Measuring the Modal Properties of Multimode Fibres

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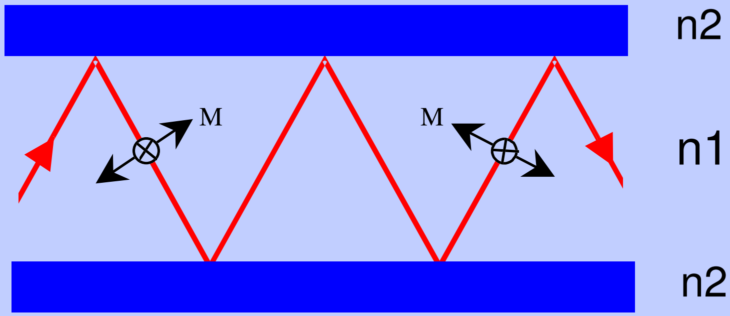
Structure of Talk

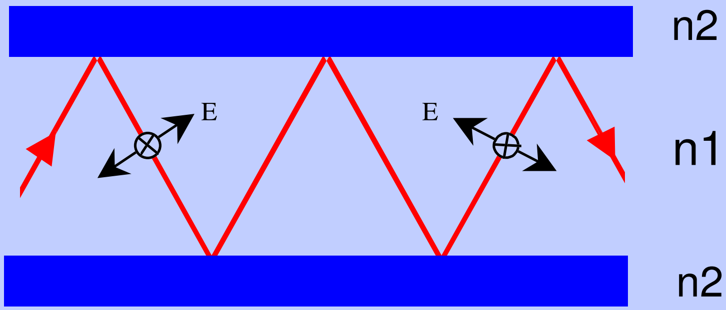
- Basic mode theory
- Measuring the mode distribution
- Measurement results

Planar waveguide:

$TE_{0,m}$ modes



$TM_{0,m}$ modes



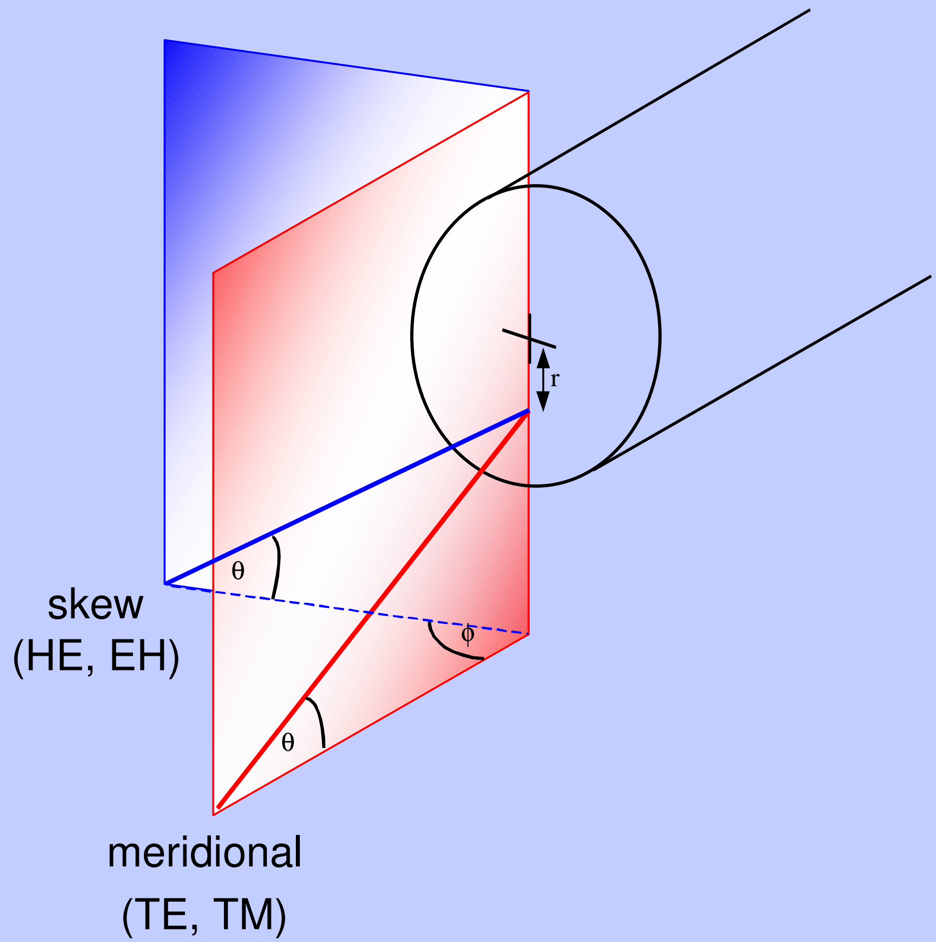
n1>n2

Circular fibre:

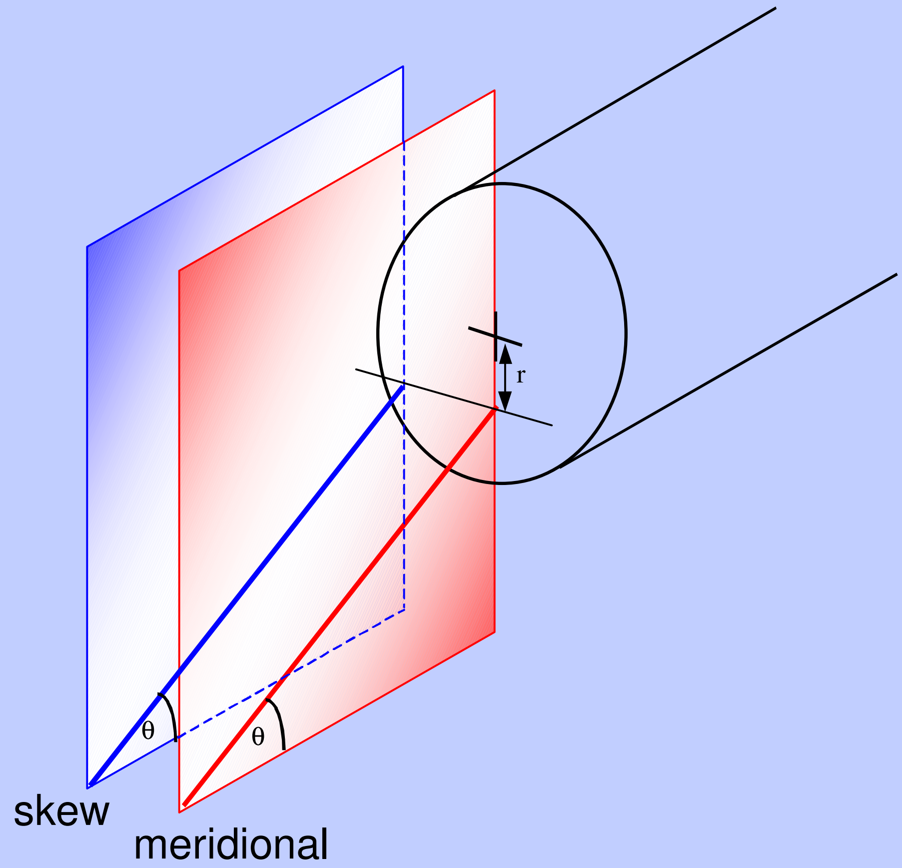
Also has helical (skew) modes,

$HE_{n,m}$ (transverse magnetic dominates)
$EH_{n,m}$ (transverse electric dominates)

There are many more skew modes than meridional modes.



