Metrology and Standardization of High Speed Pluggable Optical Interconnects

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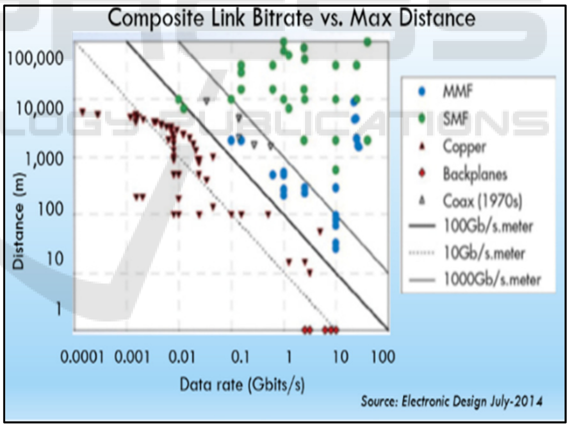
Abstract: This paper describes research carried out under EURAMET project 14IND13 on the characterization of short-range optical interconnect technology. This paper aims to disseminate to the wider communications sector the primary importance of metrology and the need for standards associated with these emerging technologies. The focus of the research is the functional performance of embedded polymer waveguides. The results of various crucial parameters are described and their relevance and influence upon existing national and international standards discussed.

1 INTRODUCTION

Continuing high growth in the world's data traffic has led to many improvements in fibre and detector technologies (Hogan, 2017). Along with these developments has been the need to develop optical short range or 'intra-rack' links within data centres to reduce the bandwidth bottleneck thereby providing seamless connectivity from external optical networks/data centres through to inter pod, cluster and rack level (Senko, 2020). Optical links on a pluggable daughter board offer vastly improved data transfer speeds compared with copper based electrical interfaces which are fundamentally limited in terms of bitrate over distance to ~100Gb/s/m compared to optical interfaces (>1000Gb/s/m). These optical links can be incorporated into PCB boards and are known as electro-optical circuit board (EOCB's).

Broadly EOCBs fall within three categories: Fibre-optic laminate, polymer waveguides (Ingham et al., 2006) and planar glass waveguides (Pitwon, 2016). In the work presented in this paper, we focused on the characterisation of the polymer waveguides and studied the thermal impact on three key parameters; namely EF, total attenuation and bit error ratio (BER).



Source: Electronic Design July-2014

Figure 1: Technology Summary of Link Bitrate vs Distance.

2 INDUSTRIAL NEED

As the technology rapidly develops there is a corresponding need to provide characterisation of these boards for the key operational parameters such as attenuation, isolation (crosstalk) and BER as well as a need to provide standardisation through the activities of international standards bodies. The market research firm CIR states, '…the lack of

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standards has held back growth in optical engine use. If such standards emerge, CIR expects the market for optical engines could reach $1.2 billion by 2022' (Lightwave Staff article, 2017). Significant recent work within the International Electrotechnical Commission (IEC) technical committee 86, has improved standardisation of critical measurements as well as the adoption of a reliable measurement definition system for optical interconnects. This is a crucial prerequisite for future commercial adoption of optical circuit board technology (IEC 62496-2:2017 (E) - Optical circuit boards - Basic test and measurement procedures - Part 2: General guidance for definition of measurement conditions for optical characteristics of optical circuit boards). As stated in 62496-2:2017 (E), 'Independent repeatability of waveguide measurements is still very difficult to achieve due to the lack of clarity on how measurement conditions are specified…such a definition system shall capture sufficient information about the measurement conditions to ensure that the results of measurement on an identical test sample by independent parties will be consistent within an acceptable margin of error'.

A clear understanding of the measurement condition goes hand in hand with an understanding of the functional performance of an EOCB. While work has been carried out in assessing passive boards by industry and academic institutions for a number of years (Selviah, 2010), less work has been carried out to understand a boards performance at operational temperatures. Industry led discussions have shown a need to investigate the potential effects of applying thermal hotspots to EOCB's to simulate expected electric components integrated within the board. These components may well be central processor units (CPU's) or transceivers. Parameters such as attenuation, BER and the Encircled Flux (EF) can be measured during applied and controlled thermal loading. Effects upon the change in refractive index ($\Delta n/\Delta t$) as well as the combined stresses on the mechanics of the board structure are important areas of investigation that need to be understood as specifications and standards develop and board technology improves and becomes more complex.

