PULSE DISPERSION IN GLASS FIBRES

Indexing terms: Fibres, Optical-propagation effects

Measurements indicate that pulses incident normally on the end of a cladded multimode fibre are broadened by less than 0·1 ns over a length of 20 m. The measured dispersions in lengths of 20 m and 35 m do not exceed 5 ps/m. However, with an angle of incidence of 17°, or with a defocused input beam, the pulses are broadened by 0·6 ns.

Following the observation[1] of broadening of pulses propagating along a length of multimode glass fibre, an experiment was undertaken[2] using a mode-locked helium–neon laser producing pulses of 1 ns duration. The resolution of the latter measurements (0·5 ns) was limited by the speed of response of the photomultiplier used as the detector, but no pulse broadening was seen. Subsequently, further authors have reported the results of similar experiments, and in each case appreciable pulse broadening was obtained. Thus Heyke[3] using single cladded fibres with a core diameter of $70\,\mu$m found that 1 ns pulses at 633 nm were spread to more than 5 ns in lengths up to 45 m, while Smiley *et al.*[4] observed 6 ns pulses widened by 3 ns at 588 nm in a fibre bundle of length 64 m.

With fibres in lengths up to 10 m and a mode-locked neodymium–glass laser with 2nd-harmonic generation, Gloge *et al.*[5] observed broadenings of more than 0·1 s. To make a comparison easier, the various results are expressed in Table 1 in the form of an effective dispersion in picosecond/metre (averaged over the length of fibres used). The effective dispersions are all appreciably greater than those obtained previously in these laboratories, and we have therefore repeated the measurements using avalanche diodes as detectors.

The experimental arrangement was basically as before, with a self-mode-locked helium–neon laser as the source, producing pulses of 1 ns halfwidth. Other workers have attempted to polish the ends of the fibre, but our experience is that it is difficult to produce an optically smooth surface in this way. We therefore cut the fibre ends and made optical contact with a thin glass flat using a drop of index-matching liquid (cinnamaldehyde) having the same refractive index as that of the core. In this way, excellent coupling of laser radiation into the core may be achieved with suitably designed optics. Several (individual) cladded fibres have been measured all having core diameters of about 50 μm, in lengths of 20 m and 35 m. The detectors were EMI, type S30500, silicon avalanche photodiodes, and the pulse shape recorded at the output from the laser was checked against that given by a Tropel type-330 photodiode. The outputs from the diodes were fed directly to a Tektronix 352 sampling unit fitted with S4 sampling heads of 25 ps risetime. The fibres were coiled in a single layer on black drums of radius 5·5 cm.

The results for a 20 m length of fibre in Fig. 1*a* show the input pulse (above) and the output pulse (below), when the input beam is launched into the core of the fibre parallel to the axis using a × 10 microscope objective of 16 mm nominal focal length. It is seen that any pulse broadening is less than 0·1 ns. Confirmation is provided by Fig. 1*b*, in which the input and output pulses are superimposed, showing that any pulse broadening does not greatly exceed the thickness of the trace. Similar measurements were made with a length of 35 m. These results confirm our earlier work, and indicate further that, if the amount of pulse broadening is a linear function of length, a pulse rate approaching 100 MHz over 1 km may be possible if the attenuation can be reduced. This remains to be seen, of course, and mode-conversion effects may well depend on the length of fibre being used. In addition, the high attenuation in the present fibres probably discriminates against higher-order modes, resulting in the small amount of pulse spreading observed, and corresponding low-loss multimode fibres may be more dispersive.

It is interesting to speculate on why our results differ from those reported elsewhere.[1, 3, 4] The method of launching may be significant, and certainly, in one case,[4] the input beam impinged on both core and cladding areas. We therefore investigated the effect of launching at an oblique angle into the core, and Fig. 1*c* shows, for example, that, when the angle of incidence is 17°, the output pulsewidth is increased to 1·7 ns. At the same time, the output beam was in the form of a thick hollow cone of corresponding radius. In a fibre with a low-loss cladding (see below), when the input beam was defocused so that it covered both core and cladding, a distinct broadening of both the trailing and leading pulse edges occurred. Since the velocity in the cladding is greater than that in the core, this result is perhaps not unexpected.

