Trilateral optical powermeter comparison between NIST, NMIJ/AIST, and METAS

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We describe the results of a comparison of reference standards between three National Metrology Institutes: the National Institute of Standards and Technology (NIST, USA), the National Metrology Institute of Japan/National Institute of Advanced Industrial Science and Technology (NMIJ/AIST, Japan), and the Federal Office of Metrology (METAS, Switzerland). Open-beam- (free field) and optical-fiber-based measurements at wavelengths of 1302 and 1546 nm are reported. Three laboratories' reference standards are compared by means of two temperature-controlled, optical trap detectors. Measurement results show the largest differences of less than 4.2 parts in 10^3, which is within the expanded ($k = 2$) uncertainty for the laboratories' reference standards. © 2007 Optical Society of America

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1. Introduction

In our previous work,[1,2] we reported the results of international comparisons of reference standards used in the calibration of optical powermeters. Those reports describe the results that were obtained by use of open laser beams[1] and optical fiber cable[2] at 1302 and 1546 nm. More recently we also compared internal National Institute of Standards and Technology (NIST) laser and optical fiber power reference standards at several laser wavelengths in the visible and near infrared[3] (NIR). In this paper, the reference standards maintained by the three laboratories were compared by launching optical power from an optical fiber, and in the case of two laboratories [NIST and the National Metrology Institute of Japan/National Institute of Advanced Industrial Science and Technology (NMIJ/AIST)] by launching power from an open beam.

For optical fiber powermeter measurements, the primary standard of NIST is the cryogenic radiometer[4] that has an uncertainty of 2 parts in 10^4. The primary standard for NMIJ/AIST is an isothermal temperature-controlled calorimeter[5] that has an uncertainty of 6.4 parts in 10^4. The Federal Office of Metrology (METAS, Switzerland) derives its traceability from the cryogenic radiometer at the National Physics Laboratory (NPL, England), which has an uncertainty of less than 2 parts in 10^4. Typically, reference standards are calibrated against the primary standards by use of collimated (open) beams but are used with divergent beams characteristic of laser light exiting an optical fiber. Most primary standards are designed to be used with collimated beams rather than divergent beams from an optical fiber; therefore the laboratories utilize other reference standards to provide calibration services for optical powermeters, and a beam geometry correction is applied.

For the comparison of reference standards we used germanium photodiodes mounted in a trap structure. It has been shown in Ref. 6 that such a configuration provides a uniform response over a wide field of view and therefore does not require a correction for beam geometry. Two Ge-trap detectors were calibrated at the three national laboratories against their reference standards. The same lasers, operating at 1302 and 1546 nm, and the same optical fiber cable were used

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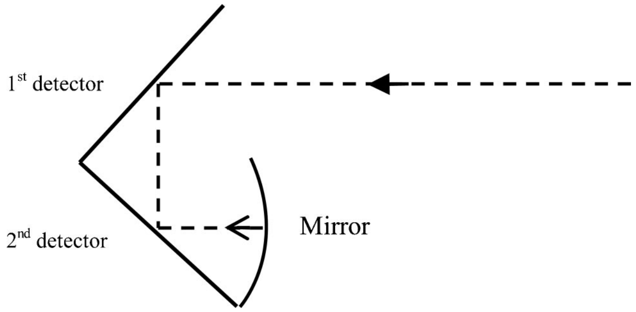

Fig. 1. Germanium-trap detector.

by the three laboratories, which employed a direct substitution method for their measurements.

2. Transfer Standard

For this comparison we used two similar transfer standards designed and built by NIST.[7] The transfer standard depicted in Fig. 1 is an optical trap detector that consists of two germanium photodiodes and a spherical mirror. The trap detector has two 10 mm diameter Ge photodiodes and a 15 mm diameter concave mirror (40 mm focal length) of aluminum coated with magnesium fluoride. The two photodiodes are oriented relative to the entrance aperture so that the principal ray of incident radiation strikes each diode once at a 45° angle of incidence and then reflects from the concave mirror back again onto the photodiodes in reverse order. The photodiodes and mirror are enclosed in a thermoelectrically cooled environment.[6]

3. NIST Measurement System

The NIST measurement system, described in Ref. 8 and depicted in Fig. 2, consists of fiber-pigtailed laser sources at wavelengths of 1302 and 1546 nm, a reference optical fiber cable, and a positioning stage for comparing the NIST reference and transfer standards. The output of each laser source is transmitted through a fiber to a fiber splitter from which about 1% of the power travels to a monitor detector. The remaining 99% of the power is transmitted through another fiber to either the reference optical fiber cable or the collimating lens.

