FLUKE®

Calibration

Calibrating Power Meters with Multi-Product Calibrators

Application Note

Modern technology, government regulations and business trends are driving the demand for increased power meter calibration.

This application note is a best practice guide that includes instruction on power calibration:

- basics
- methods
- trends
- standards
- specifications
- workload management

It also demonstrates how the Fluke Calibration 55XX Series of Multi-Product Calibrators meet these requirements.

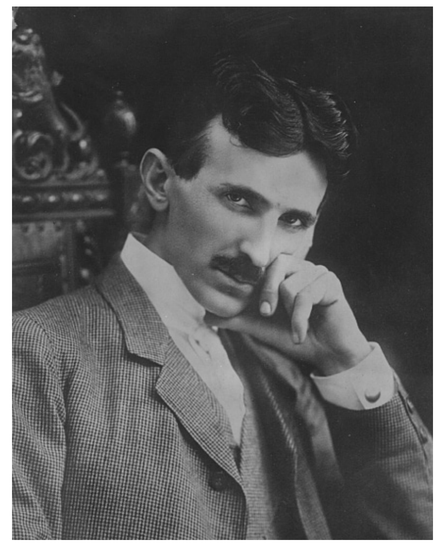
The Fluke Calibration 55XX Series Multi-Product Calibrators are designed to make calibrating a wide variety of electrical measurement tools fast and easy. When combined with Fluke Calibration MET/CAL *Plus* Calibration Management Software, the 55XX Series Multi-Product Calibrators simplify procedure generation and documentation, too.

A historical perspective

Thomas Edison developed the concept of a direct current electrical power distribution system with parallel wiring, so that the circuit would not be broken if a lamp in a series circuit was switched off. The world's first central power system, built in New York City in 1882, was based directly on Edison's plans.

About that time, a brilliant Croatian engineer named Nikola Tesla developed an alternating current system in Paris. He came to New York in 1884 with little money and a working knowledge of 12 languages. Tesla went to work for Edison, but the men soon parted ways, due to a disagreement about using direct or alternating current for power. Tesla sold his system to George Westinghouse, which precipitated a conflict between Edison and Westinghouse. However, alternating current proved the superior system due to the relative ease with which it can be generated and distributed with lower losses. In 1893, Westinghouse made a spectacular demonstration of this advantage by lighting the World Columbian Exposition in Chicago. As a result, alternating current was chosen for the Niagara Falls hydroelectric station.

Today, there is little we do that isn't affected by electrical power. Although the technology is mature, the generation, distribution, and use of electrical power is undergoing tremendous change. Fluke Calibration designed the 55XX Series calibrators to simplify and streamline the calibration of commonly used power measurement and analysis instruments.



Nikola Tesla

Thomas Edison

Power measurement basics

Power, voltage, and current

Most power meters measure voltage and current separately and display the power value in Watts. Most voltmeters use either electromechanical or analog-to-digital conversion techniques to determine voltage amplitude. Current is measured in amperes (A), which can be measured two ways:

- Many meters use an inductive coil clamped over the power line. This current clamp may be separate or part of the meter. The current in the line induces a proportional voltage (typically 1 mV for 1A of current) into the current clamp. The voltage is then measured by the meter.
- For lower currents, the power line current can be passed through a resistive shunt in the meter, and the voltage drop is measured across the shunt.

Some current/power clamps measure the true power directly, providing a proportional voltage to the meter.

Phase, harmonics, and frequency

Phase shifts

Load or line reactance shifts ac current so that it is no longer exactly in phase with the voltage; the current either leads or lags the voltage. When this happens, the effective energy or power to the load is reduced. Modern power meters indicate the phase angle and/or power factor in addition to Watts. (See Figure 1.)

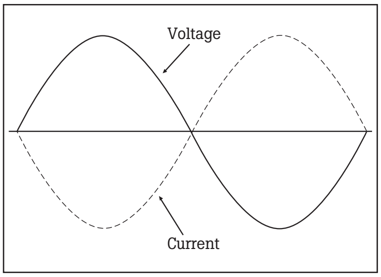


Figure 1. A phase difference between the current and voltage results in a change in the apparent power delivered.

