EFFECTIVE AREA OF SINGLE-MODE OPTICAL FIBRES - A COMPARISON OF FOUR MEASUREMENT TECHNIQUES

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Abstract: The effective areas of six optical fibres are measured using four techniques: the direct far-field scan, variable aperture in the far-field, near-field scan and transverse offset. The results are compared and the relative merits of the measurement methods discussed. In particular, the direct far-field scan and variable aperture methods are compared with regard to the treatment of side-lobes in the far-field intensity distribution.

Introduction

Non-linear effects such as four-wave mixing (FWM), self-phase modulation (SPM) and stimulated Brillouin scattering (SBS) are important considerations where intense electric fields are present in optical fibre. The effective area, A_{eff} , is a crucial parameter in predicting the degree of non-linear behaviour as it can be used to convert between aggregate optical power in the fibre and the intensity of the optical field.

Unlike mode-field diameter (MFD), effective area is defined only in terms of the near-field distribution of the fibre. Any technique must therefore be capable of measuring this distribution, either directly or through the use of transforms from other measurements. We compared four different techniques for measuring A_{eff} that have previously been used to measure MFD. These were: the direct far-field (DFF) scan, variable aperture in the far-field (VAFF), near-field (NF) scan and transverse offset (TO).

Definition of Effective Area, A_{eff}

The effective area of an optical fibre with mode-field amplitude distribution $E_a(r)$ is defined as /1/:

$$A_{eff} = \frac{2\pi\left(\int_0^\infty |E_a(r)|^2 rdr\right)^2}{\int_0^\infty |E_a(r)|^4 rdr} = \frac{2\pi\left(\int_0^\infty I(r)rdr\right)^2}{\int_0^\infty I^2(r)rdr} \tag{1}$$

where $I(r)$ is the intensity of the electric field of the fundamental mode at radius r from the axis of the fibre.

Techniques for Measuring the Mode-Field Distribution

The inter-relationship between the methods used to measure A_{eff} is shown in Figure 1. Clearly the near-field scan method is the most direct since the effective area can be calculated directly from the measured data. The other techniques all require some degree of numerical processing, which can introduce errors. However, once the practicalities of the measurements are taken into account, the most direct method, i.e. the near-field scan is not necessarily the best option.

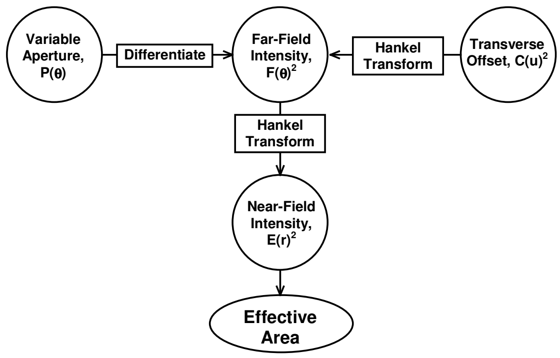

Figure 1. Relations between the techniques used to measure the effective area.

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Results

The effective areas of six fibres were measured near 1550 nm and 1310 nm. The results are shown in Tables 1, 2 and 3 for the far-field, near-field and variable aperture methods respectively. No results are presented for the transverse offset method owing to technical limitations on the measurement system.

Table 1 - Far-Field Scan Method

	1549-nm		1309-nm	
	Aeff	Std. Dev.	Aeff	Std. Dev.
	(μm^2)	(μm^2)	(μm^2)	(μm^2)
Attenuation Flattened	80.94	0.23	66.39	0.13
Dispersion Flattened	53.84	0.20	38.47	0.14
Matched Cladding	83.39	0.31	67.79	0.27
Dispersion Shifted	46.05	0.09	29.75	0.16
LEAF -'ve Dispersion	67.25	0.30	34.11	0.54
LEAF +'ve Dispersion	68.40	0.58	38.84	0.26