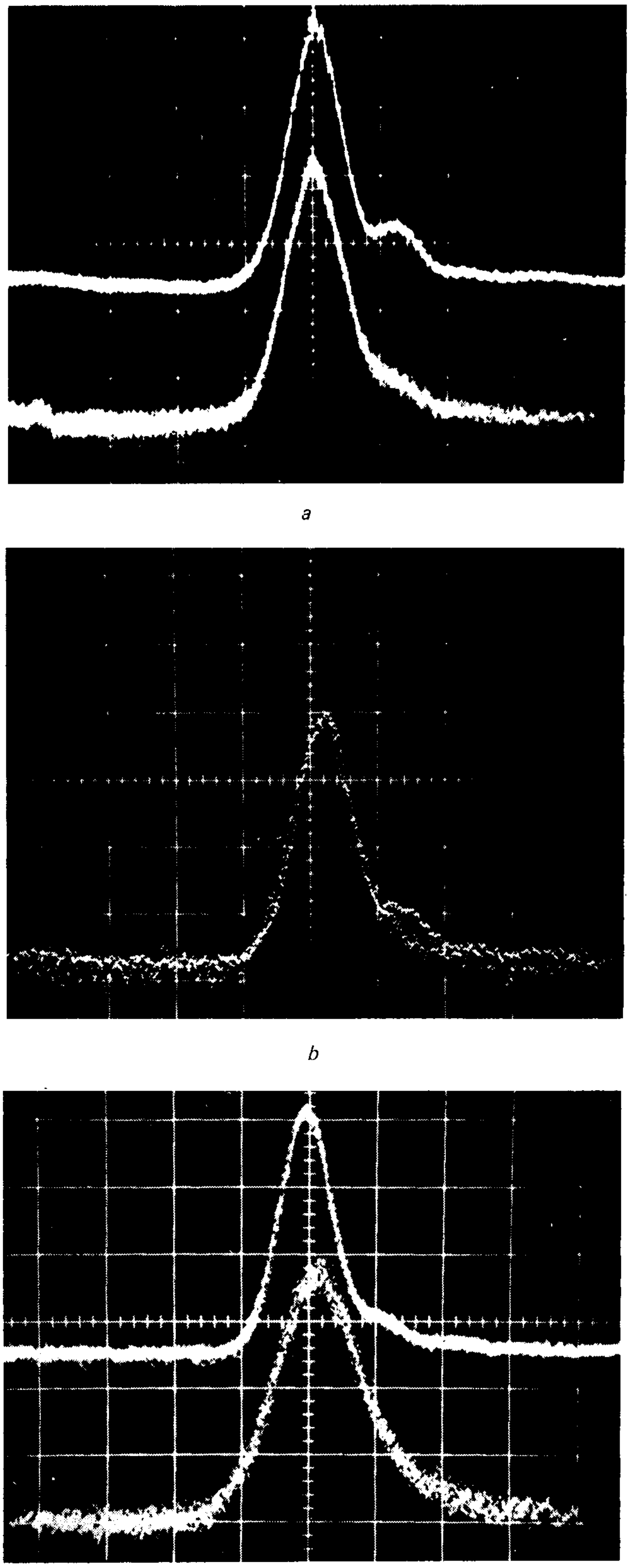

Fig. 1 *Pulse propagation along cladded glass fibres*
a Shows the input (upper trace) and output (lower trace) pulses
b Shows these pulses superimposed
c Shows broadened pulse obtained for an angle of incidence into the fibreof 17°
Horizontal scale: 1 ns per large division

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† SMILEY, V. N., TAYLOR, H. F., LEWIS, A. L., and ALBARES, D. J.: 'Pulse distortion in fibre optic bundles', *Appl. Opt.* (to be published)

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Table 1

Reference	1	2	3	4	5	Present results
Laser source	GaAs	He–Ne	He–Ne	Dye	Nd-glass	He–Ne
Fibre length, m	27	33	45	64	1–10	35
Core diameter, μm	80	50	70	46?	10	50
Effective dispersion, ps/m	110	<15	110	47	40	5

The amount of broadening increased with the degree of defocusing. It appears from these two effects that the pulse dispersion observed is dependent on the method of launching. The importance of launching conditions has been confirmed by further experiments we have conducted using pulses from a Q switched mode-locked ruby laser. The fact that, for zero angle of incidence, the same pulse spreading (<0·1 ns) was observed with both high-loss and low-loss cladding materials seems to indicate that, in our case, the pulses were propagating largely in the core. Otherwise the lower refractive index of the cladding would have caused increased dispersion for the low-loss cladded fibre.

The variation in fibre properties may also contribute to the different results. For the work reported here, we have pulled the fibres in our own laboratory using the rod-and-tube technique. The core is of Schott F7 glass with various cladding glasses and configurations. Most of the fibres have had high-loss cladding, and the resulting minimum fibre attenuations have varied from 330 dB/km upwards. Tubes of low-loss glass are not easily available, and we have therefore successfully pulled some fibres from a rod of F7 surrounded by nine closely-packed thin rods of LF5. These are the low-loss cladding fibres referred to above.

It may be concluded that, in multimode fibres, the pulse dispersion observed is very dependent, for a given fibre, on the launching conditions. For minimum dispersion, and hence maximum pulse rate, axial launching into the core is essential, as might indeed be expected.

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