SPECTRAL- AND LENGTH-DEPENDENT LOSSES IN OPTICAL FIBRES INVESTIGATED BY A TWO-CHANNEL BACKSCATTER TECHNIQUE

Indexing term: Optical fibres

Spectral- and length-dependent losses in optical fibres have been investigated using a two-channel technique for backscatter-waveform analysis. Results are compared with measurements obtained by the 'cutback' method over the wavelength range 0.82-1.07 μm. Attenuation measurements at 0.95 μm show a significant variation in OH⁻ concentration along the fibre.

Introduction: Analysis of the light backscattered by a pulse travelling in an optical fibre is widely used to estimate the local fibre attenuation and to locate faults and joints. Relative few studies, however, have been made of the differences which exist between the attenuation obtained by the backscatter method and that determined by the more conventional 'cut-back' technique, in which the throughputs of a long and short fibre length are compared. In the present work we introduce a 'two-channel' technique for analysing backscatter waveforms which greatly simplifies such a comparison, since it yields the local attenuation directly. With the aid of a dye laser and an optical parametric oscillator we apply the technique to obtain the first complete backscatter spectral attenuation curve, and contrast this with that obtained by the 'cutback' method. In addition, the diagnostic application of spectral backscatter measurements is demonstrated by tracking the evolution of an OH⁻ absorption peak along the length of a fibre.

Experiment procedure: The experimental arrangement is shown in Fig. 1. A dye laser followed by an optical parametric oscillator (o.p.o.) provides 1 μs pulses of several hundred watts peak power in the wavelength range 0.4-2.6 μm. Pulses of 80 ns duration suitable for backscatter measurements are extracted by means of a Pockel's-cell pulse slicer and launched into the fibre held in an index-matching cell. Light scattered within the fibre returns to the input in the form of an exponentially-decaying pulse and is directed by a beam splitter to a silicon a.p.d. for detection and amplification. The waveform is analysed to determine the instantaneous rate of decay, and hence the local fibre attenuation, using a new 'two-channel' technique. Two linear gates slightly separated in time are positioned at points t₁ and t₂ on the waveform by means of a time-delay generator triggered by the input optical pulse. Samples ³p(t₁) and ³p(t₂) are taken by the gates, averaged and fed to a computer which calculates the attenuation according to

\[ \delta(t₁, t₂) = \ln \left( \frac{³p(t₁)}{³p(t₂)} \right) \frac{v_g}{v} (t₂ - t₁) \]

Here ³p(t₁, t₂) represents the attenuation in the fibre between the two gate positions, i.e. in the region bound by the lengths t₁, t₂/2 and t₂, t₂/2, where v is the average group velocity. A combination of analogue averaging in the gates and numerical averaging of many samples in the computer reduces the measurement uncertainty to less than 0.05 dB/km.

The advantages of employing two sample channels are numerous. The technique is insensitive to pulse-to-pulse variations in the laser and to long-term drifts in optical power or receiver sensitivity; furthermore, it is well suited to microprocessor control. A more detailed analysis of the system performance may be found in Reference 4.

Length-dependent attenuation measurements using the two-channel technique: A graded-index fibre having a

![Fig. 1 Experimental arrangement](image)

![Fig. 2 Length dependence of fibre attenuation at wavelengths 0.966, 0.9946 and 1.006 μm](image)

Dotted lines: measurements from end A
Solid line: measurement from end B

Reprinted from ELECTRONICS LETTERS 31st January 1980 Vol. 16 No. 3 pp.77-78
GeO₂/P₂O₅/SiO₂ core and a numerical aperture of 0.20 was fabricated with a relatively thin B₂O₃/SiO₂ buffer layer in order to ensure significant absorption due to OH⁻ ions, which diffuse into the core from the substrate tube. The fibre attenuation was scanned at 25 m intervals along its entire 1.5 km length using a gate separation (t₁ – t₂) of 480 ns (a length resolution of 50 m). A mode scrambler was introduced at the launch end of the fibre to simulate an equilibrium mode distribution. Fig. 2 shows the results of backscatter attenuation measurements made at wavelengths of 0.906, 0.946 and 1.006 μm for a pulse launched into the fibre end designated A. Measurements were made in the reverse direction, i.e. from end B, at the same wavelengths; for clarity only the result for 0.946 μm is shown, since those at 0.906 and 1.006 μm were not significantly different from those obtained from end A.

