Characterization of asymmetric filtered 40 Gb/s RZ-DPSK system—strong filtering considerations

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ABSTRACT

We present the impact of frequency offsetting of strong (e.g. 35 GHz) optical filters on the performance of 42.7 Gb/s 50% RZ-DPSK systems. The performance is evaluated when offsetting the filter by substantial amounts and it is found that with an offset of almost half the bit rate there is a significant improvement in the calculated 'Q' (>1 dB). We deployed balanced, constructive single ended and destructive single ended detection, so that we could investigate the physical origins of the penalty reduction of asymmetric filtering of 42.7 Gb/s 50% RZ-DPSK system.

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1. Introduction

Phase modulation techniques are now prominent in high speed optical communications. The differential phase shift keying (DPSK), is advantageous due to its improved OSNR performance and tolerance to fibre nonlinearity over intensity modulated format. However one of the key requirements is that the 40 Gb/s channels must be compatible with the 50 GHz channel spacing used in 10 Gb/s systems. With DPSK the required filtering robustness can be accomplished using partial DPSK i.e. optimising the delay used in the receiver Mach Zehnder demodulator [1–3]. It is however important to investigate other methods to improve DPSK performance with the narrow filter bandwidths encountered in 50 GHz WDM systems. In this paper we have numerically modelled a 42.7 Gb/s DPSK system with a single optical band pass filter (OBPF) at the receiver. In [4], offset filtering was implemented at the transmitter with an offset 7.5 GHz of a 3 dB OBPF of 45 GHz. A 45 GHz OBPF been deployed in 50 GHz grid does not give an overall complete insight to the strong optical filtering performance of 42.7 Gb/s DPSK system. Thus we have captured in this work the net filtering bandwidth available in a 50 GHz grid with performances of 33 to 40 GHz OBPF. We also quantified the degree of offset filtering per optical bandwidth that results in improved performances. A detailed investigation and analysis of the performance of offset filtered DPSK system within a 50 GHz is essential so to give a comprehensive evaluation of the performance and limitation.

In the majority of the work presented here 35 GHz was chosen as the filter bandwidth since this is more representative of the typical overall bandwidth which would be encountered in a 50 GHz grid system. In this work the centre frequency of the OBPF was offset from the carrier frequency of the channel in order to examine the impact on performance of this offsets. Offsetting the central frequency of the filter normally results in a performance penalty [5] we however, found that an improved performance can be obtained for offsets which are a large fraction of the bit (symbol) rate. This paper focuses on this improvement which suggests that detuning of the transmit laser could result in significant performance improvement in the narrow optical filtering experienced in 50 GHz spaced DPSK systems.

2. System model

The system used in the simulations, is illustrated in Fig. 1. A 29 PRBS is used to drive a Mach–Zehnder modulator (MZM) to produce a 42.7 Gb/s DPSK optical signal, which is followed by a pulse carving MZM generating a 50% RZ signal. We have confirmed that longer bit sequence leads to practically the same results as with the 29 used in the below figures. Noise is added using the VOA/amplifier combination. At the receiver, the DPSK signal is first filtered by the tunable OBPF, the central frequency of which is initially centred on the signal wavelength and moved by up to 30 GHz. The signal is demodulated by a Mach Zehnder interferometer (MZI) with a one bit delay and detected by a balanced receiver. Single ended detection was also investigated in our simulations to identify the effect of offset filtering on the two received signals. The OSNR at the receiver was varied from 14 to 22 dB. The filter was generally taken as a 35 GHz bandwidth 3rd order Gaussian filter and a 30 GHz bandwidth 5th order Bessel electrical filter was used following the receiver. In the following the Q-values were calculated assuming Gaussian statistics.

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3. Results

Fig. 2 shows the calculated Q plotted against filter offset for three values of OSNR. In all three cases the Q-value initially rises, and then the performance declines as would be expected, however as the offset approaches 20 GHz a recovery is observed with a peak value which exceeds the centre filtered value. With all three OSNRs the best performance is found with an offset of 17 GHz which is half the filter bandwidth which is in turn a large fraction of the symbol rate. A pronounced minimum is found at 22 GHz which is about half the symbol rate and a further peak is obtained at around 7 GHz. In Fig. 3 we vary the filter bandwidth for a fixed OSNR. This figure shows that there are different ranges of filter bandwidth with differing offset improvement i.e. for a 40 GHz bandwidth observed offset improvement is at around 7 GHz [4]. The peak at half the filter bandwidth is particularly clearer for filter bandwidths around 35 GHz. Moreover the peak at around 5 GHz becomes more pronounced for narrower filtering and for specific filter bandwidths can exceed the larger offset peak. A third peak is observed which is only present at large OSNRs. Thus the advantage of offsetting identified here should be understood to be filter bandwidth dependent.

