Variation of Waveforms in Multimode Fibre

Due to polarization, mechanical stress and wavelength changes

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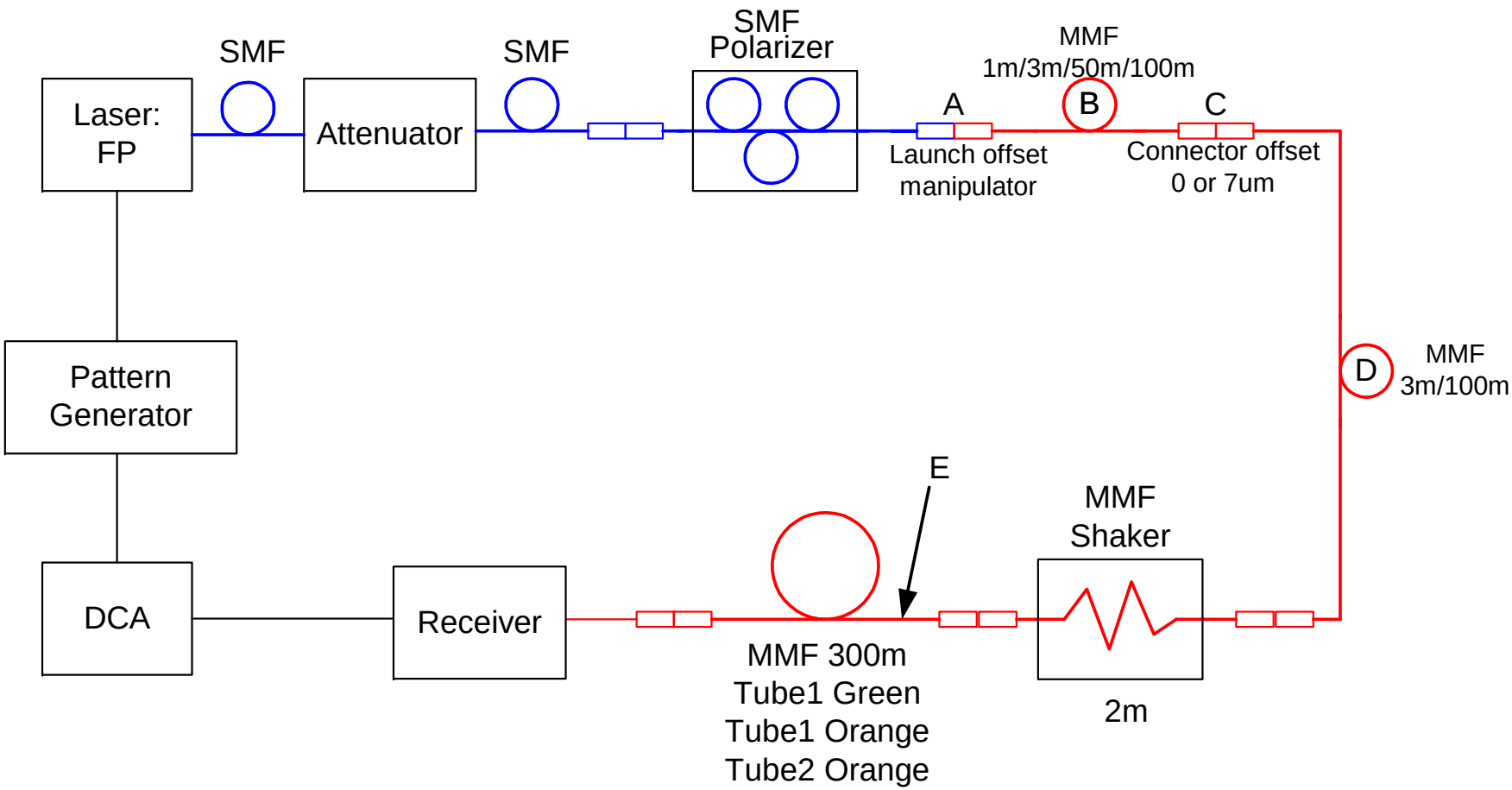
Variation of Waveforms in Multimode Fibre Introduction

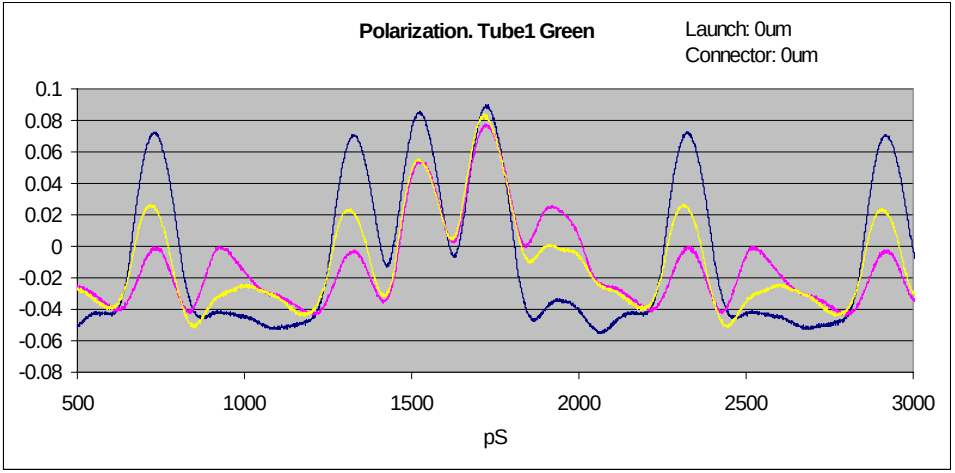
- **Observations are reported for the effects of polarisation, mechanical stress and source wavelength when applied to multimode fibre**
- **3 test fibres are investigated using an EML and FP sources.**
- **A SMF polarizer is used to control the launch conditions.**
- **The complete transmission line incorporates a variable offset manipulator, an adjustable connector, a shaker, various lengths of fibre as well as the 3 test fibres**

