Investigation of Potential MPI Effects on Supervisory Channel Transmission Below Cable Cut-off in G.654 Fibres

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Abstract *We examine supervisory channel transmission at wavelengths below cable cut-off in G.654 fibres via modelling and cabled fibre tests. We find negligible MPI and no penalty for 2.5 Gb/s transmission in a worst-case configuration up to 40 nm below cut-off.*

Introduction

ITU-T standard G.654 governs specifications for cut-off shifted optical fibre, mainly deployed in undersea systems[1]. The ITU is currently drafting a new G.654 optical fibre standard for terrestrial transmission system applications, allowing fibres with larger effective areas to reduce nonlinear impairments. The cable cut-off specification is expected to be higher than that for terrestrial G.652 fibre, and is likely to be 1530 nm.

An important component of terrestrial telecommunication networks is the supervisory channel. This is a low data-rate (<2.5 Gb/s) optical channel located outside of the main transmission band that communicates system and control information between optical amplifier sites. The wavelength of 1510 nm is often used for SC transmission[2]. Since 1510 nm falls below the likely cable cut-off wavelength specification of the new G.654 fibre standard, there has been concern that SC transmission performance could be adversely impacted by multi-path interference (MPI). In this paper we address the issue of low data rate transmission at wavelengths below the cable cut-off. While higher order modes (typically LP_{11}) may be excited below cable cut-off, the level of MPI generated depends on the coupling between LP_{01} and LP_{11} at splice points and the differential mode attenuation (DMA) between LP_{01} and LP_{11} in the cabled fibre and bend loss induced in splice trays. Here, we investigate a cabled span of G.654.B fibre through modelling and with extensive MPI and SC transmission measurements. In a worst-case configuration without splice tray loops, we demonstrate no power penalty up to 40 nm below cut-off.

System Model

We first analyse the growth of MPI in a fibre span through a simple model assuming MPI may be generated at the splice points within the span. We make the conservative assumption that any loss of the fundamental mode at a splice point results in the lost optical power being fully coupled from the LP_{01} mode to the higher order LP_{11} mode. The power coupling coefficient is given by $\varepsilon = 1 - 10^{(-L(dB)/10)}$ where L(dB) is the splice loss. By reciprocity, we assume that any optical power already in LP_{11} will couple back to LP_{01} with the same coefficient. In this way, MPI is generated as power couples both ways between the modes at splices and thus multiple crosstalk terms may build up with delays relative to the signal (due to different modal group velocities) during propagation through a span. The MPI level (ratio of total crosstalk power to average signal power) at span end is governed by the splice losses, distance between splices, and DMA.

Results from the MPI model as a function of DMA for different levels of splice loss are given in Fig. 1. The span length is 92.4 km and the splices are located every 4.2 km. The three levels of average splice loss represent measured data for G.652 and G.654 fibres, with the smaller losses representing G.654 fibres with 112 μm^2 and 150 μm^2 effective areas[3,4]. Larger splice losses of 0.1 dB are assumed at the span input and output ends where the large effective area fibre is spliced to standard single-mode fibre with smaller mode field diameter.
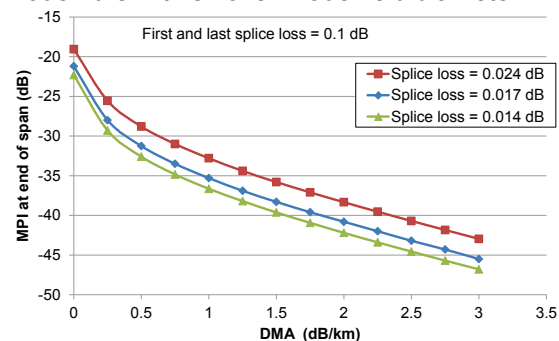

Fig. 1: MPI as function of DMA for different splice losses.

The received power penalty from MPI has been studied extensively for NRZ signals[5]. We

also made experimental measurements with a controlled MPI emulator[6] with 8 crosstalk terms for 2.5 Gb/s NRZ signals. The signal extinction ratio was 10 dB. The crosstalk terms were randomly polarized and delayed with respect to each other and the signal, as will be likely in the case for splice-generated MPI. The results in Fig. 2 show that MPI values < -32 dB should produce negligible penalty. Fig. 1 suggests DMA values as low as 1 dB/km at the SC wavelength may be sufficient to avoid MPI penalties. In practice, DMA will likely depend on cabling conditions as well as the fibre.
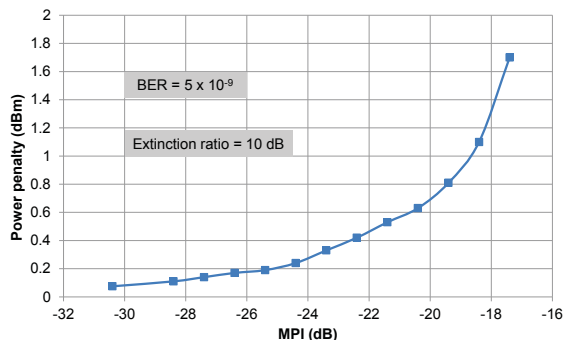

Fig. 2: Measured power penalty from MPI for a 2.5 Gb/s NRZ signal with randomly polarized crosstalk terms.

