SOA-based Wavelength Converter for Multi-service Radio-over-fiber Signals

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We present the feasibility of simultaneously routing multi-service radio frequency signals in RoF systems, by applying XGM in an SOA. Simulation results show that a three-channel QPSK, 16QAM and 16QAM-OFDM of 125 Mbit/s signal can be simultaneously wavelength converted from 1552.5 nm to 1551.7 nm, both with EVM penalties of less than 2%. We concentrate on one of the impairments of wavelength conversion of multi-service system, namely the nonlinear intermodulation distortion of the two-tone signal in the SOA. The third-order intermodulation products characterized by SFDR are calculated for different optical probe power of the SOA.

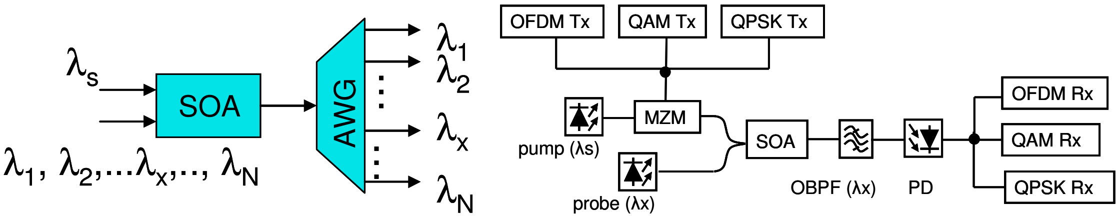
Introduction

Radio-over-fiber (RoF) technology combines the high capacity of fiber optical transmission and the flexibility of wireless access, thus provides a potentially low-cost solution for in-building wireless networks. The subcarrier multiplexing (SCM) method is very useful for RoF systems since it can merge several applications together. SCM has been implemented in the multi-service RoF links with data rate of 48 Mbit/s [1]. Apart from the transmission of the RoF signal, with the increasing capacity demanded by the end users, the dynamic capacity allocation and inter-connection between the different rooms within one in-building network are required. Such configurable cross-connections can be realized by the means of the optical wavelength routing, to improve the flexibility of the in-building networks [2].

In this paper, we firstly present feasibility of simultaneously routing of multi-service radio frequency signals using SCM scheme in RoF systems, by employing wavelength conversion. The wavelength conversion is realized by the cross-gain-modulation (XGM) of the semiconductor optical amplifier (SOA). To analyze the performance of the wavelength conversion, we also investigate the degradation of the performance introduced by the nonlinear inter-modulation in the SOA. And finally, we study the spurious-free dynamic range (SFDR) to characterize the intermodulation products in the wavelength conversion.

Routing of multi-service RoF signals

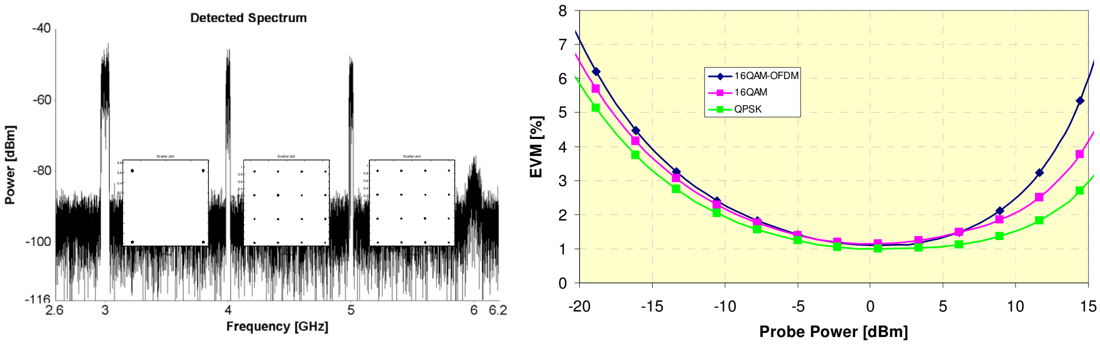
The principle of routing is illustrated in Figure 1 (a). Light at wavelength λs which is modulated with RF data signal is coupled together with a continuous-wave (CW) light at wavelength of λx into an SOA. The data signal modulates the carrier density in the SOA, and the resulting gain variations imprint the data onto the CW signal. With the help of an arrayed waveguide grating (AWG) at the output of SOA, by tuning the input wavelength of the CW light (λx), one can route the signal to different output of the AWG.



