Metrology, Calibration, and Your Tektronix Instrument

According to Dictionary.com[1], metrology is "the science that deals with measurement." Other lexicons may define the term more elaborately, but the underlying messages remain the same: 1) metrology is a science, and 2) metrology is about measurement.

1. Introduction

Metrology and calibration are intertwined. From the perspective of the measurement instrument owner/user, calibration is a valued and necessary product. You can't buy "metrology" but you can purchase a calibration that embodies the best metrology practices. Ideally a credible calibration provider will have metrology experts on staff to develop and oversee calibration procedures, monitor changing calibration standards, and control in-house equipment used for calibration.

Metrology is the discipline that defines *standards* and codifies *accreditation* and *traceability*. For the purposes of this discussion, let's look at some high-level definitions for each of these terms:

- **Standards**—Formally developed guidelines defining processes and tools for calibration. An example is ANSI/NCSL Z540.1-1994(R2002). Here, R2002 means "Reaffirmed in 2002."

  The term "standard" also denotes measurement reference standards, which are tangible realizations of weights and measures such as the standard kilogram; similarly it applies to intrinsic standards or natural constants derived from the physical properties of materials and energy.

- **Accreditation**—A process for approving compliant calibration facilities and procedures.

- **Traceability**—A means of ensuring the accuracy of calibration, implemented through a hierarchy of established measurement references for quantities such as distance, weight, electromotive force (voltage), etc.

Your instruments need to be calibrated to accepted standards so that their results can be trusted to have a universally understood meaning. If you measure a 10 MHz signal frequency in Germany with an oscilloscope, the concept of "10 MHz" needs to mean the same thing on an oscilloscope in Australia. Metrology is the basis of the standards that ensure predictable performance from your measurement tools.

Equally important, metrology provides a platform for commerce. Calibration, with metrology at its heart, is a requirement for contractual relationships among many businesses, and even more rigorously a part of businesses' transactions with government entities and the military. These are the formal institutions. Just as essential is the understanding that quantities of merchandise exchanged in trade are uniformly defined. Whether the quantity is a gram of gold or a data rate of 2.5 Gb/s, money changes hands on the basis of trust in the applicable measurement. Metrology assures this trust with clear, consistent standards and the continuing refinement of processes.

Metrology expertise plays a key role in Tektronix' reputation for accuracy, precision, and performance. Figure 1 summarizes the areas of metrology involvement at Tektronix. Metrologists oversee calibration practices in both Manufacturing and Service throughout the company. While a new instrument is still in the engineering lab, Tektronix metrologists participate in developing calibration procedures that will be used first to set up the prototypes, and then to calibrate instruments coming through the production line. Ultimately these procedures are delivered to the Tektronix worldwide Service organization for support of the product throughout its life cycle.

[1] www.dictionary.com

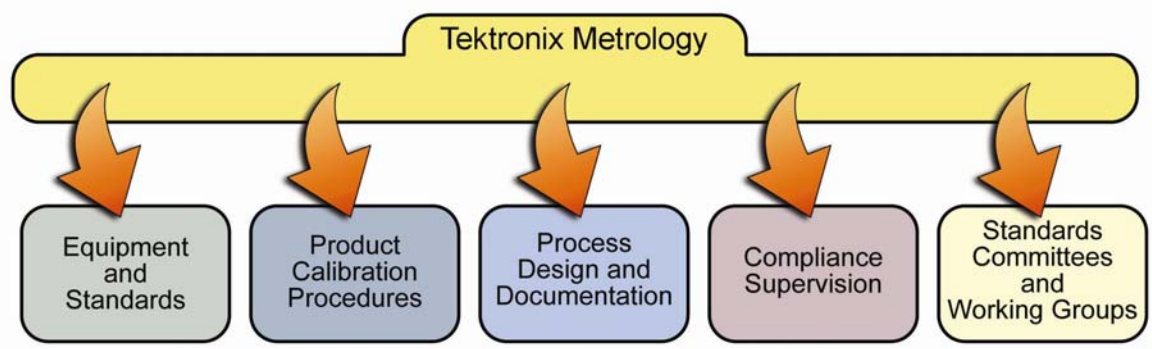

Figure 1: Areas of responsibility for metrology at Tektronix.

When you choose Tektronix as your service provider, you get the benefit of an experienced metrology staff plus seasoned technicians applying deep product-specific knowledge. Fixturing, software, and procedures are optimized for the Tektronix products that are the fundamental commitment of the Tektronix Service organization. Tektronix Service provides an unsurpassed combination of expertise and insight with one goal in mind: services guaranteed to be of the highest quality in the industry.

2. Metrology and Your Calibration Choices

Metrology ensures that your calibrated instruments deliver accurate results with provable validity. National and international standards define calibration processes, certification guidelines, and traceability requirements. At Tektronix, metrology professionals guide company-wide calibration policies and procedures. They are responsible for integrating the standards published by organizations such as ANSI and ISO into Tektronix calibration processes.

Metrology processes and standards are not static. As components and system technologies get faster; as new bus architectures emerge; as test methodologies evolve, standards must advance with them. A volt will always be a volt, but the way a volt is measured may change. National and regional metrology bodies meet regularly to plan for these technology dynamics. Tektronix metrology and service personnel participate in NCSLI, A2LA, DKD[2], and a host of other in industry committees and conferences.