Fig. 4 compares balanced detection performance with single ended at the constructive and destructive ports for an OSNR of 20 dB. This figure illustrates that, as has been noted previously [6], for this strong filter, single ended detection (at zero offset) is slightly better than balanced detection. However it is clear that the destructive port performance rapidly increases with offset so that balanced detection is generally superior to single ended performance. There is an exception around 10 GHz offset where the destructive port alone gives the best Q. The peak around 17 GHz (half filter bandwidth) is only present at the constructive port. It is clear that the improved performance at 17 GHz offset is largely due to the signal quality at the destructive port where the Q-value has increased by ~5 dB compared to the centred filtered case. The constructive port shows a ~1.8 dB penalty when the filter is offset 17 GHz from the channel wavelength.

![Fig. 1. The system modelled in simulation.](image1.png)

![Fig. 2. Q value as a function of frequency offset for a 35 GHz OBPF for three values of OSNR.](image2.png)

![Fig. 3. Q value as a function of frequency offset for 33, 34, 35 and 40 GHz, 3 dB filter bandwidth for an OSNR of 20 dB.](image3.png)

![Fig. 4. Q value dependence on frequency offset for balanced, constructive and destructive single ended detection for an OSNR of 20 dB.](image4.png)

![Fig. 5. Comparison of Q value for centred (solid line) and 17 GHz offset (dashline) as a function of OSNR for a 35 GHz OBPF.](image5.png)
which declines still further for larger offsets. The trend in Fig. 4 is also obtained for other values of OSNR.

Fig. 5, which is a key result of this work, shows the Q value dependence on OSNR comparing the 17 GHz offset with a centred filter. The difference in performance between the centred and 17 GHz offset filter is as much as 1.8 dB at large OSNR but reduces as the OSNR decreases.

Nevertheless it is remarkable that a significant improvement (~1 dB) can be observed even for low OSNR. It is worth recalling that the results presented here could be obtained by detuning the CW laser source.

4. Discussion

In order to better understand the underlying reason for the improvements observed in Fig. 5 we need to recall the effect of demodulation on DPSK signals. It is well established that the output of the constructive port is duobinary (DB) and the signal at the destructive port is alternate mark inversion (AMI) [7–9]. DB because of its narrower spectral width (than AMI) has superior performance with respect to filtering whilst the reverse is true of AMI. The effect of offsetting is to greatly reduce the penalty of the AMI performance whereas the DB penalty with frequency offset is increased. Thus we can expect an initial peak in performance as the AMI (destructive port) improves with detuning; this is observed in these calculations at around 5 GHz [4]. The second and most important peak in performance is at an offset approximately half the filter bandwidth. At this offset we can consider the DB and AMI to be reduced to something more like vestigial side band (VSB) signalling. It is known that DB may be derived from AMI by side band filtering [9]. This alteration is also evident in the spectra displayed in Fig. 6 where we see that the destructive port now has a single lobe which is characteristic of DB. At this point the constructive port spectrum changed to display a side lobe [7]. The physical origin of the peak in performance at the half filter offset coincides with the optimum position for AMI to DB conversion, underlying the mechanism which leads to this peak. The tolerance of VSB signalling [10] to tight filtering is well known with corresponding good rejection of ASE and it is therefore not surprising that the best performance occurs near the optimum for producing such signals from either port. In Fig. 7 the eye diagrams for constructive, destructive and balanced detections are compared for 20 dB OSNR. This figure shows that the constructive port offset eye resembles the DB eye seen in the constructive port for the centre filtered case. The offset constructive port is no longer DB but has a more open eye than the contrasting centre filtered destructive eye. The logical inverse relationship that exists between the constructive and destructive ports is the cause of the observed inversion of the eye diagrams for balanced detection in Fig. 7. The improvement in Q originates from the destructive port becoming DB and the constructive port remaining with a relatively good eye.

This work has examined the impact of offset filtering of a 42.7 Gb/s 50% RZ-DPSK system within a strongly filtered regime (35 GHz OBPF) on a single channel. The filter offset (or laser detuning) will inevitably increase the cross talk from adjacent channels (50 GHz away) in a WDM system. In a tight filtering environment this cross talk would not be large for small offsets (5 GHz) but a significant impact could be expected for the 17 GHz offset. Cross talk could be reduced if additional filtering is introduced for example at the transmitter as in the generation of single side band data [11] and thus realising performance improvements of >1 dB for the 17 GHz offset compared to the symmetric filtered case.

5. Conclusion

We have investigated the effect of offset filtering of a 42.7 Gb/s DPSK signal using typical filter bandwidths present in a 50 GHz grid. The results show that the performance of the strongly filtered DPSK system can be improved by >1 dB at low OSNR and by up to 1.5 dB for
an OSNR of 20 dB by detuning the laser frequency. Three values for detuning are observed with the most effective found to be around half the filter bandwidth. The precise offset required for improved performance in strongly filtered DPSK systems is filter bandwidth dependent. This interesting result could be anticipated to also occur in coherent PSK/QPSK systems and we will report on this and the tolerance to other impairments in future work.

References