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Mode-cleaning with diaphragms

Aim

The scattered light, produced by the small defects of the mirrors, if not captured by the baffles, will propagate as non-TEM00 modes which will not recombine as a dark fringe on the beam splitter and will thus be strongly transmitted toward the detection bench. It is foreseen to eliminate this spurious light using a mode-cleaner on the detection bench. It has been suggested that some diaphragms can eliminate this unwanted light[1]. It is the goal of this note to evaluate to which extend these parasitic modes can be eliminated using simple diaphragms.

Generalities

The E-field pattern of a gaussian mode TEM_{mn}, at a distance z from the minimum waist and at a position (x,y) from the axis, it is given by[2]:

$$\mathcal{E}_{m,n}(x,y,z) = \mathcal{E}_m(x,z) \times \mathcal{E}_n(y,z)$$

where $\mathcal{E}_m(x,z)$ is given by:

$$\mathcal{E}_m(x,z) = (\tfrac{2}{\pi})^{\frac{1}{4}} (\frac{\exp[j(2m+1)\psi(z)]}{2^m m! w(z)})^{\frac{1}{2}} H_m(\frac{\sqrt{2}x}{w(z)}) \exp(-jkz - j\frac{kx^2}{2R(z)} - \frac{x^2}{w^2(z)})$$

H_m is the Hermite polynomial of order m, $k = 2\pi/\lambda$ is the usual wave propagation factor, $w(z)$ is the waist at distance z and $\psi(z)$ is the Guoy phase shift

$\psi(z) = \tan^{-1}(\frac{z}{z_R})$ where z_R is the Rayleigh range: $z_R \equiv \frac{\pi w_0^2}{\lambda}$, w_0 is the minimum waist (at z=0).

The light power distribution is thus given for the mode TEM_{mn} by:

$$P_{m,n}(x,y,z) = \mathcal{U}_{m,n}(x,y,z) \times \mathcal{U}_{m,n}(x,y,z)^*$$

Effect of a single circular diaphragm

This light power distribution is illustrated on fig1 where is shown the truncation effect of a circular diaphragm (radius = two waist) on a $TEM_{1,2}$ mode. The fraction of power passing through the diaphragm is given by:

$$R_{m,n}(z) = \frac{\iint\limits_{Aperture} P_{m,n}(x,y,z)dxdy}{\iint\limits_{\infty} P_{m,n}(x,y,z)dxdy}$$

Nota: with this normalization, we have $\iint\limits_{\infty} P_{m,n}(x,y,z)dxdy = 1$

On fig2 is illustrated the evolution of R for different modes number as a function of the radius of a circular diaphragm centred on the beam axis, if the diaphragm radius is a, the attenuation factor for the $TEM_{0,0}$ mode is given by $R = 1. - e^{-2(\frac{a}{w})^2}$ as shown on the graph, the lines joining the other calculated points are just there to guide the eye. From this graph, we see that in order to remove a significant amount of power from unwanted modes, a rather small aperture diaphragm is needed. On fig3 we show the comparative effect of a cut by a circular aperture of radius

$$r = w\frac{\pi}{2}$$

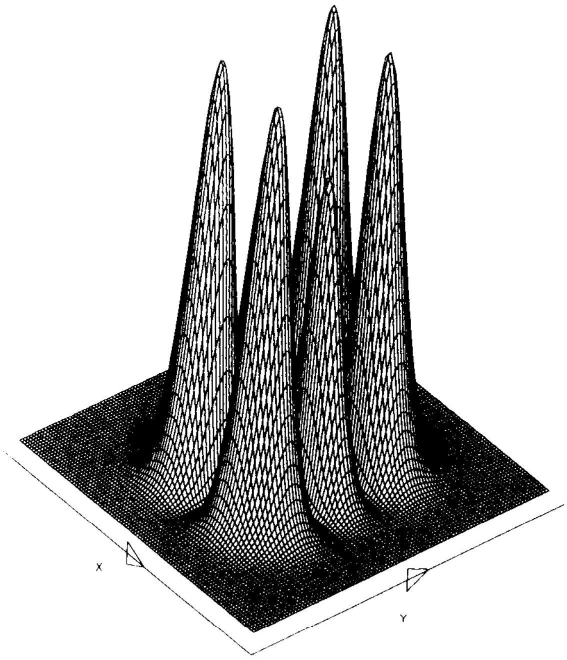
which is usually considered as a limit under which strong diffraction effects occur.

