Connector-induced offsets in optical fiber powermeters

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We discuss issues related to calibration of optical fiber powermeters. The power readings may vary when using various types of fiber connectors, or even the same type of connectors made by different vendors. We study the connector effects by calibrating four types of optical fiber powermeters using six different fiber connectors from four vendors at three wavelengths. We found variations of as much as 12% due to the different reflection properties of the detector windows, connectors, and detectors. We also compared connector measurement results with the data obtained by using open beams.

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1. Introduction

Most optical fiber powermeters (OFPMs) are being used to measure power that exits an optical fiber. When optical power is measured, the radiation propagates to an OFPM through a fiber attached to the OFPM by a fiber connector and connector adapter. Since a fiber connector is located near an OFPM's detector (and its associated window), reflections are possible. These reflections introduce errors in the power readings and can shift the measurement results.[1–5] In fact, the OFPMs read higher with a fiber and connector than with an open beam due to reflections from the detector's window, the detector itself, and/or the fiber connector ferrule. To investigate this phenomenon we conducted a study involving the calibration of OFPMs. We chose six popular connector types: ferrule connector/physical contact (FC/PC), biconic, SC, ST, FC/APC, and SMA from four vendors chosen randomly (the vendors are identified by letters A through D). These connectors were attached to single-mode fiber cables. Measurements were performed on four types of OFPMs (the meters are identified by numbers 1 through 4) at three wavelengths: 850, 1310, and 1550 nm. This work includes more extensive data than in previous papers.[3,4] Even though this paper's intent is to illustrate the nature of the fiber connector-related issues, we cannot predict the variability between connectors of the same type, or variability between connector types when using different OFPMs.

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2. Measurement System

The system depicted in Fig. 1 and described in Ref. 6 was used to perform the measurements. As a transfer standard, we used a commercially available, electrically calibrated pyroelectric radiometer (ECPR) described in Ref. 7. The detector's active area is approximately 8 mm in diameter; this detector has very low reflectance over the wavelength range from 850 through 1550 nm. The pyroelectric sensor is made of a lithium tantalate crystal, which is covered with a gold–black coating. The sensor does not have a window. The detector response of the transfer standard is insensitive to angles of incidence that constitute a fiber's NA.

The measurement system contains three laser sources and a positioning stage for comparing the outputs of the ECPR and the test OFPM. All the optical fibers in the system are single mode. Each laser source plate contains a laser diode whose output is transmitted (through a fiber) to a fiber splitter from which approximately 1% of the energy propagates (also through a fiber) to a monitor. The instability of laser power is taken into account by the monitor readings. The fiber jumper cables (used with the test OFPMs) are stationary during the calibrations. Power is coupled directly into the pyroelectric detector or the test meter. The incident power is about 100 μW or −10 dBm.

3. Results

In this section we describe the results of measurements involving connectors of different types (e.g., FC/PC, biconic, SC, etc.) and the same type, but from various vendors. In addition, we compare the measurement results obtained from various connectors and open beams. In this paper we present both new

