

SIMPLE TECHNIQUE FOR MEASUREMENT OF EQUALISATION WAVELENGTH IN SINGLE-MODE OPTICAL FIBRES

Indexing term: Optical fibres

A simple technique for the measurement of equalisation wavelength between the LP_{11} and LP_{01} modes of an optical fibre using a white light source is reported. The method provides a measurement which is insensitive to fibre bends, unlike the measurement of the cutoff wavelength of the LP_{11} mode. The use of the equalisation wavelength for fibre characterisation is also proposed.

Introduction: The measurement of the cutoff wavelength λ_c of the LP_{11} mode of an optical fibre has been an important parameter in fibre characterisation, as it determines the wavelength region of single-mode operation. Furthermore, this information, together with the wavelength dependence of the fibre spot size, has been used to predict other fibre properties such as dispersion. The cutoff point, being a secondary property of the guide, may not be precisely measured. Near the theoretical cutoff wavelength the mode is loosely bound and may continue to propagate, but is very sensitive to the state of the fibre during measurement. This requires the definition of an effective cutoff wavelength λ_{ce} , which is defined as the point where the loss of the LP_{11} mode is equal to an arbitrary value. The value of this effective cutoff wavelength can be subject to shifts as large as ± 50 nm when the fibre is inevitably subject to bends during measurement.¹ This difficulty in the measurement of λ_{ce} could introduce large errors to fibre characterisation based on λ_{ce} .

An unambiguous fibre parameter to address the above-mentioned problems would therefore be desirable. The equalisation wavelength λ_e of the LP_{01} and LP_{11} modes of a single-mode fibre operated in the dual-mode wavelength regime²⁻⁴ has been recognised as a suitable candidate for fibre characterisation. It occurs at a well defined V -value and the measurement is precise, and since wavelength rather than intensity is measured, factors such as detector linearity and the condition of the fibre do not affect the measured value. Recently,⁵ we have described a method for determining the ESI fibre parameters using λ_e . Previously the method presented for the measurement of λ_e , although simple, involved the use of a Raman laser and therefore was not acceptable as a measurement for a factory environment. In this letter we present a simple white light method for measuring λ_e using equipment already available for the measurement of λ_c , hence rendering the measurement of λ_e more acceptable to a factory environment. Also, we demonstrate the advantages of using λ_e instead of λ_c for fibre characterisation.

Measurement method: Light launched in a fibre operated in the dual-mode wavelength region will excite both LP_{01} and LP_{11} modes as long as the launching is slightly off-axis. Provided that the group time delay difference T between the modes is less than the coherence time of the light τ , ($T < \tau$) interference will be observed.

The equalisation wavelength of the fibre is the wavelength at which the group velocities of the LP_{01} and LP_{11} modes are the same. The experimental set-up for this measurement is shown in Fig. 1. White light from a tungsten halogen source is launched through a chopper and monochromator into the fibre under test. The fibre end is held on a three-dimensional micropositioner to ensure off-axis launching into the fibre.

The fibre length is chosen to be between 0.5 to 1 m, such that the interference fringes are sufficiently separated, in order to be resolved. The output end is placed on coarse micropositioners and with the aid of a lens one of the interference lobes is focused on to a small-area detector. The output is read from a lock-in amplifier interfaced to a desk-top computer.

A polariser could be inserted at the output end of the fibre to improve the visibility of the interference fringes if necessary. The intensity of one of the lobes is plotted against the wavelength as the monochromator aperture width, and detected power (with or without the polariser) for maximum visibility of the fringes. Fig. 2 shows a typical output. The range of the

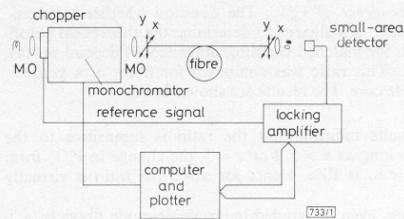


Fig. 1 Experimental arrangement for measurement of equalisation wavelength

visible fringes is from 1050 nm to 1170 nm. From the symmetry of the oscillations we can clearly locate λ_e precisely to within 2 nm. It must be pointed out that a combination of LEDs covering the wavelength range of interest is preferred to white light, but it is not always possible to obtain LEDs operating in the wavelength region of interest. The precision of the measurement is next examined as the state of the fibre is altered.