Tektronix customers have a choice of calibration “products,” or levels. These reflect the needs and obligations of particular industries and business models.

Accredited Calibration

Accredited calibration is the most comprehensive level of calibration service available from Tektronix. Typically this option is selected when the instrument owner must comply with a contract requiring accredited calibrations. The company that owns the instrument may be involved, for example, in the manufacture of products related to safety, health, or military applications. The end-users of those products rely on zero defect manufacturing and test policies, and this is where the accredited calibration comes in: it is based on rigorous procedures executed by competent personnel and documented in great detail.

An accredited calibration from Tektronix meets ISO 17025 requirements (see Calibration Standards section in this document), along with government regulations and requirements from the local accrediting body in the applicable region. Accredited calibration supports statistical process control methods; calibration details can be integrated into factory-wide tracking systems.

Accredited calibrations must be performed by competent technicians. An explanation of this term is in order here. “Competent” is one of those words that sounds unimpressive on its own, lacking the usual superlative tone. However, competent is understood in the metrology industry to mean “qualified” and “proven capable.” An accredited organization’s credentials, when granted by the certifying body, cover individual technicians who have been deemed competent. These are the only personnel authorized to perform accredited calibrations.

[2] See the glossary for a definition of these acronyms.

An accredited calibration from Tektronix typically includes adjustments necessary to restore the instrument's performance to factory specifications. Many calibration customers would be surprised to learn that adjustments to correct out-of-tolerance conditions are not required by the "letter of the law." The formal definition of a calibration, as endorsed by the leading global standards bodies, consists of comparing the instrument under test with a traceable reference standard. The results are reported in terms of the error amount or the actual measurement value.

There is no absolute requirement to correct the observed errors, although most commercial calibrations are conducted for exactly that purpose. The standards applying to accredited calibration don't prohibit adjustment to specifications; they just don't require it. Most calibration customers want these adjustments and they are commonly included in Tektronix' accredited calibration procedure.

In many situations, documentation is as important as the calibration itself. An instrument returning from an accredited calibration by Tektronix is accompanied by a Test Data Report that includes details on measurement uncertainties[3], as well as a compliant Certificate of Calibration that distinguishes the procedure as an accredited calibration.

For more information on the accreditation process, go to the Accreditation section in this document.

Traceable Calibration

Traceable calibration is by far the most common calibration product from Tektronix. This procedure brings the instrument within specifications and is sufficient for most applications.

The traceable calibration delivers a valid, useful, and reassuring set of services. It delivers a statement of received condition stating whether the instrument was received with specifications within tolerance or out of tolerance. Adjustments are made where necessary to restore performance to specifications. A Certificate of Calibration is issued, documenting facts such as the actual test instruments used in the measurement procedure, dates, and measurement conditions, received/returned condition, and more.

The Calibration Certificate documents its own unique serial number and that of the received instrument as well. This ties a specific calibration event with a specific instrument. Because the certificate also includes the model and serial numbers of the instruments used to calibrate, it sets up the first link in the traceability chain. Each of these instruments is traceable, having been calibrated in turn with traceable instruments which are identified on its certificate. This establishes an unbroken connection to national metrology institutes and artifacts.

A detailed test data report is available optionally with traceable calibrations from Tektronix.

During calibration, any adjustments must occur after the instrument's incoming performance has been evaluated, not as part of the receiving procedure. This is the only way that the condition of the instrument truly can be known. Moreover, it is the only way to know whether the instrument was doing its measurement job within acceptable tolerances during the period preceding the calibration. A thorough traceable calibration process is one of measurement, then adjustment, and then a second series of confirming measurements.

A traceable calibration is a reliable way to keep a Tektronix instrument performing at its best. It ensures that normal electronic changes in component values as well as unseen failures do not accumulate to the point where they compromise measurement accuracy. For most purposes, a Tektronix traceable calibration is considered sufficient to fulfill end-users' expectations for manufacturing and design applications.

Functional Verification

A Functional Verification procedure is appropriate for devices other than measurement instruments. An example of such an application would be a system that consists of software-based analysis tools integrated into a conventional PC. The unit under test neither creates signals nor acquires them in the usual sense; it simply analyzes data accumulated through common computer interfaces. A "calibration" would be meaningless in this context.

The functional verification certificate includes a statement of received conditions and adjustments made to restore performance to specifications. Unlike the other calibration offerings described here, the certificate does not guarantee traceability or compliance with specific calibration standards.

[3] Uncertainty reflects the fact that measurements inevitably are imperfect to some degree. Uncertainty defines the limits on how much the measured value can deviate from the true value. You will find more information about uncertainty in the section on calibration standards, and in the Glossary.

A "Guided Tour"

Providing commercial calibration services is a complex business requiring a substantial investment in equipment, infrastructure, and personnel. This white paper closes with a section titled "A Guided Tour Through The Calibration Process" that explains how Tektronix' Beaverton, Oregon, USA Service Depot takes instruments through the calibration process. Read the Guided Tour for a quick illustrated overview of the facilities and processes that support accredited and traceable calibrations at Tektronix.