The NIST reference standard is an electrically calibrated pyroelectric radiometer (ECPR) that had been previously calibrated against a primary standard, the NIST Laser Optimized Cryogenic Radiometer. The ECPR consists of a thermal detector, which is covered with gold black coating. The response of the ECPR does not depend on the wavelength of the incident radiation over the wavelength region of 1300–1550 nm.[9]

4. NMIJ/AIST Measurement System

The NMIJ/AIST measurement system, depicted in Fig. 3, is similar to the NIST system. It consists of fiber-pigtailed laser sources at wavelengths of 1302 and 1546 nm, a reference optical fiber cable, and a positioning stage for comparing the NMIJ/AIST reference and transfer standards. A fiber splitter and a monitor detector are used to monitor the power during the calibrations. The NMIJ/AIST reference and

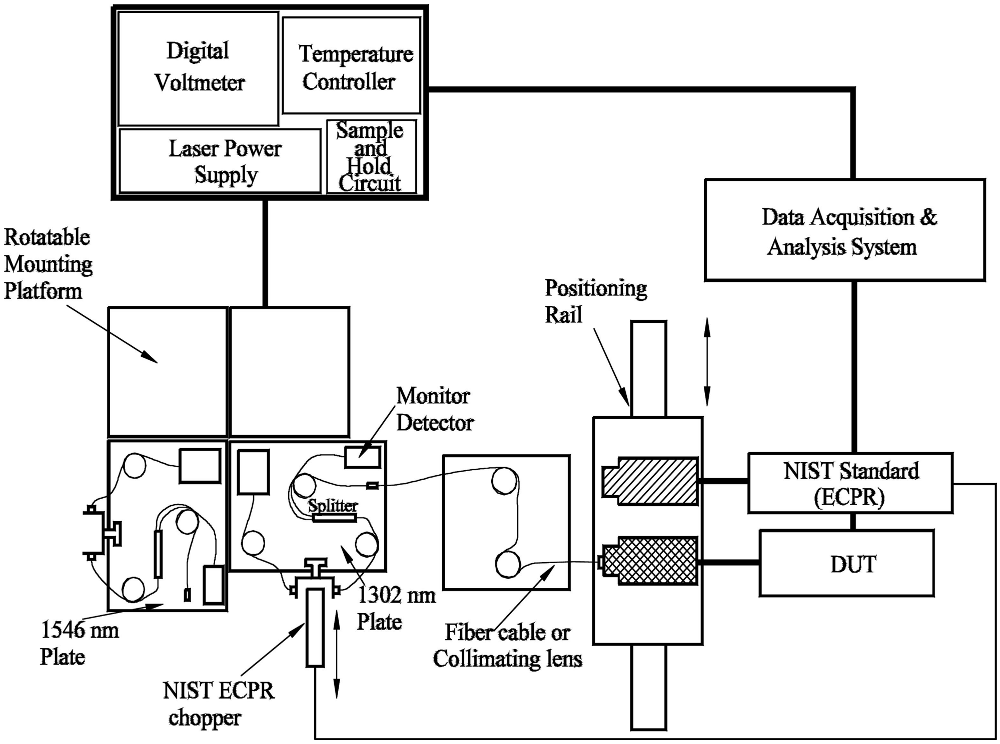

Fig. 2. NIST measurement system.

