Dispersion-insensitive, frequency-doubled SCM signal processing technique for optical label swapping

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ABSTRACT

We propose and simulate a novel optical label swapping scheme using a frequency-doubled subcarrier multiplexed (SCM) signal processing technique. This method can support a dispersion-insensitive and polarization-independent transmission and extraction of an SCM optical label using a standard fiber Bragg Grating (FBG) filter and an optical circulator without a conventional SCM coherent detection circuitry. Simulation results show that our method is applicable to an FBG filter with wide reflection bandwidth (BW), and relieves the restriction of an optical FBG filter, satisfying the wavelength tolerance of the dense WDM sources and FBG's center wavelength . Driving an external Mach-Zehnder (MZ) modulator over the full switching voltage improves the receiver sensitivity, compared to the previous standard double-sideband (DSB) SCM header processing technique.

Keywords*:* Optical label, subcarrier multiplexing (SCM), Fiber Bragg Grating (FBG), Frequency-doubled, Dispersion-insensitive

1. Introduction

Internet traffic is growing exponentially and the next generation Internet Protocol (IP) networks demand a scalable and data-oriented networking technology. All optical packet-switched networks need to handle the optical header to efficiently route optical packets to the proper destination without converting the packets from optical to electrical format and vice versa. One of the most important requirements during the header information extraction for routing purpose is that the header should be able to be processed rapidly and on-the-fly. An optical label switching networks [1-2] require a simple and effective method to swap headers in real time without affecting the payload data in order to realize low-latency packet forwarding and routing. Several optical labelling methods are reported, and they can be categorized into time division multiplexing (TDM) and subcarrier multiplexing (SCM) methods. The TDM method utilizing a part of high bit rate data stream as label information, similar to SONET/SDH overhead requires access to the high speed bit stream and needs high-speed optoelectronics to acquire optical overhead information. On the contrary, an SCM optical header attatched to each optical packet can be processed and replaced using relatively low-speed optoelectronics, while the high-speed payload data easily separated from the header data remains in the optical domain.

Several reports [3-6] have proposed and demonstrated optical network techniques incorporating SCM optical headers. Conventional coherent SCM receivers consisting of envelope detection of double-sideband (DSB) SCM optical headers exhibit rf fading effects from the interactions between the DSB-SCM signals and the optical carrier due to the fiber chromatic dispersion. Recent publications have reported optical filtering of a single-sideband (SSB) SCM header [3], optical filtering with an optical loop mirror incorporating a birefringent fiber [4], and optical filtering using a fiber Bragg grating (FBG) filter and an optical circulator [5-6]. The optical filtering method for a SSB SCM header using a tunable fiber Fabry-Perot filter can easily separate the optical label from the combined optical baseband payload and SCM label data, but requires a sophisticated optical SSB SCM transmitter. The optical filtering technique for the extraction of a standard DSB SCM using a fiber-loop mirror with a polarization-maintaining (PM) fiber as a dual-output filter [4] can simultaneously extract multiple SCM headers encoded on multiple wavelength channels, but requires careful balancing of the 2 x 2 fiber coupler, accurate matching of sideband frequencies to the narrow notch frequency bands, and cautious handling of bulky fiber loop mirrors. The SCM signal demodulation technique using an FBG filter and an optical circulator [5-6] can realize a simple, stable and dispersion-insensitive SCM header extraction configuration, but this method requires a tightly designed FBG filter and therefore is highly sensitive to the FBG filter characteristics and the wavelength drift of the dense WDM (DWDM) optical carrier.

In this study, we propose and simulate a novel technique to generate and detect a DSB SCM optical label signal which is 2 x subcarrier frequency-separated from the baseband payload data simultaneously modulated on the optical carrier, which can lessen the reflection BW-sensitivity of an optical FBG filter and satisfy the wavelength drift tolerance of a DWDM optical sources and an FBG filter's center wavelength.

2. Proposed Scheme

The proposed scheme is based on a standard DSB SCM transmitter structure and an optical FBG filter characteristic. Fig. 1 shows the operational principle of extracting the proposed 2 x subcarrier frequency (hereafter 2 x f_{sub}, f_{sub}= RF subcarrier frequency)-separated DSB SCM optical label signal from the mixed signal.