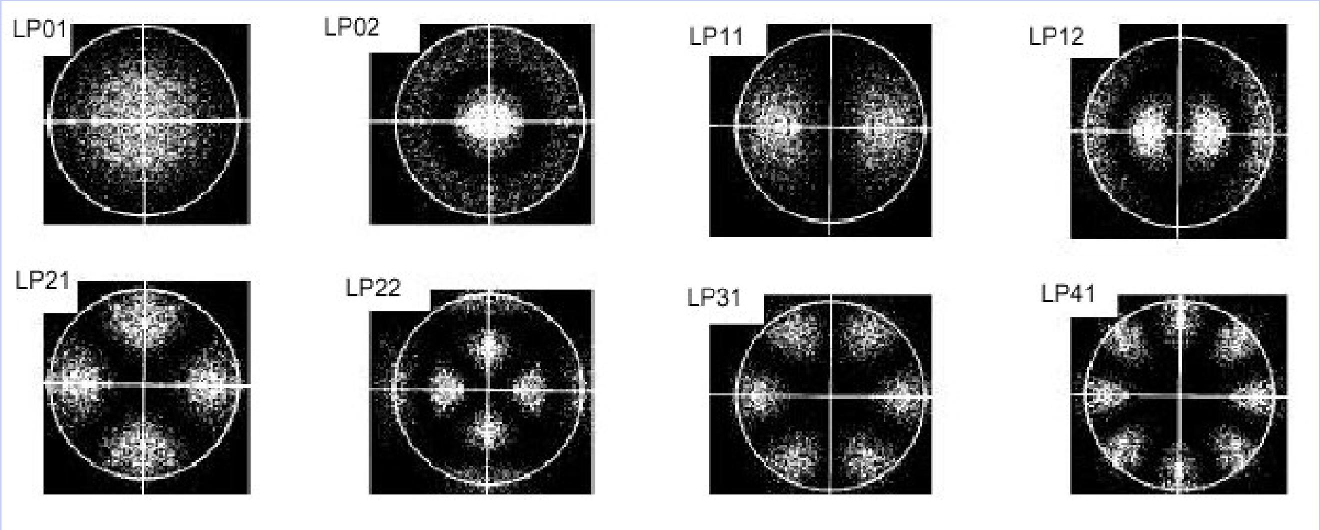
Leaky modes



Leaky modes exceed the local numerical aperture

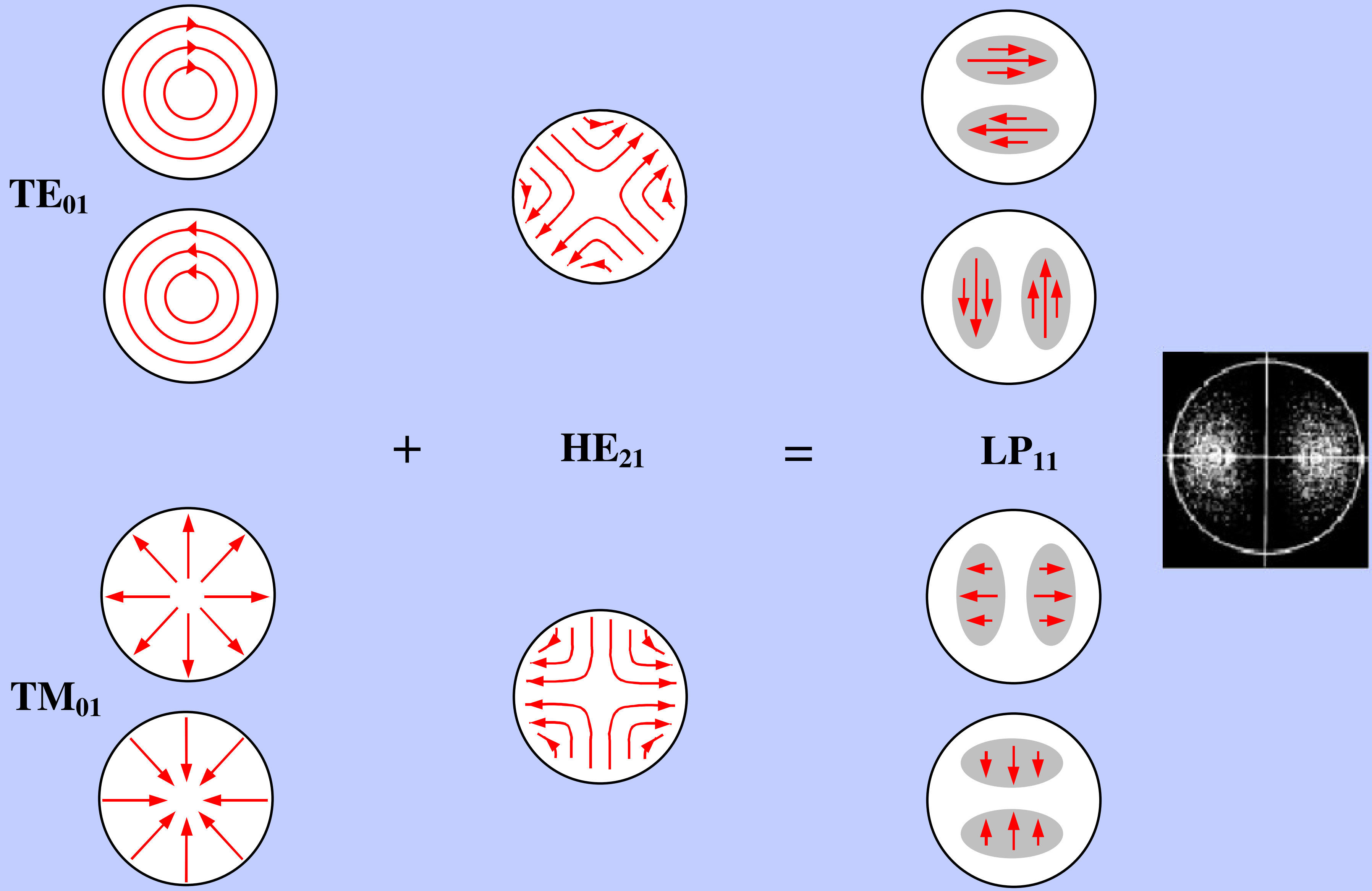
Mode properties

- Each Mode has its own propagation constant (time of flight).
- Groups of modes have the same propagation constant (degenerate).
- These groups are combined to form new modes, called $LP_{n,m}$ modes, which are Linearly Polarised.



Number of azimuthal peaks = 2n, number of radial peaks = m

Example: Four-fold Degeneracy of LP11 mode



Modal Parameters of Graded Index Fibre

Normalised frequency: (V-number) $V = \frac{2 \cdot \pi}{\lambda} \cdot a \cdot NA$

a= radius

NA = numerical aperture

Total number of modes: $N_m \approx \frac{V^2}{4}$

Number of mode groups: $N_g \approx \frac{V}{2}$

(All modes in a group have the same propagation constant)

Example:

$a = 25\text{um}$

$NA = 0.21$

$\lambda = 850\text{nm}$

$V = 38.8$

$N_m = 376$

$N_g = 19$

Mode Group Designation

β/k	1.4713	1.4705	1.4697	1.4690	1.4682	1.4674	1.4666	1.4659	1.4651
Mode group number	1	2	3	4	5	6	7	8	9
Modes per group	2	4	6	8	10	12	14	16	18
$LP_{n,m}$	01	11	21	31	41	51	61	71	81
			02	12	22	32	42	52	62
					03	13	23	33	43
							04	14	24
									05

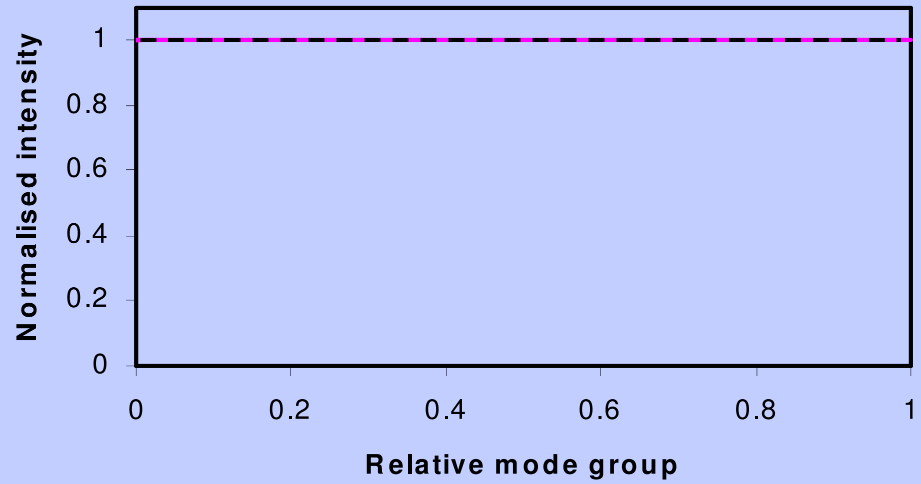
50um graded fibre, 0.21 NA,

n_{core}=1.472, n_{clad}=1.457,

850nm

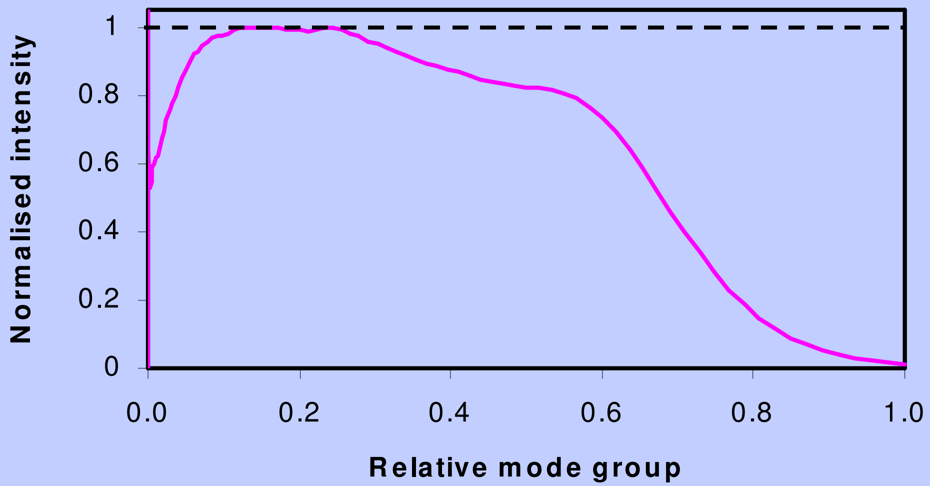
How to measure the mode distribution ...

