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Calibration and Correction of the Non-Linearity of the Response of an InGaAs Array for Mode Field Profiling

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Abstract: InGaAs arrays can be used to measure the magnified image of mode field profiles at 1550 nm. In order to make accurate profile measurements in this way the array needs to be fully characterised. In this paper details of the calibration of the non-linearity of the response of an InGaAs array are described. The responsivity of the array changes considerably with optical illumination unlike that of single InGaAs detectors. Without correction for this non-linearity the mode field diameter calculated from the measured mode field profile is overestimated by 15%.

Introduction

Mode field profile measurements of fibre and optical waveguides can be made using the well known magnified near field image technique[viii]. The experimental arrangement is simplified by the use of a detector array to record the magnified image of the mode field profile. The magnified near field profiler at NPL is based on an InGaAs array of 320 by 256 pixels, each 30 x 30 μm. The optical magnification gives an effective pixel size in the object plane of 0.375 x 0.375 μm, which is smaller than the optical resolution of the objective. Each pixel is read to 12 bits of resolution giving approximately 36 dB of dynamic range, averaging is thus required to achieve the 40 dB of dynamic range needed for accurate mode field profile measurements. The use of an InGaAs array allows the mode field profiles to be measured at 1550 nm.

In order to obtain accurate measurements it is important to characterise the detector array for pixel linearity, pixel-to-pixel uniformity and pixel-to-pixel cross talk. This paper considers only the pixel linearity. This can be tested using the well-known comparison technique [1] where the detector array is compared against a linear well-characterised optical power meter.

Measurements

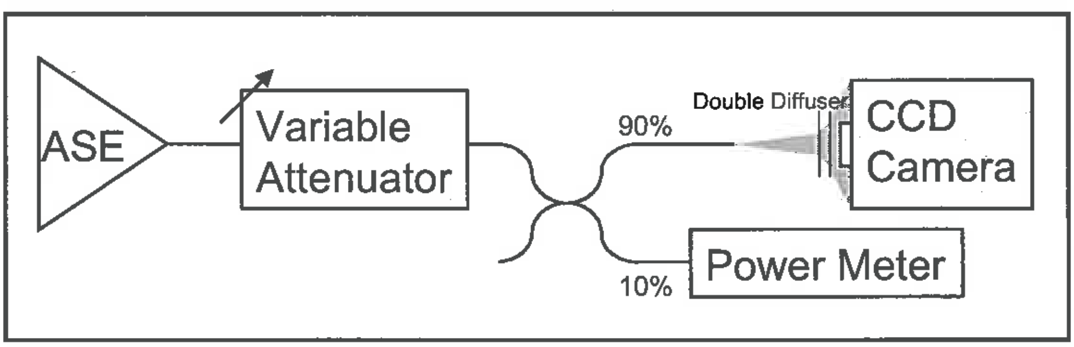

Figure 1: Experimental arrangement.

The InGaAs array under test was roughly illuminated by allowing the beam from a single mode optical fibre to expand and pass through two diffusers before falling onto the sensor array, see figure 1. This gave approximately uniform illumination of the sensor array with a variation of less than ±20%, see figure 2. An erbium-doped fibre amplifier was used as a spontaneous emission source providing the optical power, the broadband nature of this source helps to eliminate any speckle patterning. The optical power was controlled by a variable attenuator before being divided by a 90/10 splitter between the InGaAs array under test and a calibrated linear optical power meter. An assessment was made of the stability of the 90/10 splitter by replacing the InGaAs array with a second calibrated linear power meter. The combined effect of the 90/10 splitter stability and the linearity of the calibrated power meter led to an uncertainty of less than 0.2% in changes in the optical power falling onto the InGaAs array.