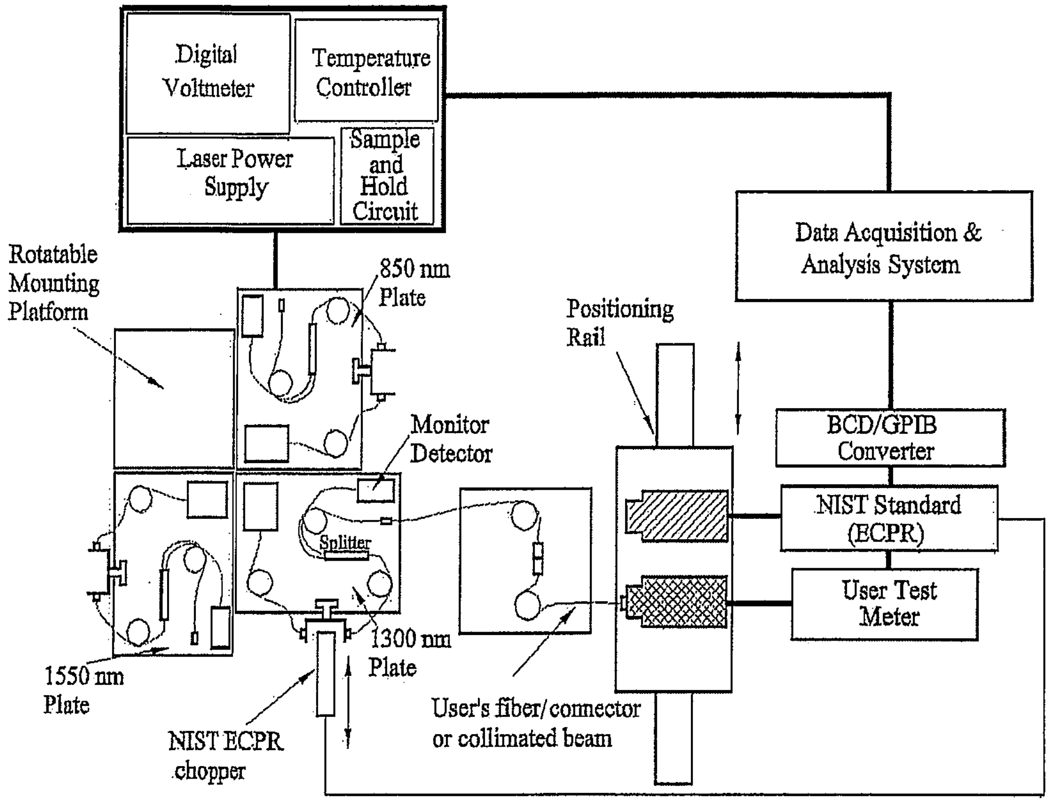

Fig. 1. Measurement system.

and some old data. Our intent was to perform all measurements on six connector types and three wavelengths, but some measurements were not taken due to the unavailability of some connector types. The variables for the connector study are given in Table 1. Each OFPM was used with a number of designated fiber connector adapters. The results of the measurements are presented in the form of tables, numbered from 2 through 8; the offsets are given in percent due to their relatively small values (most cases).

We compare calibration factors (CFs) for any given connector with a CF of a reference connector at each wavelength when using a specific type of OFPM. The offset between these CFs is calculated according to Eq. (1):

Table 1. Variables for Connector Study

Connector type:	FC/PC, biconic, SC, ST, FC/APC, and SMA
Connector vendor:	A through D
Wavelength:	852, 1307, and 1550 nm
Meter (detector type):	OFPM #1 (Si and Ge remote sensors; angled)
	OFPM #2 (InGaAs fiber-pigtailed sensor)
	OFPM #3 (Ge sensor with window; not angled)
	OFPM #4 (windowless Ge sensor; not angled)

$$\text{Offset}\ (\%) = (\text{CF}_{\text{DUT}}/\text{CF}_{\text{REF}} - 1)100, \qquad (1)$$

where CF_{DUT} and CF_{REF} are CFs of the device under test (DUT) with a fiber connector and reference connector, respectively. The calibration factor of an OFPM is a ratio of power readings of the OFPM to that of the NIST transfer standard according to Eq. (2) using the same connector type at a given laser wavelength:

$$\text{CF}_{\text{DUT}} = P_{\text{DUT}}/P_{\text{TS}}, \qquad (2)$$

where P_{DUT} and P_{TS} are power readings measured by the DUT and transfer standard (TS), respectively. CFs are unitless and their values are close to unity. CF_{REF} for the reference connector may be written in the similar way.

