# BEHAVIOUR OF ASYMMETRIC FUSED-TAPERED SINGLE-MODE FIBRE COUPLERS.

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## Introduction

Fused-tapered single-mode fibre couplers are available which have a flattened wavelength response and which are therefore useful in applications requiring a near-constant power-splitting ratio over a range of wavelengths. They are made by inducing an asymmetry in the constituent fibres, for example by pre-tapering[1] or pre-etching[2] one or both fibres prior to coupler fabrication, or by using two dissimilar fibres[2]. The maximum coupled power in these couplers has been shown to decrease with increasing asymmetry[1,2].

Couplers made from dissimilar fibres could also be useful for integrating systems made from different fibres, and it may be necessary for such a coupler to exhibit complete power transfer despite the asymmetry in fibre type. Complete power transfer has only previously been shown to be possible in dissimilar fibre couplers by differentially etching the fibres used to make the coupler, in order to adjust the extent of cladding diameter asymmetry[2]. It would be advantageous to be able to adjust the splitting ratio of these couplers without requiring close control over the cladding diameter asymmetry of the constituent fibres. We demonstrate that the maximum coupled power of an asymmetric coupler is strongly dependent on the degree-of-fusion in the coupler, and that it is possible to obtain near-total power transfer (or indeed any level of power transfer) for a given cladding diameter asymmetry by controlling the degree-of-fusion of the coupler. We therefore remove the requirement for a controllable differential etching process prior to coupler fabrication.

## Experimental Results

Using conventional fabrication techniques five couplers were made, couplers A, B and C from fibres 1 and 2 and couplers D and E from fibres 1 and 3. Fibre 1 had an outer diameter O.D.= 80$\mu$m, N.A.= 0.22 and cut-off wavelength $\lambda_c$ = 675nm, fibre 2 had O.D.= 100$\mu$m, N.A.= 0.14 and $\lambda_c$ = 525nm, and fibre 3 had O.D.= 80$\mu$m, N.A. = 0.13 and $\lambda_c$ = 575nm. The progress of fabrication for each coupler was monitored by launching monochromated light into fibre 1. For couplers A-D tapering was stopped when all power returned to the launch fibre after one coupling cycle at a wavelength near 1$\mu$m. Coupler D was then elongated through a further coupling cycle to give coupler E.

After being characterised, the couplers were cleaved at the taper waist, and the cross-sections were measured using a microscope to determine their degrees-of-fusion. To quantify this parameter, we define it to be the ratio $w/d_2$ for the cross-section, where the parameters are defined in the inset to Fig 1.

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Figs. 1 and 2 show the spectral logarithmic splitting ratios of the output powers of couplers A-C and D-E respectively. The unusual behaviour in the range below 650nm is the result of the launch fibre 1 being multimoded at these wavelengths. The degree-of-fusion and loss of each coupler are given in the appropriate figure caption.

## Discussion

Couplers A-C were made from the same pair of dissimilar fibres, and differ only in their degrees-of-fusion. The maximum splitting ratio (m.s.r.) of these couplers shows a strong increasing dependence on the degree-of-fusion. Indeed, the spectral splitting ratio of coupler C approaches that expected for a standard symmetric coupler, with complete power transfer at certain wavelengths. Hence, by adjustment of the degree-of-fusion, it is possible to obtain efficient power transfer between dissimilar fibres which have not been "dimensionally-tuned"[3] by etching. That fibres 1 and 2 are not co-incidentally dimensionally-tuned without etching is demonstrated by the inefficient power transfer of coupler A.

Comparison between couplers A-C and couplers D-E confirms that the m.s.r. decreases as the coupler diameter asymmetry increases. For instance, coupler A (made from the different-diameter fibres 1 and 2) exhibits only partial power transfer, while coupler E (made from the same-diameter fibres 1 and 3) exhibits complete power transfer as is routinely achieved in symmetric couplers, although the degree-of-fusion of E is similar to that of A. This extent of coupling is a consequence of the cladding mode nature of the single-mode fibre taper, and the tapered region of coupler E is essentially equivalent to that of a symmetric coupler. The less complete power transfer in coupler D is probably the result of a residual core effect, since coupler D was not tapered as far as coupler E.

## Modelling Asymmetric Couplers

The cladding-waveguide region of an asymmetric coupler can be simply modelled by an asymmetric two-slab planar waveguide, with a gap separating the two slabs. The slab widths represent the tapered fibre cladding diameters, while the gap represents the degree-of-fusion (a smaller gap corresponding to a greater degree-of-fusion). The slabs and the surrounding medium are taken to have the refractive indices of silica and air respectively.

Assuming that only the two lowest-order modes of the waveguide are excited by the input wave we can calculate their excitation coefficients, and the m.s.r. can be easily calculated from the ratio of these excitation coefficients. The asymmetry in slab widths gives rise to an unequal excitation of the two lowest-order modes by the input wave, directly limiting the coupling efficiency.

Under this model, the m.s.r. increases with decreasing gap width, corresponding to the increase in m.s.r. with increasing degree-of-fusion found in the real couplers of Fig 1. The m.s.r. is found to decrease with the slab width asymmetry, also corresponding to the experimental trend discussed above.

## Conclusion

We have shown that the operation of asymmetric couplers depends not only on the level of asymmetry, but also on the degree-of-fusion of the fibres. It has been shown both experimentally and for a simple slab waveguide model that the maximum power transfer in asymmetric couplers decreases with increasing diameter asymmetry, but increases with increasing degree-of-fusion.

Knowledge of these trends in the behaviour of such couplers allows for more flexibility in their fabrication. For instance, if a coupler fabrication rig always yields the same degree-of-fusion then we require good control (by pre-etching or pre-tapering) over the initial fibre diameters to achieve a given maximum power transfer. On the other hand, if we have two fibres with suitable initial diameters, then control over the degree-of-fusion of the coupler should be sufficient to obtain the required power transfer, without the need to etch or pre-taper the fibres.

