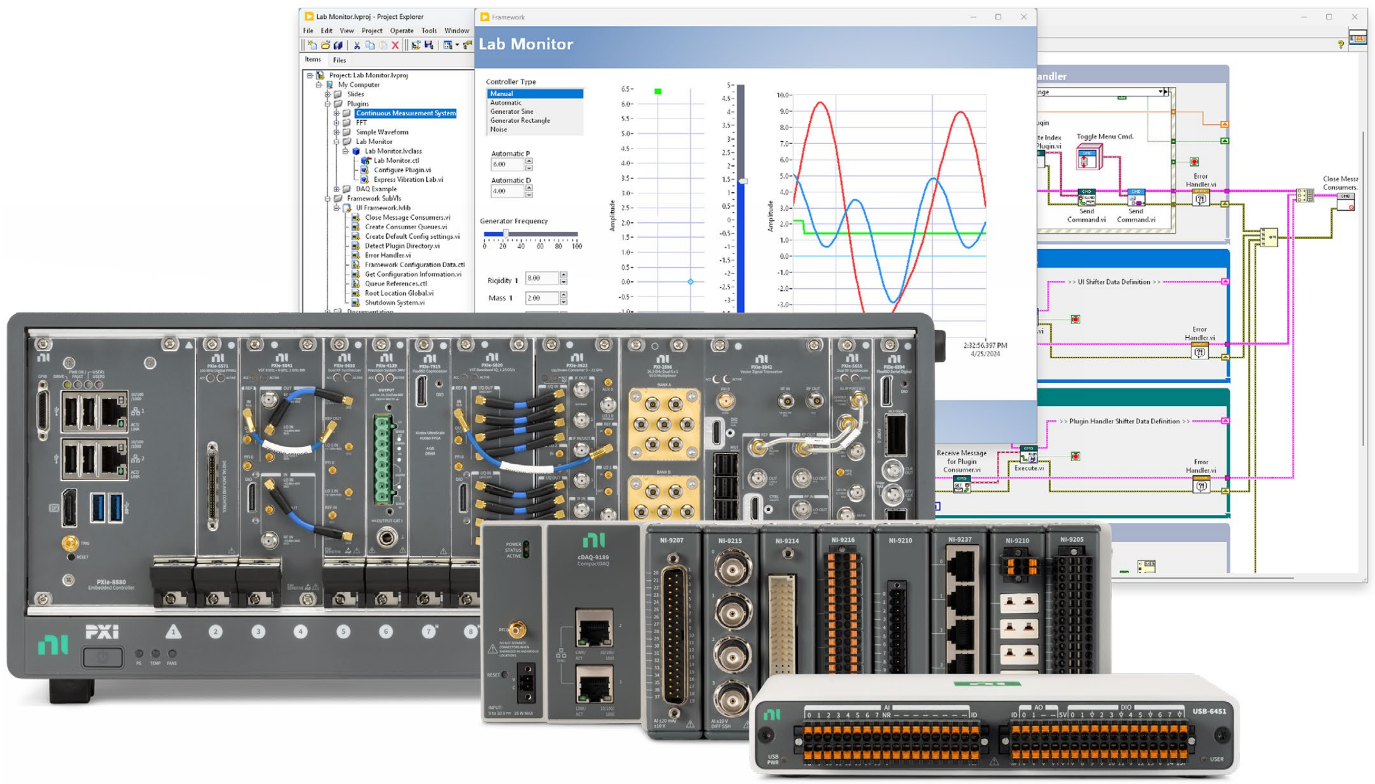


Figure 2: Transform Test Systems with NI's Open, Flexible Platform: NI PXI & NI CompactDAQ.
Source: NI

LabVIEW applies the same principle to test systems. It provides a visual model that makes parallel processes explicit, allowing engineers to trace data flow and identify issues as they occur rather than stepping through execution sequentially. The user can easily visualize the operation of two or more processes which have important dependencies on each other.

Generative code generation will come to LabVIEW in the Summer of 2026 through the latest release of Nigel AI. But more than this, LabVIEW has always been an open environment, and so the answer to tool choice lies in combining tools rather than separating them.

Using a language/AI tool of choice to vibe code tasks, algorithms or processes that do not have complexities related to measurement applications could accelerate development as long as the code made is trusted. This is similar to how in LabVIEW engineers have always imported or referenced IP using DLLs or native integration nodes. Then by integrating this into the LabVIEW environment, the benefits of application structure, hardware/data interaction, UI, target deployment, etc. can be enjoyed. This is a "best of both worlds scenario".

Test engineering is greater task than code generation

The scope of what test engineers are responsible for has outgrown any single development environment. Today, the LabVIEW+ Suite provides tools that span planning, simulation, bring-up, development, de-bugging, data visualization and more. As the expectation on test professionals grows, they need dedicated tools that allow them to work at higher levels of abstraction across more of the tasks they face.

Here, AI plays an even greater role in driving productivity for the individual. This could be in test plan generation, asset management, process optimization, data management, root cause analysis or one of any number of important tasks involved with cradle-to-grave test system design. To be effective, the AI tool used must understand the whole system, have contextual awareness between tasks, have good understanding of test methodology best practice, and maintain checks that "keep an engineer in the loop".

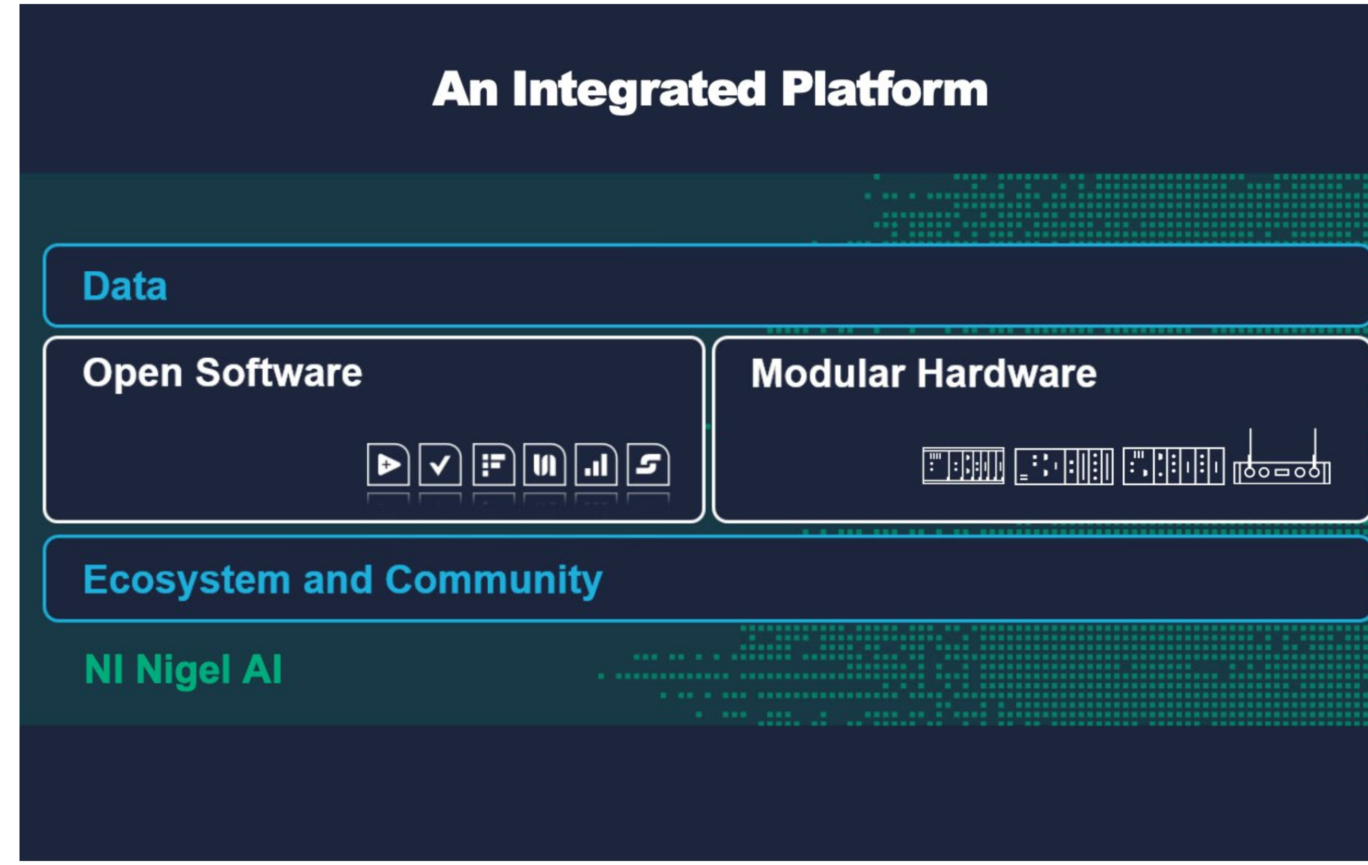


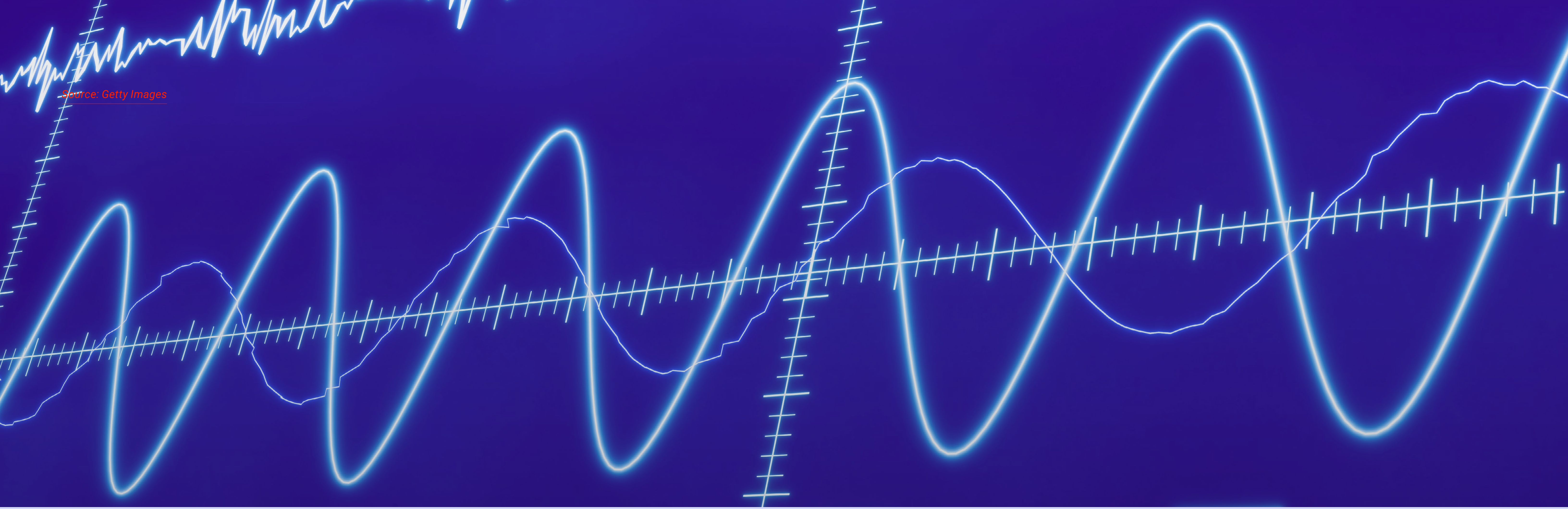
Figure 3: Nigel AI serves as a bridge between NI's other testing platforms.
Source: NI

Tools such as NI TestStand, NI FlexLogger, and NI InstrumentStudio address different parts of the workflow, but engineers move between them without losing contextual awareness of the task they are working on. The boundaries between these tools will continue to blur with Nigel AI acting as a bridge between the unique functionality they offer.

The move from a user orchestrated workflow to an AI orchestrated workflow (Figures 2 and 3) has greater potential to drive productivity in test engineering than over-optimizing test IP development by language.

Summary

Hardware choice is essential to being ready for an AI enabled test world. Combining testing tools to aid in AI code generation will increase productivity, functionality, and many other system tasks. For more information on the future of software testing, read How Software is Defining the Future of Test: A Q&A with Rudy Sengupta from NI.



Source: Getty Images

Debug with the confidence of 12-bit waveform visibility

By Abhishek Jadhav

TELEDYNE LECROY

Modern electronic systems are difficult to debug because the most critical signal behavior is hidden within the waveform. A power rail that appears stable may still contain ripple or short transients. A switching waveform that looks correct at full scale, can have small disturbances that may reveal instability or timing problems. For engineers working on power supplies, motor drives, and high-speed interfaces, the oscilloscope must show the fine details of the waveform.

