Development of an optical system with controlled launch conditions for the characterisation of polymer optical fibre (POF)

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Abstract
This paper details the development of a flexible optical system that achieves a range of quantifiable launch conditions with higher numerical aperture (*NA*) values and larger spot sizes required for large core multimode waveguides such as polymer optical fibre (POF). The launch module has been deployed in the measurement of both optical attenuation and bandwidth.

I. Introduction

The development of a controlled launch system adaptable to the needs of POF builds upon work already established at NPL [1]. The excitation of modes within multimode (MM) fibre depends on the launch conditions and a knowledge of the distribution of optical power is essential in evaluating a fibre's spectral attenuation and the effects of intermodal coupling and bandwidth. As well as requiring a lower wavelength range (typically 500-900 nm), the significant increase in core size and design *NA* of POF presents new problems for the optical design if larger spot sizes and launch *NA*s are to be generated.

II. Launch module design

Figure 1 shows alternative launch module configurations. The launch module comprises of two opposing infinity-corrected objectives *L2* and *L3* that image an interchangeable pinhole *A1*, onto the fibre end face. *NA* is controlled by limiting the diameter of the collimated beam with an aperture *A2*. Alternatively, it may be dictated by the appropriate choice of objectives where the *NA* is limited by the objective *L3*. The system incorporates a beamsplitter to allow direct viewing and measurement of the imaged spot or indirect viewing using a suitable video camera and telephoto lens. The use of different pinhole apertures and lenses provides a practical degree of flexibility in achieving a range of *NA* and spot sizes. Infinity corrected objectives were arranged to give a near 1:1 imaging system achieving a maximum *NA* of ~0.4. Fine control of the launch *NA* can be carried out with the adjustable aperture *A2*. In practice, it proved difficult to achieve both a large spot size and high *NA* due to opto-mechanical limitations and the choice of objective pairs involved a compromise. Large spot sizes (~1000 µm) were found to be easier to achieve than a high *NA*.

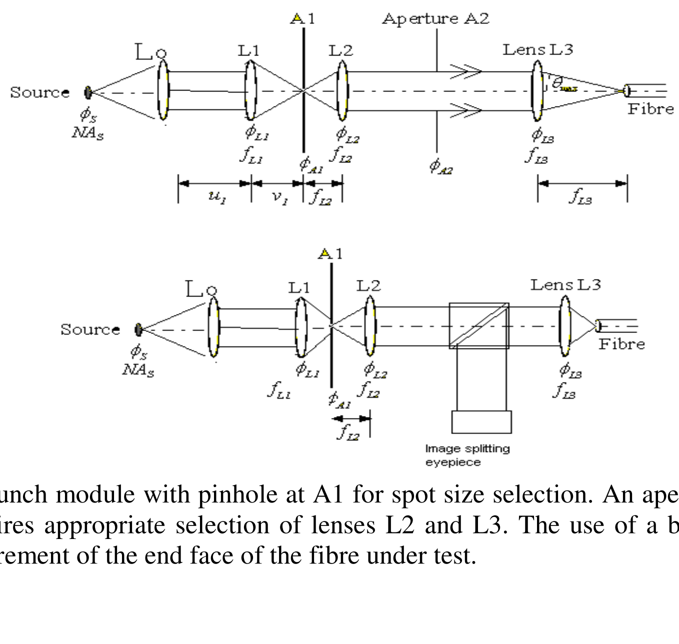

Figure 1 Optical design of launch module with pinhole at A1 for spot size selection. An aperture A2 provides control of *NA* at low values. High *NA* requires appropriate selection of lenses L2 and L3. The use of a beamsplitter between L2 and L3 facilitates viewing and measurement of the end face of the fibre under test.

