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Loose Tube Splices for Optical Fibers

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A technique for splicing optical fibers has been developed that uses a self-aligning square cross-section tube, with inner dimensions slightly larger than the optical fiber. A total loss of 0.58 dB was obtained for eight splices connected in series using a graded-index fiber with a 68-μm core diameter. The splices were made one at a time without the use of microscopes or micromanipulators; however, the fabrication process could be mechanized and extended to groups of fibers. A holding fixture could be added to adapt this technique to a connect-disconnect type splice. The size of the splice is presently 0.012 in. square, making it suitable for use within cables. Measurement set refinements that were needed to measure individual splice losses as low as 0.05 dB include an improved detector and means for better control of launching conditions.

I. INTRODUCTION

The basic requirements for low-loss splices are (*i*) accurate alignment, (*ii*) good fiber ends, and (*iii*) accurate diameter control. Transverse alignment accuracy of approximately ±0.1-fiber-core radius (typically, ±0.0001 in.) is required to achieve a splice loss of 0.1 dB. Good fiber ends may be produced by scoring and breaking,[1] grinding and polishing, or disc sawing. Accurate fiber diameter control is also needed; however, significant progress is being made in this area. Of these three requirements, accurate transverse alignment may be the most difficult problem to solve, especially when the field environment and variability of craftsmen's skill are considered.

Single-fiber splicing has been accomplished by Bisbee[2] and Dyott et al[3] using heat fusion. Someda[4] suggested using embossed plastic to obtain transverse alignment. This paper describes a splicing technique that uses a loose-fitting, square, cross-section tube to align the fibers. The splices produced are small, exhibit very low losses, and are simple and inexpensive.

Previously, snug-fitting sleeves have been suggested,[5] but three problems are usually encountered.

(*i*) If the glass sleeve is to support the fiber with the required alignment accuracy, it must be less than typically 0.0001 in. larger than the fiber. Both fiber and sleeve must be highly circular, and the fiber diameter must be controlled to at least the same tolerances. These tolerance requirements have discouraged efforts to use a snug tube as an alignment mechanism.

(*ii*) Given a snug tube of the proper dimensions, the initial insertion of a fiber into that tube is difficult. Pinnow[5] has described a method of flaring the inner diameter of capillary tubes, which reduces the initial insertion difficulty.

(*iii*) Contaminants that are scraped off the inside wall of snug-fitting sleeves during fiber insertion are trapped between the fiber ends where the effect of contamination is worst.

The "loose"-fitting square-tube splice described below reduces these difficulties substantially and appears to have potential application in several places in a fiber-optic communication system.

II. SPLICE CONFIGURATION AND ASSEMBLY

The loose-tube splice combines the alignment accuracy obtainable by using a groove for alignment[4] with the small size and simplicity of glass sleeves.[5] The fiber ends are biased to one corner of the square cross section by bending the fiber outside the tube. Figure 1 is a pictorial layout of the square tube with two fiber ends in position within the tube. The tube has nearly flat interior walls and a small radius in the interior corners, as shown in the cross section in Fig. 2. One corner of the square is used as a groove for aligning the fibers.

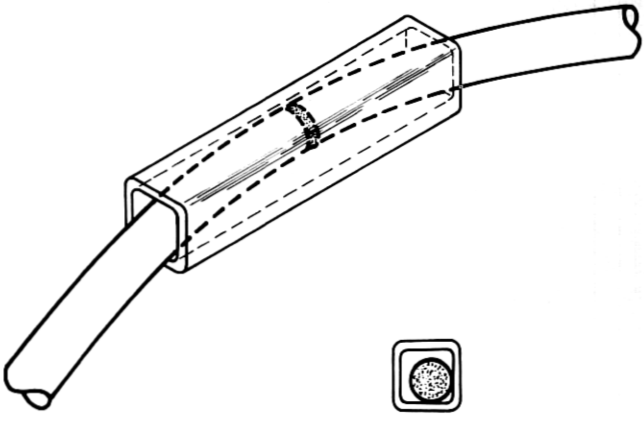

Fig. 1—Splice configuration.

