# Polarisation measurements on monomode fibres using optical time-domain reflectometry

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*Indexing terms:* *Optical fibres, Scattering*

**Abstract:** The feasibility of polarisation optical time-domain reflectometry in single-mode fibres is demonstrated. Polarisation analysis of the backscattered light clearly shows the evolution of the state of polarisation in the fibre. It is further shown that the polarised nature of the scatter return from single-mode fibres can cause errors in conventional backscatter measurements.

## 1 Introduction

Optical time-domain reflectometry (OTDR) [1] is a po' ful technique for determining the length dependence of fibre attenuation and for locating faults in multimode optical fibres. Good agreement [2] has been demonstrated with conventional two-cut attenuation measurements and a two-channel adaption has been developed to provide information on the origin of localised fibre loss fluctuations, [2, 3] and on the length dependence of $OH^-$ impurity concentration [2]. Theoretical work [4] has shown that the technique is also applicable to single-mode fibres, although to date it has been used only for fault location in this type of fibre [5].

It has recently been pointed out [6] that the scatter return in monomode fibres contains not only the usual intensity information from which the length-dependent fibre loss may inferred, but also polarisation information, since the back-scattered light mirrors the state of polarisation (SOP) of the propagating pulse. A new technique, termed polarisation optical time-domain reflectometry (POTDR), has thus been proposed in which the scatter return from monomode fibres is analysed by means of a polariser to reveal the variation of the SOP along the length.

The ability to determine nondestructively the length dependence of the SOP in long fibres is expected to be invaluable in the development of polarisation-maintaining fibres for interferometric sensors (e.g. gyroscopes, strain gauges or hydrophones) and of low-birefringence fibres for the Faraday current monitor and for telecommunications.

We present here the first measurements to be made using POTDR and give results which clearly demonstrate the feasibility of the technique. We also investigate the effect of polarisation on conventional backscatter attenuation measurements on monomode fibres and show that extreme care must be taken to eliminate the polarisation sensitivity of the apparatus if errors are to be avoided.

## 2 Experiment

The experimental arrangement is shown in Fig. 1. An optical parametric oscillator (OPO) pumped by a dye laser produces linearly polarised light pulses, the duration of which is truncated to 10 ns by an electro-optic modulator consisting of a Pockels cell and a prism polariser. The light is launched into the fibre via a pellicle beamsplitter, a focusing lens and an angled launching cell. Note that the beamsplitter is used at near-normal incidence; its reflectivity is thus almost polarisation independent. The receiver consists of a silicon avalanche photodetector followed by a 15 MHz transimpedance amplifier. The signal is fed to a transient recorder where the complete waveform is digitised and transmitted to a computer for averaging and processing. This arrangement retains the advantage of the two-channel technique, [2, 7] while reducing the measurement time considerably by acquiring samples from many parts of the fibre after each laser pulse (i.e. a 'multi-channel' technique). This is particularly useful when a source having a low pulse-repetition frequency (5–10 Hz in our system) is employed. As in 'two-channel' measurements, pulse amplitude fluctuations which would otherwise require considerable averaging are eliminated, since they are common to all samples.

