ALL-FIBRE WAVELENGTH FILTERS USING CONCATENATED FUSED-TAPER COUPLERS

Indexing terms: Filters, Fibre-optics, Optical couplers

Successive fused-taper couplers are proposed as all-fibre wavelength filters. A low-loss narrowband filter constructed from two overcoupled couplers is demonstrated.

Introduction: Single-mode optical-fibre couplers are being actively developed for wavelength-multiplexing applications.[1,2] Several fabrication approaches to provide the coupling action have been reported, the two most common being the polished coupler and the fused biconical-taper coupler. The main advantage of the polished coupler is that it is readily wavelength-tunable by adjusting the coupling length, while the advantage of the fused taper coupler is that it is more thermally stable and is quicker and more convenient to make.

The ability of a coupler to wavelength-filter light results from the rapid variation of coupled power with wavelength which occurs in an overcoupled coupler, i.e. one in which the power transfers to and fro between the cores several times along the length. The coupling length is approximately proportional to wavelength, so changing the wavelength varies the number of times the light oscillates between the two fibres. A periodic coupled-power response with wavelength is found and channel separations as low as 35 nm can be obtained.[2]

Recently we reported the properties of very long fused-taper couplers which have been made with interaction lengths as large as 600 mm.[3] The couplers have low loss and very small controllable channel separations. This suggests the possibility of concatenating several couplers together to tailor a given wavelength response such as a narrowband optical filter, in spike or comb form.

The present work describes the realisation of a narrowband optical filter. The design of the concatenated filters is first given, followed by the practical implementation of a simple two-coupler narrowband filter. The possibility of multicoupler designs and their potential spectral passband is discussed.

Theory: The spectral response $R(\lambda)$ of a highly overcoupled 4-port coupler is approximately sinusoidal with wavelength period $\Delta\lambda$, where $\Delta\lambda$ depends on the coupling strength. If two or more couplers are concatenated (inset Fig. 1), the throughput will be given by

$$P(\lambda) = \left[1 + \sin\left(\frac{2\pi\lambda}{\Delta\lambda_1} + \Theta_1\right)\right]\left[1 + \sin\left(\frac{2\pi\lambda}{\Delta\lambda_2} + \Theta_2\right)\right] \qquad (1)$$

where $P(\lambda)$ is the power in the output port, $\Delta\lambda_1$, $\Delta\lambda_2$ are the channel spacings of the 1st, 2nd couplers and Θ_1 and Θ_2 are the phase parameters of the couplers. From eqn. 1, the spectral throughput of two concatenated couplers was calculated for $\Delta\lambda_1 = 2(\Delta\lambda_2) = 100$ nm and $\Theta_1 = \Theta_2 = 0$. The result, Fig. 1*a*, shows a spike filter characteristic. As in a Lyott filter, the response can be improved by concatenating several couplers together as shown in Fig. 1*b*, where the theoretical response of four concatenated couplers is shown. Here we have used $\Delta\lambda_1 = 2(\Delta\lambda_2) = 3(\Delta\lambda_3) = 4(\Delta\lambda_4) = 100$ nm. It is clear from these Figures that if the channel spacing of the couplers can be narrowed sufficiently, an excellent spike filter characteristic can be obtained. Such a filter could be used, for example, as a wavelength drop-off filter in a wavelength-division-multiplexed communication link, or to separate a single line from a multilongitudinal-mode laser.

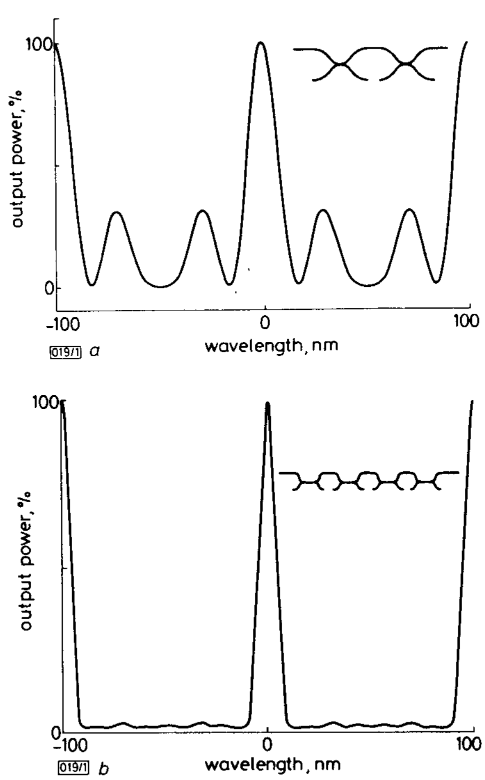

Fig. 1 *Calculated spectral response of concatenated overcoupled 4-port fibre couplers*

