Calibration & the Challenges of Choice
A poor or incomplete calibration can lead to significant errors in your measurements. The time to develop a product may exceed your original schedules and production yields may be too low if the test instruments are not performing to specification.

If your test instruments are not measured during calibration to the specifications you depend on, the devices you test are at risk. That can be costly. A detailed calibration report is the only way to verify for sure your instruments are performing to specification. Lower your risk and sleep better by reading this eBook.
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Keysight Services - Accelerate Technology Adoption. Lower Costs. 17
Why calibrate?

The warranted specifications of electronic instruments often rely on the ability to fine-tune the hardware under microprocessor control, for example amplifier gain, filter corners, DC offsets, and other functions are all adjusted during the production process. Over time, depending on the measurement environment and component aging, drift can occur. Sometimes this drift is linear over time as shown in Figure 1. Other times sudden shifts happen. Similarly, torque wrenches or precision thermometers can change based on how they are used (or abused).

The whole point of sending your instrument for calibration is to accurately measure the current performance to address the questions “Is it still fit for use? Can I continue to count on the warranted specifications?”

Your measurements matter. You make pass and fail decisions based on the measurements you make.

Proper periodic calibrations identify any out-of-tolerance test equipment drift and correct for it in a timely manner, ensuring that the accuracy of the test equipment you rely on to make your pass/fail or design troubleshooting decisions is the least of your worries.

How long is it?

- Ask three suppliers to measure a piece of wood
  - 1st supplier’s answer: “1 meter”
  - 2nd supplier’s answer: “1 meter, plus or minus 3 mm”
  - 3rd supplier’s answer: “998.0 mm, plus or minus 0.5 mm”
- How long is the piece of wood?
- Which answer do you most trust to be accurate?
- Would you choose this piece of wood if you needed something that was at least 1 meter long?
What is calibration and what needs calibrating?

A simplified definition

Calibration is periodically verifying instrument specifications by measuring actual performance using lab standards that in turn have better performance and are traceable to the International System of Units (SI) through standards maintained by national metrology institutes (NIST, NPL, PTB, NMIJ, etc.)

Depending on the service provider and the type of device, when an instrument is observed out-of-specification the calibration service may include adjustments. Electronic instruments usually require proprietary knowledge of the internal architecture so generally only the OEM can adjust them. Dimensional standards such as gauge blocks can’t be adjusted, only replaced if sufficient wear has occurred. Mechanical torque wrenches can usually be adjusted if needed.

Official Definition

“Operation that, under specified conditions, in a first step establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.”

Key Insight:

There is no substitute for accurately measuring current performance during calibration.

What needs calibrating?

It’s simple. Any instrument that you use and rely on the warranted specifications needs periodic calibration!

What happens when an instrument is out of specification?

Many, if not most, people assume that when they submit an instrument for calibration, the service includes adjustments “to the middle of the tolerance interval”. That is not true! See the calibration and repair process flow in figure 2.

Calibration laboratories run a series of performance tests. If your instrument is observed in-specification “As received”, you’ll receive a single report indicating that it “Passed”.

When an instrument is observed out-of-specification (or out-of-tolerance) your provider may be able to perform adjustments. Note for many modern electronic instruments, adjustments require complex iterative external measurements and calculations to characterize the instrument while changing internal DAC settings.

When your provider does perform adjustments you should expect to receive the measured results both of the initial performance when you submitted the instrument and after adjustments are performed. This way you can determine the impact of your Pass/Fail decisions on your own products while using an out-of-tolerance instrument. The second measurement report, “As completed” is proof of being fit for continued use.

Key Insight:
Before selecting a calibration supplier, ask them to review your instrument population and tell you which ones they can perform adjustments when measurements indicate that they are out-of-specification. For instruments they have to send to an OEM, ask if that is considered a “repair” (extra time/extra cost).

Figure 2 - Calibration and repair process flow shows adjustment
What is Measurement Uncertainty (MU)?