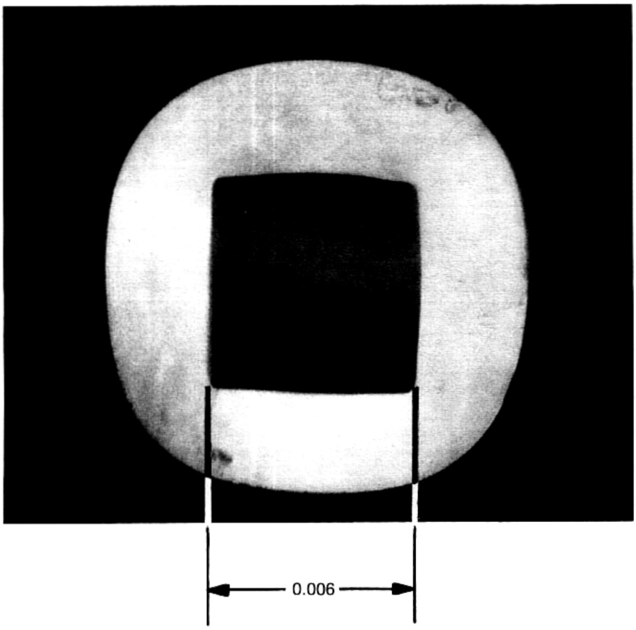

Fig. 2—Square tube cross section.

Epoxy is forced into the square tube prior to insertion of the fibers and serves several useful functions.

(*i*) The epoxy serves as an adhesive after curing to hold the splice together.

(*ii*) The epoxy also serves as an index-matching material with good glass-wetting characteristics.

(*iii*) Contamination on the fiber ends is washed away by the flow of epoxy around the fiber ends during insertion of the fibers.

Assembly of a splice involves inserting two fibers with good ends approximately halfway into each end of a square cross-section tube filled with uncured epoxy. No particular orientation of the square-tube cross section is required. The fibers are placed on a flat surface and bent in a curved pattern. This causes forces to be generated that rotate the tube so that a diagonal of the square cross section is in the same plane as the bent fibers. The tube is therefore self-aligned and the fibers biased to one corner by action of the fiber stiffness. After the bends are made, the fibers are taped to a flat surface in the bent configuration and the fibers pushed into the tube until they touch each other. Figure 3 is a cross-section photograph of a splice showing a

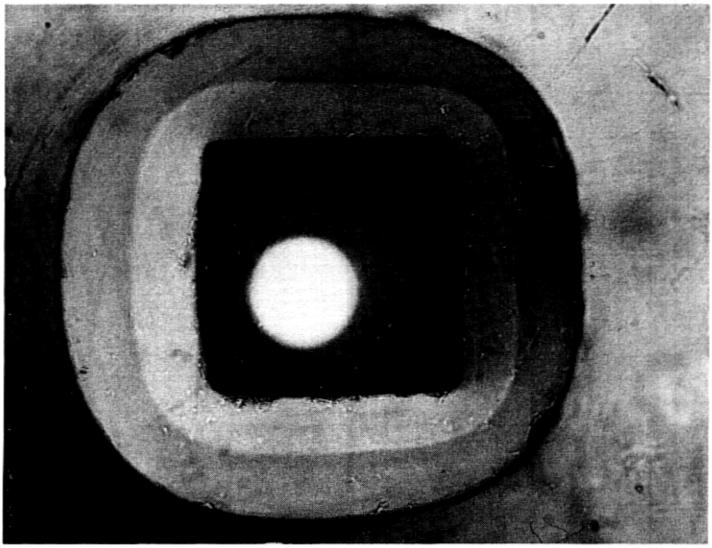

Fig. 3—Splice cross section showing position of fiber in vicinity of joint.

fiber in a corner of the square tube. Figure 4 is a magnified view of one splice, and a longitudinal section is shown in Fig. 5. In spite of the small angle between the fiber ends caused by one end not being broken