Traditional 8-bit oscilloscopes divide the vertical range into 256 discrete levels. That has been sufficient for many general-purpose debug tasks, but it limits how much low-amplitude signal detail can be resolved when a waveform contains both large and small components. Engineers often work around this limitation by zooming in, changing vertical scale, averaging, filtering, or taking multiple acquisitions. Those techniques can help, but they may also slow down the debug process.

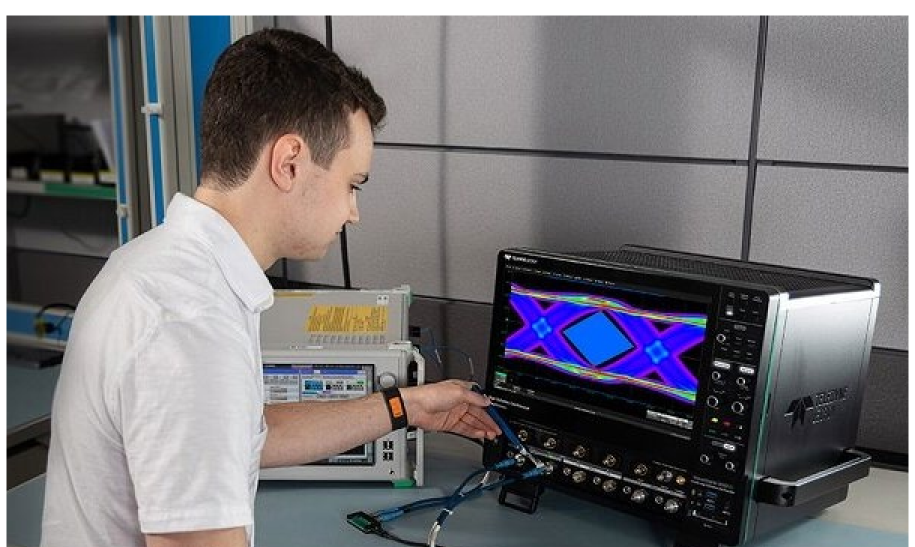
A 12-bit high-definition oscilloscope changes that trade-off by dividing the same vertical range into 4096 levels. This gives engineers finer visibility into small signal variations riding on larger waveforms. It makes it easier to analyze ripple, noise, transients, modulation effects, sensor outputs, power integrity behavior, and marginal digital signals. Teledyne LeCroy's 12-bit oscilloscope portfolio builds on this advantage that combines high vertical resolution, low-noise acquisition, mixed-signal capability, protocol tools, and power analysis options across different performance requirements.

Why 12-bit resolution is better

The vertical resolution of a digital oscilloscope determines how finely it can represent changes in signal amplitude. An 8-bit oscilloscope divides the selected vertical range into 256 discrete levels, while a 12-bit oscilloscope divides the same range into 4096 levels. This gives a 12-bit oscilloscope 16 times finer vertical resolution than an 8-bit oscilloscope on the same voltage scale.

This difference is crucial when small signal details appear inside a much larger waveform. For example, if an oscilloscope is set to 100 mV/div across eight vertical divisions, the full vertical range is 800 mV. With this setup on an 8-bit oscilloscope, each quantization step is about 3.1 mV, while on a 12-bit oscilloscope, each step is about 195 μV. The 12-bit oscilloscope can therefore show much smaller amplitude changes before they are lost in the digital waveform.

In debugging, this can help engineers see ripple on a power rail, ringing on a switching edge, small current-sense variations, or low-level noise that may be difficult to distinguish on an 8-bit oscilloscope. Higher vertical resolution does not replace bandwidth, sample rate, probing technique, or low-noise front-end design, but it gives the acquisition system more detail to work with.



Source: Teledyne Lecroy

Why bit depth alone is not enough

In ADC design, higher bit depth and higher sampling rate have been difficult to achieve together, which is why high-resolution acquisition has been associated with lower-bandwidth or software-enhanced resolution modes. In those modes, an 8-bit oscilloscope samples the signal and then applies digital filtering, averaging, or finite-impulse-response processing to reduce noise and improve vertical resolution. These techniques can be useful, but they involve a bandwidth tradeoff.

Teledyne LeCroy's HD4096 addresses this problem through a hardware-based high-definition acquisition path. HD4096 combines 12-bit ADC conversion, high signal-to-noise input amplifiers, and a low-noise system architecture. The goal is to maintain fine vertical resolution at the rated bandwidth and sample rate to allow technicians to use 12-bit resolution during real-time debug rather than only in bandwidth-reduced processing mode.

For instance, Teledyne LeCroy's WaveSurfer 4000HD and HDO4000A are two families built around the HD4096 architecture. The company still offers software-based enhanced resolution (ERES) on top of this hardware architecture. Digital filtering can further improve resolution when the application can tolerate the associated bandwidth reduction. This is useful for slower or single-shot events.

Scalable 12-bit platforms for different debug workflows

Teledyne LeCroy's 12-bit oscilloscope platforms are designed to meet different performance requirements. The WaveSurfer 4000HD and HDO4000A provide the HD4096-based environment with MAUI/OneTouch operation, large touch displays, four analog channels, mixed-signal options, serial decode, and power-analysis options.

Figure 1: Teledyne LeCroy WaveSurfer 4024HD at 200 MHz bench and four analog channels. Source: Teledyne Lecroy

The Teledyne Test Tools include T3DSO700HD, T3DSO1000HD, T3DSO2000HD, and T3DSO3000HD families that bring 12-bit acquisition to more accessible bench configurations, with varying trade-offs in bandwidth, memory depth, capture rate, and built-in analysis capabilities.

WaveSurfer 4000HD is the most accessible platform for engineers who want HD4096 acquisition in a four-channel lab oscilloscope. The family includes the WaveSurfer 4024HD at 200 MHz, 4034HD at 350 MHz, 4054HD at 500 MHz, and 4104HD at 1 GHz.

All four models provide native 12-bit vertical resolution, an optional 16-channel mixed-signal digital pod, and a 12.1-inch capacitive touch display. The series supports up to 5 GS/s when using two channels and 2.5 GS/s with all four channels active, with standard memory of 12.5 Mpts per channel and up to 25 Mpts in interleaved mode.

HDO4000A occupies the same 200 MHz to 1 GHz bandwidth class but with more features. It adds higher sample-rate capability, more memory options, compact bench depth, large offset capability, mixed-signal variants, zone triggering, and a broader analysis environment.

Other 12-bit platforms from Teledyne LeCroy include the T3DSO700HD and T3DSO1000HD, which can be used for everyday embedded debug, service benches, sensor interfaces, and basic serial communication validation. The T3DSO2000HD and T3DSO3000HD scale the T3 line into higher-performance applications.

The T3DSO3000HD is the most capable T3 HD series platform, with four channels, 12-bit vertical resolution, bandwidth options from 200 MHz to 1 GHz, up to 4 GS/s sample rate in interleaved mode, and up to 400 Mpts of acquisition memory per channel. This long memory makes it useful for long-record captures, intermittent event analysis, and protocol validation.

By moving from 256 to 4096 vertical levels, Teledyne LeCroy's 12-bit oscilloscope platforms help identify ripple, noise, and transient effects that can be difficult to contrast on an 8-bit instrument. The HD4096-based WaveSurfer 4000HD and HDO4000A families pair this resolution with low-noise acquisition and advanced analysis tools, while the T3DSO HD series extends 12-bit visibility across a range of bench configurations.

For more information, visit Teledyne LeCroy's 12-bit oscilloscopes.

Source: Getty Images

Handheld digital multimeters for modern industrial troubleshooting

By Abhishek Jadhav

BK PRECISION

Industrial electrical troubleshooting has become more demanding as facilities are increasingly equipped with electronic loads, solid-state controls, switch-mode power supplies, and variable-frequency drives. These systems often draw non-sinusoidal current waveforms, which make an average-responding multimeter inaccurate because it assumes a clean sine wave. Maintenance engineers need measurements that show the True RMS value of distorted waveforms rather than an ideal AC waveform.

Safety requirements have also changed. Measurements taken near the utility grid connection have lower source impedance, which exposes test instruments to transient overvoltages. At the same time, many industrial faults are intermittent. A loose connection, voltage sag, or contact drop may appear briefly or develop over hours. Diagnosing these problems requires more than a single instantaneous reading.

The B&K Precision 390B Series handheld digital multimeters are designed for professional electrical and industrial maintenance work. Across the family, the meters offer True RMS measurement, safety-related input protection, high-resolution dual displays, and connected data capture. The 394B extends the family into process control testing with current loop source, measurement, and simulation functions.

Measuring distorted waveforms

The 390B Series consists of four handheld True RMS digital multimeters: the 390B, 391B, 393B, and 394B. Across the family, the meters support core electrical measurement functions, such as DC voltage, AC voltage, AC+DC measurement, DC current, AC current, resistance, frequency, diode test, and continuity. The 390B, 391B, and 393B also support capacitance and temperature measurement with a K-type thermocouple, while the 394B adds process-multimeter functions for current-loop applications.

Figure 1: The B&K Precision 390B Series True RMS multimeter with up to 100,000-count, dual display.
Source: B&K Precision

The series supports broad AC and DC voltage measurements up to 1000 V, with CAT III 1000 V/CAT IV 600 V protection for use within the meter's specified measurement-category limits. The 390B, 391B, and 393B support DC and AC current measurements up to 10 A on the ampere input, subject to a duty limit of 1 minute on the ampere input followed by a 20-minute rest period. This makes the meter suitable for direct-current checks on low-current loads and control circuits, while higher-current motors may require an appropriate current-clamp accessory. When checking current draw, burden voltage is an important factor because the meter's internal shunt introduces a small voltage drop into the measured circuit. For 390B, 391B, and 393B, burden voltage is specified at 2 mV/mA on the milliampere inputs and 60 mV/A on the ampere input. The same inputs are specified with overload protection of AC/DC 400 mA at the mA inputs and AC/DC 10 A at the A input.

Monitoring resistance connections is a common maintenance task in electrical panels, terminal blocks, and control wiring. The 390B, 391B, and 393B provide resistance measurements up to 40 MΩ, while the 394B extends this range to 50 MΩ. For continuity testing, the 390B, 391B, and 393B provide an adjustable threshold between 10 Ω to 50 Ω with a buzzer response time of less than 10 ms for technicians to move quickly across dense wiring points.

Diode testing is supported with a 2 V range. For the 390B, 391B, and 393B, the diode-test function uses an open-circuit voltage of 2.5 V and a short-circuit current of 1 mA, while the 394B specifies a 2.000 V diode-test range with ±1 mA test current and a maximum open-circuit voltage of ±3.5 V.

The 390B, 391B, and 393B support capacitance measurement capability up to 40 mF. Frequency measurement up to 100 kHz supports checks on generators, control signals, sensors, and low-frequency drive outputs.

For temperature diagnostics, the 390B, 391B, and 393B support external K-type thermocouple measurement from -200°C to 1200°C. This allows maintenance engineers to correlate electrical measurements with the thermal characteristics of transformer windings or power components.

Source: B&K Precision

Resolution, accuracy, and what display count really means

A common point of confusion in test-and-measurement is the relationship between the display count, measurement resolution, and baseline accuracy.

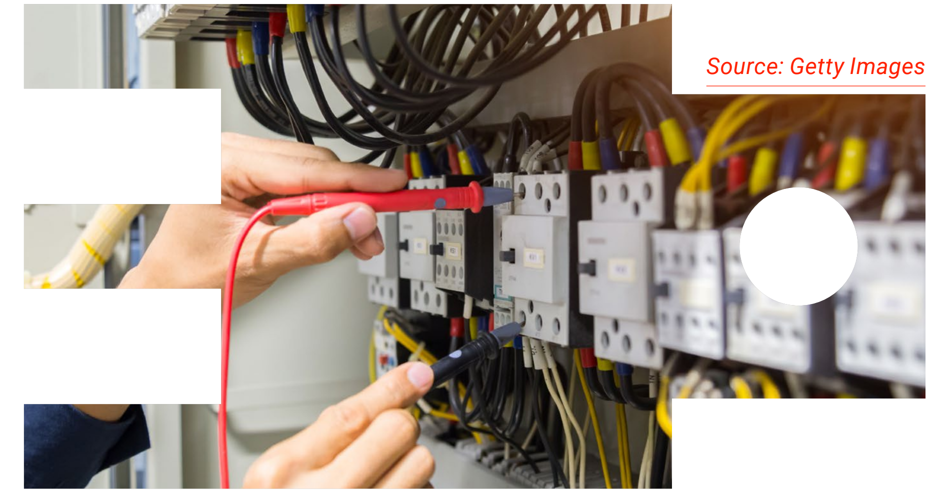
The 390B and 391B are 40,000-count instruments, the 393B is a 100,000-count instrument, and the 394B is a 50,000-count process multimeter. The higher count increases the number of distinct display increments available on a range. This improves visible resolution, allowing small changes to be seen without forcing a range change.