Experimental Set-up and Measurements

To conduct experiments, we cabled ITU-T G.654.B compliant Corning® Vascade® EX2000 optical fibre in two gel-filled buffer tubes, each of length 4.2 km. Each tube contained 11 Vascade EX2000 fibres (along with 1 other un-used fibre), which spliced together formed a 92.4 km span with a total of 21 intra-span splices. The G.654 fibre was spliced to standard single-mode fibre jumpers at the input and output ends of the span. The fibre deployed in the tubes was mainly taken from two source reels, with cable cut-off wavelengths of 1520 nm and 1480 nm, measured for 2 m lengths including 2x80 mm diameter loops. The tubes were loosely coiled in large trays, with minimum diameter of 1 m.

To create a worst-case condition unlikely to occur in the field and matching the model conditions, we spliced the fibres together without introducing the usual several ~80 mm diameter loops on each side of the splice as done in a splice tray. Each splice section was kept straight, creating a condition for maximum MPI generation. We then measured MPI as a function of wavelength by analysis of the power fluctuations of a CW laser transmitted through the span[6]. The measurement results are shown in Fig. 3. Even at wavelengths as low as 1420 nm, the MPI is ≤-35 dB. Application of the simple model assuming an average splice loss of about 0.017 dB suggests that the DMA in the fibre is minimally about 1 dB/km at 1420 nm and

increases with wavelength. We note that 1420 nm is about 60 nm below cut-off of the fibre comprising half the span, and 100 nm below cut-off of the rest of the fibre. Also shown in Fig. 3 is the upper edge of back-to-back measurements, illustrating an effective measurement floor. MPI data near or below this level taken through the span may be partially masked and could be lower than shown.
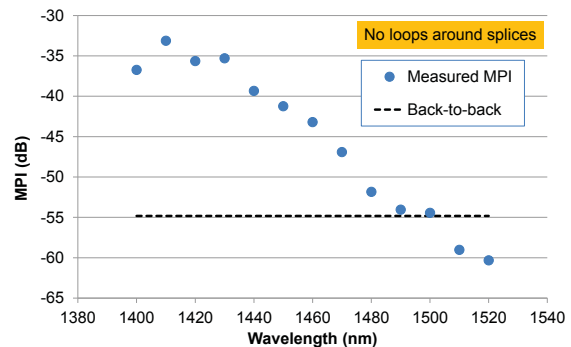

Fig. 3: Measured MPI values through 92.4 km span.

The results in Figs. 2 and 3 suggest that negligible penalty should be observed for transmission through the 92.4 km span even for wavelengths down to 1440 nm and possibly lower. We tested this by transmitting a 2.5 Gb/s NRZ signal with 10 dB extinction ratio over the fibre span. The experimental set-up is shown in Fig. 4. A tunable laser and external Mach-Zehnder modulator (MZM) allowed various wavelengths to be studied. The received power was controlled with a variable optical attenuator (VOA) and the receiver was a 2.5 Gb/s laboratory unit with clock and data recovery.
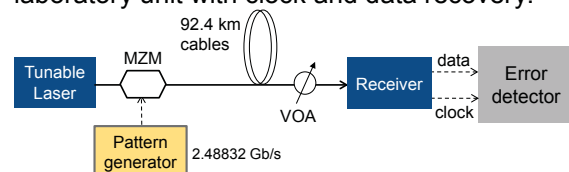

Fig. 4: Transmission system experimental set-up.

We made transmission measurements of bit error rate (BER) as a function of received power in back-to-back (B2B) and through the 92.4 km cabled fibre span for several wavelengths. Fig. 5 shows results for transmission at 1440 nm and 1480 nm. As expected from the small MPI values measured at these wavelengths, we observed essentially no penalty for transmission through the span compared to back-to-back, even though 1440 nm is 40 nm below the cut-off of the lowest cut-off fibre in the tubes.

