Calibration of optical fiber power meters: the effect of connectors

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This paper addresses the question of accurate measurement of optical power at the wavelengths and power levels of interest to the telecommunications community. In particular, we examine the calibration of power meters that are destined for use in a field environment. Connectors and adapters are shown to skew the measurements, leading to errors attributable to reflections from the connector or to angular dependence of detector response. Calibration data are taken using two popular connector types: a biconic and an SMA type. The data are sufficient to illustrate the problem but definitive conclusions cannot be drawn regarding variability of performance with connector or connector type, because of the limited data.

I. Introduction

Optical power is usually measured with commercially available power meters that are designed for field use. Those meters are calibrated in a laboratory environment, but field use frequently violates the basic tenets of accurate calibration.

We have found that, even in a controlled laboratory environment, there is considerable discrepancy in measurements made by different workers using typical local laboratory conditions. At 1300 nm, for example, we found differences of more than 3 dB between laboratories. These discrepancies were found during a round robin experiment conducted recently by the National Bureau of Standards; the results were discussed in the literature.[1] Analysis showed that much of the error was systematic, due in part to the use of small area detectors. Even when the data from the small area detectors were removed from the data base, there remained a spread of ~1.6 dB in the data. Additional insight to the calibration and measurement problem was given in other recent publications.[2,3]

The problems encountered in field measurements can be quite subtle. They frequently lead to systematic errors that remain undetected. If the meter is properly calibrated, perhaps the dominant source of error is the use of connectors and connector adapters. Unfortunately, there is a variety of connector types, each with its unique characteristics, but there are variabilities even within each type. We have examined two popular connector types in an effort to examine uncertainty of measurements and the source of errors likely to be encountered in the field.

Our intent is to illustrate the nature of the problem. The data are not exhaustive so definitive conclusions cannot be drawn. We cannot predict, on the basis of these data, the variability to be expected between connectors of the same type, or variability between connector types.

II. Background

The National Bureau of Standards effort in calibrating optical fiber power meters begins with our calorimeter, which we use to calibrate an electrically calibrated pyroelectric radiometer (ECPR); the ECPR is then used in our laboratory as a secondary standard. The pyroelectric detector is quite large (diameter is more than 0.5 cm) so collection of all the light is relatively easy. The detector response is also insensitive to angle of incidence over a comfortably wide range of angles. The uncertainty of the ECPR calibration factor is typically 1.1%. The optical fiber power meter transfer standard is calibrated from the ECPR using a parallel beam of light incident normally, in turn, on the ECPR and the transfer standard. The resulting uncertainty in calibration of the transfer meter is usually <2% (1.8% is typical). The transfer standard is made available to the fiber community for use in local calibration. The locally calibrated meter serves, in turn, as the standard against which other local instruments are compared. The meter that goes into the field, for example, is calibrated against this local standard.

The problem of interest is this: how accurately does the local instrument read power out of a connectorized fiber end? Because measurement conditions are not

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the same as those used in the calibration of the transfer standard, we would expect some error. It is generally assumed to be small, but little is known of the source of the error or of its magnitude. The measurements are generally repeatable within a family of connector types, but there is variability between connector types. Our experiment was designed to determine dominant sources of connector-related error and to assess the expected magnitude of such error.

III. Experimental Method

The experimental arrangement used for calibrating the transfer standard power meter is given in Fig. 1. The light source is a stabilized laser diode. Light is launched into a 50/125-μm fiber mode mixer. The light incident on the detector is in a parallel beam of ~3-mm diameter. This value is chosen to minimize the effects of spatial nonuniformities on the detector surface, which is ~5 mm in diameter. The calibration factor is determined by comparing the measurement of power using, in turn, the pyroelectric detector and the transfer meter. The power level is ~100 μW. The method described here will be referred to as method *B* (as in basic).

To determine the effects of a connector, we coupled light from the output of the fiber mode scrambler into a fiber pigtail that was connectorized on one end only (see Fig. 2). Power was then coupled into a 100/140-μm fiber that had a connector on both ends. This was necessary to accommodate each of two connector types. Power was then coupled directly into the pyroelectric detector and, in turn, into the meter, using an adapter provided by the meter manufacturer. The mode filter was included to eliminate cladding modes and high-order modes, if any. The coiled fiber shown in Fig. 2 was not allowed to move during the measurements. The method described here (see Fig. 2) will be referred to as method *C* (as in connectorized). Method *C* was used three times (three different conditions), as described further below. The corresponding data are labeled *C*1, *C*2, and *C*3. For each of the three conditions, ten measurements were made.

