*Fiber and Integrated Optics*, Volume 7, pp. 241–248
Printed in the UK. 

0146-8030/88 $3.00 + .00


# Calibrated Optical Fiber Power Meters: Errors Due to Variations in Connectors

XIAOYU LI*
R. L. GALLAWA

National Bureau of Standards
Electromagnetic Technology Divison

***Abstract*** *We discuss potential errors in the measurement of optical fiber power when using a calibrated power meter with connectors of various types and from different vendors. Data are given on the error and standard deviation due to biconic connectors from a limited number of vendors. We speculate that the error is due to reflecting surfaces on the connector end. To confirm the hypothesis, we tested two connectors whose reflective ends have noticeable differences. The data illustrate the variability seen among connectors. Our data indicate that a user should expect measurement error in most cases. We issue a call for caution based on the results.*

## Introduction

Commercially available optical fiber power meters are usually calibrated in a way that eliminates as many sources of error as possible. This usually implies the use of a collimated beam and normal incidence on the detector surface; the beam diameter is such that it typically covers about 60% of the detector's active area. In this paper we discuss the potential errors encountered when a meter that has been so calibrated is used in a typical field environment. In particular, we believe that connectors are frequently used in the field and users draw considerable comfort from the good repeatability that connectors yield. Unfortunately, we find that there is often a measurable offset created by connectors. The offset depends on the connector type and on the vendor for a given type. We report on the magnitude and the source of potential errors.

## Background

The National Bureau of Standards (NBS) effort in the calibration of optical fiber power meters is based on a calorimeter that is used to calibrate an electrically calibrated pyroelectric radiometer (ECPR), which then becomes the in-house secondary standard. The pyroelectric detector's active surface is large (diameter is about 8 mm) so light collection errors are not likely. The detector response is also linear and insensitive to angle of incidence.

Having taken considerable care to eliminate most calibration errors, we sus-

Received: February 23, 1988; accepted March 3, 1988.
* Guest Scientist, on leave from the Laser Division of the Beijing Institute of Machinery and Electricity, Beijing, People's Republic of China.

pect that connectors are used without properly accounting for their effect. Most connectors produce very repeatable results, which may complicate the matter because of the confidence such repeatability begets.

In an earlier study [1] we examined the offset encountered when a calibrated power meter is used with a connector and connector adapter. The study yielded information on how the offset varies with connector type. We found a noticeable difference between the two connector types (SMA and biconic) that we studied. A reflecting surface at the end of a connector seems to cause a substantial offset in the power reading. The offset usually causes the meter to read high.

In this paper we examine the logical extension to the question addressed in reference [1]: Is there a measurable difference in connectors of the same type (multimode biconic) but from different vendors? We also examine further the role of reflecting ferrules in causing the offset. We measured the error encountered with two popular single mode connectors: the D-4 and the FC/PC connectors. We noted that the end face of the FC/PC connector appears to be more reflecting than the D-4. The data seem to substantiate the feeling that the reflecting end plays a key role in the error introduced by the connector.

Our data are limited; conclusions are therefore tentative.

## Measurement Technique

We compared the power measured with a commercial NBS-calibrated meter when used with and without an intervening connector and connector adapter. The arrangement used is given in Figure 1. The light source is a stabilized laser diode. Light is launched into a 50/125 μm fiber mode filter, as shown. The mode filter was included to eliminate cladding modes and high order modes, if any. The mode scrambler was used to isolate the spatial effects of the source from the launch conditions. The arrangement allowed a comparison of the test meter with the calibrated ECPR, which has no window and has a flat, uniform, and linear response. The ECPR response is also independent of the angle of incidence. Knowing the calibration factor of the power meter without a connector, we were able