## References


1. D.B.Mortimore:
   "Wavelength-flattened fused couplers",
   Electron. Lett. 21, 1985, pp. 742-743.

2. R.G.Lamont, K.O.Hill, D.C.Johnson:
   "Fabrication of fused twin biconical taper single-mode fiber couplers : effect of unequal cladding diameters",
   O.F.C. Tech. Digest, 1985, pp. 78-79.

3. K.O.Hill, D.C.Johnson, F.Bilodeau, S.Faucher:
   "Fuse-pull-and-taper monomode-fiber directional-couplers : coupling mechanisms and pull signature diagnostics",
   O.F.C. Tech. Digest, 1987, p. 116.

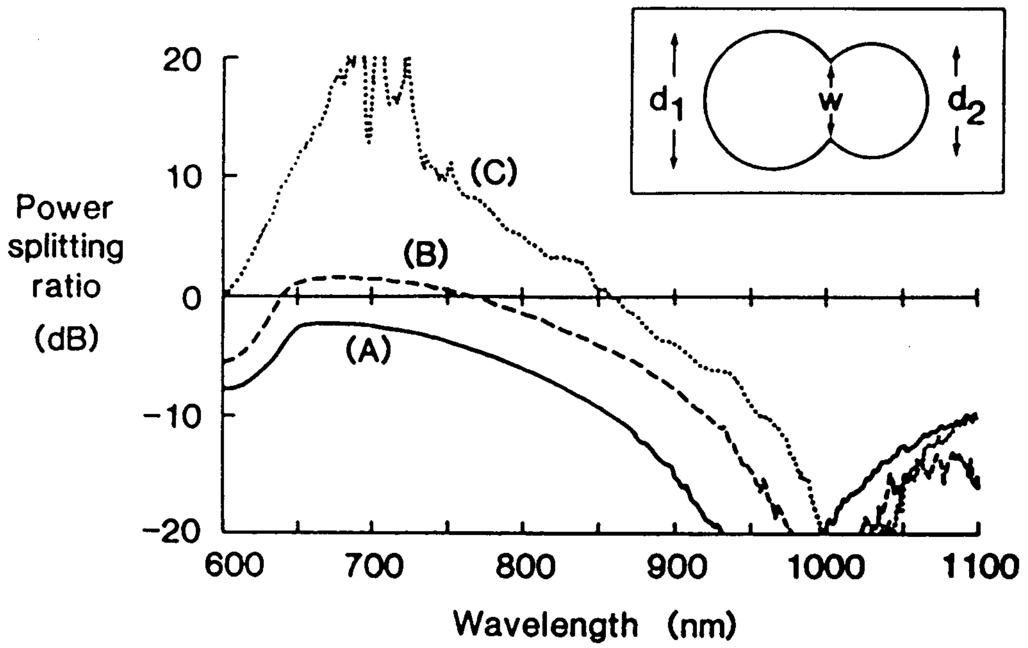


Fig. 1 Spectral power-splitting ratio for different-diameter dissimilar-fibre couplers A with degree of fusion 0.58 and loss 0.05dB, B with degree of fusion 0.72 and loss 0.4dB, and C with degree of fusion 0.83 and loss 0.7dB. Inset: Schematic of the cross-section of an asymmetric oupler; the degree of fusion is $w/d_2$.

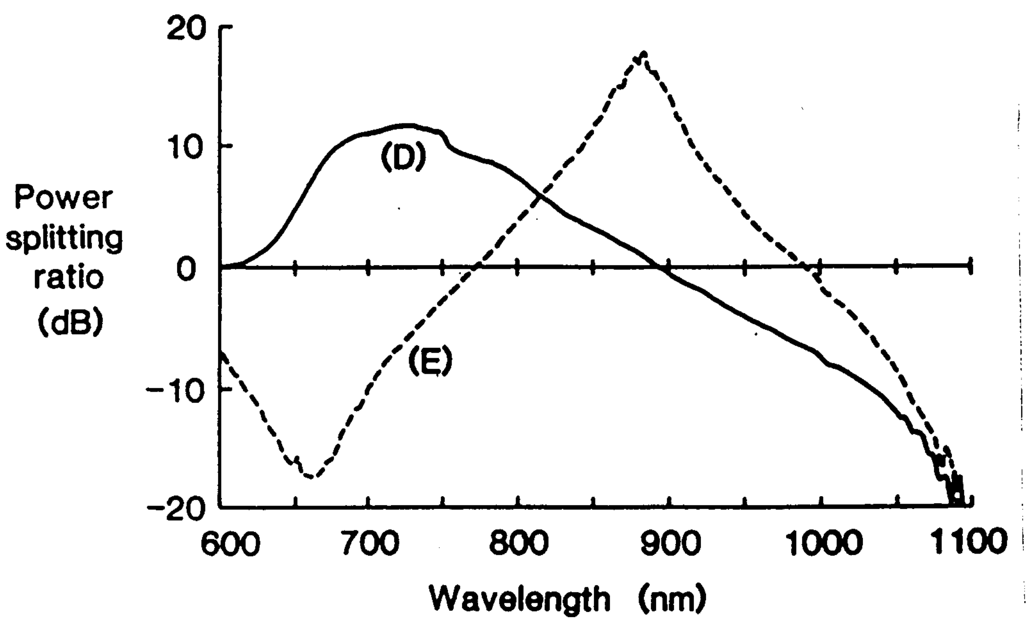


Fig. 2 Spectral power-splitting ratio for same-diameter dissimilar-fibre couplers D and E with degree of fusion 0.60 and loss 0.2dB in each case.