THE BELL SYSTEM
TECHNICAL JOURNAL

DEVOTED TO THE SCIENTIFIC AND ENGINEERING
ASPECTS OF ELECTRICAL COMMUNICATION

Volume 54 | March 1975 | Number 3

Preparation of Optical-Fiber Ends for Low-Loss Tape Splices

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(Manuscript received September 18, 1974)

We describe a reliable method of preparing planar fiber tape ends by fiber fracture. Using this technique, with suitable precautions to preserve cleanliness during splice preparation, we have measured a splice loss of less than 0.25 dB in 99 percent of all attempts.

The alignment of fibers in prefabricated grooves[1] so far remains the simplest and most reliable method of connecting fibers, even in the case of fiber cable subgroups (tapes).[2,3] Two problems were identified as most serious:

(*i*) The preparation of satisfactory fiber ends was found difficult in the case of tapes and cables, because all ends must be in one cross-sectional plane. Grinding and polishing has proven feasible, but may not be entirely satisfactory, particularly in the preparation of field splices.

(*ii*) The splice losses have been higher than expected on the basis of single-fiber splice tests[4] and have been scattered over a wide range.

Although we are not certain that groove alignment necessarily provides the best splicing technique, we have used an advanced form of this technique developed by Cherin[3] to take a closer look at the problems identified above. Even if other techniques prove more promising later on, the problems mentioned may still be present in some form or other and seem serious enough to require thorough analysis now.

The preparation of fiber ends discussed here is a modification of fracture techniques reported earlier for single-fiber splices.[4] The device used for this purpose was a compact and simple hand tool that could easily be operated in a cramped and narrow space. The essential element of this tool was a spring-steel strip over which the fibers were stretched. The mechanical characteristics of this strip primarily determined the stress distribution in the fibers, and, thus, by a proper choice of strip thickness, we were able to choose the appropriate ratio of bending to tensile stress for the particular fibers to be fractured.

To prepare the ends of the fiber tape for splicing, one proceeds as follows:

(*i*) The plastic of the tape is removed over a short distance so that the fibers are exposed in the area where the end is to be prepared.

(*ii*) The tape is placed between a spring-steel strip and two friction plates, so that the exposed area is located under a diamond stylus.

(*iii*) The spring-steel strip and the tape are bent. At the same time the friction plates slide a small distance along the spring-steel strip. This sliding action exerts an additional amount of tension on the tape, so that the optimal ratio between longitudinal and bending stress is obtained in the fibers.

(*iv*) The diamond stylus (tip radius 50 μm) is now drawn across the exposed fibers to produce scores. The slight pressure of a few grams imparted by a phosphor bronze spring suffices to produce scores of a few micrometers in depth. As each fiber is scored, a fracture starts at the score and proceeds across the fiber producing a flat surface perpendicular to the fiber axis.

For a more detailed explanation of this process, see Ref. 4. The order of the steps explained above is not imperative. As an alternative, the scoring can be done before tension is applied.

Figure 1 shows a typical array of fiber ends obtained in this way. The fibers used were multimode fibers having a high-silica core with a diameter of about 80 μm and an outer diameter of 120 μm. To make a tape splice, we prepared the ends of two tapes in the way discussed above. The tapes were then positioned slightly above a small grooved chip made from lead, copper, or aluminum (see Fig. 2). The chip was roughly 1 cm long and 3 to 4 mm wide. The grooves were embossed using a stainless-steel head that had six adjacent 90-degree grooves, each 80 μm deep. As shown in Fig. 2, the fibers were lowered into

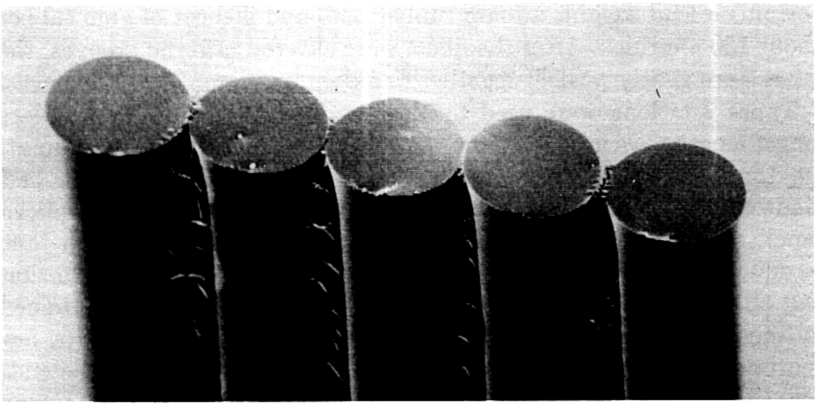

Fig. 1—Tape end prepared by simultaneous fracture of fibers. Fibers were epoxied together after end preparation to keep them aligned for electron micrograph process.