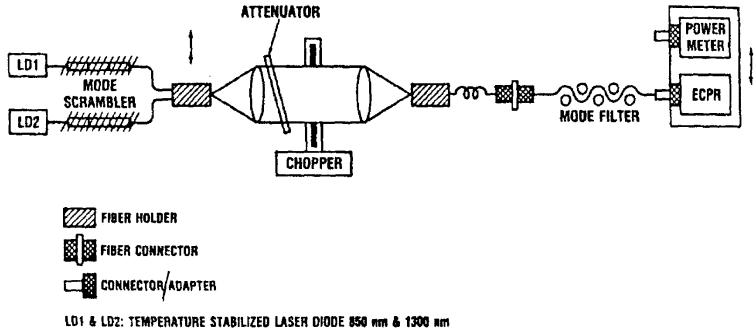


Figure 1. Block diagram for the measurement arrangement for the calibration factor with the connectors.

to determine the effect of the connector on the power reading. The insertion loss of the connector did not play a role in offset. The power level was about 0.1 mW. The fibers were not allowed to move during the measurements.

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 Figure 1). Power was then coupled into a 50/125 μm fiber that had a connector on both ends. This was necessary to accommodate each of the connectorized jumpers. Power is coupled directly into the pyroelectric detector and, in turn, into the meter by means of an adapter provided by the meter manufacturer. To determine how the offset varies with vendor, we concentrated on the biconic connector used with 50/125 μm fibers. We used jumper samples from five vendors, with no special care taken in choosing the jumpers. We presume that the data taken are therefore representative of what would be encountered by a user buying from the same five vendors. The vendors are identified by letters A through E. We avoided bookkeeping that might have associated a vendor with a letter, but were careful to note that all jumpers from vendor A, for example, were properly identified to avoid mixing samples. We separated the samples into two classes: those made of nonmetallic resin (vendors A, B, and C), and those made of aluminum (vendors D and E). Vendor D anodizes the aluminum; vendor E does not. In addition, the ferrule that houses the fiber in the end of the connector is different in each case. The ferrule used by vendors D and E is reflecting; vendors A, B, and C used a nonreflecting ferrule. We think the differences are the major cause of the variations.

We did not originally intend to divide the connectors into the two groups, but decided to do so after our previous experience with reflecting ends.

We used a slightly different version of Figure 1 to conduct further tests on the effect of reflecting end faces on power meter error. This test was conducted with single mode connectors. For this experiment we used a single mode jumper that had a biconic connector on one end, to mate with our experimental arrangement, and the single mode test connector on the other end; the second end was coupled to the meter. We used two connector types for this test: the D-4 and the FC/PC connectors, the latter being a low reflectance model of the FC. Data were taken only at 1,306 nm. The arrangement again insured that the insertion loss did not influence the results.

Both of these connectors have a reflecting end, but the FC/PC connector seems, to the naked eye, to be more highly reflecting. We therefore expected the offset for the FC/PC connector to be higher than that for the D-4. The experimental evidence confirms those expectations. The standard deviation is acceptably low in both cases.

## Results

The results are given in the form of histograms and tables. Figures 2 and 3 show histograms for the biconic connectors from all vendors for the two wavelength windows of interest: 850 nm and 1,300 nm. Note the change of horizontal scale on the two figures. The measurement offset is labeled "calibration factor" in the figures. This is in keeping with the spirit of the experiment. The data suggest that anodizing the aluminum makes little difference. This is verified in Figures 4 and

