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Issues in Purchasing and Maintaining Intrinsic Standards

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Abstract

Intrinsic standards offer many advantages relative to conventional artifact standards, including state-of-the-art uncertainty and the lack of need for periodic re-calibration. Because of the recent increased interest in intrinsic standards, the NCSL International formed the Intrinsic and Derived Standards Committee which has developed a "Catalogue of Intrinsic and Derived Standards," as well as several recommended practices that describe procedures necessary for realizing specific standards. Intrinsic standards can require considerable maintenance and knowledge before purchasing, depending upon the level of uncertainty to be realized. When purchasing intrinsic standards, some key considerations include: the level of uncertainty required; compatibility with existing laboratory equipment and standards; and compatibility with the laboratory environment. Maintenance activities can include general characterization tests or measurements that are required to be performed before the intrinsic standard can be used for the first time (e.g., sample characterization). In addition, specific maintenance activities may be required each time the intrinsic standard is used, or at periodic intervals, in order to confirm proper system operation. In many cases, these maintenance activities yield data that are needed for the uncertainty analysis for the intrinsic standard. Almost all intrinsic standards need to be periodically intercompared with similar intrinsic standards in order to confirm proper operation. In addition, most intrinsic standards need local control or trend charts to be maintained in order to ensure proper operation of the standard between the periodic intercomparisons. Finally specific issues in purchasing, setting-up and operating several intrinsic standards are presented and discussed.

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DISCLAIMER

Introduction

In the past several years, intrinsic standards have become very widespread and commercially available. This is because these standards offer several advantages relative to conventional artifact standards, the primary advantage being they often represent the best level of uncertainty for realizing a specific metrological parameter. In addition, since intrinsic standards do not require periodic calibration, the metrology laboratory saves calibration costs by an external laboratory or National Metrology Institute (NMI) of their top-level artifact standard, shipping problems are eliminated, and the laboratory does not lose calibration capability during the off-site re-calibration of the artifact. In many cases, an intrinsic standard allows the metrology laboratory to support ever increasing requirements from their customers for higher accuracy calibrations.

However, before purchasing an intrinsic standard, a metrology laboratory needs to understand specific issues concerning the standard and the resources required to maintain the standard in the laboratory. This paper discusses various aspects of intrinsic standards related to their purchase and maintenance in order to increase the awareness of the metrology community about these issues. Additional information about various concerns with intrinsic standards, and the ability to operate at the forefront of metrological capability, is contained in two recently published articles. [1, 2] These references also deal with the definition of an intrinsic standard and procedures to ensure proper operation and measurement traceability.

The Intrinsic and Derived Standards Committee of the NCSL International† has championed the adoption of intrinsic standards by the metrology community by clarifying the equipment and procedures needed for successful operation. [3-7] The committee has adopted a proposed definition for an intrinsic standard which is presented in the next section of this article. The section following provides a general discussion of issues specific to the purchase of intrinsic standards, including material properties, compatibility with laboratory environment, compatibility with other equipment, and the possible need for additional standards. Next, there is a general discussion of issues specific to maintaining intrinsic standards, including periodic characterization measurements, periodic intercomparison, maintaining local control/trend charts, developing an uncertainty analysis, operational costs, and safety.

Purchasing of each intrinsic standard requires attention to all hardware and software details. Installation and maintenance activities vary in magnitude with respect to labor, environmental conditions, and costs. In the final section, experiences gathered over the last 15 years by two of the authors (Pettit and Jaeger) are presented with reference to the following intrinsic standards: Josephson Voltage Standard for DC voltage; Quantum Hall Resistance Standard for DC resistance; Nuclear Magnetic Resonance for magnetics; Atomic Frequency Standards for frequency dissemination; Interferometry for length; and Temperature Fixed Points used to calibrate Standard Platinum Resistance Thermometers.

† Formerly the "National Conference of Standards Laboratories."

Intrinsic Standards and a Proposed Definition

In this section, background information on intrinsic standards is presented, including a listing of intrinsic standards and a proposed definition for intrinsic standard, as well as the objectives of the NCSL International Intrinsic and Derived Standards Committee.