Variation of Waveforms in Multimode Fibre Experimental setup



Variation of Waveforms in Multimode Fibre
The effects due to Polarisation

- Measurements with FP laser (slides 5, 6 and 7)
- Variable offset SMF to MMF launch set at 0um, 5um or 15um
- Connector offset set at 0um or 7um
- Polarizer adjusted to show maximum and minimum waveform changes
- Pattern (16 bit word) set to 1000001010100000
- Fibres B & D lengths set at 3m
- On graphs the blue waveform is the short reference fibre condition


Polarization. Tube1 Green
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Connector: 0um
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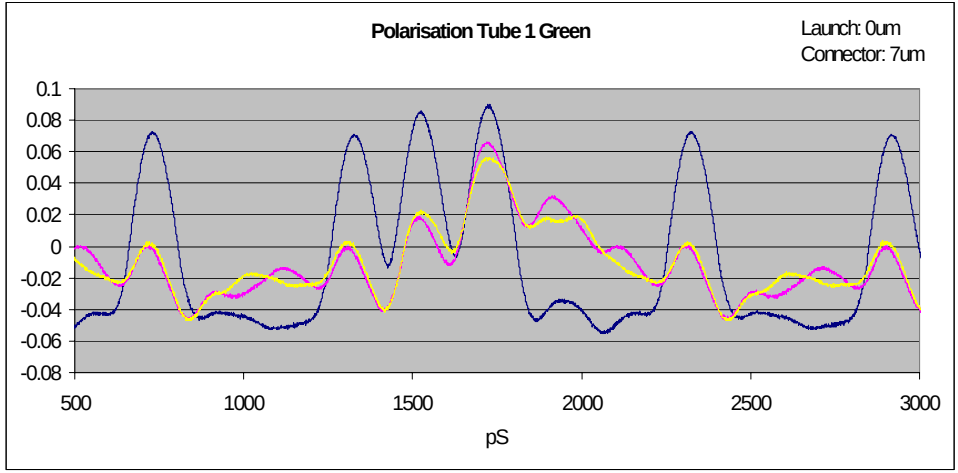
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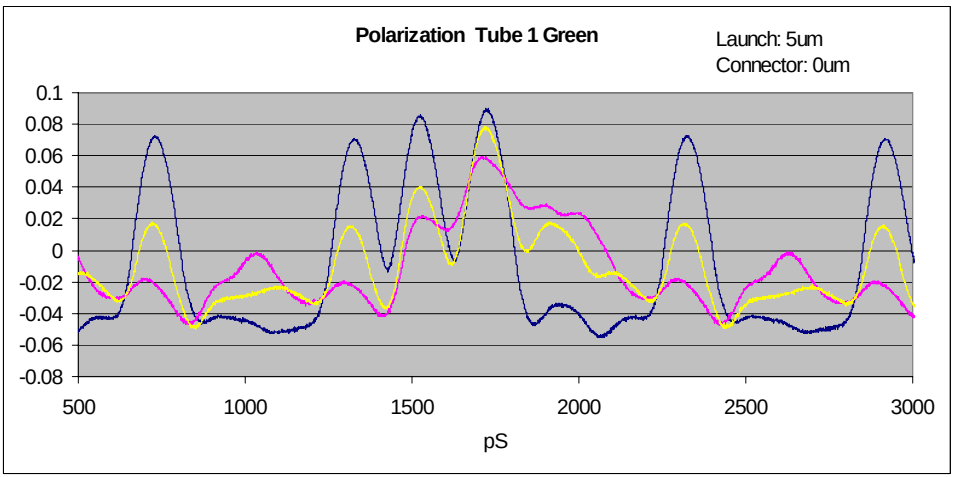
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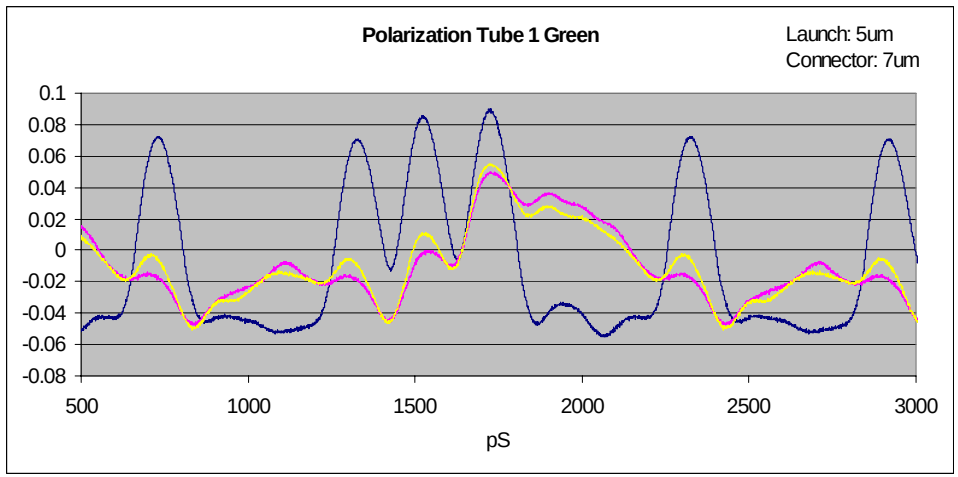
Polarization Tube 1 Green
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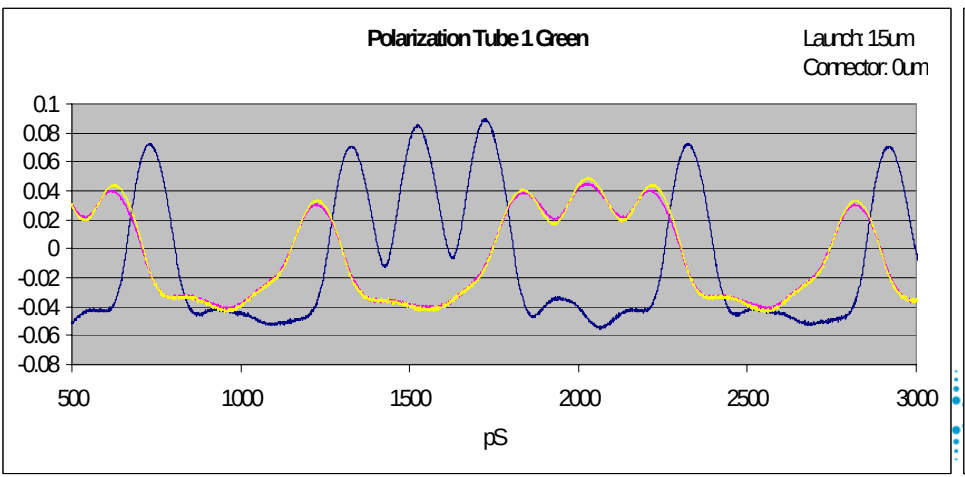
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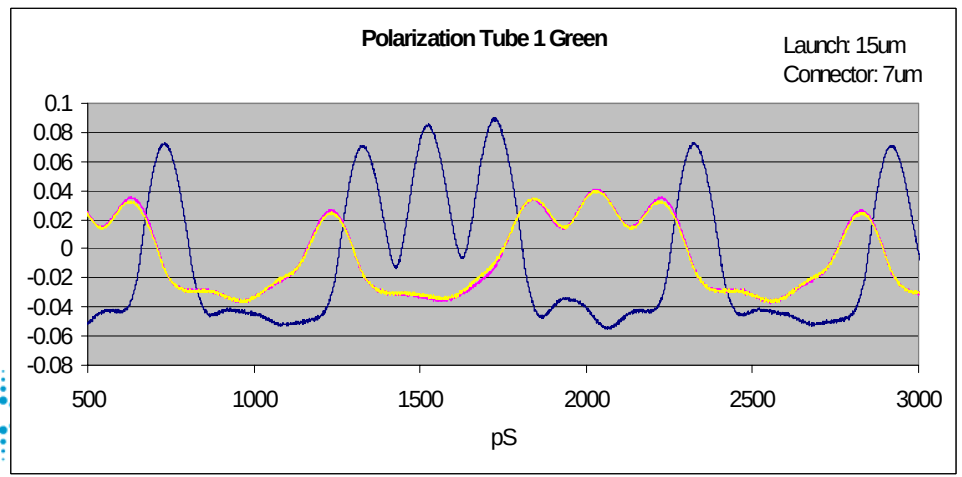
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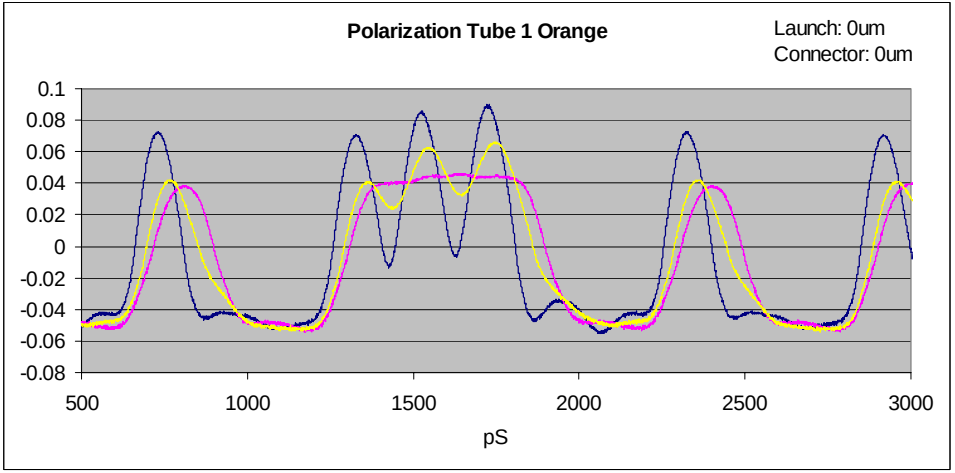