There are no perfect measurements, as they involve errors and imperfections. Engineers carefully review the accuracy specifications of instruments before they put them into their test systems. System accuracy is usually an engineering estimate of the combination of all potential measurement error sources. In calibration, international standards\(^2\) require identification of the different error and inaccuracy contributors involved in the measurement of your instrument. These are then to be accounted for as the so-called “Measurement Uncertainty” (MU). So, while MU may sound unfamiliar, think of it as the standard deviation estimate of the combined error sources during calibration. In plain English, it means the measurement inaccuracy.

Large calibration uncertainty increases the risk that your instrument is operating out-of-specification, risking measurement errors that impact the quality or performance of your design. As the calibration MU of your test equipment contributes to your overall test system inaccuracy, knowledge of what it is and keeping it small will save you cost and schedule time. As seen in figure 3 the red area under the curve shows that smaller MUs reduce your out-of-specification risk. Look at what appears to be equivalent test results from two different calibration vendors, Lab A and Lab B. Lab A has a relatively small MU represented by the vertical bar. Lab B has larger MU as seen by the longer vertical bar. The risk that your instrument is operating out-of-specification is represented by the red areas. Clearly, Lab A offers less risk than Lab B.

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With smaller measurement uncertainty during calibration, you can be more confident whether your product being tested meets or does not meet your performance limits, and you’ll have lower risk of failing “good” products or passing “bad” products. This affects yield in production and design cycle time in R&D.

**Key Insight:**
The actual instrument accuracy you can depend on is only as good as the expanded measurement uncertainty of your last calibration.

**The official definition**
Parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand. *(Also referred to as “measurement uncertainty”)*

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**What are the possible reasons for inaccuracy here?**
- ARROW: Weight, aerodynamic properties
- ARCHER: Strength, technique, competence
- BOW: Weight, material
- TARGET: mobility, design, distance
- ENVIRONMENT: Wind velocity, direction, visibility

With enough information about how these contributions affect performance and an equation to describe it, we may calculate the probability of hitting the target.
What is traceability?

Traceable measurements ensure uniformity of manufactured goods and industrial processes. Common measurement references are critical to the world-wide exchange and acceptance of products, services and technology.

Traceability is one of the challenges faced in design and manufacturing. Linkage to common standards is critical to measurement correlation, particularly for teams in different geographic locations.

A simplified definition

A traceable measurement is one that is linked to recognised standards having known better accuracy through an unbroken chain of comparisons.

Records are required to link a product or service event to a process, status or time. If the process is measurement, detail about the equipment, procedure, uncertainty, test conditions and personnel are all relevant to demonstrating traceability.

The official definition

Traceability is a “Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.”

Key Insight

As long as the laboratory that calibrates your instruments can demonstrate traceability, measurements made on one of your prototype designs in one country will correlate closely to your test systems in other countries.

Are standards important for calibration?

Yes! When it comes to calibration the standards that are most important are shown in figure 5.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILAC-G8:03/2009</td>
<td>Guidelines on Assessment and Reporting of Compliance with Specification</td>
</tr>
<tr>
<td>ILAC-P14:01/2013</td>
<td>Policy for Uncertainty in Calibration</td>
</tr>
<tr>
<td>ANSI/NCSL Z540-1-1994</td>
<td>Rescinded 2007, but still in regular use for existing Aero/defense work</td>
</tr>
<tr>
<td>ANSI/NCSL Z540.3-2006</td>
<td>Requirements for the calibration of Measuring and Test Equipment</td>
</tr>
<tr>
<td>ISO 9001:2015</td>
<td>Quality management systems - requirements</td>
</tr>
</tbody>
</table>

Figure 5.

Note: ILAC is the “International Laboratory Accreditation Cooperation” - a network of mutual recognition arrangements among accreditation bodies.