The NCSL International Board of Directors formed the Intrinsic and Derived Standards Committee in 1988 for the purpose of providing solutions to several concerns and needs identified by the NCSL membership in the 1986 US National Measurement Requirements Committee report. [Note: The most recent US National Measurement Requirements Report is available from the NCSL International Business Office located in Boulder, CO (http://www.ncsl-hq.org/).] In order to meet this goal, the objectives of the committee are:

1. To identify appropriate standards that can be established as intrinsic or derived standards.
2. To establish procedures and specify systems to realize, maintain, and operate such standards.
3. To work to obtain acceptance by appropriate agencies and organizations of these standards as valid sources of traceability to realizations of the SI.

Meeting these objectives is accomplished primarily by developing and publishing a Recommended Intrinsic/Derived Standard Practice (RISP). A RISP describes the necessary equipment, operating procedures, uncertainty analysis, quality control processes, etc. necessary for the practical realization of the standard. Published RISPs are disseminated to all NCSL International members and are available for purchase from the NCSL International Business Office. To date, four RISPs have been published, and there are currently several in process.

As part of the Intrinsic and Derived Standards Committee's efforts to identify appropriate standards, it has published a listing of intrinsic standards in a document titled Catalogue of Intrinsic and Derived Standards. [3] The catalogue provides information on current recommended practices and/or references that describe the various standards, as well as summarizing important characteristics of each standard. The recommended practices and references can be used as a starting point for metrologists who are interested in realizing the standard or in improving their understanding of the standard. The catalogue currently has a total of 46 entries covering intrinsic and derived standards [4] in metrology areas including electrical, pressure, microwave, temperature, optical, and mechanical. Of these, 20 entries are classified as intrinsic standards and are listed in Table 1 below. Each catalogue entry summarizes important characteristics about the standard including the following information:

- A brief description of the standard.
- How traceability is achieved for the standard.
- Typical uncertainties for the standard.
- References to relevant recommended practices or to published literature.
- Additional supporting comments.

In a recent activity, the Intrinsic and Derived Standards Committee developed and adopted a definition for an intrinsic standard [5]; the definition, including three notes, is reproduced below. According to the definition, one important component in the uncertainty assigned to an intrinsic standard relates to details in its construction and implementation; these sources of uncertainty usually need to be verified at appropriate intervals and thus represent an important maintenance activity for many intrinsic standards. In addition, the proper operation of the intrinsic standard should be ensured either by using consensus test methods or by intercomparisons among comparable intrinsic standards; again these procedures represent important maintenance activities. Several of these points are discussed in References [1] and [2], and will be further illustrated in the sections below.

DEFINITION: Intrinsic (measurement) standard: Standard recognized as having or realizing, under its prescribed conditions of use and intended application, an assigned value the basis of which is an inherent physical constant or an inherent and sufficiently stable physical property.

Notes:

1. An intrinsic standard usually consists of a device or system based on the requirements of a documented, consensus method.

2. The value of an intrinsic standard is assigned by consensus and does not need to be established by calibration or comparison with another standard. Its uncertainty is determined by considering two components: (a) that associated with its consensus value and (b) that associated with its construction and implementation.

3. To establish and ensure stability and/or traceability, the value of an intrinsic standard and the uncertainty associated with its construction and implementation should be verified at appropriate intervals. Verification may be carried out by applying a recognized consensus test method or by intercomparisons among comparable standards. Such intercomparisons may be accomplished with standards in a local quality control system or with external standards including national and international standards.

Electrical:

- Josephson Voltage Standard
- Microwave Phase Shift
- Microwave Voltage Doubler
- Nuclear Magnetic Resonance
- Quantum Hall Resistance Standard
- Quality Factor of Capacitors or Inductors
- Thompson-Lampard Calculable Cross Capacitor
- Microwave Cryogenic Noise-Temperature Std.

