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Measurements of Loss Due to Offset, End Separation, and Angular Misalignment in Graded Index Fibers Excited by an Incoherent Source

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Transmission losses versus fiber end offset separation, and angular misalignment of graded index fibers excited by an incoherent source, have been measured in two independent experiments. The measurement setup, fiber diameter, and length were different in the two experiments, yet the measurement results are strikingly similar. The loss measurements clearly show that transverse offset is much more critical in connector and splice design than angular misalignment and end separation. Two-tenths of the fiber core radius in transverse offset alone may cause 0.5 dB loss while one fiber core radius in axial separation combined with 1° in angular misalignment may cause 0.5 dB loss.

I. INTRODUCTION

It is essential to know the transmission loss caused by misalignment of the fiber ends in designing fiber connectors and splices. Graded index fibers are important to fiberguide transmission applications that require low dispersion characteristics. The study of the transmission loss caused by misalignment of fibers having graded index profiles is thus necessary. Theoretical investigations of the loss versus offset at zero axial separation have recently been published.[1–4] Further studies of the problem—i.e., loss versus offset, end separation, and angular misalignment of graded index fibers—have been done experimentally.[5–7] This paper presents the results of two separate experiments.

II. EXPERIMENTS

The experiments were conducted independently in different laboratory locations. The first experiment (Fig. 1a) yielded the loss versus offset and end separation only. The second experiment (Fig. 1b) included angular misalignment along with end separation and offset. In both