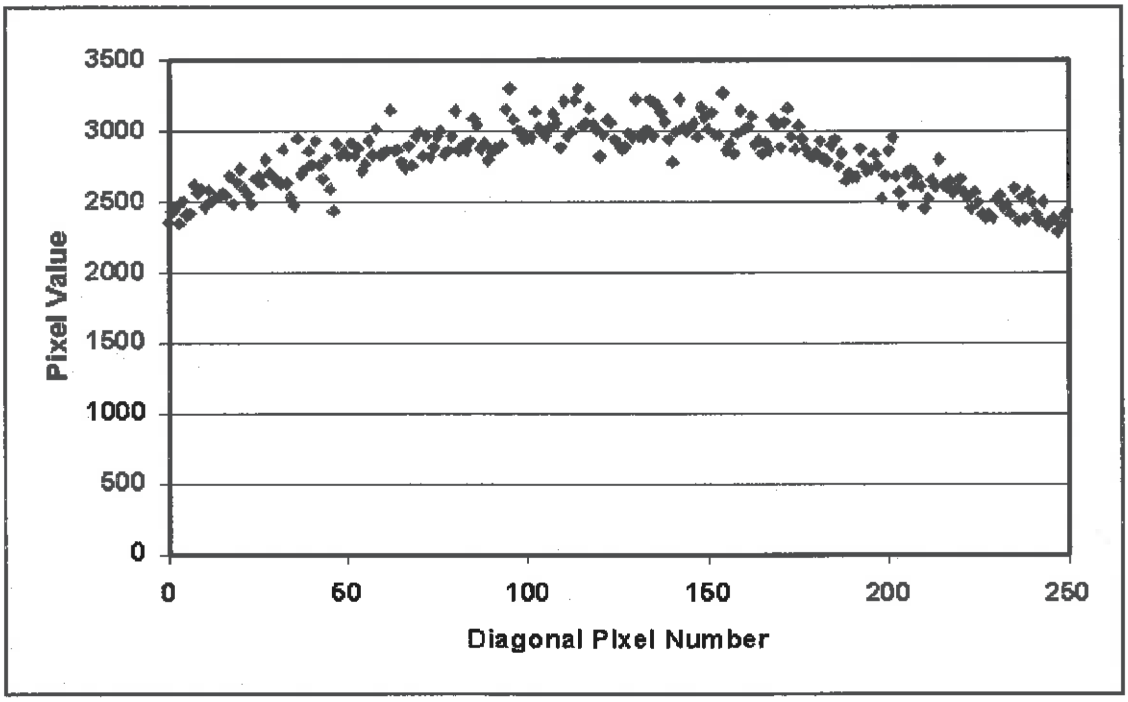

Figure 2: Diagonal cross section of the intensity falling onto the CCD array. Diagonal pixel number 125 is in the centre of the array, 0 is top left and 250 is bottom right.

The calibration of the linearity of the InGaAs array was controlled by computer. The variable attenuator was stepped from 0 dB to 50 dB in 1 dB steps. For each attenuator setting a light and dark image was recorded from the InGaAs array. Each image was an average of 200 frames taken with a 25 μs integration time. This setting having previously been found to give the best signal to noise. The 10% pick-off optical power was also recorded from the power meter.

Data Analysis

At each attenuator setting a light and dark average of 200 images were recorded. The first stage of data processing involved subtracting the dark image from the light image and removing the bad pixels. Bad pixels are defined as pixels with either an a-typical dark value or an a-typical responsivity. A look up table of the position of bad pixels is maintained and updated after the calibration process.

We now have a large number of pixels each measured with optical input intensity at 1 dB intervals over 50 dB. However as the optical illumination was not completely uniform and each pixel may have a different responsivity each pixel has a different expectation value for a given attenuator setting and measured 10% pick-off power. It is necessary to normalise the pixel value in order to determine the pixel linearity. This was done by determining, for each individual pixel, the power meter reading that would result in a pixel value of 1000, $P_{10\%}(1000)$. This was found by interpolation of the three power levels that gave pixel readings around 1000, giving a reference pick-off power for each individual pixel. The pixel non-linearity, nl(v), for a pixel value, v, is defined as [2]

$$nl(v) = \frac{r(v)}{r(1000)} - 1 = \frac{v}{P_{10\%}(v)} \cdot \frac{P_{10\%}(1000)}{1000} - 1 \qquad (1)$$

where r(v) is the responsivity and $P_{10\%}(v)$ is the 10% pick-off power for a pixel value, v. The expected pixel value $v_{expected}$ is given by

$$v_{expected} = \frac{v}{nl(v)+1} = p_{10\%}(v) \cdot \frac{1000}{P_{10\%}(1000)} \qquad (2)$$

Results

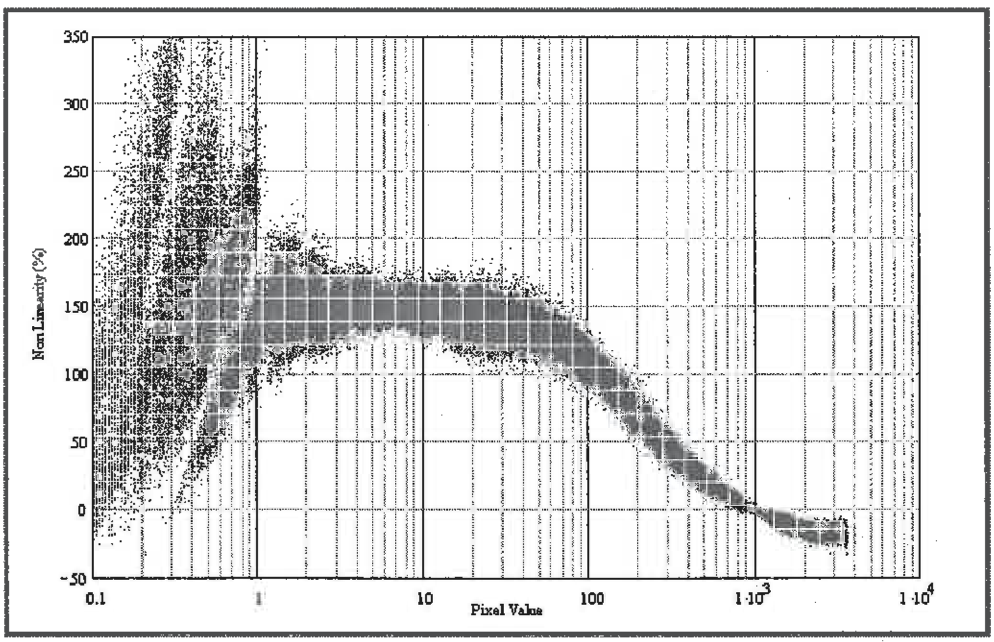

Figure 3: Non linearity vs pixel value, referenced to a pixel value of 1000.