III. Spot Size and *NA*

As the diameter of the pinhole was increased beyond 500 µm, the edges of the corresponding image became poorly defined compared to that of a point source and it became necessary to increase the *NA* of the transmitted beam by introducing a thin diffuser at the pinhole aperture. This enabled the opposing objectives (*L2* and *L3*) to be better illuminated over their design *NA*, generating a cone that overfilled the fibre under test (FUT). The optical system formed a real image of the diffuser, enabling the pinhole aperture rim to be more clearly imaged and adjusted to be coincident with the face of the FUT. The diameter of the imaged spot on the fibre end face was measured by inserting a commercial image-shearing microscope head into the viewing position. By using the shearing head's micrometer control, the outer diameter of the FUT can be used to provide a reference value in micrometre per division providing a scaling factor from which the imaged spot can be measured. This method provided an accuracy of measurement to better than +/- 5 %.

In practice, achieving a high *NA* at the launch required various modifications to the opto-mechanical arrangement. This was dependent upon the monochromator exit slit *NA* and the pinhole illumination *NA* from lens L1, even with the use of the scattering screen at the pinhole. The development work showed that although a large spot size of up to 900-1000 µm could be achieved with relative ease through the use of a near 1:1 imaging system, the *NA* was limited to ~0.3 *NA*. This applied even when objectives were used whose design *NA* was higher. A higher *NA* was possible but it noticeably affected the definition of the spot image, making it difficult to quantify spot size. Conversely, with larger pinholes it was only possible to produce full illumination over a lower range of *NA* values. *NA* was measured by using a knife-edge controlled by appropriate X-Y translation stages arranged to cut the launched beam. Signal losses at the detector determined the geometrical position of the launch beam. Measurements obtained a level of accuracy of +/- 0.015 *NA* for a single measurement and +/- 0.005 *NA* for a repeated sample.

IV. Attenuation Measurement

The launch module was inserted into a system that consisted of a tungsten halogen lamp and a stepper controlled monochromator incorporating modulated silicon detectors. The established cutback technique test method for measuring spectral attenuation [2] was used over a wavelength range of 600-900 nm. Preliminary results in Figure 2 show variations in attenuation with *NA* and spot sizes.