Thermodynamic:

- Temperature Fixed Points
- Pressure Fixed Points
- Optical Fiber Thermometry
- Black Body Radiation Thermometry
- Liquid Manometers

Dimensional:

- Angle
- Length (Interferometry)
- Planeness & Bending of Optical Flats

Optical:

- Wavelength
- Monochromatic Optical Power

Atomic Frequency Standards

- Cesium and Rubidium (Cs; Rb)
- Hydrogen Maser

Table 1: Listing of intrinsic standards from the NCSL International publication "Catalogue of Intrinsic and Derived Standards." [3]

Issues in Purchasing Intrinsic Standards

Before purchasing an intrinsic standard, there are some key properties and tradeoffs that must be considered, including: (1) ultimate uncertainty desired for measurements made using the standard; (2) compatibility with existing laboratory environmental conditions; (3) compatibility with the other supporting standards and the intended workload; and (4) the possible need for upgraded or additional support standards. These issues are discussed below.

1. Uncertainty of Standard

The first question to answer is "What uncertainty is required for the intrinsic standard?" The reason for this question is that all intrinsic standards are not equivalent. Each realization is unique. What this means is that specific procedures and processes may be necessary to realize the intrinsic standard at a desired level of performance. Some of the procedures or processes may be very time consuming, require expensive materials, and/or require additional equipment, especially if the best levels of uncertainty are to be realized. If the best levels of uncertainty are not needed, then considerable time and effort may be saved.

For example, many intrinsic standards are based on the physical properties of a specific material, usually a pure element (mercury, helium, cesium, etc.) or substance (water, etc.). In these cases, it is important that the material used in the standard meets or exceeds specific purity requirements, depending upon the uncertainty level desired. In many situations, the certificate obtained from the supplier for the material used in the standard (including traceability and measurement technique information) can be used as evidence that a specific purity requirement is met. Obtaining this information with a purchased intrinsic standard is particularly important in cases where the purity can not be determined at a later time. Thus if the material is placed in a sealed cell (for example, fixed point temperature standards), then the purity can not be directly verified or measured without breaking the cell, thus damaging the intrinsic standard.

In other cases, important performance characteristics of the intrinsic standard must be within specifications in order to ensure proper operation and a useful lifetime. The measurement of these characteristics quantify important properties of the intrinsic standard, its construction, or operation. For example, quantum hall resistance samples require characterization of the magnetic flux density dependence, contact resistance, longitudinal resistance, etc. before they can be determined to have stable resistance plateaus that are appropriate for a high-quality resistance standard. [7] The results and documentation of these performance tests should be requested and reviewed before purchasing these intrinsic standards. As another example, temperature fixed points should display stable melting plateaus that indicate pure material and proper furnace functioning.

2. Compatibility with Laboratory Environments

In general, intrinsic standards represent the best realization of a metrological parameter. Therefore, realizing optimum operating performance can depend upon maintaining a stable laboratory environment for the standard. Usually this means controlling parameters such as temperature, vibration, humidity, electromagnetic interference, etc. at the highest levels. Because of this sensitivity, the laboratory environment where the intrinsic standard will be located should be analyzed before it is purchased in order to ensure that the environment will be adequate to support the intrinsic standard. If the environment is not currently adequate, plans to upgrade the laboratory environment, and the associated cost and construction time, must be factored in the overall purchasing process.

Examples of intrinsic standards that are sensitive to the environment include interferometric standards that are used to measure dimensional properties. The temperature of the local laboratory where the standard is used usually must be controlled to a level on the order of ± 0.1 °C; otherwise the optimum performance of the intrinsic standard will not be fully realized. As another example, vibrations can adversely affect measurement of the liquid surface position in liquid manometry standards used in pressure metrology, and thereby render the intrinsic standard unstable or seriously degrade its performance.

3. Compatibility with Standard & Workload

In many cases, an intrinsic standard will become the highest level standard in a metrology laboratory, replacing the existing artifact standard. However, it is possible that the intrinsic standard may not be able to be used to calibrate all of the laboratory's workload for that parameter. This is because the intrinsic standard may be incompatible with specific standards due to input noise characteristics, equilibration times, sensitivity, etc. In addition, many intrinsic standards realize only a fixed point (e.g., temperature fixed point standards or the quantum hall resistance standard) or have a limited range (e.g., Josephson voltage chips operate only from 0-12 V DC). Therefore, the metrology laboratory may need to maintain all of their present standards, in addition to the intrinsic standard. This means that the laboratory is adding to the calibration systems that must be maintained, not necessarily replacing existing equipment. The result is that the overall time spent maintaining the laboratory's calibration systems will increase, not decrease, as might be expected.