The characteristic feature of the POTDR optical arrange-

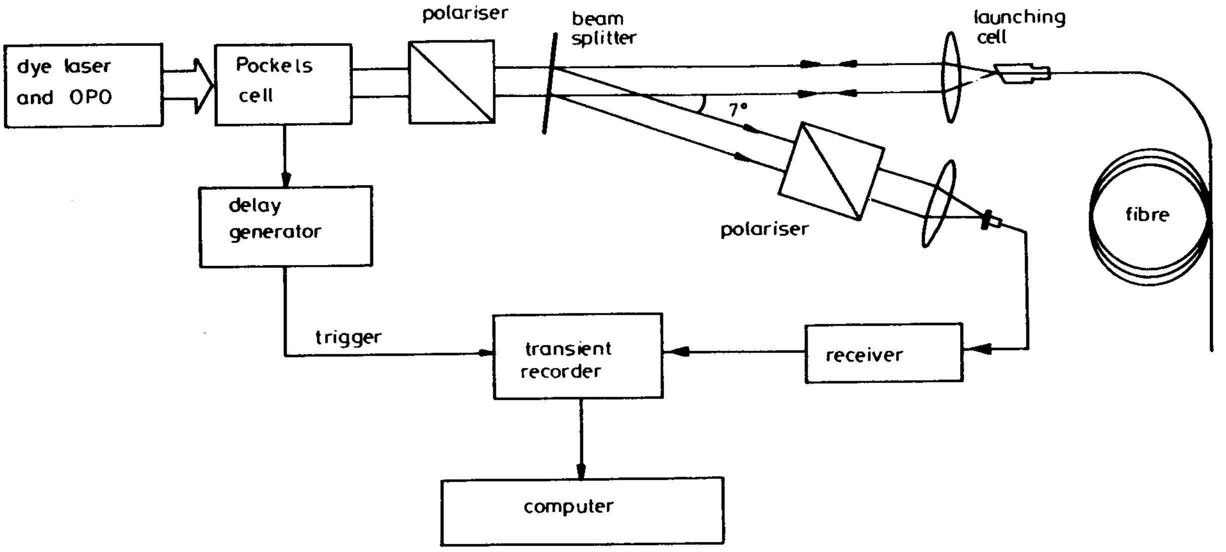


**Fig. 1** *Experimental arrangement*

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ment is the polariser placed in front of the photodiode to analyse the time variation of the SOP in the scatter return. The analyser converts polarisation information to intensity variations; thus, for example, in a fibre having only linear birefringence, the backscatter signal is expected to vary sinusoidally with a period determined by the characteristic polarisation beat length.

## 3 POTDR measurements

POTDR measurements were made on a 450 m length of germanoborosilicate fibre having a cutoff wavelength of 860 nm. The results shown in Fig. 2 were measured at

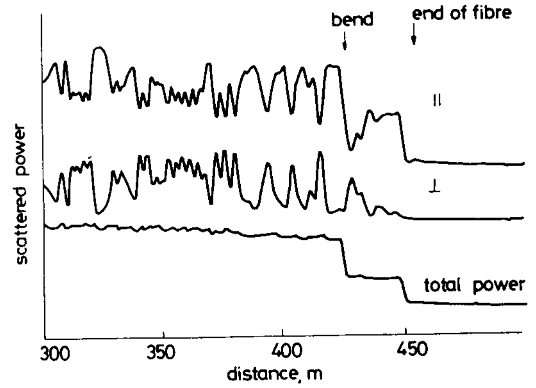


**Fig. 2** *Returned scattered power as a function of position in fibre*

Top curve is for analyser parallel (∥) and middle curve for crossed (⊥) with respect to input beam polarisation. Bottom curve shows total returned power. Note power drop caused by tight bend (see text)

885 nm on the final 150 m section of the fibre. The POTDR traces recorded with the receiving polariser parallel and orthogonal to the polarisation launched into the fibre exhibit strong and rapid fluctuations of power along the length, corresponding to the evolution of the SOP in the fibre. Note that the features of the two POTDR traces are precisely anticorrelated and thus sum to a near-constant value; the fluctuations which are observed thus correspond to variations in the polarisation of the received power and are not found in the total intensity of the backscatter trace (lowest curve) which was measured without the receiving polariser: the curve is almost featureless by comparison.

The POTDR traces of Fig. 2 were found to be stable and reproducible over a period of minutes. However, measurements made during the course of some hours showed a gradual variation of the individual features as the polarisation characteristics of the fibre changed with temperature. In principle it is possible to analyse POTDR curves in order to obtain the local fibre linear-birefringence and circular-retardance values. However, the processing required is complex since it is clear that the local retardance is not uniformly distributed along the fibre length. Nevertheless, the curves provide an indication that the polarisation beat length in this fibre is about 10 m, a typical value.

