BEND BEHAVIOUR OF POLARISING OPTICAL FIBRES

Indexing terms: Optical fibres, Polarisation

Experimental results are presented which show how both bend radius and the orientation of the fibre in the bend considerably affect the single-polarisation operation of bow-tie fibres.

Introduction: Bow-tie fibres[1] exhibit extreme values of birefringence ($B \sim 10^{-3}$) as a consequence of their optimal cross-sectional geometry (inset Fig. 1) which maximises thermal stress.[2] Recently we have shown that bow-tie fibres can be operated in a wavelength region where only one polarised mode propagates,[3] a property which makes them suitable for the many applications requiring a stable, linearly polarised fibre output.

Polarising behaviour in a bow-tie fibre results primarily from differential radiation loss (leakage) between the two linearly polarised modes and can be characterised by measuring the extinction ratio at the fibre output and the transmission loss of the guided mode. It should be noted that although the polarisation coupling occurring at sharp bends and twists[4] must ultimately limit both the extinction ratio and transmission loss, the effect is minimised by maximising the fibre birefringence as in a bow-tie fibre.

It has been indicated[3,5] that the differential loss mechanism in bow-tie fibres is associated with bending or microbending. A similar observation has been reported[6] in a leaky cladding-mode fibre design. The purpose of the present work is therefore to quantify experimentally the effect of bends on the polarising performance of bow-tie fibres, with particular reference to the relationship between transmission loss and extinction ratio outlined above. Characteristics of the fibres used in the experiments are shown in Table 1, fibres A and B being bow-tie fibres having depressed stress producing parts, and fibre C being a matched elliptical jacket fibre.[7]

Table 1 CHARACTERISTICS OF FIBRES USED IN EXPERIMENTS

	Fibre A	Fibre B	Fibre C
Type	Bow-tie	Bow-tie	Elliptical jacket
Core Δ%	0·32%	0·08%	~0·3%
Cutoff wavelength	580 nm	580 nm	~600 nm
Birefringence B	$5 \cdot 3 \times 10^{-4}$	$5 \cdot 3 \times 10^{-4}$	$1 \cdot 9 \times 10^{-4}$

Refractive index differences Δ are expressed relative to silica

Results: The polarisation extinction ratio against wavelength of a single loop of fibre A is shown in Fig. 1 for three different loop-radii R. Also shown is the loss of the guided (linearly polarised) mode. It can be seen that tighter bends shift the wavelength at which polarising behaviour occurs to shorter wavelengths. Thus, for this fibre, the operating wavelength of a single-loop 25 dB polariser can be tuned from 810 nm (10 mm radius bend) to 900 nm (50 mm radius) by varying the loop size. Only the smallest bend had a measurable transmission loss and therefore compact, low-loss multiple-loop polarisers with extremely high extinction ratios are possible.

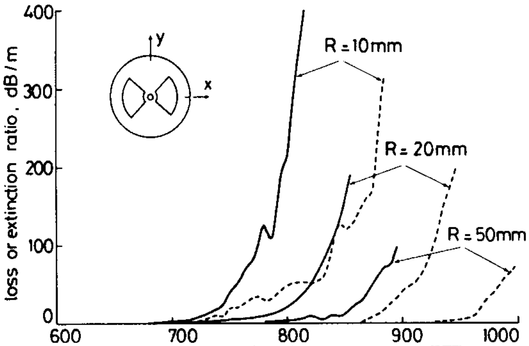

Fig. 1 *Spectral polarisation extinction-ratio (solid lines) for a single loop of bend radius shown*

Results are for fibre A and have been extrapolated to dB/m
Also shown (broken line) is the spectral transmission loss of the guided (x-polarised) mode for the same three bend radii

Similar results have been obtained on a number of bow-tie fibres having a variety of geometries, birefringence and core index differences. In all cases but one, no polarising effect could be obtained in a perfectly straight fibre up to 1000 nm (the limit of our measurements). This effect is unexpected, as Reference 5 indicates that the y-polarised mode should leak when the y-mode equivalent index has dropped to the level of the cladding index seen by the x-polarised mode. For the low numerical-aperture fibre (fibre B) this occurs at about 640 nm. However, the straight fibre showed no polarising behaviour, whilst the bent fibre was wavelength tunable to below the second-mode cutoff.