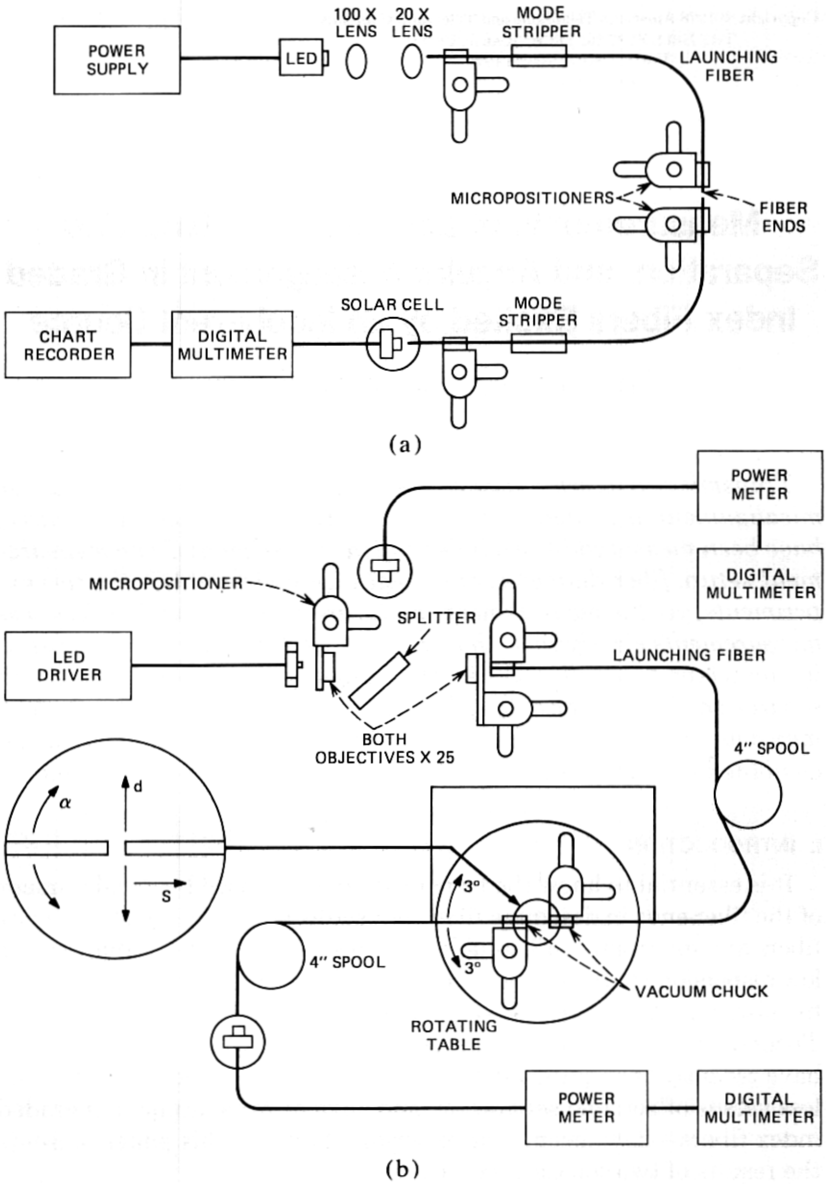
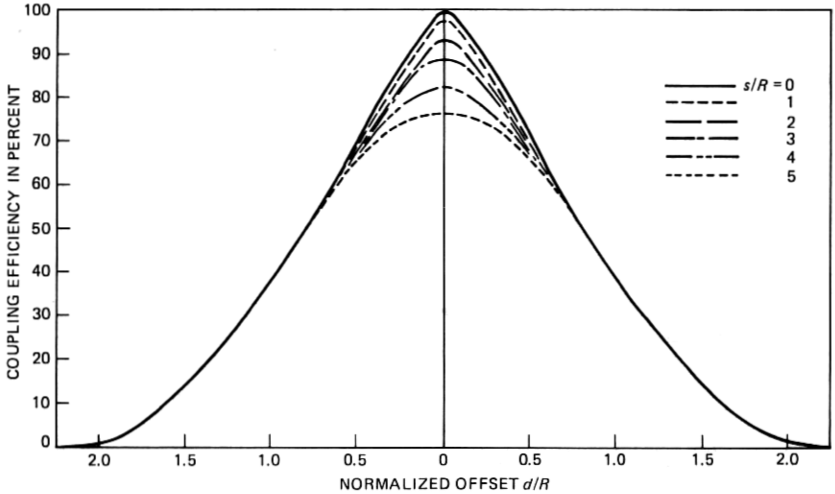
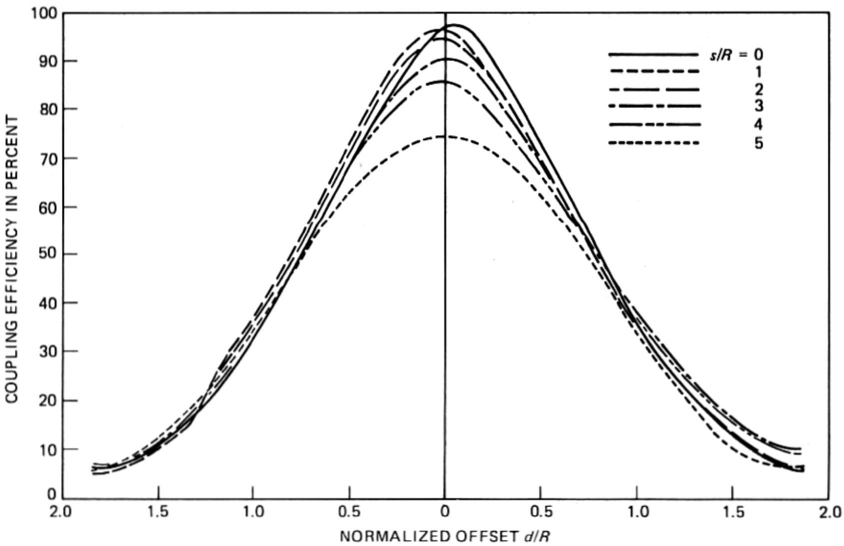


Fig. 1—(a) Coupling loss vs. fiber end misalignment measurement setup in the first experiment. (b) Coupling loss vs. fiber end misalignment measurement setup in the second experiment.

experiments, a Burrus-type LED having a 50 μm diameter emitting surface was used. The LED in the second experiment was internally modulated whereas the first was not modulated. Microscope objectives



(a)



(b)

Fig. 2—(a) Coupling efficiency vs. normalized offset d/R at various separations s/R from the first experiment. (b) Coupling efficiency vs. normalized offset d/R at various separations from the second experiment.

were used to collect and focus the light into the launching fiber. Alignment was achieved by using micropositioners. In both experiments the output of the receiving fiber was detected by a power meter and monitored by a digital multimeter.