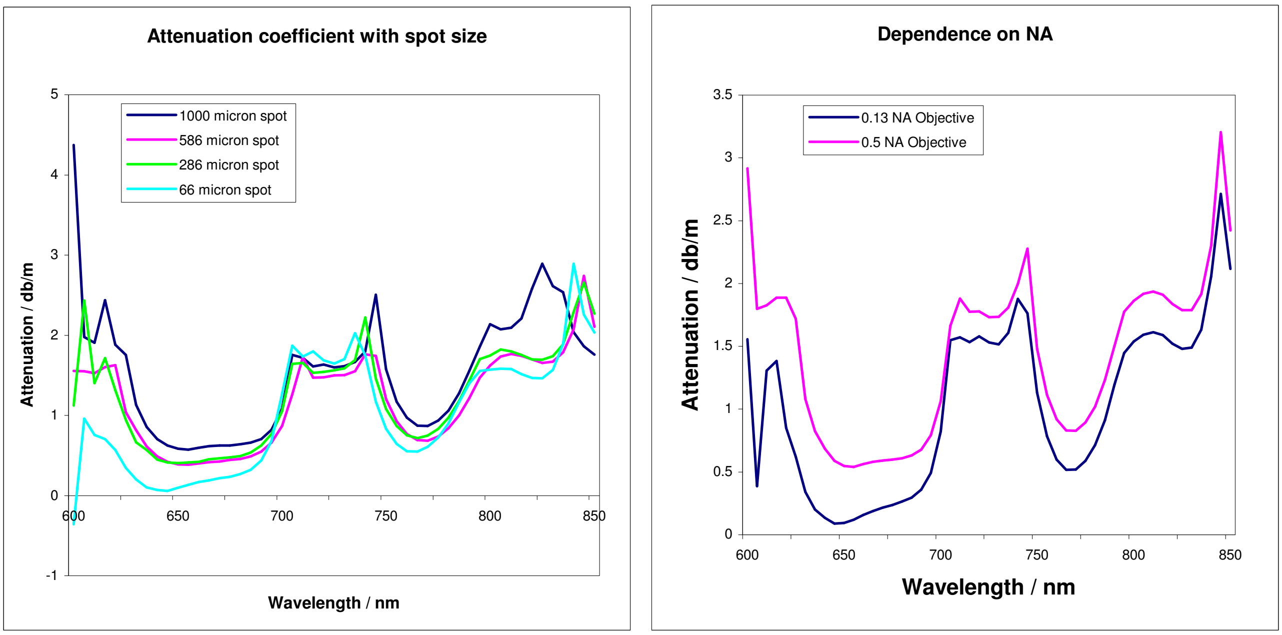

Figure 2 Graphs showing variations in attenuation with *NA* and spot size using a multistep index OM-GIGA fibre with fibre lengths of ~11-12 m. *NA*s quoted are the design *NA* of the objectives used.

The results display the higher attenuation values expected from the excitement of higher order modes and associated losses. Further measurements made use of the launch module to investigate the relationship between *NA* and length dependency as well as repeatability of the system with respect to end face quality.

V. Bandwidth Measurements

The launch module was incorporated into the setup and measurements of bandwidth carried out in the frequency domain. A modulated vertical cavity surface emitting laser (VCSEL) source was used. The collimated output of the source required the addition of a diverging lens to fully illuminate the lens L0. The measurements utilised a fast detection system with an integrated amplifier in conjunction with a frequency scanning system [3]. The chosen detector was specified to operate up to 1 GHz. Using a synthesizer as a reference a range of frequencies was scanned and the respective amplitudes measured. The data was analysed and the results show the normalised attenuation plotted against frequency for the ratio of long to short lengths with dark readings subtracted. The bandwidth frequency is taken as the –3 dB point from the maximum. Bandwidths for other length/spot size combinations are given in Table 1.