However, display count is not the same as accuracy. By definition, resolution is the smallest change the display can show, and accuracy defines how close the displayed value is expected to be to the actual value under specified conditions.

According to the 390B Series datasheet, accuracy is expressed as ± (% of reading + counts of the least significant digit) at 23°C ± 5°C, with relative humidity below 80% RH and a one-year calibration cycle. Outside the 18°C to 28°C range, the specified temperature coefficient adds 0.1 × the stated accuracy per °C.

This implies that a 100,000-count meter is not automatically more accurate than a 40,000-count meter in every situation. The higher-count display can make small deltas easier to see, but confidence in those deltas still depends on the selected range, the accuracy specification, ambient temperature, calibration status, and waveform frequency.

The addition of a dual-line display allows two measurements, or one measurement plus a math function, to appear simultaneously on the screen. This is important because it allows the field technician to monitor a primary electrical quantity while also viewing a related derived value or a secondary reading needed for interpretation.



Source: Getty Images

Diagnostics through Bluetooth and isolated USB

Data collection is critical for preventative maintenance programs. The 390B Series offers two primary data interfaces: wireless Bluetooth connectivity and an optically isolated USB port.

The model 390B comes with integrated Bluetooth connectivity for direct connection to the B&K Precision Link mobile application on compatible Android or iOS devices. This wireless link provides several advantages in field environments such as enhanced operator safety, remote, multi-point monitoring, and mobile data logging.

For long-term bench logging or field monitoring near sensitive computer equipment, all models in the 390B Series include a hardware-isolated USB interface. Standard USB cables establish a direct copper connection between the multimeter's input terminals and the computer's chassis ground. If a fault occurs while measuring a high-energy industrial circuit, high-voltage transients can travel down the USB. The 390B Series prevents this by using an optical isolation barrier.

The series supports various data logging configurations to capture intermittent faults, monitor system changes, and track startup behavior. Field technicians can configure the multimeter to record measurements directly to its internal non-volatile memory. The 390B can store up to 40,000 readings, while models 391B and 393B can store up to 20,000 readings.

Using the provided PC application software, technicians can log up to 100,000 data points (for 394B) in graphical or tabular format. The software can display logged data in real time to make it easy to identify trend shifts, voltage sags, or thermally induced drift over hours or days.

For technicians working in noisy, electrically dense environments, the B&K Precision 390B Series shows how a handheld multimeter can move beyond basic voltage, current, and resistance checks to support more complex industrial diagnostic work. By integrating True RMS measurement, high-resolution dual-display operation, and process-control functions across the product family, the series gives maintenance teams a broader view of what is happening within electrical and control systems.

To learn more, visit [B&K Precision 390B Series handheld digital multimeters.]

Video spotlight

HAMMOND

RCH equipment rack cabinets

A simple rack cabinet solution. Multi-use RCH series rack cabinets provide easy access to rack components and equipment. With a variety of size configurations, range of accessories, strong steel construction, and four adjustable depth EIA-compliant 19” rails, RCH series cabinets make a robust addition to server rooms, AV and IT applications, and more.

Learn more

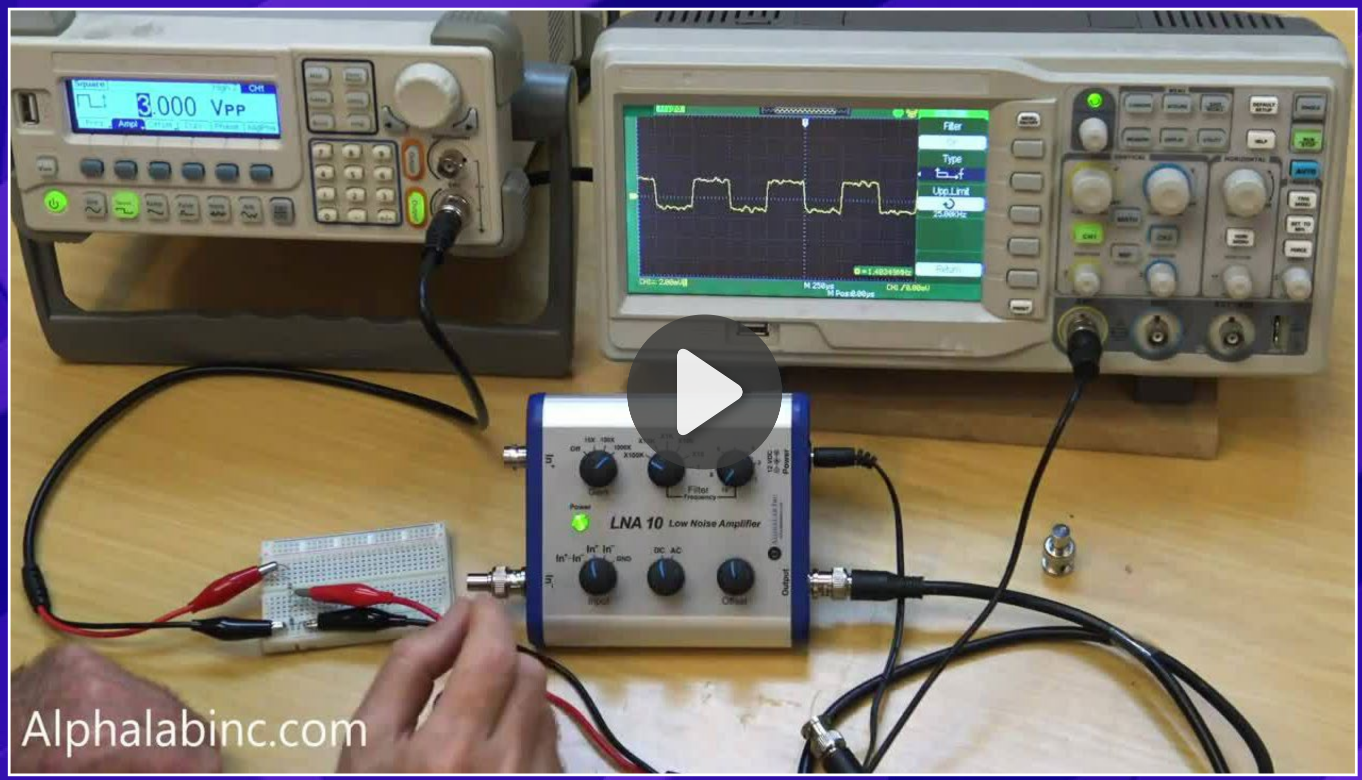
Pomona ELECTRONICS

Increase the functionality of your digital multimeter

Pomona partners with leading digital multimeter brands to deliver high-quality test leads and probes. Built with premium materials to meet rigorous standards, Pomona connects you from IC testing to distribution panels.

Learn more

Video spotlight



TELEDYNE FLIR

Flir C8 compact thermal camera

Flir C8 is a thermal imaging camera designed for electrical and mechanical maintenance, vehicle inspections, and other troubleshooting applications. Featuring 320 × 240 thermal resolution the C8 captures sharp thermal images for accurate diagnostics.

Learn more

AlphaLab Inc.

Significantly reduce oscilloscope noise with a low-cost low-noise differential probe

The AlphaLab, Inc. LNA-10 preamplifier enables sub-μV signals on oscilloscopes that only go down to 1mV/div on the vertical axis, featuring analog true differential input and low-pass filtering for better signal performance below 1MHz.

Learn more

TechForum

Process meter first steps: source vs. simulate mode in a 4-20 mA loop

By Aaron Dahlen, MSEE

A 4-20 mA process meter is used to troubleshoot, test, and calibrate analog devices. It may be configured to simulate a two-wire sensor or it can provide a controlled loop current to an actuator.

This brief presents two experiments to get you started with your process meter. It is focuses on the two modes associated with the 4-20 mA current loop including:

- Simulation mode: The process meter simulates a 4-20 mA sensor.
- User-selected current source mode: The meter provides a current as manually set by the user. Alternatively, the meter provides a current that automatically varies with time. The user can configure the meter to provide a smooth current sweep or a stairstep change.

Figure 1: Image of the process meter configured for transmitter mode simulating a sensor operating at 75% of span which corresponds to 16 mA.
Source: DigiKey

When does a process meter become essential?

The process meter moves from luxury to essential when system downtime exceeds the cost of the meter. Depending on the size and complexity of your facility, that's somewhere between 5 minutes and one hour of lost production. However, maintenance crews need to be trained to quickly configure the instrument and interpret the results. Hence this document. There is also an argument for saving time by testing and calibrating field devices either on the bench or locally in the installed equipment.

If you are looking for a rule of thumb, may I suggest the process meter becomes increasingly important in an industrial setting with between 10 and 20 analog sensors or actuators.

Required components

- Process meter such as the Fluke 789 shown in Figure 1
- Conventional multimeter
- 24 VDC power supply
- 1.5 kΩ 1/2 W (minimum) resistor

Experiment in sensor simulation mode

Configure the process meter experiment using familiar test equipment. Figure 1 shows a current loop including:

- 24 VDC power supply
- Process meter wired to simulate a 4-20 mA sensor
- Conventional meter set to measure current

The conventional meter stands in for the device that normally receives and processes the sensor's output such as a PLC or an industrial panel mount display. Without the current meter, we are missing a critical component that is present in every operational current loop. It also provides a measure of truth indicating that the current loop is active. For additional information, refer to this article which provides a brief introduction to analog scaling and I/O card configuration for a Siemens S7 PLC.

Adjusting the current

The user may adjust the loop current using the meter's arrow keys as shown in Figure 2. Alternatively, the meter may be configured to automatically change the loop current. There are settings for a smooth ramp up and down through the entire 4-20 mA range. The user can also command a stairstep with steps at 4, 8, 16, 20, and 25 mA. Consult the datasheet for additional settings such as configuring the meter for a 0-20 mA range.

Pushbutton	Adjustment
▲ RANGE COARSE	Adjusts up 0.1 mA
▲ MIN MAX FINE	Adjusts up 0.001 mA
FINE Hz ▼	Adjusts down 0.001 mA
COARSE REL Δ ▼	Adjusts down 0.1 mA

Figure 2: Manual adjustment to the loop current as shown in the Fluke 789 datasheet.
Source: Fluke Electronics

Tech tip: The process meter is not supplying energy while operating in simulation mode. Instead, it is acting as a two-wire transmitter allowing more or less current to pass through the loop. This is the same operation performed by a 4-20 mA sensor as it responds to its environment.

As a mental model, the meter behaves like a variable resistor adjustable from 6.0 kΩ to 1.2 kΩ corresponding to 4 to 20 mA. As a student, make sure you understand the Ohm's law relationship between the 24 VDC (nominal) supply and stated resistance.

In practice, the "variable resistor" is a pass transistor such as a BD139 (or SMD equivalent) tightly controlled by a dedicated 4-20 mA transmitter IC such as the Texas Instruments XTR116.

Next step for sensor simulation mode

In this experiment, the process meter simulates a sensor. The next step is to connect our simulated sensor to a real 4-20 mA receiver such as a PLC analog input module or an industrial display like the Red Lion PM-50.

Experiment in fixed source mode

The process meter is configured to source current.

- A 1.5 kΩ resistor serves as a load. This resistance was chosen to pull approximately 16 mA from a 24 VDC source.
- The Fluke 87 in Figure 3 is used to measure the voltage drop across the resistor.

Figure 3 reveals the cause and effect nature of the setup. The process meter is configured to supply 16.000 mA. In an ideal setting, we expect the voltmeter to display 24 VDC. However, the resistor is not precisely 1.5 kΩ. In fact, given the 5% tolerance, we can realistically expect a voltage reading between 22.8 and 25.2 VDC. I invite you to verify my calculations.

Continue the experiment by manually adjusting the loop current (Figure 2). Also explore the sweep functionality of the process meter.