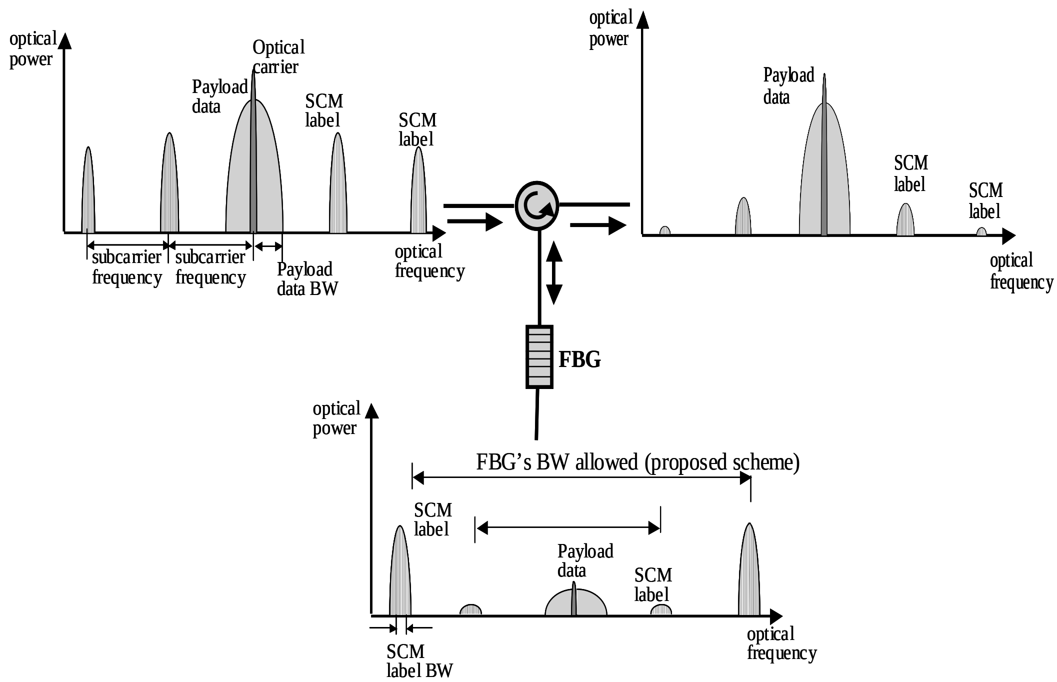


Fig. 1 Operational Principle for separating the DSB SCM label signal from the baseband payload siganl

Configuring appropriately the DSB SCM transmitter is necessary to generate 2 x f_{sub} –separated DSB SCM optical label signal from optical carrier frequency. The baseband payload data and SCM label signal are encoded on the same optical carrier by means of a single electrode external Mach-Zehnder (MZ) modulator and a high power distributed feedback laser diode (DFB-LD). The input signal to an optical circulator and an FBG filter, generated by a standard single electrode DSB SCM MZ modulator, is composed of a baseband payload signal and a spectrally 2 x f_{sub} –separated DSB SCM label signal. The wavelength of the transmitter is matched to that of the FBG, so the FBG filter reflects the payload signal and transmits 2 x f_{sub} –separated DSB SCM label signal. The extracted label signal is detected by a simple square law detector, because the extracted label signal contains no payload component . At the second optical node (optical router), we can attatch a new SCM label to the reflected optical payload signal by the similar method and can process the optical payload data transparently without optical to electrical conversion.

