Modal Excitation of Optical Fibers

(3.): Offset Launch with Gaussian Spot

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1. Summary/Outline

This note is a continuation of the June 15, 1998 [1] and June 25, 1998 [2] notes which summarize the background for estimating the mode power distribution P_m from measurements of the nearfield $I(r)$ and give some examples.

The development assumes that the multimode pulse can be characterized adequately as the sum of delta functions corresponding to the individual modes, each weighted by the relative power P_m and shifted by a relative mode delay τ_m:

$$P(t) = \sum_m P_m \delta(t - \tau_m) \qquad [1]$$

The calculations use the modal functions $\psi_m(r)$ and assume that the near field intensity can be expressed as the sum

$$I(r) = \sum_m P_m \psi_m^2(r) \qquad [2]$$

In this SHORT note, following up on some comments by Gair Brown at the Vancouver meeting of the TIA 2.2 task group in June 1998, we go over some examples of an offset launch of a diffraction-limited Gaussian spot. As Gair noted, if we assume complete coupling within a mode group, the predicted $I(r)$ is monotonically decreasing even for this extreme case.

2. Results

The modal power distribution due to an offset Gaussian spot is one example where the initial electric field, overlap integrals, and consequent modal power distribution can be calculated exactly [3]. The offset launch is of particular interest because of its relation to the DMD measurement [4] and to a suggested method of improving multimode bandwidth by exciting only a portion of the modes [5].

Examples were calculated for diffraction-limited Gaussian beams launched into standard 62.5um 2% Δ fiber at 1300nm. The mode power distribution P_m and the near field intensity distribution $I(r)$ were calculated. The width of the spot is optimized so that it couples completely with the fundamental mode for a zero-micron offset.

Figure 3.1 shows the mode power distributions for offsets in the range of 18-23um. These are plotted as P_m vs. mode group number. The numbering scheme used is the natural one which numbers the groups in order of decreasing propagation parameter β. Groups 1,3,5,etc. have a radial mode in them. This launch can be contrasted with an ideal overfill launch (OFL) which puts equal power in all the mode groups.

Figure 3.2 shows the intensity distribution $I(r)$ corresponding to the mode power distributions in figure 3.1, calculated using equation 2. The predicted nearfield distribution has exactly uniform intensity from $r = 0$ out to a specific radius, and the offset position corresponds approximately to the point of maximum slope at the outer edge of the $I(r)$ curve. This shape of $I(r)$ may seem nonintuitive because of the large offset positions shown in figure 3.1 and the negligible power in the fundamental mode. Note the shapes in figure 3.2 need to also be contrasted with the $I(r)$ for an OFL launch, which looks parabolic (see the June 15 note [1]).

Nevertheless, it is somewhat surprising that discrete modes would generate such a flat, uniform I(r). The result was checked in **figure 3.3** for an offset of 20um. It shows the 'cumulative' growth of $I(r)$ as each modal group component is added in. Each ψ_m^2 has waves due to the constituent individual modes, but the P_m are such that the sum is extremely uniform.

3. Discussion and connection to ITM-3 procedure

Although the calculated results in the June 25 note [2] showed that certain mode power distributions can give local minima and maxima in the intensity distribution, the offset launch examples do not show such features. In particular, the intensity distributions are amenable to analysis by the approximate method described in the TIA ITM-3 procedure. In fact, because the derivative $-d/drI(r)$ is used, where the intensity $I(r)$ is uniform in figure 3.3 (from 0 to 15um), the ITM-3 procedure predicts $P(m/M) = 0$.

It has been suggested that the structure seen in nearfields of VCSEL and CD-laser sources is due to incomplete coupling within mode groups and that the modes need to be considered individually. These results suggest that the offset launch may be a useful way to check this, and the intensity distribution can be compared to the near-uniform distributions show in figure 3.2

Note the offset launches shown in this example are made clearer by having the offset large enough that all the launched power is on one side of the center of the fiber.

4. References

[1] Abbott, J.S., "Modal Excitation of Optical Fibers. Estimating the Modal Power Distribution", *TIA 2.2tg Draft Notes* June 15, 1998.

[2] Abbott, J.S., "Modal Excitation of Optical Fibers. Initial Results: Calculation of Modal Power Distribution", *TIA 2.2tg Draft Notes* June 25, 1998.

