Characterization of Crosstalk-Impaired OOK Signals in WC-MCF Systems with High and Low Skew×Bit Rate

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Abstract

The received amplitudes of crosstalk-impaired on-off keying signals in weakly-coupled multicore fibre (WC-MCF) systems are experimentally assessed for high and low skew×bit-rate. Gaussian-distributed crosstalk-induced amplitudes are shown for high skew×bit-rate. The mean of these amplitudes can also be modelled by Gaussian distributions.

1. Introduction

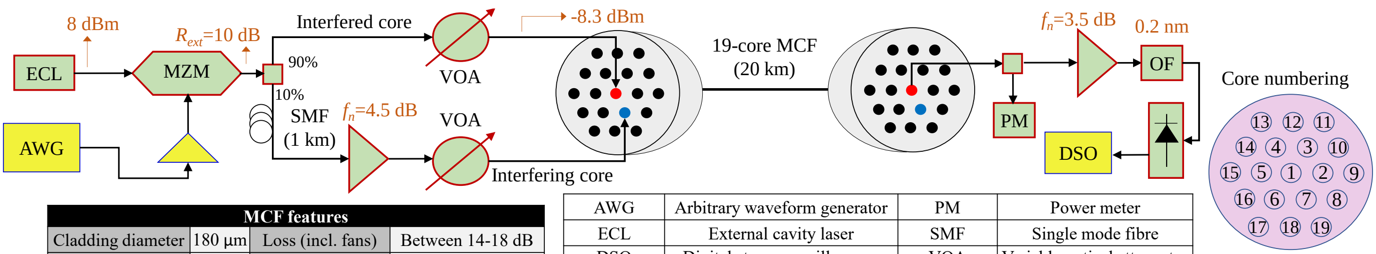
Weakly-coupled homogeneous multicore fibres (MCFs) are a potential solution to overcome the capacity crunch of optical networks foreseen for the next years [1]. These fibres are less impaired by the intercore crosstalk (ICXT) than strongly coupled MCFs [2] and do not require complex digital signal processing techniques. Thus, they present high potential to be employed in short-reach on-off keying (OOK) systems, as intra data-centres or 5G fronthauling, where low cost and low complexity subsystems are key requirements.

The ICXT in weakly-coupled MCFs has been widely investigated over the last years. Firstly, the ICXT generated by a continuous wave signal was characterized by a random variation along the longitudinal direction of the fibre [3] and the corresponding ICXT power was modelled by a chi-square distribution [4,5]. Other works have also shown that the short-term average crosstalk (STAXT), i. e., the ICXT power measured at the output of the interfered core by an optical power meter in a very short time interval (<< 1 second), when an unmodulated signal is launched into the interfering core, changes randomly over time and frequency [6,7]. The power fluctuations of the STAXT induced by modulated signals were also monitored over time [8]. Measurements revealed that, for carrier-free signals, the ICXT-induced power fluctuations can be relieved by using MCFs with high skew-bit rate product. In contrast, it was shown that signals containing a strong optical carrier, like OOK, present a high level of ICXT-induced fluctuations even for large skew and symbol rates. Therefore, it was concluded that an additional performance margin may be required to guarantee a given signal quality in carrier-supported intensity modulated signals. Recently, the outage induced by ICXT in MCF systems employing OOK signalling and low skew-bit rate product was theoretically characterized [9]. For high skew-bit rate product, further studies revealed additional complexity on the theoretical characterization of the outage.

In this work, the impact of the skew-bit rate product on the received amplitudes of the OOK signal impaired by ICXT is assessed experimentally. Differences on the histograms of the received amplitudes and on the statistical distribution of the mean amplitude of bits 1 and 0 are identified and discussed. These studies provide useful information for the statistical characterization of the outage in OOK ICXT-impaired systems.