Introducing the Mode Transfer Function



All modes equally excited by Lambertian source

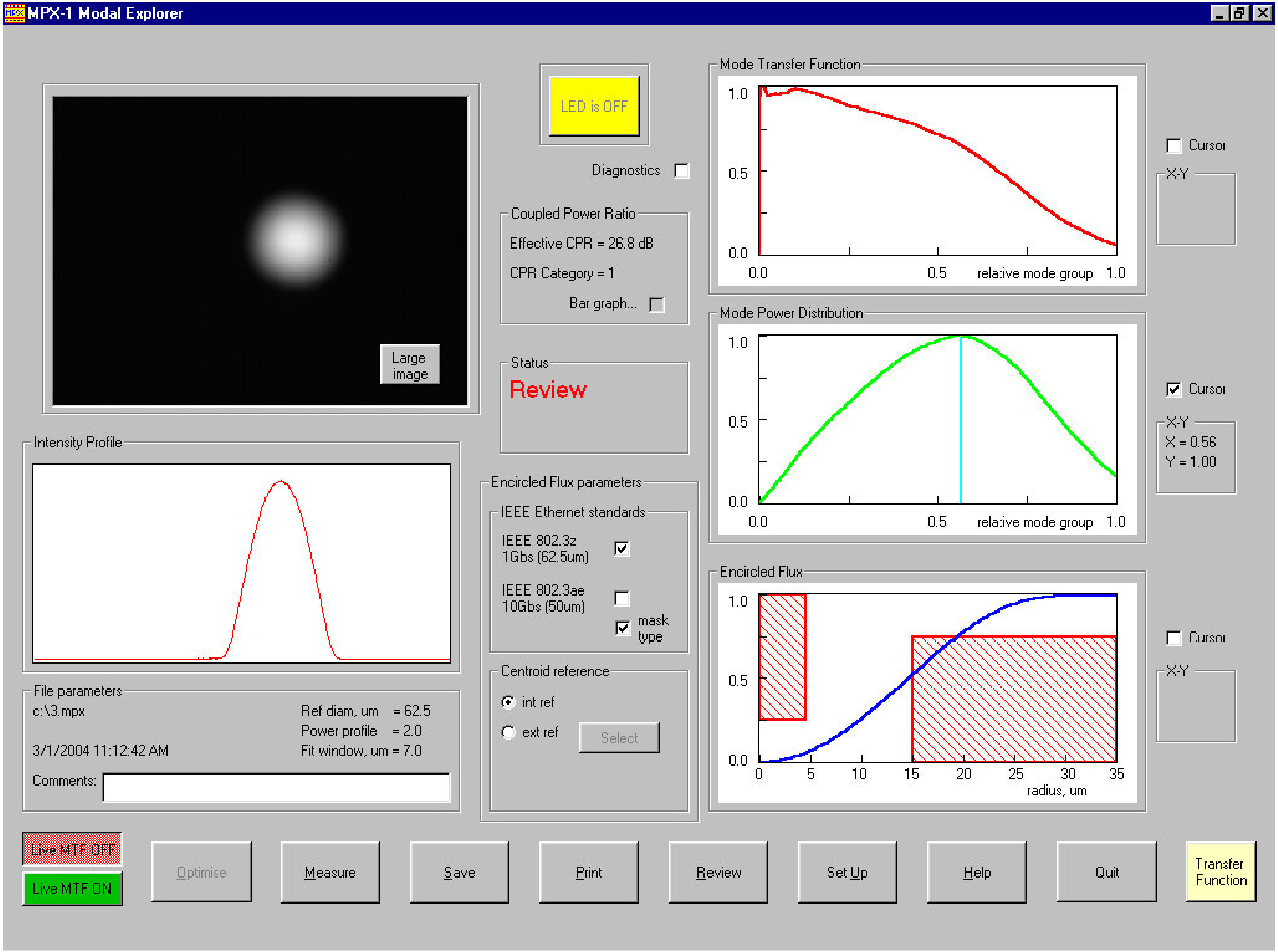
- fully-filled fibre



Middle-order modes preferentially excited

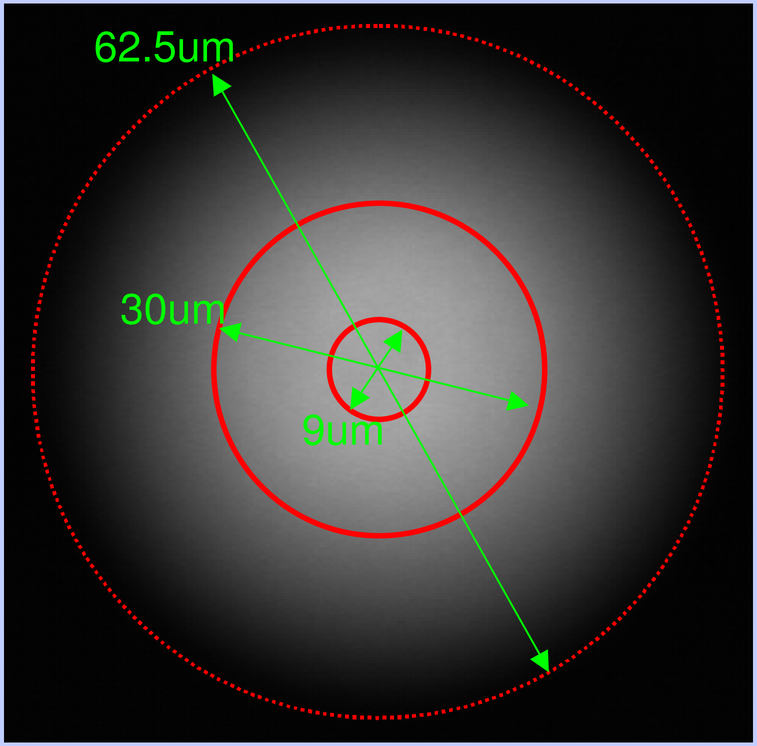
- under-filled fibre

MPX-1 Modal Explorer



MPX-1 Modal Explorer
LED is OFF
Diagnostics
Coupled Power Ratio
Effective CPR = 26.8 dB
CPR Category = 1
Bar graph...
Status
Review
Large image
Intensity Profile
File parameters
c:\3.mpx
3/1/2004 11:12:42 AM
Ref diam, um = 62.5
Power profile = 2.0
Fit window, um = 7.0
Comments:
Encircled Flux parameters
IEEE Ethernet standards
IEEE 802.3z 1Gbs (62.5um)
IEEE 802.3ae 10Gbs (50um)
mask type
Centroid reference
int ref
ext ref
Select
Mode Transfer Function
1.0
0.5
0.0
0.0
0.5
relative mode group
1.0
Cursor
X-Y
Mode Power Distribution
1.0
0.5
0.0
0.0
0.5
relative mode group
1.0
Cursor
X-Y
X = 0.56
Y = 1.00
Encircled Flux
1.0
0.5
0.0
0 5 10 15 20 25 30 35
radius, um
Cursor
X-Y
Live MTF OFF
Live MTF ON
Optimise
Measure
Save
Print
Review
Set Up
Help
Quit
Transfer Function

Encircled Flux - IEEE Gigabit Ethernet Standard,



1 Gbs 62.5um (IEEE 802.3z) :

<25% of power inside 9um circle

>75% of power inside 30um circle

10 Gbs 50um (IEEE 802.3ae) :

<30% of power inside 9um circle

>86% of power inside 38um circle

How the MPX-1 works.

Near-field intensity profile:

$$I(r) \propto \int_{f(r)}^{1} MTF(m) \cdot dm$$

where: MTF(m) is the mode transfer function

m is the normalised mode group number

f(r) is the profile function of power-law fibre

Inverting gives:

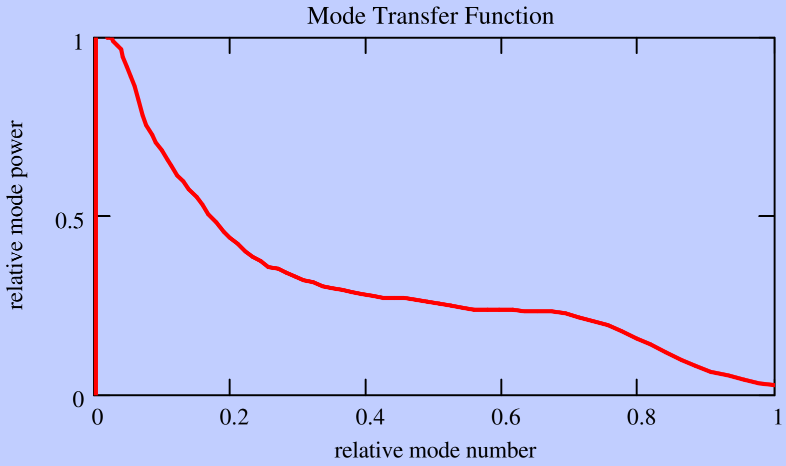
$$MTF(m) \propto \left[\frac{dI(r)}{dr} \Big/ \left(\frac{r}{a} \right)^{\alpha - 1} \right]_{m=f(r)}$$

where: $f(r) = \left(\frac{r}{a} \right)^{\alpha}$

(Calzavara, M., Electronic Letts., pp543-545, v.17, no.15, 1981)

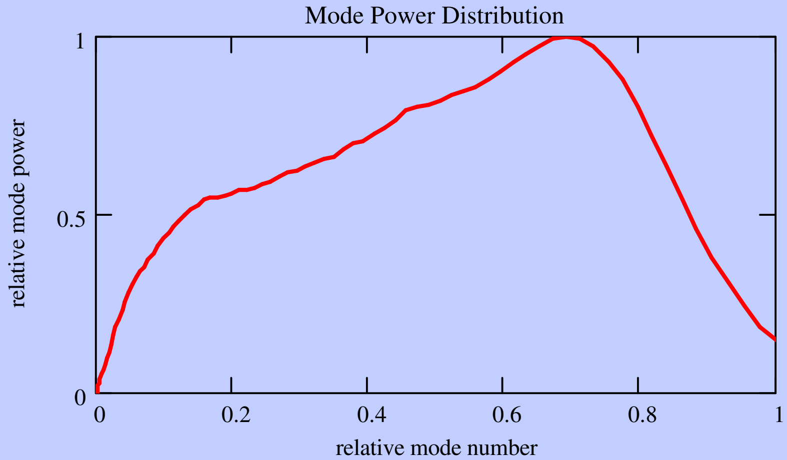
How the MPX-1 works.