3 CHARACTERIZATION

The principal instrument used to assess the functional performance of embedded waveguides is the Variable Launch System providing a flexible platform to permit a range of *NA*'s and spot sizes to be focused onto the entrance facet of a particular waveguide (Ives et al., 2011). Transmission through the waveguide is then received on an IR camera and the image analysed in a variety of ways to provide assessments of total attenuation, isolation and EF. Combining this platform with a suitable unit to apply a controlled thermal load to a mounted EOCB, provides a powerful way of assessing the functional performance of waveguides on a particular board with respect to the simulation of thermal effects of incorporated electrical components. The unit chosen to provide thermal controlled loading was a Thermostream ATS – 505 purchased from inTEST Thermal Solutions, Corporation, USA. The temperature range demanded by the EOCB functional environment was determined to be ~ -5 to 80°C (IPC-TM-650, 1997).

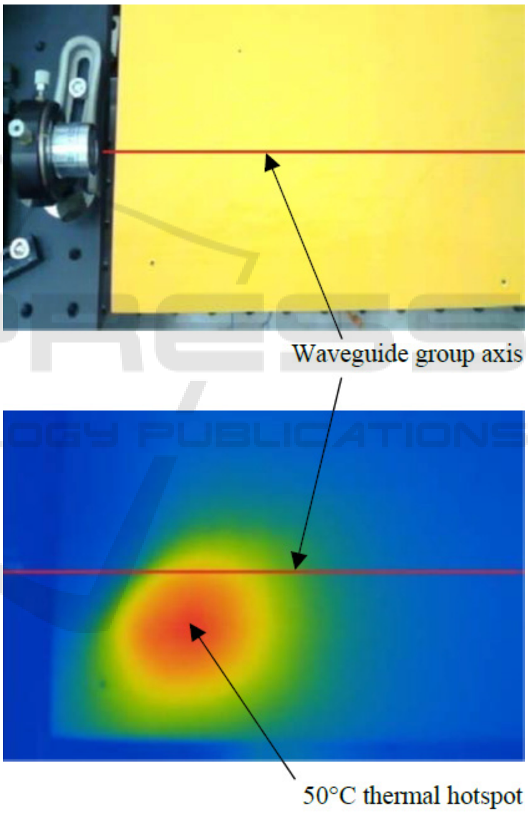

Figure 2: Visible and infra-red images of an example thermal hotspot on the EOCB using the Thermostream nozzle and selected circular shroud.

The siloxane (Kai Su et al., 2005) polymer waveguides of the test EOCB were produced photolithographically and mounted on an FR4 substrate board. Each waveguide supports many modes so there is necessarily an importance placed on the nature of the light that enters the guide as this will determine modal and energy distribution exiting the guide. Ideal launch conditions should occur if the light is distributed through the whole core (IEC 61300-1, 2016). With multimode waveguides, launch conditions may typically be characterized as being underfilled or overfilled, neither of which are considered optimal as both can result in measurement variations. Knowing and controlling the launch condition is therefore important to make sense of any measurements upon parameters that help characterize link losses and bandwidth utilisation.

In order to assess the launch conditions of the NPL system, an Arden Photonics' Modal Explorer MPX-1 was placed to accommodate the 850 nm launch spot. By altering the launch *NA* and spot size of the system preliminary measurements showed the EF was within prescribed EF templates as stipulated in IEC 61280-4-1/Ed3/CD:2015. Modal conditioning was also incorporated into the variable launch system to ensure conformity to key recommended launch profiles as defined in Table 1 of IEC 62496-2:2017 (E). The 'L2' launch profile was preferred '…in which the modal profile is generated, which complies with the restricted launch EF requirements of IEC 61280-4-1/Ed3/CD:2015' (*Ibid.*) and to achieve this launch profile, modal conditioning was used (IEC 61300-1, 2016). The source was passed into a 5m graded index multimode fibre (GI-MMF) which is wrapped 20 times around a 38 mm diameter mandrel. The output of the mandrel is then passed through a commercial mode conditioner supplied by Arden Photonics, producing a mode filtered optical intensity profile, which complies with EF requirement of IEC 61280-4-1. This is then used as the input to a 5 m GI-MMF, which is wrapped 20 times around the 38 mm diameter mandrel to produce a mode-stripped optical intensity profile at the GI-MMF launch facet. Once the launch condition has been established measurements could be carried out for the attenuation, EF and BER of selected waveguides.