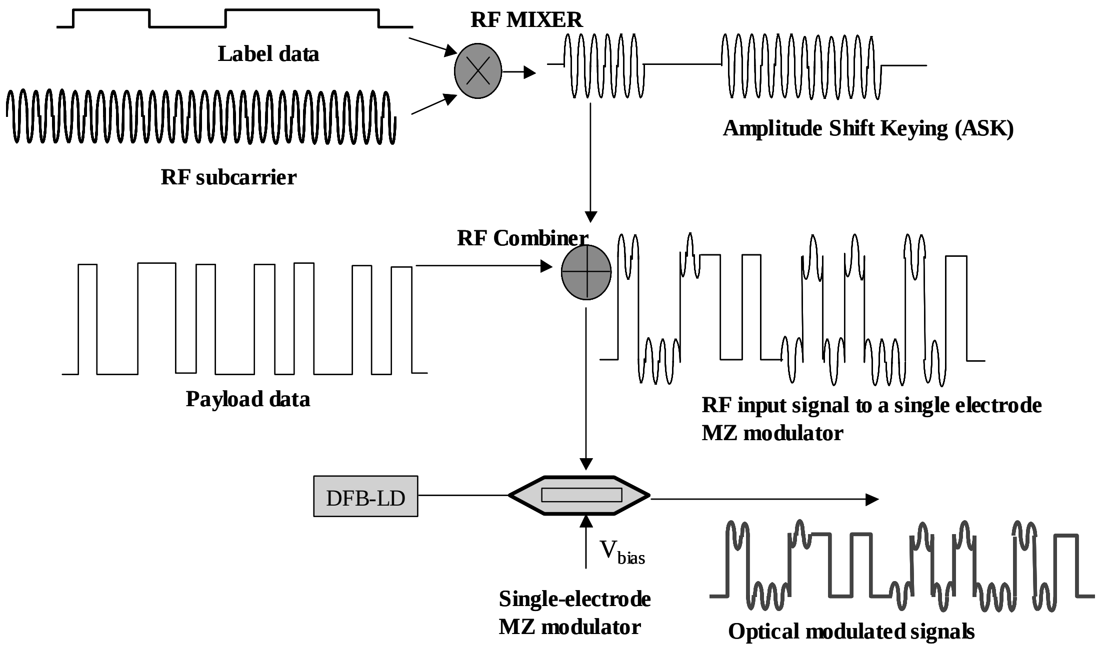


Fig. 2 Schematic architecture of our DSB SCM transmitter using a single-electrode MZ modulator

Fig. 2 shows the architecture of our DSB SCM transmitter using a single-electrode MZ modulator. A relatively low speed (155-622Mb/s) NRZ label data is generated and mixed with an RF subcarrier, resulting in an electrical DSB SCM amplitude shift keying (ASK) signal, and 2.5Gb/s NRZ baseband payload data is generated and are amplified, respectively. The two signals are combined by means of high frequency 3dB combiner and the combined signals are being drived by the external single electrode MZ modulator. Using ASK for encoding SCM label data allows for the use of a simple square-law detector. There is a trade-off between the baseband payload performance and SCM label performance, which are strongly dependent on the baseband signal amplitude and the subcarrier power before combining two signals. We can adjust the optimum modulation ratio between two signals following the generation scheme [7] which has analyzed the differential MZ modulator case, but can be applied to the high frequency combiner (3 dB coupler).

In general, a MZ modulator is biased at a quadrature point and operated in the linear regime to reduce the nonlinear effects of the MZ modulator's nonlinear transfer function. The proposed scheme, nonetheless, utilizes the nonlinear transfer function feature of a MZ modulator, and makes second harmonic spectral components of DSB SCM label signal, which are spectrally 2 x f_{sub} – separated from the optical carrier frequency. Careful control of the payload amplitude, subcarrier modulated label amplitude, and the bias voltage of the MZ modulator can reduce the nonlinear signal distortion and the intermodulation penalty. Concept-proof and optimization simulations are realized with the simulation tool VPI Transmission Maker 4.0 [8].

3. Simulation results and Analysis

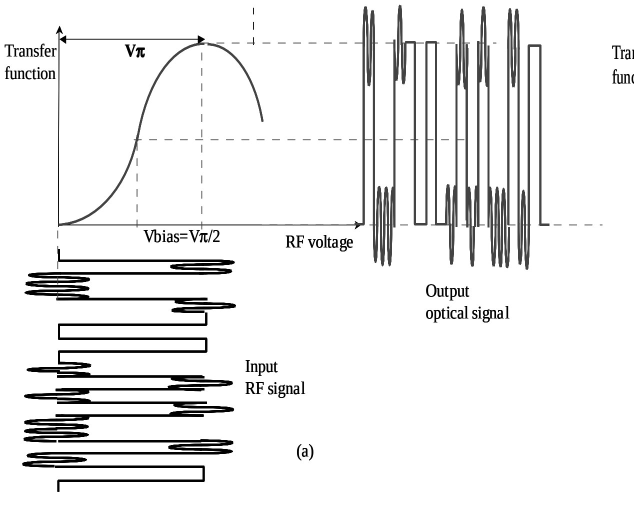


Fig. 3 Operation diagram of a single electrode MZ modulator (a) proposed scheme drived to the maximum and the minimum points at a quadrature bias point, (b) standard scheme drived over the linear region of the MZ modulator's transfer function at a quadrature bias point

Fig. 3 shows the concept of the proposed scheme. In this scheme, we make use of the nonlinear transfer function characteristcs of the external single-electrode MZ modulator. Around the maximum and the minimum points, the SCM label data is drived and therefore both the 1st harmonic- and 2nd harmonic- f_{sub} spectral components are generated.