Almost everyone is familiar with the ISO 9001 quality management standard. Almost all companies comply. However, regarding calibration, it contains few specifics to ensure the competence of calibration laboratories, how to estimate inaccuracy (which you now know is measurement uncertainty), what belongs in calibration reports, etc.

For calibration, ISO/IEC 17025: 2005 is the single most important international standard for calibration.

It is the International standard for competence of calibration laboratories and covers all aspects of standards used, development of calibration procedures and corresponding MU, proper reporting of results and personnel training amongst other requirements. ISO 17025 also includes the management requirements of ISO 9001.

Key Insight

It’s not your job to understand all the calibration standards! But you will learn a lot if you ask prospective calibration laboratories which standards they comply to, and why they think their compliance is important to the ongoing measurement accuracy of your instruments.
Why does accreditation matter?

Accreditation is the confirmation of competence and compliance with ISO/IEC 17025 from an independent Accreditation Body (AB) by means of formal audit.

A laboratory seeking accreditation must provide their documented procedures and measurement uncertainty analysis for the scope (see next paragraph) of capability they require. Then the AB selects one or more assessors who are measurement experts in that field. For each parameter the assessor evaluates the documentation, facility and the competency of staff. If the lab complies with the necessary criteria of the AB the scope of accreditation is published. This can be readily reviewed by either requesting it from a prospective calibration lab or by searching the list of accredited laboratories at the AB website.

Please note that being accredited alone doesn’t mean a labs scope of accreditation covers all measurement capabilities. In fact, calibration capabilities can vary greatly between labs as shown in figure 7. For example, ABC lab is not accredited for RF/Microwave parameters.

Key Insight:
If you require accredited calibration make sure the laboratory is accredited for the requirements of your instruments.
Would you believe calibration can materially affect new product time-to-market or production yield?

It’s true. Whether you are the lab manager responsible for time to market or a production engineer responsible for yield, calibration can affect your results.

It’s all about the math.

The impact of calibration varies by team.

<table>
<thead>
<tr>
<th>R&amp;D</th>
<th>Production</th>
<th>Finance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meet on time design validation and test development</td>
<td>Increase yield</td>
<td>Reduce total cost of test</td>
</tr>
<tr>
<td>Meet project schedule</td>
<td>Increase production margin</td>
<td>Protect margins</td>
</tr>
<tr>
<td>Meet budget</td>
<td>Reduce total cost of test</td>
<td>Make financials more predictable</td>
</tr>
</tbody>
</table>

Figure 8 - Impact of calibration from R&D, production and financial perspective
How does calibration impact time to market?

Being first to market or first to production is critical in many industries. In wireless, the first company to innovate in evolving technology standards has the leading edge in market position. Required customer specifications may come from marketing research or external standards. Either way, before a design prototype can proceed to production it must pass a design review where measured performance exceeds target specifications with suitable production margin. If a design fails to meet a target test line limit, then engineers have to re-submit new chip fabrications or board layouts. Extra material fabrication costs and lost time associated with re-testing can have large negative implications to a company's revenue stream.

So how does calibration fit in? Whenever Pass or Fail decisions are made, such as a checkpoint for transitioning a design to production, measurement errors from instruments operating out of specification can result in either falsely rejecting a “good” product or falsely passing a “bad” product.

Calibration also ensures data correlation through your design chain through to manufacturing teams. This keeps the teams from wasting time identifying where a problem exists.

**Key Insight:**

Good trouble shooting relies upon the accuracy of your measurements. Proper calibration of your instruments provides that confidence.

Figure 9 - Design to production
Pass/Fail Decision risk. Sounds bad. Is it?

Whenever you measure a product or device and make a binary Pass or Fail decision compared to a specification, there is some probability of making an incorrect decision. The bigger the measurement uncertainty, the greater the chance of falling into the black boxes as represented in Figure 10.

In figure 10 the vertical axis indicates the true state of a product, either “Good” or “Bad”. But we can’t know the true state, only what we can measure, which is indicated on the x-axis. Hopefully, most of the time when you determine that a product is acceptable it actually is or alternatively if you reject a product you are correctly removing a bad product from reaching your customer.