Tech tip: A connection to a real-world device will reveal a minor technical point that is not addressed in this article. Specifically, the concept of a burden resistor. Up until now, the current is passing through the near zero impedance of the Fluke 87 meter's current measurement loop. By contrast, a PLC or an analog process meter will have a fixed input resistance. This is OEM- and equipment-specific, but is generally in the 100 Ω to 1.5 kΩ range.

The voltage developed across this burden resistor may be used during analog troubleshooting. For example, by measuring the voltage drop across a PLC's analog 4-20 mA input resistor, we can identify gross loop malfunctions such as short or open circuits.

Source: Fluke Electronics

Source: Getty Images

Next step for source mode

In this experiment, the meter is configured to simulate a PLC's 4-20 mA analog output. You are encouraged to use the process meter to drive an actuator. A representative example of a 4-20 mA field device is a proportional pressure regulator such as the [Festo VPPE-3-1-1/8-6-420-E1](#).

Figure 3: Process meter configured for source mode driving a 1.5 kΩ load resistor.
Source: DigiKey

Tech tip: Note that the resistor gets noticeably warm (see Figure 3). This is a clear indication that power is being supplied by the meter. It also explains this note from the Fluke 789 datasheet, "Source mode depletes the battery faster than simulate mode, so use simulate mode whenever possible."

Parting thoughts

Let's recap the functionality of a process meter:

- It can stand in for a sensor where it modulates a known user-adjustable current within the externally power loop. This is useful for troubleshooting or commissioning a system. For example, alarm and trip points can be quickly verified using the meter as opposed to swinging the real-world plant to those extremes.
- It can command an actuator via its 4-20 mA current output. The current-to-pressure regulator is a good example. With the meter connected directly to the regulator, you can quickly set the minimum and maximum pressure to match the desired 4-20 mA control signal.
- As a student, the process meter is a natural companion to PLC programming. It allows you to simulate field devices (sensors and actuators). The meter configuration and physical connection to the PLC analog module become part of the lesson plan.

As a final thought, be sure you can explain the difference between setting the current in simulate vs setting the current source mode. Remember that the terms "setting" has two very different meanings.

Related Information

Please follow these links to related and useful information:

[DigiKey's Field Guide to Industrial Automation and Control](#)

Source: Fluke Electronics

Detecting high-impedance ground faults: limitations of standard GFDI and active diagnostic solutions

By Rakesh Kumar, Ph.D.

In solar operations and maintenance (O&M), inverter status indicators are a primary metric for system health. However, a normal operation status does not necessarily indicate a fault-free system. Standard inverter ground fault detection interruption (GFDI) devices have detection thresholds designed to prevent nuisance tripping. Consequently, leakage currents that fall below these thresholds may go undetected.

While these currents are often insufficient to trigger a shutdown, they can cause long-term insulation degradation and equipment damage. This article examines the technical limitations of standard GFDI, the physics of high-impedance faults, and the practical challenges of locating them in 1500 V arrays. It will explore the transition from invasive troubleshooting to non-contact active diagnostics, detailing how signal injection technology identifies hidden faults to improve operational efficiency and asset longevity.

The limitations of the standard GFDI

Standard ground fault protection typically employs one of two methods: fuse-based detection (common in transformer-based central inverters) or residual current detectors (RCDs) (common in transformer-less string inverters).

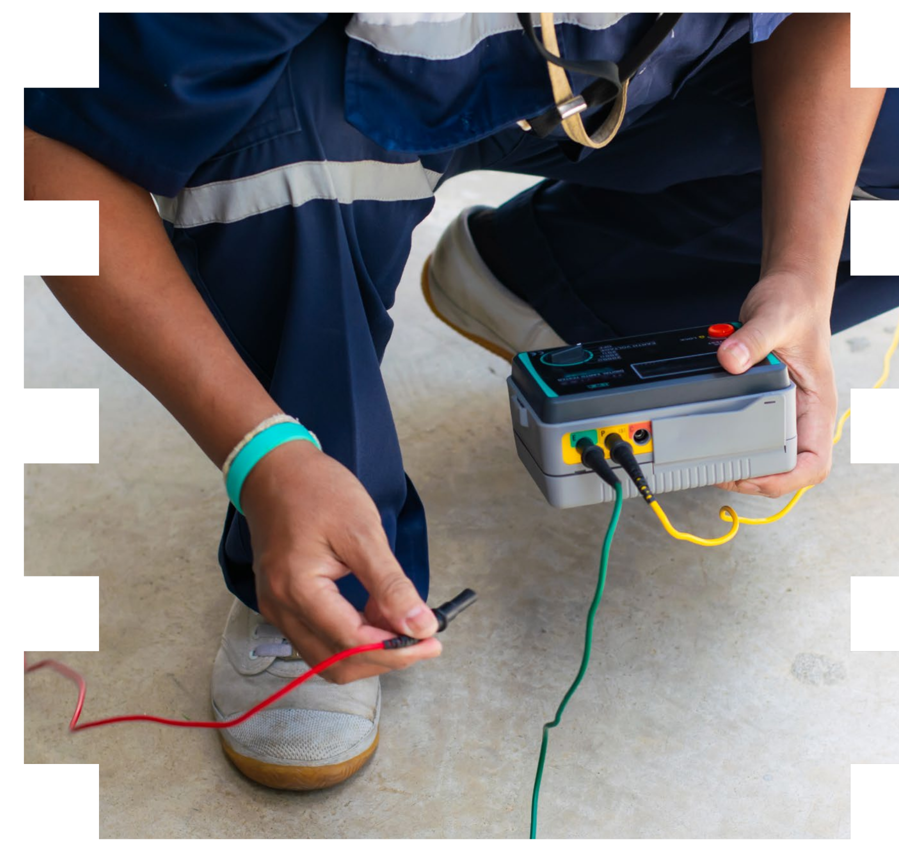
Both systems function based on minimum amperage thresholds. Fuse-based systems typically require a fault current of 1 A or more to open the circuit. RCDs are generally more sensitive, with detection thresholds often around 300 mA. However, faults caused by slow insulation breakdown, moisture ingress, or wiring abrasions often begin as high-impedance connections with leakage currents well below these levels (e.g., 50 mA to 100 mA).

Electrically, this leakage remains below the trip threshold and is treated as normal operating leakage by the inverter. Physically, however, the current tracks across surfaces and generates heat, leading to carbonization and further insulation damage.

Environmental factors, such as morning dew, can temporarily lower the resistance of a fault, allowing current to flow. As moisture evaporates, resistance increases, and the fault becomes undetectable by passive monitoring. The physical damage to the conductor remains, potentially worsening with every thermal cycle.

The risks of undetected faults

A single ground fault in a floating or high-impedance grounded system locks the potential of the faulted conductor to ground. While the system may continue to operate, this condition creates a return path for current if a second fault occurs.



Source: Getty Images

Test method	Insulation resistance testing (IRT)	Voltage-to-ground testing	Advanced ground fault location testing
Best for	▪ Hard faults ▪ Some intermittent faults	▪ Hard faults ▪ Rough fault location	▪ Hard faults ▪ High-resistance faults ▪ System mapping ▪ Precise fault location
Use case	▪ Initial fault isolation ▪ Comparing strings for anomalies	▪ Estimating fault position ▪ Spotting faults by measuring voltage differentials	▪ Rapid diagnosis and pinpointing fault location ▪ Open-circuit or layout issues
Limitations	▪ Doesn't give exact location ▪ Requires disconnecting strings	▪ Requires disconnecting strings ▪ Less effective on intermittent faults	▪ Requires training ▪ May return inconclusive results on high-capacitance and resistance systems

Table 1: Why traditional testing methods often fail to locate intermittent or high-impedance faults effectively.
Source: Fluke Electronics

If a second ground fault develops on a conductor of the opposite polarity, current can bypass the inverter's load and GFDI protection mechanisms. This creates a DC short circuit through the array's racking or conduit.

Limitations of traditional troubleshooting methods

When a ground fault is suspected, the standard troubleshooting procedure often involves isolating strings. Technicians measure voltage at a combiner box and then physically disconnect strings sequentially to isolate the fault.

On 1,500 V systems, this process introduces specific risks. Repeatedly mating and unmating MC4 connectors can degrade seals and contacts, potentially introducing moisture or increasing resistance. Furthermore, the voltage-to-ground method requires technicians to perform manual calculations to estimate the fault's position.

Additionally, passive tools such as digital multimeters (DMMs) or insulation resistance testers (IRTs) have operational limitations in this context. A DMM identifies the presence of voltage but does not pinpoint the leak location. IRTs provide accurate insulation characterization but require the system to be de-energized and circuits to be isolated, which increases setup time.

Intermittent faults present a specific challenge for passive tools. A fault active during wet conditions may dry out by the time a technician arrives, resulting in normal voltage and resistance readings. Passive tools cannot locate a fault that is not electrically active at the time of testing. Table 1 provides a side-by-side comparison of these standard testing methods with advanced ground-fault location methods.

Active diagnostics with the Fluke GFL-1500

The Fluke Electronics GFL-1500 solar ground fault locator is a comprehensive troubleshooting solution designed for utility-scale and commercial PV systems. As shown in Figure 1, the kit includes three essential components: the transmitter for injecting the traceable signal, the receiver for pinpointing faults along the cable path, and the signal-tracing clamp for isolating faulted strings without disconnecting conductors.

Figure 1: The Fluke GFL-1500 solar ground fault locator includes the transmitter, receiver, and signal-tracing clamp for end-to-end ground fault location.
Source: Fluke Electronics

To detect high-impedance faults that standard GFDI and passive tools may miss, technicians can use active diagnostics. This method involves injecting a signal into the system to trace the fault path. The Fluke GFL-1500 solar ground fault locator utilizes this approach.

The GFL-1500 uses FaultTrack™ technology to inject a modulated frequency signal into the DC system. It operates at 6.25 kHz for fault tracing and at 32.764 kHz for open-circuit detection. These frequencies keep the signal distinct, ensuring accurate detection even in electrically noisy environments where signal clarity is typically reduced.

To maintain safety during live tracing while ensuring signal strength, the Transmitter adjusts its output current based on the selected mode. In Array HIGH mode, it outputs 30 mA RMS, while Unit HIGH mode can output up to 120 mA RMS. Furthermore, the Transmitter is dual-powered. It can operate using the array's own DC voltage or its internal batteries, ensuring consistent signal injection whether the string is energized or completely dead. This allows technicians to trace faults over long distances without generating hazardous current levels.

The device features an "Analyze" mode that characterizes the fault before physical isolation begins. By connecting the Transmitter to the combiner box, the tool measures leakage resistance and voltage to ground.

It categorizes fault resistance into specific ranges (e.g., ≈ <5 kΩ, 10 kΩ, 50 kΩ, up to >1 MΩ), allowing technicians to visualize the severity of the impedance that the inverter is ignoring. Figure 2 illustrates an example of these diagnostic results on the transmitter display.

Built for rugged field conditions, the transmitter and receiver are rated IP54 for dust and splash resistance and operate over a temperature range of -20°C to +50°C. The accompanying signal clamp features a 61 mm (2.4 in) jaw opening, capable of accommodating large conductors such as 500 MCM main cables. Additionally, the receiver offers a detection range of up to 4.75 m (15.6 ft) in Array Mode, allowing technicians to trace cables in overhead racks or deep cable trays from a safe distance.