Since NRZ signals are more sensitive to MPI and crosstalk with lower extinction ratios[5], we then changed the signal extinction ratio to 6.0 dB and made measurements at both 2.5 Gb/s and 1.25 Gb/s. Results at 1460 nm from these experiments are shown in Fig. 6. No penalty

was observed for either signal. The 2.5 Gb/s signal through the span was error-free after 18 hours at a received power of about -26.5 dBm.
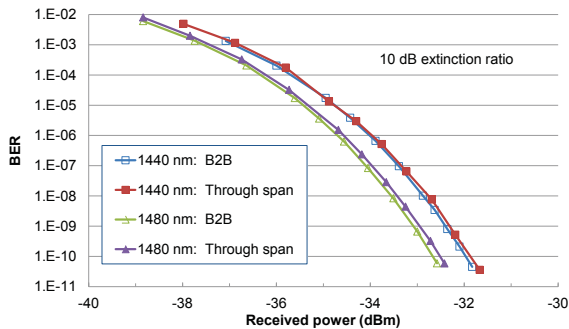

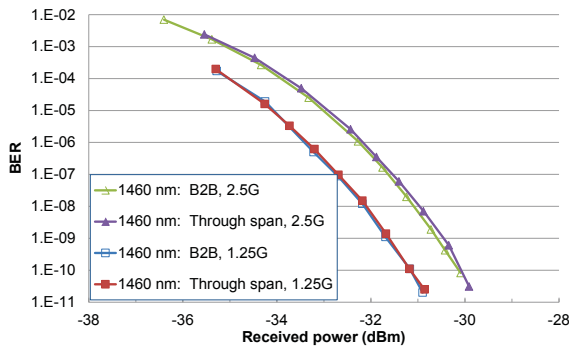**Fig. 5:** BER vs. received power for 2.5 Gb/s channel with 10 dB extinction ratio.

Fig. 6: BER vs. received power for 2.5 Gb/s and 1.25 Gb/s channels at 1460 nm with 6 dB extinction ratio.

As mentioned earlier, the MPI and transmission measurements made over the span with no loops or wraps in the splice trays surrounding the splice represent a worst case. We also examined the effects of adding these loops, as would be standard practice in the field. We first measured the loss of the LP_{11} mode for the bare fibres with an 80 mm diameter bend using a cut-back approach[7]. The measurement results are shown in Fig. 7 in units of dB/turn. For wavelengths ~20 nm below cut-off, the loss is about 3 dB/turn. Only a few 80 mm loops on each side of the splices will serve to reduce the MPI below what is generated without the turns.
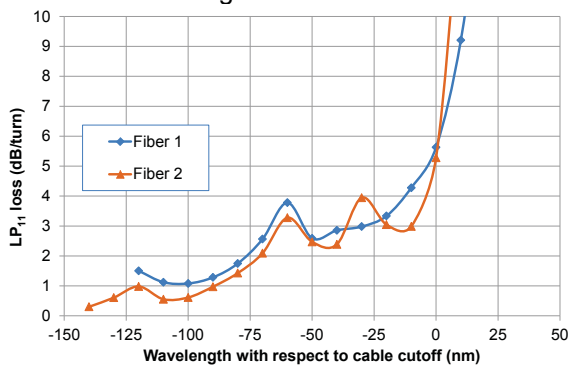

Fig. 7: Measured LP_{11} mode loss for 80 mm bend diameter.

We then introduced 2-3 loops of this size before and after each splice and repeated the MPI measurements from 1400 nm to 1480 nm. The results in Fig. 8 demonstrate that the MPI was significantly reduced at all wavelengths and was below -50 dB for wavelengths down to 1430 nm. Thus in a standard deployment, there should be no concern about MPI impacting supervisory channel transmission at any practical wavelength below the cable cut-off.
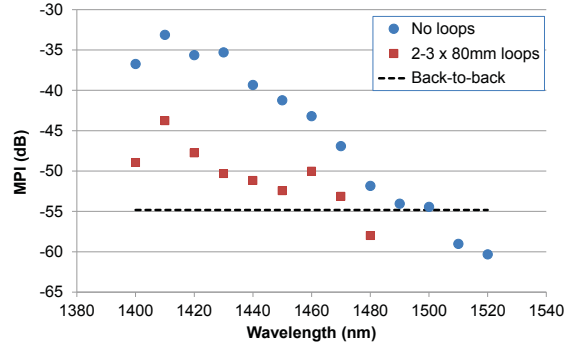

Fig. 8: Measured MPI values through span with 2-3 x 80 mm diameter loops on each side of splices.

Conclusions

We have investigated the possibility of MPI adversely affecting transmission performance of supervisory channels below cable cut-off for G.654 fibres. Through modelling and experiments with a 92.4 km span comprised of high cut-off G.654 fibre, we have demonstrated negligible MPI and no power penalty at wavelengths far below average cut-off even in a worst-case condition. These tests confirm that with standard terrestrial deployments, G.654 fibre with cable cut-offs up to 1530 nm should have no detrimental effects on supervisory channel transmission at shorter wavelengths.

Acknowledgements

References

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