Example of MTF(m):

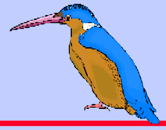


Mode Power Distribution:

$$MPD(m) \propto MTF(m) \cdot m$$



Assumptions for the Mode Profiling Method



- Modes within a mode group carry the same power.

  - strong coupling generally occurs between modes in a degenerate mode group.

- Large number of modes launched (geometrical approximation)

  - but take care with leaky mode contribution.

- Random phases between the propagating modes.

  - use incoherent (wideband) source or ‘shaking’ to avoid speckle noise.

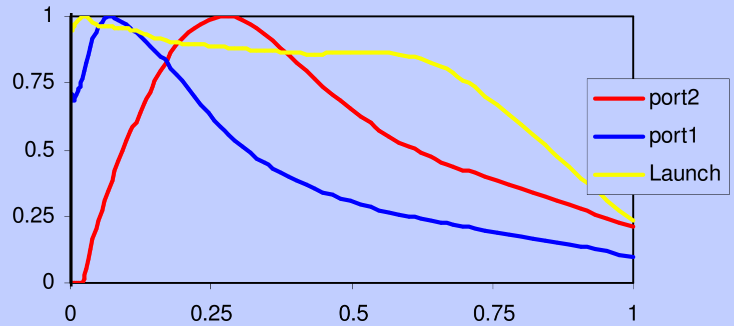
Examples of mode distribution measurements...

Couplers/splitters

50-50 coupler

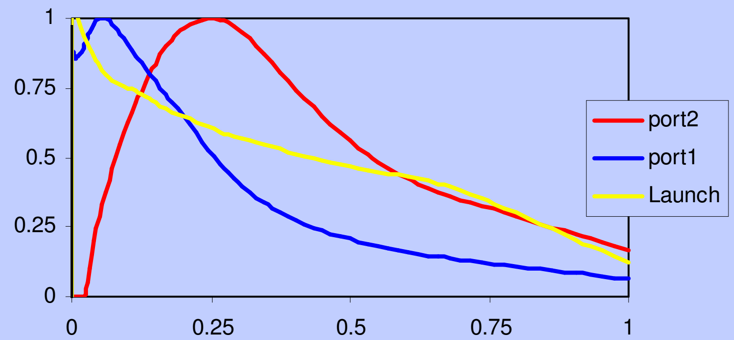
Split ratio port1/port2

Well-filled launch



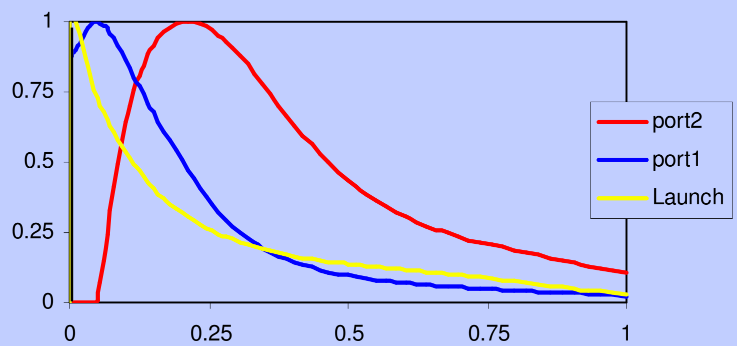
1.12

Medium-filled launch



1.17

Under-filled launch



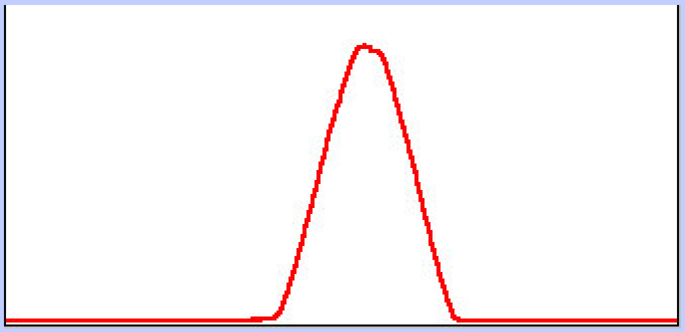
1.35

95-5 coupler

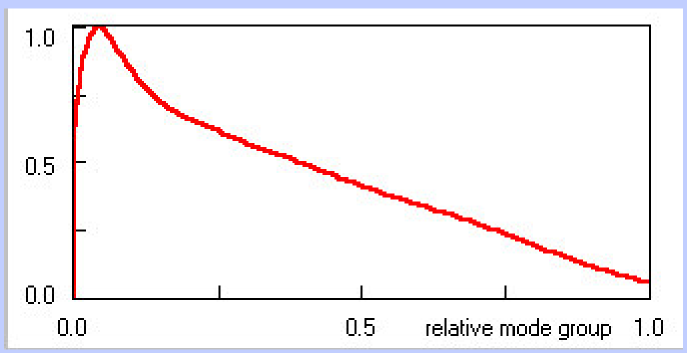
95% port (through-path)	5% port (cross-path)

95% port (through-path)

near field

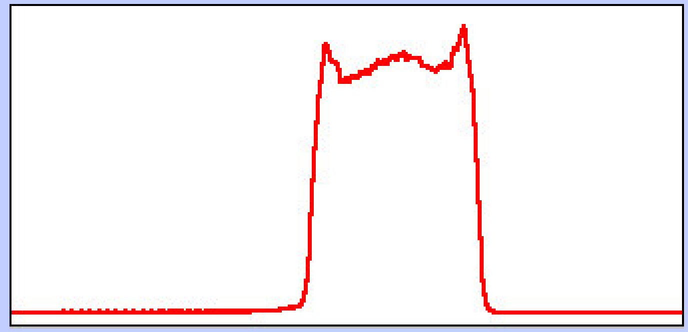


MTF

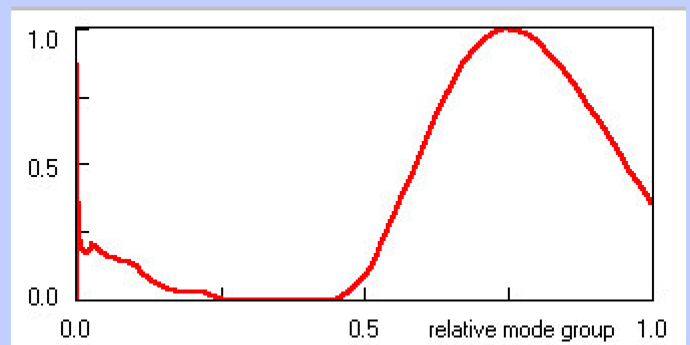


5% port (cross-path)