3. Calibration Standards Bring Order to a Complex Task

Standards are structured requirements for a process such as calibration or compliance. Most standards embody the deliberations of interested industry participants, commonly with input from governmental regulators. Parliamentary procedures within the committees ensure fairness in approving and administering all aspects of a standard. Standards published in written form are the cornerstone of calibration.

Without rigorously enforced standards for processes, performance, and record-keeping, calibration would be meaningless. A written standard ensures that consistent measurement entities (voltage, current, temperature, time) will be used.

Proper calibration means compliance with standards, including traceability requirements, documentation, processes, and competencies. A compliant calibration means confidence in the results. Without compliance, the calibration—and its measurement results—may be invalid. An instrument calibrated with non-compliant tools or procedures is itself non-compliant, although that fact may not be known until the unit starts to cause problems.

Standards and accreditation are two sides of the same coin. Any discussion of standards requires some mention of accreditation. Similarly, the information under the Accreditation heading later in this document will bring out details relevant to standards.

The following three key industry standards govern the way calibration is done around the world today:

- ISO/IEC/EN 17025
- ANSI/NCSL Z540.1-1994(R2002)
- ISO 9000

Local governmental regulations may add requirements beyond these standards.

ANSI/ISO/IEC/ 17025:2000

ANSI/ISO/IEC[4] 17025 is the most rigorous globally-accepted standard. In everyday conversational terms the standard is known simply as ISO17025. On the international scene, ISO17025 supplants or supplements several earlier standards including ANSI/NCSL Z540 and ISO/IEC Guide 25.

The standard prescribes "General Requirements for the Competence of Calibration and Testing Laboratories." Note, however, that its requirements pertain to specific measurements rather than a laboratory as a whole. In other words, a lab that meets ISO 17025 mandates for personnel competence, documentation, and quality certification can perform accredited calibrations but can claim accreditation only for the approved measurements.

A distinctive feature of ISO17025 is its requirement to provide uncertainty information to support its calibration offerings. The calibration vendor must analyze the uncertainty of each measurement and use that information to configure the test procedure and determine the limits thereof. The uncertainty data might affect, for example, the number of frequency points that must be tested across the bandwidth of the instrument being calibrated.

Uncertainty data must accompany the instrument when it is returned to its owner. This gives the end-user insight into the degree of accuracy that the calibration laboratory can provide with its ISO17025-compliant calibrations. It is also a valuable tool for judging the capability of the calibration lab as compared with other providers.

[4] ANSI = American National Standards Institute; ISO = International Organization for Standardization; IEC = International Electrotechnical Commission

ISO17025 calibrations are the benchmark of calibration performance. Due to the costs associated with accreditation and compliance, plus the time and cost of supporting the more elaborate procedures and documentation, ISO17025 calibrations are more expensive than other alternatives. In general, ISO17025 calibrations are purchased when local regulations, specific industry standards (automotive, aerospace, etc.), or individual customer contracts require them.

ANSI/NCSL Z540.1-1994(R2002)

The ANSI/NCSL Z540.1-1994(R2002) standard, commonly known as "Z540," is a U.S. standard that sets compliance guidelines for "Calibration Laboratories and Measuring and Test Equipment." Like the ISO 17025 standard, the Z540 guidelines are meant to apply to specific calibrations, not a whole institution such as a calibration laboratory.

The Z540 standard expresses guidelines for every aspect of the calibration process, from technical management to the environmental conditions within the calibration facility. In general, the Z540 guidelines do not make quantitative requirements on the calibration lab. The guidelines do not extend to specifying such things as the ambient temperature in the calibration facility or the educational credentials of the management and technical staff, or for that matter the accuracies and tolerances of specific measurements. These judgments are left to the calibration vendor, its customers, and the market.

The standard goes to some lengths to ensure that calibration labs are equipped with the correct tools for the job, and equally important, that these tools are maintained, calibrated, and documented as such. There are also stipulations about traceability—instruments used in calibration processes must be traceable to national, international, or intrinsic[5] standards. Lastly, the minimum required content for calibration certificates is itemized.

The ANSI/NCSL Z540.1-1994(R2002) standard mandates specific itemized information on the certificate. In particular, the standard requires the provider to identify the procedures that were used in the calibration. But there is no stipulation about the nature of this procedure. Technically this allows the provider to adapt a calibration procedure from a source other than the manufacturer of the equipment being calibrated.

All Tektronix certified traceable calibrations are performed to meet the specifications published in each instrument's original service manuals. These in turn reflect the performance of newly-manufactured instruments.

The ANSI/NCSL Z540.1-1994(R2002)-compliant calibration is the basic traceable calibration product offered by Tektronix for its customers in the United States. Equivalent service levels are of course available in other regions, but the Z540 designation may not apply.

ISO 9000

ISO 9000 is a set of "generic management system standards[6]" pertaining to quality. It is most important to note here that ISO 9000 and its adjuncts are not calibration standards. In fact, they are not even management practice standards.

The ISO 9000 series provides a framework for developing and documenting a process or system wherein quality management can be effectively implemented. The stated intent is to enhance customer satisfaction, meet customer needs and regulatory mandates, and steadily improve performance in these same areas. ISO 9000 is not limited to the production of electronic products. The ISO 9000 series may apply equally to an auto manufacturer, a bank, a government agency… or a calibration lab.