(a) **(b)**

Figure 1 (a) Principle of routing. (b) Simulation setup.

In order to evaluate the routing performance of the SOA based wavelength converter, a VPI platform is built as shown in Figure 1(b). The RoF signal consists of three-channel QPSK, 16QAM and 16QAM-OFDM signal with the carrier frequency of 3 GHz (f_1), 4 GHz (f_2) and 5 GHz (f_3) respectively and the data rate of 125 Mbit/s. The OFDM signal has 64 subcarriers. Three-channel signals are added together and modulate a laser with center wavelength of 1552.5 nm via a Mach-Zehnder modulator (MZM). The modulated laser light (*pump*) is then coupled into a SOA together with a CW laser operating at wavelength of 1551.7 nm which serves as the *probe* signal for the wavelength conversion. Due to the XGM process inside SOA, the modulated data is copied from the pump wavelength to the probe wavelength. Then the probe wavelength is filtered out by an optical bandpass filter and detected by a photo diode. The detected signals are analyzed by QPSK, 16QAM and 16QAM-OFDM receivers respectively.



(a) **(b)**

Figure 2 (a) Detected spectrum and constellation diagram of QPSK, 16QAM and 16QAM-OFDM signals at optimum probe power. (b) EVM versus probe power for three-channel signals.

Figure 2 (a) illustrates the detected spectrum and constellation diagram of the received QPSK, 16QAM and 16QAM-OFDM signals. Both pump and probe power are set at 0 dBm and SOA is biased at 250 mA. The constellation diagram shows the good recovery of the detected three channel signals. The error vector magnitude (EVM) values are calculated at different optical input power of the probe signal with the pump power of 0 dBm, which is shown in Figure 2 (b). There is an optimum value of probe power for the system performance. The high EVM values at lower probe powers are caused by the low carrier-to-noise ratio; while at higher power level, an increase in the probe power will increase its contribution to the gain saturation and thereby reduce the conversion efficiency. EVM values of less than 2% can be achieved over a large span of probe power (around 15 dB).

However, we observe a peak at 6 GHz in the detected spectrum which is distortion from both the second harmonic ($2f_1$) and the third-order intermodulation products ($f_2+f_3-f_2$, $2f_3-f_2$). Nonlinear distortions introduced by the SOA wavelength converter can limit considerably the system performance. These dynamic distortions result from the interaction of photons and electrons in the SOA, which is described by the rate equations. A perturbative approach up to the third order can be assumed to solve the rate equation and derive the harmonic distortion and intermodulation products for the converted signal [3].

SFDR measurement

In order to characterize the linearity of the wavelength converter, a two tone test is performed to measure the SFDR of the SOA wavelength converter. Figure 3 shows the simulation setup.