Finally we have computed the attenuation factor R, for symmetrical modes TEM x,x , passing through a circular aperture of radius $r = w\frac{\pi}{2}$, this attenuation is plotted, as a function of x on fig4. The shape is well described by:

$$R = 0.032 + \frac{0.43}{x - 1.41}$$

it shows a quite ineffective attenuation, at x=10 we have R=8.2% and when extrapolated at x=16 ,R=6.1%.

We conclude that a single diaphragm cannot be considered as a serious mean of cleaning out unwanted modes from a $TEM_{0,0}$ beam.



TEM $_{1,2}$

No diaphragm

TEM $_{1,2}$

After a diaphragm
of radius 2 waist

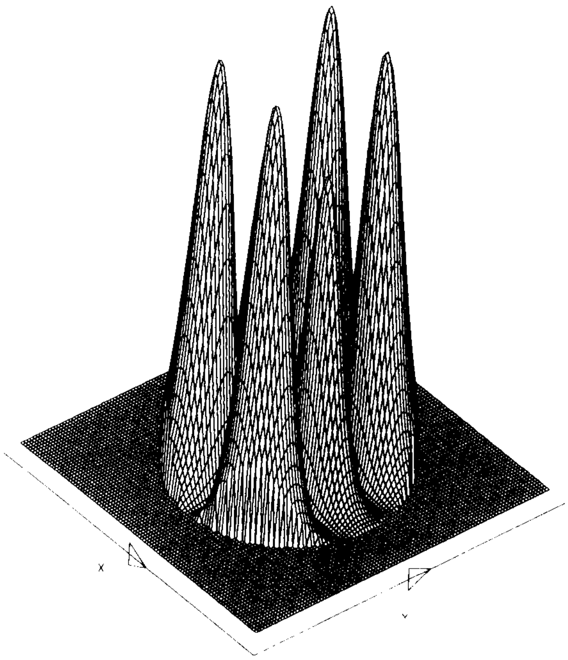
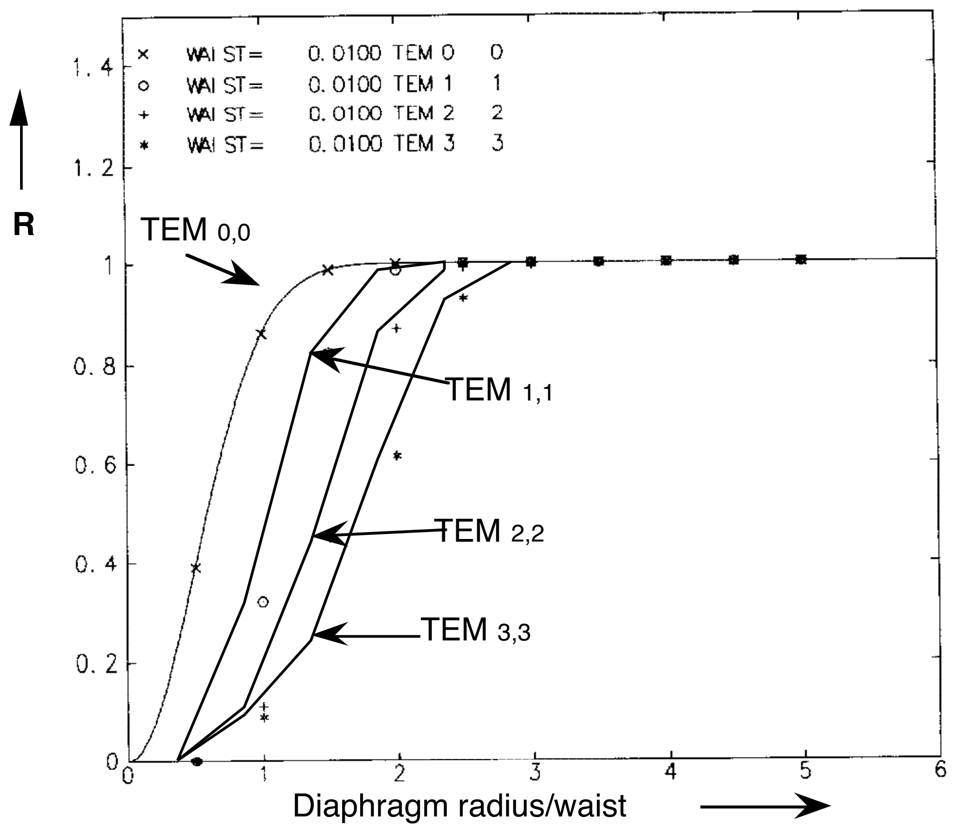