Harmonics

Modern electronic equipment draws current in abrupt pulses rather than in a smooth, sinusoidal manner. This causes distorted current wave shapes, that in turn, cause higher-frequency harmonic currents to flow into other parts of the power system. Harmonics can cause overheated transformers and neutrals, trip circuit breakers, and affect computers and induction motors.

Harmonics are whole-number multiples of the fundamental frequency. Part of the supply current is at the harmonic frequency. Often, much of the harmonic energy is at the third harmonic, with smaller amounts at higher harmonics. (See Figure 2.)

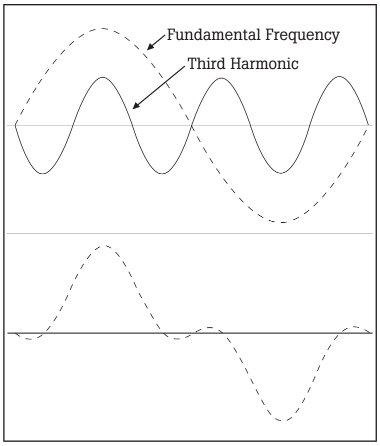


Figure 2. Graphic showing harmonic distortion.

To determine whether harmonic distortion exists, measure current first with an average-responding meter, then with a true-rms current measuring meter. (True-rms meters respond to harmonics differently than an average-responding meter does.) Divide the first measurement by the second. A ratio of 1 indicates little or no harmonic distortion. If a problem exists, a good handheld harmonic analyzer will determine the extent of the problem.

Power distribution systems use three phases for greater efficiency. Ideally, each phase of a three-phase system should differ by 120 degrees (1/3 cycle), and each line should have 1/3 of the total power. However, power delivered by

- **Phase angle ϕ.** The angle of ac current shift from the voltage.
- **Active (true or real) power.** The power usable by the load, often stated as VA COSϕ for sinusoidal waveforms.
- **VA (apparent power).** The simple multiple of the supply voltage and current, as it is seen by the supply line.
- **Power factor.** The ratio of the active (non-reactive) power used by the load to the VA (apparent power) power seen by the supply line. Applies to all waveforms.
- **Displacement power factor.** The cosine of the phase angle, which is equal to 1 for no phase shift and 0 for 90 degree phase shift. The terms “phase angle” and “power factor” are used interchangeably. Displacement power factor applies to sinusoidal waveforms only.
- **Virtual or phantom power.** Voltage and current are sourced separately to simulate actual power. Eliminates the need to source high voltage and current together.

each of the three phases may differ from each other due to different power factors, harmonics induced by loads, and load currents. Also, the phase rotation of a three-phase system may not be exactly 120 degrees, creating an imbalance.

Frequency
Most common frequencies are 50-60 Hz. Marine vessels and aircraft are often at 400 Hz. Fluorescent lights use much higher frequencies internally for efficiency.

Calibrating power instruments

Accurate power meters and power analyzers measure active and apparent power, power factor, frequency and phase, and harmonic problems over a wide range of frequencies. Multiple measurement functions with various display and calculation capabilities have helped make these instruments sophisticated tools for troubleshooting, service and repair.

Increasing attention on the detection and diagnosis of power system problems makes it increasingly important to ensure the accuracy of the tools used through calibration. Power instrument calibration presents a number of challenges, particularly where newer, more complex tools are concerned.

Most calibration laboratory managers prefer to meet the requirement with a minimum of equipment, training and support costs. The 55XX Series Multi-Product Calibrator were designed with that in mind. In a single, portable instrument, a 55XX Series calibrator is a complete solution for calibrating single-phase low frequency wattmeters and power analyzers. In addition, it supports a wide variety of other dc/low frequency measurement tools, including multimeters, current clamps and clamp meters, oscilloscopes, electronic thermometers and thermocouple simulators, chart recorders, panel meters and more. Unlike other alternatives, the 55XX Series calibrators are single, portable, easy-to-use instruments that can source voltage and current (or voltage plus voltage) simultaneously with precision phase control, multiple waveforms and the ability to generate harmonics.