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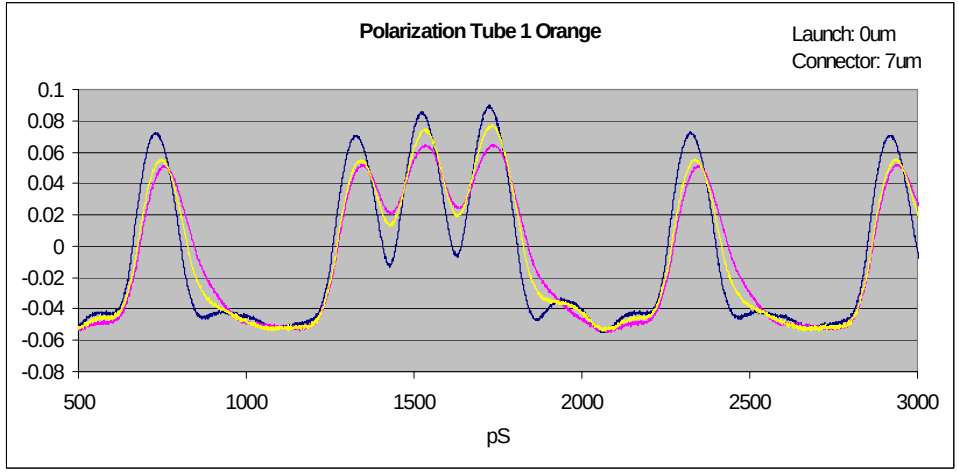
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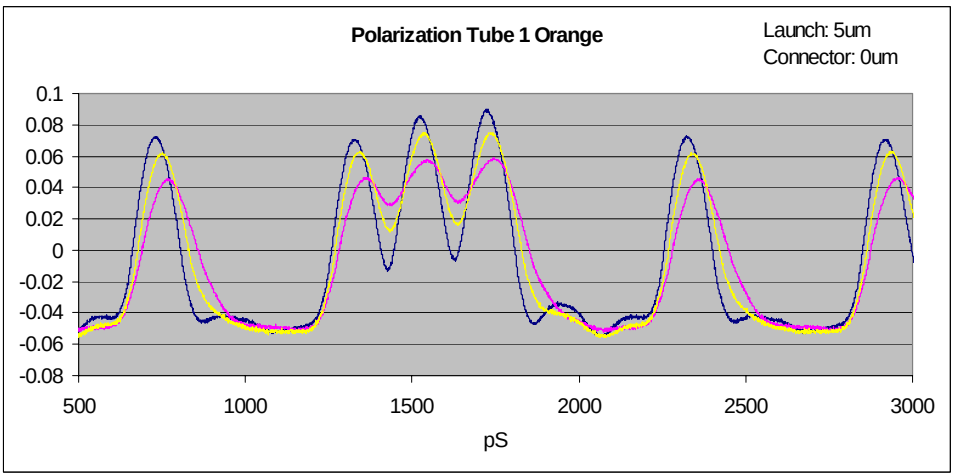
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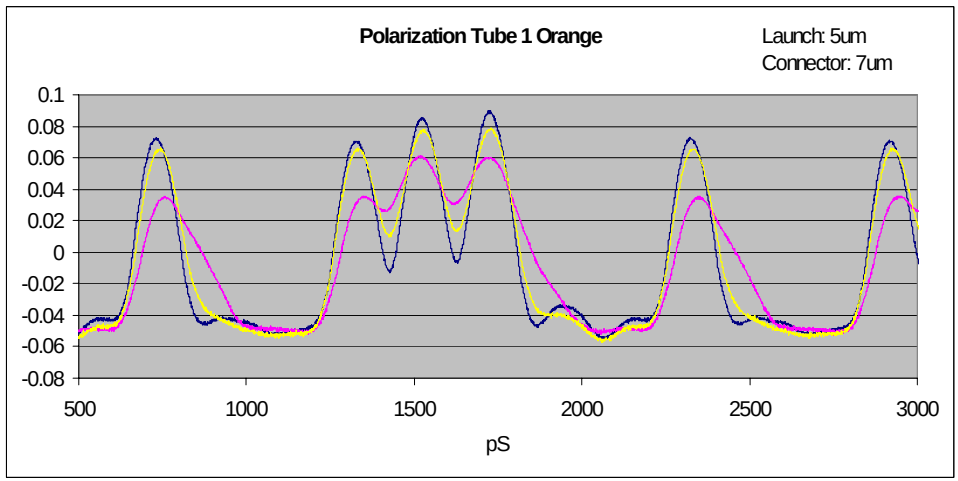
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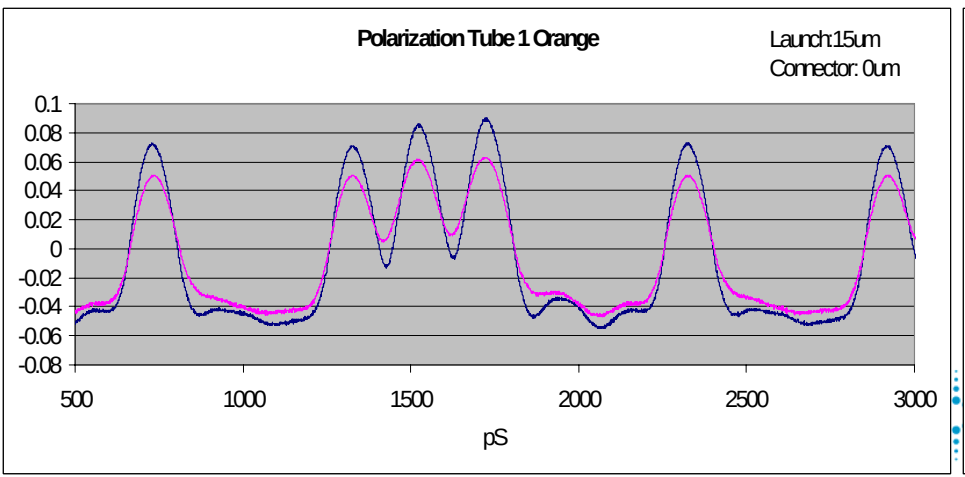
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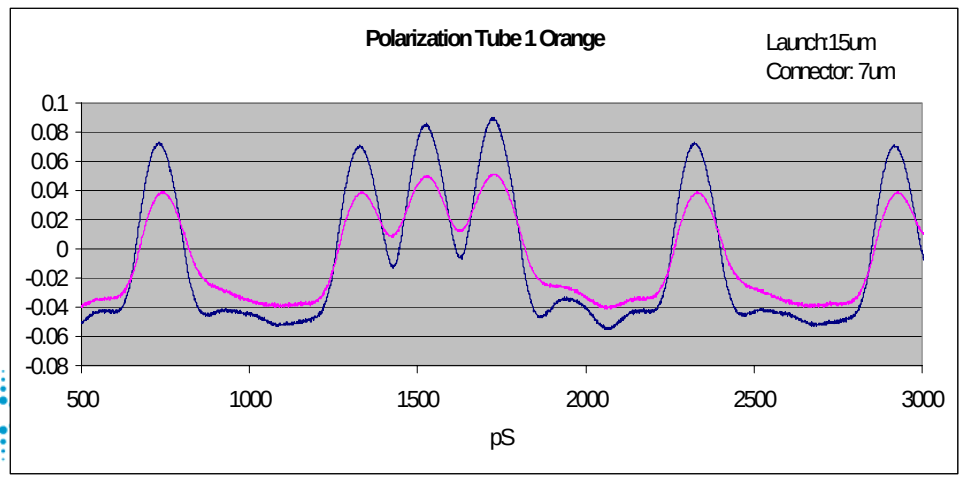
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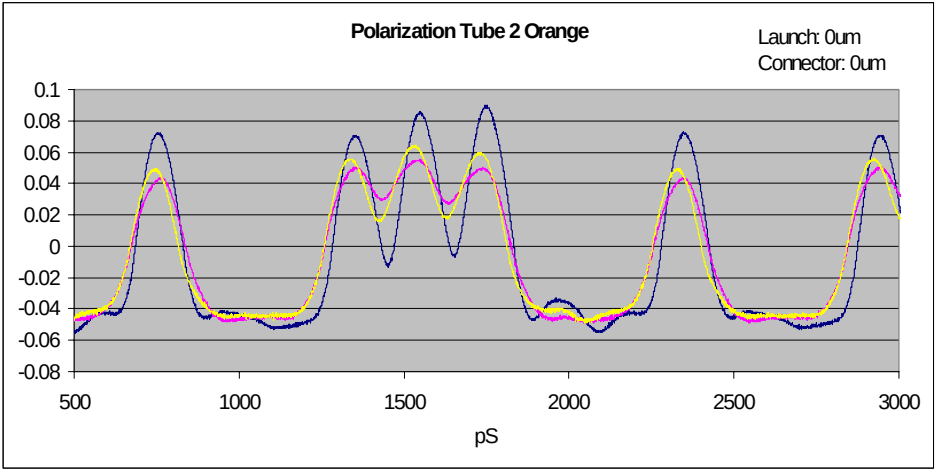
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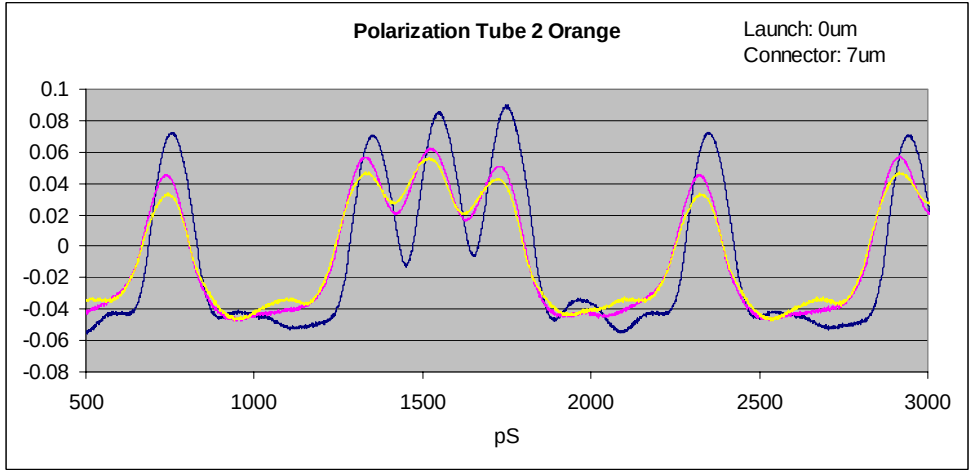