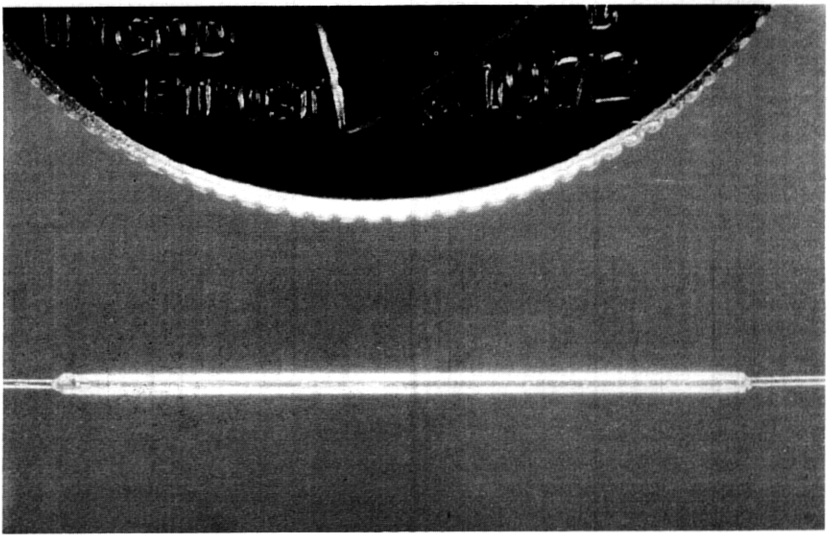

Fig. 4—Single loose tube splice, with tube approximately 0.5-inch long and 0.012-inch wide.

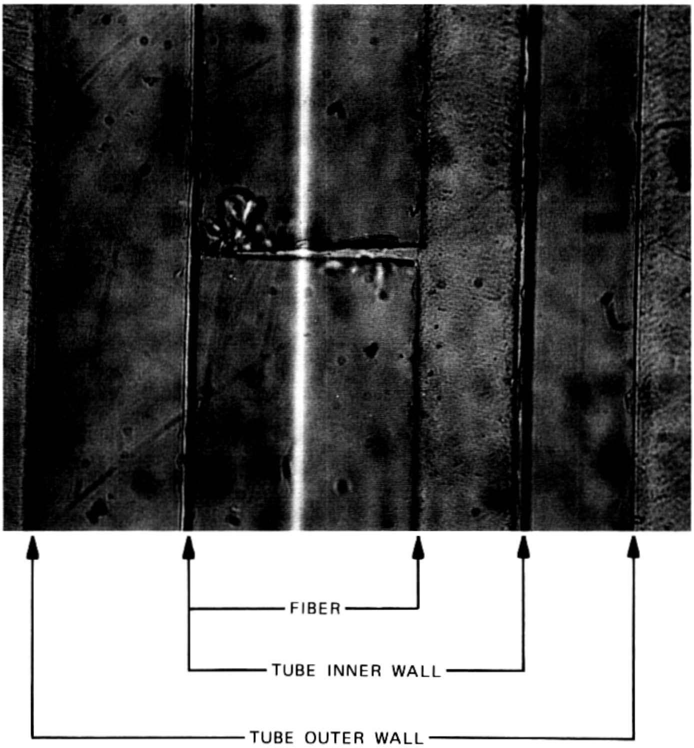

Fig. 5—Longitudinal section, 250X.

perpendicular to the fiber axis, the splice loss for the splice in Fig. 5 was only 0.07 dB.

III. END PREPARATION

Good fiber ends are necessary for the fabrication of low-loss splices. As mentioned earlier, several techniques exist for preparing suitable ends. A score-and-break technique[1] was used for end preparation on all splices reported in this paper. A single fiber is clamped in the apparatus shown in Fig. 6 with approximately 100-g load applied to the fiber by a spring. The fiber rests in a groove along a 2-in. radius arc and is scored lightly with a hand-held diamond knife edge. Fiber ends prepared by this method are nearly perfect, as shown in Fig. 7. A very small amount of edge chipping is present where the fiber was scored.

IV. SPLICE-LOSS MEASUREMENTS

After constructing just a few square-tube splices, it became evident that the measurement set-up being used was not adequate for losses

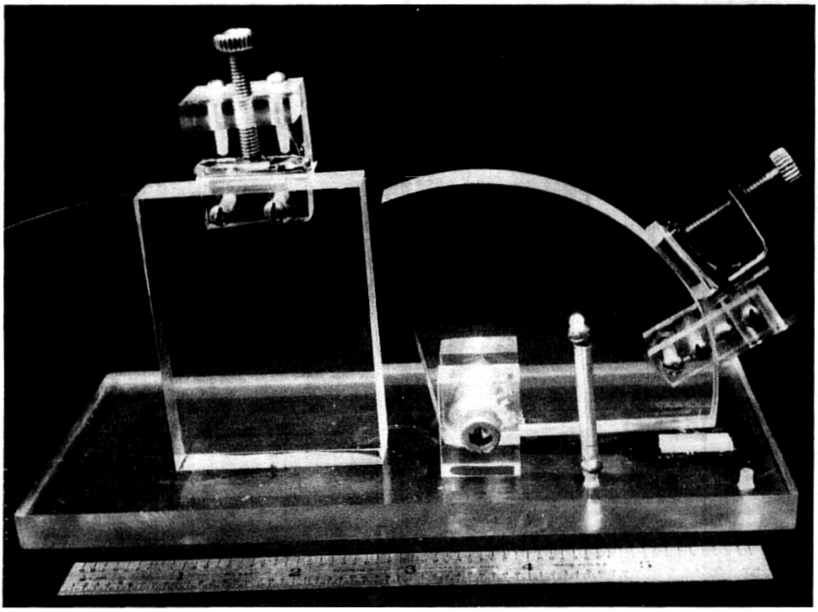

Fig. 6—End preparation apparatus.

