JOINT LOSS IN SINGLE-MODE FIBRES

Indexing terms: Losses, Optical couplers, Optical fibres

The losses arising in a joint between single-mode fibres when both transverse offset and angular misalignment are present have been calculated. It is found that the individual losses are additive only when the defects are small. The total loss depends on the relative directions of the tilt and the plane of polarisation.

Introduction: Losses in single-mode fibre joints arise mainly from the three defects of separation, lateral offset and angular misalignment between the ends of the two fibres. Of these, end separation of itself is not serious in practical splices, and the main problems arise from lateral offset and angular misalignment. The resulting losses are usually calculated[1-3] separately as if the effects were independent. In fact offset and tilt are present simultaneously and it is by no means obvious that the total loss will be the simple arithmetic sum of the two components.

Rigorous calculation of joint loss in terms of the true HE_{11}-mode fields is difficult but a certain degree of simplification is possible. Thus it has been shown[2,3] that the field distribution is almost Gaussian, as evidenced by the attainment of launching efficiencies from a TEM_{00} laser beam of greater than 99%. Thus jointing calculations can be considerably simplified by replacing the HE_{11}-modes of the incoming and outgoing fibres by their transformed Gaussian fields.

Theory: In the following it is assumed that the spot sizes in the two fibres are the same since we have shown[4] that, for a given numerical aperture (NA), the spot size is almost independent of normalised frequency (V) over the range $1{\cdot}8 < V < 2{\cdot}4$. This requires only that the numerical apertures are equal and the core diameters can be quite different within this limitation. End separation is also neglected since its influence can be made small.

As illustrated in Fig. 1 the transverse offset D is normalised to the core radius a and the axis of the incoming fibre makes an angle α with that of the outgoing fibre. The projected rotation angle on the transverse plane and relative to the displacement is ϕ. The corresponding polarisation angle of the HE_{11}-mode is δ. It has been shown that under these conditions the transmission efficiency η through the joint is[2,3]

$$\eta = \frac{\exp[-(D/w)^2]}{w^4\pi^2}\left|\int_0^{2\pi}\int_0^{\infty}\exp\left[-\frac{R^2 - RD\cos(\theta-\delta)}{w^2} - \frac{jnV\alpha}{NA}\{R^2 + D^2 - 2RD\cos(\theta-\delta)\}^{1/2}\cos(\theta-\phi)\right] R\,dR\,d\theta\right|^2 \qquad (1)$$

where w, the normalised spot size of the HE_{11}-mode, is given[2] by

$$w = (0{\cdot}65 + 1{\cdot}62V^{-1\cdot5} + 2{\cdot}88V^{-6})/2^{1/2} \qquad (2)$$

n is the core refractive index and R, θ are the normalised polar co-ordinates.

In the simplified approach referred to above, the loss due to lateral offset T_l is obtained from eqn. 1 by putting $\alpha = 0$ to give

$$T_l = 2{\cdot}17(D/w)^2\,\text{dB} \qquad (3)$$

and similarly the loss due only to angular misalignment ($D = 0$) is

$$T_a = 2{\cdot}17(\alpha w n V/NA)^2 \qquad (4)$$

In these cases T_l and T_a are independent of δ and ϕ.

It has not proved possible to deduce analytically from eqn. 1 whether the total loss T is given by the arithmetic sum of the independent losses T_l and T_a and the double integrals have therefore been evaluated numerically by computer. A normalised frequency $V = 2{\cdot}4$ has been taken, with the angular misalignment normalised to $n\alpha/NA$.

The total loss in Fig. 1*a* as a function of D is given for various ϕ values with $\delta = 0$ and $n\alpha/NA = 0{\cdot}524$. (For $n = 1{\cdot}5$ and $NA = 0{\cdot}1$ this corresponds to $\alpha = 2°$). Fig. 1*b* shows the loss as a function of α for $D = 0{\cdot}6$ and $\delta = 0$, again for a range of ϕ parameters. It can be seen that the loss, as expected, depends strongly on α and D and for the larger misalignments it also varies appreciably with ϕ. The dashed curves in Fig. 1*a* and *b* indicate $T_l + T_a$, from which it may be concluded that $T \approx T_l + T_a$ only at small values of α and D, whereas at larger values T may be appreciably larger, or smaller, than $T_l + T_a$ depending on the orientation ϕ.