Finally, many intrinsic standards are not automated or require continuous operator presence for proper operation. In this case, although the intrinsic standard may be capable of being used to calibrate all of the laboratory's workload, there may be a significant increase in the time required for each calibration. Thus it may be advisable to maintain both the current standards and new intrinsic standard in order to optimize the calibration time, the uncertainty assigned to the calibration, and the overall calibration costs.

4. Additional Support Standards

Since intrinsic standards usually provide improved performance compared to existing standards and in many cases the best level of uncertainty, they may require support standards or measurements that are more accurate than the metrology laboratory currently supports. In this case, the laboratory will need to upgrade the support standards to the level required by the intrinsic standard.

As an example, the Josephson Voltage Standard requires a traceable frequency input since it is basically a frequency-to-voltage conversion device. In order to realize an uncertainty better than 1 part in 10E7 in voltage, the frequency standard should have an uncertainty that is better than about 1 part in 10E9. If a frequency standard of this quality is not available, the laboratory will need to purchase and maintain one. Another example might be a Black Body Radiation Standard that requires accurate temperature measurements, depending upon the uncertainty to be realized.

Issues in Maintaining Intrinsic Standards

Intrinsic standards can require considerable maintenance during routine operation. Maintenance activities can include general characterization tests or measurements that are required either before initial use, or at periodic intervals, or each time the intrinsic standard is used. These characterization tests or measurements typically provide data that are needed to support the uncertainty analysis for the intrinsic standard. Unless recognized consensus test methods have been established, almost all intrinsic standards need to be periodically intercompared to similar intrinsic standards in order to ensure their continued integrity. In addition, the maintenance of local control or trend charts are needed to ensure proper operation of the standard in between the periodic intercomparisons. Finally, the costs of these maintenance activities should be considered, as well as any safety concerns.

1. Periodic Characterization Measurements

Once an intrinsic standard is purchased and operating, there may be either periodic or one-time characterization measurements that are required to be performed in order to ensure the proper operation of the system. These measurements may also be needed in order to generate specific values for parameters that are used in the uncertainty analysis for the overall system or for each calibration of a secondary standard when using the system. These characterization measurements require operator time and can require the use of additional auxiliary equipment that may need to be purchased. For example, in a Josephson Voltage standard, leakage currents must be measured to ensure that they are small and that they do not adversely affect the system performance. As another example, it is advisable to compare atomic-frequency standards against an external reference, or intercompare several standards since it is possible for the standard to fail without giving any indication of a problem. [3] Other examples of these types of measurements are contained in several of the NCSL International Recommended Intrinsic/Derived Standards Practices (RISPs) developed to support intrinsic standards. [6, 7, 8] In addition, characterization measurements may need to be performed each time the intrinsic standard is operated; in this case these measurements are usually a part of the calibration process of the secondary standard and may be included as an important factor in the assigned calibration uncertainty.

2. Periodic Intercomparisons

In order to demonstrate the proper operation of the intrinsic standard, periodic intercomparisons with comparable intrinsic standards are often carried out in order to ensure their continued integrity. In many cases, the uncertainty associated with the intercomparison may be limited by the short term stability, or other characteristics, of the transfer standard. Therefore, intercomparisons cannot be relied upon to determine all possible problems with the realization of the intrinsic standard. In many cases, these intercomparisons should involve either a National Metrology Institute as a direct participant in the intercomparison or a participant that has previously intercompared to a NMI. It should be noted that an intercomparison involving the NMI should not be used to assign a value or uncertainty to the intrinsic standard (unless traceability to the NMI is claimed); the intercomparison only indicates the compatibility between the laboratory's realization of the intrinsic standard and the intrinsic standard maintained by the NMI.

3. Maintain Control/Trend Charts

In order to ensure the continued proper functioning of an intrinsic standard, the user may need to maintain local control or trend charts that show the measurement results for typical standards or artifacts that are calibrated by the laboratory using the intrinsic standard. These data demonstrate the stability of the intrinsic standard in between performing the periodic characterization measurements, as previously discussed, or in between periodic intercomparisons. It is advantageous if the chart control limits are equal to or better than the uncertainties assigned to the artifacts normally calibrated by the intrinsic standard. In this way, these charts ensure valid operation and calibration of customer standards. Finally, these charts can be used to check proper system performance when training new operators; detect changes in procedures, data analyses, software, etc. as they are implemented; or detect adverse changes in system operation after component replacement or repair.