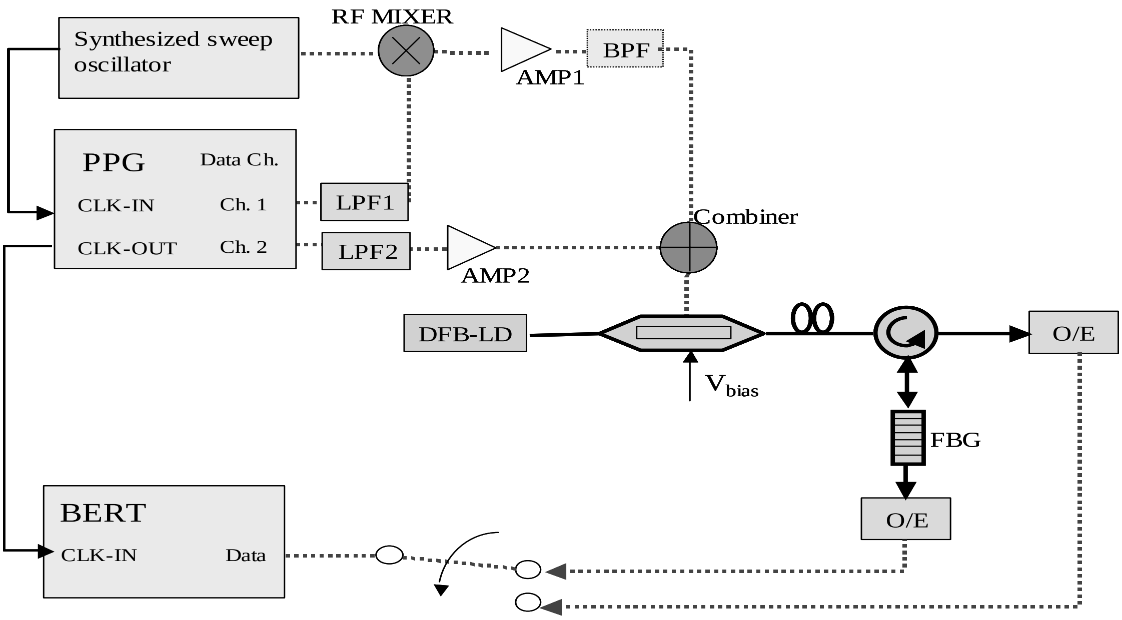


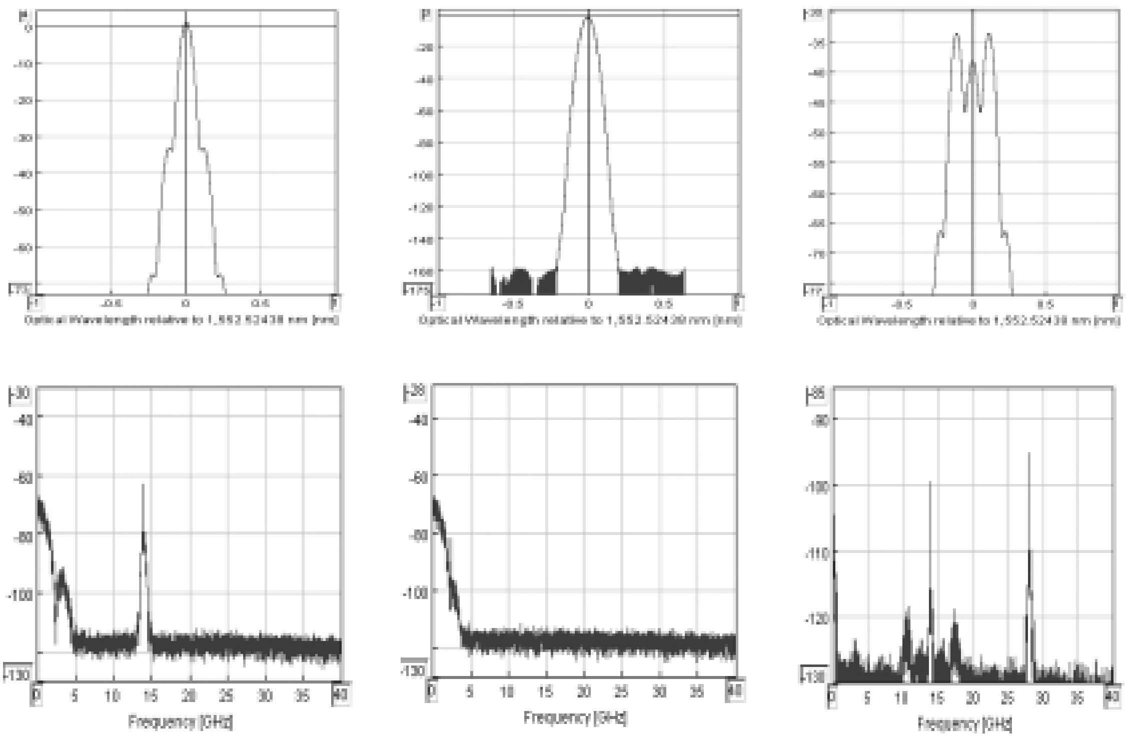
Fig. 4 Simulation diagram for the proposed scheme

Fig. 4 shows the simulation diagram for the proposed scheme, which closely resembles a real experimental setup, afterwards to verify and compare the experimental data with the simulated ones in the similar experimental configuration.