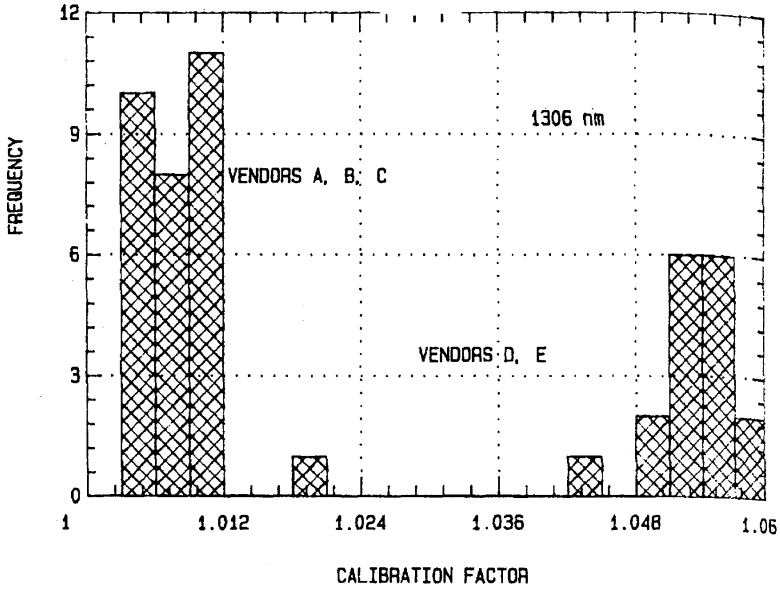


**Figure 2.** Calibration histogram for all biconic connectors at 1,306 nm.

**Table 1**
Calibration Factors for Biconic Connectors

| Vendor | Wavelength nm | Number of samples | Cal. factor | Std. dev. $\times 10^4$ |
|---|---|---|---|---|
| A | 850 | 10 | 1.015 | 6.6 |
| B | 850 | 10 | 1.012 | 11.9 |
| C | 850 | 9 | 1.014 | 7.6 |
| D | 850 | 8 | 1.110 | 121.9 |
| E | 850 | 10 | 1.119 | 98.7 |
| A + B + C | 850 | 29 | 1.014 | 17.0 |
| D + E | 850 | 18 | 1.115 | 117.2 |
| A | 1306 | 10 | 1.008 | 10.7 |
| B | 1306 | 10 | 1.005 | 2.9 |
| C | 1306 | 9 | 1.010 | 4.0 |
| D | 1306 | 8 | 1.051 | 35.3 |
| E | 1306 | 10 | 1.051 | 109.0 |
| A + B + C | 1306 | 29 | 1.008 | 21.5 |
| D + E | 1306 | 18 | 1.051 | 82.5 |

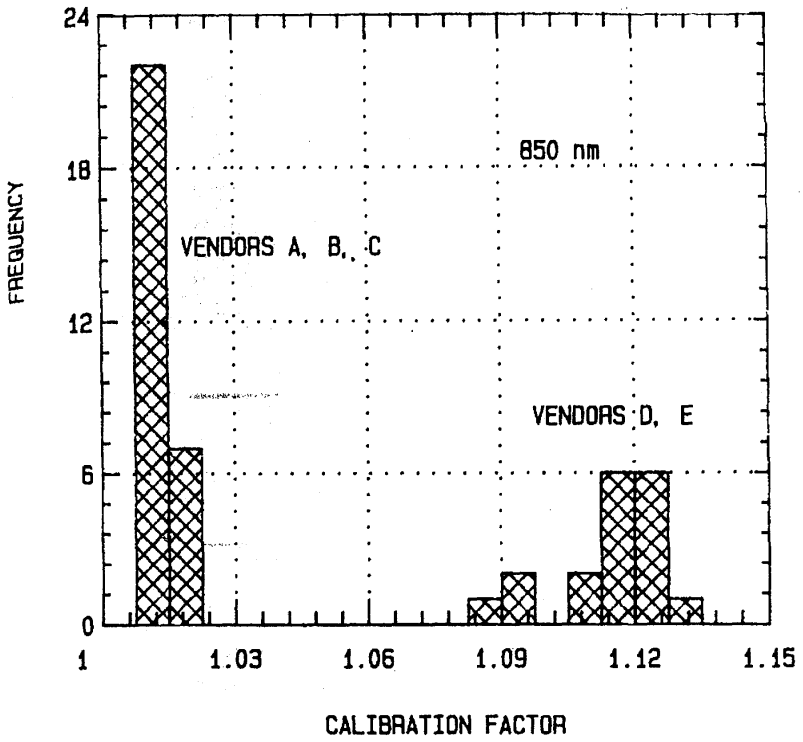


**Figure 3.** Calibration histogram for all biconic connectors at 850 nm.

5, which give separate histograms for the connectors from vendors D and E at 1,306 nm. The data are given in tabular form in Table 1. The data for 850 nm (not shown here) are similar. Note that the standard deviation is a function of vendor, with vendors D and E showing greater standard deviation than vendors A, B, and C. Evidence indicates that the use of reflecting ferrules to house the fiber may be a major contributor to the measurement offset. The connectors from vendors D and E have a ceramic ferrule holding the fiber in the aluminum housing. Because the data for the anodized aluminum connectors are similar to those for the unanodized aluminum ones, we suspect that the major difference between connectors in the two classes is not the aluminum but the ceramic (reflecting) ferrule, which is not found in the connectors from vendors A, B, and C.

