Experimental assessment of the effect of polarization mode dispersion on an FSK/IM signal

J.J.Vegas Olmos[†], I.Tafur Monroy[†], J. Prat[‡] and A.M.J. Koonen[†]

[†] COBRA Research Institute, Faculty of Electrical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands.

[‡] GCO Optical Communications Group, Universitat Politècnica de Catalunya, Barcelona, Spain.

The effect of first-order PMD on the performance of a combined FSK/IM modulated signal is evaluated experimentally. The payload and the label have a bit-rate of 10 Gbit/s and 100 Mbit/s, respectively. The performance of the combined scheme is assessed for injected first-order PMD up to 50 ps. The IM signal does not achieve error free operation for PMD values above 40 ps of DGD while the FSK signal suffers a power penalty on its receiver sensitivity at a bit error-rate of 10^{-9}.

Introduction

While current optical network architectures are mostly based on the circuit-switched SONET approach, a lot of research is done on future transparent optical packet switched (OPS) networks to enable the implementation of IP over WDM. Multiprotocol label switching (MPLS) approach was introduced to achieve fast forwarding of data packets by performing the appropriate routing functions in the electrical domain at edge routers and label swapping at the core nodes. In order to improve the efficiency, scalability and throughput of the network, the all-optical label swapping (AOLS) technique has been proposed [1], where the packet routing and forwarding functions are carried out either all-optically in the optical layer, or label processing is done in the electrical domain while the payload remains in the optical domain.
Several approaches have been studied for labelling the optical packets [2], but the combined method of frequency-shift keying/intensity modulation (FSK/IM) seems to be one of the most promising methods due to its in-band character and simplicity of implementation.
Although the power penalties due to the label swapping process inside the intermediate nodes have been studied in depth [3-4], and the chromatic dispersion is well managed even in a broad spectrum signal due to the FSK modulation, the effect of first-order polarization mode dispersion (PMD) for a combined FSK/IM signal has not been assessed yet. PMD effects become a major signal quality impairment in long-haul optical transmission, at high bit rates of 10 Gbit/s and above [5].
We present an experimental assessment of the impact on the FSK and IM signal performance due to the first-order PMD which can be used for engineer the power budget in the metro networks design.

First-Order PMD

PMD results from a difference between the propagation delays corresponding to the two principal states of polarization (PSP), due to birefringence along the link. The difference between these two delays is called differential group delay (DGD) and quantifies the pulse broadening during propagation.
The signal field after transmission over a link with 1st-order PMD can be described as

$$E_T(t) = A_x \cdot \cos(\omega_o t + m \cdot \phi(t))\hat{x} + A_{y_\tau} \cdot \cos(\omega_o (t - \tau_0) + m \cdot \phi(t - \tau_0))\hat{y} \tag{1}$$

where τ_0 is the delay caused by the slow axis of the fibre, namely DGD, m the modulation index, ω_o the angular frequency, $\phi(t)$ the phase of the signal and $\hat{x}$ and $\hat{y}$ the normalization of each axis .
After photodetection, assuming the optical power is distributed in each axis by a factor γ and the photodetector has a responsivity R, we can obtain the resulting photocurrent i_d. Doing the Fourier transform of the autocorrelation function of the output current, we can obtain the electrical spectral power density $S_I(w)$ of the detected NRZ IM signal with first-order PMD

$$S_I(w) = \frac{R^2 P_0^2}{4} \left\{ \left(\gamma^2 + (1-\gamma)^2\right) \left(\delta(w) + \frac{4}{T_b} \frac{\sin^2 w \frac{T_b}{2}}{w^2} \right) + \gamma(1-\gamma) \left(2\delta(w) + \frac{8}{T_b} \frac{\sin^2 w \frac{T_b}{2}}{w^2} \right) \cdot \cos(w\tau_0) \right\} \tag{2}$$

where T_b is the bit period and P_o are the pulse form of the pseudo-random pattern and the power level of a transmitted '1'. As we can observe from Equation (2), the spectrum shows a strong distortion depending on both the power division γ factor and the value of the DGD, imposing a spectral minimum at the frequency $f_{min}=½\tau_0$. Considering values of PMD in the range of the spectral minimum and comparable to the FSK frequency deviation, PMD manifests itself not only as pulse amplitude broadening but also as pulse phase distortion, which contributes to frequency chirp that may impair the FSK performance [6]. These effects are more pronounced for high values of the DGD. The effect of PMD needs to be quantified for proper system design of a combined FSK/IM modulation optical signal labeling system.

Experiment and results

In OLS networks, the label swapper erases the label and re-inserts a new one. This means that the FSK signal is re-inserted at each node [1] and only node to node good performance is crucial for the system. In contrast, the IM signal is maintained fully in the optical domain, end-to-end, being re-shaped during the wavelength conversion through the semiconductor optical amplifier – Mach-Zehnder interferometer (SOA-MZI) [4], which is the key element that performs the label swapping. The FSK signal is generated by modulating the current applied to the phase
section of a grating-assisted coupler sampled reflector (GCSR) tunable laser source at 100 Mbit/s with a 2^7-1 PRBS data stream. The current applied to other sections of the GCSR (coupler, reflector and gain) was used for tuning among 41 channels with 100 GHz spacing. For the experiment reported here, a FSK frequency deviation of 6 GHz was selected. The experimental setup is shown in Figure 1.

