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F. J. Achten[1], T. Boone[2], P. Pepeljugoski[2], C. Brokke[3], P. Pleunis[1]

[1] Draka Fibre Technology
P.O. Box 1442
5602 BK Eindhoven
The Netherlands

[2] IBM Research Division
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598

[3] Photon Kinetics
9305 SW Gemini Drive
Beaverton, OR 97008

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F.J. Achten[1], T. Boone[2], P. Pepeljugoski[2], C. Brokke[3], P. Pleunis[1]

[1]Draka Fibre Technology, P.O. Box 1442, 5602 BK Eindhoven, The Netherlands
[2]IBM Research, P.O. Box 218, Yorktown Heights, NY 10598, USA
[3]Photon Kinetics, 9305 SW Gemini Drive, Beaverton, OR 97008, USA

Summary

The results of Differential Mode Delay (DMD) measurements using three different measurement set-ups have been compared in a three partner inter-company round robin. The tested fibres included twelve 850-nm laser-optimised, 50 μm core diameter graded index multimode optical fibres designed for 10 Gigabit Ethernet applications. The measurement results show on average good agreement for fibres with moderate DMD values. From the detailed comparison of the results improvement issues were derived which have been used for further up-grading of the set-ups to measure low DMD fibres.

1 Introduction

The increasing demand for higher bit-rates in data-systems has led to the development of 10 Gigabit Ethernet and Fibre Channel local area networks. In the IEEE 802-3ae standard for these networks, a new Graded Index Multimode (GIMM) fibre with a 50 μm core diameter is considered as a feasible low cost solution at 850 nm for distances up to 300 metres. Qualification of this new fibre for its challenging performance [1] sets severe requirements on the test methods. Additional to the traditional overfilled launch bandwidth measurement, the performance of the multimode fibre is tested using the Differential Mode Delay (DMD) measurement, according to the standardized IEC test method [2]. DMD measurements provide far more information on fibre modal dispersion compared to traditional bandwidth measurements, and this information allows manufacturers to insure 10 Gb/s performance. From the DMD profile of the fibre the Effective Modal Bandwidth (EMBc) can be calculated [3] which is a far more useful indicator of system performance than the overfilled launch bandwidth.

To measure DMD, an 850 nm pulsed laser beam is launched into the fibre under test by either a launch fibre, or a lens system, both fulfilling the requirement of a spot size diameter of 5.0 ± 0.5 μm. The launch spot is transversely scanned across the core of the fibre under test, starting at the optical centre of the core, and moving towards the cladding. At a discrete number of evenly spaced transverse positions the pulse leaving the fibre under test is detected and stored. Collectively these output pulses form the DMD [ps/m] profile of the fibre. This profile represents the delay time differences between the various principal mode groups excited at subsequent launch positions. An ideal fibre shows a DMD profile with ‘unchanged’ pulses, all leaving the fibre at exact the same time.

To be able to measure the DMD profile in a reliable way, one has to take care to exclude or compensate for chromatic dispersion effects on the pulses travelling through the fibre. This either requires a laser with very narrow line width (e.g. typical 0.2 nm RMS-width at 850 nm when measuring a 1km fibre length), or a reasonably narrow spectrum laser to which chromatic dispersion corrections can be applied [2,3]. The objective of this is to ensure that errors due to chromatic dispersion effects are limited to less than 10% of the measured DMD value. Second key requirement is a short laser pulse duration to have a sufficient measurement resolution, typically ≤ 160 ps FWQM (= full width at 25% (quarter) of maximum height).

In view of the rather high level of accuracy requirements to the DMD set-ups, it makes sense to gain confidence in the results by organizing comparisons between the test results of different set-ups all testing the same fibre sample. In this paper, we compare the results of different DMD test set-ups as were achieved in a round robin with 3 participants, mentioned in the article heading. Although DMD tests are possible on much longer fibre lengths, the focus in this paper is on rather short sample lengths

to prevent the averaging effect originating from occasional longitudinal in-homogeneities along the fibre axis.
The set-ups of the participants have been developed independently and are compliant with the measurement standard recently adopted by the IEC [2] and TIA [3].

2 Measurement set-ups

Potential sources of differences in measurement results are:

- Method of alignment when tracing the optical centre of the fibre.
- Method of launching light into the fibre under test (direct imaging from a launch fibre, or using beam optics to image the launch spot).
- Spatial resolution, repeatability and accuracy of the launch fibre translation unit.
- Spectral, temporal and noise characteristics of the pulsed laser source.
- Trigger stability of the laser control unit and signal analyser.

Although there is a great similarity between the basics of the 3 set-ups, yet there are some differences requiring separate description of the individual set-ups.