Table 1. Main Parametr characteristics for the simulation

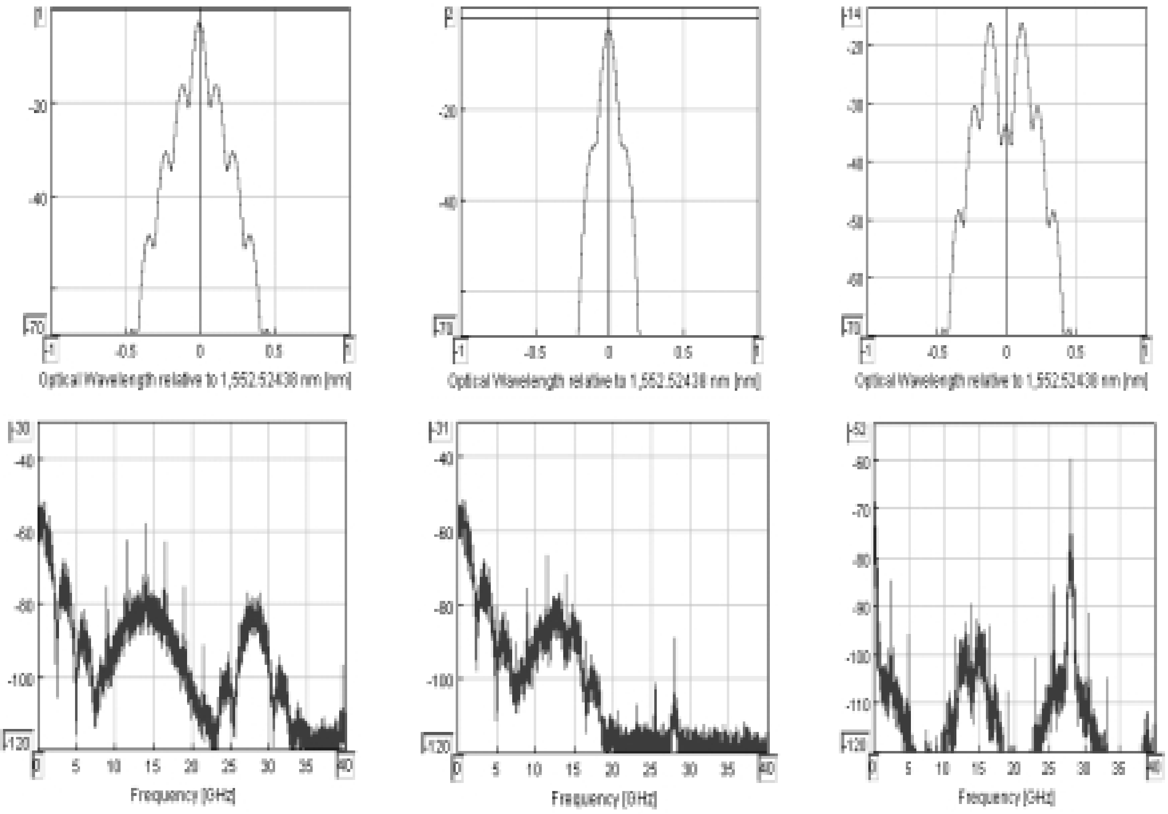
Main components	Characteristics
Single-electrode MZ modulator	Vπ=3.84V Insertion loss=6dB, Extinction ratio=20dB
Payload data	2.5Gb/s NRZ PRBS 2^{23}-1
Label data	622Mb/s NRZ PRBS 2^{23}-1
Subcarrier	Frequency f_{sub}=14GHz
Mixer	Ideal (dc-18GHz supported)
Combiner	Ideal (dc-18GHz supported)
DFB LD	Power=5mW, Frequency=193.1THz
BPF	Not applied
LPF1 for label data	0.7*622MHz
LPF2 for payload data	0.7*2.5GHz
FBG filter	Center Frequency=193.1THz, Bandwidth=0.32nm, Reflectivity=30dB

Table 1. summarize the main parameters of the simulation. Especially, the lowpass filters (LPFs) are required to prevent the sidemodes spectral components of the 2.5Gb/s payload NRZ data from interfering with the ASK subcarrier signal. Adjusting the above parameters, we compare our scheme to the standard DSB SCM method and can find the optimum condition for the proposed scheme.