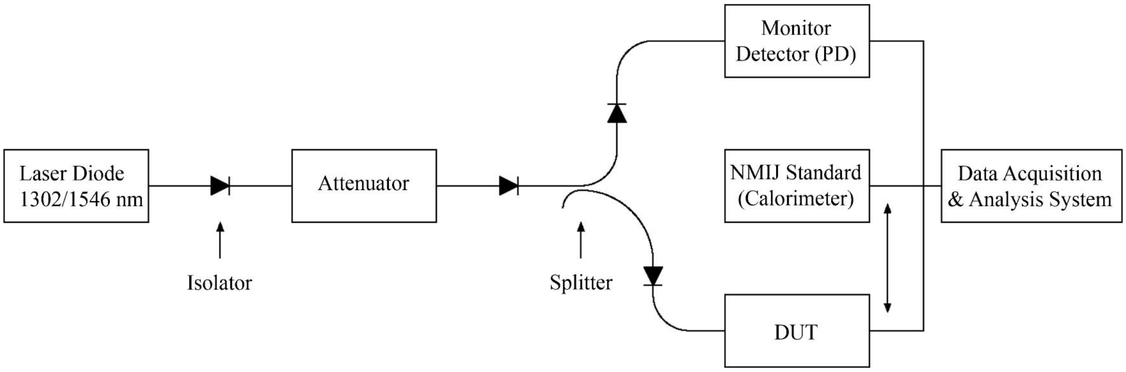

Fig. 3. NMIJ/AIST measurement system.

working standards are placed together on a positioning stage.

The NMIJ/AIST reference standard described in Ref. 10 is an isothermal temperature-controlled calorimeter that had been calibrated against the NMIJ/AIST primary standard.[5]

5. METAS Measurement System

The METAS measurement system is depicted in Fig. 4. The power launch system consists of fiber-pigtailed laser sources at wavelengths of 1302 and 1546 nm, a reference optical fiber cable, and an adjustable optical attenuator. The reference power level is then successively measured with three InGaAs reference detectors and by the trap detector under test (DUT). The calibration is achieved by calculating the difference between the power levels measured with the three reference detectors and with the DUT. The reference detectors are connected to current-to-voltage converters, and the output voltages are measured with a multiplexed digital voltmeter (DVM). The calibration process is computer controlled. An automated control system (ACS) allows the connectors to be mated without contaminating the InGaAs reference detectors. The connector and adapter mating is performed manually.

The METAS reference standards had been previously calibrated against the NPL cryogenic radiometer.

6. Results of the Comparison

The NIST, NMIJ/AIST, and METAS reference standards were compared by means of two Ge-trap transfer standards, described earlier, using both open beams and the reference optical fiber cable at wavelengths of 1302 and 1546 nm. The power was approximately 100 μW, or −10 dBm.

A. Open Beam

Only two laboratories (NIST and NMIJ/AIST) participated in the open beam configuration comparison. At NIST, six measurement runs were taken with a relative standard deviation of 1.3×10^{-3} at a wavelength of 1302 nm and a relative standard deviation of 0.7×10^{-3} at a wavelength of 1546 nm. At NMIJ/AIST, five measurement runs were taken with a relative standard deviation of 3×10^{-4} at 1302 nm and a relative standard deviation of 2×10^{-4} at 1546 nm. The beam size at both wavelengths was 1.7 ± 0.1 mm in diameter at $1/e^2$ intensity points. In this dual comparison both laboratories used trap detector 1. The results of the comparison are given in Table 1.

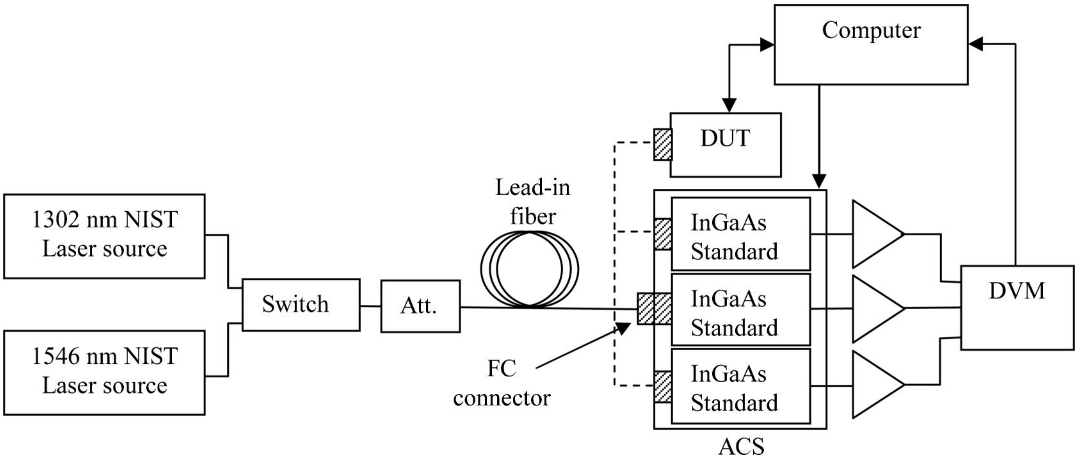

Fig. 4. METAS measurement system.