Because compliance with ISO 9000 is a requirement of the prevailing calibration standards (including ISO17025 and Z540), its influence is felt in the calibration community. However, there is no such thing as an ISO 9000 calibration, nor does ISO 9000 certification imply adherence to ISO17025 or Z540 standards. Moreover, calibration in an ISO 9000-compliant facility does not imply that the calibration procedures are accredited in any way.

ISO 9000 is a series of standards with several components. Tektronix' regional sites are registered to the ISO 9001:2000 standard. In addition, the corporate headquarters in Beaverton, Oregon and the Tokyo, Japan facility are registered to the ISO 14001:1996 standard for environmental management processes.

[5] Intrinsic standards are those that relate to observable physical phenomena, typically based on behaviors at atomic level or at certain light wavelengths.

[6] As defined by the ISO website, http://www.iso.org

4. Traceability Brings World-Class Standards to Local Calibration Labs

Traceability is the thread that connects your calibrated tools to established references and standards. It confirms that your instruments will measure accepted units (whether electronic, optical, or dimensional) to agreed levels of accuracy. Traceability is essential to meeting worldwide measurement, trade and regulatory requirements.

ISO 9000 quality standards require traceability in calibration labs. Compliant facilities must "calibrate… against certified equipment having a known valid relationship to internationally or nationally recognized standards." Tektronix service and calibration facilities are ISO 9001-registered.

Certified measurement products sold by Tektronix are traceable to national metrology institutes and the SI International System of Units. Tektronix measurement products are shipped with Certificates of Traceable Calibration. This same level of calibration is supported by, and can be purchased from, Tektronix throughout the instrument's life cycle.

Tektronix measurement instruments built in the United States are compliant with ANSI/NCSL Z540.1-1994(R2002) requirements, traceable to one or more of the following national metrology institutes: NIST, NPL and PTB. The facility is ISO 9001 registered. Tektronix measurement instruments built in China comply with ANSI/NCSL Z540.1-1994(R2002) requirements, traceable to one or more of the following national metrology institutes: NIM, NIST, NPL and PTB. The facility is ISO 9001 registered.

Traceability begins with standards maintained in national metrology institutes (NMI). There are more than 100 of these institutes distributed around the world. National metrology institutes throughout the world regularly compare their standards with one another, ensuring consistency across national borders. NMIs form the uppermost tier of the hierarchy shown in Figure 2, which illustrates a typical Tektronix traceability process[7] that ends with an individual unit under test—in this case an oscilloscope and its amplitude (voltage) measurements. The NMI maintains a standard representing a quantity of 10 volts with appropriate uncertainties.

The NMI 10V standard is the reference for a subordinate tier of "in-house" standards in independent or corporate laboratories. The in-house standards become the everyday calibration reference for the laboratories' voltage calibration work. These of course must be maintained and calibrated at regular intervals to ensure continued accuracy and compliance.

Tektronix Metrology steps in at the next tier. A high-resolution digital multimeter (DMM) is responsible for carrying the quality of the in-house standard to the Calibrator that will ultimately calibrate the unit under test. The DMM's precision is confirmed by measuring upward in the hierarchy: it is checked against the 10V in-house standard. Once this has been established, the DMM turns "downward," where it measures the working standard—the oscilloscope calibrator. The calibrator sources 10 volts, and the DMM reads the result. If the measurement is within tolerance, then the calibrator is ready to make amplitude measurements on a unit under test: an oscilloscope. This entire process, from the in-house standards on down, is performed at specified calibration intervals. The process ensures that traceable instruments are calibrated with traceable instruments and standards, ultimately conferring a known degree of traceability to the unit under test.

[7] Figure 2 is a simplified traceability flow chart. Sample traceability maps can be accessed from http://www.tek.com/service/metrology/accreditation.html.

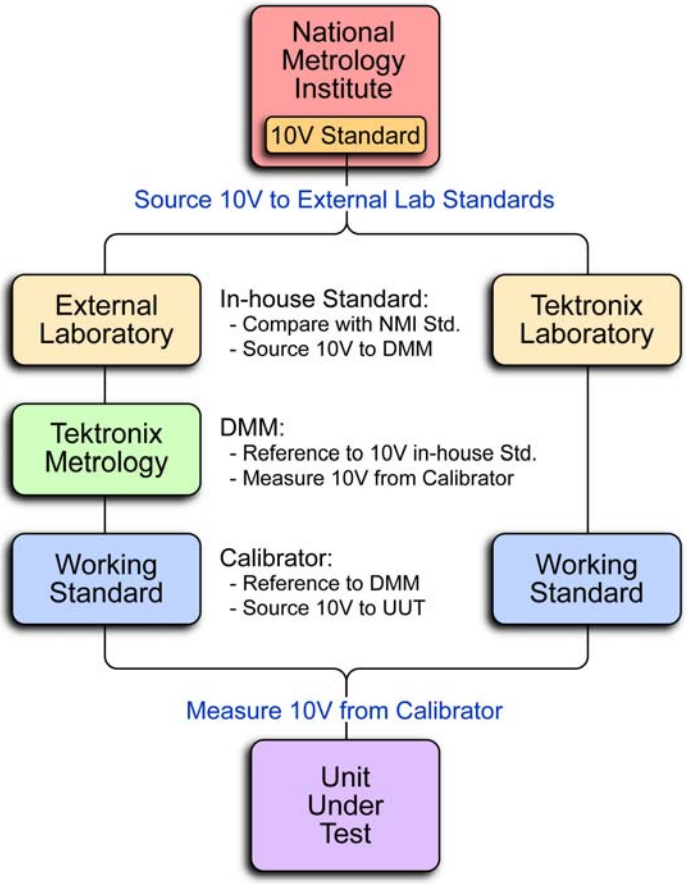

Figure 2: The hierarchy of traceable calibration. A 10V standard in a national metrology institute becomes the definitive source for external 10V references used to calibrate "working" standards.