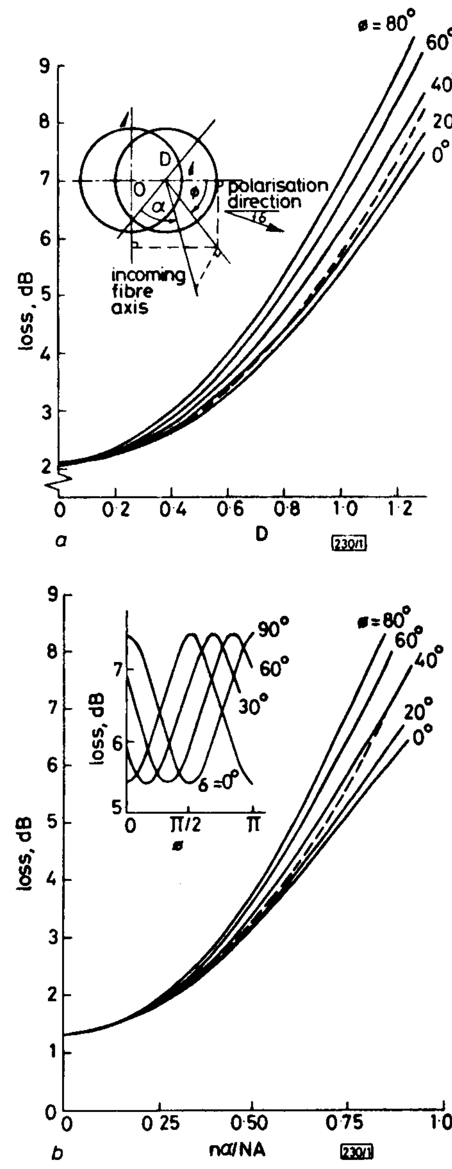

Fig. 1 *Joint loss*

As a function of
(*a*) Normalised offset
(*b*) Tilt angle
for various misalignment directions when $V = 2{\cdot}4$, $n\alpha/NA = 0{\cdot}524$ and $\delta = 0$
The dashed curves indicate $(T_l + T_a)$. The inset to (*a*) shows the co-ordinate system and that to (*b*) illustrates the relative effects of ϕ and δ

The inset to Fig. 1*b* shows how the loss depends on the relative values of ϕ and δ for $D = 0{\cdot}6$ and $n\alpha/NA = 0{\cdot}785$. T(dB) varies sinusoidally with ϕ and, for example, with $\delta = 0$ it is a maximum at $\phi = \pi/2, 3\pi/2$ and a minimum at $\phi = 0, \pi$. However, the direction of the input plane of polarisation δ does not affect the maximum and minimum values of the loss but only the ϕ positions at which these extrema occur. The former require that $\phi - \delta = \pi/2,\ 3\pi/2$ and the latter $\phi - \delta = 0, \pi$. In a practical situation where the variations in ϕ and δ are random, the worst case must be assumed.

The pairs of values of α and D required to cause given losses are illustrated in Fig. 2. Again the dashed curves indicate

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$T_l + T_a$ confirming that $T \approx T_l + T_a$ only for small losses. Finally a good approximation to the total loss is given by the expression

$$T = 3{\cdot}6D^2 + 7{\cdot}6(n\alpha/NA)^2 + 6{\cdot}0(Dn\alpha/NA)^2 \qquad (5)$$

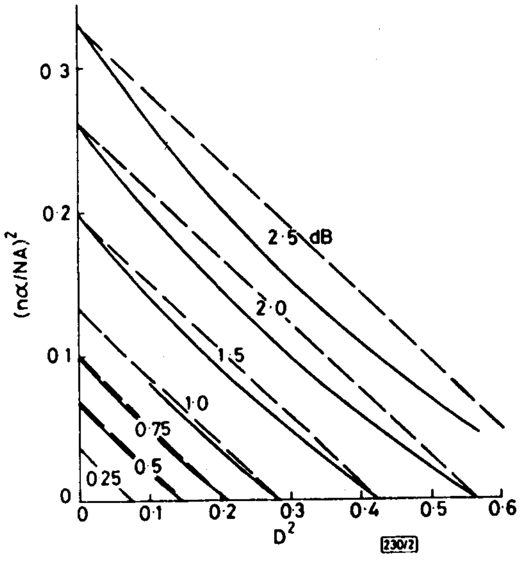

Fig. 2 *Contours of constant joint loss in the α^2/D^2 plane*

The dashed curves are for $T_l + T_a$

Conclusions: The losses arising in a joint between single-mode fibres when both transverse offset and angular misalignment are present have been calculated. It is found that the individual losses are additive only when the defects are small. The total loss depends on the relative directions of the tilt and the plane of polarisation. An approximate equation in terms of D and α is given by eqn. 5.

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