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Passive, wavelength self-adjusting and tracking optical filter

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Abstract

A passive, self-adjusted filter is presented which consists of an unpumped, twin-core erbium-doped fibre. The filter characteristics depend on the fibre and optical parameters. For a fibre NA of 0.3, the optimum filter performance is achieved for average optical powers of about 0dBm (±3dB). The device can also operate as a soliton sliding filter providing a filter centre-wavelength offset of ~0.1nm from the incoming centre wavelength.

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I. Introduction. Dual-core fibres have been proposed as optical filters and (linear/nonlinear) switches in various optical systems [1,2]. In the case of nonlinear switches, the optical non-linearity of fused silica can be resonantly enhanced by doping the fibre cores with appropriate materials, such as erbium [3,4], resulting in a dramatic reduction of the switching power. The twin-core fibre geometry has also been utilised to implement a passive channel-equalising erbium-doped fibre amplifier. The device operation relies on this geometry-induced wavelength separation and the concomitant spatial "hole" burning [5-6].

In this communication, a passive, self-adjusted, bandpass optical filter is described which consists of an erbium-doped, unpumped, twin-core fibre and its operation is based on a principle similar to the twin-core channel equaliser [5-6]. The filter characteristics, i.e. optical bandwidth, extinction ratio and insertion loss, depend on the fibre geometry and saturation properties of the dopant. In general, it exhibits relatively low extinction ratio. It can however be advantageously used in reducing the noise level in multistage, amplified optical links. In addition, when operated at the proper wavelength, the filter exhibits passive-sliding characteristics which could be particularly useful in soliton communications.

For the sake of clarity and simplicity and before extended to pulse-trains, the filter operation is described in terms of two signals of different wavelengths and unequal input powers. This idealised case is applicable to the compression of the noise pedestal associated with relatively strong amplified signals.

II. Device discription - Principle of operation: The filter consists of a twin-core fibre with both cores being Er^{3+}-doped. Only one core is used as input while, in contrast with all the other twin-core filter designs, *both* cores are used as output. The power of each signal varies periodically along each fibre core, with a period depending on its wavelength. In the case of two propagating signals, the powers evolve in- and out-of-phase periodically along each fibre core. This spatial period is hereafter called the *characteristic length*. The device can be several characteristic-lengths long. The signal spatial decoupling takes place predominantly around the middle half-part of each characteristic length (where the powers of the two signals are in anti-phase) and accumulates with the fibre length. The filtering is accomplished by the power-dependent saturable absorption provided by the dopant. The partially separated signals saturate predominantly different parts of the active medium in both cores and experience dissimilar losses depending on their local power. Namely, the low-power signal suffers stronger attenuation than the high-power one resulting in a pronounced differential loss and effective filtering. The transmission loss of the strongest signal determines the *insertion loss* of the filter, while the differential loss between the two signals determines its *extinction ratio*.

Typical filtering characteristics are shown in Figure 1, where the signal differential loss (or filter extinction ratio) is plotted as a function of the wavelength difference. The signal#1 wavelength and input power are 1.555μm and 0dBm, respectively, and the signal#2 input power is -20dBm. The fibre length and normalised core separation are 2.475m and 10, respectively. The fibre NA is 0.3 and the dopant concentration is 10^{25} ions/m^3. The other optical parameters refer to germano-silica erbium-doped fibres [7]. The proposed device exhibits characteristics of a *bandpass filter*. The bandwidth (*BW*) of the filter is related to the characteristic fibre length and is, therefore, determined by the fibre parameters, i.e. fibre length and intercore separation. From Figure 1, it is clear that the strong signal#1 determines the centre frequency of the bandpass filter.

III. Bandwidth - Extinction ratio - Insertion loss: In Figures 2(a) & (b), the bandwidth, as well as, the extinction ratio and insertion loss of the filter are plotted as a function of the fibre length, for a number of normalised core-to-core separations. The input powers of signal#1 and signal#2 are 0dBm and -20dBm, respectively. Firstly, it is shown that (Fig. 2(a)), for a certain core-to-core separation, the filter bandwidth decreases inversely with the fibre length. Variations in fibre length, in addition to bandwidth, affect the extinction ratio and insertion loss, as shown in Figure 2(b). For a given dopant concentration and core-to-core separation, increasing the fibre length, decreases the bandwidth and, at the same time, increases the extinction ratio and the insertion loss. For a fixed fibre length, core-to-core separation affects the bandwidth but has negligible effect on the filter extinction ratio and insertion loss. Intercore separation can, therefore, be used to control the filter bandwidth independently from its extinction ratio and/or insertion loss. Alternatively, for a certain bandwidth, the extinction ratio can be controlled by varying the dopant concentration.