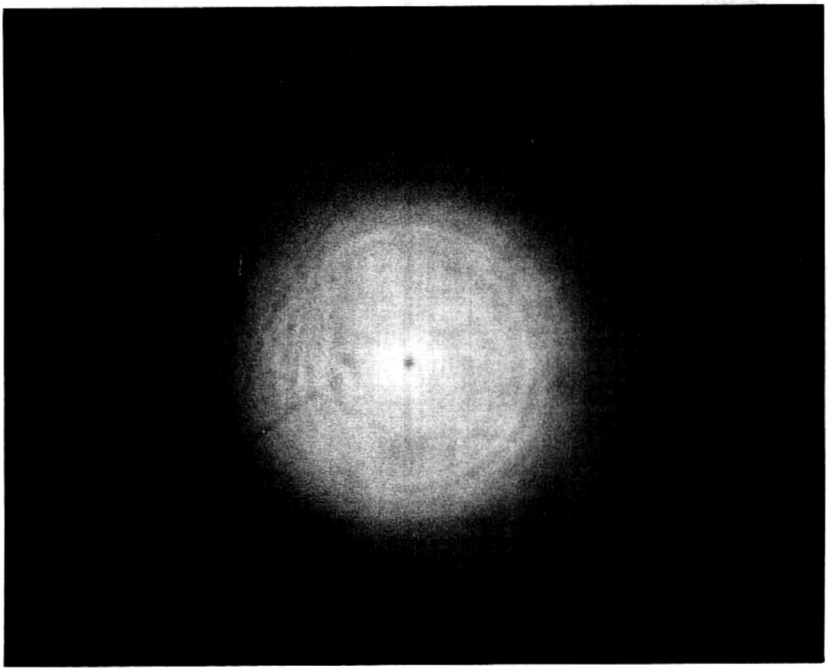

Fig. 7—Good fiber end.

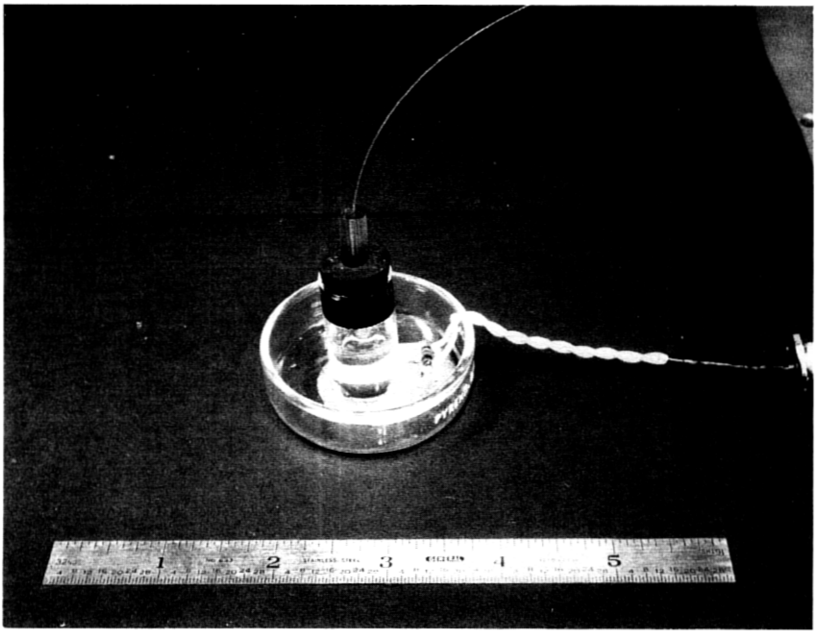

Fig. 8—Single fiber detector.

below 0.1 dB. A new detector was built, which repeated to within ±0.015 dB. Accurate positional repeatability was accomplished by using a 0.05-in. inner-diameter capillary tube which was tapered to 0.006 in. inner diameter by heating and pulling. The fiber is easy to insert in this detector, and the positional repeatability is excellent. The solar cell sensor was immersed in index-matching liquid to reduce reflections, and a microscope cover slip was used to protect the cell from damage by the fiber being measured. A photograph of the detector is shown in Fig. 8. At the input end of the measurement set, a vacuum chuck was added to ensure repeatability of launching conditions. This chuck positions the fiber accurately along the optical axis of the 30X launching objective lens and the laser. The overall repeatability of splice-loss measurements is within ±0.03 dB.