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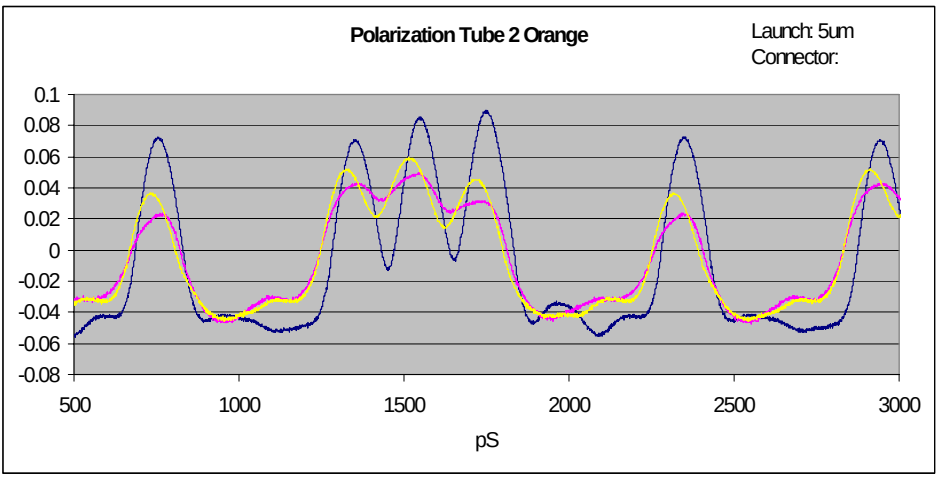
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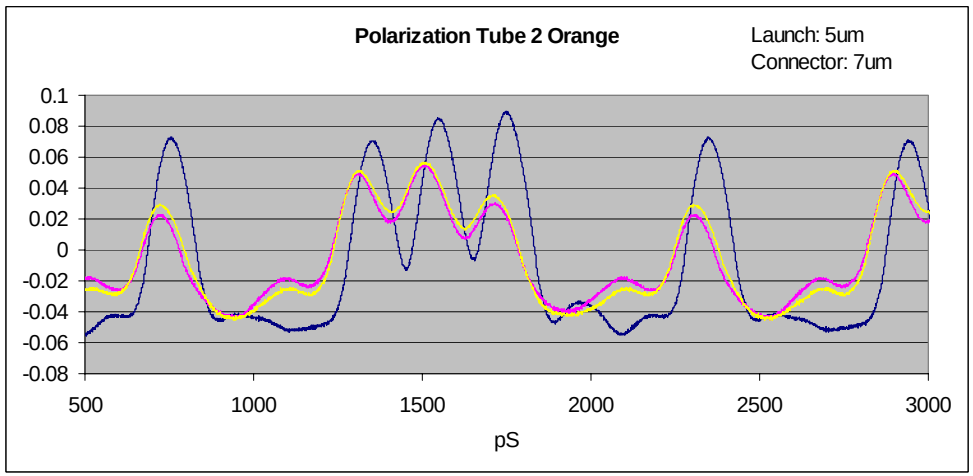
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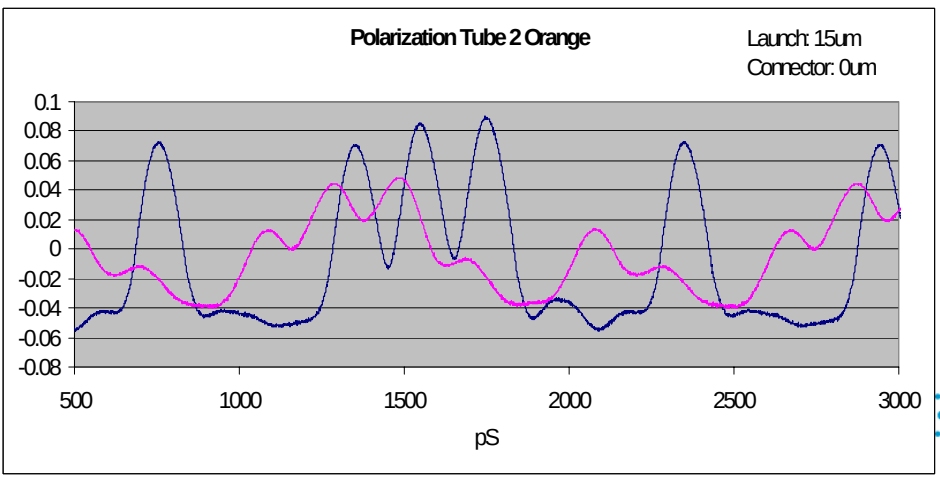
Polarization Tube 2 Orange
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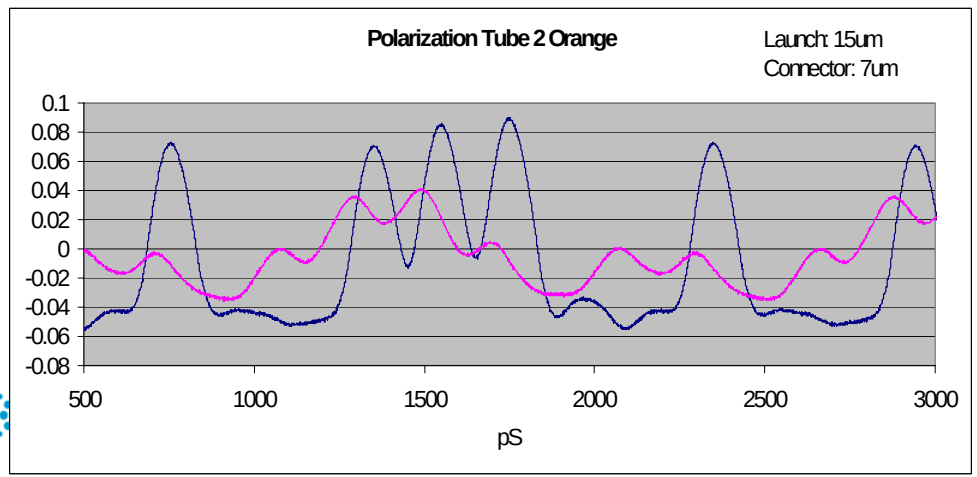
Polarization Tube 2 Orange
Launch: 15um
Connector: 7um
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Variation of Waveforms in Multimode Fibre Effective PIE-D figures of merit