Comparing two-calibrator and single-calibrator methods

One method for calibrating wattmeters is to use two or more meter calibrators. This method is complicated to set up, and phase-locking the two units and varying the phase can prove to be a challenge. Also, some calibrators may not have adequate voltage or current range to calibrate some instruments fully. Automation is difficult. And the user has to purchase, maintain and calibrate two instruments instead of one.

With a 55XX Series Multi-Product Calibrator, power calibration is available from a single instrument and there are no phase lock problems to resolve. The 55XX Series calibrators' phase angle/power factor control allows you to easily set either the displacement power factor or the phase angle between the voltage and current. Either output channel can lead or lag. And the 55XX Series' 1020 V and 20.5 A capabilities (20.9 kW) take care of the most common meter workload without additional amplifers.

Of course, with a single instrument, there is less for the user to have to learn or to remember, and there is only one instrument to buy, maintain and calibrate.

How the 55XX Series calibrate power meters

Simultaneous voltage and current outputs
The Fluke 55XX Series calibrators calibrate wattmeters up to 20,910 watts by simultaneously supplying voltage and current into a phantom load. To simulate current clamps where current is converted to voltage for the meter input, the calibrator can source two voltages simultaneously.

Voltage and current capability for power calibration
For calibrating power, the 55XX Series' voltage range is 33 mV to 1020 V; the current range is from 29 uA to 20.5 A, at 10 Hz to 10 kHz. This output capacity is sufficient for most handheld meter calibrations.

The 55XX Series will drive wattmeters like the Yokogawa Model 2041 Wattmeter (a portable, single-phase, low-power-factor wattmeter) on all current and voltage ranges without requiring any boost.

The Fluke Calibration 5522A Multi-Product Calibrator at work calibrating a Fluke power quality analyzer.

Calibrating the power factor

The voltage or current from the 55XX Series AUX output terminals can be phase shifted with respect to the voltage on the NORMAL output up to ± 180 degrees with a 0.02 degree resolution. Select either the phase angle or power factor control.

Calibrating harmonics

To simulate a current harmonic to the power meter, the AUX output current waveform can be set to any harmonic (multiple) of the fundamental frequency of the NORMAL terminal output up to the 50th harmonic. Only one harmonic is output at a time.

Frequency range

The calibrator doesn't require a synthesizer or frequency standard. It supplies ac output at frequencies from 0.01 Hz to 2 MHz.

Waveform selection

Part of the 55XX Series' versatility is due to their ability to output sine, square, triangle, or truncated sine signals from the NORMAL and AUX terminals. The waveform for each output can be selected independently. Some calibration procedures may call for current or voltage to be output with something other than a sine wave. A truncated sine wave, for instance, more accurately simulates what happens in a power distribution system with distorted current waveforms.

How to calibrate different types of power instruments

Make sure that you use high quality test leads, and take care not to use leads that are excessively long. Lead resistance, capacitance and inductance can cause errors. Take care in how the connections are made. If grounds are interconnected, loops can be created where current can find multiple paths to ground, distorting the voltage measurements being made.

Four-terminal wattmeters

These are the most common wattmeters and use either digital or analog display. The voltage and current terminals are separate. The voltage measurement circuit measures the voltage drop through a resistive shunt and calculates the current per Ohm's law. Many four-terminal wattmeters have circuitry to measure the phase relationship and display phase angle/power factor. Some devices may measure current using an inductive current clamp. These devices feature two voltage inputs, with the clamp converting the current to a voltage, usually 1 mV per amp. Fluke 39 and 41B Power Harmonics Analyzers are examples.

Connecting the a 55XX Series calibrator to a four-terminal power meter is straightforward and intuitive (see Figure 3). From the front panel terminals, connect the calibrator's voltage and outputs to the wattmeter's voltage and current inputs. Operating the calibrator is straightforward and intuitive too. Direct the output either as voltage plus current (to the meter shunt) or as voltage plus voltage (to simulate a current clamp on the meter current terminals).

Three-terminal wattmeters

These power meters really have four terminals, but the voltage and current "low" terminals are connected internally. Yokagawa 2534 and the Valhalla 2100A are three-terminal wattmeters. Figure 4 illustrates a simplified representation of three-terminal wattmeter connections.