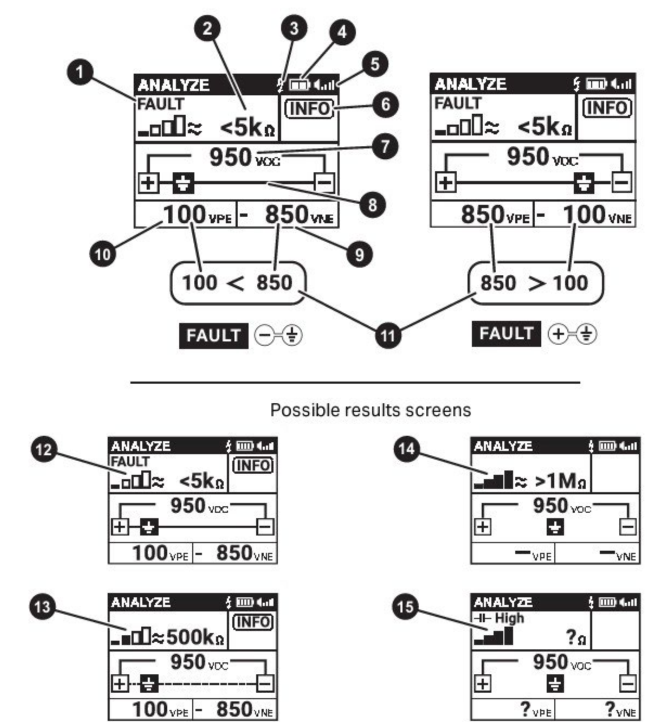


Figure 2: The display categorizes fault resistance (e.g., <5 kΩ) and measures voltage-to-ground, allowing technicians to characterize the fault before tracing.
Source: Fluke Electronics

Non-invasive signal tracing workflow

The GFL-1500 allows for fault location without disconnecting high-voltage connectors. The typical workflow is as follows:

1. ***Analyze:*** The technician connects the GFL-1500 Transmitter to the positive and negative busbars and the ground terminal at the combiner box or inverter, as illustrated in Figure 3. The "Analyze" function runs a diagnostic test to confirm the presence of a ground fault and measure its resistance.
2. ***Inject:*** The technician initiates the signal injection. The GFL-1500 sends a tone through the system. This can be performed on energized systems (up to 1500 V).
3. ***Trace:*** Using the GFL-1500 Signal Tracing Clamp, the technician scans the homerun cables. The Clamp detects the tone on the specific string carrying the fault current, allowing the technician to identify the faulted circuit among parallel strings without disconnecting wires. The handheld Receiver can also be used for tracing, though it may require isolating parallel strings for clear branch identification.
4. ***Pinpoint:*** The technician follows the signal along the identified string using the Receiver. For precise detection, the device must be oriented perpendicular to the conductor as shown in Figure 5. The signal strength indicates the location of the fault, with the tone stopping or changing at the exact point of the fault. The Receiver provides both visual signal-strength bars and variable-pitch audio, allowing the technician to hear the fault location while keeping their eyes on the terrain or overhead hazards.

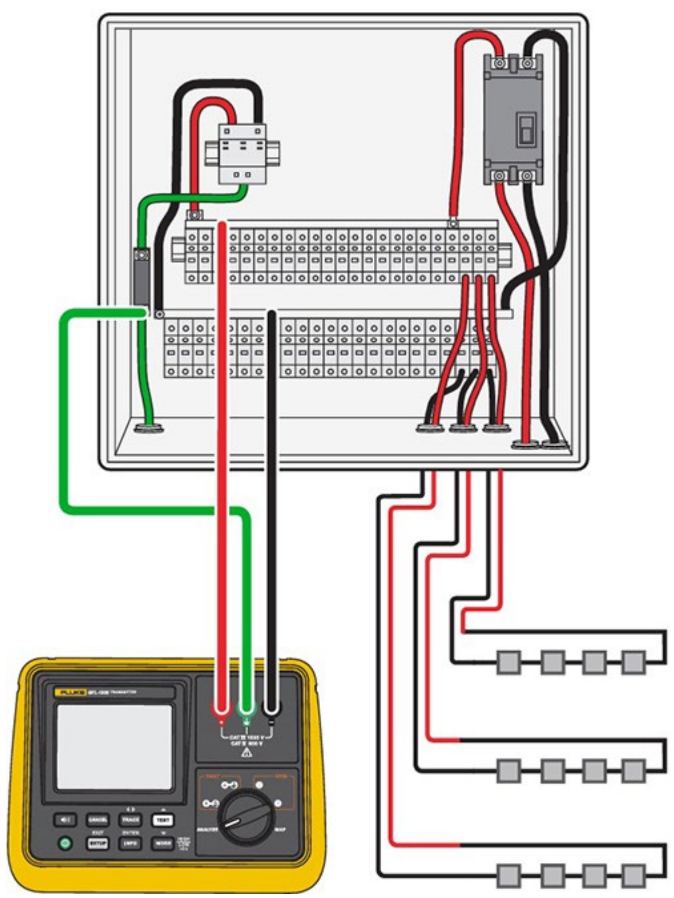


Figure 3: Wiring the GFL-1500 for analysis and signal injection.
Source: Fluke Electronics

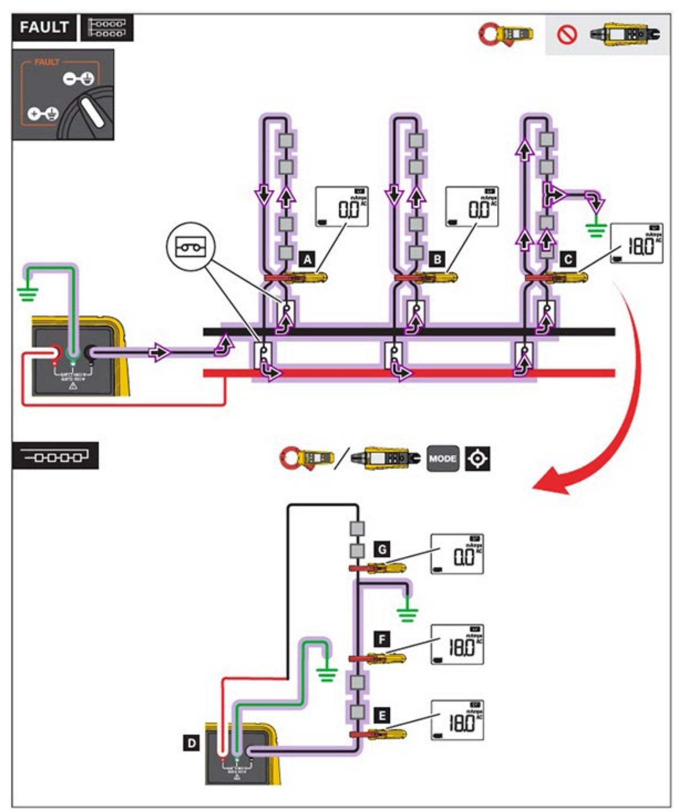


Figure 4: Identification of the active fault path among multiple parallel circuits using the clamp without disconnecting fuses.
Source: Fluke Electronics

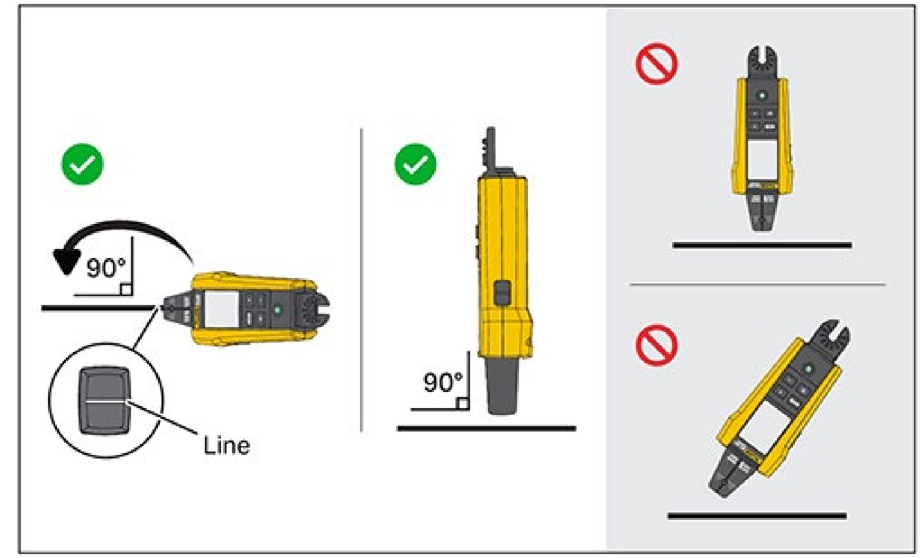


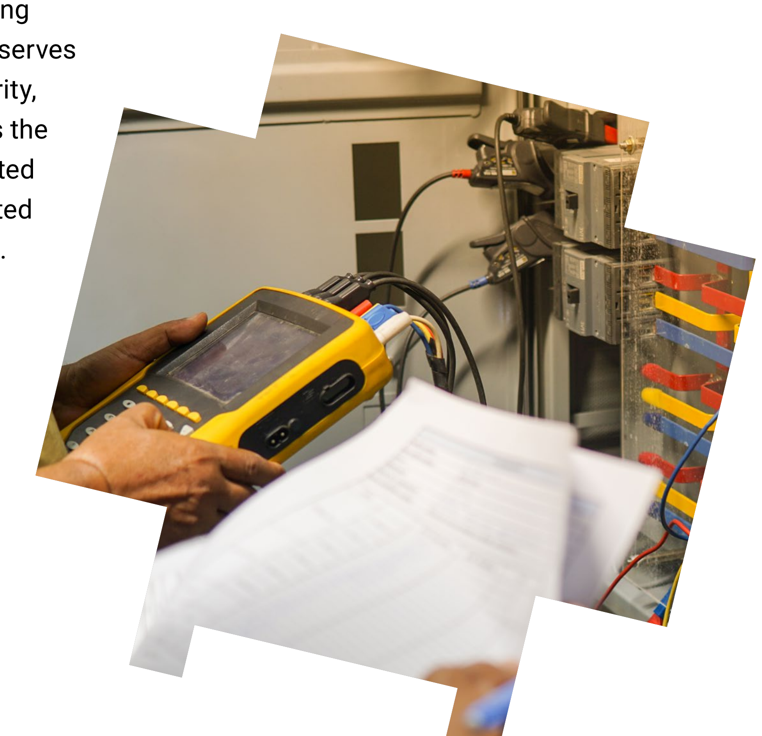
Figure 5: To pinpoint the fault location, the receiver must be held perpendicular to the wiring path to maximize signal detection.
Source: Fluke Electronics

Note: Standard safety procedures, such as verifying current levels with a tool like the Fluke 393 FC clamp meter, should be followed before making any connections.

Conclusion

Inverter status indicators provide operational data but do not offer comprehensive safety assurance. As solar assets age and 1,500 V systems become standard, identifying high-impedance faults becomes increasingly important for system safety and longevity.

Adopting active diagnostic tools, such as the Fluke GFL-1500, allows O&M teams to detect faults that fall below inverter detection thresholds. This approach reduces reliance on invasive troubleshooting methods, preserves cabling integrity, and mitigates the risks associated with undetected ground faults.



Source: Getty Images

Safe thermal inspection access using IR windows

By Art Pini

Source: Fluke Electronics

Thermal inspection systems in hazardous environments can be challenging, but specialized equipment such as infrared (IR) windows, significantly mitigates the risk. Let's look at how IR windows operate in the context of thermal imaging and how the windows are selected and applied.

First, some definitions. The IR spectrum lies between the microwave and visible regions of the electromagnetic spectrum. IR radiation is a form of visually undetectable thermal energy, commonly known as heat. IR thermography, also known as thermal imaging, is a non-contact method for detecting and measuring temperature differences by analyzing IR radiation levels and graphically displaying the results.

The graphical display, often called a thermogram, uses colors to indicate temperature, with each color representing a specific temperature range. For example, the thermogram of an operating electric motor (Figure 1) shows the temperature of each area on the motor. The scale on the side of the thermogram shows the color-to-temperature mapping.

An IR thermal imaging camera, also called a thermal imager, generates thermograms. Unlike a conventional camera, the thermal imaging camera responds to long-wavelength IR radiation to develop a measured device's heat signature. The resulting IR image is often significantly different from a visible-spectrum image. Many IR cameras also include a visible-light camera to capture a standard visible-spectrum image simultaneously, pixel-by-pixel, alongside the IR image. The combination of these two types of display images adds structural detail and provides physical context for temperature data, making it easier to interpret.

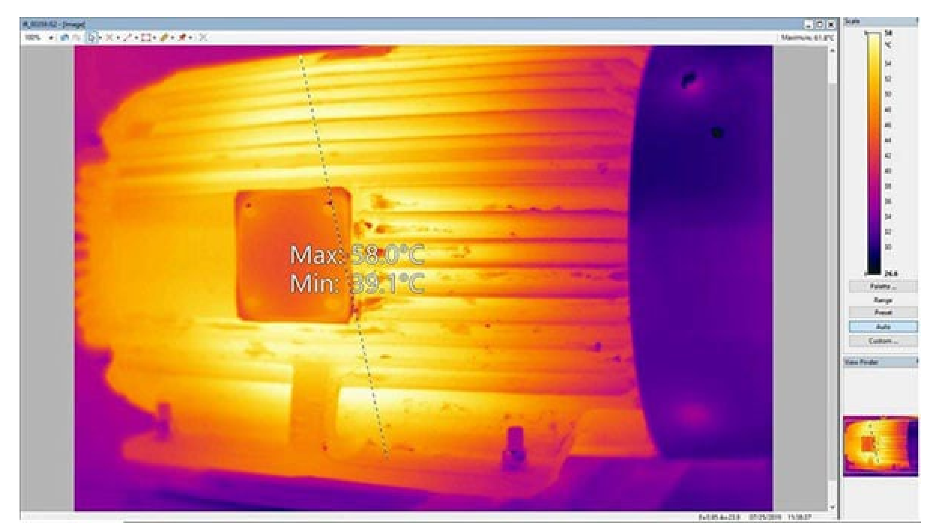


Figure 1: Shown is a thermogram of an operating electric motor; the colors indicate the temperature of each part of the motor.
Source: Fluke Electronics

Applications for thermal imaging

There are many applications for thermal imaging. For example, it can be used to detect overheating in electrical distribution panels, indicating high-resistance connections or overloaded conductors. In mechanical systems, thermal imaging can detect motor winding and bearing defects. Architectural applications include locating heat loss in structures. It is also used in security applications to detect both animal and human intruders.