Referring to the Figure, it may be seen that the fibre attenuation at 0.906 and 1.006 μm is reasonably uniform along the length with small fluctuations attributable to minor variations in diameter, numerical aperture or scattering coefficient. The reproducibility of the two-channel approach is indicated by the correlation which is observed between the features of the two curves. The attenuation at the OH⁻ absorption peak of 0.946 μm, however, shows a marked variation with length, indicating a reduction of OH⁻ concentration along the length from end A to B. The effect is confirmed in that measurements from both ends of the fibre show good agreement, except close to either launch end. The latter effect was not significant at the other wavelengths and can be attributed to differential mode attenuation, presumably caused by the diffusion profile of the absorbing OH⁻ ions which exists across the fibre core.

Possible causes for the variation of OH⁻ content along the fibre length are the tapering of the deposited layer thickness which occurs at the beginning of each c.v.d. pass and the consequent reduction in buffer-layer thickness, or a possible temperature overshoot following burner flyback resulting in increased diffusion. Stereocan studies, however, showed no variation of buffer-layer thickness, or core diameter, along the 1.5 km section; the origin of the length-dependence of OH⁻ ion concentration is thus at present unidentified.

**Fig. 3** Spectral dependence of fibre attenuation

Dotted line: backscatter result
Solid line: cutback result

Spectral attenuation measurements by the backscatter method: Since the attenuation of a multimode fibre depends to some extent on the excitation conditions, it is important in any comparative study to ensure that the launch conditions are similar. In our case this was achieved by measuring the last 1 km of the 1.5 km length. For the backscatter measurement a mode scrambler was used to excite the test fibre and the linear gates sited at times corresponding to 500 m and 1500 m from the launch end. In this way near-equilibrium conditions prevail within the 1 km under inspection. For the 'cutback' measurements, light from a tungsten lamp was focused with a numerical aperture of 0.25 into the fibre and the output from 1500 m compared with that after shortening to 500 m. Thus a comparison of the results under closely similar conditions is achieved, since in both cases equilibrium conditions should exist in the section being measured. Furthermore, the two-channel technique permits siting of the sampling gates across the same section of fibre as will be measured using the cutback technique.

Fig. 3 shows the results for both methods plotted over the range 0.820–1.070 μm obtained in the case of the backscatter measurement by tuning the o.p.o. It can be seen that the two techniques give remarkably similar results, the difference between the curves being within experimental error at all wavelengths. We believe that this excellent agreement is largely the result of our systematic attempt to compare the two methods under like conditions; similar comparisons made under differing conditions we found to yield differences of up to 1 dB/km.

Conclusions: A two-channel technique for backscatter wave- form analysis has been developed and shown to give accurate and reproducible results. The technique is capable of providing high-resolution data on the length dependence of fibre attenuation, as evidenced by its application to the determination of the variation with length of OH⁻ concentration. Application of the technique permits a firm basis to be established for comparison of backscatter and cutback measurements. A complete spectral attenuation plot shows that under the correct conditions virtually identical results can be obtained.

Acknowledgments: Acknowledgments are made to the Association of Commonwealth Universities (A. J. Conduit), the University of Southampton (A. H. Hartog), the Pirelli General Cable Co. (D. N. Payne) and Ministry of Defence (AWEU) for financial support. The authors are also indebted to R. J. Mansfield for fibre fabrication.

A. J. CONDUIT
A. H. HARTOG
D. N. PAYNE

Department of Electronics
University of Southampton
Southampton S09 5NH, England

24th December 1979

References
2. Mathurine, P., and De Blok, C. M.: 'Measurement of splice insertion loss using the backscattering method', Proceedings 5th European conference on optical communication, Amsterdam, 1979, pp. 9.5-1–9.5-4

0013-5194/80/030077-02$1.50/0