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FARADAY ROTATION IN TUNED OPTICAL FIBRE COILS

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Compact devices based on Faraday rotation in optical fibres have not been developed because linear birefringence, either inherent to the fibre or induced by bending[1], acts to quench the rotation (circular birefringence)[2]. However, it was recently demonstrated that quenching can be largely overcome if the sense of the magnetic field alternates along the fibre in successive half-beat-length increments of the linear birefringence[3]. In this paper we describe practical, easy-to-manufacture devices based on this principle.

The required condition can be met by placing a fibre coil in which the birefringence-beat-length is equal to the circumference in a magnetic field perpendicular to the coil axis (Figure 1). The tangential component of the magnetic field is therefore $B_t = B \cos (z/R)$ where B is the applied field, R is the coil radius and z is distance along the axis of the fibre. The required tuning condition is $1/R = 2\pi/L_p = \Delta\beta$ where L_p is the birefringence beat length ($L_p = 2\pi/\Delta\beta$) and $\Delta\beta$ is the linear birefringence. To satisfy this we actually make use of the bend-induced birefringence, choosing the dimensions of the fibre and coil so that the necessary 360° of birefringence per turn is exactly obtained. In good agreement with reference 1 we find that for a given fibre radius, r, the required coil radius, R, is given by $R = Cr^2$, where for a given wavelength C is a constant of the fibre material.

Using Jones calculus and the appropriate matrix for Faraday rotation in a birefringent medium[2] it is possible to numerically compute the change of polarisation state as light

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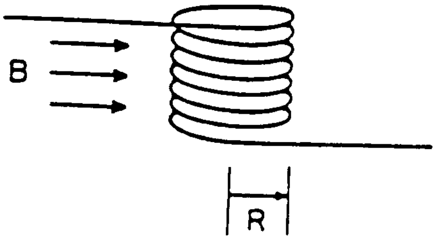
passes through the device. Figure 2 shows a Poincare sphere representation resulting from such a computation for the case where the light at the input is linearly polarised along one of the principal birefringent axes of the coil. The polarisation state follows a spiral trajectory which would eventually fill the entire sphere, collapsing to the equator at a point opposite its origin, that is to say the orthogonal linear polarisation state. After each full turn the polarisation state is linear and rotated by successively greater amounts from the input state. After odd numbered half-turns a similar situation exists except that the rotation is in the opposite direction. If, for the same case, the power in each of the orthognal polarisation states is plotted as a function of distance along the fibre (Figure 3) one finds that the functional dependence, though complex, is well approximated by

$$\frac{|E_y(z)|^2}{|E_x(z)|^2} \approx \sin^2\left(\frac{VBz}{2}\right)$$

where V is the Verdet constant of the fibre. Thus the effect is half as strong as it would be if there were no linear birefringence. For $V = 1.7^{\circ}\mathrm{cm}^{-1}\mathrm{T}^{-1}$ and a magnetic field of 0.3T one therefore needs about 1.75m of fibre to attain a rotation of 45°.

If the birefringence of the coil differs slightly from 360°/turn, the spiral trajectory on the Poincare sphere reaches a maximum radius depending on the degree of mismatch and then collapses to the original polarisation rather than to the orthogonal state. Figure 4 shows the effect of mismatch for a 40 turn coil approximately 15mm diameter. From similar analysis we project that for certain types of Faraday devices, such as isolators or circulators which require an isolation ratio of 25dB or more, one must maintain the matching condition to within about 0.1 per cent.

We have succesfully achieved this accuracy using two different fabrication methods. In the first case, we take advantage of the excellent reproducibility of the bend birefringence in a free standing (i.e. former removed) coil. After empiric adjustment of the coil diameter one finds that



1 For a fibre coil of radius R with a uniform magnetic field, B, parallel to the input and output leads, then component of the field parallel to the fibre axis is given by Bcos(z/R) where z is measured along the fibre axis.