Additional evidence is seen in Figure 6, which shows the offset between two connector types, D-4 and FC/PC, as labeled. The FC/PC has a more highly reflecting end than the D-4. The data show its effect. Table 2 gives the tabular form of the data shown in Figure 6.

All calibration factors are greater than unity, indicating that the connector caused the meter to read high in every case.

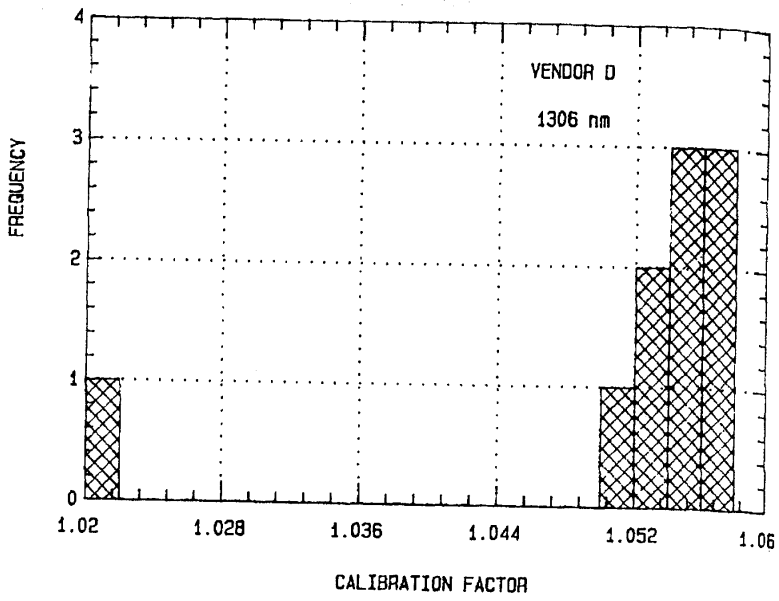


**Figure 4.** Calibration histogram for biconic connectors from vendor D at 1,306 nm.

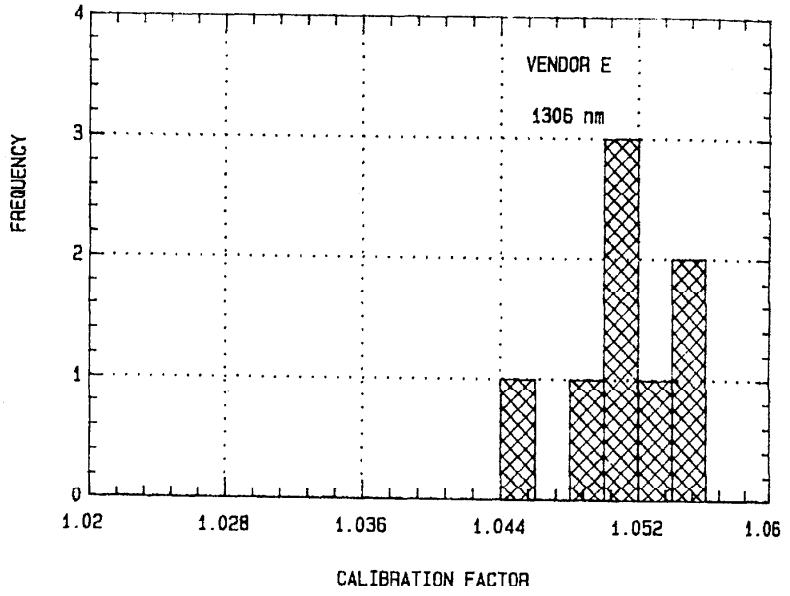


**Figure 5.** Calibration histogram for biconic connectors from vendor E at 1,306 nm.

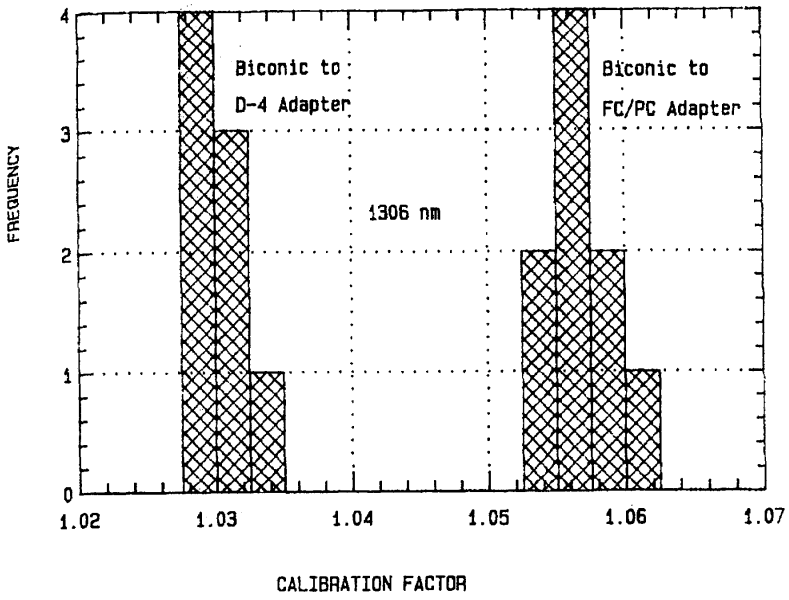


**Figure 6.** Calibration histogram for D-4 and FC/PC connectors at 1,306 nm.

## Conclusions

We have found that potential error is encountered when measuring optical power with an optical fiber connector and a calibrated power meter. Our data show that the measured power is substantially different when using different copies of the same biconic connector type, although the agreement is good if we restrict attention to connectors that do not have the ceramic ferrule holding the fiber. The standard deviation of the measurements is different for the different vendors. See Table 1. The data show that the repeatability is good but the offset (error) is substantial. The offset is small if the biconic connector does not have a reflecting end.

We hypothesize that a connector with a reflecting end will cause the meter to read incorrectly (usually high). The offset (called the "calibration factor" in the histograms) seems to depend strongly on the nature of that reflecting end. The