Table 2 - Near-Field Scan Method

	1549-nm		1309-nm	
	Aeff	Std. Dev.	Aeff	Std. Dev.
	(μm^2)	(μm^2)	(μm^2)	(μm^2)
Attenuation Flattened	80.63	0.23	66.18	0.13
Dispersion Flattened	-	-	38.26	0.15
Matched Cladding	83.04	0.31	67.57	0.27
Dispersion Shifted	45.72	0.09	29.56	0.16
LEAF -'ve Dispersion	66.73	0.31	33.88	0.53
LEAF +'ve Dispersion	67.89	0.57	38.57	0.26

Table 3 -Variable Aperture in the Far-Field Method

	1550-nm		1310-nm	
	Aeff	Std. Dev.	Aeff	Std. Dev.
	(μm^2)	(μm^2)	(μm^2)	(μm^2)
Attenuation Flattened	79.44	0.70	63.68	0.53
Dispersion Flattened	54.3	2.0	37.72	0.23
Matched Cladding	81.94	0.80	65.41	0.34
Dispersion Shifted	45.8	1.0	29.52	0.57
LEAF -'ve Dispersion	67.38	0.72	34.16	0.31
LEAF +'ve Dispersion	68.1	1.3	39.00	0.60

The results from these three methods can be seen to be generally in good agreement. The notable exceptions to this are the VAFF results for the attenuation-flattened and matched cladding fibres, which are consistently lower than the values from the other two methods. The reason for this is the inversion of side-lobes in the far-field intensity distribution.

Not all fibre types exhibit side-lobes. However, where they appear, the amplitude of the far-field must be given the correct sign before using the Hankel transform to calculate the near-field. Failure to do so can lead to an underestimate of the effective area of typically 2-3%. This is the origin of the discrepancies between the VAFF results and the DFF and NF results for the attenuation flattened and matched cladding fibres. The VAFF system used incorporated 23 apertures - giving 23 angular intensity values. It can be seen from Figure 3 that the scarcity of points makes side-lobe identification difficult.

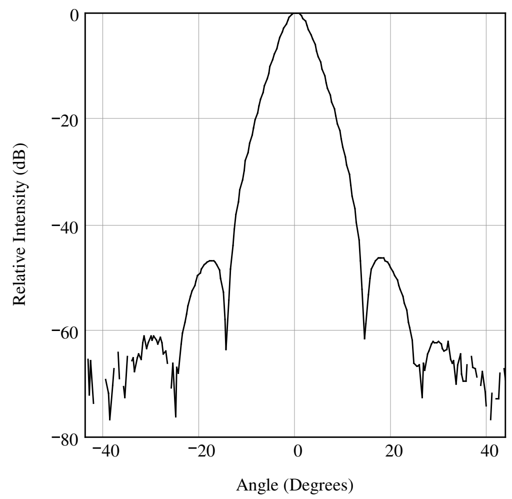

Figure 2. Example of a measured far-field intensity distribution including side-lobes. Matched cladding fibre at 1551 nm.

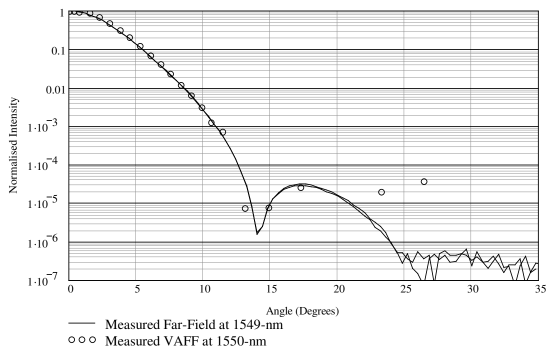

Figure 3. DFF and VAFF measurements of the far-field distribution from an attenuation-flattened fibre.

Summary

Four techniques have been used to measure the effective area of single-mode optical fibre. The near-field scan method is the most direct but requires an imaging system, which can introduce uncertainty through aberrations. The variable aperture method is quick and convenient but may not permit side-lobe inversion. The transverse offset technique is difficult to perform in practice since it requires precise positioning and is highly sensitive to vibration. The far-field scan method has been chosen as the basis for an effective area measurement service due to its ease of operation, repeatability and facility to invert side-lobes.

References

/1/ ITU COM 15-273-E "Definition and Test Methods for the Relevant Parameters of Single-Mode Fibres - Appendix on Nonlinearities for G.650", (1996).