In most cases when comparing different connector types, the reference connector is an FC/PC type connector. We chose this connector because it is one of the most popular fiber connectors used in our laboratory. For each measurement, we performed five data runs; the results show good repeatability when a specific connector is used. Connectors' offsets are consistent. The standard deviation of five data runs is usually less than 0.1%. We also describe the maximum offset between any given connector type and the reference connector as the offset with the largest positive value (not necessarily the largest absolute value). Conversely, the minimum offset has the largest negative value. Tables 2 through 4 and Table 8

Table 2. Connector Effects for OFPMs #1 and 2 Compared to FC/PC at 852 nm

Powermeter	OFPM #1				OFPM #2			
Connector/Vendor	A	B	C	D	A	B	C	D
Biconic	−0.12	−0.76	−0.34	−0.15[a]	0.18	−3.5	0.70	0.68[a]
SC	−0.33	−0.21	−0.31	—[b]	0.88	1.4	1.2	—
ST	−0.51	−0.67	−0.64	—	−1.8	−0.33	0.28	—
FC/APC	—	−0.39	−0.90	—	—	0.01	0.42	—
SMA	—	—	−0.35	0.26[a]	—	—	2.8	1.3[a]
Maximum offset	−0.12	−0.21	−0.31	0.26	0.88	1.4	2.8	1.3
Minimum offset	−0.51	−0.76	−0.90	−0.15	−1.8	−3.5	0.28	0.68

[a]Compared to ST connector of vendor D.
[b]— Not available.

contain both values for maximum and minimum offsets. The data in the tables are self-explanatory.

A. Connectors of Various Types From the Same Vendor

In this paper we use the following connector types: FC/PC, biconic, SC, ST, FC/APC, and SMA. All connectors have ceramic ferrules except the metallic connectors from vendor B and SMA from all vendors. Tables 2 through 4 describe the results of measurements taken with four OFPMs for four different vendors at three laser wavelengths. Note: Tables 2 through 4 reference the measurement results to FC/PC connectors of vendors A through C (each column references measurement results to the FC/PC connector of each vendor). The last column of Tables 2 through 4 references the measurement results to the ST connector of vendor D. Table 2 describes the results of measurements taken with the connectors of four different vendors and OFPMs #1 and #2 at 852 nm (no measurements were taken at 852 nm for

Table 3. Connector Effects for OFPMs Compared to FC/PC at 1307 nm

Powermeter	OFPM #1				OFPM #2				OFPM #3				OFPM #4			
Connector/ Vendor	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Biconic	0.10	0.01	0.10	0.60[a]	0.36	0.31	0.59	0.13[a]	−4.1	−10.3	−4.3	−4.2[a]	−0.59	−1.8	−0.34	−0.07[a]
SC	0.30	−1.6	0.20	—[b]	0.62	0.66	0.91	—	−2.5	−2.8	−2.3	—	−0.52	−2.1	−0.23	—
ST	−0.59	−0.49	−0.49	—	−0.48	−0.29	0.66	—	−0.18	−0.41	−1.2	—	−0.45	−0.51	−0.54	—
FC/APC	—	−0.89	−0.99	—	—	−0.17	0.17	—	—	−1.7	0.90	—	—	−0.93	0.11	—
SMA	—	—	−0.01	0.50[a]	—	—	0.83	0.28[a]	—	—	6.1	−1.5[a]	—	—	1.2	−0.34[a]
Maximum offset	0.30	0.01	0.20	0.60	0.62	0.66	0.91	0.28	−0.18	−0.41	6.1	−1.5	−0.45	−0.51	1.2	−0.07
Minimum offset	−0.59	−1.6	−0.99	0.50	−0.48	−0.29	0.17	0.13	−4.1	−10.3	−4.3	−4.2	−0.59	−2.1	−0.54	−0.34

[a]Compared to ST connector of vendor D.
[b]— Not available.