**Table 2**
Calibration Factors at 1,306 nm

| Connector type | Number of samples | Cal. factor | Std. dev. $\times 10^3$ |
|---|---|---|---|
| D-4 | 9 | 1.033 | 8.4 |
| FC/PC | 8 | 1.057 | 2.3 |

data in Figure 6 and Table 2, taken for two single mode connector types, give credence to this hypothesis.

The data given here and in [1] give a clear indication that the use of a connector is likely to cause measurement error unless the user has determined the calibration offset for the connector being used and takes steps to compensate for that offset. The repeatability of the connector measurements (see Tables 1 and 2) indicates that a "global" calibration may be possible, wherein the offset for a given connector type and/or vendor can be factored into the meter calibration.

We caution the power meter user to be aware of the manner in which the meter calibration was performed and to be alert to the possibility of errors introduced when the meter is not used in strict accordance with the calibration procedures. In short, the user is cautioned: The use of a calibrated meter *does not guarantee* that the power measurement will be correct.

## Acknowledgments

The authors acknowledge the constructive comments of Mr. Dennis Horwitz, Photodyne, Inc., Mr. Germain Lamonde, EXFO Electrooptics Engineering, and Mr. Duane Cowan, AT&T Technologies, Inc. Some of the components tested were provided by Photodyne, Inc. Their help is appreciated.

## References

1. Robert L. Gallawa and Xiaoyu Li, "Calibration of Optical Fiber Power Meters: The Effect of Connectors," *Appl. Opt.* **26(7),** 1170–1174, 1987.