If you connect the a 55XX Series calibrator to a three-terminal meter the same way you might calibrate a four-terminal meter, a number of errors can occur.

If you connect the voltage source to the source terminals of the unit under test, there will be an error in the displayed voltage due to the voltage drop through the shunt used to measure current. For example, if the 55XX Series calibrator is sourcing 100 V and 1 A, and the drop through the shunt is 1

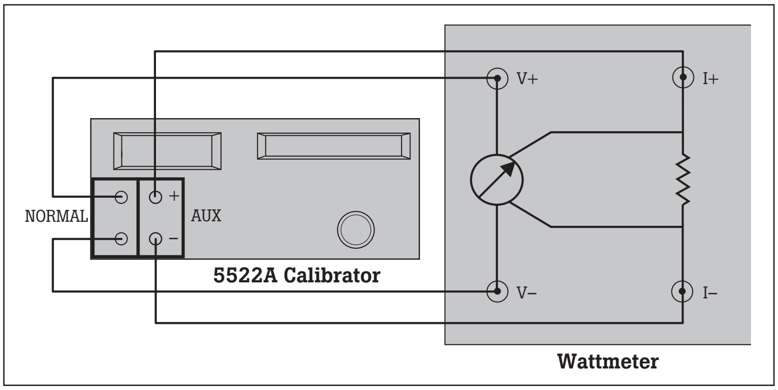


Figure 3. How to connect the 5522A to a four-terminal wattmeter.

V, the unit under test will only display 99 V, a 1 % error. The solution here is to connect the 55XX Series voltage outputs to the load side of the unit under test.

This solution creates another potential problem. The lows of the calibrator's voltage and current outputs are tied together internally, unless the operator has pressed the "LOs Open" softkey. In addition, current can find an alternative return path to ground through internal protective circuitry. In either case, current bypasses the shunt. The unit under test measures less current and you risk damaging the calibrator. The solution is somewhat counter-intuitive. Connect the "Hi" side of the 55XX Series calibrator's current output to the neutral or low input of the unit under test, and connect the "Lo" side to the 55XX Series current output to the + or high side of the unit under test current input. This solves the ground loop problem, but because the current is now flowing backwards through the shunt, it is 180 degrees out of phase, and the load appears negative, that is, sourcing power. This is easy to remedy by using the calibrator phase menu, shifting the phase 180 degrees. In addition, it is important to connect the voltage output of the 55XX Series to the load terminals of the wattmeter.

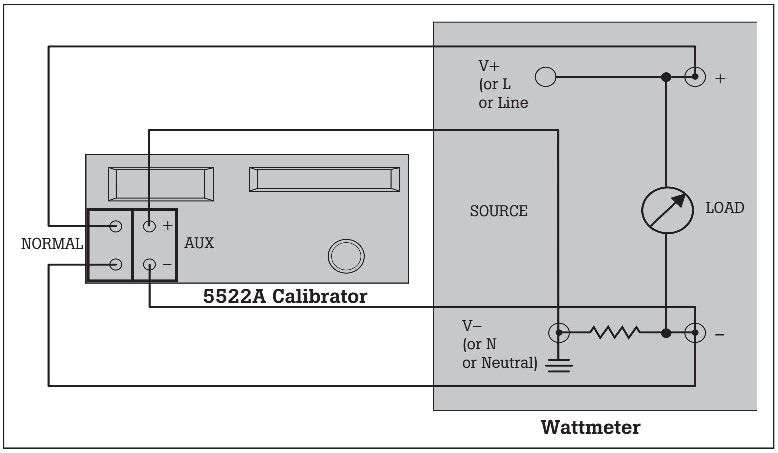


Figure 4. How to connect the 5522A to a three-terminal wattmeter. Note that the phase setting of the 5522A needs to be shifted 180 degrees to get a proper reading.

Power and harmonics analyzers

These are more complex handheld instruments that can measure up to the thirty-first harmonic, determine the power factor, and measure phase relationships. These analyzers display data in a waveform or text format and record minimum, maximum, and average power measurements over a period of time. These instruments compare voltage and current waveforms, compare the waveform phase relationships, and analyze sine-wave quality. Examples of power and harmonic analyzers include the Fluke 39 and 41B Power Harmonics Analyzers.

