U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
ELECTRONICS & ELECTRICAL ENGINEERING LABORATORY
Boulder, Colorado 80305

Report of Calibration (42110CA)

LASER POWER METER
Labsphere Model: 3P-LPM-040-SL, **S/N** 05076191
Keithley Current Amplifier Model: 428, **S/N** 1154940
Keithley Digital Multimeter Model: 2100, **S/N** 1148559

Submitted by

LIGO Hanford Observatory
ATTN: Richard Savage
127124 North Route 10
Richmond, WA 99354

Table 1. Calibration results

Wavelength (nm)	Nominal input power	N	Calibration factor (Rdg/W)	Standard deviation (%)	Expanded uncertainty (k=2) (%)
1047	289 mW	4	3.3418	0.07	± 0.86

Calibration summary

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NIST ID: 814788
Folder Number: 278356-10
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Reference: 05-MAR-2010, CHECK

The laser power meter was compared to NIST standard calorimeters at a wavelength of 1047 nm (Diode laser). The laser beam had a nominal diameter of 5 mm on the detector surface, and the test detector was centered in the incident beam. The power impinging upon the test instrument was measured concurrently using a calibrated beamsplitter and a NIST standard calorimeter (see Figure 1). The beamsplitter ratio was calibrated for each data set using two NIST standard calorimeters.

Before the measurements began, the test instrument was allowed to reach equilibrium with the laboratory environment. Readings were recorded visually from the test meter. The calibration factor was then found by dividing the test instrument reading by the calculated incident power. The ambient temperature during these measurements was 22 ± 1 °C. The detector diode temperature controller was set to -10 °C.

A summary of the measurements is given in Table 1. If the readings of the test instrument are **divided** by the appropriate calibration factor listed in the table, then, on the average, the resulting values will agree with those of the NIST measurement system.

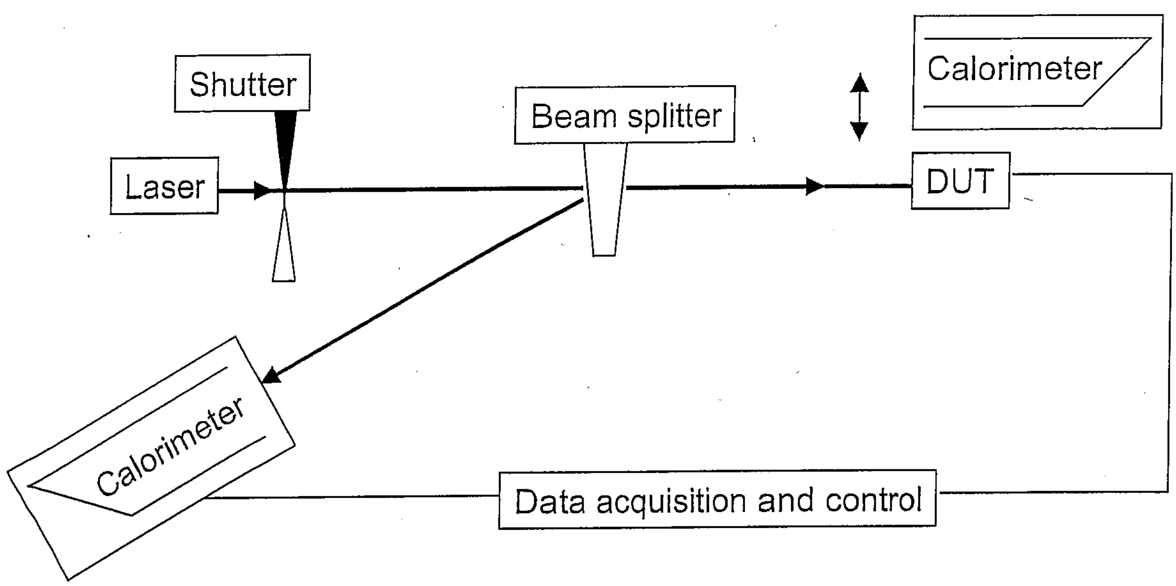

Figure 1. Measurement setup

Uncertainty assessment

The uncertainty estimates for the NIST laser energy measurements are assessed following guidelines given in NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" by Barry N. Taylor and Chris E. Kuyatt, 1994 Edition. To establish the uncertainty limits, the error sources are separated into (1) Type B errors, whose magnitudes are determined by subjective judgment or other non-statistical method, and (2) Type A errors, whose magnitudes are obtained statistically from a series of measurements.

All the Type B error components are assumed to be independent and have rectangular or uniform distributions (that is, each has an equal probability of being within the region, $\pm \delta_i$, and zero probability of being outside that region). If the distribution is rectangular, the standard uncertainty, σ_s, for each Type B error component is equal to $\delta_i/3^{1/2}$ and the total "standard deviation" is approximated by $(\Sigma\sigma_s^2)^{1/2}$, where the summation is performed over all Type B error components.

The Type A errors are assumed to be independent and normally distributed, and consequently the

$$S_r = \sqrt{\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{N}}{N-1}} ,$$

standard deviation, S_r, for each component is
where the x values represent the individual measurements and N is the number of x values used for a particular Type A error component. The standard deviation of the mean is $S_r/N^{1/2}$, and the total standard uncertainty of the mean is $[\Sigma(S_r^2/N)]^{1/2}$, where the summation is carried out for all the Type A error components.

The expanded uncertainty is determined by combining the Type A and Type B "standard uncertainties" in quadrature and multiplying this result by an expansion factor of 2. The expanded uncertainty, U, is then

$$U = 2\sqrt{\Sigma\sigma_s^2 + \Sigma\frac{S_r^2}{N}} .$$

The values used to calculate the NIST uncertainties are listed in Tables 2 and 3 for the power levels tested.

The number of decimal places used in reporting the mean value of the calibration factor listed in Table 1 was determined by expressing the total NIST uncertainty to two significant digits.

Table 2. NIST measurement uncertainties at 1064 nm, 30 mW

Source		Type B δ_i	Type A S_r	N
Standard calorimeter				
	Inequivalence	0.15 %		
	Absorptivity	0.01 %		
	Electronics	0.10 %	0.10 %	30
	Heater leads	0.01 %		
	Window trans	0.11 %	0.02 %	6
Measurements				
	Inject time	0.05 %		
	Laser power drift	0.50 %		
	Standard meter ratio	0.50 %	0.01 %	8
	Transfer meter ratio		0.07 %	4
Relative expanded uncertainty (k=2)				0.86 %

For the Director,
National Institute of Standards and Technology

Marla L. Dowell, Group Leader
Sources, Detectors and Displays Group
Optoelectronics Division

Report Reviewed By:

Joshua Hadler, Calibration Leader
Sources, Detectors and Displays Group
Optoelectronics Division

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