4. Develop Uncertainty Analysis

The uncertainty that is assigned to the intrinsic standard itself and the uncertainty associated with each type of standard that is calibrated by the intrinsic standard must be established by the laboratory for their specific realization of the intrinsic standard. The development of this analysis can be very time consuming and usually requires as input the results of the periodic characterization measurements. An uncertainty analysis may need to be performed for each calibration, so that a unique uncertainty is assigned for each use of the intrinsic standard and is based on the specific performance of the intrinsic standard and standard being calibrated. As with most calibration systems, the uncertainty assigned to standards calibrated by the intrinsic standard are always larger than the fundamental uncertainty assigned to the intrinsic standard itself. This is because the uncertainty assigned to the secondary standard must include effects of the transfer process, as well as the characteristics of the specific standard being calibrated. The recommended process for developing and combining uncertainties is described in the International <u>Guide to the Expression of Uncertainty in Measurement.</u> [9]

5. Operational Costs

Operational costs should be considered and included in the planning process. Sources of these costs can include training of staff on system operation and any safety training; purchasing supplies that are consumed during the operation of the standard (e.g., liquid helium for quantum standards); staff time spent performing intercomparisons and developing/updating control/trend charts; replacing components that have a limited life or that fail (e.g., the Josephson voltage chip); and personal protective equipment, safety reviews, etc.

A detailed analysis of the return on investment is usually the best means for justifying the purchase of the intrinsic standard. In the analysis, the following costs should be considered: (1) Cost for normal calibration by an NMI or other source; (2) shipping and handling of the artifact; (3) time required for data analysis and uncertainty calculations; (4) lost time when the artifact is being calibrated; (5) cost of duplicate standards, if any; (6) economic advantage of reduced uncertainties; and (7) additional cost of safety considerations. Furthermore other factors must be considered besides these direct costs; for example, by maintaining an intrinsic standard, which represents the highest level standard in a laboratory, all the quality control aspects of the standards are under the control of the calibration laboratory. This should make auditing more straight forward and less costly. Finally, if the working standard that is calibrated using the intrinsic standard is suspected of being out of tolerance, recalibration of the working standard can be performed almost immediately and the working standard quickly brought back on line. These additional factors, as well as others, could also result in significant cost savings over time to the calibration laboratory.

6. Safety

As with all standards and equipment, safety aspects associated with the specific intrinsic standard, and their associated costs, must be considered. For example, some materials may be toxic (e.g., mercury in temperature fixed point standards or manometers); cryogenic fluids can cause burns or displacement of oxygen in the laboratory environment. Other safety issues that may need to be considered include: developing and maintaining documented safety procedures; specific safety training of staff; purchasing protective equipment; and performing periodic safety reviews.

Experiences

In this section, we present a discussion of some historical developments associated with several intrinsic standards and, in addition, practical information related to setting up and operating these standards. It should be noted that this section is based on the experience of two of the authors (Pettit and Jaeger) and may not represent the general experience of others for these standards. However, it is hoped that this information will be useful to anyone who is interested in developing these or other intrinsic standards. Finally, this section provides some practical examples of the issues that need to be addressed when purchasing and maintaining intrinsic standards, as discussed earlier. Please note that literature references are not included for the standards discussed below; instead the reader is directed to the pertinent references for each standard contained either in the NCSL International Catalogue of Intrinsic and Derived Standards [3] or in the appropriate RISP's [6, 7, 8].

1. DC Voltage

Since 1972 the realization of the DC volt has been based on the ac-Josephson effect. Initially Josephson junction systems were available only in one or two junction versions, yielding output voltages in the 5 to 10 millivolt range. Such low voltages required the use of high precision bridges to step up to practical levels of 1.0 volt or 1.018 volt in order to allow comparison to Weston cells. By the mid 1980s, NIST personnel in Boulder, CO had the first few multi-junction arrays of Josephson Junctions available. By early 1986, a few were made available to outside laboratories. These array Josephson junctions (AJJ) consisted of up to 3,000 junction in series and allowed realization of direct DC voltages from about 140 microvolts to about 1.2 volt. The first industrial system was on-line and operational in September 1986. Further developments improved the junction manufacturing process and yielded arrays which could realize voltages of 1.0, 2.0 and 10.0 volt. The latter increased the junction numbers to over 20,000. In the US, ten volt arrays saw their first applications outside of NIST by the end of 1987 and early 1988.