Fig. 2 shows the extinction ratio for a 20 mm-radius bend, measured as a function of orientation θ of the fibre in the bend (inset b defines θ). The wavelength edge for 15 dB polarising performance is seen to shift from 820 nm to 880 nm with fibre orientation. A shift to longer wavelength implies stronger guidance for both polarised modes and, as expected, this occurs at $\theta = 0°$ (inset a). At this orientation the large index-depression of the bow-tie sectors tends to confine the mode to the core, thus preventing radiation loss in the bend. The effect is contrasted by fibre C (elliptical jacket) which showed almost no effect with orientation θ, the wavelength of 15 dB extinction ratio varying by only 15 nm, compared to 60 nm for the bow-tie fibre. The orientation effect is further emphasised by comparing for fibres A–C the separation of the leakage edges for the two polarised modes. At $\theta = 0°$ all three fibres exhibited a separation of 60 nm. However, at $\theta = 90°$, fibre A gave 110 nm, fibre B 120 nm and the elliptical jacket fibre, fibre C, remained unchanged at 60 nm.

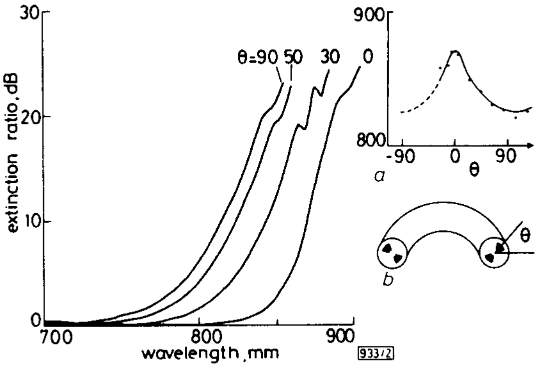

Fig. 2 *Spectral extinction ratio for a single 20 mm-radius loop of bow-tie fibre as a function of bend orientation θ (see inset b)*

Inset *a* shows wavelength variation with orientation of 15 dB extinction level

The above experiments refer to the short-length performance of bow-tie fibres as polarisers. As an indication of their potential use in fibre gyroscope coils, a 500 m length of fibre A was successively wound on two drums of 15 cm and 6 cm and the spectral loss of the two polarised modes measured. The results are shown in Fig. 3. In both cases the loss at 820 nm of the guided mode remained unchanged at ~5 dB/km, while the loss of the suppressed mode was immeasurably high (> 80 dB/km). However, reference to the Figure shows that improved performance results when the fibre is wound on the smaller (6 cm) drum, as evidenced by the very much sharper attenuation edges.

Conclusions: Differential bend loss for the two polarised modes has been shown to be the predominant polarising mechanism in bow-tie fibres. Furthermore, the orientation of the fibre in the bend affects its polarising characteristics. Optimum performance occurs when the bow-tie sectors are oriented radially outwards. The results show that a range of

Reprinted from ELECTRONICS LETTERS 18th August 1983 Vol. 19 No. 17 pp. 679-680

very high-quality polarisers and gyrocoils can readily be constructed using these fibres.

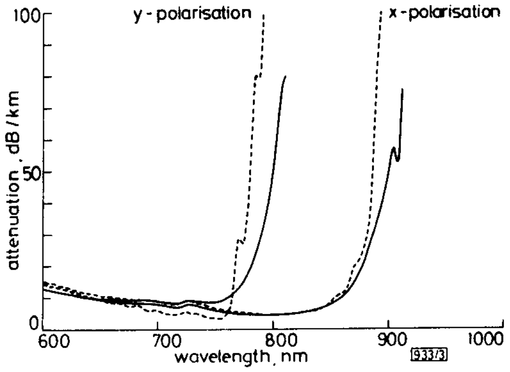

Fig. 3 *Spectral attenuation plot of bow-tie fibre for two bend radii showing different loss edges for x- and y-polarised modes*

- - - - 6 cm coil radius
——— 15 cm coil radius

Acknowledgments: Acknowledgments are especially made to Dr. A. J. Barlow, Dr. A. H. Hartog, Dr. C. M. Ragdale, Dr. K. Okamoto, S. B. Poole and to Prof. A. W. Snyder for their continuing help and useful discussions. A Research Studentship (MPV) was provided by British Aerospace plc and a Research Fellowship (DNP) by Pirelli Cable Company plc.

M. P. VARNHAM
D. N. PAYNE
R. D. BIRCH
E. J. TARBOX

Department of Electronics
Southampton University
Southampton, SO9 5NH, England

5th July 1983

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