

Calibration and Specification Considerations When Using Modular Instrumentation

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Abstract

Modular instrumentation, such as PXI or AXIe modular instruments, offers significant configuration flexibility, plus interchangeability, speed, and size advantages when it comes to deploying measurement systems. However, the architecture that enables these advantages also presents unique challenges when calibrating modular instruments. Calibration often occurs outside of the use environment. For modular instrumentation, this may mean performing calibration on a module with a different chassis and its related electronics. Additionally, the module's ambient environmental conditions depend upon chassis fan speed, the use of slot blockers and EMC filler panels and the presence of other modules. The operating software and CPU for modular instruments are contained outside the module in an external computer, which may not travel with the module for calibration. Modular instrumentation may require multiple modules configured together to provide measurement capability. This may require calibration on the set of modules as a system or, a method to relate system level performance to the calibrated performance of individual modules. These issues affect both the calibration and the calibration report and influence how manufacturers may define specifications for modular instrumentation. This paper examines these issues in detail and considers both in situ calibration and calibration performed outside the use environment. Recommended is information to be included on the measurement report that is unique to calibration of modular instrumentation. Addressed are the requirements for assuring the ability to make traceable measurements using calibrated modular instrumentation.

1. Introduction

Modular instrumentation refers to instruments designed to conform to one of several modular platform definitions. This includes instruments that conform to the PXI or AXIe specifications. Modular instruments plug into a compatible system chassis and the calibration of individual modular instruments is performed either in situ, or at a calibration laboratory. A goal of the calibration is to enable the modular instruments to make accurate and traceable measurements. Figure 1 shows an example of a PXI modular chassis with several modules inserted into it and filler panels covering the unused chassis slots.



Figure 1. PXI Modular Instrument.

Modular platforms provide distinct advantages for testing. The modular system chassis supplies mechanical support, power, cooling, and communication/control services to the modular instruments. Since these functions and services are common to, but separate from the individual modules, the modular instruments are themselves compact. This allows for small floor space requirements, plus the ability to quickly add, remove or replace modular instruments.

Taking full advantage of the modular platform, however, does present unique challenges when calibrating individual modular instruments. When removing a modular instrument from the chassis and sending it to the calibration laboratory, not all of the functional components that affect measurement accuracy travel with the instrument. Additionally, the operating environment for an individual instrument in the use location may be significantly different from the operating environment in the chassis at the calibration laboratory. Finally, specifications may cover the accuracy of multiple modules working together as a system.

The remainder of this paper examines the calibration issues associated with modular instruments and provides recommendations for dealing with them.

2. Environmental Conditions

Almost without exception, instrument specifications include the environmental conditions over which the instrument shall meet its accuracy specifications. This is true for all instruments, not simply modular instruments. ISO/IEC 17025 [1] places a requirement on calibration laboratories to ensure the environmental conditions of the laboratory meet the requirements of the instrument calibration and do not adversely affect the results¹. What does this mean for modular instruments? Even while holding the ambient conditions outside the modular chassis constant, the ambient conditions for individual modular

¹ ISO/IEC 17025:2005 section 5.3.1.

instruments depend on several factors (see Webb [2]). The total number of modules inserted into the chassis greatly affects the amount of heat the chassis must dissipate. The chassis houses cooling fans and the system integrator sets the fan speed. Additionally, system integrators have available air inlet kits, slot blockers and filler panels (see Figure 2).



Figure 2 PXI Air Inlet Kit, Slot Blockers and Filler Panels.

Air inlet kits and slot blockers insert into open chassis slots and affect the airflow within the chassis. Filler panels cover open slots, which also affect airflow. Manufacturers of modular instruments may specify, or simply recommend, that air inlet kits, slot blockers or filler panels are used in open chassis slots. The use of these devices and the ability to control fan speed gives system integrators maximum flexibility when deciding how to best cool the chassis. As a final point, the cooling operation of one manufacturer's chassis may be materially different from another manufacturer's chassis.