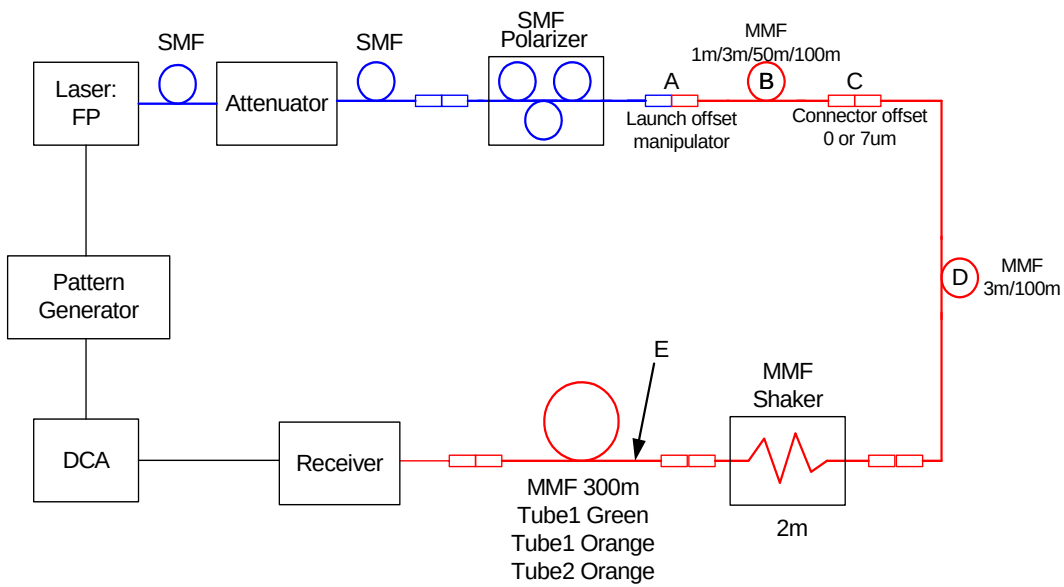
Fibre	Launch (um)	Connector (um)	min (dB)	max (dB)
Tube 1Green	0	0	1.8	3.7
	0	7	3.1	3.5
	5	0	2.5	3.1
	5	7	2.6	2.8
	15	0	1	1.4
	15	7	1	1.1
Tube 1 Orange	0	0	1.2	1.6
	0	7	1.1	1.3
	5	0	1.2	1.7
	5	7	1.7	1.8
	15	0	1.7	1.7
	15	7	1.2	1.2
Tube 2Orange	0	0	0.8	0.9
	0	7	1.1	1.2
	5	0	1.1	1.4
	5	7	1.6	2.1
	15	0	2.7	2.7
	15	7	3	3