Thermal imaging has an advantage over other monitoring technologies in that it does not require physical contact with the devices being measured. This is particularly important in specific applications where the measured device operates at high temperatures, carries high voltages, or must be measured while operating.

IR and multispectral windows

Some applications for thermal imaging can pose hazards to technicians while they are taking measurements. For example, an electrical breakdown in a power distribution panel can result in an arc flash generating extremely high temperatures and light levels. The fault also generates an arc blast, a supersonic shock wave that produces deafening noise and superheated shrapnel, leading

Figure 2: Shown is an example of an IR window mounted on a control panel, allowing access for a thermal imaging camera.
Source: Fluke Electronics

to severe injury. Arc events can occur even at voltages as low as 120 volts, but the likelihood increases with increasing voltage.

While personal protective equipment (PPE) can be used to defend against arc events, a safer, less costly alternative is to use inspection windows to isolate and protect workers.

An IR or multispectral window enables more efficient thermal imaging by allowing you to view the inside of electrical panels and enclosures without opening them, thereby preventing arc flash and blast exposure and enhancing worker safety (Figure 2).

Fluke Electronics offers IR windows compatible with their IR cameras and thermal imaging systems.

The ClirVu CLKT and ClirVu CV windows offer critical protection for technicians and engineers, allowing access to inspection areas without opening panels or enclosures. The IR windows are permanent fixtures made of arc-resistant crystal optics mounted in high-strength alloy die-cast frames with high-pressure gaskets for superior protection against arc blast. The optical windows are made of calcium fluoride (CaF2) coated with Fluke's broadband ClirVu coating for improved IR transmission and protection against moisture degradation. Covers protect the optics against dust and accidental damage. They have a continuous operating temperature range of -40 to 232°C (-40 to 450°F).

Both series offer windows with diameters of 2, 3, and 4 inches (in.) (50, 75, and 100 millimeters (mm)) and a choice of three different door latch types (Figure 3).

The Fluke CV301 (Figure 3, center) is a 3 in. (75 mm) IR window using a security key latching mechanism. The 4 in. (100 mm) window version is the Fluke CV400 (Figure 3, right). This window uses a hand-turn latching mechanism that does not require a security key. The Fluke FLK-050-CLKT (Figure 3, left)

Figure 3: These examples of the CLKT and CV windows show the available door latch selections.
Source: Fluke Electronics

features a 2 in. (50 mm) window with a twist-lock latch. The CLKT series features a multispectral window that utilizes Fluke's QUADRABAND optical technology. The optical lens handles not only short-, medium-, and long-wave IR but also ultraviolet and visible light. It enables display fusion in compatible IR imagers, combining IR and visible light views for a more intuitive representation.

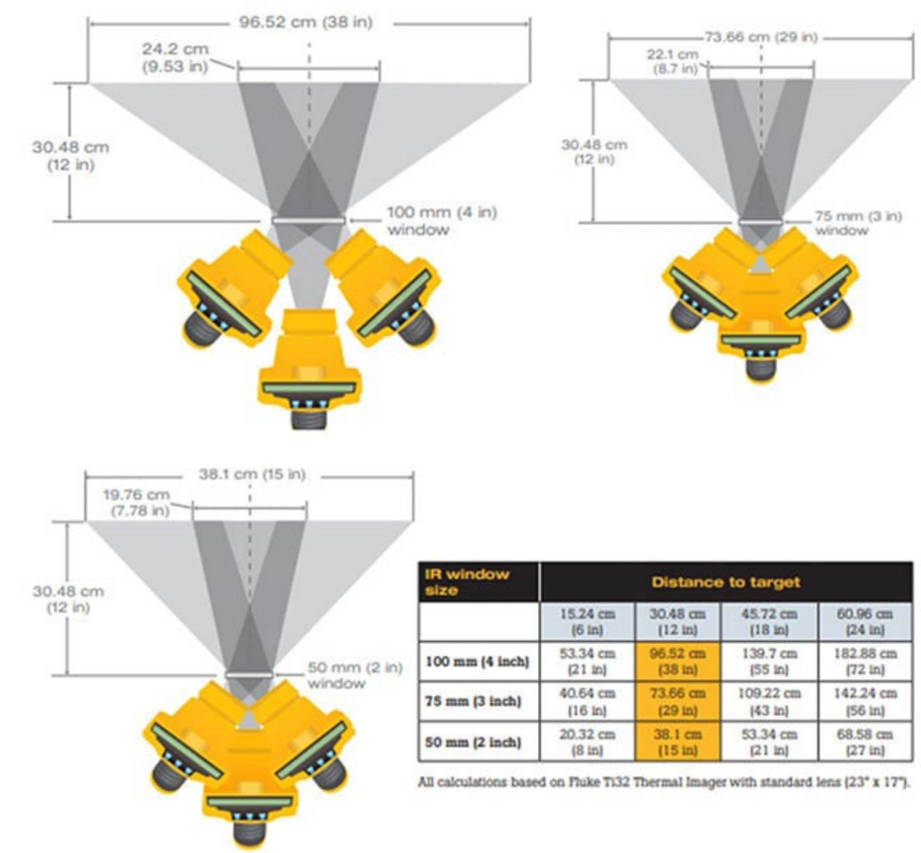
The CV series undergoes 30 cycles of testing and is rated to withstand arc events up to 63 kiloamperes (kA). The CLKT series is rated at 30 cycles of a 50 kA arc event.

These windows comply with multiple safety, arc-testing, and environmental compatibility standards.

Selecting an IR window

The selection of an IR window begins by determining which inspections will be required and whether they can be performed with the IR window and IR camera combination you plan to use. The camera's field of view and its alignment with the window play a role, but the window size and the distance to the target from the window determine the field of view through it (Figure 4).

The table in Figure 4 shows the field of view for three different-sized windows (50, 75, and 100 mm) and the distance from the window to the target. Highlighted are the fields of view for three window sizes at a distance of 12 in. (30.48 centimeters (cm)) to the target. The field of view increases with window size and distance to the target.



IR window size	Distance to target			
	15.24 cm (6 in)	30.48 cm (12 in)	45.72 cm (18 in)	60.96 cm (24 in)
100 mm (4 inch)	53.34 cm (21 in)	96.52 cm (38 in)	139.7 cm (55 in)	182.88 cm (72 in)
75 mm (3 inch)	40.64 cm (16 in)	73.66 cm (29 in)	109.22 cm (43 in)	142.24 cm (56 in)
50 mm (2 inch)	20.32 cm (8 in)	38.1 cm (15 in)	53.34 cm (21 in)	68.58 cm (27 in)

All calculations based on Fluke Ti32 Thermal Imager with standard lens (23° x 17°).

Figure 4: The field of view through the windows depends on the size of the window and the distance to the target from the window.
Source: Fluke Electronics

Conclusion

IR and multispectral windows are key to safe diagnostic thermography. They isolate test personnel from potentially harmful arc events, high temperatures, and moving machinery while allowing access for thermal imaging devices.

How to speed system design, validation, and production test using modular instruments and software

By Jeff Shepard

Source: Getty Images

Numerous test and measurement (T&M) instruments are needed when designing, validating, and production testing components and systems for automotive, consumer, industrial, medical, and other applications. These suites of T&M instruments need to be compact and have high performance. They need low latency plus high channel density and bandwidth. In addition, design needs can change over time, so modularity is a big plus to future-proof the system. In many cases, these T&M activities involve repetitive testing, or collaboration among geographically dispersed teams, making software-defined testing a highly desirable feature.

The use of a group of conventional instruments is a potential solution. However, issues with system integration of devices from a range of makers, including information being presented on multiple screens, software compatibility, masses of cabling, and the amount of space required for numerous discrete instruments, can be challenging.

Instead, T&M system designers can turn to bundles of high-performance modular instruments and other I/O modules with specialized synchronization and key software features, ranging from device validation to automated production testing. These bundled units are available in a compact, five-slot PXI Express measurement system that is controlled with a laptop or desktop computer through a Thunderbolt USB-C port.

This article begins by briefly reviewing the performance metrics of modular instrument systems, including analog instrumentation categories. It then presents a comparison of the performance of various buses for modular instrument systems and looks at the challenges related to increasing resolution and decreasing latencies. It concludes by presenting PXI Programmable Power Supply (PPS) bundles from NI, including modules for digital multimeters, LCR meters, oscilloscopes, multifunction I/O, waveform generators, and source measurement units, along with software tools for automating the T&M process.

What kind of measurement is needed?

The process of determining what type of T&M instrument is needed begins with a couple of basic questions:

- Is the signal being measured an input, an output, or both?
- Is the signal frequency direct current (DC) or alternating current (AC), and if it's AC, is it in kilohertz (kHz), megahertz (MHz), or gigahertz (GHz)? The answers to these questions help to determine if the instrument needed is for DC and power, low-speed analog, high-speed analog, or radio frequency (RF) and wireless applications (Table 1).

Analog instrument specs

After determining the general type of instrument needed for a measurement task, it's time to identify the specific performance requirements including:

- Signal basics include ensuring that: the signal range is large enough to capture the required signals, the impedance supports the loading of the DUT and frequency requirements of the measurement, and the isolation from ground supports the required levels of noise immunity and safety.
- Bandwidth, in kHz, MHz, or GHz, needs to be adequate to handle the signals being measured, and the analog-to-digital converter (ADC) needs to be fast enough in terms of samples per second, such as kilosamples per second (kS/s), megasamples per second, (MS/s), or gigasamples per second (GS/s) to capture the required signal nuances.
- Resolution and accuracy are also important considerations. Is 8-bit, 24-bit or other level of resolution needed? What is the maximum error rate in terms of percentage or parts per million that can be tolerated? Additionally, what is the required sensitivity in absolute units like microvolts (µV) or nanovolts (nV) that is needed?

	DC and power	Low-speed analog	High-speed analog	RF and wireless
Input, measure	Digital multimeter	Analog input, data acquisition (DAQ)	Oscilloscope, frequency counter	RF analyzer, power meter (spectrum analyzer, vector signal, analyzer)
Output, generate	Programmable power supply	Analog output	Function/arbitrary, waveform generator (FGEN, AWG)	RF signal generator (vector signal generator, CW source)
Input and output on the same device	DC power analyzer	Multifunction data acquisition (multifunction DAQ)	All-in-one oscilloscope	Vector signal transceiver (VST)
Input and output on the same pin	Source measure unit (SMU)	LCR meter	Impedance analyzer	Vector network analyzer (VNA)

Table 1: There are several basic categories of T&M instruments based on input and output characteristics and performance levels. Source: NI

	Input isolation and termination	Input coupling and filtering	Input amplifier	Analog-to-Digital converter (ADC)
Specification determined	Isolation input impedence	AC/DC coupling, analog bandwidth	Max voltage range, min voltage sensitivity	Sample rate resolution
Example DMM:	Isolated up to 330 V Cat II 10 MΩ (selectable)	DC coupled 200 kHz bandwidth	Up to 300 V input down to 10 nV sensitivity	10 kHz reading rate 6.5-digital (24-bit) resolution
Example: Oscilloscope:	Ground referenced 50 Ω or 1 MΩ (selectable)	DC or AC coupled (selectable) 350 MHz bandwidth	Up to 40 VPP input down to 1 mV sensitivity	Up to 5 GS/s sample rate 8-bit resolution

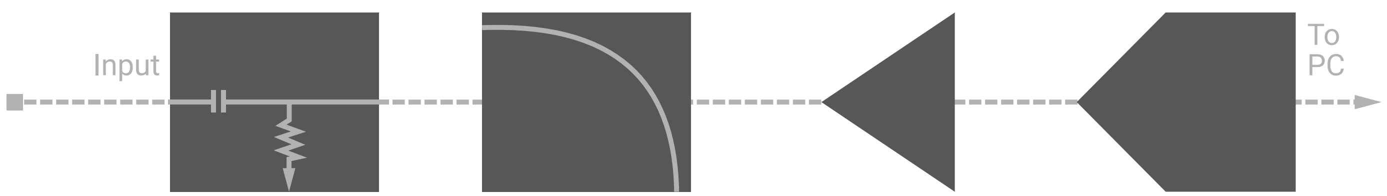


Table 2: Different T&M instruments, such as a DMM and an oscilloscope, can require widely varying performance characteristics for a given measurement.
Source: NI

Various types of T&M instruments require different input isolation and impedance ranges, input coupling and filtering specs, amplifier sensitivities, and measurement resolution and accuracy, as shown in the measurement instrument analog-input path example (Table 2).