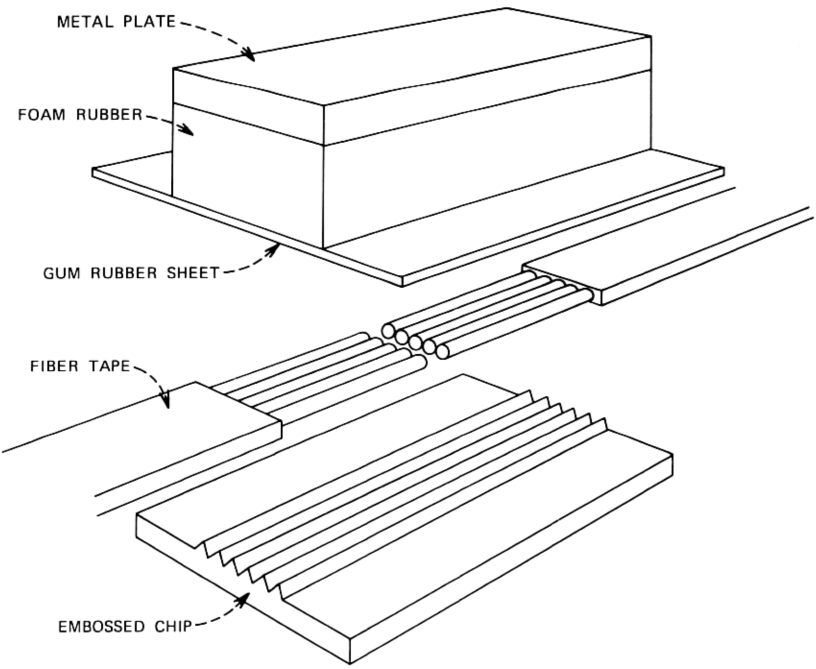

Fig. 2—Sketch of splice arrangement before assembly.

grooves by pressing from the top with a stack made of (from top to bottom) a lead weight, a foam rubber pad, and a sheet of gum rubber about 150 μm thick. After the fibers were lowered into the grooves, the tapes were gently pushed together in axial direction.

Tapes 2 m long were used to measure the splice loss. To simulate longer lengths, we injected light with a power distribution approximating the steady-state distribution of these particular fibers. We first made a large number of loss measurements in unbroken and unspliced tapes, switching back and forth between the five fibers of each tape to determine the measuring uncertainty. We found a distribution that had an rms value of 1.7 percent. The splice loss was then determined by measuring the transmission before and after a small part (a few centimeters) was removed from the middle of each tape and the ends spliced together as explained above, adding a drop of index-matching oil or glycerin before covering the arrangement with the gum rubber sheet. The optical loss of the length of fiber removed was insignificant. Figure 3 shows a histogram of the splice losses measured in 60 attempts. Evidently some loss values were negative as a result of the measuring inaccuracy. Figure 4 shows the (smoothed) cumulative loss distribution as measured and after the 1.7-percent rms measuring uncertainty was discounted. Of all measurements, 99 percent show a loss of less

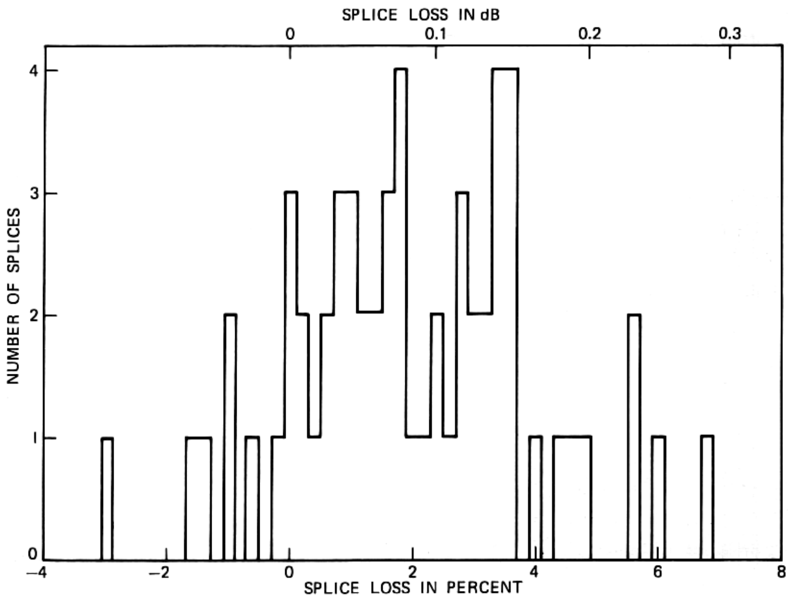

Fig. 3—Histogram of measured splice loss.