Using AJJ's when they were first available was difficult and required very careful attention to details. The associated electronics were not well developed and wave-guide technology needed major improvements. Operation was at a temperature of 4.2 K, requiring liquid Helium cooling. Removing the probe and the associated AJJ chip from the Helium dewar was always challenging and frequently resulted in damage to the device. Clearly a better and more cost effective approach was required. The scenario changed drastically with the introduction of a new 10 volt chip manufactured with more stable superconducting materials, together with improved electronics and a new dielectric wave-guide. Because the sensitivity to temperature cycling is always a potential problem, many laboratories have decided to leave the chip permanently immersed in liquid Helium. This was accomplished by designing a new flange so that the Helium dewar could be refilled with a transfer tube while leaving the AJJ probe installed in the operating dewar. Another successful technique involves transferring the AJJ probe from one dewar into another within 5 seconds. Currently, there are several 10 volt AJJ systems in use that have seen continuous operation with the same AJJ chip for the past 12 years.

All systems, old or new, continue to go through constant improvements, many developed by personnel at NIST, Boulder. Periodic software updates are provided and associated electronics continue to be improved and are made available for purchase from commercial vendors. The chips themselves are now available commercially and intercomparisons between existing AJJ systems in North America (there are currently a total of 17 systems) are undertaken every 2 to 3 years. [10] Additional information on these systems is contained in References [6] and [11].

2. DC Resistance

Since 1990 the realization of DC resistance, or the ohm, has been based on the quantized Hall effect (QHE). This effect was first discovered in 1980 and saw its first realization in the NMI's by mid 1980. Commercial systems using superconducting magnets and Helium-4/Helium-3 refrigeration technology were on the market by 1989. QHE samples were hard to manufacture initially but are now readily available through NIST and the Bureau Internationale des Poids et Mesures (BIPM). The first system outside the NMI's was put into operation in 1990.

Operation of QHE systems requires careful attention to many components. Since it is not economically justifiable to maintain a Helium-4/Helium-3 refrigeration system under operation on a continuous basis, the system is typically used only 2 or 3 times a year. When starting the refrigeration system at the beginning start of each new run, the system has to be purged, leak checked, cooled down, etc. In addition, the superconducting magnet needs to be cooled down;

this requires an independent Helium 4 cooling reservoir. However, once the system is cooled down, the electronics checked out, and the software brought on line, the entire system is very forgiving. The system can be stabilized on a particular resistance plateau and essentially left unattended at this point for several days. (However, one has to pay attention to the liquid He boil off rates and ensure that there is an adequate supply of liquid He over this time period.)

Comparison of the Hall resistance with the unknown resistor requires high accuracy measurements of the applied current at all times. Hence a very stable current source is required, such as an Hg battery. All connections are switched back and forth over time and the drain of the battery is monitored very carefully. Automation of the data acquisition makes this comparison relatively straight forward, though the measurement process is time consuming and tedious. Overall once the system is operational, it is very stable and requires minimal attention. Additional information is contained in Reference [8].

3. Magnetics

Calibrations for magnetic flux have been, for many years, based on Nuclear Magnetic Resonance (NMR) utilizing proton, deuterium, lithium, etc. probes. Because of the unique resonance signature exhibited by the NMR and probe assembly, a clear signal is easily attained within a strong magnetic dipole field.

Recently, these systems have been superseded with the introduction of the Flowing Water NMR system. Magnetic flux calibrations are now possible from 1.4 microtesla (0.014 gauss) to 2.1 tesla (21,000 gauss). Calibration of fixed magnets can be accomplished in short calibration times. The Flowing Water system is still under development but will eventually replace all the old magnetic flux systems utilizing distinct proton probes.