Graded index fibers were used in both experiments. The first exper-

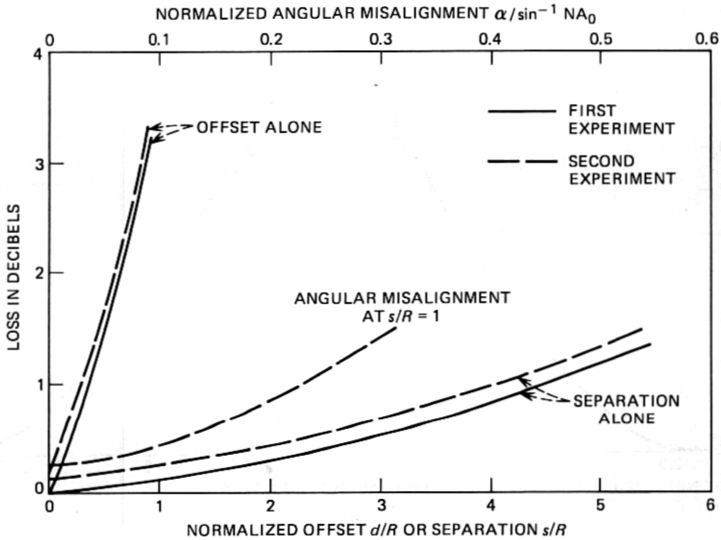


Fig. 3—Loss in dB vs. normalized offset d/R, separation s/R, and angular misalignment $\alpha°/\sin^{-1} NA_0$.

iment used a 50 μm diameter core/100 μm diameter cladding fiber while the second used a 55 μm diameter core/110 μm diameter cladding fiber. The indices of refraction of the core center and cladding of both fibers were 1.472 and 1.458 respectively. A 1.83 m length fiber was used in the first experiment and a 20 m length in the second.

In both cases the experiments began by optimizing the power output from the fibers. The fibers were then cut in the center and aligned using

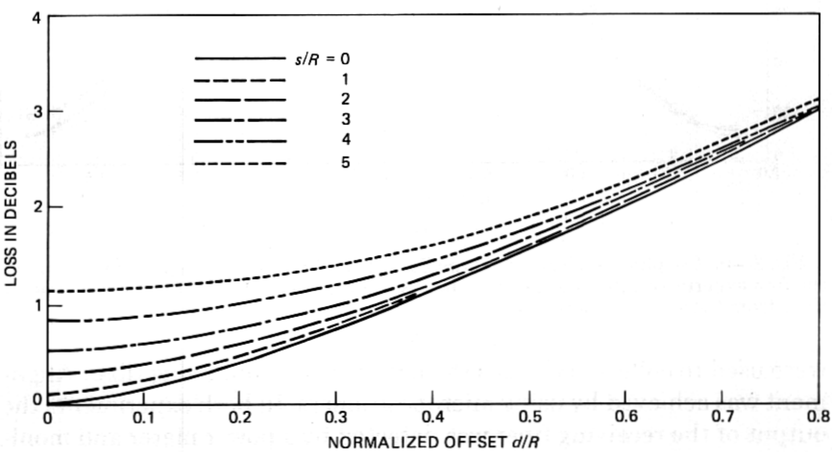


Fig. 4—Loss vs. normalized offset d/R at various normalized separations s/R from the first experiment.

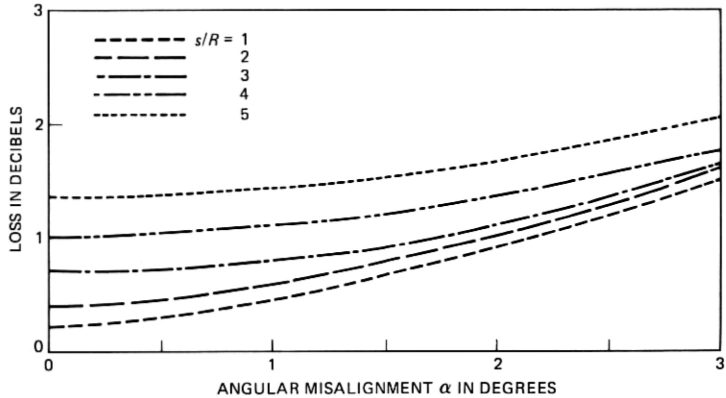


Fig. 5—Loss vs. angular misalignment α in degrees at various normalized separations s/R.