Fig 1



R
WAI ST= 0.0100 TEM 0 0
WAI ST= 0.0100 TEM 1 1
WAI ST= 0.0100 TEM 2 2
WAI ST= 0.0100 TEM 3 3
TEM 0,0
TEM 1,1
TEM 2,2
TEM 3,3
Diaphragm radius/waist

FIG 2

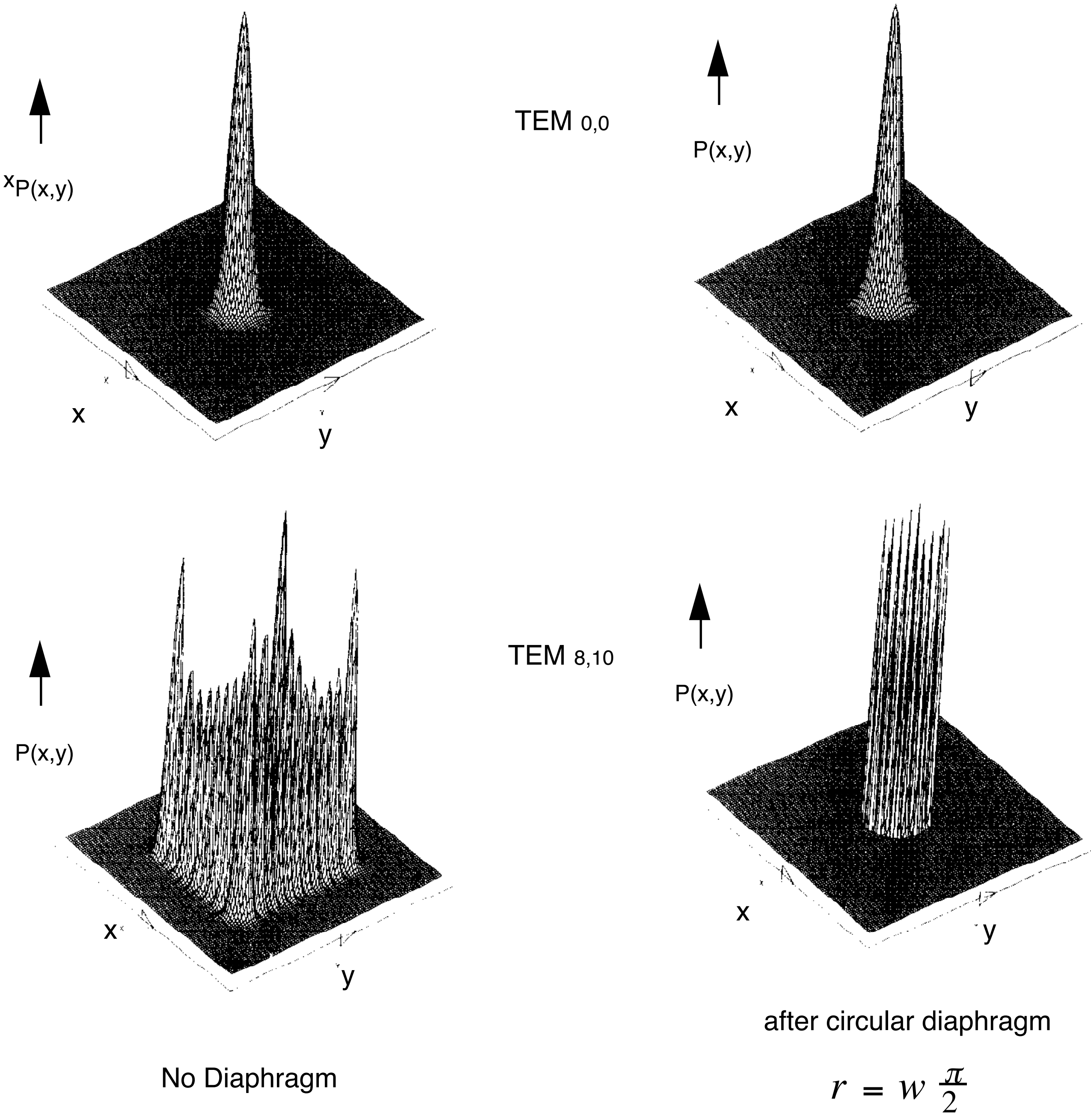

TEM 0,0
P(x,y)
x
y
TEM 8,10
P(x,y)
x
y
No Diaphragm
after circular diaphragm
$r = w \frac{\pi}{2}$