[3] see, for example, Saijonmaa, J., et al., "Selective Excitation of Parabolic-index Optical Fibers by Gaussian Beams", *Applied Optics* **19** no. 14, 15 July 1980, pp.2442-2452.

[4] Marcuse, D., *Optical Fiber Measurements.* New York: Academic Press, 1981. (p.288 ff.)

[5] Raddatz, L., et al., "An Experimental and Theoretical Study of the Offset Launch Technique for the Enhancement of the Bandwidth of Multimode Fiber Links", *J. Lightwave Technology* **16** no. 3, March 1998, pp. 324-331.

Figure 3.1

P_m for various offset launches

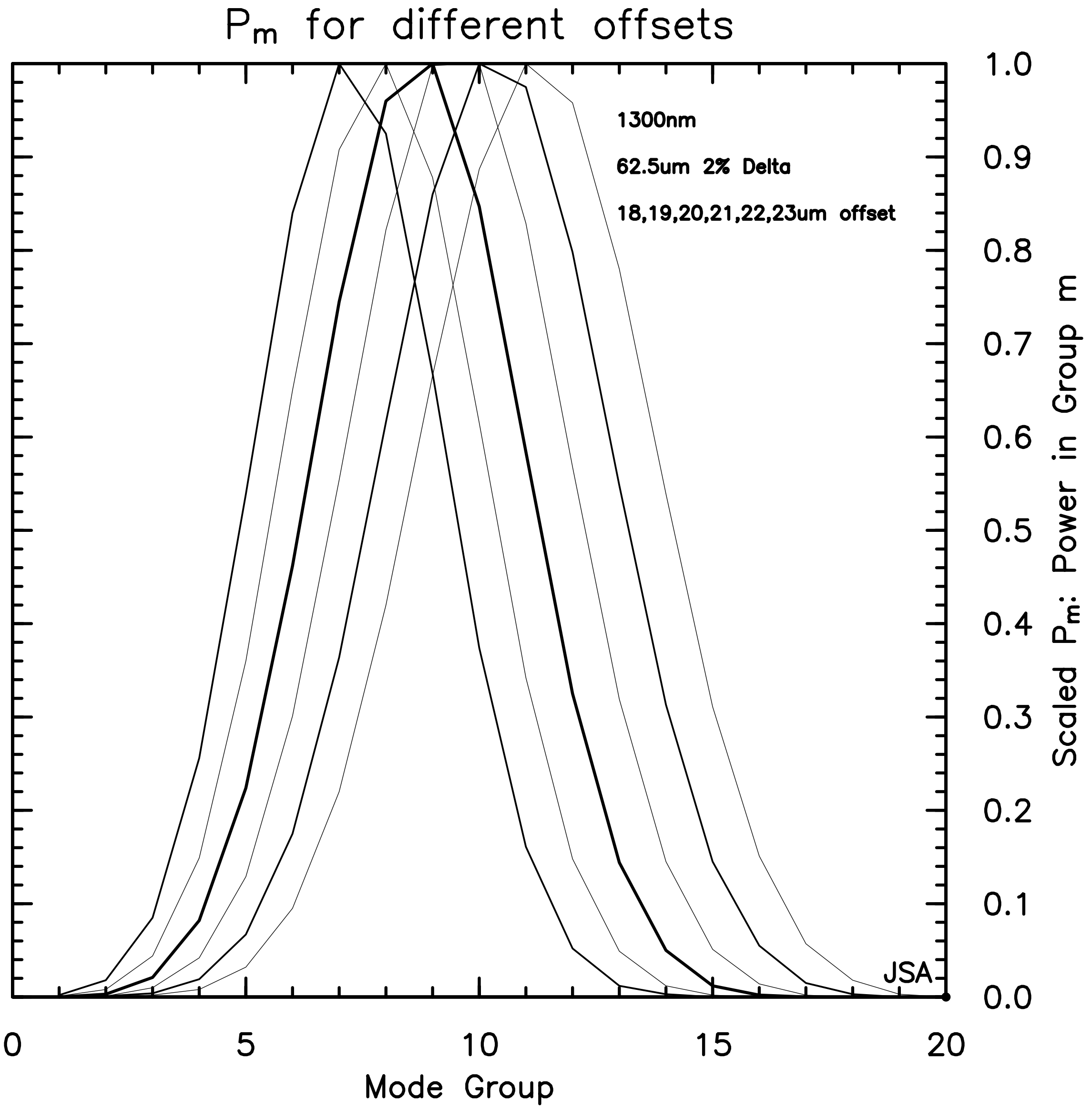

Figure 3.2
I(r) corresponding to the offsets in figure 3.1

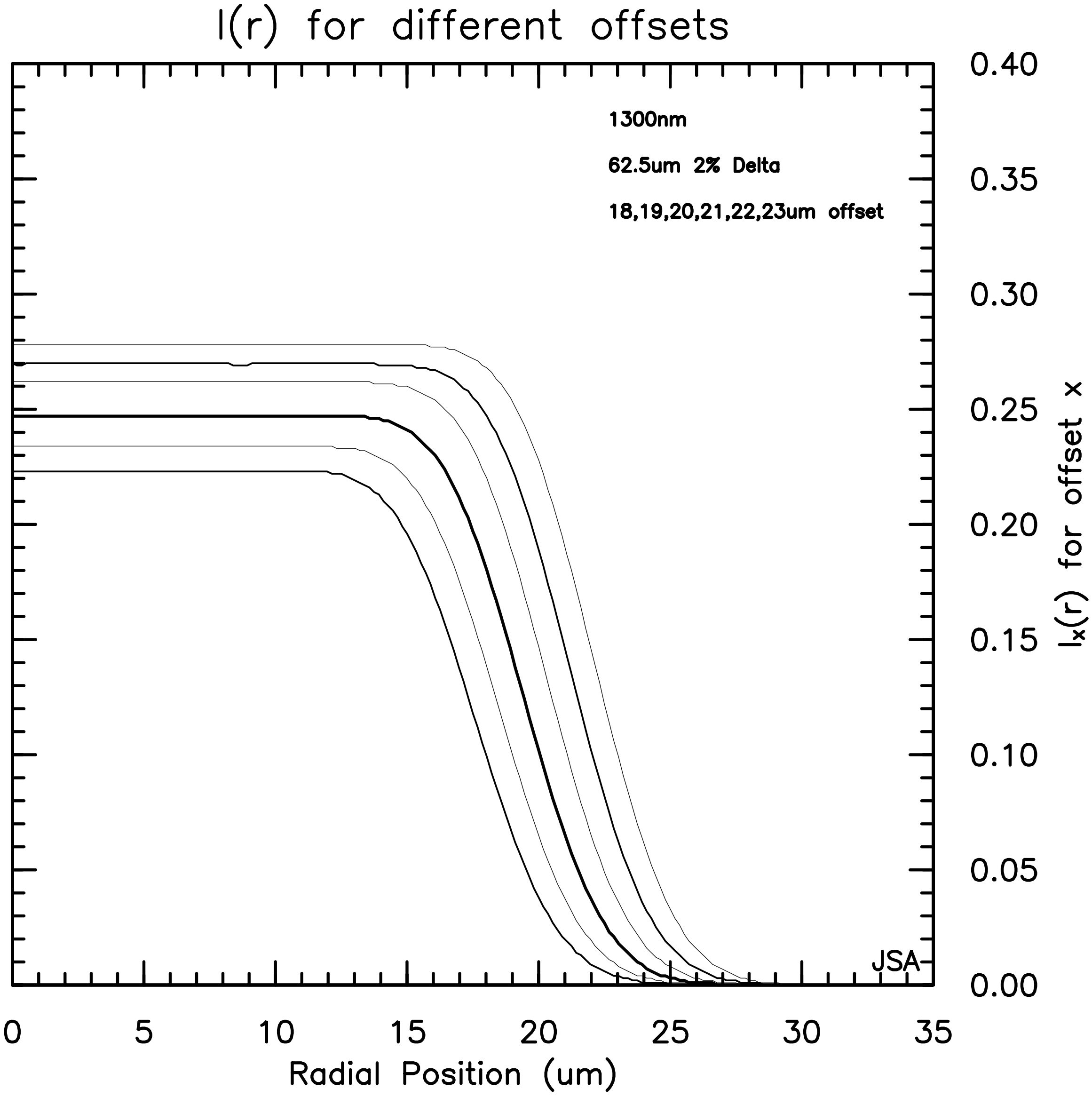

Figure 3.3

Each curve is the cumulative I(r)
as an additional mode group is added