near field

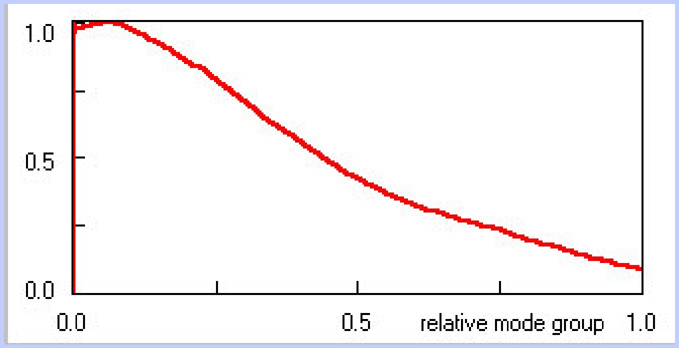


MTF

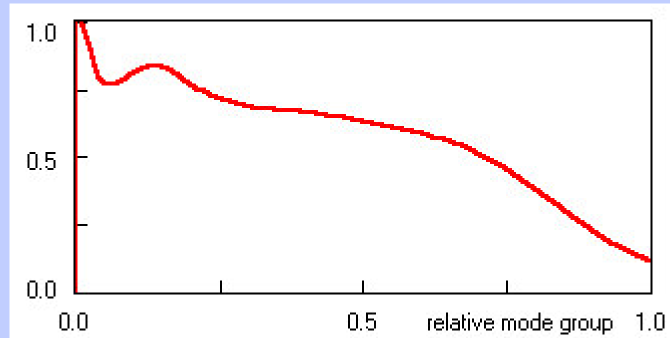


Commercial LED Sources

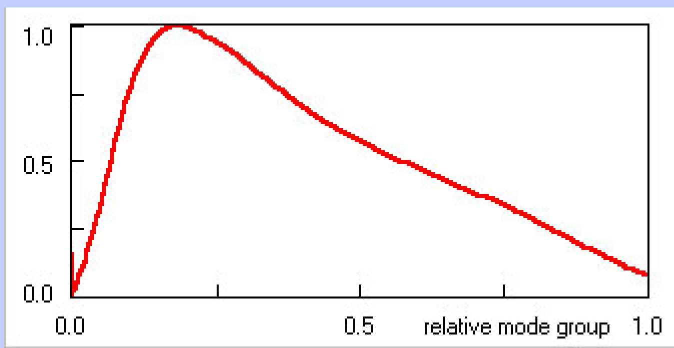
Commercial LED Sources



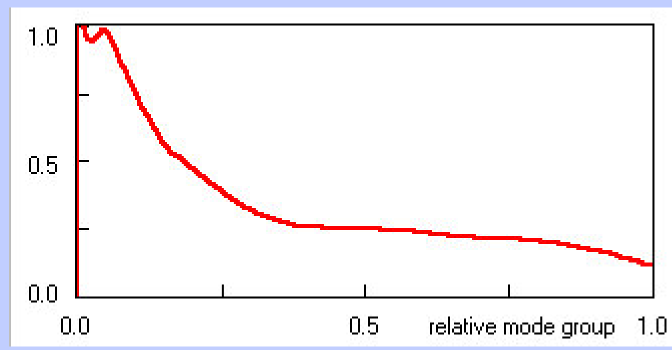
source A



source B



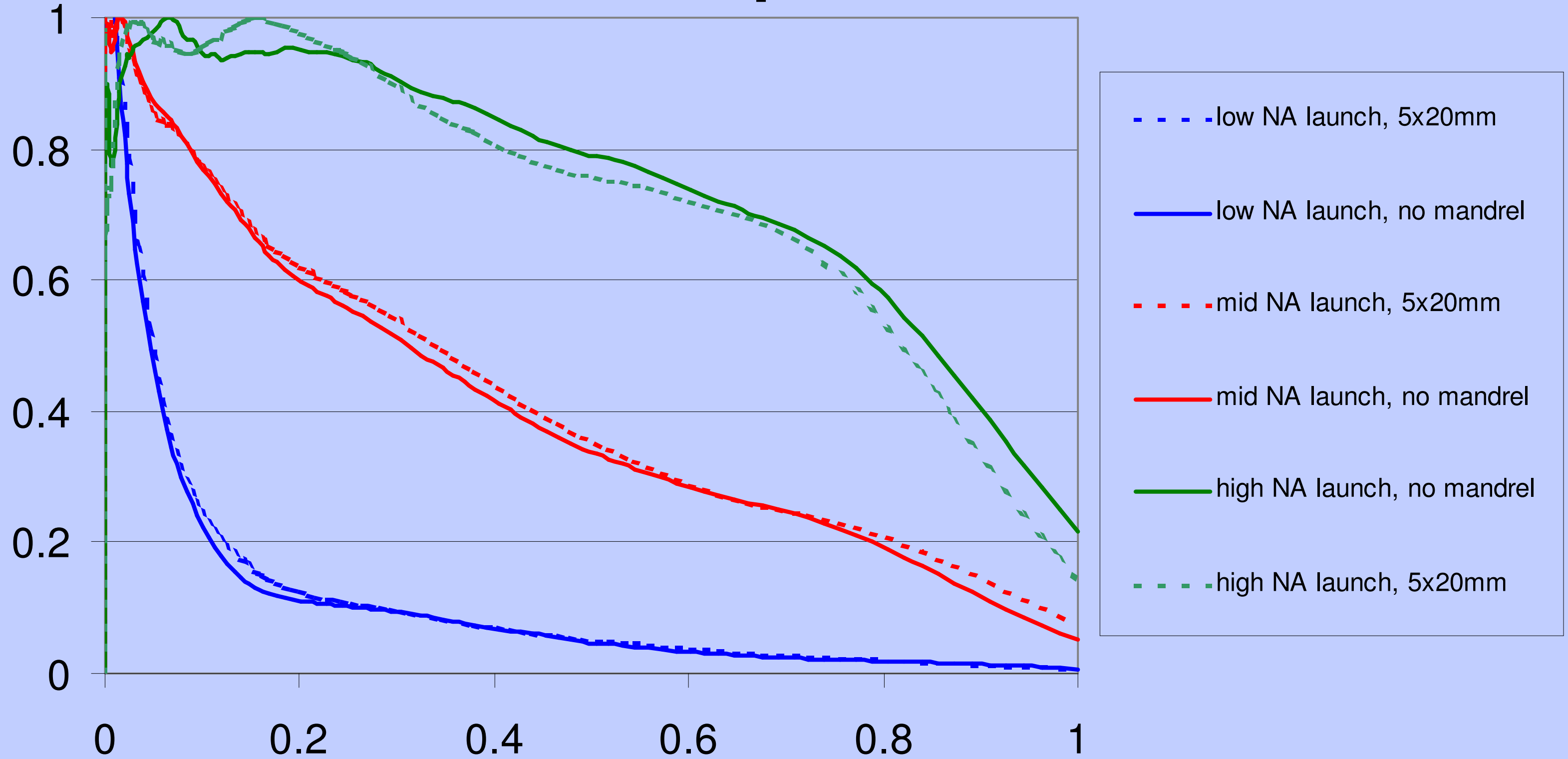
source C



source D

Mandrel-wrap mode-filters

Effect of mandrel wrap on output from 62.5um patchcord

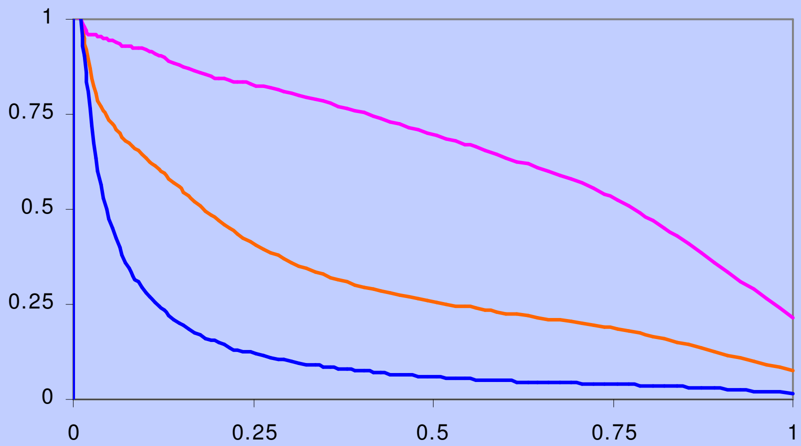


→ No mode equalisation is occurring