Care was taken to place the fiber in the same coiled configuration after splicing so that bending losses before and after splicing would be similar. Fiber loss of approximately 0.01 dB/m was subtracted from the total loss measurements so that losses stated are for the splices only. All loss measurements were made at a wavelength of 0.6328 μm.

V. RESULTS

Initially, a fixture was used to hold the square tube and control the fiber bending. Although the maximum loss measured on 25 consecutive splices fabricated with this fixture was 0.21 dB, it was found that the tube would align itself if allowed to rotate. Losses were lower and the assembly of the splice, as previously mentioned, was much easier.

Eight epoxied square-tube splices fabricated in series using no fixtures except the end-making apparatus produced a total splice loss of 0.58 dB or 0.073 dB per splice. The splices had approximately $1\frac{1}{2}$ m of fiber between each splice and on each end and were put together in series to increase the total loss to an accurately measurable quantity.

It has been found that splices measured in series have higher losses than when measured individually. Ten earlier splices were fabricated in series and measured 1.37 dB. The ten-series splices were measured separately and gave the distribution shown in Fig. 9. The average loss per splice was 0.077 dB compared to 0.137 dB in series, or a nearly 2-to-1 increase for splices in series. The process of peaking up the power through a single splice probably selects the launching conditions and therefore the mode structure best suited to the particular imperfections of that splice. A loss measurement made in this way gives a value that is too low. That is, the loss of a splice with long lengths on either side or with other splices nearby is apt to be considerably higher than when measured separately with short fibers on each side of the splice. The eight-series splices mentioned earlier were not measured separately because losses as low as 0.03 dB, which would be expected based on the series loss, could not be accurately measured.

A slight longitudinal separation of fiber ends within the tube occurred during epoxy cure for the 10 splices in series. Loss measured before epoxy cure was 0.69 dB and 1.37 dB after epoxy cure as stated above. Fibers were bent in a 90-degree arc and taped to an optical table while the epoxy cured. This configuration applied very little, if any, force component to hold the fibers in place during cure. The eight-series splices were bent through an arc of approximately 45 degrees and

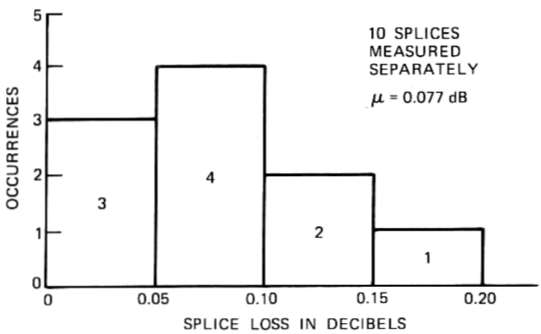

Fig. 9—Splice loss histogram.

taped to the table with a definite force applied to keep the fiber ends in contact. Although this force (a result of the fiber stiffness) is small, end separation did not occur and a loss of 0.58 dB was measured before and after epoxy cure.

These extremely encouraging results have stimulated thinking as to how loose square-tube splices could be applied to other types of splices, e.g., connect-disconnect configuration.

VI. CONNECT-DISCONNECT SPLICE FOR SINGLE FIBERS

Several configurations based on the square tube can be envisioned for a connect-disconnect splice, that is, a splice that can be reassembled many times and used as a connector. Figure 10 is a photograph of a simple fixture that supports a single square-tube splice by the fibers on each side of the splice. The splice itself is suspended in air. This fixture is not intended to be a finished design, but it does produce losses of 0.1 dB or less. The clamps are lined with a thick, soft EVA layer that grips the fibers and holds them in position. More practical designs are sketched in Fig. 11. An index-matching material is necessary to achieve 0.1 dB, although a liquid index-matching material may be feasible.

