TECH NOTE

Accuracy and Repeatability of Power Measurements Using the FMH-8220 Fiber Optic Power Meter

OVERVIEW

Two key performance considerations when selecting an optical power meter are the accuracy and repeatability of the instrument. This technical note addresses these issues for the FMH-8220 Fiber Optic Power Meter and heads.

MEASUREMENT ACCURACY

The accuracy of an instrument is the "…closeness of agreement between the result of a measurement and a true value of the measurand."[1] In contrast, the uncertainty of a measurement reflects the lack of exact knowledge of the value of the measurand. Though there is a very real difference between measurement accuracy and calibration uncertainty, the terms are sometimes interchanged. This document describes the calibration uncertainty of the FMH-8220 and its associated measurement heads, and uses that as a guideline for expression of measurement accuracy.

There are two distinct categories of calibration uncertainty components discussed here: those which are the product of the calibration apparatus, and those which result from the particulars of each head design. The former are common to all heads, while the later must be evaluated for each model of measurement head.

Uncertainty contributions that are associated with the calibration apparatus include the calibration uncertainty of the parent transfer standard, wavelength calibration of the monochromator, measurement accuracy of instrumentation, spatial uniformity of responsivity of the parent transfer standard, and band pass effects. Typical combined uncertainty for these components is on the order of ±0.8%.

Uncertainty contributions that are unique to the particular measurement heads being calibrated include temperature coefficient of the unit under test, polarization dependent response (PDR), port effect and FOV effects (PE/FOV), linearity of responsivity (Linear), and sensitivity to beam geometry (displacement and divergence), and measurement repeatability (Repeat).

A temperature coefficient accounts for temperature related changes in responsivity over the reference conditions (21 ± 3°C).

Linearity accounts for deviation from ideal linear photodiode behavior. Each head is designed such that non-linear behavior is minimized.

Port effect is a contribution that is unique to integrating sphere based heads. It accounts for changes in integrating sphere transmission as a function of the optical properties of objects at the input port of the integrating sphere. In the case of the FMH-8715 and FMH-87107, this refers to the optical properties of the different types of fiber optic adapters that are available for these heads.

One advantage of integrating sphere based heads is that compared to bare photodiodes, they are insensitive to beam divergence and displacement, which is particularly useful when dealing with fiber coupled laser diodes, where beam divergence can vary substantially. A bare photodiode detector based head is prone to errors due to spatial non-uniformity of responsivity, angle of incidences, and beam divergence while integrating sphere based heads are relatively insensitive to these factors.

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UNCERTAINTY CALCULATIONS

Each contribution to calibration uncertainty is evaluated according to the NIST Handbook of Statistical Methods[2]. Accordingly, individual components are summed by root-sum-squares (RSS), and relative expanded uncertainty is reported. The relative expanded uncertainty describes the interval over which the true value of a measurement can be expected to lie with 95% confidence. For further detail about the calibration process or uncertainty analysis please refer to reference 3, Calibration and Traceability of ILX Lightwave Optical Power Meters.

The transfer standard used in the calibration of the FPM-8220 measurement heads is a temperature controlled germanium photodiode. It is calibrated annually at NIST and typical calibration uncertainty is on the order of ±0.2%. Calibration is transferred to the FMH-87XX heads by means of the substitution method. The table below illustrates the primary contributions to calibration uncertainty for all three of the FMH-87XX measurement heads at two common laser diode wavelengths.

	λ	CAL Stn	FPM	TempCo	PDR	PE	Linear	Noise	Displace	Diverge	Repeat	2*Uc
FMH-8705	1310	0.64	0.35	0.35	0.08	0.00	0.27	0.06	0.29	0.87	0.40	2.63
	1550	0.83	0.35	0.35	0.08	0.00	0.27	0.06	0.29	0.87	0.40	2.83
FMH-8715,	1310	0.64	0.35	0.35	0.08	0.64	0.27	0.06	0.14	0.18	0.08	2.19
FMH-87107	1550	0.83	0.35	0.35	0.08	0.64	0.27	0.06	0.14	0.18	0.08	2.42

Values listed in the table state the standard relative uncertainty (1σ) for each of the components. The column on the right lists the expanded relative uncertainty (2σ) for each head and wavelength.

The FMH-8715 and FMH-87107 are integrating sphere based heads, and as such they are less sensitive to beam geometry related errors. The trade off is that they are more sensitive to port effect. Because the two heads use the same integrating sphere geometry, they have nearly identical individual uncertainty components. The dominant components are the calibration system, temperature coefficient, and port effect.

REPEATABILITY TEST PROCEDURE

The following procedure was used to measure the repeatability of measurement for each of the FMH-87XX measurement heads. The output fiber of a 1557nm DFB laser diode module was coupled via FC/APC terminated fiber optic patch cord into the unit under test. Optical power was measured and recorded. The fiber optic patch cord was then removed, cleaned, and replaced, and the measurement repeated. This entire sequence was repeated 30 times for each head. The difference between the maximum power and the minimum power, expressed as a percentage of the average power, was then reported as repeatability of measurement.

Because the FMH-8715 and the FMH-87107 use the same integrating sphere design, only the FMH-8715 was tested for repeatability of measurement.

REPEATABILITY RESULTS

Given that the FMH-8705 is more sensitive to variations in the placement of the fiber end face relative to the photodiode active area (beam geometry effects) than the FMH-8715 and FMH-87107 integrating sphere based heads, it is not surprising that it does not provide the same degree of repeatability of measurement as the integrating sphere based heads under these measurement conditions.

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The following table shows the repeatability of measurement for the FMH-8705 to be about ±0.64%, and the integrating sphere based heads are about three times better with a repeatability of about ±0.23%.

	Max Deviation	Min Deviation	Repeatability (Total Deviation)
FMH-8705	0.40%	-0.24%	0.64%
FMH-8715, FMH-87107	0.13%	-0.10%	0.23%

SUMMARY

The FMH-8220 and associated FMH-87XX measurement heads provide a high level of measurement accuracy and repeatability. For the most demanding applications, the FMH-8715 and FMH-87107 are capable of measurement uncertainty of ±2.5% or better, while the FMH-8705 provides a lower cost alternative that still achieves a calibration uncertainty of ±3.5%. This accuracy is bolstered by measurement repeatability sufficient to support these ambitious measurement accuracy goals.

REFERENCES

1. *JCGM 100:2008. Evaluation of measurement data - Guide to the expression of uncertainty in measurement, Joint Committee for Guides in Metrology.*
2. *NIST/SEMATECH e-Handbook of Statistical Methods*, *http://www.itl.nist.gov/div898/handbook/, 2011.*
3. *App Note #36, Calibration and Traceability of ILX Lightwave Optical Power Meters*