The device operation relies on the power-dependent saturable absorption of the dopant and, therefore, the filter extinction ratio and insertion loss will be dependent on the relative input powers of both signals. In Figures 3(a) & (b), the filter extinction ratio and insertion loss are plotted as a function of the signal#1 input power, respectively, for various signal#2 input powers. The rest of the parameters are as in Fig. 1. The extinction ratio increases gradually as the signal#1 (writing signal) input power increases. For the parameters employed, the maximum extinction ratio is obtained for input powers of the (strong) writing signal (P_{S1}) around 0dBm ($\sim$-3dBm to $\sim$+2dBm). For higher P_{S1}, the active medium oversaturates and the extinction ratio decreases. The insertion loss decreases monotonically with increasing P_{S1} following closely the saturation of the medium. It can be seen that the insertion loss is relatively small over the maximum-extinction-ratio range.

At present, in transpasific/atlantic links the amplifier gain-peak and the fibre dispersion minimum have to be carefully matched. Insertion of the new filter periodically along the link would allow the wavelength of minimum loss of the link to be set by the operating signal wavelength and, thus, matched easily to the dispersion zero.

IV. Pulse Filtering - Sliding Filter: So far, the investigation of the filter performance has been focused on the reduction of the noise pedestal associated with strong amplified signals. The device can also be used for filtering repetitive or pseudo-random pulse trains such as used in soliton communications, in which case, it can also exhibit sliding-filter characteristics [8]. The offset (sliding) of the filter centre frequency from the centre frequency of the incoming data depends on the spectral characteristics of the added saturable absorber. It occurs due to variation of the emission and absorption cross-sections of the dopant (saturable absorber) across the spectrum of the data. The sign of this slope defines the direction of the shift. At 1.555μm, the filter slides to longer wavelengths. In Figure 4, the transmission characteristics of an erbium-doped germano-silicate [7] twin-core fibre (solid line) are plotted for an incoming Gaussian pulse of centre frequency 1.555μm. The dashed line corresponds to the transmission of the device without the spectral variation of the various cross-sections taken into account. In this case, a shift of the centre wavelength of $\sim$0.1nm is observed. However, this shift can be varied by design. The spectrum shift exhibited by the filter enables it to be used as a passive sliding filter to reduce the noise-induced jitter in long communication soliton links [8]. The sliding effect can be counteracted or further enhanced by cascading the twin-core filter with a properly wavelength-tuned broadband fixed filter.

V. Conclusions: A passive, wavelength self-adjusting and tracking optical filter has been presented which consists of an unpumped, twin-core erbium-doped fibre. It relies on the wavelength-dependent spatial separation and the power-dependent saturable absorption to differentially attenuate the various incoming wavelengths. The filter characteristics depend on the fibre and optical parameters. For a fibre NA of 0.3, the optimum filter performance is achieved for average optical powers of about 0dBm ($\pm$3dB). The proposed filter shows relatively low extinction ratio. However, it can be used in long amplified optical links in order to reduce the noise level and passively match the operating (low loss) wavelength to the dispersion minimum. The device can also operate as a sliding filter in soliton communications providing a centre-wavelength offset of $\sim$0.1nm.

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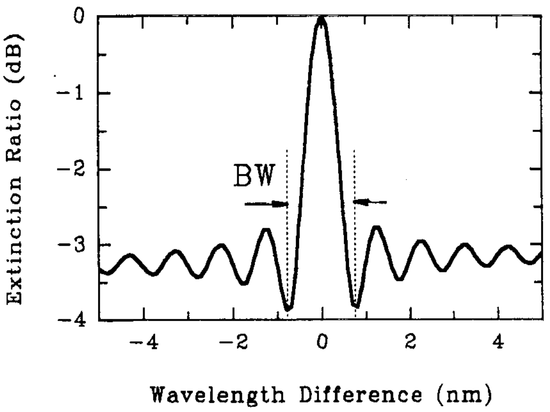

FIGURE 1: Filter extinction ratio as a function of the wavelength difference.