The cooling design for a modular system, therefore, depends on the specific requirements of a given system and the system integrator's decisions. This translates into a potentially wide range of environmental conditions for modular instruments even for given ambient conditions outside the chassis. That is, knowing ambient environmental conditions outside the chassis is not necessarily a good indicator of the ambient environmental conditions for individual modules. This is an important point if modular instrument calibration occurs in a different chassis, with potentially a different configuration, from modular instrument intended operation. Manufacturers do address this issue, for example [3], by specifying both the ambient temperature requirements outside the chassis and the temperature requirements as measured internally by the modular instrument.

ISO/IEC 17025 requires test reports and calibration certificates to include the environmental conditions that influence the measurement results². For modular instruments, where the system configuration affects the environmental conditions for individual modules, this requirement extends to relevant environmental conditions inside the chassis.

3. Operating Software

For non-modular instruments, the controlling software, or firmware, is typically inseparable from the instrument. However, for modular instruments, the controlling software is not stored in the instrument. This is not to say that modular instruments do not perform computations as they may perform internal calculations. The controlling software for modular instruments is the software layer that allows control of the instrument hardware. This software is referred to as the instrument driver and it resides on an

² ISO/IEC 17025:2005 sections 5.10.3.1.a, 5.10.3.2.e, and 5.10.4.1.a.

external computer. Instrument control is either through automated test software written by the test designer that uses the instrument driver, or through the instrument driver's graphical user interface. To use a modular instrument, it must be inserted into the chassis, the chassis must either be connected to a computer, or, a computer must be inserted into the chassis, and, the instrument driver must be installed on the computer.

The instrument driver can affect the accuracy of the modular instrument. That is, the measured results for a given modular instrument can change when using a different revision of the driver.

When sending a modular instrument to a calibration laboratory, the calibration laboratory likely uses its own computer to control the modular instrument. Therefore, the instrument driver must be installed at the calibration laboratory. Manufacturers do periodically update instrument drivers. Ideally, both the calibration laboratory and the user of the modular instrument take care to ensure instrument drivers are up to date. This is not always feasible, however. For example, the qualification of the end-use system may assume a specific revision of the instrument driver, and the cost of re-qualification may preclude using different instrument driver revisions. To ensure a valid calibration, it is best to calibrate using the same driver version as used during modular instrument intended operation. Given the impact instrument drivers have on the measured results, reporting the instrument driver revision on the calibration report is necessary.

4. Multi-module Instrument Accuracy

Modular instruments fit one of several form factors. Single-module, one or two slot-wide instruments are common. For larger and perhaps more complex instruments, a modular design allows for instruments consisting of multiple modules. That is, a multi-module instrument. Figure 1 shows an example of a chassis containing a multi-module instrument with modules of varying widths.

For many multi-module instruments, instrument accuracy depends on a combination of modules. That is, removing and replacing any one of the modules of a multi-module instrument may affect instrument accuracy. While an advantage of the modular system allows removing and replacing any module within a chassis, care must be taken to ensure calibrated accuracy of a multi-module instrument. One way to manage multi-module instrument calibration is to calibrate the interdependent modules as a set. The advantage of this strategy is that it results in very high confidence that the multi-module instrument, as a set of modules, performs with a quantifiable accuracy.

ISO/IEC 17025 requires an “unambiguous identification of the item(s) tested or calibrated³.” Multi-module instruments do not typically have an identifier for the set of interdependent modules; rather, each module within the set has its own unique identifier. Therefore, an identifier for the set must be created. An identifier derived from each module's unique identifier is sufficient. With this scheme, however, replacing one of the modules from the set changes the unique identification of the set, which would then require a new calibration. This is as it should be. If changing a module of a multi-module instrument affects the accuracy, then any previous calibration of that multi-module instrument no longer applies to the current set of modules.