The 55XX Series accommodates the calibration requirements of these tools by:

- Generation of voltages from both the NORMAL and AUX terminals with precise phase control.
- Generation of the second to the fiftieth harmonic of the voltage on the NORMAL output from the AUX channel.
- Choice of sine, triangle, square and truncated sine on either output channel.

Other equipment

In addition to calibrating wattmeters and power quality/harmonics analyzers, the 55XX Series calibrators have the functionality to meet the calibration requirements of a wide range of measurement equipment, including:

- Current clamps and clamp meters.
- Digital and analog multimeters, true-rms and average reading.
- ScopeMeter® test tools and similar instruments.
- Oscilloscopes (analog and digital) to 300 MHz (with the 5500A-SC option).
- Data loggers.
- Process calibrators.
- Chart and XY recorders (Triangle wave shape down to 0.01 Hz for linearity testing).
- Thermocouple and RTD type temperature indicators.

Simplifying the calibration process

Because the 55XX Series calibrators provide you with the dual voltage or voltage plus current outputs, phase control, multiple waveforms and harmonics, you need only one instrument to calibrate the bulk of the wattmeters in use today. It eliminates the need for multiple instruments and removes the complication of phase locking two voltage sources or a voltage and current source together and matching the output frequencies to prevent distortion. All functions are

The 55XX Series calibrators do the job of eleven or more traditional calibrators.

controlled from a single front panel. Automation is vastly simplified. And acquisition and support costs over the life of the calibrator are reduced.

Ease of operation also enhances operator confidence and productivity. Ease of use features applying to wattmeter calibration include:

- Simple, straightforward control of voltage, current, frequency, phase/power factor harmonics and waveform functions.
- Controls that are laid out in a natural, left-to-right pattern, with clear labels and a standard numeric 10-key pad.
- All connections to the units under test are made on the front panel.

Control settings are displayed in the right window of the calibrator, and output is displayed on the left. If you set 5 A 100 V, the calibrator will display those values in the left window and display 500 W in the right window.

Calibrating a typical power analyzer (the Fluke 41B) demonstrates these easy-to-use features:

1. Begin by connecting the voltage leads from the 55XX Series calibrator's NORMAL terminals to the UUT voltage input terminals and a cable from the calibrator's AUX terminals to the UUT current clamp input using a BNC to banana adapter.
2. Set the meter in voltage and waveform modes.
3. Type 120 V 100 mV 60 Hz ENTER OPR. (V, mV, Hz, OPR, and Enter are easily recognizable keys.) The analyzer will display about 12 kW. (The 100 mV simulates 100 A at 1 mV per amp, at the current clamp input.) The analyzer display will show the 60 Hz sine wave.
4. Determine the meter error by using the calibrator's edit knob to slew the voltage or current output. Turn the knob until the meter indicates *exactly* 12 kW. Read the error value in the calibrator output window and the error percentage or ppm in the control window.
5. Press the calibrator PHASE softkey. Type in 45 ENTER. Notice that the current waveform has shifted 45°. You have just simulated a phase shift. Notice that the displayed power on the unit under test is reduced to about 8.5 kW.
6. Press the calibrator SHOW PF softkey. The control value display changes from 45° to 0.707.
7. Press the calibrator's HARMONIC MENUS softkey, press HARMNIC, and type 3 ENTER. The calibrator is now sourcing the fundamental frequency to the meter's voltage input and the third harmonic (180 Hz) to the meter's current clamp input. Verify the meter is reading the third harmonic.

Standards, traceability, and specifications

Why calibrate?

Measurement quality is becoming a core concern throughout industry. Modern quality programs and standards stress controlling and managing processes. A central method for doing that is to make meaningful measurements of those processes. Calibration makes measurements meaningful.

Meaningful measurements

For any measurement to be meaningful, it must be traceable to a recognized standard, in most cases, a national or legal standard for the quantity being measured. This traceability is accomplished through a documented series of comparisons from one level of standards to increasingly accurate standards.