Draka Fibre Technology (DFT):

To trace the optical centre of the fibre, a closed loop nm resolution system is used scanning the launch spot along the core of the fibre under test. Due to this system, backlash effects are reduced resulting in a repeatability in the order of 0.1 μm. Two perpendicular scans are performed with decreasing step size to mark four specific distances from the core-cladding interface. The central position between these marked positions determines the optical centre of the fibre. Repeatability of central position is about 1 μm. The pulse is launched from a single mode fibre with mode field diameter of 5.5 μm at 850 nm.
The laser is a pulsed diode laser (repetition rate 20 MHz) with an external Fibre Bragg Grating (FBG) to narrow the spectral line width to 0.1 nm. The pulse duration is about 160 ps FWQM. This kind of laser has the advantage of being laser class 1, so safer to use within production environment compared to commonly used high power mode-locked lasers. Disadvantage is the relatively higher line width and larger pulse duration, limiting the resolution of the measurement.

Photon Kinetics (PK):

A narrow line width 845 nm diode laser without external cavity, is pigtailed with a single mode fibre with a 5 μm mode field diameter. Through a set of lenses, the output of the single mode is imaged 1:1 onto the fibre under test. The typical spectral line width of the laser is 0.15 nm. The pulse used for the measurements has a width of 160 ps FWQM. Pulsing of the laser occurs at a repetition rate of 62.5 kHz.

Locating the centre of the fibre under test is achieved with the following routine. The maximum of the first received pulse is detected after which the launch spot is moved to the edge of the core and the edge is searched for a pulse that is about 20% of the magnitude of the first pulse. This pulse and the precise position are recorded. The launch spot is then moved to the other edge of the core to find the equivalent pulse with the same height at that edge. The centre of the fibre core in this direction is then defined at the centre of both located edge positions. Using the same process, but orthogonally to the previous scan direction and combining the results defines the exact position of the fibre core centre. The positional accuracy for this centre find routine is 0.5 μm.

IBM Research:
The mechanical portion of the DMD set-up is similar to the ones described above. The resolution of the mechanical system is 0.1 μm, and its accuracy 0.5 μm. In the set-up a Ti:Sapphire mode locked laser is used with a repetition rate of 80 MHz. The source line width is 0.1 nm and in the tests the pulse duration was detector limited at 40 ps FWQM. The intrinsic pulse duration is between 2 and 5 ps. The low line width and pulse duration offer good resolution and less need to rely on calculations.
The optical centre is found similarly to the previous procedures by performing two scans in perpendicular directions and optimising the received power. However, there still may be some residual

error in finding the optical centre. Therefore, the DMD scans are performed from both directions of the centre of the fibre, and the error in the signals that are assumed to be at the same distance from the centre of the fibre is calculated. The new optical centre is the one that minimises the error in the signals from both directions.

3 DMD measurement comparison

An optical fibre cable has been tested on each of the three set-ups. The cable consists of twelve 850-nm laser-optimised, 50 μm core diameter, GIMM optical fibres for 10 Gb/s applications, with a rather short length of 571 m. The fibres have been identified by their colours. In the round robin, all measurements are performed well in time, with special attention on fibre preparation to avoid bad cleaving influences on the result. The DMD value (outer mask 0 – 23 μm) of the fibre is determined according to recommendations outlined in [2-4], using the method of subtracting the launch pulse duration from the DMD value. The DMD measurement results are not corrected for chromatic dispersion effects because all used lasers has sufficiently small RMS line widths for this rather short test length.
The results, as plotted in Fig.1, clearly show a good correlation in the results with respect to absolute DMD values, but also systematic differences between the three set-ups for most fibres. The explanation of the results is restricted to a few items only, resulting from an in-depth comparison of the total test results.

The DFT set-up shows on average the highest DMD values, and in particular on fibres with the lowest DMD values. This can be attributed to the larger laser pulse width, as well as contribution of trigger and pulse instabilities. This resolution limiting effect has been investigated accordingly and improvements have been made to the setup. Measured DMD numbers start being inaccurate to some extend at 571 m length fibres and using an 160 ps duration input pulse when DMD is below 0.25 ps/m, as is the case in the DFT and PK set-ups [3]. Because of the small pulse widths used due to the fast laser-detector combination, the IBM setup is able to show more mode structure, as evident from the traces for 0 and 1 μm offsets on Figure 2c, while the other two setups show smooth pulses. With this in mind, and ruling out launch spot and position accuracies, it is plausible to consider the IBM result as a reference for the fibres with the lower DMD values. Furthermore, errors due to deconvolution of the system impulse response are minimised when short pulses are used because smaller quantity is subtracted from a large quantity. However, in all cases, the deconvolution procedure described in [3] was used and therefore the impact of the actual pulse shape is additional source of error.