2. Experimental Setup

Fig. 1 shows the experimental setup employed in the lab to study the impact of the skew-bit rate product on the photodetected OOK signal. To avoid significant degradation induced by laser phase noise [7], an external cavity laser (ECL) with 100 kHz linewidth is employed. The electro-optic conversion is realized by a Mach-Zehnder modulator (MZM) with 10 dB extinction ratio. The OOK waveform is generated by an arbitrary waveform generator with 2^{14} bits. Two OOK signals, generated with data rates of 165 Mb/s and 10 Gb/s, are considered. After the MZM, the OOK signal is split to obtain the signals to be launched into the interfering and interfered cores. A spool of 1 km-long single mode fiber is placed before the interfering core in order to decorrelate the signals. The MCF is a 20 km-long weakly-coupled homogeneous 19-core fibre whose main features are shown in Fig. 1. Two pair of cores are tested in this work to analyse the impact of high and low skew-bit rate products on the OOK signal impaired by ICXT. Cores (11,12), with S_{nm}=0.4 ns, are used to transmit the



MCF features			
Cladding diameter	180 μm	Loss (incl. fans)	Between 14-18 dB
Core diameter	≈9 μm	Dispersion param.	≈20 ps/nm/km
Core pitch	32 μm		

AWG	Arbitrary waveform generator	PM	Power meter
ECL	External cavity laser	SMF	Single mode fibre
DSO	Digital storage oscilloscope	VOA	Variable optical attenuator
OF	Optical filter		

Fig. 1: Experimental setup employed to assess the influence of the skew-bit rate product on the photodetected OOK signal.

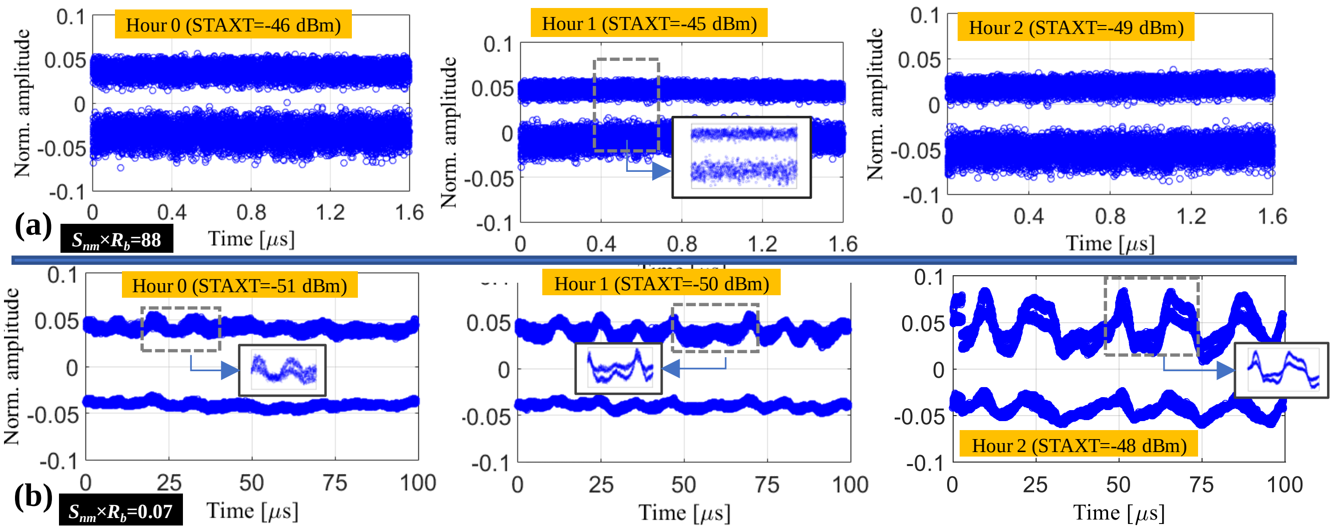


Fig. 2: (a) Normalized amplitude of the received bits considering three different time fractions, each separated by one hour, and a skew-bit rate product of (a) 88 and (b) 0.07. In (a), the crosstalk level is -11 dB. In (b), the crosstalk level is -14 dB.

165 Mb/s OOK signal. In this case, the skew-bit rate product (S_{nm}×R_b) is 0.07. Cores (4,12), with S_{nm}=8.8 ns, are used to transmit the 10 Gb/s OOK signal leading to S_{nm}×R_b=88. Cores (11,12) and (4,12), are characterized by a decorrelation bandwidth of the ICXT, given by the inverse of the skew between cores [10], of 2.5 GHz and 114 MHz, respectively. For the two pairs of cores, the decorrelation time of the ICXT [11] is a couple of minutes. At the MCF output, the OOK signal impaired by the ICXT is amplified to increase the power injected in the photodetector. The amplified spontaneous emission noise power introduced in the system is much lower that the mean ICXT power levels under study in this work. After amplification, the signal is filtered to remove noise and photodetected. The received OOK signal is captured by a real-time oscilloscope operating at 20 Gsamples/s. The OOK signal is then digitally filtered by a 4th-order Bessel low-pass filter with bandwidth of 80% of the bit-rate. The received OOK signal is monitored over 48 hours with captures taken periodically at each 30 seconds (for S_{nm}×R_b=88) or 54 seconds (for S_{nm}×R_b =0.07). In each capture, a bit stream with 2^{14} bits is saved and analysed using offline processing. The time fraction occupied by each bit stream is close to 1.6 μs and 100 μs for R_b=10 Gb/s and R_b=165 Mb/s, respectively.