The drop in scattered intensity which may be observed in Fig. 2 at about 15 m from the fibre end is caused by a deliberately introduced 180° bend having a radius of 3.5 mm. This reproducibly gives a loss of 2 dB, as indicated in Fig. 2. To our knowledge this is the first measurement of single-mode-fibre bending loss to be made using the backscatter technique.

## 4 Errors in backscatter loss measurements caused by polarisation effects

Light backscattered in single-mode fibres is almost inevitably polarised. It is therefore of utmost importance that backscatter test equipment designed for single-mode fibres should not contain polarisation-sensitive components. Insufficient attention to this point would lead to spurious features in the loss/distance curves. For example, a semi-transparent beamsplitter at an angle of 45° is commonly used in backscatter experiments to separate the forward- and backward-travelling light. Fig. 3 shows a measurement made in this way of the same length of fibre as in Fig. 2. The result

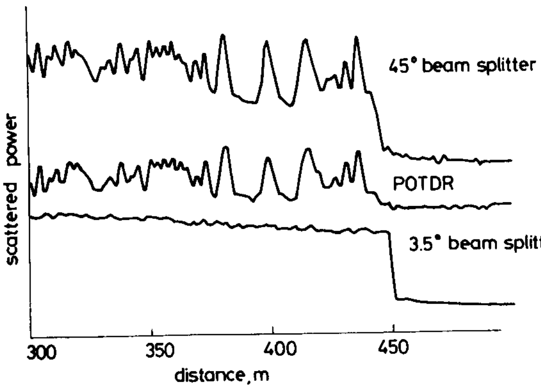


**Fig. 3** *Errors in backscatter loss measurements caused by polarisation effects*

Top curve: loss measurement using conventional 45° beamsplitter
Middle curve: Corresponding POTDR curve
Bottom curve: using polarisation-insensitive arrangement of Fig. 1

(Fig. 3 top) shows a large number of spurious features which are not real attenuation fluctuations but which are associated with the variation of reflectivity of the beamsplitter with the SOP of the returned light. This interpretation is confirmed by the correlation which exists between these features and those of the POTDR curve (middle curve). The bottom curve shows the results obtained using the polarisation-insensitive beam-splitter arrangement of Fig. 1.

In addition to external components, the fibre itself may well exhibit polarisation-dependent loss, caused for example by severe bends. This would lead to anomalous features in the backscatter curve and caution should thus be exercised in the interpretation of the results.

## 5 Conclusions

We have demonstrated the feasibility of POTDR and have presented some of the first measurements using the technique. In addition to revealing the potential of POTDR for polarisation studies, our measurements show that extreme care must be exercised in interpreting conventional OTDR loss measurements on monomode fibres, owing to the presence of polarisation effects.

## 6 Acknowledgments


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## 7 References


1 BARNOSKI, M.K., ROURKE, M.D., JENSEN, S.M., and MELVILLE, R.T.: 'Optical time-domain reflectometer', *Appl. Opt.*, 1977, **16**, pp. 2375–2379

2 CONDUIT, A.J., HARTOG, A.H., and PAYNE, D.N.: 'Spectral and length-dependent losses in optical fibres investigated by a two-channel backscatter technique', *Electron. Lett.*, 1980, **16**, pp. 77–78

3 CONDUIT, A.J., PAYNE, D.N., and HARTOG, A.H.: 'Optical fibre backscatter-loss signatures: identification of features and correlation with known defects using the two-channel technique'. Proceedings of 6th European conference on optical communication, York 1980, pp. 152–154
4 BRINKMEYER, E.: 'Backscattering in single-mode fibres', *Electron. Lett.*, 1980, **16**, pp. 329–330
5 HEALEY, P., and HENSEL, P.: 'Optical time-domain reflectometry by photon counting', *ibid.*, 1980, **16**, pp. 631–633
6 ROGERS, A.J.: 'Polarisation optical time-domain reflectometry', *ibid.*, 1980, **16**, pp. 489–490
7 CONDUIT, A.J. HULLETT, J.L., HARTOG, A.H., and PAYNE, D.N.: 'An optimised technique for backscatter attenuation measurements in optical fibres', *Opt. & Quantum Electron.*, 1980, **12**, pp. 169–178

