OPTICAL FIBRE BACKSCATTER-LOSS SIGNATURES: IDENTIFICATION OF FEATURES AND CORRELATION WITH KNOWN DEFECTS USING THE TWO-CHANNEL TECHNIQUE

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1. INTRODUCTION

A pulse propagating in an optical fibre returns scattered light to the source as an exponentially decaying waveform, the instantaneous slope of which yields the local attenuation at a corresponding point in the fibre[1]. However, plots of local attenuation with length (the backscatter-loss signature) frequently exhibit severe fluctuations[2] and anomalies such as negative values. We report here a study based on the newly-developed two-channel technique[3,4], aimed at verifying the accuracy of the average loss determined by backscatter measurements and correlating features in the signature with known fibre defects. In particular, a complete spectral backscatter attenuation measurement preformed over a wide spectral range has been obtained, thus allowing an effective comparison to be made with that obtained by the conventional cutback technique. Furthermore, backscatter-loss signatures are presented which clearly show correlation with programmed fibre defects and indicate that, in contrast to the conclusions of ref. 2, in many cases diameter fluctuations are the cause of unidentified features in the backscatter waveform. Moreover, it is possible to infer the nature of the diameter variation from its loss signature.

2. EXPERIMENT

The optical source and two-channel signal acquisition system[3] used for the experiments is shown in figure 1. A dye laser followed by an optical parametric oscillator injects pulses tunable over a wide wavelength range into the fibre. The returned backscatter signal is analysed by two linear gates which sample the waveform at times t_1 and t_2. Large time separations can be used to obtain the average fibre loss over a given length and thus simulate the attenuation which would be obtained by the cutback technique; small time separations permit the slope of the backscatter waveform to be determined and hence allows examination of local loss features. A combination of analogue averaging in the gates and numerical averaging of many samples reduces measurement errors to less than 0.05 dB/km for gate separations of 50m. This degree of precision is a result of the ability of the two channel technique to reveal the attenuation directly and of its tolerance to variations and drift in the equipment.

Measurements were performed on a 3.2km graded-index fibre having a $GeO_2/P_2O_5/S_iO_2$ core of 0.2 n.a. and a B_2O_3/S_iO_2 buffer layer. The latter was chosen to be relatively thin to ensure that the fibre would have a measurable spectral feature, namely the 950nm absorption peak caused by the presence of OH^- ions which diffuse from the substrate. In addition, the fibre diameter was controlled to <0.2 µm r.m.s. for the first 1.7 km, after which a series of tapers were programmed along the length.

3. SPECTRAL ATTENUATION RESULTS

A comparison of spectral attenuation results obtained by the backscatter method with those given by the cutback method is given in fig. 2. Both measurements were performed under conditions of similar excitation; the gates were sited 1km apart at the points in the constant diameter section of the fibre which were subsequently used in the cutback measurement. They are thus average values for the length chosen. The agreement is excellent over the full spectral range, despite the existence of differential mode attenuation which must have been present in the region of 950nm as a result of the localisation of the OH^- ions near the core/cladding boundary. The curve represents the first demonstration of backscatter loss measurements over a wide spectral range and lends considerable confidence to the efficacy of the technique.

4. LOCAL ATTENUATION RESULTS

The results for the local attenuation variation along the length of the fibre using a gate separation of 50m are given in fig. 3, together with a schematic representation of the diameter variation for comparison. Measurements were performed from both ends of the fibre at a wavelength of 1.006 µm and are shown vertically displaced for clarity. The loss in the well-controlled section of fibre is remarkably featureless when measured from either end and demonstrates both the accuracy of the measurement and the quality of the diameter control. In the tapered sections of fibre, however, strong fluctuations exist which are closely correlated with the diameter variations. Moreover, the measurements from either end are in exact anti-correlation with one another and, by examination, clearly follow both magnitude and sign of the derivative of fibre diameter with length (i.e. the slope of the taper). For example, the curve measured from end A exhibits the infamous negative loss at 2.4km which we can now associate with a contracting fibre section, (the inverse of what might have been expected) whereas from end B the same feature produces an apparent positive loss. Moreover, the double taper at 2.0km gives both positive and negative losses, but of smaller magnitude since the taper slope is less. Even the slope of the small triple taper at 2.2km is faithfully reproduced.

The effect can be explained in terms of the mode conversion which occurs on traversing a taper and the influence this has on the distribution of modes returned to the source.

Note that there is a strong peak at 1.8km which is the only feature that correlates when measured from either end. Reference to our diameter charts (not shown) reveals that at this point a major change in fibre diameter occurred spontaneously for a few cms owing to the presence of a bubble in the preform. Although unprogrammed, this feature serves to show how regions of actual loss can be separated from diameter variations in the fibre loss signature.

As a demonstration of the interpretation of features in the loss signature, the curve for a fibre pulled without diameter control feedback is given in fig. 4. Here a reasonably flat section with minor anticorrelated features indicates good diameter stability and no scatter centres. However, the region from 1.8km onwards exhibits considerable anti-correlated fluctuation implying diameter variation; it is known that at this point the feed-rod weld entered the furnace and caused diameter changes for the final kilometer.Some minor correlated features may be seen indicating small scatter centres.The signature taken at 0.87 μm shows virtually identical features.