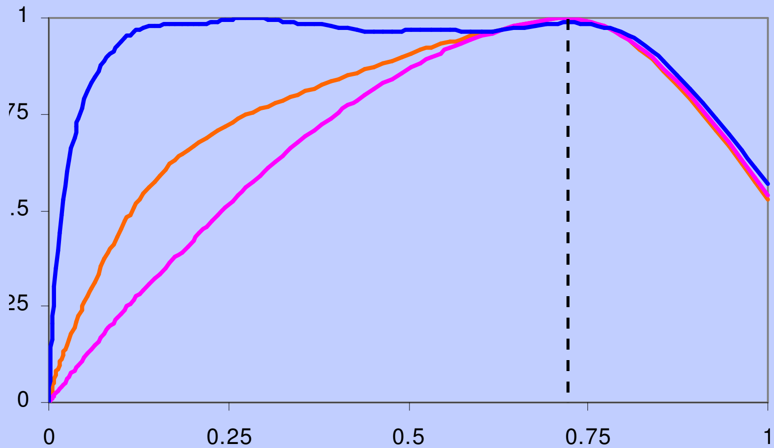
Long fibre lengths

Fibre A: shows little mode filtering effect

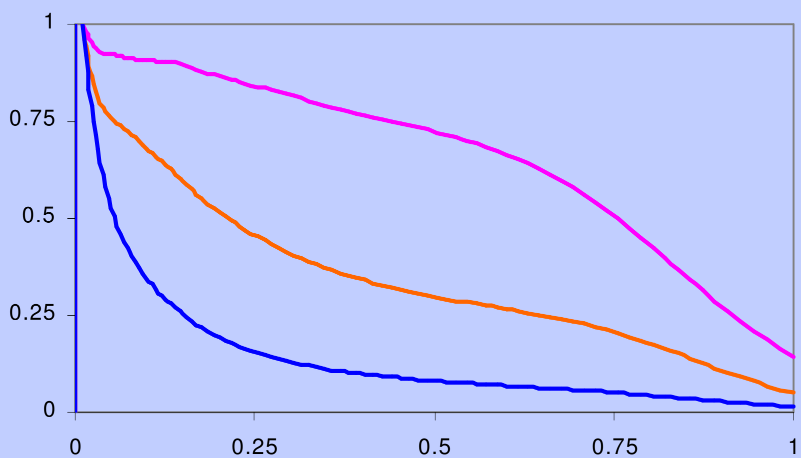
MTF - 2m



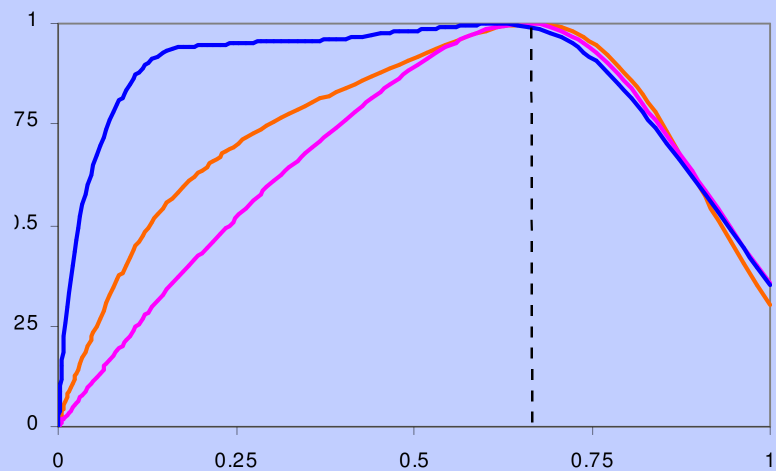
MPD - 2m



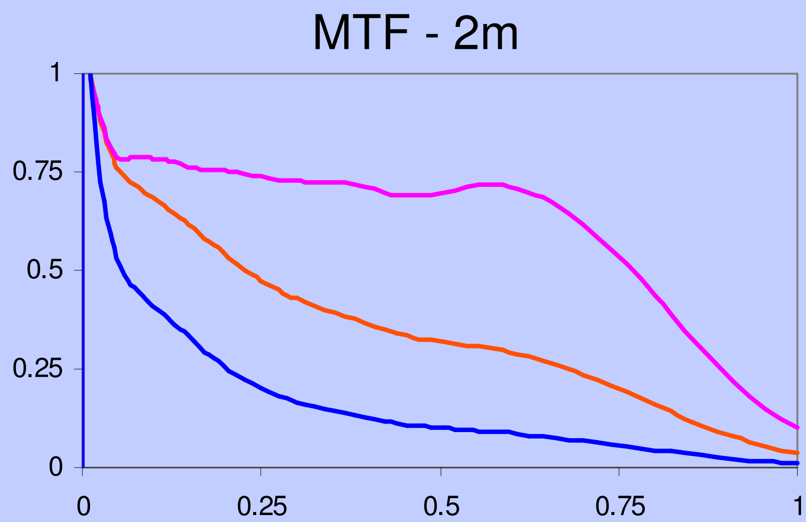
MTF - 300m

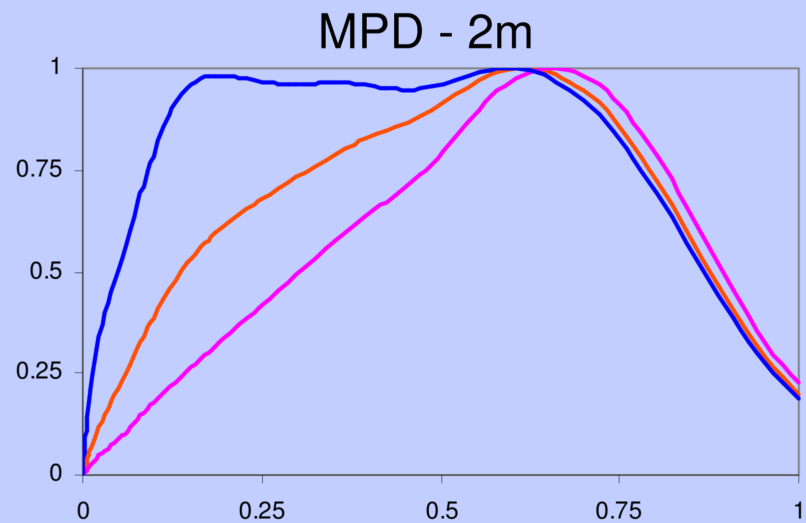


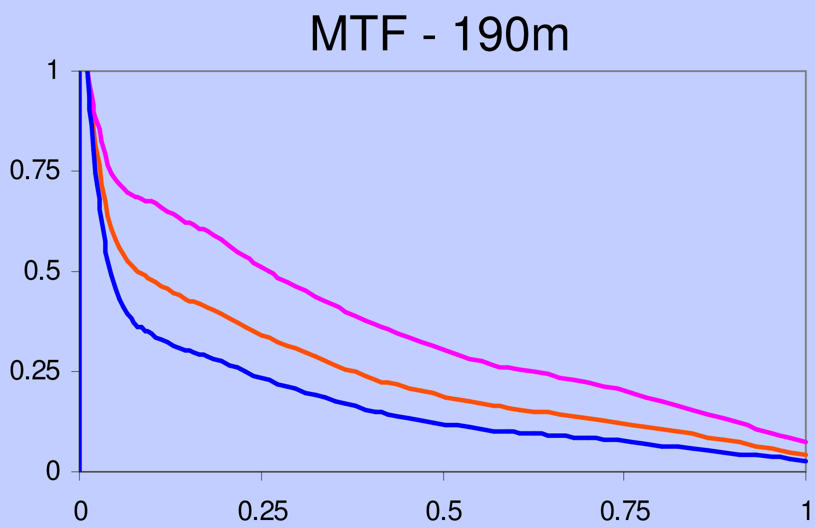
MPD - 300m

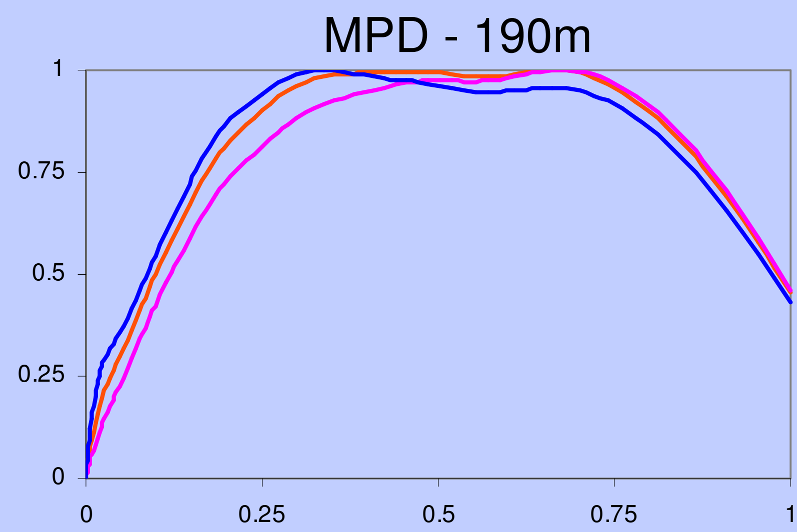


Fibre B: shows a mode filtering effect

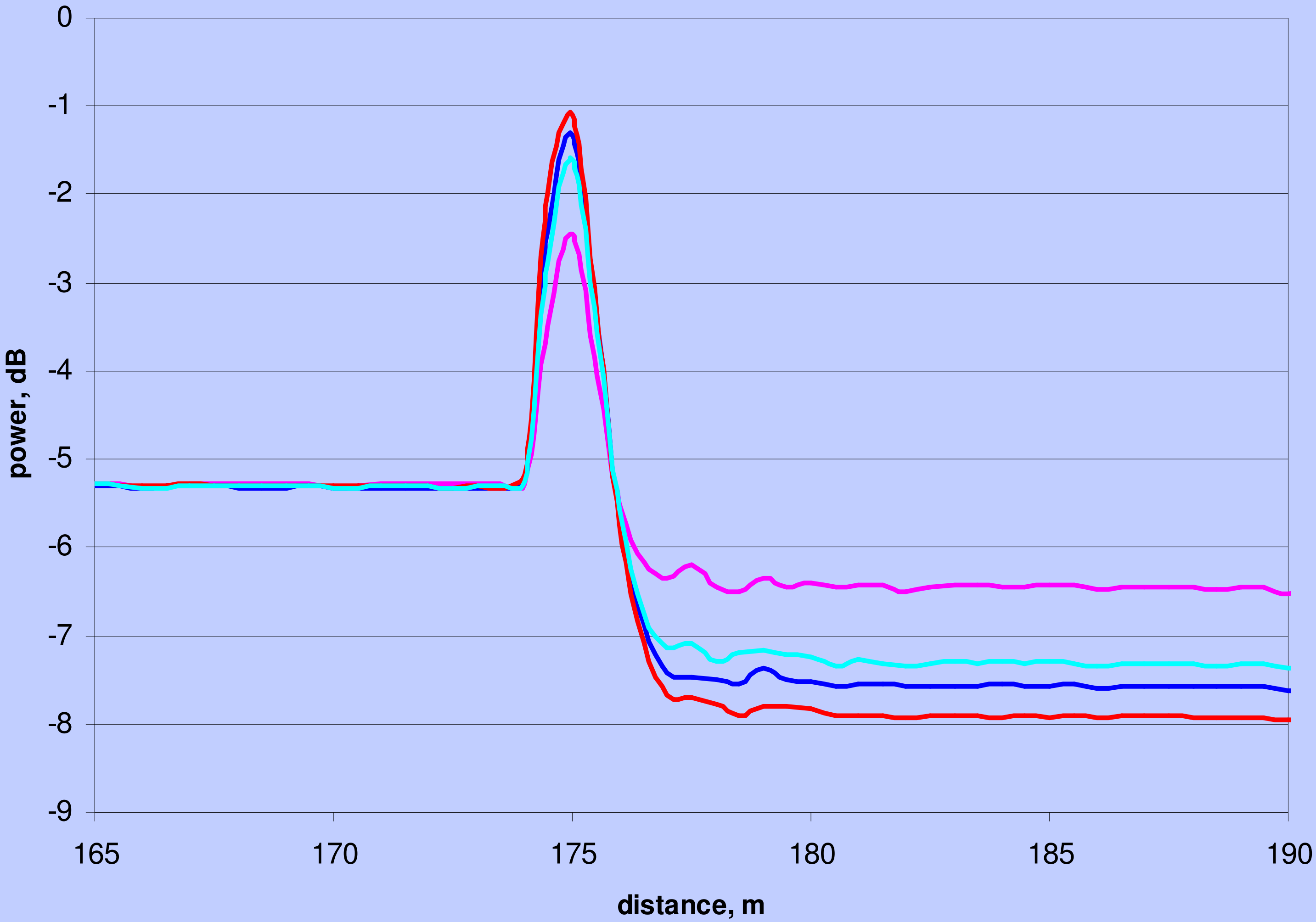