Polymethylmethacrylate (PMMA) was suggested as an alternative index-matching material by Pinnow.[5] This thermoplastic could be drawn into a fiber and inserted into the square tube. Heat could then be applied to melt the PMMA, the fibers inserted, and the PMMA allowed to cool. The splice could be disassembled by again heating the tube and removing the fibers. These connect-disconnect splices may

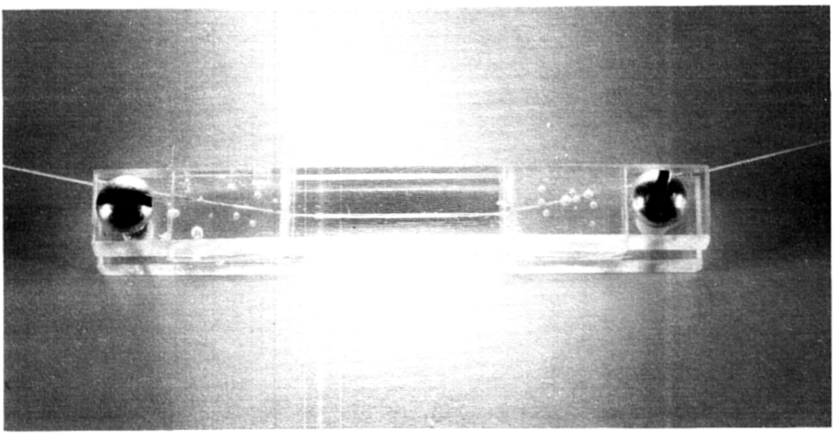

Fig. 10—Quick-connect holding fixture.

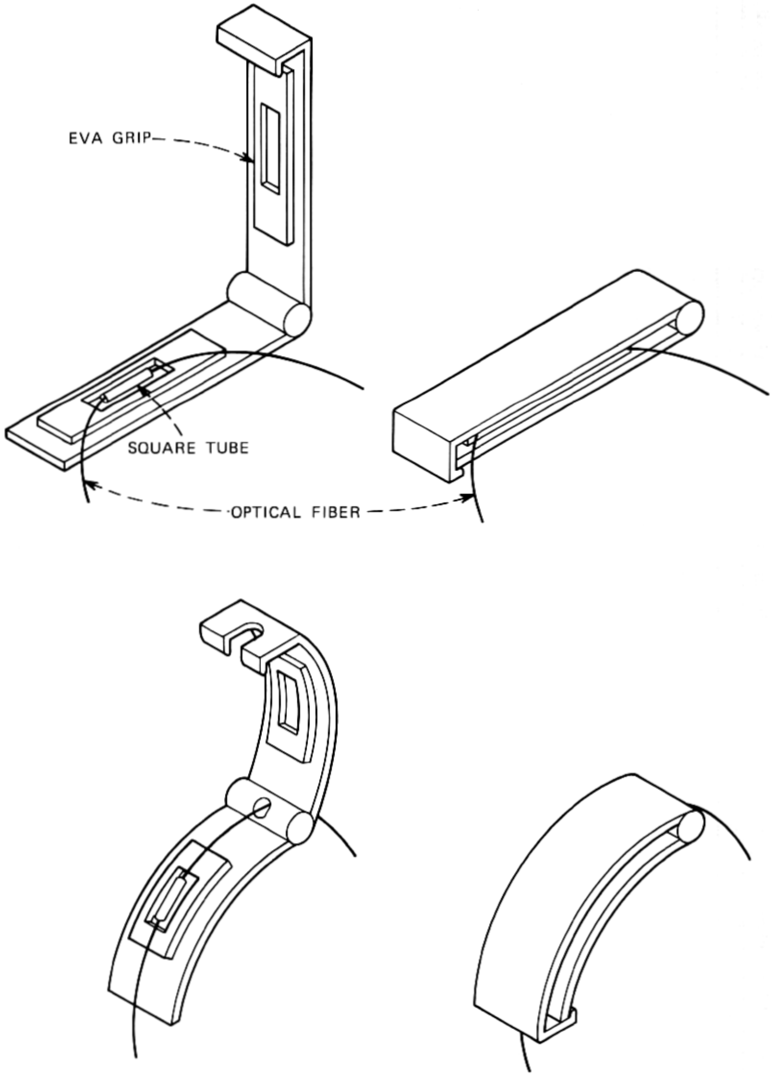

Fig. 11—Connect-disconnect holders for single-fiber splices.

be useful as methods for connecting sources, detectors, and line regenerators in a fiber-optic communication system.

VII. ACKNOWLEDGMENTS

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