4 RESULTS

4.1 Total Attenuation across the Thermal Range

The board was mounted on a large translation stage and secured using silicone gel pads that provided a method to prevent the board from moving during the measurement runs and to counter any possible low frequency vibrations. Careful alignment was necessary to ensure that the launch spot was centrally located on the front facet of the selected waveguide. The receive board was brought into place and alignments carried out to ensure the image of the illuminated waveguide was projected onto the centre of the CCD. The signal image was analysed to find the centre of the intensity and the total power was found by summing all the pixels contained within a circular area around this centre. The diameter of this virtual pinhole was adjusted to capture all the light exiting these waveguides. In the case of these relatively large waveguides a 150 µm virtual pinhole was used. To calculate attenuation, the ratio of the total input to the input image reference was divided by the ratio of the total output to its reference. This measurement technique provided the insertion loss of the waveguide under test, which includes intrinsic waveguide loss and coupling losses. The results for a selected waveguide are shown below.

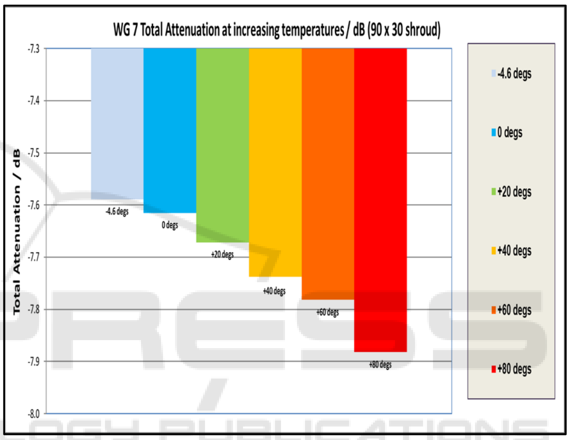

Figure 3: Total attenuation against temperature for a particular waveguide.

The increase in applied thermal load indicates a small, but observable increase in the total attenuation. The maximum range of the measured total attenuation was ~0.3 dB using the 90 x 30 mm shroud centrally placed over the waveguide group. The expanded uncertainties associated with the measurements are estimated as ranging from U95 < +/- 0.1 dB at 20°C and +/- 0.20 dB at 80°C. These are derived from observed repeatable measurements and the established system uncertainties (Ives et al., 2011).

4.2 Encircled Flux across Thermal Range

The board was again setup to receive the controlled launch condition 'L2'. The MPX-1 was used at the output facet of the waveguide and the focus optimized. EF measurements were made covering the same thermal range as for the attenuation measurements and the same size of shroud and position on the board. Measurements were carried out on two waveguides (WG5 and 7) using 1000 averages in order to capture the modal energy distribution. In each case the ambient temperature was recorded. As with the total attenuation, the increase in applied thermal load indicates a small but observable shift in the Encircled Flux profiles consistent with higher order modes being decoupled from the guide due to the effects of the increased thermal load upon the guide and associated changes in the core cladding refractive index ratio. Preliminary uncertainties estimated for the EF measurements at the worst-case repeatability of 80°C give a U95 of +/- 0.0045.

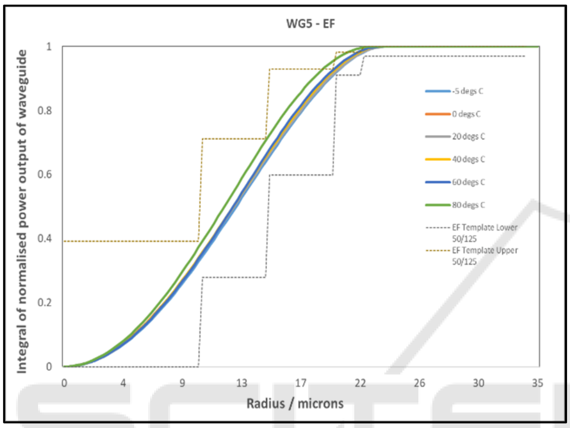

Figure 4: Encircled flux EF defined as the fraction of cumulative near-field power to the total output power as a function of radial distance from the optical centre of the core. This progressive shift is significant as it approaches and exceeds limits defined by EF templates (as specified in IEC 61280-4-1/Ed3/CD:2015 at the elevated temperature of 80°C.

4.3 BER across Thermal Range

An arbitrary waveform generator was used to generate a pseudo-random binary sequences (PRBS) electrical signal to drive an SFP+ transceiver module. The intensity modulated signal was launched onto waveguides 2 and 7 of the board (WG2 and WG7). The transmitted signal recovered from the photo-receiver was analysed on a real-time oscilloscope sampling at 20 GSa/s. An eye diagram of the transmitted signal from the experimental setup is shown in below.