To help manage multi-module instrument calibrations, manufactures have added “electronic calibration manager” features to modular instruments (for example, see [4]). With an electronic calibration manager, calibration information is stored in the modules giving a unique identification to the interdependent modules and allows for automatic detection if any module from the set is removed and

³ ISO/IEC 17025:2005 section 5.10.2.f.

replaced. Additionally, electronic calibration managers allow setting calibration intervals and provide automatic end-of-period reminders.

Calibrating interdependent modules as a set somewhat constrains the flexibility of modular systems. Namely, replacement of a module from a multi-module instrument is possible; however, it becomes necessary to calibrate the multi-module instrument after doing so. An alternative to calibrating multi-module instruments as a set is to calibrate each module individually. The multi-module instrument accuracy is then determined from the individual module calibrations using the methods of the GUM [5]. This allows individual module calibration to occur at different times and allows module replacement without the need to recalibrate the multi-module instrument as a set.

The GUM methods require a measurement equation, and in this case, one that models the multi-module instrument accuracy as a function of individual module accuracy. The measurement equation may or may not be available from the multi-module instrument manufacturer. It may be challenging to achieve the specified accuracy of the multi-module instrument when propagating uncertainties from individual module calibrations, and is one reason manufacturers may require calibration of the module set. It is likely that the uncertainty when calibrating the multi-module instrument as a set is better than the combined uncertainties propagated from each individual module calibration. However, if the combined uncertainty meets the needs of the intended use of the multi-module instrument, even if the uncertainty is greater than the specified accuracy, then managing calibrations this way may be practical.

Regardless of the method for managing multi-module instrument calibrations, some amount of disassembly and reassembly may be necessary after calibration. Interconnections and cabling between modules is common with multi-module instruments as can be seen in Figure 1. Clearly, proper reassembly and verification is critical. Many multi-module instrument drivers include self-check routines that will ensure proper operation after reassembly.

5. In situ Calibration

When in situ calibration is possible or practical, it addresses many of the presented issues. In situ calibration means that calibration takes place with modular instruments in the same chassis and with the same or nearly the same environmental conditions as the environmental conditions during the intended use. Disassembly and reassembly is avoided or minimized. It is possible to sidestep instrument driver revision issues by employing the same computer during calibration as is used for the intended use. Multi-module instrument considerations remain, however. In situ calibration has little bearing on calibrating interdependent modules as a set versus calibrating individual modules and propagating uncertainties.

Given modular systems, it is possible to insert or add calibration standards into the modular chassis as suggested by Manor and Dewey [6]. In this way, the standards modules in the chassis enable in situ calibration of the other modular instruments in the same chassis. This approach provides several benefits in addition to the benefits of in situ calibration. The presence of calibration standards in the chassis provides maximum flexibility as to when to calibrate, can minimize downtime, and, with dedicated resources, the calibration can be tailored to the specific measurement requirements of the system. However, the calibration standards themselves require their own calibration and are subject to the same calibration challenges as any other modular instrument. Nonetheless, this strategy offers significant flexibility for managing multi-module instrument calibrations.

6. Summary

If the objective is to make accurate and traceable measurements with modular instruments or simply to provide confidence that modular instruments are operating within tolerance, then special attention should be giving to following modular instrument calibration issues.

- Environmental conditions for individual modules are highly dependent on system configuration. Modular instruments may have unique environmental requirements that must be met during calibration and reported on the calibration report.
- Instrument drivers may affect modular instrument accuracy. Care must be taken to ensure the use of the correct driver during calibration and the driver revision should be included on the calibration report.
- Special consideration must be made to ensure valid calibration for multi-module instruments. This may require calibration of interdependent modules as a set and assigning the set a unique identification. Alternatively, the GUM method of propagation of uncertainty from the calibration of individual modules may allow quantifying multi-module instrument accuracy. In either case, after any disassembly and reassembly, operational verification is very important.

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