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CDR D. A. HART

13 JUL 1977

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COLLOQUIUM ON OPTICAL FIBER CABLE,
INSTITUTION OF ELECTRICAL ENGINEERS (U.K.)

by

CDR D. A. HART

The Institution of Electrical Engineers (IEE) held a one-day colloquium on Optical Fiber Cable in London on 17 May 1977. Although it was claimed that the IEE planned their Colloquium first, the date conflicted with an AGARD Symposium on "Optical Fibers, Integrated Optics and Their Military Applications," which was held in London from 16-20 May. Nevertheless, the attendance at the IEE meeting was very good (about 200) and a number of people were able to attend the remainder of the AGARD Symposium by missing only the one day of overlap.

The progress in development of fiber-optic systems has been extremely rapid over the last few years, and the tone of the IEE Colloquium was one of reviewing successes as opposed to presenting unsolved problems. It seems that some significant progress has been made in the U.K. in moving fiber optics from the laboratory to pre-operational communication links, and a major portion on the IEE colloquium was devoted to discussions of the Post Office Research Center's (PORC) installation of fiber-optics cable into operational ducts and the test results obtained in these experiments. In total, there were 13 papers presented with six being on propagation and cable manufacture, three on strength of fiber and cable, and four on installation and testing. The Colloquium was concerned with single fiber technology only and optical-fiber bundles were not discussed.

The IEE Colloquium began with an invited tutorial review by Professor W. A. Gambling (University of Southampton), who presented some of the fundamentals of fiber-optics propagation. Optical fibers for the transmission of modulated light are composed of a core, typically about 30 μm in diameter, surrounded by a cladding of lower refractive index which gives the fiber an overall diameter somewhere around 100 μm . Fiber-optic waveguides are classified into several types, among which are: step-index multimode, graded-index multimode and single-mode fibers. Step-index multimode fibers will propagate light rays which enter the core at angles up to some value, depending on the core and cladding indices of refraction. If the angle of entry is large, one does not get total internal reflection and some energy is lost. Also, in step-index fiber the rays travel different path lengths leading to multipath problems which limit

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the bandwidth of the cable. Graded-index fibers with square-law radial profiles of refractive index remove multipath dispersion but don't equalize skew rays, thus some dispersion remains. The so-called Alpha profile reduces mode dispersion more than square-law fiber and theoretically allows bandwidths on the order of 20 GHz/km (but practically more like 1 GHz/km). Single-mode fibers (core thickness of a few microns) were not described. Gambling also discussed some of the other practical problems of optical fibers, such as leaky rays (rays which propagate in modes not bound to the fiber) and micro-bends (small bends which cause mixing of modes and result in loss of energy and spreading of pulses).

It is thought that there might be a few people at PORC that did not contribute to their paper on the transmission performances of three graded-index fiber cables installed in operational ducts, but I will list the authors religiously anyway: M. Eve, P. C. Hensel, A. M. Hill, P. J. Malyon, J. E. Midwinter, B. P. Nelson, J. R. Stern and J. V. Wright. To date, 42 km (21 km of 2-channel cable) of Corning PSP graded-index fiber has been laid by the PORC between Ipswich and Martlesham, Suffolk. This 42 km consists of three links; an 8-km link of 8 Mbits/sec, a 6-km link of 140 Mbits/sec, and a 6-km link of 8 Mbits/sec capacity. The 6-km 8 Mbits/sec link was tested to show a total loss of 24.2 dB measured attenuation (against 24.4 predicted) for a mean in-the-duct attenuation of 4.26 dB/km. The bandwidth over this link was measured on individual sections and then cumulatively, but the cumulative results differed from that predicted either by a linear extrapolation or a Gaussian network theory. One of the anomalies was due to a 1-km section of the link which was found to have a step in the outer extreme of the index profile. The other anomaly was related to the problem of matching segments of the fiber cable and was discussed in the next paper by M. Eve (PORC) titled, "A Statistical Model for Prediction of the Bandwidth of an Optical Route Applied to the Martlesham-Kesgrave Link." His analysis shows that there is an optimum method of joining graded-index fiber sections by alternating "under-" and "over-" compensated sections. The over-compensated and under-compensated segments are those with alpha profiles for which alpha differs either side of the optimum value (≈ 2.05), thus leading to higher order modes transiting the cable slower or faster than the lower order modes.

R. J. Slaughter, J. E. Taylor and D. J. Martin [BICC (British Insulated Callenders Cables) Research and Engineering, Ltd.] presented a paper, "Alternative Approaches to Optical Fiber Cable Making." BICC is developing a six-fiber cable of helical cavity design. The central member is steel surrounded by plastic. The fibers are individually coated with rubber and are laid between larger diameter threads of polyethylene. The results of this study have shown that higher numerical-aperture (NA) fibers give less attenuation (due

to microbending) upon cabling in the configuration than small NA fibers. The tensile behavior of the cable is determined by the steel, and extension is limited to about 0.25% of the length.