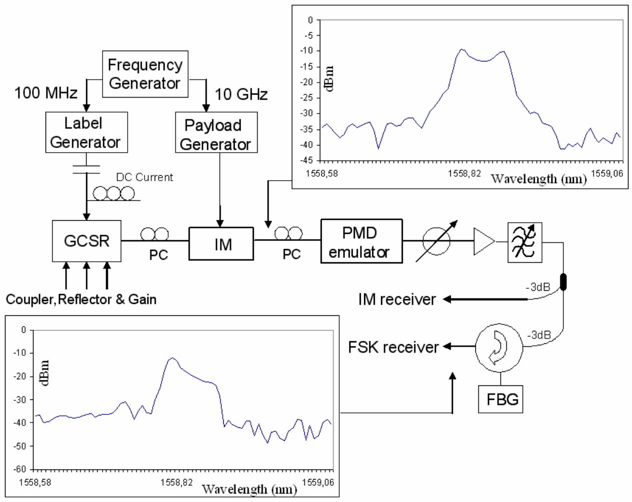

Figure 1. Experimental setup. The insets show the spectrum before and after the demodulation by using direct detection of one tone of the FSK signal.

The optical FSK modulated signal was then fed into an optical Mach-Zehnder intensity modulator operated at 10 Gbit/s with a 2^{31}-1 PRBS data stream, resulting in a combined FSK/IM modulation format labeling scheme. The extinction ratio (ER) of the IM is adjusted to 6 dB, which is found to allow both the FSK and the IM receivers to perform at acceptable receiver sensitivity. The FSK/IM signal was injected into a polarization controller. Then, the signal was launched into a PMD emulator that enabled us to introduce up to 100 ps delay in the slow polarization axis. The IM signal is detected by direct detection and the FSK by using a fiber Bragg grating as a wavelength discriminator, as reported in [7].

In Figure 2, the bit-error rate (BER) is presented, as a function of the receiver input power for different amounts of introduced PMD, starting from 0 ps up to 50 ps.

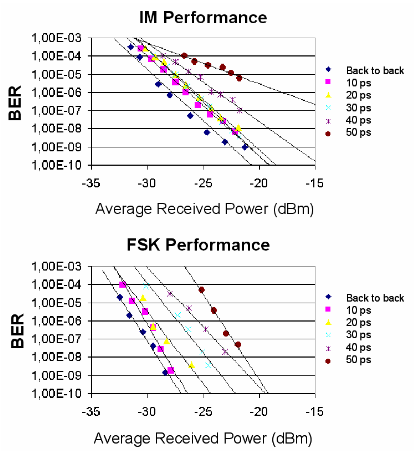

Figure 2. BER vs. Optical Power Received of the IM and the FSK signal.

Inset a) of Fig. 2 shows that the IM signal yielding a BER of 10^{-9} was measured at –23 dBm of average received power for 0 ps of DGD. This value increases to –21 dBm for

30 ps of DGD. For PMD values of 40 and 50 ps, however, error free operation is not possible, due to pulse spreading. Inset b) of Fig. 2 shows that the FSK receiver sensitivity at a BER of 10^{-9} is penalized approximately by 1 dB for each 10 ps of increment in PMD. We observe that the IM receiver sensitivity penalty is comparable to the FSK power penalty, although they operate at different in bit rate. This effect, as said before, is due to the amount of intersymbol interference (ISI), caused by the PMD, that smoothes the IM pulses, in amplitude and in phase. As the PMD values increase the larger the IM pulse widening which in its turn results in a lower SNR of the FSK signal. Moreover, the introduced pulse phase distortion causes frequency chirp. However, because of the low frequency electrical filtering at the FSK receiver, the effect of the 1st –order PMD is limited and the signal is moderately robust against PMD for an FSK signal with a 6 GHz swing.

Conclusion

We presented an assessment of the impact of PMD on a FSK/IM combined modulation scheme, with a bit-rate of 100 Mbit/s and 10 Gbit/s for the label and the payload respectively. The results show that the receiver sensitivity of the IM signal, with an ER of 6 dB, for PMD values below 40 ps suffers a power penalty of up to 3 dB, similar to the case of an IM only modulated signal. For PMD values above 40 ps the IM signal does no reach a BER of 10^{-9}. In contrast, the FSK receiver sensitivity is degraded by 1 dB power penalty for every 10 ps of 1st –order PMD up to 50 ps, however, it can be still detected correctly. Therefore, the combined FSK/IM scheme is suitable for labeling signal in metro networks, with an estimated link reach or 100 km, in the presence of PMD.

Acknowledgment

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