the micropositioners, and index matching fluid (glycerol) was applied to the joints. The power output in the first experiment was measured to be 0.01 dB less than the maximum power obtained before the fiber was cut. This figure was 0.07 dB in the second experiment.

The loss versus offset measurement (in both experiments) at zero separation was done by offsetting one fiber end (at the butt joint) to the

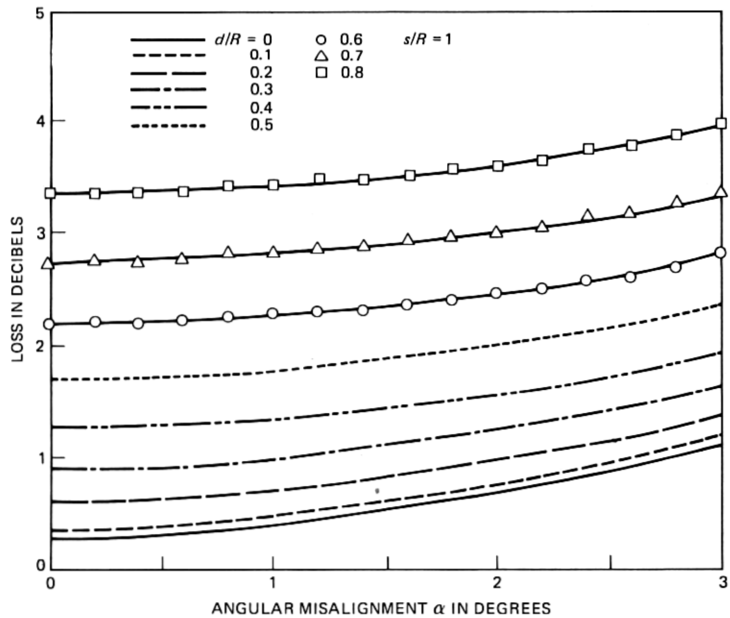


Fig. 6—Loss vs. angular misalignment α in degrees and various normalized offsets d/R at constant separation $s/R = 1$.

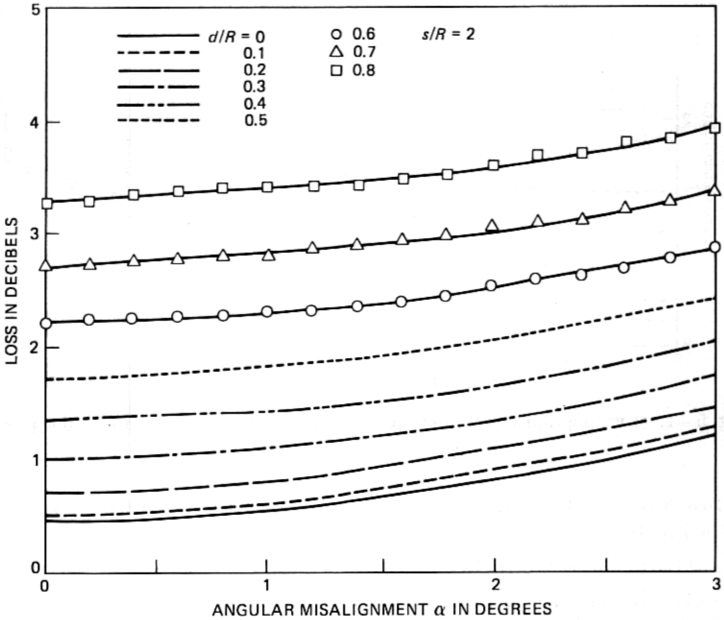


Fig. 7—Loss vs. angular misalignment α in degrees and various normalized offsets d/R at constant separation $s/R = 2$.

other by known amounts and the power output of the receiving fiber was recorded. This was repeated at normalized axial separations of 1, 2, 3, 4 and 5. The normalized separation and offset are defined as s/R and d/R, where s is the axial separation in μm, d is the offset in μm, and R is the fiber core radius in μm. The loss-versus-angular misalignment measurement (in the second experiment) began with aligning the receiving fiber with the center of rotation of the table so that the angular alignment could be changed while the axial separation and offset remained constant. The angular alignment was varied from $-3°$ to $+3°$ in increments of 0.2° at normalized axial separations of 1, 2, 3, 4 and 5.