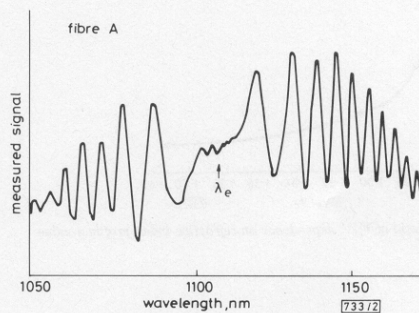


Fig. 2 White light interferogram as obtained from equipment shown in Fig. 1

Insensitivity of λ_e to bends: The dependence of λ_e on fibre bending is important to determine the reliability of the measurement. For this, the fibre in the experimental set-up of Fig. 1 was wound on to cylinders of different diameters. The wavelength was scanned and λ_e was measured for cylinders of decreasing diameter. Four samples of the results are shown in Fig. 3. We can clearly determine λ_e and λ_{ce} from the traces. Therefore, with a single experiment, these parameters can be determined. As the bend radius decreases, the cutoff wavelength shifts to shorter wavelengths, whereas the value of λ_e remains consistent to within 1 nm. Sharp bends therefore make the measurement difficult (or even impossible) but never inaccurate. For example, Fig. 3 shows that, for bend radii less than 28 mm, λ_c is equal to or even less than λ_e . This could also be used as the basis of a standard test on fibre sensitivity to bending. For example, a standard length, say 0.5 m, of fibre could be used to measure the bend radius for which $\lambda_e = \lambda_c$. The insensitivity of λ_e to bends is therefore a major reason for the choice of λ_e instead of λ_c for fibre characterisation.

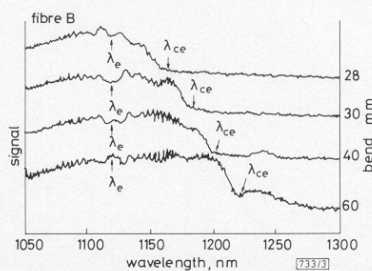


Fig. 3 Dependence of λ_e and λ_{ce} on bend radius

Profile dependence of V_d/V_c : The question whether the measurement of λ_e is sufficient to determine the theoretical cutoff wavelength for matched cladding fibres would depend on the ratio V_d/V_c . This ratio was computed for fibres of a graded-index profile core. The results are shown in Fig. 4.

The results indicate that the ratio is insensitive to the α -value so long as $\alpha > 5$. For $\alpha = 5$, the change in V_d/V_c from that of $\alpha = \infty$ is 10%. Hence for $\alpha > 5$ the ratio is virtually constant.

Therefore, even for graded-index single-mode fibres ($\alpha > 5$) the measurement of λ_e can be used to predict the theoretical cutoff wavelength, or indeed substitute λ_c with λ_e .

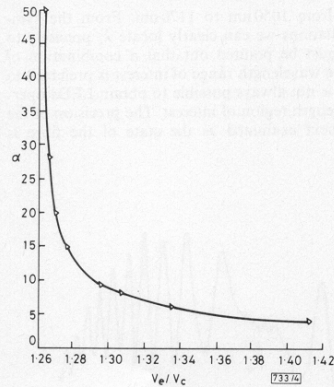


Fig. 4 Ratio of V_d/V_c dependence on refractive-index profile α -value

Conclusions: A new method is demonstrated for the measurement of the equalisation wavelength λ_e of optical fibres, using a white light source. The measurement uses the same experimental set-up as that for the measurement of the cutoff wavelength λ_c . We have shown that the measurement of λ_e is insensitive to the state of fibre (i.e. is unaffected by bends), unlike λ_c . For typical quasi-step-index fibres of matched cladding design λ_e/λ_c is also insensitive to profile variations. We propose to use λ_e instead of λ_c for the characterisation of matched cladding optical fibres.

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