In recent years, "intrinsic" standards have gained favor as a top-level calibration reference, sometimes nomenclated as an artifact. Intrinsic standards use the physical properties of materials and energy to create very accurate, very controllable calibration references. An example is the Josephson junction array which, when exposed to microwave radiation, emits a DC potential (voltage) based on the frequency of the radiation, the charge on the junction, and Planck's constant. Simply stated, a Josephson junction is a frequency-to-voltage converter with accuracy in the range of 2/100 of a ppm or better (≤.02 parts per million) at 10 volts. Calibration standards such as ANSI/NCSL Z540.1-1994(R2002) allow the use of intrinsic standards in calibration.

5. Accreditation Approves Calibration Process, Measurement by Measurement

Accreditation is a rigorous certification process that ensures compliance with applicable standards. It enforces traceability and consistency across an entire calibration process. Accreditation ensures the competence of a calibration process, as confirmed by an accepted accreditation body. In the language of standards and metrology, the terms "competent" and "competence" denote the verified ability to carry out calibration procedures in compliance with applicable standards.

A laboratory entitled to perform accredited ISO 17025 calibrations, for example, will have proven facilities and equipment and competent personnel. ISO 17025 accreditation requires review and approval of every single measurement step in the calibration procedure. In the case of a complex instrument such as an oscilloscope or spectrum analyzer, this amounts to thousands of measurements. These are documented in reports sent to the accrediting body.

Every accredited lab has a "scope of measurements[8]," among its accreditation documents. This defines the specific types of measurements for which the lab is certified: DC voltage, resistance, etc. Traceability, too, is a requirement in accreditation.

Four Tektronix calibration labs are accredited for ISO 17025-compliant calibrations:

- Beaverton, Oregon, USA; accredited by A2LA
- Cologne (Köln), Germany; accredited by DKD
- Taipei, Taiwan; accredited by TAF
- Singapore; accredited by SAC-Singlas

As explained earlier in the Calibration Standards heading, Procedures submitted for accreditation by third-party calibration vendors may not be the same as those recommended by the instrument manufacturer. Tektronix accredited calibrations comply fully with the specifications outlined in the original service manuals.

Accreditation requirements are not uniformly implemented around the world. Standards such as ISO 17025 are almost universally accepted but host governments and local bodies in individual countries may add requirements over and above the industry standards. Moreover, some regions have certain requirements that must be met before the word "accreditation" can even be used!

6. Calibration Certificates Document Your Instrument's Calibration Experience

A calibration certificate is the tangible part of the value a customer receives with a calibration. The certificate is proof that accepted industry standards have been met; that the instrument is performing to specifications at the time the calibration is completed; and that contractual requirements, if any, have been complied with. Both accredited calibrations and traceable calibrations from Tektronix include a Calibration Certificate that accompanies the instrument when it is returned to its owner.

The calibration certificate documents essential information about the instrument's condition, both before and after the calibration, and also provides details about out-of-tolerance conditions, special measurement conditions, and more. Each certificate has its own unique serial number and also documents the serial number of the calibrated device. This associates one calibration with one instrument. The certificate is important because it may be required by the end-users of products tested with the instrument, especially in the case of government contracts.

While there is no one "standard" form for calibration certificates, standards such as ISO 17025 and Z540 require a certain minimum amount of information. Most important are the "Received Condition" report and the complementing "Returned Condition" report. When an instrument is received, its performance is checked and recorded *before any adjustments are made*. When a parameter fails to meet specifications, its quantified out-of-tolerance values are provided.

Why is it so important to withhold adjustments until after the Received Condition is determined? Because the incoming measurements are meant to pinpoint the instrument's performance preceding the calibration. This will reveal whether the instrument in question is out of tolerance, and may have been delivering inaccurate results in its measurement application. Products or equipment tested with instrumentation that is demonstrably out of tolerance may have hidden defects that need to be corrected.

After the Received Condition tests, necessary adjustments and repairs are made and the whole measurement procedure is repeated. Now the corrected values are reported (along with a description of any adjustments made) in detail that depends on the options the customer has chosen. If necessary, a Test Data Report can be provided—a report up to 50 pages in length that lists measurements, values, and limits. The Test Data Report is a standard deliverable for accredited calibrations and optional with traceable calibrations from Tektronix.

[8] Sample accreditation and scope of measurements certificates for Tektronix calibration in the U.S. and other regions can be viewed at http://www.tek.com/service/iso/iso17025-usa.html.