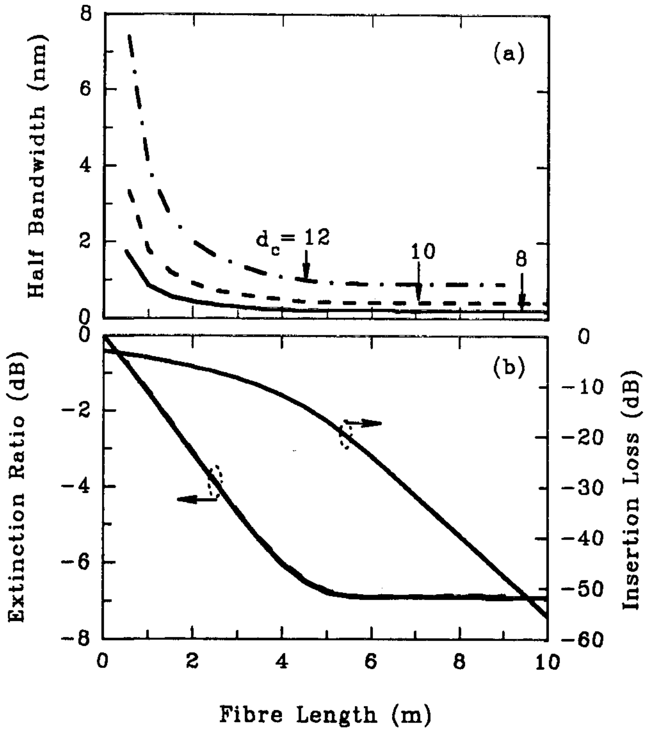

FIGURE 2: (*a*) Filter bandwidth, and (*b*) filter extinction ratio as a function of the fibre length for different normalised intercore separations.

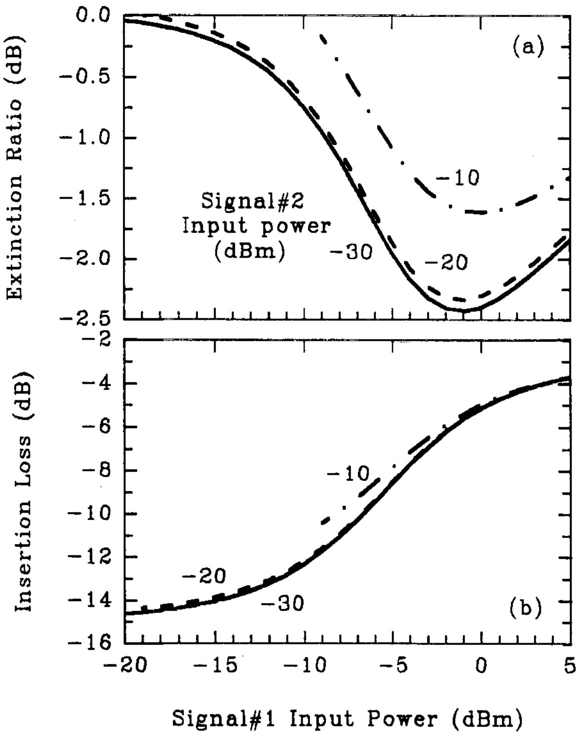

FIGURE 3: (*a*) Filter extinction ratio and (*b*) insertion loss as a function of signal#1 input power, for various signal#2 input powers.

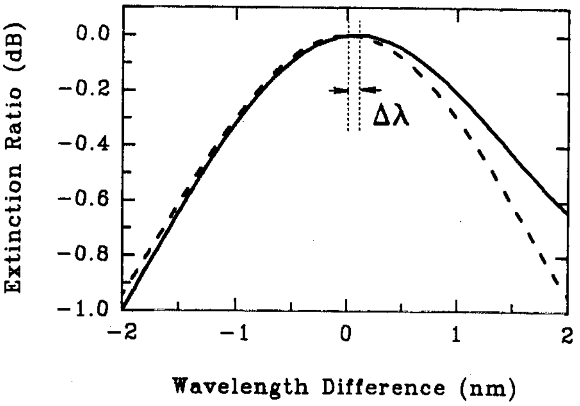

FIGURE 4: Relative spectral positions of filter with (solid line) and without (dashed line) sliding.