FBG-based asymmetrical off-centred VSB filters for transmission with 0.8 bit/s/Hz spectral efficiency

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Abstract: We propose a novel approach to ultra-narrow optical filtering based on a specially designed slightly asymmetric VSB filter and fabricate a fibre Bragg gratings with desirable spectral response. A feasibility of 8x40Gbit/s DWDM RZ transmission with 0.8 bit/s/Hz spectral efficiency (without polarization multiplexing) over 1170km of SMF/DCF link without FEC has been confirmed by numerical modeling.

1. Introduction

Ultra-narrow optical filtering is one of the key technologies to achieve the ultimate spectral efficiency that maximizes the system capacity over a given spectral range [1-3]. Narrow filtering is realized at the expense of increasing nonlinear penalties due to closer channel spacing and accompanying signal waveform distortion. Therefore, to maximize the advantage of spectral filtering, it should be performed synchronously with optimization of carrier pulse characteristics in the temporal domain. Vestigial Side Band (VSB) format exhibits narrow signal bandwidth and partial carrier suppression, in which the transmission passband is filtered to reject either the upper or lower side band. We propose here a novel approach to ultra-narrow optical filtering based on specially designed slightly asymmetric VSB filter allowing us to take advantage of cross talk suppression while minimizing waveform distortions.

2. Asymmetric VSB filter design

The purpose of VSB filtering is to reshape the channel spectra, in order to isolate one of the side bands and reduce cross-talks between adjacent channels. Detuning the narrow passband filter off the carrier enhances the favored side-band, while making efficient reduction of cross-talk. The best system performance is achieved as a complex trade-off between cross talk suppression and waveform distortion leading to propagation penalties. Therefore, when designing an advanced VSB filter, it is important to establish an optimal combination of filter bandwidth, detuning and temporal signal characteristics.

To better realize a function of a proper adjacent channels isolation while maintaining a signal waveform quality we propose a special design of an asymmetric VSB filter, with a super-Gaussian shape (10^{th} order) on the one side (in this case the left) and a super-Gaussian (SG) shape of n^{th} -order (n=2,4,6,8,10) on the other (right side), as shown in Fig. 1.

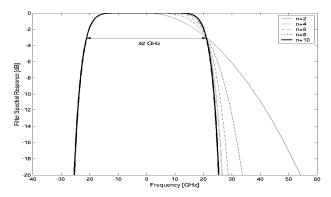


Fig.1 Spectral response of the proposed VSB filter

To illustrate the operation of the proposed filter, first, without loss of generality we investigate back-to-back performance in terms of standard Q-factor and employ VSB filtering with MUX/DEMUX functions in 8x40Gb/s DWDM systems, using RZ signal with 80% spectral efficiency (channel spacing of 50GHz) as shown in Fig. 2. For this particular application a bandwidth (at -3 dB level) of the designed filter was set to be 42GHz.

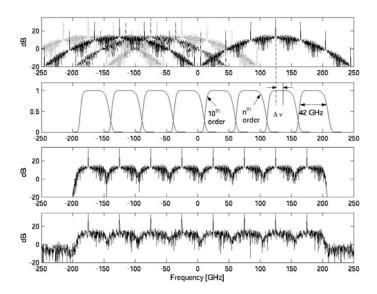


Fig.2. Top: Channel spectra of optical signal combined without filtering, on the right - a single channel before MUX; VSB filters shape and location (second from the top); Spectra after filtering via MUX (third from the top); Spectra after propagation over 1170km of SMF/DCF (bottom).

By varying the value of n and simultaneously optimising the duty cycle and filter detuning, we observe the best result in the back-to-back performance of the considered system for n = 8.

Table 1. Best regimes in the back-to-back performance.

n	Duty cycle	Δν [GHz]	Q (linear)
2	0.52	12	6.1
4	0.32	6	12.9
6	0.24	5	22.8
8	0.2	-2	34.3
10	0.2	-3	31.5

Table 1 lists the best results for different *n* and corresponding optimal values of duty cycle and detuning.

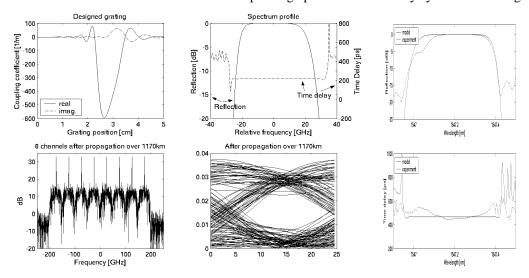


Fig.3. Real and imaginary parts of the coupling coefficient for VSB filter design using FBG (top left), spectrum profile of the grating (top middle) and its performance after propagation over 1170km of SMF/DCF: channel spectra (bottom left) and 4-th channel eye (bottom middle). Comparison between modelled and fabricated gratings: in reflection (top right) and in time delay (bottom right)

3. VSB filter fabrication using fibre Bragg grating

There are different ways to fabricate the proposed VSB filter. We present here the design of a fibre Bragg grating (FBG) (Fig.3, top left) that has the required response (reflection) function (Fig. 3, top middle). Figure 3 also shows transmission (bottom) performance of such FBG-based asymmetric VSB filter.

The apodisation profile of the grating was calculated using the layer-peeling algorithm described in [4,5]. Note that introduction of a slight asymmetry of the grating response function does not require significant modification of the fabrication technique compared to symmetric design of similar FBG with sharp edges transfer function. The right hand column of Figure 3 illustrates a good agreement between experimentally obtained and modelled reflection spectrum and time delay.

4. Evaluation of VSB filter performance in transmission

Next we examine the performance of the proposed technique in transmission. Without loss of generality we consider the following fibre line depicted in Fig. 4. A periodic dispersion map consists of 50km standard single mode fibre (SMF) and 8.5 km dispersion compensating fibre (DCF) followed by EDFA (noise figure NF=4.5 dB) and a similar block with the reverse order of SMF and DCF. The span average dispersion is zero. VSB filtering has been realised at both MUX and DEMUX (see Fig.2).

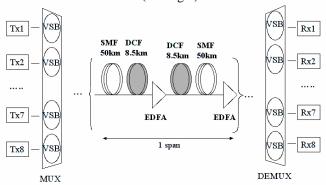


Fig.4. Scheme of the 8 x 40 GB/s WDM SMF/DCF transmission system used to evaluate performance of the proposed filtering technique.

Transmission performance of eight channels (8x40Gb/s) spaced by 50GHz has been modelled using 2^7 –1 pseudorandom binary sequence data signal. Averaging over five numerical runs with different patterns has been applied to account for patterning effects. Error-free transmission distance was defined using the standard requirement (linear Q-factor > 6 or BER < 10^{-9}). Optimization of the key system/signal parameters has demostrated that error-free DWDM 8x40Gb/s transmission over 1170 km of SMF/DCF link with 0.8 bit/s/Hz spectral efficiency is feasible.

5. Conclusion

We examined ultra-narrow optical filtering technique based on specially designed slightly asymmetric VSB filter that realizes a balanced trade-off between cross talk suppression and minimization of waveform distortions. We propose a design and fabricated a fibre Bragg grating with required spectral response and flat time delay across the reflection band. Using proposed VSB filter a feasibility of 8x40Gbit/s DWDM RZ transmission with 0.8 bit/s/Hz spectral efficiency (without polarization multiplexing and FEC) over 1170km of SMF/DCF link has been confirmed.

6. References

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