The adapter allowed us to mate the connectorized end of the fiber pigtail to the meter. We believe these same adapters are used frequently in field operations. Method *C* yielded a new calibration factor for each of two connector types: SMA and biconic. These two types are among the most popular. In addition, the two types represent two extremes in connector design. One (the SMA) has metallic reflecting surfaces between the connector and the detector, while the other (biconic) does not.

IV. Experimental Results

Data were collected using four methods: Method *B* refers to the basic calibration procedure. To track the effects of various contributors to calibration errors, one of the connectors (the SMA type) was used in three conditions, referred to as methods *C*1, *C*2, and *C*3. Data were taken with the biconic connector using only method *C*1. Method *C*1 involves use of the connector

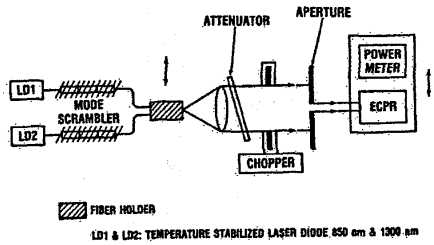

Fig. 1. Block diagram of measurement arrangement for the basic calibration, referred to in the text as method *B*.

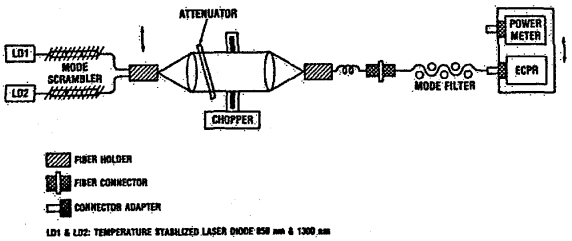

Fig. 2. Block diagram of measurement arrangement for calibration with the connectors.

without modification. This method probably simulates the method used in local laboratories that attempt a global calibration intended to account for the connectors.

The SMA connector and adapter both have obvious reflecting surfaces between the connectorized fiber end and the detector surface. Methods *C*2 and *C*3 were devised to determine the effects of those surfaces. First, the reflecting portion of the adapter was blackened using flat black paint. Nothing was done to the tip of the ferrule which houses the fiber end. The data taken using the blackened adapter are said to be taken using method *C*2. The ferrule tip was then blackened using a black marking pen. The end of the fiber was carefully avoided. The darkened tip was used with the blackened adapter in method *C*3.

Data for the biconic connector were taken using only method *C*1. Neither the connector nor the adapter has an apparent reflecting surface, so blackening the parts did not seem necessary.

The results are given in Table I and in Figs. 3–6. The figures give frequency histograms for ten measurements made in each of the three conditions. Each histogram is labeled according to the method it represents. The calibration factor is larger (the meter reads higher) for methods *C*1, *C*2, and *C*3 than for method *B*. Furthermore, the difference (between methods *C* and *B*) depends on connector type, the difference being larger for the SMA type than for the biconic type. Even though we blackened the ferrule tip (for the SMA connector only) as carefully as we could, there remained some reflecting surface which we could not cover without endangering the fiber tip. We believe the remaining exposed surface was the major contribu-

Table I. Power Meter Calibration Factor and Standard Deviation, 850 and 1300 nm, SMA and Biconic Connectors

Connector	Method	Wavelength (nm)	Calibration factor	Standard deviation	Ratio	Ratio value
None	*B*	850	0.957	1.98×10^{-3}	—	—
SMA	*C1*	850	1.077	7.00×10^{-4}	C1/B	1.125
SMA	*C2*	850	1.068	8.23×10^{-4}	C2/B	1.116
SMA	*C3*	850	0.988	6.68×10^{-4}	C3/B	1.032
Biconic	*C1*	850	0.973	7.20×10^{-4}	C1/B	1.017
None	*B*	1300	1.029	2.30×10^{-3}	—	—
SMA	*C1*	1300	1.113	6.13×10^{-4}	C1/B	1.082
SMA	*C2*	1300	1.108	6.57×10^{-4}	C2/B	1.077
SMA	*C3*	1300	1.059	7.25×10^{-4}	C3/B	1.026
Biconic	*C1*	1300	1.039	1.67×10^{-3}	C1/B	1.010