(a) (b) (c)

Fig. 5 Optical spectra and rf electrical spectra for (a) the input signal, (b) the reflected payload, (c) the extracted label of the standard DSB SCM method with an FBG filter characteristic of reflection BW=0.08nm, reflectivity=35dB (the resolution of OSA set to 0.05nm, the resolution of rf spectrum analyzer set to 10MHz)



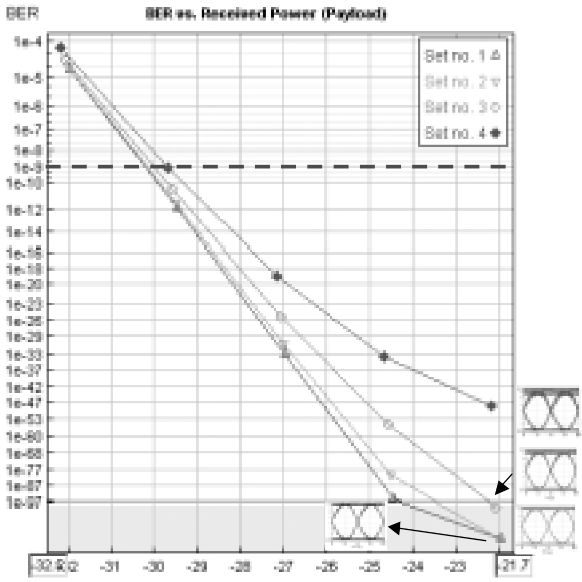
(a) (b) (c)

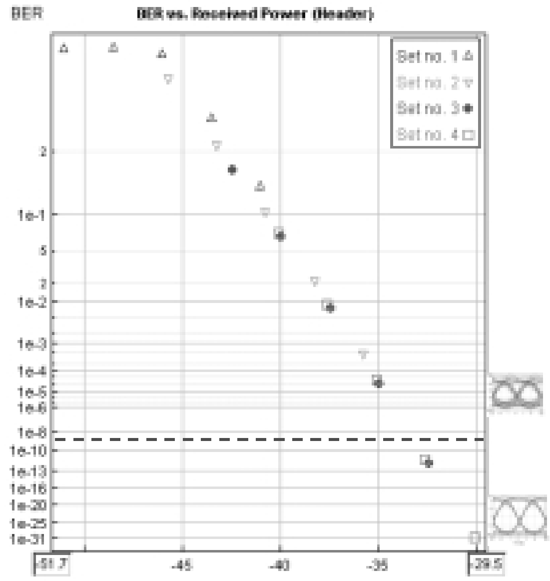
Fig. 6 Optical spectra and rf electrical spectra for (a) the input signal, (b)the reflected payload, (c)the extracted label of the proposed scheme with an FBG filter characteristic of reflection BW=0.32nm, reflectivity=30dB (the resolution of OSA set to 0.05nm, the resolution of rf spectrum analyzer set to 10MHz)

To confirm that our scheme operates well, the spectral properties of the two methods are invetigated before and after an FBG optical filter by means of the spectral power densities of an optical spectrum analyzer (OSA) and an electrical rf spectrum analyzer. Comparing Fig. 6 with Fig. 5, we can make sure that both the 1st harmonic- and the 2nd harmonic- microwave subcarrier spectral components are shown after the external MZ optical modulation. In the standard DSB SCM method, we set the optical modulation index (OMI) at 30% for both payload data and SCM label signal. In the proposed scheme, we set the SCM label amplitude 30% relative to the payload amplitude and then drive RF mixed signals over the full switching voltage of the MZ modulator as in Fig. 3(a). In both schemes, an FBG filter and an optical circulator can separate the DSB SCM label signal from the mixed signals. The extracted label signal contains no payload component (more than 30 dB spectral density suppressed in both schemes), so can be demodulated by a simple square-law detector without chromatic dispersion- induced RF fading. But we can relieve the restriction of an FBG filter' reflection bandwidth which is decided as the spectral separation between the optical carrier frequency containing the payload baseband and the DSB SCM label-modulated subcarrier frequency by making use of the 2 x f_{sub} – separated label component.

After confirming that the proposed scheme operates well, we investigate in detail the effects of the subcarrier label amplitude relative to the payload amplitude and the various reflection BWs of an FBG optical filter for our porposed frequency-doubled SCM signal processing scheme. Following the analysis [7], we vary the subcarrier amplitude among 5%-45% relative to the baseband payload amplitude for combining two signals by means of an RF combiner and find the trade-off between the payload data performance and the label data performance. To reduce the nonlinear distortion and intermodulation penalty, we simulate and optimize the BER performance for SCM label amplitudes relative to the payload amplitude.