Buses, bandwidth, and latency

The T&M instruments need to be connected to a controller to form a test system. The requirements for signal bandwidth and latency of the connecting bus are important considerations. Bandwidth measures the speed at which data is transmitted, typically in megabytes per second, while latency measures the delay in the data being transmitted. Commonly used buses have widely varying combinations of bandwidth and latency. Another factor is the transmission distance that the bus supports. For example, the general purpose interface bus (GPIB) and the universal serial bus (USB) can support similar levels of latency, but USB offers higher bandwidth. For its part, Gigabit Ethernet has medium bandwidth and higher latency but can transmit over much longer distances.

When designing T&M systems, PCI and PCI Express are often used. They are designed for short-range links, up to about 1 meter (m), and provide high bandwidth and low latency (Figure 1). An important characteristic of PCI Express is that it provides dedicated bandwidth for each device on the bus. This makes PCI Express the preferred interconnect bus for high-performance and data-intensive applications like real-time T&M systems where it's necessary to integrate and synchronize the operation of multiple instruments.

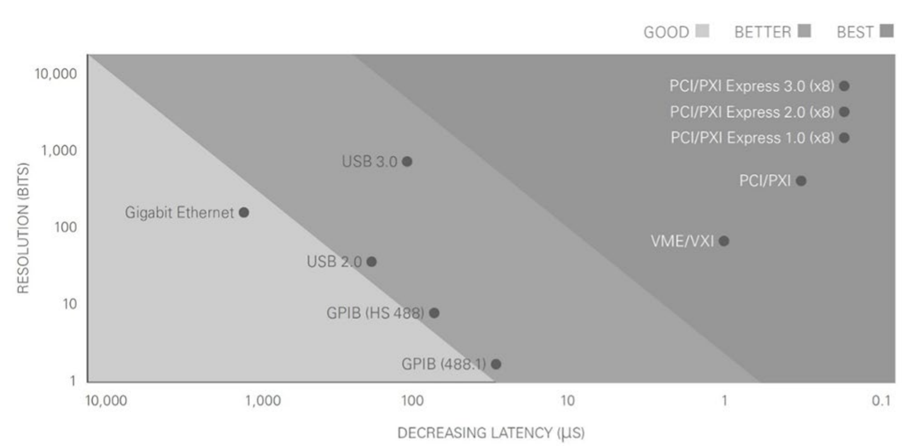


Figure 1: PCI/PXI Express offers the highest performance combination of resolution and latency.
Source: NI

Figure 2: A basic PXI PPS bundle includes a controller, a PPS module, and slots for four more PXI instruments.
Source: NI

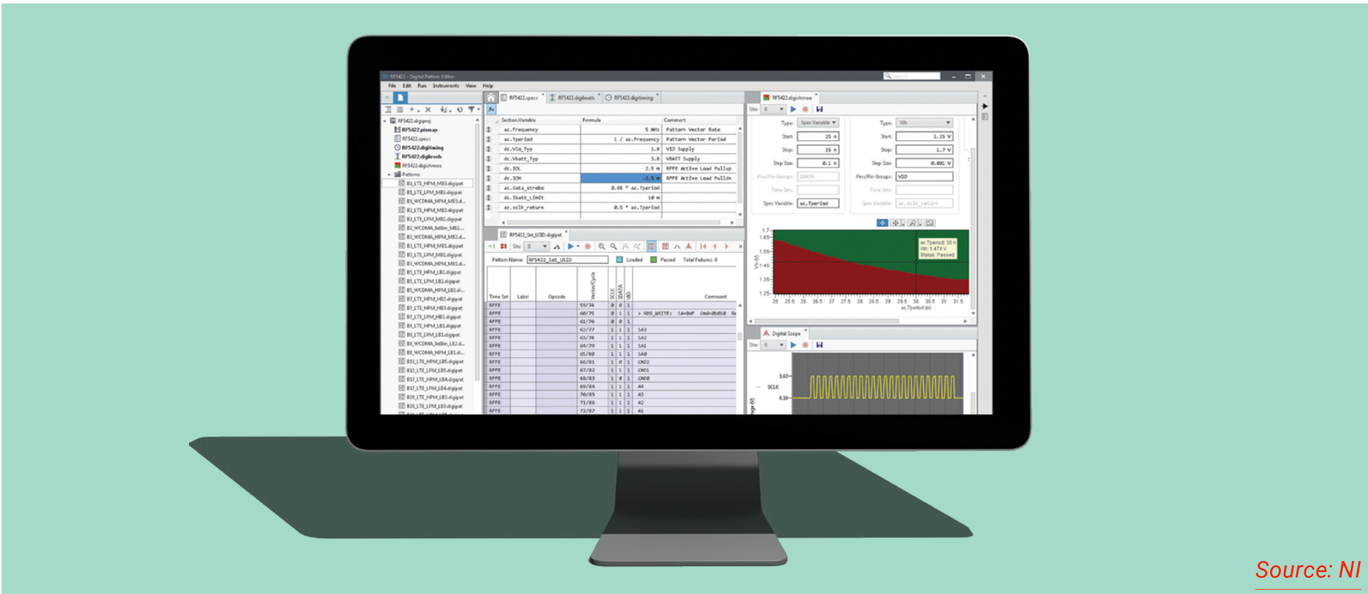
T&M instrument bundles

Designers can turn to the PXI PPS bundles from NI as the basis for high-performance T&M systems. The PXI PPS modules provide for the basic power needs of the DUT and can be expanded with numerous T&M modules to support a range of device characterization, design validation, and manufacturing test applications. The chassis supplies up to 58 watts of power and cooling for additional instruments, high-performance PXIe interconnects, and an integrated Thunderbolt link for connecting with an external desktop or laptop computer, acting as the system controller (Figure 2).

The PPSs can be used to supply programmable power to a DUT while controlling and monitoring the current and voltage levels to measure power consumption. They have two isolated 60-watt channels with remote sensing to correct for losses in system wiring, with a typical efficiency of 78%. The channels also include output disconnects that can isolate the DUT when it's not being tested.

Examples of expandable PXI PPS bundles with 120 watts of power for the DUT include the 867117-01 with a PXIe-4112 two-channel PPS (like model 782857-01) that can deliver a maximum of 1 ampere (A) at 60 volts DC per channel, and the 867118-01 with a PXI2-4113 two-channel PPS (like model 782857-02) that can deliver up to 6 A at 10 volts DC per channel (Figure 3).

Figure 3: PXI PPS bundles are available with a choice of power supplies having outputs of 60 volts DC (left) or 10 volts DC (right).
Source: NI



Source: NI

Jumpstarting T&M system development

NI offers designers a range of PXI bundles to jumpstart their T&M system development efforts. Examples include:

PXI Waveform Generator Bundles that can be used to generate standard functions and user-defined, arbitrary waveforms. The PXI waveform generator bundles feature up to two output channels with bandwidths of up to 80 MHz, a ±12 volt output range, and an 800 MS/s maximum sample rate. For example, the 867119-01 includes a 20 MHz arbitrary function generator.

PXI Oscilloscope Bundles feature up to eight channels that can sample at speeds of up to 5 GS/s with 1.5 GHz of analog bandwidth. Bundle 867010-01 includes a 60 MHz oscilloscope module.

PXI Source Measure Unit (SMU) Bundles, like the 867111-01, are designed to automate DC measurements and tests. The SMUs feature four-quadrant operation, ranges up to ±200 volts and ±3 A, and sensitivity as low as 100 femtoamperes (fA). PXI SMU bundles combine the ability to perform high-power sweeps and low-current measurements.

PXI LCR Bundles such as the 867113-01 can be used to make DC and impedance measurements by combining an LCR meter and an SMU in a single instrument. This instrument provides fA current and femtofarad (fF) capacitance measurements in a single-slot PXI form factor.

PXI DMM Bundles support hand-probed, switched, and automated DMM measurements with high accuracy and resolution of up to 7.5 digits. A high sampling speed allows users to characterize transients without the need for an oscilloscope. Users can also configure triggers for acquisition and/or sequencing. For example, the 867115-01 features a 6.5-digit display.

PXI Nanovolt Meter Bundles are high-resolution analog input modules with up to 28-bit resolution. They include a chopping mode that uses a pair of channels to provide high levels of noise rejection, which enables accurate and repeatable nV measurements and on-board signal averaging and filtering, as well as auto-zero measurement switching. Model 867125-01 features 32 channels, 28-bit resolution, and 2 MS/s sampling.

PXI Multifunction I/O Bundles, like the 867124-01, provide a mix of analog I/O, digital I/O, counter/timer, and triggering functions. The PXI multifunction I/O bundles feature up to four analog output channels, 48 bidirectional digital channels, 80 analog input channels, and a sample rate of 2 MS/s.

Figure 4: InstrumentStudio can present data from multiple instruments on one screen. For example, from an oscilloscope (large left panel), a DMM (top right panel), and a function generator (bottom right panel).
Source: NI

Software defines the system

In addition to comprehensive hardware modules, NI offers T&M system designers a choice of software development environments, including InstrumentStudio and LabVIEW.

Included with NI PXI instruments, InstrumentStudio gives test engineers a single no-code software environment to monitor and debug automated test systems. Additionally, users can create screens that present data from multiple instruments simultaneously (Figure 4). Tools enable users to capture screenshots and measurement results and save project-level configurations for DUTs that can be reused or shared with other developers.

LabVIEW is NI's software-defined testing development environment. With its graphical user interface (GUI), test engineers can quickly develop automated research, validation, and production test systems. At a basic level, LabVIEW's graphical approach enables nonprogrammers to drag and drop virtual representations of instruments to build T&M programs, create interactive user interfaces, and save data to .cvs, .tdms, or custom-defined binary files.

More advanced programmers can benefit from available drivers for Python, C, C++, C#, .NET, and MATLAB. NI also offers a bundle of software tools for the development of comprehensive T&M environments including:

- TestStand or creating automated test sequences
- G Web development software for building web applications
- DIAdem for interactive data analysis
- FlexLogger for T&M data acquisition and logging

Conclusion

Creating software-defined test environments for design, validation, and production testing of components and systems requires the use of several T&M instruments. Instead of using instruments from multiple suppliers with associated connectivity, cost, and space requirements, test engineers can turn to instrument bundles from NI that can be used to produce compact, flexible, and high-performance testing systems. NI also offers a choice of software environments to speed the development process.

Suggested reading

1. How to Build a Compact Data Acquisition System
2. Apply Benchtop Power Supplies' Programmability, Networking, and Leadless Remote Sensing Features

Source: Getty Images

A framework for wall-mount rack enclosures in edge computing deployments

By Rakesh Kumar, Ph.D.

The edge computing strategy, which moves data processing closer to its source, requires deploying essential IT equipment in non-traditional environments. These locations, such as retail stockrooms, classrooms, and factory floors, pose a primary challenge because they often lack the dedicated floor space, physical security, and climate-controlled conditions of a traditional data center.

Due to these limitations, standard specification criteria are insufficient for the experts responsible for physical deployment. The primary objective of this article is to provide a technical framework for this exact challenge. It describes a technical specification framework that prioritizes serviceability, physical security, and space footprint for these small, uncontrolled areas.

Core challenges in non-traditional IT deployment environments

Edge deployments present three main types of problems, distinct from those encountered during data center construction.

1. ***Absence of available floor space:*** The most immediate constraint in these environments is the absence of dedicated floor space. Most of the time, vertical space is the only available space. As a result, wall-mount solutions are a valuable alternative to traditional floor-standing racks for storing equipment.