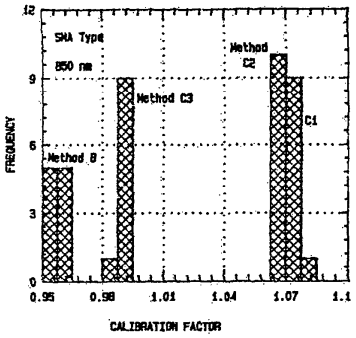

Fig. 3. Histogram of measurements at 850 nm using the SMA type connector.

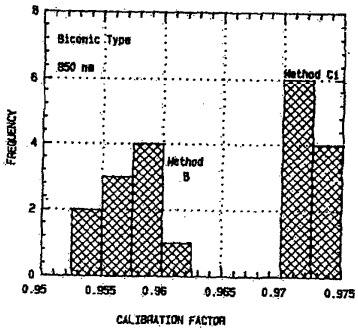

Fig. 5. Histogram of measurements at 850 nm using the biconic connector.

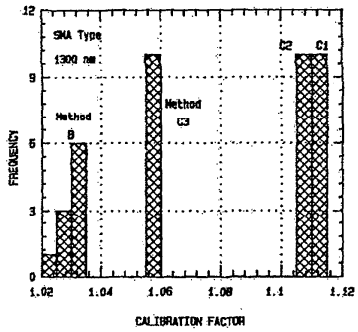

Fig. 4. Histogram of measurements at 1300 nm using the SMA type connector.

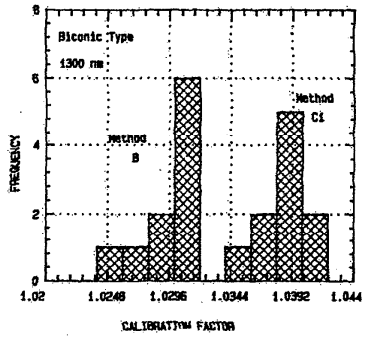

Fig. 6. Histogram of measurements at 1300 nm using the biconic connector.

tor to the difference in calibration for the SMA (method *C3*) and the biconic (method *C1*). Note that there is obvious consistency in the two wavelengths.

The response of a germanium detector depends on angle of incidence. Thus, the numerical aperture of the fiber or connector end may affect the calibration. We made no effort to quantify the effect. We examined the response of the detector and found that it increases with increasing angle of incidence, in agreement with what had been seen earlier.[2] This may be due to interference effects in the passivation layer of the detector surface. The effect depends on wavelength and passivation layer thickness. Figure 7 gives typical results that we saw on a single cooled germanium detector at 850 and 1300 nm. The angular range covered in Fig. 7 is quite large; a fiber having N.A. = 0.2, for example, has an emission half-angle of only 11.5°. Figure 7 should be viewed accordingly. Nevertheless, the angular effect might be a contributor to the calibration error. Our limited data preclude definitive conclusions on the magnitude of the effect. The spatial averaging inherent in the calibration procedure tends to reduce the dependence on angle of incidence. Additional discussion on this matter is given below.

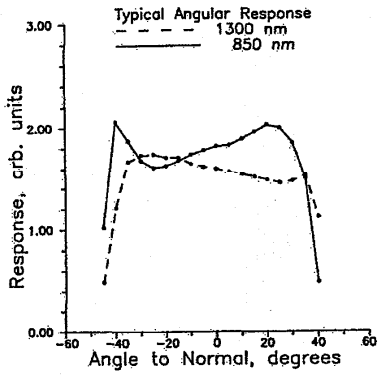

Fig. 7. Typical angular dependence of response for a cooled germanium detector.

The response of the pyroelectric detector is independent of incident angle.

The data shown in the histograms of Figs. 3–6 are strikingly consistent and show that a reflecting surface can cause considerable offset in the calibration. The data also show that the repeatability of measurements made with a connector is quite reliable. The error encountered with the connector is consistent, the reflections of the SMA causing a significant increase in the calibration factor. The error in the biconic is small and probably due to a small reflection (even though the connector seems to be black) with an additional contribution from the angular dependence of the detector response.