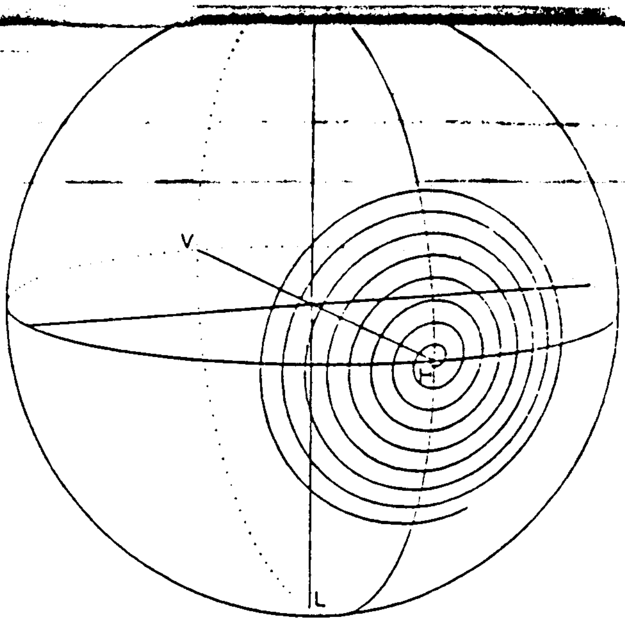
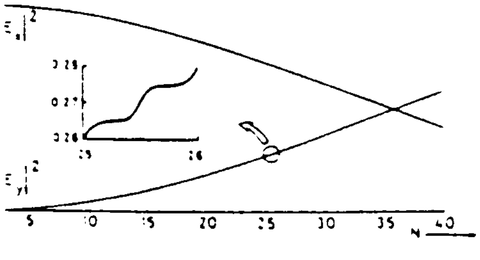


Fig. 2 Poincare sphere representation of the polarisation state along the coiled fibre.



3 Power in each of the orthogonally polarised modes as a function of the number of turns, N, for the case where $E_x(0) = 1$, $E_y(0) = 0$. Coil diameter 15mm.

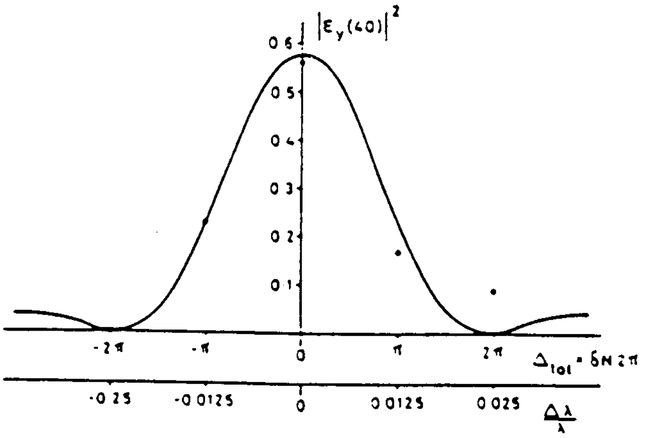


Fig. 4 Power, $|E_y(z=40 \text{ turns})|^2$, converted to the orthogonal mode for 15mm dia. coil as a function of the total mismatch. Individual point points were obtained by applying tension to the coil to vary the fibre birefringence. Lower abscissa shows the spectral response that would be obtained if the coil were used as an optical fibre.

it is possible to achieve a mismatch of less than 0.1 per cent with good reproducibility. Furthermore, we find a temperature coefficient of the bend birefringence of about 1 x $10^{-4}/^{\circ}C$ so the devices have a useful operating temperature range of at least ± $10^{\circ}C$. As an alternative fabrication technique we have designed a coil former that can be expanded slightly, placing the fibre under a small amount of tension and increasing its birefringence. Starting with a slightly oversized former it is thus possible to adjust the coil for proper matching. We can also, in this way, verify the mismatch analysis of Fig. 4, obtaining the data points indicated as the tension is increased. The expandable former approach has the advantage that it is not necessary to know the operating wavelength exactly in advance. A disadvantage is that its temperature stability is inferior to that of the free standing coil.

It will be possible, using this approach, to produce a full range of Faraday devices in optical fibre. To date we have concentrated on the development of an isolator for use at 632.8nm. An isolation ratio of 27dB has been measured on a 30 turn, 22mm diameter free standing coil with a mismatch of 0.06 per cent. This is in good agreement with numerical analysis. The performance of the coil as an optical filter can be inferred from Figure 4 by relabelling the abscissa in terms of wavelength as shown. In general the relative spectral width of the filter is about 1/N where N is the number of turns in the coil. For moderately high magnetic field, $B \sim 10^{-3}T$, it is possible to construct a very simple magnetic field sensor by placing the coil between crossed polarisers. Other configurations yet to be fully examined should lead to the detection of much smaller fields.

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