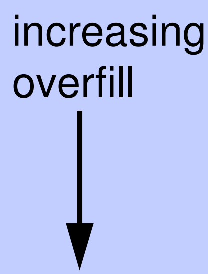






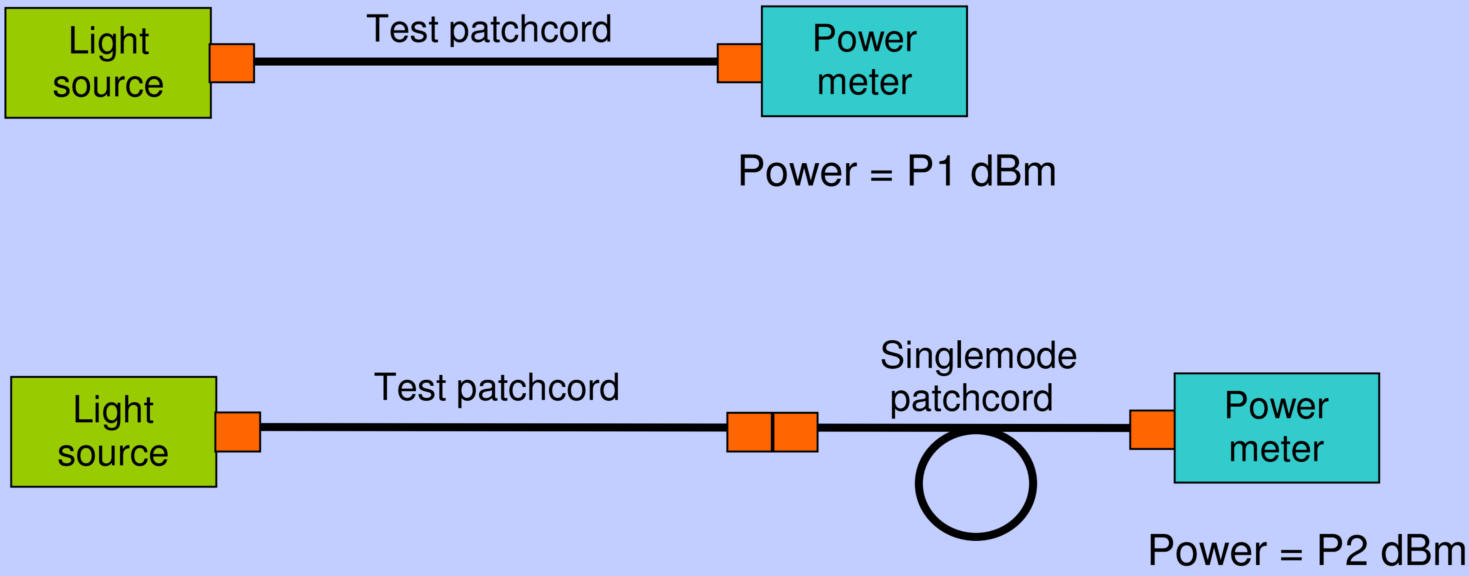
OTDR of Point Defect in Fibre B





Compare with ‘Coupled Power Ratio’

Measurement of Coupled Power Ratio (IEC 61300-3-31)

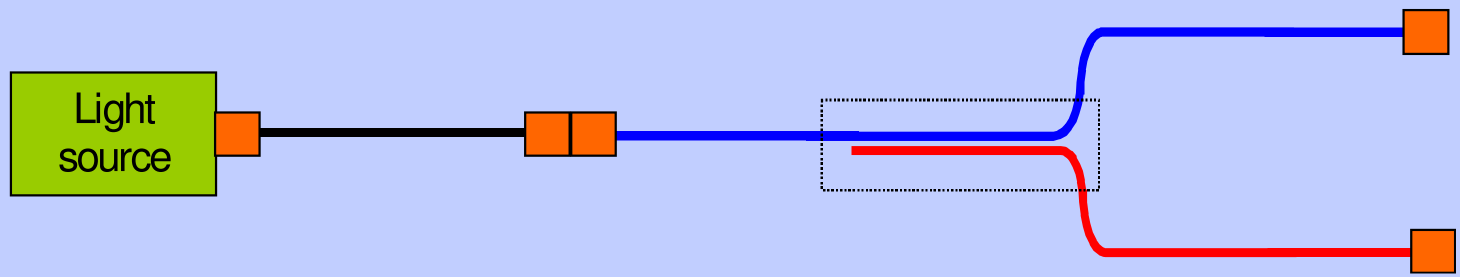


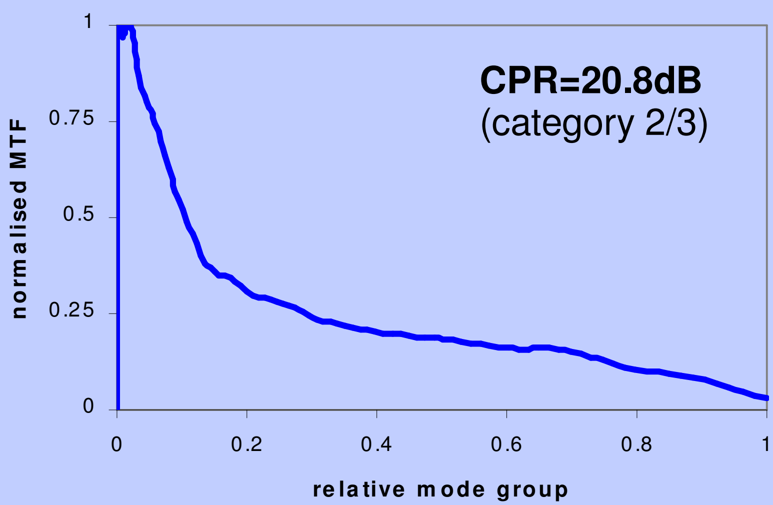
$$\mathrm{CPR} = \mathrm{P1} - \mathrm{P2} \quad \mathrm{dB}$$

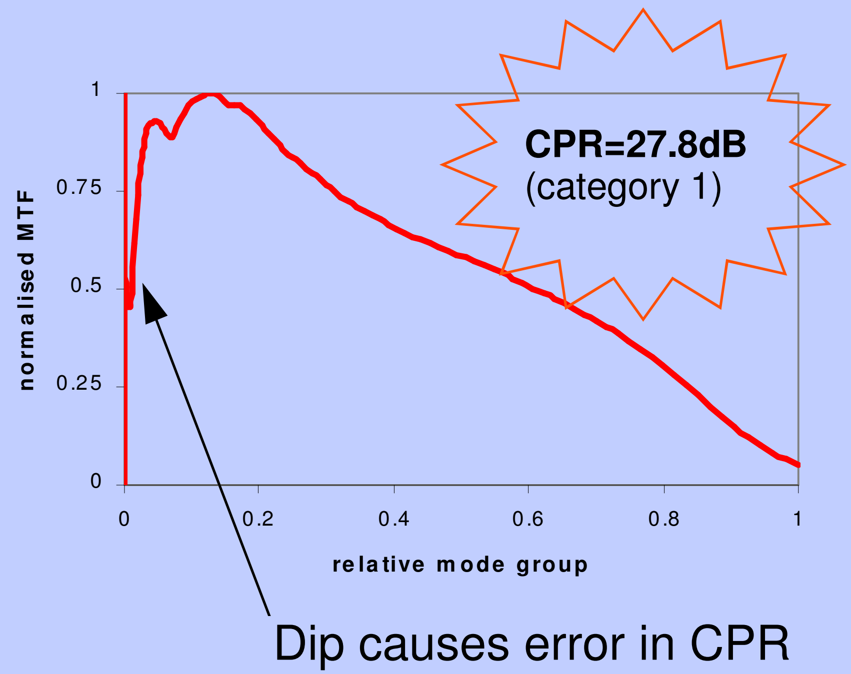
Table of CPR values in dB at 850nm. (IEC 61280-4-1)