III. RESULTS

The coupling efficiencies in percentage-versus-normalized offset at six normalized axial separation are shown in Fig. 2a and b (first and second experiment, respectively). The facts that the results of two experiments are very similar and the transverse offset is by far the more important parameter can be seen in Fig. 3, in which the loss-versus-normalized offset d/R at zero separation, the loss-versus-various normalized separations s/R at zero offset, and the loss-versus-normalized angular misalignment $\alpha°/\sin^{-1}\mathrm{NA}_0$ at constant separation $S/R = 1$ are plotted. Here $\mathrm{NA}_0 = \sqrt{\mathrm{n}_1^2 - \mathrm{n}_2^2}$ and n_1 and n_2 are the index of refraction

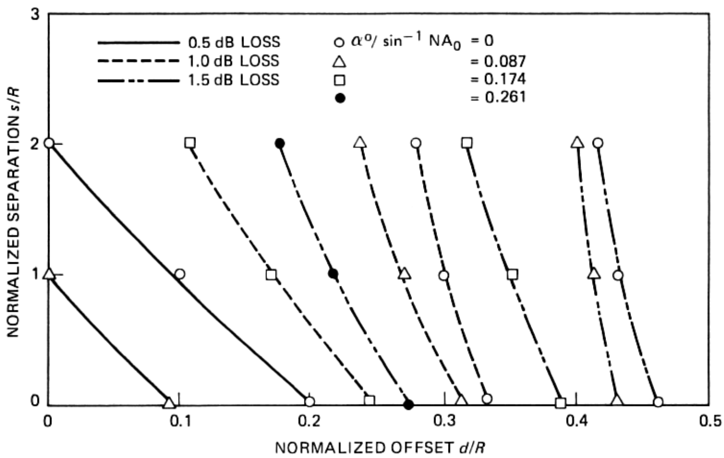


Fig. 8—Constant loss lines as the results of fiber end offset d/R, separation s/R, and angular misalignment $\alpha°/\sin^{-1} NA_0$.

of the fiber core center and cladding, respectively. The difference between the two experiments at zero offset and zero separation is due to the different amount of initial misalignment of the fiber ends after it was broken and butt-jointed. In the first experiment, the power output from the receiving fiber was 0.01 dB below the maximum power obtained before the fiber was broken; this figure was 0.07 dB in the second experiment. The designers of fiber connector or splice will be interested in the region where loss is low. Figure 4 shows the loss in dB versus small ofset ($d/R \leq 0.8$) at various separations. Figure 5 shows the loss due to angular misalignment at normalized separations of 1 through 5. Figures 6 and 7 show the loss due to angular misalignment and offsets at normalized separations of 1 and 2, respectively. Figure 8 shows constant loss curves as caused by various kinds of misalignment. As an example, consider various kinds of misalignment that all produce 0.5 dB loss: a normalized offset of 0.2 alone; a normalized separation of 2 alone; a normalized angular misalignment of 0.087 and normalized separation of 1; a normalized offset of 0.1 and normalized separation of 1. Designers of connectors will have to pay very close attention to offset, then angular misalignment and separation, respectively.

IV. CONCLUSION

Loss versus various kinds of misalignment of two ends of the same fiber has been measured in two independent experiments. The measurement setup, fiber diameter, and length were different in the two experiments, yet the measurement results are strikingly similar. Transverse offset is shown to be the most critical parameter in the design of fiber connectors and splices. The present results provide only the minimum loss that would arise in actual fiber connectors and splices, since additional losses might be caused by other factors such as fiber diameter and index profile mismatch.

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