Table 4. Connector Effects for OFPMs Compared to FC/PC at 1550 nm

Powermeter	OFPM #1				OFPM #2				OFPM #3				OFPM #4			
Connector/ Vendor	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Biconic	0.40	0.20	0.20	0.80[a]	−0.01	0.10	0.20	0.57[a]	−4.9	−11.7	−4.7	−5.2[a]	0.18	−3.5	0.70	0.68[a]
SC	0.01	−1.0	0.10	—[b]	−0.10	−0.20	−0.41	—	−2.8	−3.7	−2.1	—	0.88	1.4	1.2	—
ST	−0.30	−0.30	−0.30	—	−0.58	0.70	−0.20	—	−0.66	0.58	−1.4	—	−1.8	−0.33	0.28	—
FC/APC	—	−0.70	−0.75	—	—	0.01	−0.10	—	—	−1.7	−0.01	—	—	−0.17	0.42	—
SMA	—	—	0.01	0.10[a]	—	—	0.80	0.97[a]	—	—	6.8	−1.2[a]	—	—	2.8	1.3[a]
Maximum offset	0.40	0.20	0.20	0.80	−0.01	0.70	0.80	0.97	−0.66	0.58	6.8	−1.2	0.88	1.4	2.8	1.3
Minimum offset	−0.30	−1.0	−0.75	0.10	−0.58	−0.20	−0.41	0.57	−4.9	−11.7	−4.7	−5.2	−1.8	−3.5	0.28	0.68

[a]Compared to ST connector of vendor D.
[b]— Not available.

Table 5. Connector Effects for Different Vendors Compared to Vendor A at 852 nm

Powermeter	OFPM #1			OFPM #2		
Connector/ Vendor	B	C	D	B	C	D
Biconic	−0.44	−0.25	−0.38	−0.69	0.20	−0.01
ST	0.04	−0.16	−0.14	4.6	1.8	1.3

OFPMs #3 and #4 because these OFPMs utilize germanium detectors). Tables 3 and 4 describe the results of measurements taken with the connectors of four different vendors using four OFPMs at 1307 and 1550 nm, respectively. The difference between the values of maximum and minimum offset gives the span of possible offsets for a particular OFPM at a certain laser wavelength for a given fiber connector manufacturer. From Table 2, the largest span at 852 nm was observed for OFPM #2 when using connectors of vendor B. From Tables 3 and 4, the largest spans at 1307 and 1550 nm were found for OFPM #3 when using connectors of vendor B.

B. Connectors of the Same Type but Various Vendors

We opted not to show all the connector data that we have collected. Tables 5 through 7 compare connectors of various vendors using a specific OFPM and connector type (biconic and ST). The results for Tables 5 through 7 are calculated the same way as for Tables 2 through 4. Table 5 shows the results of measurements taken with the OFPM #1 (angled silicon and germanium remote sensors) and OFPM #2 (InGaAs fiber-pigtailed sensor), and compares the measurement results from three vendors to the reference connectors of vendor A. From Table 5 the largest offset at 852 nm was observed for OFPM #2 when using an ST connector of vendor B. Tables 6 and 7 show the results of measurements taken with four OFPMs and compare the measurement results from three vendors to the reference connectors of vendor A at 1307 and 1550 nm, respectively. From Tables 6 and 7 the largest offsets at 1307 and 1550 nm were found for OFPM #3 when using ST connectors of vendor B.

C. Connector Results Compared to Open Beam

We previously compared CFs for different connectors to a reference connector. In this subsection we compare results of measurements using connectors and open beams for three different OFPMs. For this comparison we chose connectors of vendor C only. We performed measurements at three wavelengths of 852, 1307, and 1550 nm for OFPM #1, and at two wavelengths of 1307 and 1550 nm for the OFPMs #3 and #4. Due to the detector geometry (fiber pigtailed), an open beam cannot be launched into the OFPM #2. Open beams of 1.7 ± 0.1 mm diameter at $1/e^2$ intensity points were used with the OFPMs #1, 3, and 4. Open beams of 2.5 ± 0.1 mm diameter at $1/e^2$ intensity points were used with the transfer standard. Table 8 shows the results of measurements taken with three OFPMs and compares the measurement

Table 6. Connector Effects for Different Vendors Compared to Vendor A at 1307 nm

Powermeter	OFPM #1			OFPM #2			OFPM #3			OFPM #4		
Connector/Vendor	B	C	D	B	C	D	B	C	D	B	C	D
Biconic	0.30	0.40	0.30	0.07	−0.10	−0.05	−0.11	−0.10	−0.13	0.11	0.02	0.06
ST	0.20	0.20	0.10	0.32	0.80	0.66	7.5	−0.97	0.18	1.3	−0.33	−0.01