Trends

Because of its central role in process control, measurement quality has gained a more widely recognized place in today's quality standards. Examples include the ISO 9000 series, the U.S. auto manufacturer's QS9000, U.S. Food and Drug Commission's GMPs, and the Nuclear Regulatory Commission's 10CFRs. The one thing these standards have in common is the requirement that measurements affecting quality be adequate and documented traceable to recognized standards.

Technology advances have put greater measurement and troubleshooting power in the hands of more people. The 55XX Series calibrators were designed with that in mind—making simple and efficient-to-perform traceable calibrations of the kinds of electronic test tools commonly in use today.

Truth in specifications

Many specifications are hard to understand. Some list several independent factors, so that when you combine them, you get surprises. Sometimes, it is almost impossible to compare specifications of one instrument to another due to the

- **Uncertainty.** A range of values typically centered on the nominal value. Uncertainty is measured in parts per million (ppm) or percentage of the output or setting.
- **Confidence level.** The percentage of probability that the true value will lie within the uncertainty range. As a rule, Fluke specifications meet or exceed 99%.
- **Test Uncertainty Ratio (TUR).** The ratio of the specified unit under test uncertainty divided by the uncertainty of the calibrating instrument. For instance, an acceptable TUR between a DMM and a Multi-Function Calibrator (MFC) is 4:1.

differences. Good power meter calibrator specifications are complete, are easy to use and interpret, and adequately define environmental and load effects. Reputable manufacturers will describe calibrator performance as accurately and simply as possible without hiding areas of poor performance.

To make the 55XX Series' specifications easier to use and interpret, Fluke Calibration combines all the sources of measurement uncertainty into a single, 99 % confidence-level uncertainty specification. You could say that Fluke wrote the book on instrument specifications. In fact, two of our technical publications, *Calibration: Philosophy and Practice* and *Understanding* and *Comparing Instrument Specifications,* provide industry-standard guidelines for understanding and using instrument specifications.

Automating the calibration process

Making the measurements is only part of the calibration process. The calibration manager also must assure that his process is:

- Performing consistently.
- Has documented, controlled and understandable procedures.
- Has traceability to accepted standards.
- Can report information quickly.

The power, flexibility, and easy customization of the optional Fluke Calibration software helps you meet these requirements with a minimum of effort and administration. The convenience that Fluke Calibration software provides is especially valuable in ISO 9000 documentation programs, where keeping calibration records and assessing test results validity are important program functions.

Calibration software

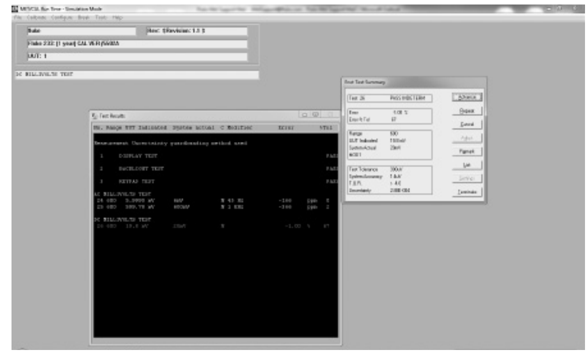
Calibration with the 55XX Series calibrators can be fully automated with MET/CAL *Plus* Calibration Management Software. MET/CAL *Plus* uses hundreds of procedures to automate the 55XX Series and other calibrators. A full procedure listing is available online at www.flukecal.com/procedures.

MET/CAL software supports both the RS-232 pass-through interface and the IEEE-488 interface of the 55XX calibrator.

MET/CAL *Plus* software provides the user with an environment for developing, testing and executing calibration procedures, collecting and reporting results and managing the calibration system.

MET/CAL software provides:

- Flexibility and a growth path to accommodate changing needs.
- The ability to configure calibration programs for future performance requirements.
- Testing consistency: Instruments tested will be calibrated the same way, every time.
- Reliable documentation: The software generates complete, readable calibration procedures.
- Documented calibration results: The software automatically records the measurements, calculates and records the error, and reports the results.
- Comprehensive reporting: Report formats include calibration certificates, summaries, detailed results, as-found/as-left and test uncertainty ratio reports, traceability, and the calibration environment. The procedures, data collection functions and reports meet all ISO 9000 ISO Guide 25 and other requirements.
- Improved productivity: Fluke



Calibration with the 55XX Series calibrators can be fully automated with MET/CAL *Plus* Calibration Management Software.