Variation of Waveforms in Multimode Fibre Additional Measurements

- EML source also used.

- Linear polarisation was measured at points A & C. Fibre B had its length changed from 1m to 3m

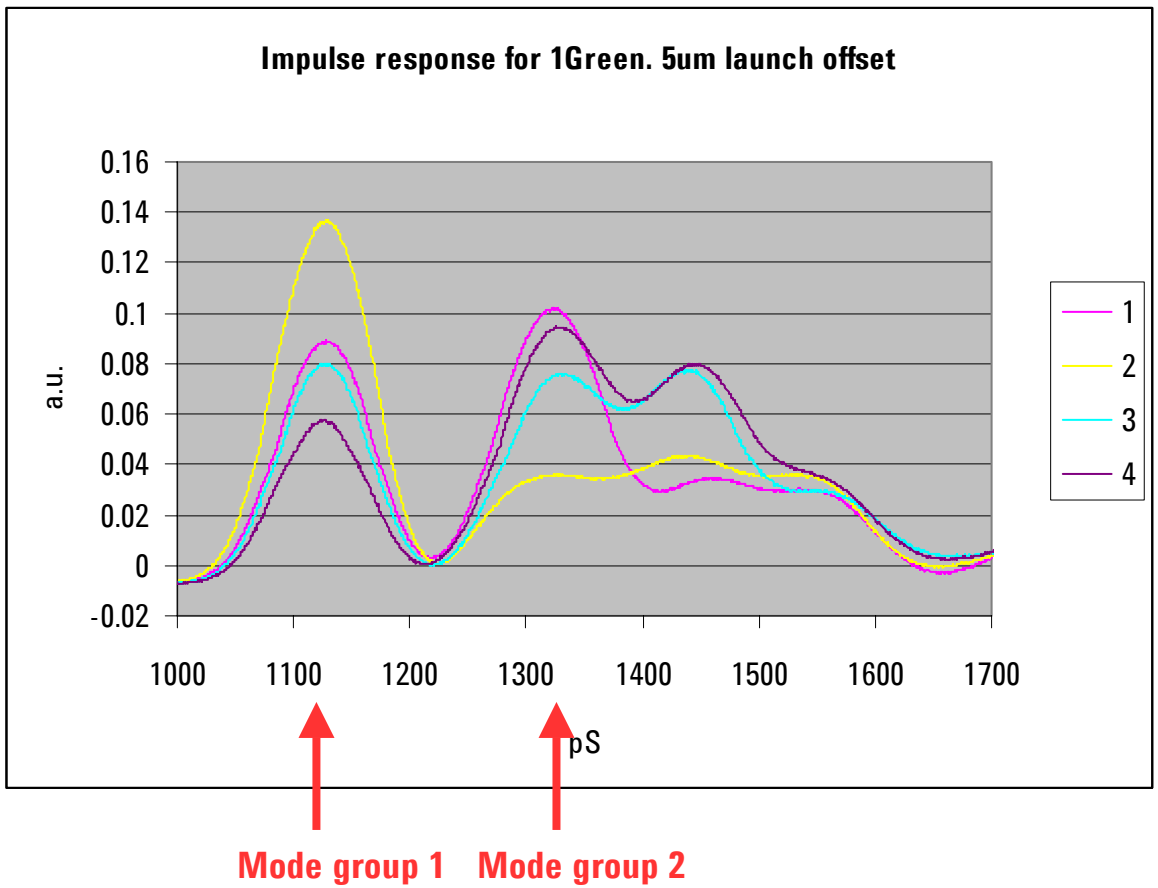
•Effects of waveform responses were observed with different lengths of fibre between the polarizer and shaker; with and without connector offset and also the effect of mechanical movement on the fibre with no connector (Reference point E)



Variation of Waveforms in Multimode Fibre

Detailed impulse response: Observed mode group coupling

- Single impulses from an EML



- Four waveforms captured from changing polarisation launch or hand moving the shaker.

Area under each waveform (1000ps to 1700ps)			
1	2	3	4
48.86	49.32	50.31	51.92

Variation of Waveforms in Multimode Fibre Observations: polarization

- Linear polarization is lost in multimode fibre by 3m. Extinction ratio from 17.1dB to 6.9dB when centre launched and to 1.5dB when 20um offset launched.

- Variations in waveforms are observed when the launch polarization is changed. The actual amount of disturbance depends on the fibre. For those fibres with central defects (1Green), the effect is most pronounced around a few microns from its centre.

- For the three fibres tested: the larger the offset launch is away from the centre, the less the effect of polarization launch. [That is not to say it has disappeared but that the mixing is within similar bandwidth modes.]

- Changing the source to an EML produced the same results.

- The 0um to 7um connector offset can reduce the delta in waveform with polarization (1Green and 1Orange), but can also enhance the effect (2Orange 5um)

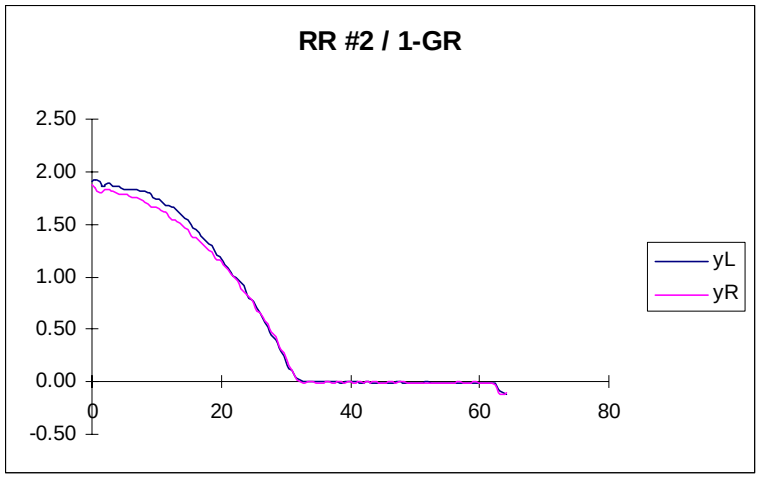
Variation of Waveforms in Multimode Fibre Observations (cont)

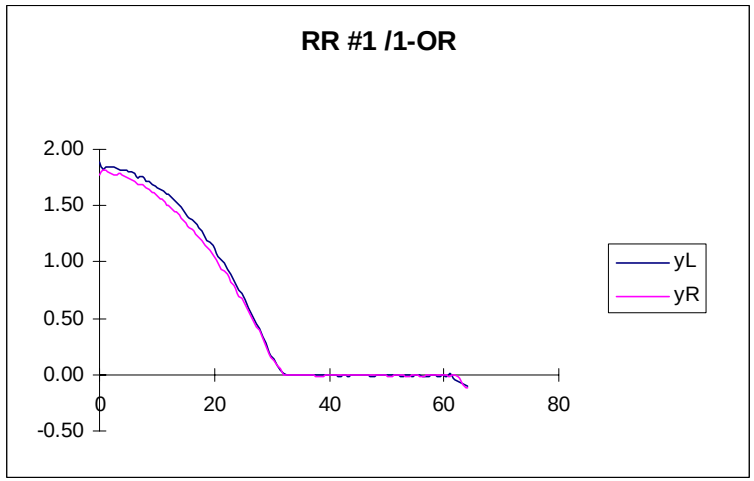
- The observed effects seen with polarization ALSO occur with the shaker. This effect is independent of the fibre distance (up to 100m) between the shaker and launch: That is change in polarization or shaking the fibre are observed to be equivalent. It was necessary to step change the shaker (by hand) to observe the different states. No new states were observed with fibre movement as opposed to polarizer.