Figure 3 shows the measured non-linearity vs pixel level and shows considerable non-lineartiy, this would significantly affect the mode field profile. In order to correct the CCD array output the non-linearity curve was fitted to a quartic function against the log of pixel value. Using the log pixel value allows the fit to be better weighted across the dynamic range of the CCD array. Figure

Figure shows the corrected pixel value vs the expected linear pixel value. The correction was calculated from data taken two months earlier, showing good reproducibility. This shows good linearity over 40 dB of dynamic range with a pixel error of <1 dB over a 35 dB range rising only slightly due to the noise at lower levels.

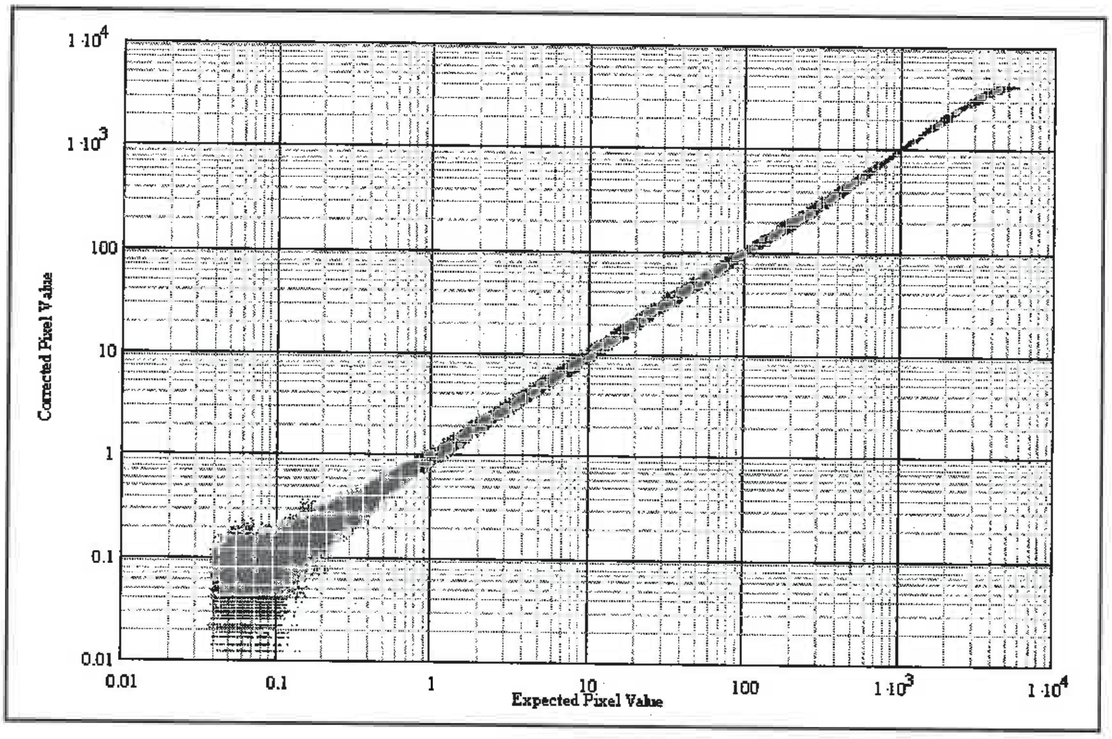

Figure 4: Corrected pixel value vs expected pixel value

Conclusions

The non-linearity of an InGaAs array was characterised using the comparison method. It was found that the variation in the responsivity of the array with optical input was much larger than that for a typical single InGaAs detector or power meter. After correction the InGaAs array shows good linearity within the noise. The correction factors used were found to remain suitable for several months suggesting that the non-linearity characteristic of the InGaAs array is stable. The correction factors used were independent of the actual pixel and it was found that no significant improvement could be made by using a pixel specific correction. The results of averaging 200 frames give a total dynamic range in excess of 40 dB with a pixel error of <1 dB over a 35 dB range. This is suitable for the measurement of mode field profiles. It has been found that an error of about 15% on the mode field diameter would result of the non-linearity corrections were not applied to the measured data.

Acknowledgements
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References

[1] W. T. ANDERSON, D. L. PHILEN, "Spot Size Measurements for Single-Mode Fibers – A Comparison of Four Techniques", J. of Light. Tech., Vol LT-1 No 1, March 1983, pp20- 26.
[2] IEC 61315 Ed. 1.0: "Calibration of fibre-optic power meters".