Table 7. Connector Effects for Different Vendors Compared to Vendor A at 1550 nm

Powermeter	OFPM #1			OFPM #2			OFPM #3			OFPM #4		
Connector/Vendor	B	C	D	B	C	D	B	C	D	B	C	D
Biconic	0.10	0.20	0.40	0.10	0.20	0.01	−0.55	−0.25	−0.67	0.30	−0.01	0.10
ST	−0.10	−0.01	0.10	1.3	0.38	0.01	8.5	−1.1	0.29	2.9	−0.68	0.10

Table 8. Connector Effects for Vendor C Used with 3 OFPMs Compared to Open Beam

Powermeter	OFPM #1			OFPM #3		OFPM #4	
Connector/Wav (nm)	852	1307	1550	1307	1550	1307	1550
FC/PC	0.77	0.20	0.20	5.7	4.9	1.5	3.9
Biconic	0.42	0.30	0.40	1.2	−0.10	1.2	0.90
SC	0.45	0.40	0.30	3.3	2.7	1.3	2.7
ST	0.12	−0.30	−0.10	4.4	3.5	0.94	2.1
FC/APC	−0.14	−0.79	−0.55	6.7	4.9	0.11	0.96
SMA	0.41	0.20	0.20	12.2	12.0	2.7	4.4
Maximum offset	0.77	0.40	0.40	12.2	12.0	2.7	4.4
Minimum offset	−0.14	−0.79	−0.55	1.2	−0.10	0.11	0.90

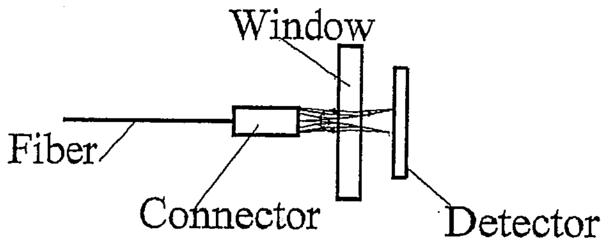

Fig. 2. Schematic of OFPM showing possible interference effects.

results for these OFPMs to the results obtained with the open beam at three wavelengths. The largest spans of offsets (from maximum to minimum) at 1307 and 1550 nm were found for OFPM #3 when using various connectors of vendor B.

4. Conclusions

The use of various connector types of the same connector manufacturer and variability within a single connector type obtained from different vendors may produce large (up to 12%) measurement offsets when using the same OFPM. When changing types or manufacturer of connectors on fibers connected to various OFPMs, a user should be aware of potential offsets that might occur during measurements. We suggest that a transfer standard, which is insensitive to the connector types' effects, could be a useful tool during OFPM calibrations. Due to multiple reflections from the OFPM window, detector and connector we also suggest that the transfer standard should not have a protective window (see Fig. 2). The multiple reflections may produce interference effects, which will make an OFPM read higher. Placing a sensor at a small angle will decrease reflections between the sensor, the sensor's window, and the connector.

Also, the OFPM user should not assume that the results (calibration factors) obtained from fiber-connectorized measurements would be the same as those obtained with open beams when using the same OFPM. From our previous measurements (not included here) we found that a connector adapter could contribute up to 4% offset in a calibration of an OFPM. Therefore the connector adapter used with the connector should be an integral part of the optical fiber power measurement.

We found that the magnitude of the connector-induced offsets depends on the wavelength. We cannot predict the magnitude of these offsets; an accurate measurement of optical power is required for each wavelength. We also observed that the connector-induced offset is small if a connector does not reflect power to the detector's window or an OFPM's detector is slightly angled. A connector (or connector adapter) with a reflecting surface will cause the OFPM to read incorrectly, usually higher. It is very important to calibrate an OFPM with the same type of connector and connector adapter that are used in the actual measurement.

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