5. CONCLUSIONS

The two-channel backscatter technique is capable of producing loss measurements with sufficient accuracy to allow detailed fibre diagnostics. Comparisons of the results obtained for a complete spectral plot with those of the cutback method reveal no significant differences under similar mode excitation conditions. The features commonly observed in backscatter loss signatures are shown to be explicable in terms of fibre diameter fluctuations and are separable from losses caused by scatter centes. In future it may be possible to determine the exact nature of diameter variations in this manner.

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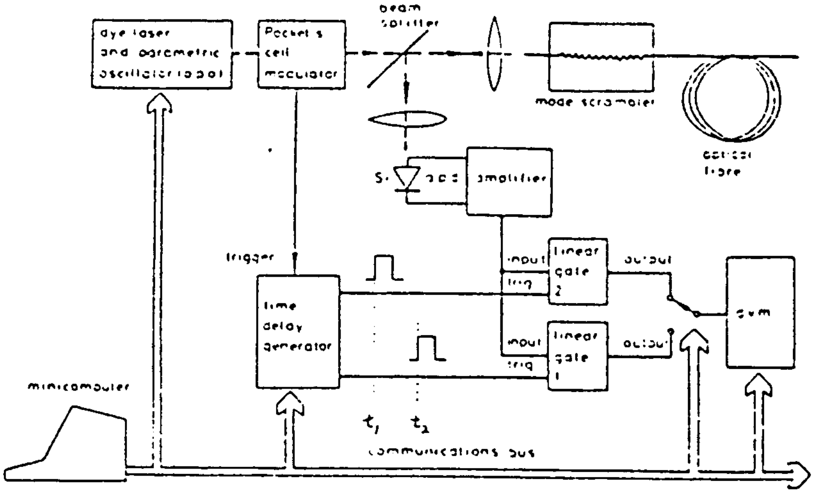

Fig. 1 Experimental arrangement

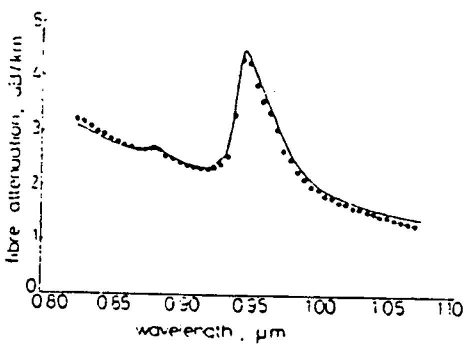

Fig. 2 Spectral attenuation
dots: backscatter; solid: cutback

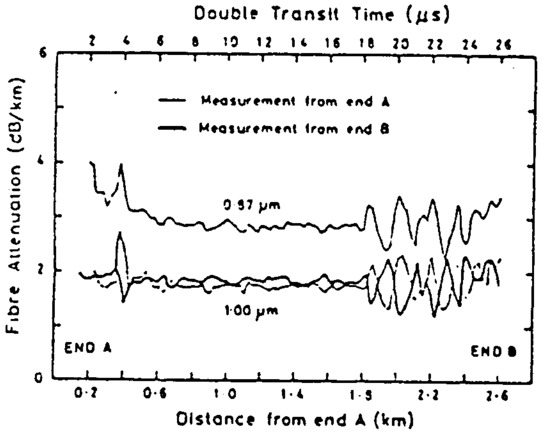

Fig. 4 Effect of random
diameter changes

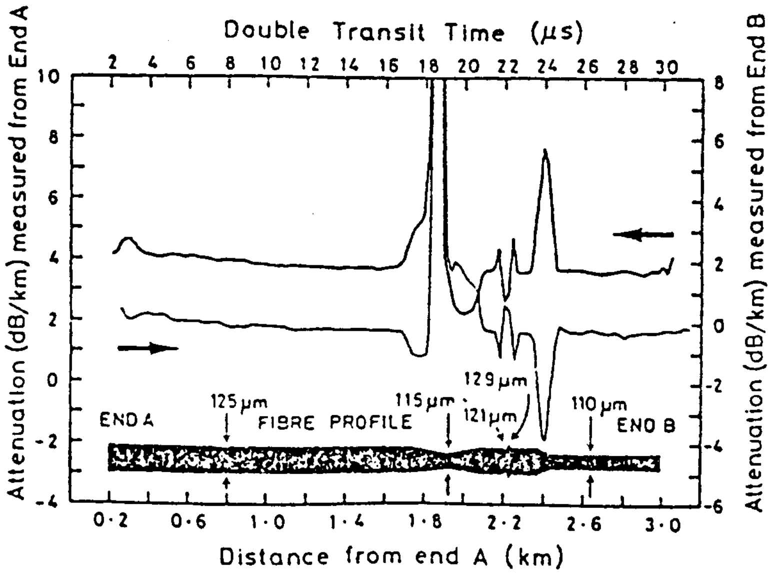

Fig. 3 Effect of programmed diameter changes