MET/TEAM is a powerful, browser-based application for managing calibration assets and workflow.

Calibration software uses the familiar Microsoft Windows user interface to make learning and running the software easy. The software takes control of the 55XX Series calibrator and speeds it through its paces. It steps the technician through connections, visual verifications, and UUT control steps. And the technician doesn't need to record data.

- Flexible workload management: The procedures that come with Fluke Calibration software will probably cover most of your oscilloscope calibration workload. Use Fluke calibration procedures as is, change them to reflect local laboratory protocols, or use them to write new procedures.
- Easy procedure development: If you prefer, you can write your own procedures. You

FLUKE® Calibration

don't have to be a programmer to write them. The calibration software uses a modular approach to create readable procedures. You can also use the Autopro utility to fill out a spreadsheet with specifications from a data sheet. And if you need help developing your procedures, Fluke Calibration training is available.

Metrology workload management

MET/TEAM™ Test Equipment Asset Management Software is a powerful, flexible, and scalable solution for managing your calibration assets. Designed by metrologists for metrology, it is ideal for calibration professionals who need to manage workflow through the calibration laboratory. MET/TEAM software enables you to:

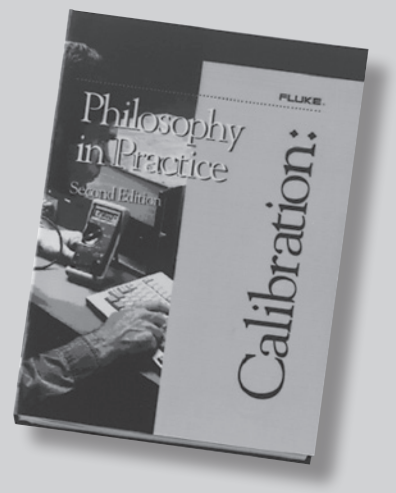
- Manage all aspects of your calibration operation with one paperless solution
- Improve productivity and reduce operating costs
- Maintain compliance with regulatory standards
- Configure and customize for your business rules
- Report to meet a wide range of requirements
- Schedule maintenance events
- Perform batch receiving
- Create, track and close work orders
- Track assets as they move through the lab
- Create and print calibration reports
- Maintain an audit trail
- Manage shipping information
- Track customer and vendor information
- View business statuses
- Create data templates and store procedures
- Choose from optional modules for onsite calibration, customer web portal, and billing/quoting/contract pricing.

Training and technical support

A good instrument is not the total product. Training and support services can help you achieve maximum efficiency and satisfaction from Fluke Calibration products.

Workshops and applications courses

The best way to get the most performance and productivity from your Fluke Calibration equipment is to spend just a few days training with the company that knows it best. Visit **www.flukecal.com/caltraining** for course information, schedules and online registration.



Fluke Calibration "wrote the book" on calibration. *Calibration: Philosophy and Practice* is an extensive reference on all aspects of calibration programs, elements of metrology, and calibration laboratory management.

Fluke Calibration. *Precision, performance, confidence.*™

Electrical	RF	Temperature	Pressure	Flow	Software

Fluke Calibration
PO Box 9090, Everett, WA 98206 U.S.A.

Fluke Europe B.V.
PO Box 1186, 5602 BD
Eindhoven, The Netherlands

For more information call:
In the U.S.A. (877) 355-3225 or
Fax (425) 446-5116
In Europe/M-East/Africa +31 (0) 40 2675 200 or
Fax +31 (0) 40 2675 222
In Canada (800)-36-FLUKE or
Fax (905) 890-6866
From other countries +1 (425) 446-5500 or
Fax +1 (425) 446-5116
Web access: http://www.flukecal.com

Printed in U.S.A. 7/2012 1262701B A-EN-N
Pub-ID 11915-eng