# Book review

**Diffraction theory and antennas**
R.H. Clarke and John Brown
*Horwood/Wiley, 1980, 292 pp., £25.00*
*ISBN: 0-85312-182-6*

An arbitrary waveform in time can be expressed, using the Fourier integral transform, as a summation or spectrum of elementary sinusoidal waveforms – electrical engineers are well accustomed to this important technique and understand the advantages of such a decomposition into components when dealing with frequency-sensitive circuits, and the limitations when dealing with nonlinear circuits. Not so many engineers will be aware that an arbitrary electromagnetic field, at a single frequency and propagating in free space, can be represented similarly by an 'angular spectrum' of plane waves propagating in all possible directions; under certain conditions, the propagation constant becomes imaginary and a spectrum of nonpropagating, or evanescent, waves must be taken into account.

This book offers an application of these concepts to the theories of radiation from planar antennas and of diffraction by obstacles. The authors claim 'that the theory is not only more comprehensible but is also more precise than conventional theories of diffraction'. Their exposition is, in general, lucid and the first part of their claim appears to be justified; however, they do not present any comparison with experiment, or indeed with other theories, and it is not clear on what their claim of precision is based.

They use the angular plane-wave spectrum for representation of 2- and then 3-dimensional fields, and apply the results to the transmitting and receiving properties of planar antennas. The angular plane-wave spectrum of the field radiated by a planar aperture is shown to be the 2-dimensional Fourier transform of the tangential electric field in the plane of the aperture. The field at any point in the halfspace in front of the plane of the aperture is then given in terms of the angular spectrum; and in particular the far-field polar diagram is found to be proportional to the angular spectrum. The antenna used as a receiver is then discussed and the important reciprocity and coupling theorems are developed. Huygens' principle and Fresnel diffraction are discussed at length, and reflection from flat and curved surfaces is also treated. The theory is applied to practical aperture antennas, to horns and to parabolic and cassegrain reflectors; a brief discussion of radiation from nonplanar apertures completes the body of the book. In addition, there are two lengthy appendixes on transmission lines, plane waves, and simple waveguides, and on Maxwell's equations and some of their consequences.

This elegant presentation of invaluable concepts is to be welcomed, and yet in some respects it is disappointing. Because of the paucity of numerical results, it will probably not be very helpful to the practising engineer closely concerned with the design and use of antennas. Radiators based on metallic and dielectric strips or lines are not covered – surely the VHF/UHF aerial is numerically the most important form of antenna? The radar or communication engineer seeking information on how to limit the rear lobes in the polar diagram of his antenna will find little or no help in this book.

These practical problems are perhaps not suited to a presentation directed presumably towards students of engineering science, but it has defects even in that context. It does not discuss any limitations that there might be in the range of application – will the spectrum be helpful in discussing propagation in a non-homogenous or stratified atmosphere? Does it have validity for a field within a nonisotropic medium? Some indication of any such limitations would have been useful.

One can also criticise the authors for not discussing more fully how the aperture is excited. They use, from the beginning a model of an aperture cut in an infinite conducting sheet and postulate excitation in the form of a plane wave incident, normally on the sheet from the rear halfspace. They fail to take into account the wave reflected back into the rear halfspace from the conducting sheet, and only in one section do they appear to discuss the spectrum of waves radiated into the rear halfspace from the aperture. This oversimplified model should trouble a student who is beginning to believe he understands electromagnetic fields. Perhaps it is better to postulate directly the existence of a tangential field in the aperture or to use the cavity model discussed by D.R. Rhodes in a book to which the present authors refer.

Despite these shortcomings, perhaps of minor significance, this book will provide a sound base for an understanding of important aspects of radiation.

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