A more troubling scenario is if you reject a product that is actually good, you will then either scrap it or return it for unnecessary manufacturing rework. This is shown in the upper left quadrant which represents the “False Fail” scenario. The lower right quadrant illustrates a “False Pass” scenario, where you determine that a product is acceptable but it isn’t really. In this case you mistakenly ship bad products to customers.

While not initially obvious, this will likely result in warranty or defect replacement costs and customer satisfaction issues. If many customers are disappointed, your brand could suffer.

Measurement uncertainty defines which quadrant your product will fall into on the graph. You could be testing a good product and it passes or testing a bad product and it fails. That’s good but you could also be testing a good product and it fails. You then either scrap it or rework it unnecessarily. Or you could test a bad product and it passes. This is even more dangerous for your company because of customer dissatisfaction and product recalls - damaging the perception of the quality of your products.

Key Insight:
Maintaining low rates of “False Accept” and “False Reject” is just good business. The smaller your measurement uncertainties in final test, the lower these rates will be. Use accurate instruments and make sure they are in-tolerance with periodic proper calibration.
In this eBook we have explored some of the important aspects of calibration. When you select a calibration laboratory, be sure to ask:

- How are their procedures developed?
- What equipment do they use for reference standards?
- What reports do they provide as proof of work performed?
- How small are their uncertainties for your instruments?
- If you are seeking accredited calibration, are they accredited in the parameters needed to test your instruments?
- Can they prove traceability?

Most often you will find that laboratories differ in each of these characteristics.

Once you’ve gained clarity on the technical aspects of calibration you can then consider other factors that become important in the use of calibration services. Be sure to build the following into your decision process by selecting a service provider that:

- Has small uncertainties in order to improve yield, product quality & reduce scrap.
- Is mature, trustworthy and well organized with reliable and fast turnaround times to reduce downtime, decrease time to production & market.
- Can manage all your equipment regardless of manufacturer to reduce supplier complexity.
- Has asset management tools to archive calibration certificates and data/test reports, manage service requirements, making passing audits a breeze!
“A cal is a cal, right?”

Hopefully as you have read and thought about the calibration related topics in this eBook, you are a more informed consumer of calibration. At Keysight services our goal is to make sure you get the performance that you paid for from all your instruments, including all those instruments not manufactured by us. That’s why we accurately measure the current performance of your instruments, regardless of manufacturer for every warranted specification, every option, every time. We think you shouldn’t settle for less.

Figure 11 - Actual Performance Measured for a Keysight N5182A MXG RF vector signal generator
Dear customer,

We are excited to share this eBook, designed for individuals who are responsible for their company’s calibration of all test assets and end users looking for ways to improve their results.

To provide even more comprehensive support, Keysight is expanding our services portfolio. We now offer one-stop calibration services because we see a growing need from our customers to manage services for all instruments from one supplier to improve operational performance, reduce logistical complexity and improve turnaround time. Today we perform over 450,000 calibrations for a growing list of Keysight and non-Keysight electrical, physical, dimensional and optical instruments. And to be close to you, we have service centers in 30 countries and are accredited with 18 accreditation bodies in 20 countries around the world.

Please call your local service representative to learn more.

Sincerely,
John Page

President, Services Solution Group
Keysight Services is an industry-leading array of people, processes and tools focused on helping you implement new technologies and engineer improved processes. Engage with our experts today and find new ways to maximize asset utilization, streamline engineering operations and achieve lower costs.

We hope you found this information useful. Please call a Keysight expert and learn more about our calibration services.

Further insights at below links

- Calibration Video Series
- Insights Unlocked Blog
- Keysight Services Master Class Series
- The Six Axes of Calibration Application Note
- Defining Your Calibration Requirement
- The Real “Total Cost of Ownership” of Your Test Equipment Application Note
- Contact an Expert

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5992-1899EN
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