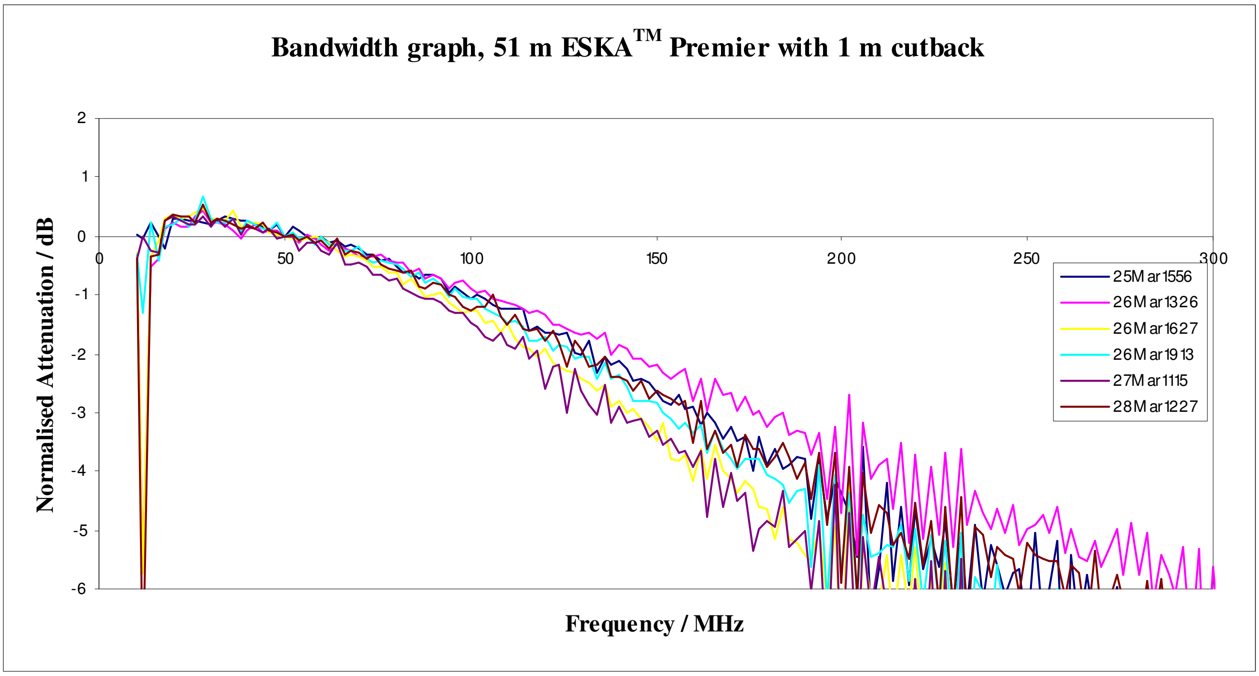

Figure 3 Graph showing normalised transmission plot through a length of 51 m ESKA™ step index fibre with an estimated bandwidth of 145 MHz. A reference of 50 MHz was chosen arbitrarily as this represented the lowest frequency at which signal levels were stable.

Table 1 Estimated bandwidth for step index fibres of different lengths and spot sizes are given. Bandwidths and uncertainties are quoted to the nearest 5 MHz.

Fibre Type	Length / m	Spot size / µm	Estimated bandwidth / MHz
ESKA™ Mega MH4001	50	1000	200 ± 25
ESKA™ Premier GH4001	51	1000	145 ± 25
ESKA™ Premier GH4001	30	800	375 ± 80
ESKA™ Premier GH4001	15	800	695 ± 130

Note that for a sample of multi-step index (MSI) fibre the bandwidth was too large to be measured on the system and required the use of a faster detector and improved light collection.

VI. Launch module limitations

Current limitations of the system include a low image contrast and the need for careful alignment as well as errors associated with the geometry and quality of the end face of the FUT. It is important to note that no account is taken of any effects due to beam energy distribution of the imaged spot that may arise either as a function of the wavelength distribution from the monochromator grating (for attenuation) or from the VCSEL source (for bandwidth). Uneven illumination intensities on the launch spot can result in differences in the modal power distribution within the FUT. However, diffusing the illumination would result in significant signal loss. The high attenuation of POF, typically anywhere between ~0.01-0.1 dB/m, means that the system signal loss had to be minimised and opportunities to maintain power in the beam constantly sought (for example using a more efficient blazed grating). Constraints upon *NA* include beam divergence between the opposing objectives *L2* and *L3*, the limiting apertures of the objectives themselves and the limitation imposed through the *NA* of the monochromator.

VII. Summary

A system to provide controlled and quantifiable launch conditions in order to characterise such parameters as spectral attenuation and bandwidth of different types of POF has been constructed. The launch module has been shown to be capable of producing spot sizes in excess of 1000 μm with *NA*s up to ~0.4. The flexibility and range of achievable launch conditions as well as the portability of the launch module as a whole are notable successes of the work undertaken. This has been largely achieved with existing equipment without the need for expensive, dedicated optics. It is anticipated that the versatility of the module will ensure it has a role within future developmental work.

Acknowledgements

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References

[1] Billington, R., *Evaluation of Multimode Optical Fibre Components*, NPL Report ISSN – 1369 6807,April 2000.

[2] International Electrotechnical Commission (IEC), 793-1, Generic specification for optical fibres. International Telecommunications Union (ITU) Recommendation G.650: 1995: Definition and test methods for the relevant parameters of single mode fibres. British Standards Institute (BSI), BS EN 188000:1994, generic specification for optical fibres.

[3] G.W. Day, 'Measurement of optical fiber bandwidth in the frequency domain', NBS technical note 1046, US Department of Commerce/National Bureau of Standards, Issued September 1981.