Entries on the calibration certificate range from the date completed to details about the calibration equipment used. Most Tektronix certificates will include the following information:

- Dates and environmental conditions at the time of calibration
- Condition of instrument when received.
  - In Tolerance or Meets all measurement specifications.
  - Operational Failure - Function(s) affected to extent that no determination can be made on measurement accuracy. Certificate will provide a brief explanation of the failure.
  - Out-of-Tolerance - Measurement accuracy problem. Certificate will provide the following additional details:
    - Measurement parameter(s) affected
    - Measured value(s)
    - Measurement limit(s)
    - Where applicable, reference to an attached calibration data report and uncertainty data
  - Limited or Special Specifications.
- Returned Condition
  - In Tolerance or Meets all Specifications (may be in certificate statement).
    - The certificate will provide a brief description of the returned condition if the instrument is not In Tolerance. Also (where applicable), it will reference an attached calibration data report and uncertainty data
- Certification of traceability and compliance with a specific standard
- Model, manufacturer, and Serial Number of calibration tools used in the calibration. Associates specific traceable instruments with this certificate.
- Calibration Due Date of the equipment used in the calibration. Confirms that the calibration equipment is itself properly calibrated.
- Calibration procedure used, including revision level if applicable.
- Calibration interval and source of recommendation: Tektronix or customer
- Contact information for inquiries about this Certificate

Conclusion

Metrology is the foundation of every credible calibration institution. Metrology guides the process and oversees execution and documentation. By setting requirements for traceability and accreditation as well as refining and monitoring the underlying standards, metrology practitioners play a quiet but crucial role in commerce and industry today.

A Guided Tour Through The Calibration Process

This section explains the process an instrument follows when it is sent in for a traceable calibration procedure to the Tektronix Beaverton, Oregon U.S.A. Service Depot. Here, skilled technicians calibrate instruments ranging from individual probes to high-end laboratory equipment. The Depot is just one of many Tektronix facilities equipped to provide calibration and repair services to customers.

1. Check-In Time

Most calibrations begin and end at the loading dock. Here, delivery trucks make several visits per day, dropping off instruments sent in by customers around the world[9]. When a unit arrives, it is promptly unpacked and inspected, and its work order is called up on the computerized tracking system (Figure 3). The administrative details and customer instructions are logged in on the Depot's computerized tracking system, a tool optimized for service applications. These steps ensure that any physical damage is documented, and that the customer's instructions—calibration or repair—are on hand and understood. The instrument and its documentation are never separated until the unit is shipped out from the loading dock. From this moment on, the instrument's whereabouts and status can always be established.

Figure 3: Incoming instruments are logged in, entered into the tracking system, and checked for physical damage.

During the course of the instrument's stay at the Beaverton Service Depot, the tracking system accumulates information about the instrument and its calibration. It records the product's whereabouts as it moves from one cal station to another, and tracks exactly who has worked on it. Ultimately the tracking system generates the calibration certificate and other necessary paperwork documenting the procedure.

[9] Typically a service center's work consists of work drawn from its own region. However the Beaverton Service Depot is the clearinghouse for some Tektronix models.

2. Into the Depot and On To The Calibration Bench

Now the instrument enters the Depot itself, where it is staged temporarily (Figure 4) until it is picked up in order of its promised delivery (return) date.

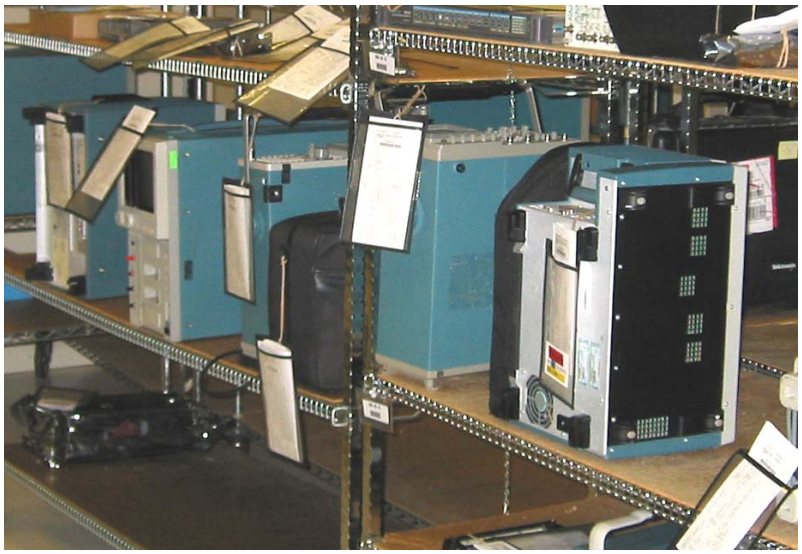

Figure 4: Instruments are tagged and queued for calibration.

Now the real work of calibration begins. Many products are supported by state-of-the-art automated calibration systems using software-based tests developed under the supervision of staff metrologists. Depending on the number of measurement points in the routine (one particular spectrum analyzer model, for example, must have its response checked at 100 Hz intervals across its full 40 GHz range), the test itself may last just a few minutes, or it may take almost an entire shift to run. Tests run under the control of a local PC, which records results as well as sequencing the tests.