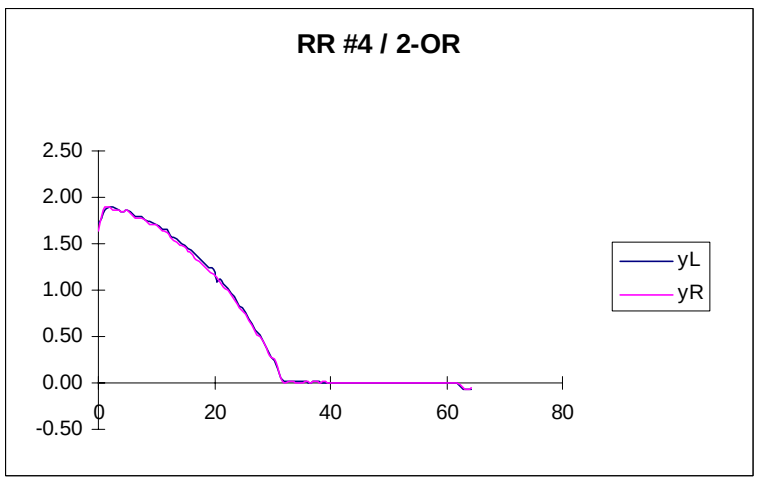
- In all cases of either polarisation or mechanical stress changes, the waveform changes were SLOW. The waveform transitioned smoothly from one **mode group** to an adjacent one. The impulse waveforms (slide 10) shows these transitions. Note the 300 pS DMD. Energy was not lost in the transitioning as the areas under each waveform are within 6% of each other.

- The waveform disturbance can also be created when just the 300m test fibre is moved (point E): In this case there is no connector except at the receiver

Other information: Refractive index profiles of Fibres 1G, 1O and 2G from TIA 1996 report



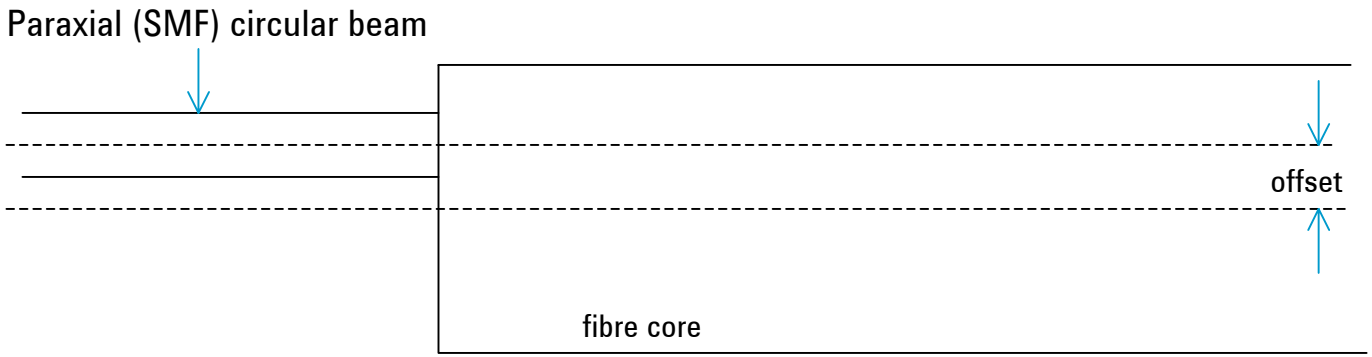




HPLB Bandwidth Measurements from 1997

Fibre	OFL BW	Centre Launch	Offset Launch	Units
1G	570	330	720	MHz.km
1O	1100	920	1350	MHz.km
2O	460	1200	555	MHz.km

Theory of launch into MMF



This is the geometry of the Agilent experiments at the launch points. Normal incidence is used.

This geometry was analyzed and documented in:

“Variation of the power coupled to the mode groups of a circular core square law multimode fibre from a circular single spatial mode laser” David G. Cunningham, 3rd November 2004, Version 2

Which can be found on 10GBASE-LRM webpage in the Task Force material section.

Theory of launch into MMF

The analysis uses standard theory for graded-index multimode fibre having an axial-symmetric refractive index profile to investigate the power coupled from a circular, single spatial mode, monochromatic laser into the multimode fibre.

It is shown that:

- The excited mode power distribution (MPD) is independent of the orientation of the optical polarisation of the laser source.
- The coupled power is not equi-partitioned between the individual modes within a group.
- At the launch, the optical polarisation of the excited fibre modes are the same as that of the exciting laser.
- For axial-symmetric refractive index distributions the impulse response remains constant when the angle of optical polarization is rotated.

Theory of launch into MMF

Variation in impulse response as a function of launch polarisation.

For cylindrical symmetric refractive index profiles, the modes within a mode group that exchange power with each other as the polarization angle is changed have the same propagation constants and delay times. Therefore, according to the theory presented in this document for cylindrical symmetric refractive index profiles the impulse response is independent of launch polarisation.

Therefore, the experimentally observed variation in impulse response must be caused by some other effect. The variation in impulse response is not predicted by standard multimode fibre launch theory for cylindrical symmetric refractive index profiles.

DGC believes the effect is due to mode coupling between mode groups within the fibre: it is not intrinsically a launch effect.