In this comparison measurement, each fibre is measured once only. As launch spot position accuracies and fibre preparation induce statistical differences, accuracy may be improved by performing multiple measurements. However, in a fibre production environment this will increase cost. In this respect, the achieved agreement in the measurement results per individual fibre is quite acceptable.

As a detailed example of the comparison results the DMD curves of the red fibre has been plotted in Fig. 2 for the three set-ups. Please note the difference in timescales. Comparing the three figures, a severe difference between the PK and DFT set-ups can be noticed. This fibre shows some dominant pulse broadening at a radial position of 23 μm with the DFT set-up determining largely the recorded DMD value. Apparently, the measurement result is very critical on the exact radial position and spatial shape of the launch spot. At 23 μm radial position some part of the light is launched into the cladding. The amount of light is depending not only on launch position accuracy, but also on occasional non-circularities of the fibre core and small disturbances on the core-cladding interface. By checking the power of the ’23 μm pulse’, which appeared to be lower in the DFT set-up than in the other set-ups, it is clear that the DFT set-up measures relatively closer towards the cladding, so is more sensitive to near cladding disturbances in the fibre profile [3].

4 Conclusions

Measurement results on the three DMD set-ups show on average good absolute agreement, and indicate that the overall accuracy of the DMD measurement procedure is satisfactory for fibres with moderate DMD values. Excluding the fibres with very low DMD values, the average error between the

PK and IBM setup was ~15%. Systematic differences can be explained to a reasonable extent, but more research on launch spot position, size and light distribution and pulse shape impact is necessary to get a full understanding. This is particularly important for the characterization of very low DMD fibres, where better resolution will be required. For this reason, and taking into account the results of this round robin, both the DFT and PK set-up recently were up-graded with lasers that generate shorter pulses. We believe that when these issues are properly addressed, that differences of less than 10% can be achieved in DMD measurements in different setups.

References

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Fig. 1: Measurement results of DMD values for twelve cabled fibres, each with a 571 m length, on three different DMD set-ups. Colours indicate fibres.