Figure 5 shows a typical PC-controlled calibration station set up for mid- and high-performance oscilloscopes in the Tektronix TDS family. In this example, the unit under test (UUT) is a TDS6604, a DSO with four channels and 6 GHz bandwidth. Here, the technician is attaching cables to the UUT prior to commencing the tests.

On the uppermost shelf of the calibration bench, a Rohde & Schwarz SMT06 RF signal generator acts as the main high-frequency stimulus source. Just beyond the SMT06 is the PC used to control the calibration instruments, to sequence the procedure, and importantly, to apply corrective offsets for delays and losses in the system elements.

The SMT06 drives a switch bank in the Keithley multi-channel microwave switch on the benchtop next to the oscilloscope. The switches direct the test signals to the oscilloscope inputs in a sequence determined by the control software.

On the shelf below the SMT06, a Fluke 9500B oscilloscope calibrator feeds a second switch input in the Keithley unit via a Fluke 9530 output head. Next to the Fluke 9500 sits a Keithley 2000 Series DMM used for precision DC measurements.

The calibration station in Figure 5 applies to certain families and models of Tektronix oscilloscopes. The instruments used are matched to the performance needs of the target oscilloscopes. Other calibration stations have similar functionality and precision but use different stimulus and measurement tools to deliver greater or lesser bandwidth, as appropriate.

Figure 5: Setting up an automated calibration for a high-performance oscilloscope.

At this stage, the calibration does not involve any adjustments. The role of this series of tests is strictly one of documenting the received condition. If adjustments are required, then a second full test series must be applied after the adjustments.

3. The Infrastructure of A Calibration Lab

Not surprisingly, there are many test system variants and configurations. A broad infrastructure of systems and fixturing supports hundreds of Tektronix models and product types. Some benches house cutting-edge signal generators to exercise Tektronix' fastest real-time and sampling oscilloscopes, as shown in Figure 5. Some stations are set up to calibrate probes and sampling heads, another demanding application. Some are configured strictly for optical calibration. Other benches are geared to the needs of portable instruments, as in Figure 6. Note the mass of instruments needed to calibrate one low-cost portable instrument, the NetTek Base Station Analyzer!

Figure 6: The compact, portable NetTek analyzer requires a bench-full of calibration equipment.

Each calibration bench requires specialized equipment, connected and controlled according to test plans whose development is supervised by Tektronix metrologists. Individual cables and switching elements connecting calibrators to instruments are characterized to minimize differences in the arrival times of the signals passing through them. This thorough procedure is necessary to support accepted calibration performance standards and, equally important, customers' expectations.

Fixturing and reference devices play a key role in calibrating high-performance instrumentation, albeit one that is almost invisible to most observers. For example, calibrating an optical TDR may require great lengths of calibrated fiber-optic cable. In effect the cable itself becomes a calibration tool whose properties should read out correctly on the TDR after the instrument has gone through a calibration and adjustment cycle. Figure 7 shows a fiber-optic “test fixture” that, though it appears nondescript, actually contains 204 kilometers (126 miles) of singlemode fiber cable. This sort of capital equipment is not common, even among vendors whose sole business is calibration.

Figure 7: Just another piece of luggage? No, this is a test fixture containing more than 200 kilometers of singlemode optical fiber cable.

Older Tektronix instruments have their own dedicated calibration stations, and get the same level of attention as the latest high-end products. In addition, an array of vintage analog oscilloscopes, curve tracers, and other tools (Figure 8) is maintained for the express purpose of servicing instruments of similar age.

Figure 8: Classic Tektronix instruments support calibration and repair efforts on their contemporaries.

Within the Depot, Tektronix metrologists and service personnel have devised a system of rigorous precautions to protect customers' equipment from ESD (Electrostatic Discharge) in particular, and from undue variations in temperature and humidity. Floor coverings, benchtops, and shuttle carts are grounded to prevent static buildup. All personnel who enter the calibration area must wear anti-static shop coats and conductive shoe straps. Because dry air fosters static electricity, humidity is measured (along with temperature) at numerous points in the building (Figure 9). Any anomalous environmental conditions are recorded. Necessary corrective action proceeds within minutes.

Figure 9: Temperature and humidity sensors keep environmental conditions within standard limits, and protect against static electricity buildup.

4. Your Tektronix Instrument Has Left The Building…

At any point in the calibration process, an instrument found to be defective can be diverted into the service facility on the same premises. An on-site stockroom stores a substantial inventory of replacement parts for instruments that require repairs during the calibration process. This hastens troubleshooting and minimizes delays that might otherwise affect the promised return date.

With the calibration completed, all that remains is to compose the calibration certificate and prepare the instrument for shipping. The information supporting the traceable calibration certificate has been kept current in the calibration tracking system with each step in the process. Information such as the instruments used in the calibration, identified by serial number, is part of this database. A package containing the calibration certificate and other relevant information joins the oscilloscope in a pre-shipping area, where it is picked up in turn for outgoing packaging.

In the shipping department, the instrument is matched with a corrugated box of the proper size and packed with impact-resistant foam. Many instruments will receive form-fitted expandable foam to isolate them from the injuries common in long-distance shipping. Instruments received in travel cases are of course returned in the same cases—these too are tracked in the Service Depot software.

The Tektronix Depot process is summarized in Figure 10. The process is designed to provide responsive services that not only comply with the highest industry standards, but also meet real world customer needs for accuracy, precision, and repeatability.