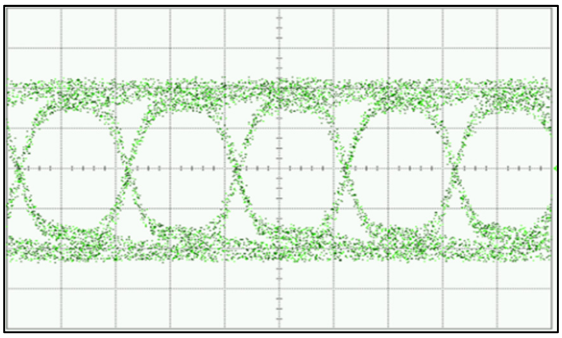

Figure 5: Eye diagram of the transmitted signal.

The BER was measured at the operating temperatures -4.4 ºC, 23 ºC and 80 ºC using the Thermostream chamber and involved using the same controlled launch conditioning ‘L2’ as that applied to attenuation and Encircled Flux measurements. The BER results are shown in Figure 5. Signal degradation was observed for the transmitted data at the extreme temperature of 80 ºC for both waveguides. The reduction in performance can be attributed to the increased total attenuation over the temperature range.

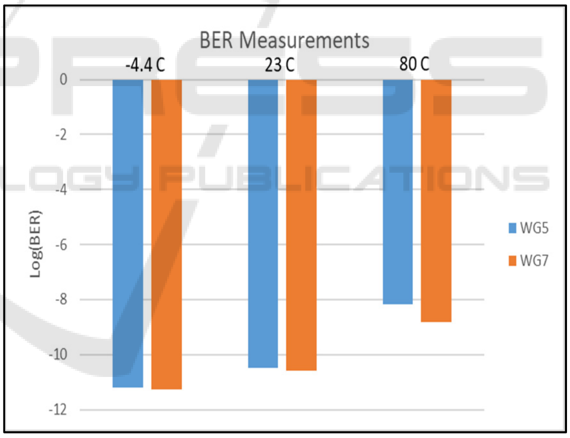

Figure 6: BER measurements on two waveguides for the operating temperatures -4.4 ºC, 23 ºC and 80 ºC.

5 CONCLUSIONS

The Data Centre Network has significantly increase in speed, reduced in power and cost in the past 5 years. With continuous pressure to be faster and cost effective, focus on optics is to overcome limitations of copper in every aspect (speed and power). This has encouraged the migration of optical interconnect onto the board and device level. As the technology rapidly develops there is a corresponding need to provide characterisation of these boards for key operational parameters such as attenuation, isolation (crosstalk) and bit error ratio (BER) as well as a need to provide standardisation through the activities of international standards bodies. The market research firm CIR states, '…the lack of standards has held back growth in optical engine use. If such standards emerge, CIR expects the market for optical engines could reach $1.2 billion by 2022' (Lightwave Staff article, 2017). Significant recent work within the International Electrotechnical Commission (IEC), principally through the work of the IEC technical committee 86, has improved standardisation of key measurements as well as the proposed adoption of a reliable measurement definition system for optical interconnects. This is seen as a crucial prerequisite for future commercial adoption of optical circuit board technology. As stated in IEC 62496-2:2017 (E), 'Independent repeatability of waveguide measurements is still very difficult to achieve due to the lack of clarity on how measurement conditions are specified…such a definition system shall capture sufficient information about the measurement conditions to ensure that the results of measurement on an identical test sample by independent parties will be consistent within an acceptable margin of error'. It is now the case that a Measurement Identification Coding (MIC) system has been incorporated within the standard with the principal aim to support harmonization of global reference measurements of these pluggable interconnects (IEC 62496-2, 2017).

A clear understanding of the measurement condition goes hand in hand with an understanding of the functional performance of an EOCB. While work has been carried out in assessing passive boards by industry and academic institutions for a number of years (Selviah et al., 2010), less work has been carried out to understand a boards performance at operational temperatures. Industry led discussions have shown a need to investigate the potential effects of applying thermal hotspots to EOCB's to simulate expected electric components integrated within the board. These components may well be central processor units (CPU's) or transceivers. Parameters such as attenuation, BER and the Encircled Flux (EF) can be measured during applied and controlled thermal loading. Effects upon the change in refractive index ($\Delta n/\Delta t$) as well as the combined stresses on the mechanics and materials of the board structure are important areas of investigation that need to be understood as specifications and standards develop and board technology improves and becomes more complex. Optics has the potential to replace certain functionality of electronics such as for optical switching, optical storage and optical signal processing. Continuous innovation in optics will continue to be a big part of future DC networks but will require corresponding metrological assessment and standardization.

ACKNOWLEDGEMENTS

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