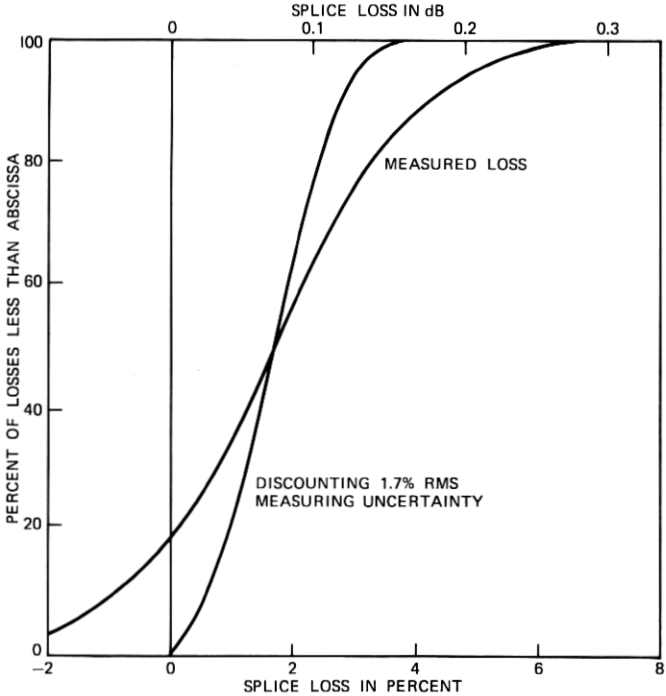

Fig. 4—Cumulative distribution of splice loss as measured and after discounting the 1.7-percent rms measuring uncertainty.

than 0.25 dB. However, a large part of the scatter of these measurements results from the measuring process and the actual cumulative distribution would predict that 99 percent of all splices would have a loss of less than 0.15 dB.

We attribute the low-loss values obtained not only to the quality of the end faces, but also to the extreme care taken during these measurements to keep the splice area clean. Earlier microscopic observations of groove-aligned fiber array splices taught us that, generally, losses in the 10-percent range can be correlated with a contamination in the splice area which reveals itself by large-angle scattering at the joint. In most cases, we were able to identify the contaminating material on the end face of the fiber even after the splice was taken apart; these materials tenaciously adhere to the fiber surface often even after ordinary cleaning procedures. We learned that an extended period of ultrasonic cleaning with isopropyl alcohol of *all* parts involved in the splice was necessary before the splice loss decreased to the levels measured. The contaminant is usually not added during the end preparation; it is not the result of dust accumulation from the surrounding air caused, for example, by electrostatic forces. We believe that the contamination results from a contact of the fiber ends with contaminated surfaces, such as the grooved chip or the rubber sheet. We believe, also, that this sensitivity to contamination is a sufficient reason to consider splicing processes in which the fiber end surfaces are prepared and exposed after alignment has been achieved.[5]

Permanent splices on the basis of the techniques described here were prepared by replacing the index-matching oil with a special epoxy. This epoxy flows down along the grooves and the fibers and permanently attaches the tape ends to the embossed metal chip and the gum rubber sheet. The rubber sheet ends extending beyond the chip (see Fig. 2) are then folded around the chip and attached to its bottom surface. Figure 5 shows a finished five-fiber splice. Splices of this kind were found to have sufficient intrinsic strength to be used as splices of cable subgroups; additional armor would of course in this case be provided around a stack of such subgroup splices in a cable. The loss distribution for these permanent splices showed no deviation from that of splices made using index-matching fluid, and no aging effect was noticed, at least not within the period of a few days. The epoxy has a room-temperature curing time of several hours, but faster-curing epoxies are being studied and should replace the one used without significant alteration of the results.

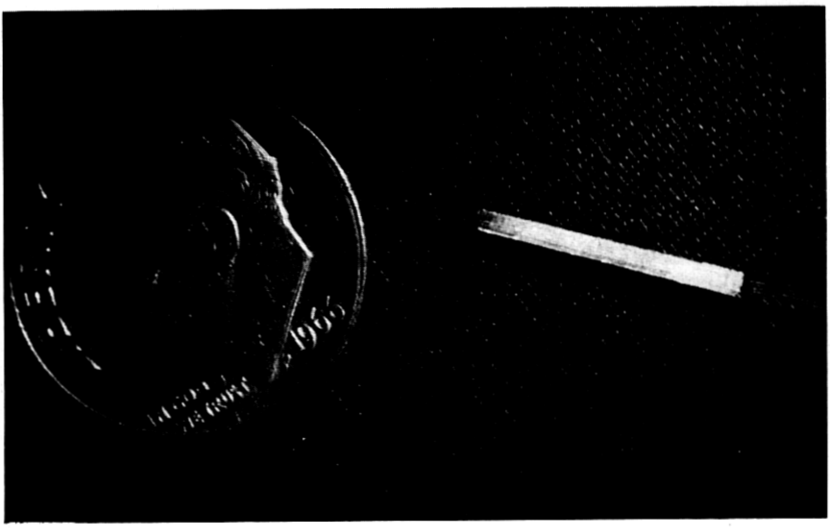

Fig. 5—Finished five-fiber splice.

We are grateful to R. D. Standley who prepared the electron micrograph of Fig. 1.

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