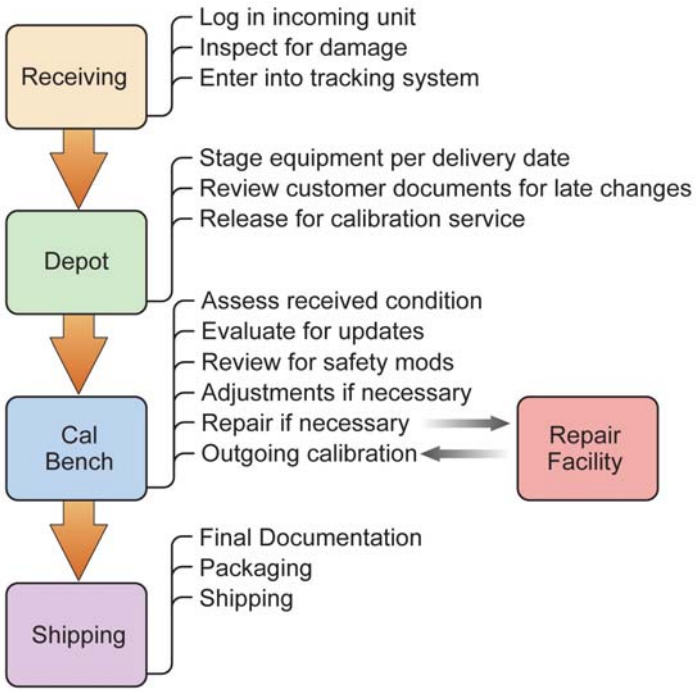

Figure 10: Flowchart of a typical calibration procedure at the Beaverton, Oregon, U.S.A .service center.

For more information on Tektronix calibration service, including on-site service and metrology, visit www.tektronix.com/serviceandsupport

Metrology References and Resources

Fundamental SI Units

A full listing of Fundamental SI Units is beyond the scope of this white paper. For more information, go to http://www.tek.com/service/metrology/si-units.html.

Common Acronyms

A2LA: American Association for Laboratory Accreditation, a non-governmental organization that provides services for laboratory accreditation based on ISO 17025.

ANSI: American National Standards Institute.

DKD: Deutsche Kalibrierdienst, an association of calibration laboratories and entities in Germany.

ISO: International Organization for Standardization, chartered to implement quality standards such as ISO 9001.

NCSLI: National Conference of Standards Laboratories, an independent industry organization.

NIM: National Institute of Metrology, China's governmental metrology institute.

NIST: National Institute of Standards and Technology, U.S. government standards institute; maintains U.S. measurement artifacts.

NPL: National Physical Laboratory, United Kingdom's metrology institute.

PTB: Physikalisch-Technische Bundesanstalt, Germany's metrology institute.

SAC-Singlas: Singapore Accreditation Council-Singapore Laboratory Accreditation Scheme

TAF: Taiwan Accreditation Foundation

Metrology Glossary

Accuracy

Conformity to fact, exactness. A measure of the closeness of an instrument's reading to the actual value of the parameter it is measuring (e.g. 99.998% accurate). Accuracy specifications often include stipulations as to range and other variables that affect accuracy.

Artifact

A reference standard to which subordinate standards are traceable. Typically maintained and supervised in a national metrology institute such as NIST in the United States. For example, a particular standard 10 volt artifact is presumed to be the most accurate available representation of 10 volts of electromotive force in that country.

Calibration

To check or determine by comparison with a “standard” the readings from a measurement device. Ideally the standard is a device whose accuracy is traceable through a succession of higher standards.

In calibration, the intent is to determine how far the unknown instrument deviates from the standard. A calibration product may also include adjustment of any unknown instrument readings to bring them closer to those obtained from the standard.

Measurement

The execution of a predetermined set of operations on a device with the intent of determining some physical property of same.

Metrology

The science of weights and measures. The field of knowledge concerned with all measurements.

Precision

The state or quality of being precise; exactness. The measure of the ability of an instrument to repeat a measurement and get the same answer. Note *that this does not necessarily imply the correct answer*--that is a function of accuracy.

Repeatability

Closeness of the agreement between the results of successive measurements of the same measure and carried out under the same conditions of measurement.

Reproducibility

Closeness of the agreement between the results of measurements of the same measure and carried out under changed conditions of measurement.

Resolution

The fineness of detail that an instrument can present. For example, a mechanical clock with two hands (hours and minutes) has a resolution of one minute. Adding a hand for seconds improves the resolution to one second. However, higher resolution is no guarantee of accuracy. The clock with one-second resolution may be two hours slow.

Tolerance

The allowable variation from a standard. The limits of the range of values that apply to a properly functioning instrument.

Traceability

The 'pedigree' of a calibration. The documented proof that the measurements taken during a calibration can be traced back to an accepted standard. This means that every measurement made during a calibration was made by an instrument whose calibration is certified as being performed correctly using proper standards that are traceable

Uncertainty

The estimated amount by which an observed or calculated value may differ from the true value. The term “uncertainty” (e.g., uncertainty of +/-300 ppm + 10mV) is preferred over “accuracy” when describing measurements. Traditionally uncertainty is reported in terms of the probability that the true value lies within a stated range of values.