Fig 3

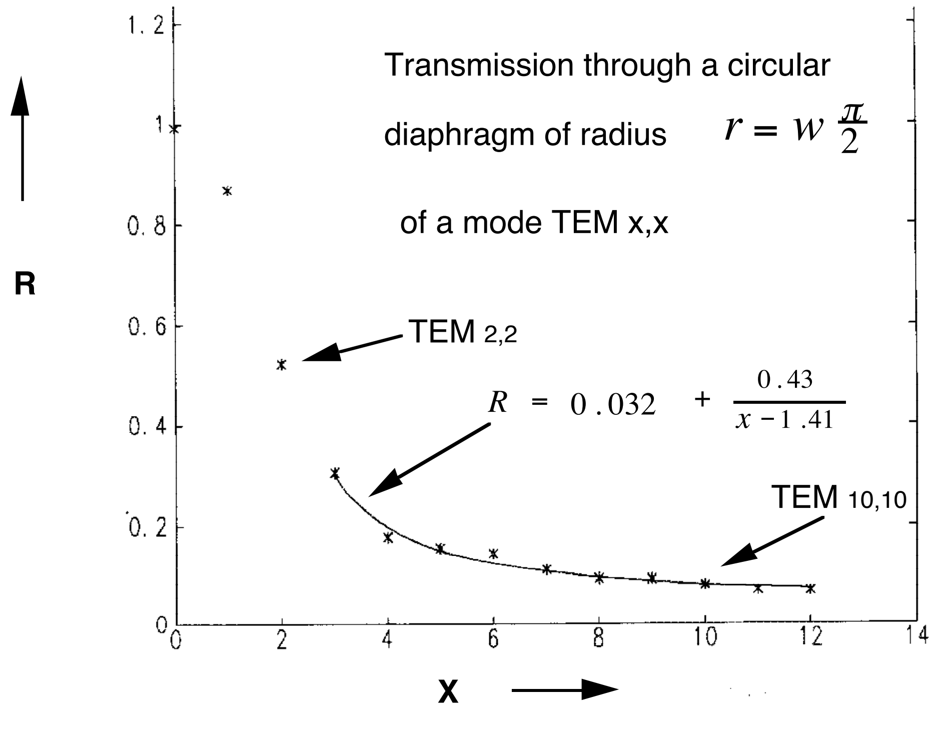


Fig 4

Effect of a multi-diaphragm system

Since a single diaphragm is inefficient, it might be conceived that a combination of diaphragms, thanks to interferences effects, might nevertheless eliminates high modes. In order to test this idea, using the SIESTA simulation program, we have investigated the combined effect of several diaphragms. The principle is sketched on fig5, a laser beam of mode TEM x,y is attenuated using a first circular diaphragm of radius a1, a second and a third circular diaphragm (radius a2 and a3) are located at distance z2 and z3. The radius a1,a2,a3 are adjusted (as a function of their distance z) in order to have a value of $4w$ where w is the waist of the TEM0,0 mode, this value of $4w$ has been chosen in order to avoid spurious diffraction effects on the wanted TEM 0,0 beam.