Source: Getty Images

2. ***Uncontrolled physical security:*** A data center is a secure facility with controlled access. On the other hand, edge locations are often open to customers, general staff, and students, which poses security risks. In such an environment, an open-frame rack is a liability because it allows network switches, servers, and Uninterruptible Power Supply (UPS) systems to be accidentally disrupted, maliciously tampered with, or stolen.

3. ***Uncontrolled environments and access:*** Edge locations lack consistent service access and dedicated cooling.

   - *Climate:* There are no cooling systems for these IT deployments. Therefore, dust, ambient air, and temperature changes can affect equipment. The enclosure itself must be capable of managing thermal loads through passive ventilation.
   - *Access:* When a rack is placed in this manner, non-IT objects may obstruct the service and make it challenging. Longer service times increase the Total Cost of Ownership (TCO) if a technician cannot access the back of the equipment.

The role of wall-mount enclosures as a solution

The suggested solution is to use fully enclosed, locking cabinets rather than open-frame brackets. A simple wall-mount bracket may hold a patch panel, but it fails to solve the core edge challenges. It offers no security, inadequate airflow management, and non-professional cable organization.

Instead, a custom-built wall-mount enclosure works as a standalone micro data center. It is a heavy-duty steel unit that, in a single solution, solves all three challenges:

- Equipment is moved from the floor to a secure wall.
- Unauthorized access is prevented via locking steel doors and side panels.
- Equipment is protected from dust and debris, while airflow is managed via vented panels.

Hence, the selection of such an enclosure is a technical decision that must extend beyond a simple U-height requirement.

A 3-point specification framework for enclosure selection

A successful deployment is dependent on specifying the correct features. These three questions must be answered to avoid common, costly procurement mistakes:

1. ***Depth:*** What is the maximum depth of the deepest component (e.g., a server or UPS) that is to be installed?
2. ***Security and access:*** What are the access control requirements, and who must be prevented from access? How will technicians service the equipment post-installation?
3. ***Sizing and load:*** What is the total required U-space, including room for expansion, and what is the total weight of all components?

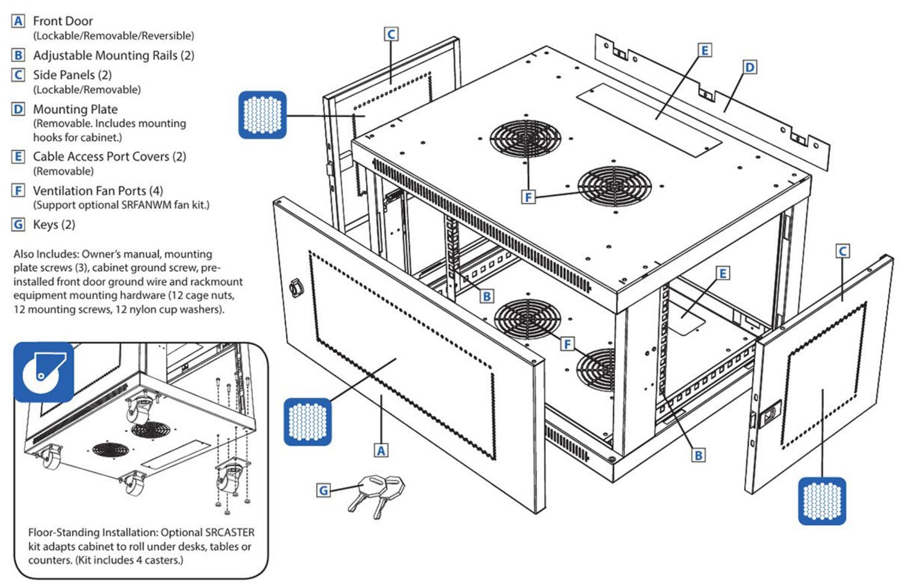


Figure 1: An exploded diagram of the SmartRack SRW6U, a representative Switch-Depth (Shallow) enclosure.
Source: Eaton

Specification point 1: component depth analysis

A common mistake in procurement is failing to verify the component depth against the enclosure's internal specifications. This mistake could stop a deployment if a part is too deep for the chosen cabinet. First, the component with the greatest depth needs to be measured, and an enclosure that fits it needs to be selected.

Wall-mount enclosures are usually grouped by depth.

- Switch-Depth (Shallow): These are compact enclosures, typically 16.5 inches deep, designed for shallow equipment, such as patch panels and standard network switches. For a simple network drop, a shallow rack such as the Eaton Tripp Lite SmartRack SRW6U, shown in Figure 1, is a suitable choice.
- UPS-Depth (Mid-Depth): Depths in this group range from 20.5 to 24.5 inches, making it practical for many uses. This extra space is needed to fit most rack-mount UPS systems and larger Power over Ethernet switches, which are often deeper. Even if the U-height is the same, this difference is still significant. For example, Figure 2 shows the SmartRack SRW18US offering a 20.5-inch depth for switch-heavy deployments, while the SmartRack SRW18USDP extends to 24.5 inches to accommodate the extra room required by UPS systems.

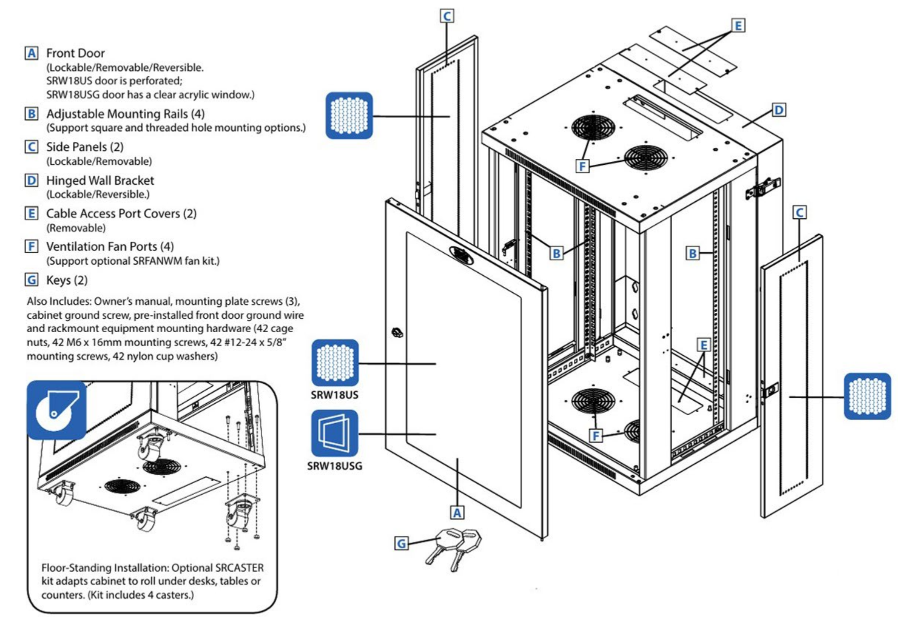


Figure 2: Key components and features of the SmartRack SRW18US wall-mount enclosure.
Source: Eaton

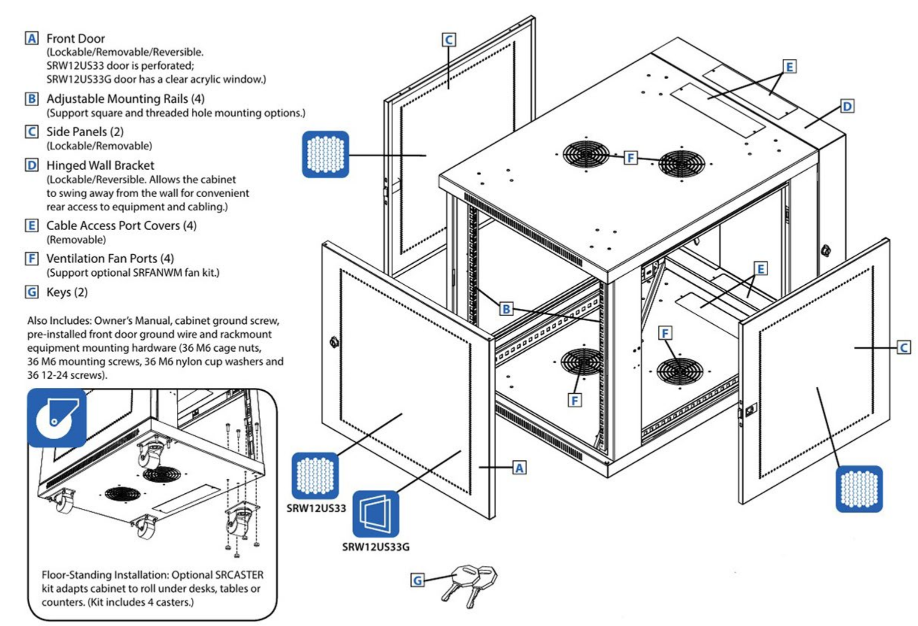


Figure 3: An exploded diagram illustrating the components of the SmartRack SRW12US33G wall-mount enclosure.
Source: Eaton

- Server-Depth (Deep): While many edge deployments do not require servers, this enclosure class is available for those that do. If a deployment requires a 1U server, a "Server-Depth" enclosure is necessary. The SmartRack SRW12US33G (Figure 3), for example, provides a maximum device depth of 32.5 inches, making it one of the few wall-mount solutions that can accommodate 1U servers.

Specification point 2: analysis of security, visibility, and service access

After confirming depth, the next consideration is how the equipment will be secured and serviced.

1. ***Physical security and compliance:*** In public areas, the enclosure is the primary physical security measure. All Eaton Tripp Lite enclosures discussed in this article are made of heavy-duty steel and feature doors and side panels that lock. As part of compliance standards like PCI DSS (Payment Card Industry Data Security Standard), this is an important feature that protects physical equipment and media.
2. ***Visibility and aesthetics:*** A solid steel door is secure, but it prevents visual inspection. For this purpose,

Figure 4: The SmartRack SRW12USG, illustrating the acrylic front window for visual inspection.
Source: Eaton

Figure 5: The SmartRack SRW6UW, demonstrating the white-finish option for aesthetic installations.
Source: Eaton

"G" models, such as the SmartRack SRW12USG, feature a shatter-resistant, clear acrylic front window. Figure 4 shows the model with the acrylic window in the front. This aspect enables at-a-glance monitoring while maintaining a locked state and can help reduce audible fan noise. Additionally, aesthetics are a valid requirement in settings such as clinics and modern offices. In this case, models like the SmartRack SRW6UW in Figure 5 come in a white powder-coat finish to match the surroundings.

3. ***Service access and TCO:*** One of the main factors that affects TCO is how easy it is to service. A static, fixed-back enclosure, such as the SmartRack SRW12U, is initially cheaper to purchase, but it can be challenging to service because technicians often have to remove the equipment from the rack. For a small extra cost, hinged-back cabinets like the SmartRack SRW12US and SRW18USDP (Figure 6) are a better choice. With these models, the entire cabinet body can swing away from the wall, making it easy to access the back panels and cables. This capability can significantly affect service times.

Figure 6: The SmartRack SRW18USDP, a hinged-back enclosure specified for its ability to reduce service times and TCO.
Source: Eaton

Specification point 3: U-height, weight, and load capacity calculation

Finally, after confirming depth and access requirements, the total size and load must be calculated.

1. ***U-Height:*** A "U" is a standard 1.75-inch unit of vertical space. The total U-height of all current equipment should be calculated. It is recommended to add 25-50% more U-space for future expansion and to improve airflow between components. For 5U of equipment, a 6U rack (e.g., SRW6U) offers minimal expansion space, whereas a 12U rack (e.g., SRW12USG) provides ample room.

2. ***Weight and load capacity:*** The wall must be able to safely support the weight of the enclosure and all the equipment installed inside it.

   - *Enclosure Capacity:* The rack's load rating must be checked. The SRW6U is rated for 200 lbs, and the larger SRW18USDP is rated for 250 lbs.
   - *Wall Integrity:* This capacity depends on the quality of the wall's construction. For standard wall-stud placement, all of these enclosures have mounting holes that are 16 inches apart. To keep the enclosure safe, it must be bolted to the building's studs or a suitable concrete structure.

Conclusion

There is no need to sacrifice security, dependability, or serviceability when moving IT infrastructure to edge locations. If an organization uses an objective, facility-focused specification method, it can avoid making common deployment mistakes.

To solve the problem, a custom-built wall-mount enclosure is needed. Organizations can confidently and safely deploy IT infrastructure in any location by following a three-point framework: first, verify the device depth; then, assess the security and access features; and finally, check the U-Height and load capacity. These steps can transform an unusual space into a safe and usable micro data center.