Optical fiber power meters: a round robin test of uncertainty

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The proliferation of optical fiber systems has spawned a variety of optical power meters. These meters are important to the analysis and maintenance of fiber communication systems. One obvious attendant concern is with the uncertainty of the meter readings. In this paper, we give the results of an interlaboratory test conducted to circumscribe and define the extent of the problem. The test yielded 46 data points from 11 participants collected over a period of ~9 months. The results indicate that the variation in power meter readings taken in different laboratories is unreasonably large. The variance improved when measurements taken with very small detectors were excluded from the data base. This suggests that errors are being made in the collection of power in typical laboratory environments.

I. Introduction

Measurement of optical power represents a significant challenge to the continuing development of optical fiber systems. It has long been thought that there may be significant discrepancy among optical power measurements made at different laboratories. It is, of course, difficult to identify the source of those discrepancies, if they exist. We have attempted here to determine the magnitude of the discrepancies and identify their single most likely cause. In particular, we have identified the size of the active detector area as an important indicator of the variability one can expect from the measurement. There are surely others.

In this paper, we concentrate on the uncertainty of optical power measurements under typical laboratory conditions. That is, we attempt to determine the interlaboratory uncertainty found in typical power measurements. Data were taken at the two wavelengths of interest to the fiber-optics community (850 and 1300 nm). We make no effort to compare the reported values with the correct value. The interlaboratory variation is primarily random, although errors encountered in a given laboratory may be systematic. Consequently, the uncertainty reported here is a complicated and undefined combination of uncertainties introduced by both random and systematic errors. We feel that the information collected will nevertheless be important in defining the need and scope of calibration services.

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That the errors encountered in any given laboratory (i.e., by any one participant) might include a systematic component is only implicit in the data given here. We note, for example, that some of the participants reported data that were consistently biased in one direction. Evidence of this is seen in the frequency histograms (Figs. 1–4), where some of the data imply a bias. It thus seems that there might have been systematic errors that were undetected by the participant. Details of this bias, if any, are not known.

II. Method

The method used in this test is intended to emulate the method used under usual laboratory conditions. Eleven laboratories participated in the test. Each participant was asked to couple light into the meters under test in a manner consistent with his normal procedures. The light was coupled first to the participant's meter and then to a reference meter provided by NBS. Both readings were reported to NBS. Those readings form the basis of the data given below.

The reference meter had been decalibrated so its reading would have no meaning to the participant. In this sense, the test was blind. The participant had no reason to adjust his method or his readings to conform to a perceived correct value.

The reference meter had no fixed method of light coupling. Thus, if the usual procedure was to use a coupler to mate the fiber to the meter, the participant was free to use that method. The large size of the detector on the reference meter made it easy to couple power directly into the meter. If a coupler were used, the participant was obliged to account for its loss.

Participants were asked to report the source wavelength and size of the active area of the meter used.

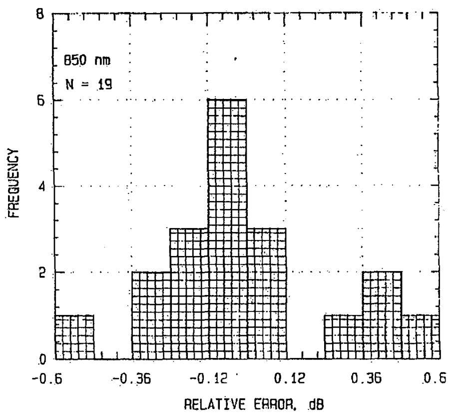

Fig. 1. Frequency histogram for data at 850 nm.

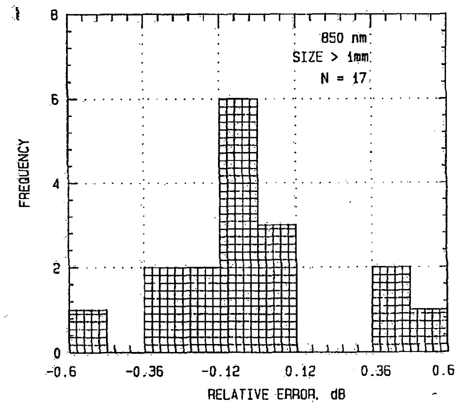

Fig. 3. Frequency histogram for data at 850 nm excluding data taken on small area detectors.

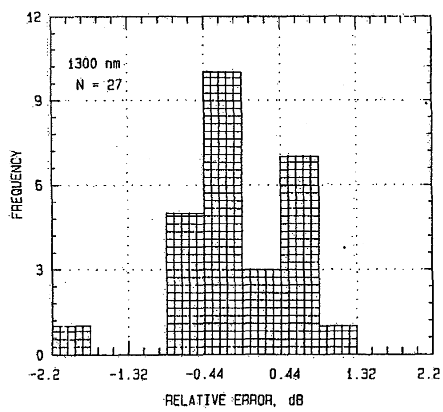

Fig. 2. Frequency histogram for data at 1300 nm.