a Two series couplers
b Four series couplers

Experiment: An optical bandpass filter was fabricated from two concatenated overcoupled monomode fibre couplers which have 20 mm and 150 mm interaction lengths, respectively. To avoid the necessity of splicing the couplers together, they were made in succession on the same fibre. The spectral throughput of this dual-coupler bandpass filter is shown in Fig. 2. At the centre wavelength, 650 nm, the filter has a throughput of 95% (a loss of only 0·2 dB) and a 3 dB spectral width of 20 nm. The two sidelobes at 620 nm and 675 nm are present at 25%.

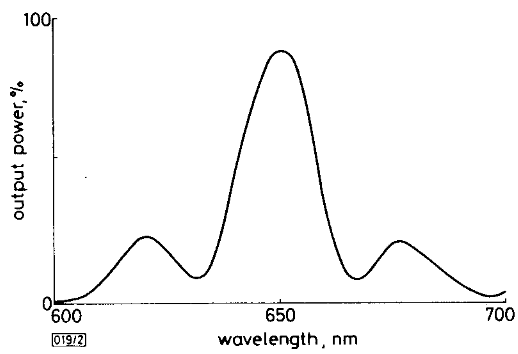

Fig. 2 *Experimental spectral response of two series 4-port couplers*

Although the response between 600 nm to 700 nm clearly resembles the theory given above, the repeat response between 700 nm and 800 nm was found to be somewhat distorted. This is due to the phase parameter terms in eqn. 1, and also to the fact that the channel spacings $\Delta\lambda_1$ and $\Delta\lambda_2$ are not uniform with wavelength.

Preliminary measurements of the thermal stability of overcoupled couplers in the temperature range 20°C–70°C has shown that their wavelength characteristics can be surprisingly stable.

Discussion: The above experiment clearly demonstrates that low-loss optical bandpass filters can be fabricated by concatenating fused-taper couplers. In order to evaluate the bandwidth which could potentially be obtainable from these filters, the spectral response of a coupler with a 300 mm-long interaction length was measured. The loss of the coupler was < 1 dB. The spectral response, Fig. 3, has a modulated sinusoidal characteristic with channel spacings as low as 2·5 nm. The reason for the modulation is that the two orthogonally polarised modes experience different coupling strengths.[3]

Couplers have been successfully fabricated with interaction lengths as large as 600 mm, all with losses less than 1 dB. However, the channel spacing in these couplers is too small for our measurement system to resolve, and therefore the potential bandwidth of a spike filter is as yet unknown, but is certainly much less than 2·5 nm.

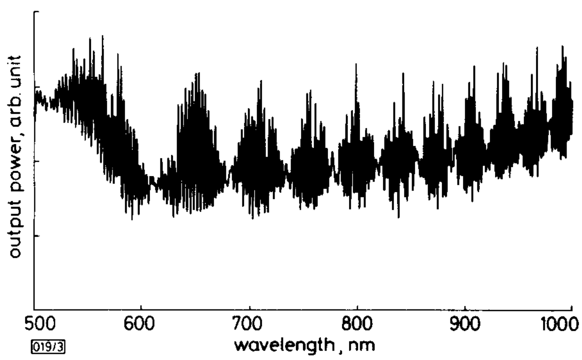

Fig. 3 *Spectral response of 300 mm-long highly overcoupled 4-port coupler showing potential for construction of narrow bandpass filters*

Conclusions: The concatenation of fused-taper couplers to make optical bandpass filters has been described and the responses of dual and quadruple coupler filters calculated. A dual-coupler filter was successfully fabricated from couplers having 20 mm and 200 mm interaction lengths, respectively. The filter had a throughput of 95% and a 3 dB bandwidth of 20 nm. The potential bandwidth of these filters is much smaller, a 300 mm-long coupler having a measured channel spacing of only 2·5 nm, while longer couplers have been made with channel spacing so narrow as to make measurement difficult. Improved fabrication control should provide the ability to tailor a number of different responses using multiple-coupler arrangements.

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