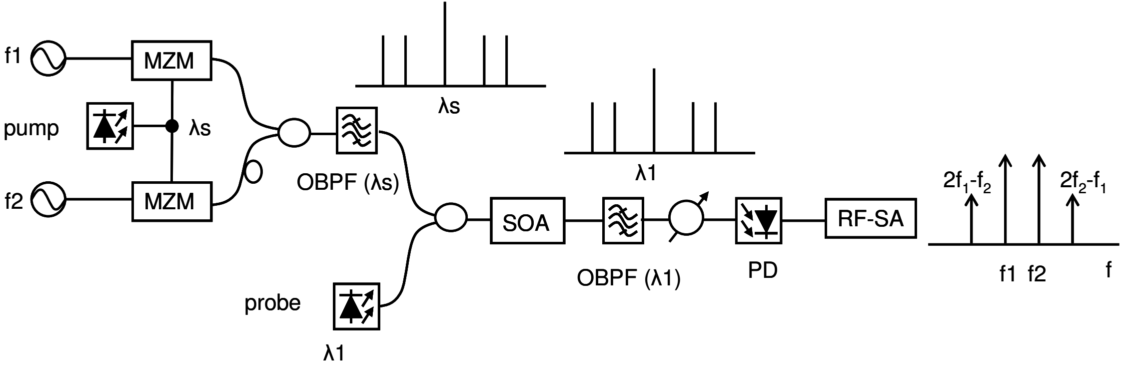
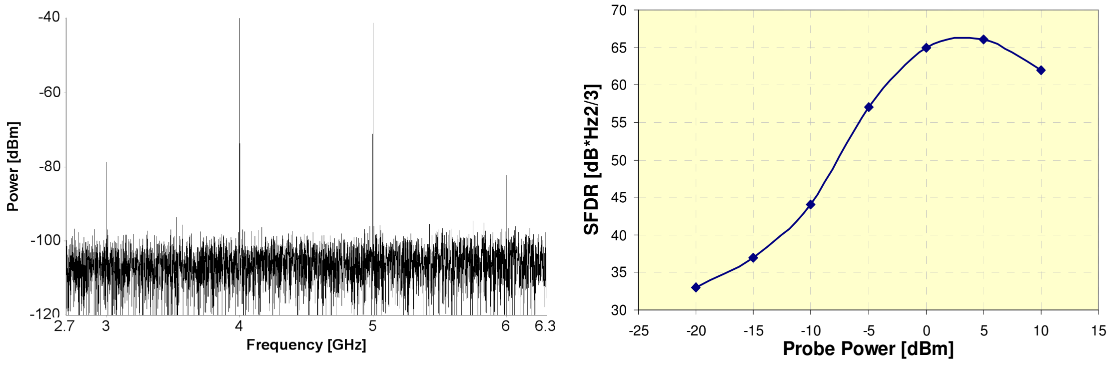


Figure 3 Two tone test simulation setup.

The optical pump signals at λ_s = 1552.5 nm. For generating RF subcarriers, two MZMs biased at the quadrature point are intensity-modulated independently at 4 GHz (f_2) and 5 GHz (f_3). The reason for using two modulators is to prevent the influence of the third-order intermodulation distortion effects of the modulator itself. We utilize only one optical source for two modulators to avoid complexities from the unwanted four-wave mixing terms produced by two optical sources with closely spaced wavelengths. In order to prevent coherent beating between two optical signals that makes detected signals unstable, an optical delay line is introduced at one modulator output path [4]. An optical band pass filter is used to filter out the unwanted second harmonics arise from the nonlinearity of MZM. An optical attenuator is used before photodetector (PD) to eliminate influence of PD nonlinearity. The detected RF spectrum after wavelength conversion is shown in Figure 4 (a) where the third-order intermodulation distortion products (IMP3) at the frequencies of 3 GHz ($2f_2$-f_3) and 6 GHz ($2f_3$-f_2) are clearly observed.



(a) (b)

Figure 4 (a) Detected spectrum for 2-tone RF. (b) The dependence of SFDR on probe power.

Figure 4 (b) shows the measured SFDR as a function of SOA probe powers ranging from -25 dBm to 10 dBm with 5 dB increment. The pump power is set at 0 dBm and

SOA is biased at 250 mA. The results show that SFDR values larger than 65 dB·Hz$^{2/3}$ are obtained with probe powers between 0 and 7 dBm.

Conclusions

We present the feasibility of simultaneously routing of three-channel RoF signals by applying XGM in the SOA. EVM value of less than 2% can be achieved over a large span of probe power (around 15 dB). The nonlinear inter-modulation distortion properties of the SOA-based wavelength converter are investigated. We measured the dependence of SFDR on the probe powers of SOA. With an optimum value of probe power, SFDR larger than 65 dB·Hz$^{2/3}$ can be achieved.

Acknowledgement

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