Fig. 7 show that the optimum ratio for SCM label amplitude relative to the payload amplitude is about 25-30% for our application. Above the ratio 35%, the BER curve of the payload data is saturated and the receiver sensitivity of the payload data is very high. In the case of the SCM label performance, the receiver sensitivity of the label data is very small , nearly –33dBm for 25% SCM label amplitude. So we can set the ratio 25% as the optimum ratio for our label swapping application.





(set no. 1=5%, set no.2=10%, set no.3=15%, set no.4=20%)

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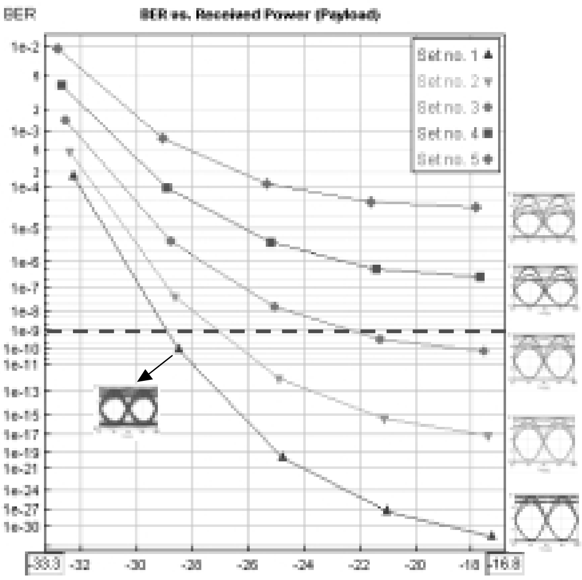

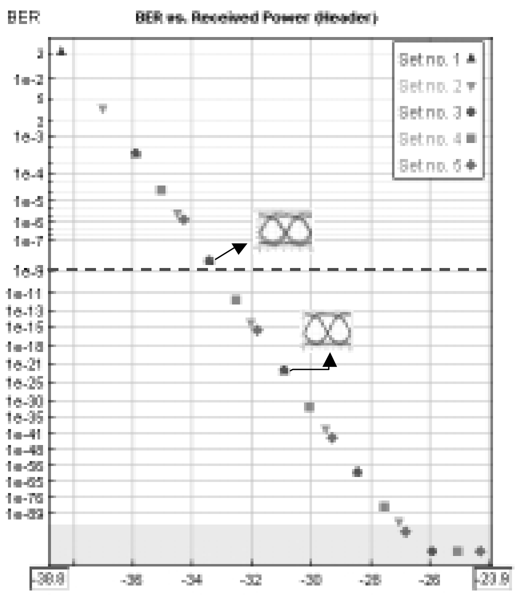

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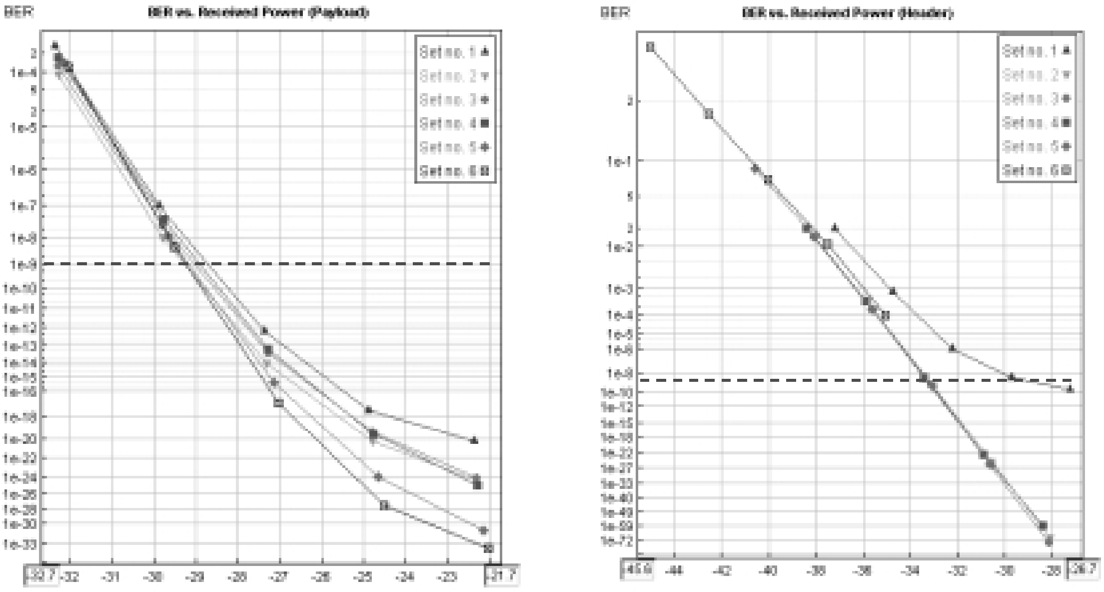
(set no. 1=25%, set no.2=30%, set no.3=35%, set no.4=40%, set no..5=45%)