4. Frequency Dissemination

Most laboratories use the commercially available cesium or rubidium beam frequency standards to realize frequency. The fractional offset of the standard can then be compared against Coordinated Universal Time via the Global Positioning System. Output from the cesium beam is used together with frequency and time interval analyzers with extended range to provide traceable frequency measurements. Stable outputs from the standards are available at nominal frequencies of 100 kHz, 1 MHz, 10 MHz, and/or 100 MHz. In addition, a source locking counter provides additional frequency range coverage, which together with an external mixer, can extend frequency measurements up to 110 GHz.

These systems have over the years proven to be extremely reliable and consistent. They are utilized in many metrology facilities. The only drawback has been the limited lifetime and expense of replacing of the cesium beam tube, which requires periodic replacement or refurbishing, typically every 5-7 years.

5. Length

Intrinsic standards for length calibrations are based on the stabilized iodine laser system. In this system, the operator selects one of seven narrow-band iodine absorption frequencies. These absorption frequencies are hyperfine structure components of an iodine-absorption line. The laser's frequency is tuned to the iodine absorption frequency by changing the laser's optical cavity. Next, the unit under test, in this case another laser, usually a He-Ne laser is compared against the Stabilized iodine laser by a heterodyne technique. The frequency difference is noted and retained in the computer system.

The laser calibrated using this technique is then used in a two laser automated gage block interferometer measuring system to calibrate a set of primary gage blocks to fractions of an interference fringe. These primary gage blocks are then used as reference for calibration of other blocks using mechanical comparators.

These interferometric calibration systems, based on the iodine stabilized lasers, have proven to be very reliable. The associated software and automation make the use and application very easy and efficient. Uncertainties are typically $\pm$ 30 nm from 1 mm to 25 mm. [3]

6. Temperature

Temperature calibrations are based on fixed points ranging from -272.5 °C (He-3) to 1084.62 °C (Cu). For the cryogenic region, the triple point gases hydrogen, neon, oxygen and argon can be used. However, these cells only allow the calibration for short-stem resistance thermometers. For the standard long-stem Standard Platinum Resistance Thermometers (SPRT), freezing or melting point cells of metals are used in addition to two triple point systems: Argon and water.

The triple point of water is the pivot point of all the temperature scales. For high accuracy temperature measurements, these cells require the use of a maintenance bath that can sustain the cells for months. The long stem triple point of argon system has proven to be very useful and so have all the primary metal freezing point cells like tin, zinc, aluminum, and silver. Currently, the mercury freezing point cell is readily available, as well as the gallium and indium cells with associated ovens.

The reliability of all these cells has been very high. All cells are readily available with proven purity of materials. Ovens and maintenance bath technologies are well understood and utilized throughout the metrology community. Uncertainties depend upon the material purity and method of realization; typically they vary from $\pm$ 0.4 mK to $\pm$ 8 mK. [3]

Summary

Intrinsic standards are widely used in the metrology community because they realize the best level uncertainty for many metrology parameters. For some intrinsic standards, recommended practices have been developed to assist metrologists in the selection of equipment and the development of appropriate procedures in order to realize the intrinsic standard. As with the addition of any new standard, the metrology laboratory should consider the pros and cons relative to their needs before purchasing the standard so that the laboratory obtains the maximum benefit from setting up and maintaining these standards. While the specific issues that need to be addressed depend upon the specific intrinsic standard and the level of realization, general issues that should be considered include ensuring that the intrinsic standard is compatible with the laboratory environment, that the standard is compatible with the current and future workload, and whether additional support standards will be required in order to properly maintain the intrinsic standard.

When intrinsic standards are used to realize the best level of uncertainty for a specific metrology parameter, they usually require critical and important maintenance activities. These activities can including training of staff in the system operation, as well as safety procedures; performing periodic characterization measurements to ensure proper system operation; carrying out periodic intercomparisons with similar intrinsic standards so that proper operation is demonstrated; and maintaining control or trend charts of system performance. This paper has summarized many of these important issues and therefore should be beneficial to any laboratory that is considering the purchase of an intrinsic standard.

References

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3. Catalogue of Intrinsic and Derived Standards, available from the NCSL International Business Office, 1800 30th Street, Suite 305B, Boulder, CO 80301.

4. As discussed in Reference 2, a derived standard is simply a primary standard which is not intrinsic. Derived standards are not discussed in this paper.

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