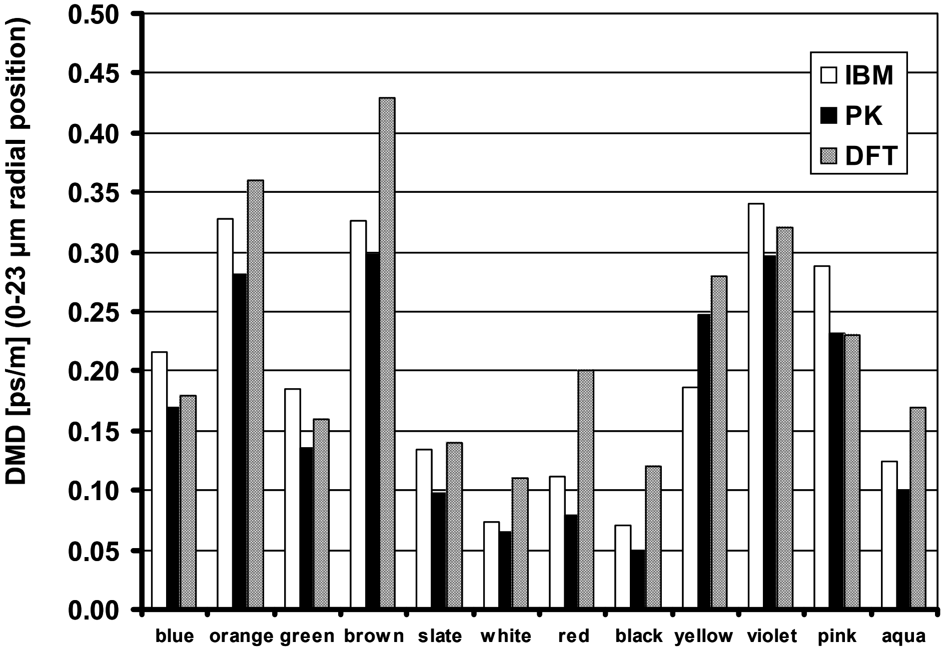

Fig.1

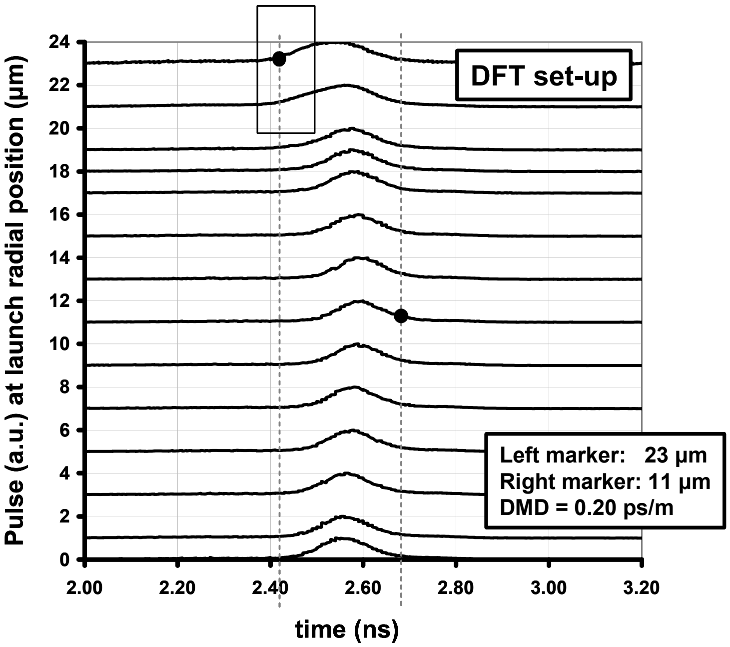

Fig.2a: DMD profile of red fibre on DFT set-up showing the onset of other mode groups near the core edge (see square insert)

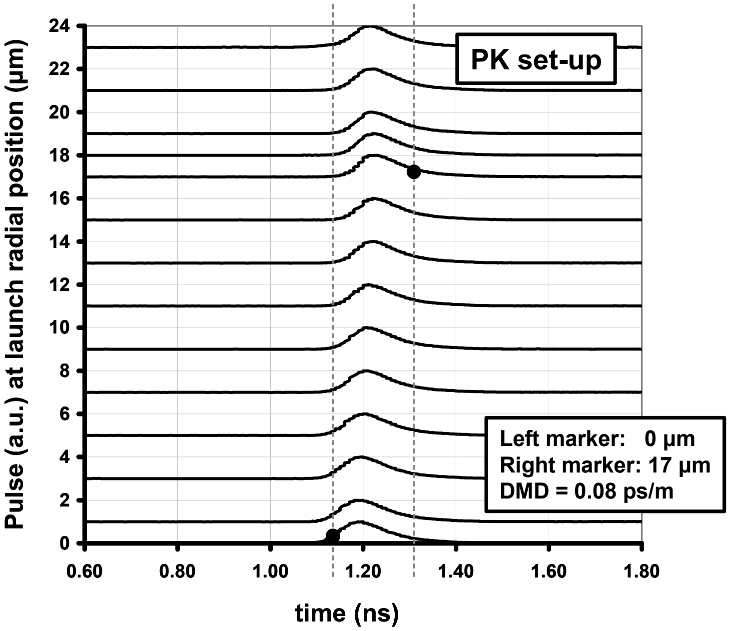

Fig 2b: DMD profile of red fibre on PK set-up

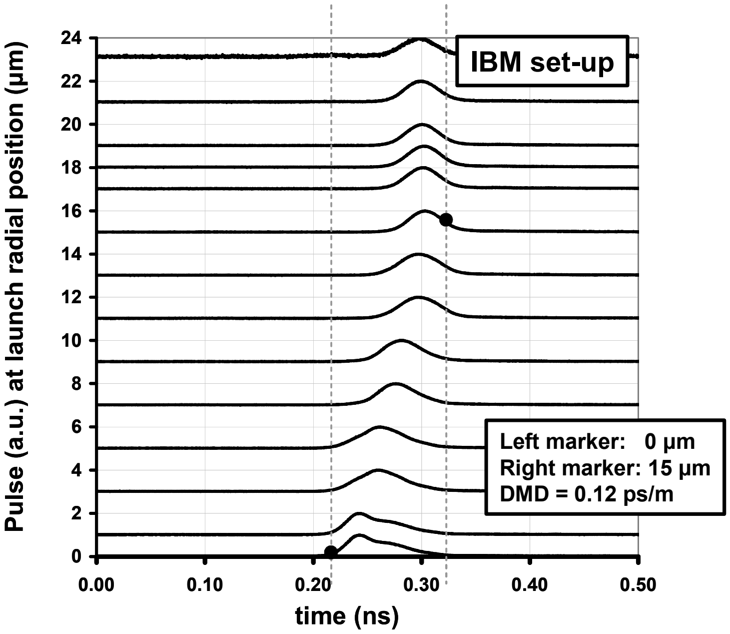

Fig 2c: DMD profile of red fibre on IBM set-up