(a) (b)

Fig. 7 Simulated BERs for (a) the transmitted payload and (b) the extracted label for the various label amplitudes relative to the payload amplitude (results for 5%-45%)

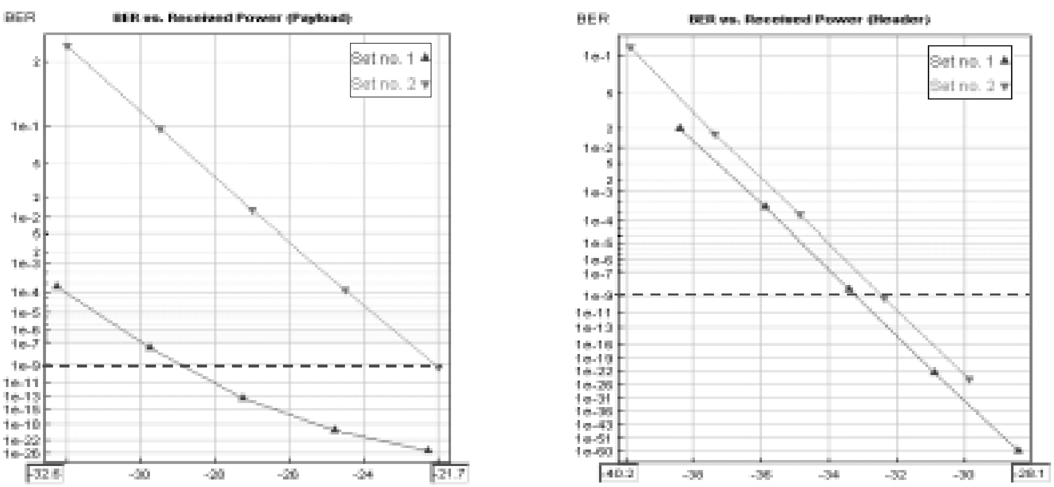


(a) (b)

Fig. 8 Simulated BERs for (a) the transmitted payload and (b) the extracted label for the various 3 dB reflection bandwidths of an optical FBG filter. (set no.1=0.08 nm, set no.2=0.16nm, set no.3=0.24nm, set no.4=0.32nm, set no.5=0.40nm, set no. 6=0.48nm, and the reflectivity set to the same value of 30 dB at peak for all cases)

Fig. 8 shows that the an FBG filter with broad range of the 3 dB reflection bandwidth can be applicable to the proposed scheme, which relieves the restriction of an FBG optical filter. The penalty of the receiver sensitivity of the payload data is within 1 dB for the broad range of FBG's reflection BWs of 0.08nm-0.48nm, and the penalty of the receiver sensitivity of the SCM label is near zero for the range of 0.16nm-0.40nm. For the standard DSB SCM method, the reflection bandwidth and the reflectivity of an FBG' filter should be tightly controlled (the FBG's reflection BW should be below twice the microwave subcarrier frequency).

Finally, we compare the simulated BER performance between the proposed scheme and the standard DSB SCM method for the received power gain because of driving full range of MZ modulator's switching voltage.



(a) (b)

Fig 9. Comparison of the received power gain (receiver sensitivity improvement) for (a) the transmitted payload and (b) the extracted label of the proposed scheme (set no. 1) and the standard DSB SCM method (set no.2)

It is difficult to directly compare the BER performance of the two methods, but Fig. 9 shows that our scheme gets high received power gain, and improves the receive sensitivity (the receiver sensitivity defined as the received power to achieve 10^{-9} BER) of about 7 dB gain of the payload performance and 1 dB gain of the SCM label performance over the standard DSB SCM technique for the described operating conditions.

4. Conclusion

We propose and simulate a novel optical label swapping scheme using a frequency-doubled subcarrier multiplexed (SCM) signal processing technique, and find the optimum SCM label amplitude (25%) relative to the payload amplitude. Our method relieves the restriction of an optical FBG filter, which is applicable to the broad range of an FBG's reflection bandwidth (0.16-0.40nm) with the reflectivity of 30 dB. This relieved restriction of an FBG filter can also satisfy the wavelength drift tolerance of a DWDM optical sources and an FBG filter's center wavelength. Driving a external MZ modulator over the full switching voltage gains high received powers, and improves the receive sensitivity.

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