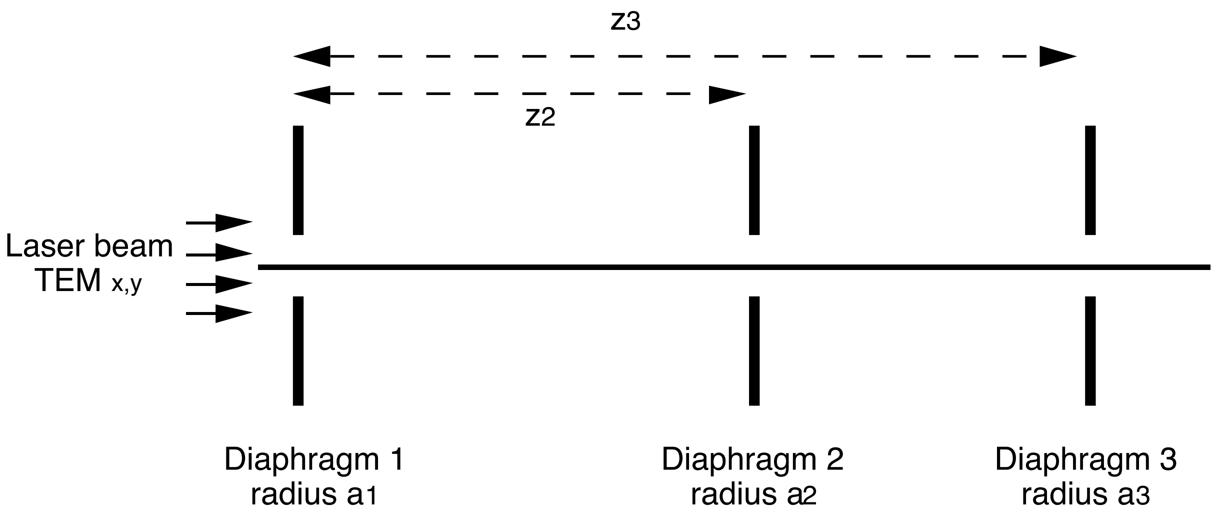


FIG 5

The results of this simulation is summarized on fig6 where we show the attenuation, as a function of the position of diaphragm 2, of the input beam.

Conclusion

From this results, we see that low modes are almost not attenuated and we conclude that combining several diaphragms does not help in a significative way in cleaning the unwanted high modes. The scheme suggested by Meers[1], might prove useful if tuned toward the elimination of a given mode but has no chance to work as a serious multi-mode cleaner. We suggest to install on the detection bench several diaphragms in order to shield from the scattered light, their effect will be welcome in the mode-cleaning process but they can in no way be considered as effective mode-cleaners.

