Short Communication

Comparison of reference standards for measurements of optical-fibre power*

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Abstract. National reference standards for determining optical-fibre power maintained by the National Institute of Standards and Technology (NIST, USA) and the All-Russian Research Institute for Optophysical Measurements (VNIIOFI, Russian Federation) were compared at wavelengths near 1300 nm and 1550 nm at a power level of 0.5 mW. Instruments from both laboratories are based on thermal detectors capable of electrical calibration. The comparisons indicate relative differences of 2 parts in 10^3 or less, which is easily within the combined uncertainty of the two laboratories.

1. Introduction

Optical-fibre power is determined by measuring the absolute power leaving the output end of an optical fibre. The accurate measurement of this quantity supports the growing lightwave communications industry. Laser-diode sources are provided in fibre-pigtailed packages; specifications are therefore based on the light emerging from the pigtail. In addition, other commonly used components such as optical-fibre amplifiers rely on specifications at input ports. The power levels of interest range from 10 μW to 10 mW, for laser diodes used as system sources, to several hundred milliwatts, for laser diodes used as pumps for optical-fibre amplifiers. Wavelengths in this comparison were confined to the popular 1300 nm and 1550 nm telecommunications windows. Compared with the measurement of free-space, collimated laser beams, measurement of the power emerging from optical fibres presents additional challenges. The polarization state is not known and may fluctuate, and the angular extent may approach a numerical aperture of 0.3 (multimode telecommunications fibre). Also, input/output connections may introduce systematic errors through multiple reflections with the detector surface [1].

2. NIST measurement system

The NIST system, which is in routine use, consists of pigtailed, intensity-stabilized laser-diode sources. The power from the output ends is measured with a commercially available, electrically calibrated pyroelectric radiometer (ECPR). This detector is made from lithium tantalate and is covered with a gold-black coating approximately 1 μm thick. Gold black is a common absorber for thermal detectors and is approximately 99 % absorbent in the visible and near-infrared regions. The optical-fibre path from the source contains an open-air, collimated region created by a stable U-shaped fixture. A mechanical chopper wheel, required for the proper operation of the ECPR, can be placed in the open-beam region. A fibre splitter is also used to couple out approximately 1 % of the source power to a detector that monitors power during the measurements. Small power changes occurring during the measurements are taken into account by recording the monitor output. Calibration of the device under test (or comparison) is accomplished by direct substitution with the ECPR.

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Table 1. Comparison results. The expanded uncertainties are determined using a coverage factor of 2. This terminology and treatment of uncertainty is consistent with international practice and is covered in [2].

Source wavelength/nm	100 × Difference VNIIOFI – NIST	100 × Standard deviation	100 × NIST expanded uncertainty*	100 × VNIIOFI expanded uncertainty
1308	0.21	0.10	0.58	0.10
1543	0.02	0.15	0.59	0.16

*This is the uncertainty assigned to the complete measurement system; the uncertainty of the NIST primary standard is much less (4 parts in 10^4).

The ECPR serves as a transfer standard to the NIST primary standard, which is a laser-optimized cryogenic radiometer (LOCR) capable of electrical calibration. Absolute calibration of the ECPR is accomplished by frequent comparison with the LOCR, which has an expanded uncertainty of less than 4 parts in 10^4. The expanded uncertainty for the complete NIST calibration system at the wavelengths and power levels of the comparison is 5.9 parts in 10^3 or less (Table 1); this includes various uncertainties assigned to the primary standard, transfer standard, fibre connector variability, and source stability [2].

3. VNIIOFI standard

The VNIIOFI primary standard is a compact thermal detector operating at room temperature and capable of electrical calibration. It incorporates two sensitive cavity-type absorbers (receiving and compensating) with a substitution heater for electrical calibration. Calibration is accomplished by direct substitution of electrically injected power using techniques to reduce drift in ambient conditions. A high fraction of the incident power (0.9996) is absorbed by the cavity with little spectral dependence. Equivalence of optical and electrically injected power is high with an equivalence coefficient of 1.0018. The detector exhibits a sensitivity of 0.25 V/W. Input to the detector is achieved through an optical-fibre connector. The detector is capable of being evacuated; under these conditions the expanded uncertainty is less than 1.4 parts in 10^3 for optical powers in the range 10^{-4} W to 10^{-2} W and over the spectral range 800 nm to 1600 nm. The uncertainty can be improved for single powers and wavelengths. For this comparison, the detector was not evacuated, and the expanded uncertainty was 1.6 parts in 10^3 or less (Table 1).

4. Results of the interlaboratory comparison

The VNIIOFI standard was brought to the NIST for comparison. The output of the NIST measurement system for this comparison was a single-mode fibre with FC/PC connectors. Before measurements began, instruments were allowed to reach equilibrium with the laboratory environment. The stability of the laboratory temperature placed ultimate limits on the precision of the comparison. Nine measurements were made at a wavelength of 1308 nm and five at a wavelength of 1543 nm. The power level used in the comparisons was 0.5 mW. Table 1 gives the average results. At 1308 nm the difference between VNIIOFI and NIST standards was 2.1 parts in 10^3, and at 1543 nm the difference was 2 parts in 10^4. The expanded uncertainty of the complete NIST measurement system was 5.9 parts in 10^3, while the uncertainty of the VNIIOFI standard detector was 1.6 parts in 10^3. The interlaboratory differences observed are less than the stated uncertainties of the NIST measurement system.

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References

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