3. Results and Discussion

In this section, the impact of the skew-bit rate product on the amplitudes of the OOK signal is experimentally analysed.

Fig. 2a) and 2b) show the amplitude of the photodetected bit stream for a crosstalk level, defined as the ratio between the mean ICXT and signal powers at the output of interfering core, of -11 dB for S_{nm}×R_b=88 and -14 dB for S_{nm}×R_b=0.07, respectively. These crosstalk levels lead to an outage probability close to 10^{-2}. Results captured in three different time fractions, one in each hour, are presented. As the decorrelation time of the pair of cores under analysis is of the order of a couple of minutes, the ICXT generated in time periods separated by one hour is uncorrelated. Fig. 2a) and 2b) show that the received amplitudes of the ICXT-impaired OOK signal are significantly affected by the skew-bit rate product. Fig. 2a) shows that, when S_{nm}×R_b=88, i. e., when the bit rate of the OOK signal is much higher than the ICXT decorrelation bandwidth, the received amplitudes of bits 1 and 0 present a noise-like behaviour. This occurs because the ICXT induced in the interfered core results from contributions of several bits transmitted in the interfering core. When S_{nm}×R_b=0.07, the ICXT induced in the interfered core depends only on the amplitude level of the interfering core at the same bit period. As only two levels (associated with bit 1 or bit 0) are transmitted in the interfering core, the received amplitudes of the interfered core show only two distinct levels, as shown in Fig. 2b). The separation between these two levels increases with the increase of the STAXT level.

Fig. 3a) and 3b) depict the histogram of the received amplitudes of the OOK signal considering S_{nm}×R_b=88 and S_{nm}×R_b=0.07, respectively. Results for the three time fractions of Fig. 2a) and 2b) are shown. The probability density function (PDF) of the Gaussian distribution, evaluated with the mean and standard deviation of the amplitudes of Fig. 2a) and 2b), is also shown as reference. Two main conclusions can be drawn from the inspection of Fig. 3a) and 3b). (i) When S_{nm}×R_b=88, a significant ICXT-induced variation over time of the mean of the histograms of the received amplitudes of bits 0 and 1 is observed. In contrast, a much lower variation of the mean over time is observed when S_{nm}×R_b=0.07. This conclusion holds when the crosstalk level increases. (ii) Despite the mean of the received amplitudes may be considerably affected by the ICXT, the results of Fig. 3a) indicate that the histograms of bits 1 and 0 are adequately characterized by a Gaussian PDF even when the system is being impaired by strong ICXT. This is a consequence of the high number of amplitudes resulting from the contribution of several bits in the interfering core to the induced ICXT. In contrast, Fig. 3b) reveals that, for high STAXT levels, the histogram of the received amplitudes associated with bits 0 and 1 is roughly estimated by the Gaussian PDF. This is due to the two amplitude levels induced by the ICXT in the interfered core, as shown in Fig. 2b).

To further assess the time variation of the mean of the received amplitudes, additional measurements of the OOK signal impaired by the ICXT were taken continuously over 48 hours.