Table 1. Results of NIST and NMIJ/AIST Comparison Using Open Beams and Trap Detector 1

Source Wavelength (nm)	Difference (%)	Combined Standard Uncertainty (%)
1302	−0.42	0.35
1546	−0.41	0.38

The standard uncertainties for the NMIJ/AIST and METAS optical power measurements were evaluated in accordance with International Organization for Standardization (ISO) document standards,[11] and the standard uncertainties of the NIST measurements were evaluated in accordance with NIST guidelines.[12] At 1302 nm the difference between the NIST and NMIJ/AIST results was 4.2 parts in 10^3, and at 1546 nm the difference was 4.1 parts in 10^3. The NIST combined standard uncertainty ($k = 1$) was 1.7 parts in 10^3 at 1302 nm and 2.2 parts in 10^3 at 1546 nm, while that of NMIJ/AIST was 3.1 parts in 10^3 at both wavelengths. Table 1 provides values of relative combined standard uncertainty for NIST and NMIJ/AIST. These values are calculated by taking a square root of the sum of the squares of each laboratory combined uncertainty. A more detailed uncertainty analysis can be found in Refs. 8 and 10. The observed interlaboratory differences are less than the relative expanded ($k = 2$) uncertainties for the laboratories' reference standards.

B. Optical Fiber Cable

All three laboratories participated in the optical power launch using the same optical fiber cable. When comparing NIST and NMIJ/AIST, at NIST six measurement runs were taken with relative standard deviations of 1×10^{-4} at both wavelengths of 1302 and 1546 nm. At NMIJ/AIST, five measurement runs were taken with a relative standard deviation of 3×10^{-4} at 1302 nm and a relative standard deviation of 4×10^{-4} at 1546 nm. In this dual comparison both laboratories used trap detector 1. The results of the comparison are given in Table 2.

At 1302 nm the difference between the NIST and NMIJ/AIST results was 1 part in 10^3, and at 1546 nm the difference was 3 parts in 10^3. The NIST combined standard uncertainty was 1.9 parts in 10^3 at 1302 nm and 2.4 parts in 10^3 at 1546 nm, while that of NMIJ/AIST was 3.1 parts in 10^3 at 1302 nm and 3.2 parts in 10^3 at 1546 nm.

Table 2. Comparison of NMIJ/AIST and METAS Results Relative to NIST's Using an Optical Fiber Connector

Laboratory/ Detector #	Source Wavelength (nm)	Difference (%)	Combined Standard Uncertainty (%)
NMIJ/AIST/1	1302	−0.10	0.36
	1546	−0.30	0.40
METAS/2	1302	−0.26	0.39
	1546	−0.04	0.42

When comparing NIST and METAS measurements, at NIST six measurement runs were taken with a relative standard deviation of 8×10^{-4} at 1302 nm and a relative standard deviation of 6×10^{-4} at 1546 nm. At METAS, nine measurement runs were taken with relative standard deviations of 5×10^{-4} at both wavelengths of 1302 and 1546 nm. In this dual comparison both laboratories used trap detector 2.

At 1302 nm the difference between the NIST and METAS results was 2.6 parts in 10^3, and at 1546 nm the difference was 4 parts in 10^4. The NIST combined standard uncertainty ($k = 1$) was 2 parts in 10^3 at 1302 nm and 2.4 parts in 10^3 at 1546 nm, while that of METAS was 3.4 parts in 10^3 at both wavelengths of 1302 and 1546 nm. Table 2 provides values of relative combined standard uncertainty for NIST and NMIJ/AIST and NIST and METAS. These values are calculated by taking a square root of the sum of the squares of each laboratory combined uncertainty. The observed interlaboratory differences are less than the relative combined ($k = 1$) uncertainties for the laboratories' reference standards.

7. Conclusion

This optical powermeter comparison shows a reasonably good agreement between NIST, NMIJ/AIST, and METAS connecting North America, Japan, and Europe in the realm of international scales. These scales are important to establish a worldwide consistency in measurements of optical power in the area of optical telecommunication.

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