Fibre size	Category 1 Overfilled	Category 2	Category 3	Category 4	Category 5 Greatly underfilled
50/125	20-24	16-19,9	11-15,9	6-10,9	0-5,9
62,5/125	25-29	21-24,9	14-20,9	7-13,9	0-6,9
100/140	30-34	26-29,9	18-25,9	10-17,9	0-9,9

Example of CPR Measurement of Multimode Fibre coupler

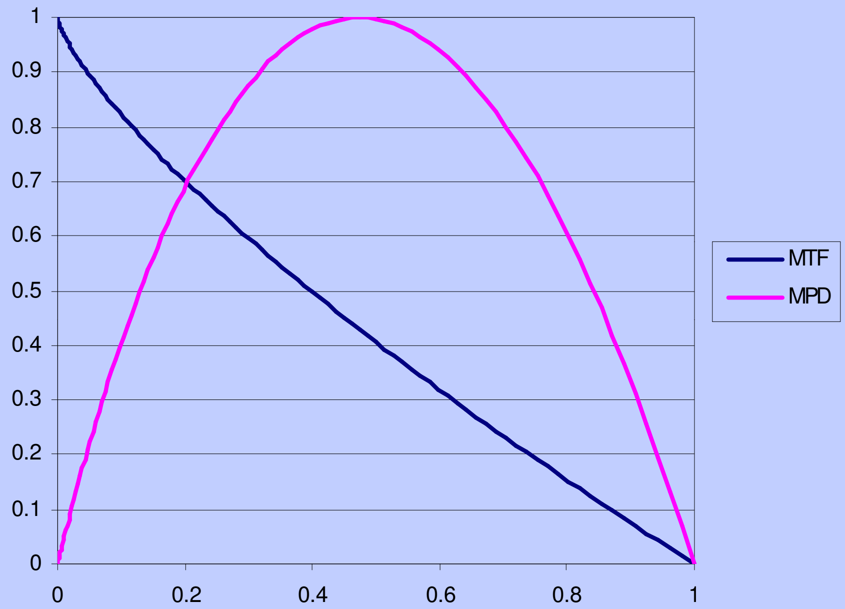






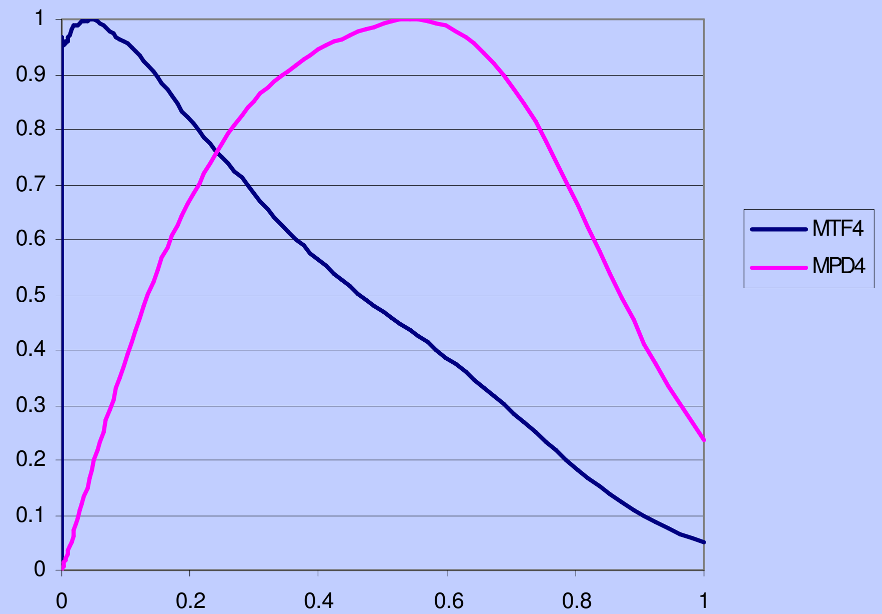
Controlling the mode distribution using scramblers and filters

Equilibrium Mode Distribution



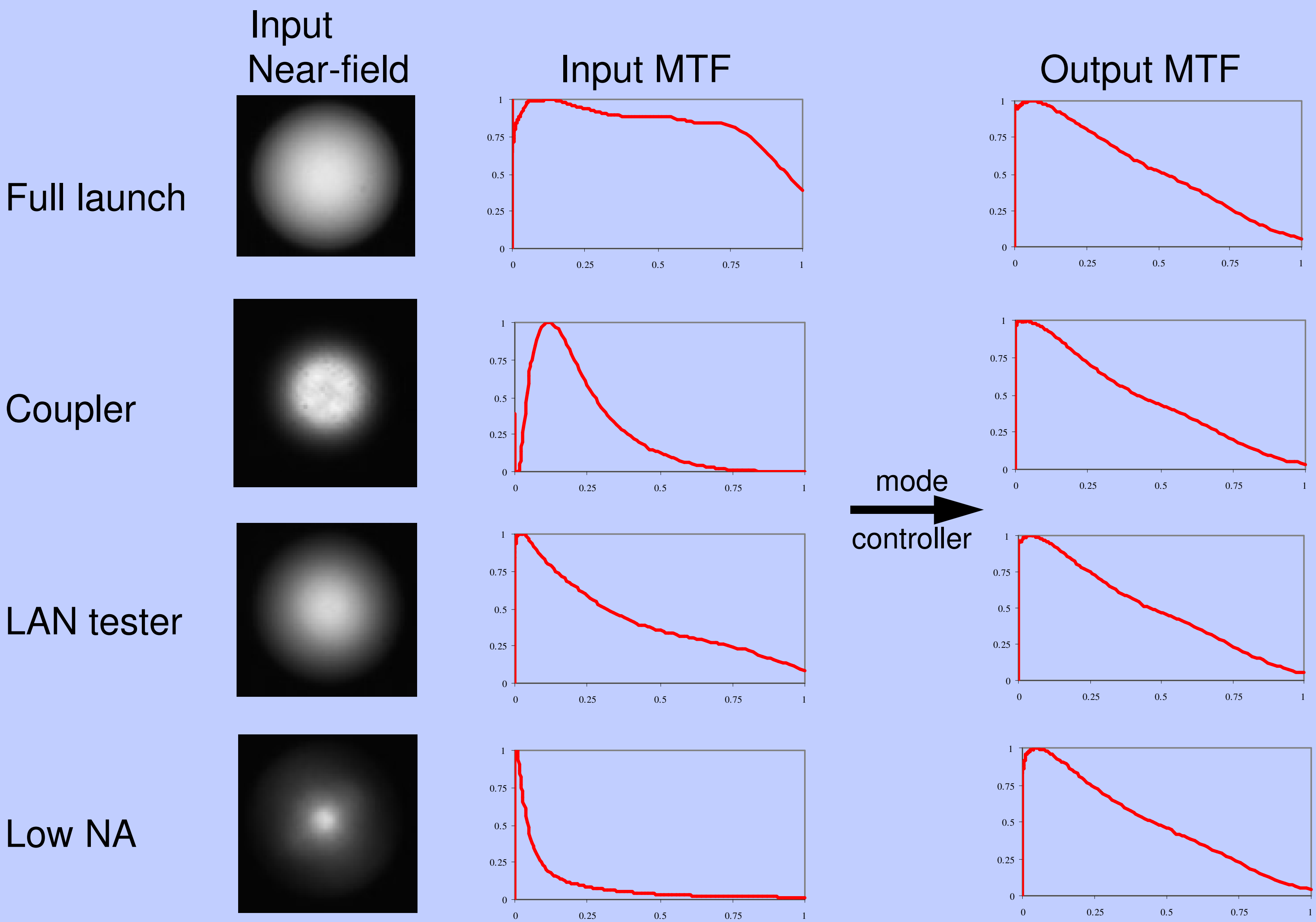
Theoretical EMD

(Yamashita, JLT, v3, n3, 1985)



Output of noval mode controller

Mode Control Device - results



Summary

- Mode Profiling gives a direct, real-time, measurement of MPD, that is more meaningful than Coupled Power Ratio.
- Mode Profiling also measures Encircled Flux to IEEE standard.
- Component performance depends on mode distribution.
- EMD does not readily occur in long fibre lengths or with mandrel wrapping.

Discussion topic: What mode distribution is optimum for measurements?

(Thank you for your attention)

For more details contact Andy Hallam: ahallam@halcyon-optical.co.uk