L. J. Arnold, S. L. Cundy, D. L. Lewis and C. J. Peachy (General Electric Co., Ltd., Hirst Research Center) are investigating the design of non-metallic optical cables in order to meet some military requirements where electromagnetic interference must be avoided. Temperature extremes are also a consideration, and the goal is to survive from -25°C to $+125^{\circ}\text{C}$. These workers have chosen Kevlar 49 (Dupont brand) for strength members in their cable. The design of the cable uses 6 Kevlar strands disposed symmetrically around the single optical fiber and extruded with Hytrel plastic for an outside diameter of 7 mm. These cables have been tested for crushing with a 100-kg roller without any change to attenuation. Bend testing to 2-cm radius also produces no degradation, but temperature cycling does produce some (although results are "encouraging").

Since the Standard Telecommunications Laboratories (STL), Ltd., produced their first silica fiber-optic cable in 1973, they have had design and process groups looking for ways to improve performance while still being able reliably to produce cable that has wide applicability. P. W. Black, A. Cook, A. R. Gilbert, and J. Irven have examined two competing designs each with eight fibers. One candidate has a central-strength member (coated polymer or steel) with 1-mm fibers stranded helically around it. The assembly is wrapped with polyethylene terephthalate tape and sheathed with polyethylene for a total diameter of 7 mm. The other candidate has the strength members on the outside of the cable, and the fibers are loosely grouped in a central cavity. The first candidate (central-strength member) has been found to have superior properties. The reproducibility is quite good, and the excess attenuation resulting from cabling has been only 0.16 dB/km (mean) for 8-fiber cable. The STL optical fibers are made with germanium borosilicate graded-index cores, vapor deposited within a silica cladding. After pulling, the individual fibers are given a silicone resin primary coating and an extruded polypropylene secondary coating to an outside diameter of 1 mm.

To introduce the second session of the Colloquium (on strength of fibers and cable), L. A. Jackson (PORC) gave a tutorial review on fiber strength. For telecommunications applications, users are looking for fiber-optical cables that will withstand the environment for 20-40 years. Breakage of fibers occur at locations where microcracks are present. These begin with dimensions of about $100\text{-}\text{\AA}$ surface width. Coatings greatly improve fibers by slowing the growth of microcracks and give a high tensile strength compared to bare fiber. Statistics of fiber-failure data are usually plotted as Weibull distributions, showing the percent failures versus the percent strain at which breakage occurs.

S. G. Foord and M.K.R. Vyas (STL) have been developing testing methods to give accurate information on load/strain characteristics up to the break point without incurring errors associated with the grips on the testing machine. Several types of grips have been examined including a self-tightening grip, a radial clamping grip with rubber insert, and a cylindrical capstan. True values of strain have been obtained by observing the relative movement of gauge marks situated away from the grips on the testing machine (a procedure which requires four men), and these data have been correlated with information on the separation of the grips themselves. Some results of the testing of STL 100- μ m coated fibers are shown in the plot on page 6. It is of interest to note that the STL fibers are capable of elongation up to about 7% before breakage. This could be significant for applications in underwater towing where elongation of at least 3% is needed for fibers integrated into towing cables.

S. G. Foord, L. J. Poole and M. M. Ramsay (STL) presented information on techniques developed for mechanical and environmental tests of optical fiber cables. Special tests have been evolved which have relevance to the Post Office duct installation and use. These include strain versus tension tests, cyclic load, crush, bend, impact, and environmental tests. The careful work at STL has particular importance as it may have strong influence on the types of tests on fiber-optic cables which will eventually become standard. Having done a thorough job of developing testers and methods, STL is in a strong position to influence testing methods for future civil and military applications. It is understood that STL is acting in an advisory capacity to the Royal Signals and Radar Establishment which has the responsibility for establishing standards for military applications of fiber-optic cables.

P. C. Hensel, P. J. Malyon, B. P. Nelson and J. V. Wright (PORC) described the measurement and joining techniques used in the PORC demonstration of fiber optics on the Martlesham-Kesgrave link. Joints were made using a V-groove technique. Finished joints were sealed with epoxy into standard Post Office sleeves. Losses of under 0.2 dB were obtained in the field. To test cables in the ducts, two test vans equipped with loss and bandwidth measuring apparatus were used. Bandwidth was measured with a pulsed SH GaAs laser. Received pulses were displayed on a sampling oscilloscope, and time domain results were converted to phase and amplitude-frequency response and impulse response functions. Loss was measured with a modulated LED and a non-avalanche photodiode. Receivers were calibrated with a local stable source module.

The remaining papers described the installation techniques employed in pulling cables into Post Office ducts. A description was also given of an experimental fiber-optic cable installation between electrical power-transmission towers.

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In summary, the IEE Colloquium was an extremely informative overview of fiber optics and a good review of progress in the U.K. toward applying optical-fiber cable for communications applications. It is apparent that many problems have been solved in this field, and confidence in the use of fiber optics is growing on the basis of installation techniques and testing methods which are becoming quite mature. As the Chairman of the last session, A. W. Horsley (STL), remarked, "There is all good news at this time, and the problems are less worrisome than just a few years ago." The only real problem which seems to be unanswered is what happens to fiber-optic cables over a long period of time (such as the 40 years the Post Office would like for telephone links).

Copies of the digest (No. 1977/32) of this Colloquium can be obtained from the Institution of Electrical Engineers, Savoy Place, London WC2R OBL, at a price of 75 pence plus postage.

Additional information on many of the subjects is also available from the writer of this report.