The last column of Table I gives additional insight into the error introduced by the two connector types. The column shows a definite trend, appropriate to these data only. For example, the data for the biconic connector for the two wavelengths are in reasonably good agreement (within 0.7%). The calibration is high by 1.7% and 1%, respectively. This is not the case for the SMA connector, for which there is a 4% difference between the two wavelengths in the extreme case.

The 0.7% difference between the 1300- and 850-nm data for the biconic connector might be attributable to the difference between the angular dependence at 850 nm and at 1300 nm (see Fig. 7). We are struck by the agreement between the biconic and the SMA connectors in this regard. The difference between the 850- and the 1300-nm data is almost identical for the two connector types: 0.007 vs 0.006 (see Table I, last column, rows 4 and 9, 5 and 10). We speak here only of the difference in the spatial dependence at the two wavelengths and not of the spatial dependence at either wavelength.

The reflections remaining in the SMA connector, even after carefully painting the end of the connector tip, probably account for most of the residual error. Extreme care was called for. Some of the metal tip probably remained unpainted. Compare the data for the two connector types.

Apparently it may be possible to perform a global calibration, including the effect of a connector. However, based on the data we have collected, each connector type would require its unique calibration. We found considerable difference between the two types that we considered.

Unfortunately, the calibration is complicated by the differences in the adapters, not discussed here. We noted measurable differences between three adapters made by the same company for a single connector type. On examination, we saw a difference in fiber positioning, probably due to manufacturing tolerance.

V. Discussion

Connectors and connector adapters present special problems in calibrating meters. Nevertheless, the repeatability that we saw was encouraging and indicated that calibration is possible. Repeatable and accurate meter correction can be made to account for the connector and the meter adaptive fixture. A carefully calibrated meter is quite versatile and its use with connectors can be reliable. Unfortunately, our data also show that the calibration (or correction) depends on connector type. Thus, a meter should be calibrated for each connector type of interest. Furthermore, data should be taken to determine the uncertainty introduced by the tolerance on the adapters.

In one case, we saw a noticeable calibration discrepancy between two adapters of the same type. Visual examination revealed the probable cause. The two adapters yielded a noticeable difference in the position of the fiber relative to the input to the detector. If that difference is typical of the fixtures being used in the field, uncertainty increases. Our data are not sufficient to draw definitive conclusions on the resulting increase in uncertainty.

Our data reveal that the calibration of a power meter is useful only when the user is aware of the conditions in which the calibration was performed. The power meter transfer standard used by the National Bureau of Standards is calibrated using a parallel beam incident normally on the detector. If the transfer standard is used to calibrate an in-house reference meter for local use, connectors and fixtures, if any, must be properly accounted for. We have the feeling that this is not always being done.

VI. Conclusions

An optical power meter transfer standard can be useful in calibrating a local reference meter. Its utility, however, depends on its proper use. With suitable care, laboratories can be assured that subsequent measurements are on a reasonable base. Unfortunately, we find that some laboratories use the transfer standard and the local reference meter with connectors and associated adaptive fixtures to emulate the conditions in which their meters are being used in the field. Thus, they attempt to calibrate the connector, fixture, and local reference meter in one global calibration. Our data reveal that the errors encountered in so doing may be significant. The error is due to improper use of the transfer standard since the local calibration does not emulate the method used in the original calibra-

tion. Unfortunately, the method we refer to as method $C1$ is probably the one used most often by workers who rely on a transfer standard. The potential error is then significant, as can be seen by comparing methods B and $C1$ in the figures. We found that errors of 10% are possible.

The data reveal that the connectorized data are quite repeatable (see Table I), indicating that it is indeed possible to consider a global calibration. The calibration factor in that case will depend on connector type. The stated uncertainty should then reflect the uncertainty encountered owing to the differences in connector adapters. Our data are too limited to allow definitive conclusions in this regard, but they indicate that the differences may be noticeable.

The data show that errors are probably caused by multiple reflections from the connector hardware and the dependence of detector response on incident numerical aperture. Unfortunately, the latter affect is difficult to quantify; the effect also depends on wavelength, further complicating analysis and compensation.

The data presented here were taken on a single power meter using a cooled germanium detector. In addition, only one sample of each connector was used. The data should be interpreted accordingly. In particular, the conclusions may not be appropriate to other brands or other types of meter or to other connectors.

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