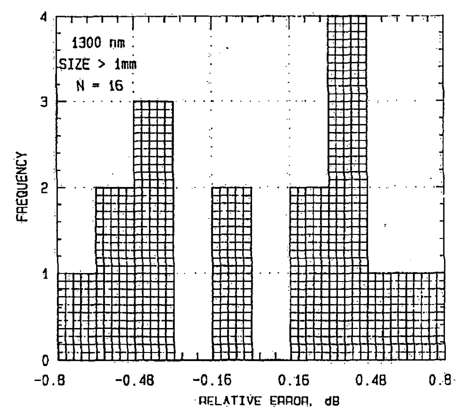

Fig. 4. Frequency histogram for data at 1300 nm excluding data taken on small area detectors.

Readings were taken in a rather restricted range of power levels appropriate to the levels usually encountered in optical fiber work (a few tens of microwatts). Laboratory temperature and the number of readings taken for each set of data were reported.

The reference meter provided by NBS was selected from several candidate commercial meters on the basis of suitability for this test and nothing more. The criteria were thermal stability, detector uniformity, linearity, and detector size. The meter was decalibrated and sent to participants who had agreed to compare the reference meter with their own meters using their usual laboratory techniques. The participants provided the optical light source, so not all power readings taken by a participant were taken at the same wavelength. The measurements were in two wavelength categories: 850 and 1300 nm. Some of the participants made readings at 1550 nm, but those readings are not reported here because of the paucity of data.

The calibration curve of the reference meter was used to normalize readings at wavelengths close to 850 nm. The results are given as part of the 850-nm data. A similar approach was used for 1300-nm data.

Each data point in the following is based on the results of measurements by a participant at one wavelength using one of his power meters. In most cases, each data entry reported is the average of ten or so readings. The number of readings taken for each data point varied from participant to participant. If one participant used more than one power meter or if power was measured at more than one wavelength, each of those measurements represented a separate data entry. In one case, for example, a participant contributed 11 data points because of the variety of meters used and the variety of wavelengths at which readings were made. The test resulted in a data base consisting of 46 entries.

In the interest of obtaining reliable uncertainty data, we decided to reference all readings to the average of the participants' measurements. The results given below are based on this average.

Table I. Measurement Results

Wavelength (nm)	Standard deviation (dB)	No. of data points
850	0.27	19
1300	0.67	27

Table II. Results when Small Area Detectors are not Included

Wavelength (nm)	Standard deviation (dB)	No. of data points
850	0.27	17
1300	0.44	16

III. Results

The results of the experiment are given in Tables I and II and Figs. 1–4. The standard deviation is that of the participants' readings about the mean of the readings. We note first that the standard deviation is higher for the 1300-nm data than it is for the 850-nm data. We can only speculate on the reason; however, germanium detectors are quite temperature sensitive, and this may have been a factor. In the interest of minimizing detector noise, germanium detectors are also usually quite small. The reference power meter uses a cooled germanium detector of 5-mm diameter. Because of the comfortable size of this detector, we assume that all the power was collected consistently when the reference meter was used. The cooling provides stability and low noise in spite of the detector's large area.

Table II gives the results for the case when the data based on small area detectors (< 1 mm diameter) are eliminated. We feel that the area may cause power collection errors and lead to an unreasonably high standard deviation. The standard deviation was unchanged when the data based on small area detectors at 850 nm were eliminated. The number of data points changed by only two in this case, however. Eleven of the meters used at 1300 nm had detectors smaller than 1 mm in diameter.

Figures 1–4 give histograms of the measurement data. The histograms show the number of measurements (data points) as a function of relative error. The distribution is not expected to be normal if there is a component of systematic error. The data suggest that systematic error may indeed be present in some cases. Figures 1 and 2 are for all data, and Figs. 3 and 4 include only the data taken on detectors having a diameter larger than 1 mm.

IV. Conclusions

We have found a disturbing inconsistency in the power meter readings taken by different laboratories using normal measurement techniques and using the meters normally used in each case. The comparison was facilitated through use of a reference power meter provided by the National Bureau of Standards. The reference meter was decalibrated to allow a reasonable blind test of uncertainty.

We have found that an unreasonably small detector size may increase the uncertainty of the measurement even though the small size reduces the detector noise. The standard deviation decreased from 0.71 dB (~ 15%) to 0.47 dB (~ 10%) when we excluded data taken using germanium detectors of 1 mm or smaller diameter at 1300 nm. Eleven of the meters used at 1300 nm had active detector diameters of < 1 mm.

We believe that the deviation seen in these tests is unreasonably high. Refined measurement procedures and a suitable reference standard will contribute greatly to reducing the variability in measurements. Work is progressing in that direction.

References

1. Calibration and Related Measurement Services of the National Bureau of Natl. Bur. Stand. U.S., Standards, Spec. Publ. 250 (Oct. 1982).

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