Power traversing diaphragm 2 and 3 versus position of diaphragm #2

Input power = 1 Watt

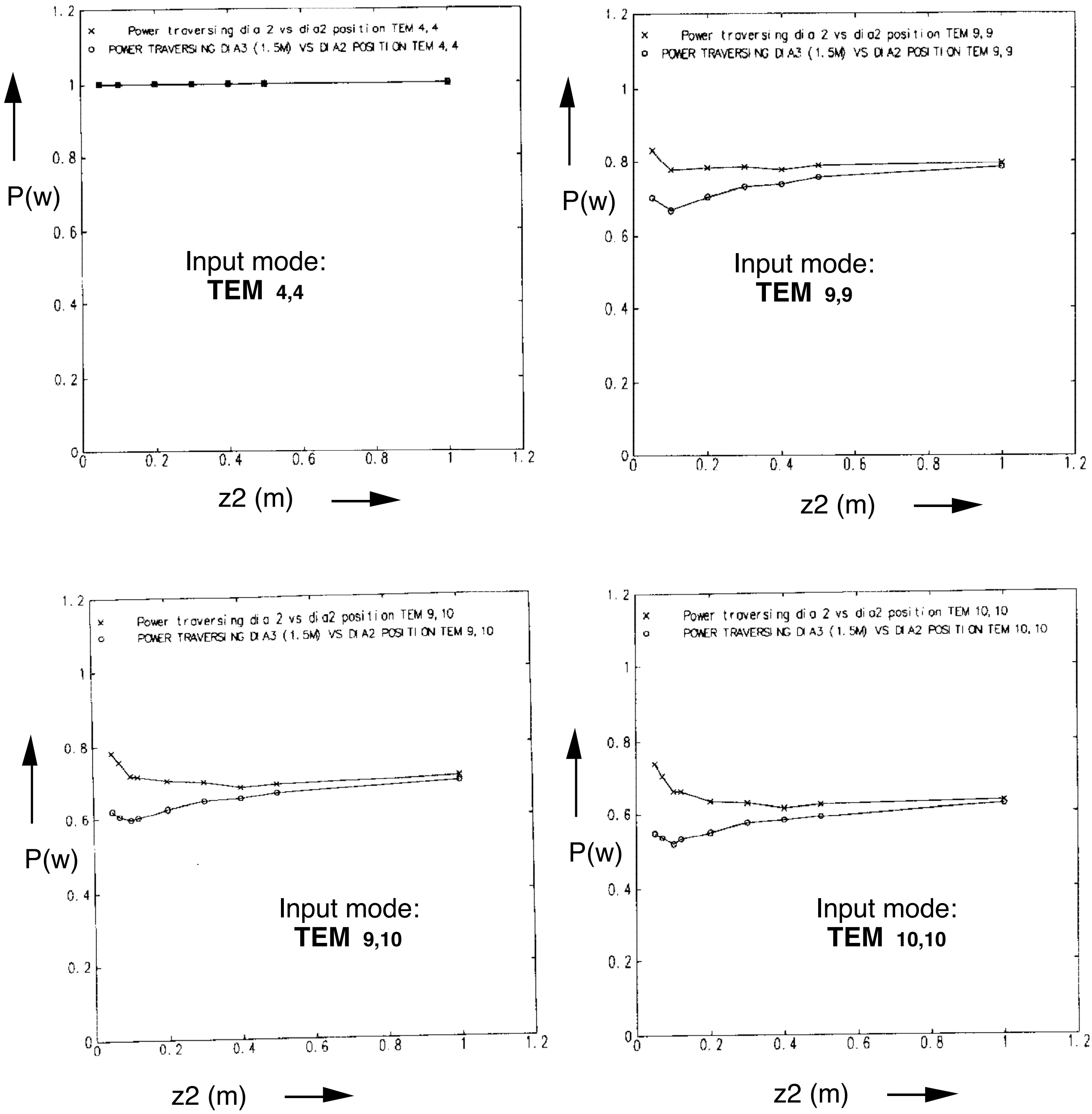


FIG 6

References:

1)- B.J. Meers
Optics Communications 47(1983)237
2)- The notations used are those of Siegman in
LASERS Anthony E. Siegman
University Science Book Mill Valley, California (1986)