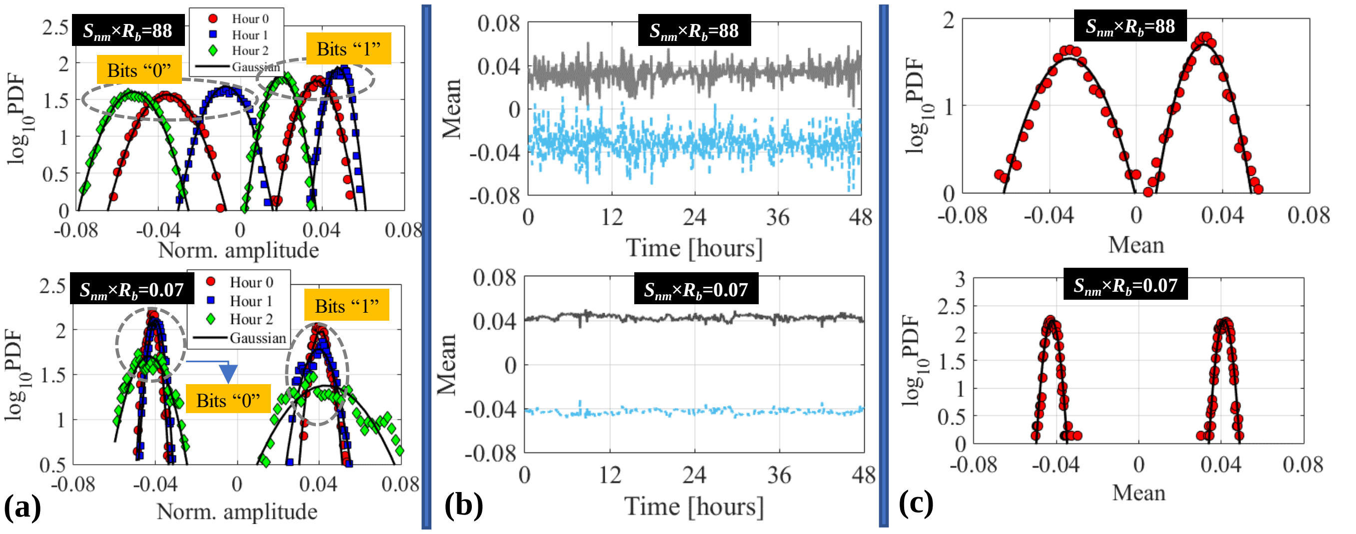


Fig. 3: (a) Histograms of the normalized amplitude of bits 1 and 0 considering three different time fractions, each separated by one hour, and a skew-bit rate product of 88 and 0.07. (b) Mean amplitude of bits 1 and 0 as a function of time for a skew-bit rate product of 88 and 0.07. (c) Histograms of the mean amplitude of bits 1 and 0 for a skew-bit rate product of 88 and 0.07.

From these measurements, the mean of the received amplitudes of bits 1 and 0 in each time fraction was evaluated. Then, the histograms of the mean of these amplitudes were drawn and compared with a Gaussian PDF whose mean and variance have been determined from the mean amplitudes used to obtain the histograms. These results are shown in Fig. 3c) for $S_{nm}\times R_b$=88 and $S_{nm}\times R_b$=0.07. It is shown that the histogram of the mean obtained for both skew-bit rate products is reasonably well described by a Gaussian PDF. This information, combined with the procedure employed in [9], can be used to find a theoretical bound for the outage in ICXT-impaired OOK systems with high skew-bit rate product. Fig. 3c) shows also that the fluctuations of the mean of the received amplitudes over time lead to a variance of the Gaussian PDF that is much higher when $S_{nm}\times R_b$=88 than when $S_{nm}\times R_b$=0.07. Further investigation showed that this variance tends to increase when the ICXT power also increases. These low/high fluctuations of the mean of the received amplitudes over time caused by the ICXT may lead to additional concerns on the design of optical transceivers employed in next generation MCF-based networks. In fact, as the two cases of skew-bit rate product may coexist in the same MCF in real networks, optical transceivers with high dynamic range may be required to accommodate low and high fluctuations of the received amplitudes over time.

4. Conclusion

The influence of the skew-bit rate product on the photodetected amplitudes and statistical properties of OOK signals has been experimentally shown. The received amplitudes show a Gaussian noise-like ICXT induced perturbation when the skew-bit rate product is much higher than one. For small skew-bit rate product, these amplitudes show two distinct levels, that are induced by the ICXT generated by bits 1 or 0 in the interfering core in the same bit period, and that deviate the received amplitude statistics from the Gaussian distribution. It has been also shown that the fluctuation over time, induced by the ICXT, of the mean of the received amplitude of bits 1 and 0 is reasonably well described by a Gaussian distribution. For high skew-bit rate product, the variation over time of the mean is much larger than for small skew-bit rate product. This information is useful to derive an outage bound for this kind of ICXT-impaired OOK systems.

5. Acknowledgements

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6. References

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