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延时干涉结构辅助的电吸收调制波长变换研究

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摘 要:基于电吸收调制器,对比分析了无延时干涉仪装置和有延时干涉仪装置条件下波长变换的情形. 10 Gb/s 归零码光信号波长变换的实验证明,延时干涉仪装置可有效消除变换后光信号的脉冲拖尾,并极大地改善信号的消光比指标. 分析了电吸收调制器偏置电压、数据信号功率、变换波长等工作参数对波长变换性能的影响,发现无论有无延时干涉仪装置,均需合理设置偏置电压来优化波长变换信号的接收灵敏度;在-3.0 V 偏置电压条件下,有延时干涉仪装置时,灵敏度增益达 2.0 dB.

关键词:电吸收调制器;延时干涉仪;交叉吸收调制;波长变换;消光比
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Wavelength Conversion Using Electroabsorption Modulator Assisted by Delayed Interferometer Structure

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Abstract: Wavelength conversion using electroabsorption modulator was analyzed for two operating conditions: without delayed interferometer structure and with delayed interferometer structure. It's proved by 10Gb/s return-to-zero signal wavelength conversion experiment that long pulse trailing edge of the converted signal can be mitigated obvisouly and the exticion ratio of the coverted signal can be improved sigificantly. Meanwhile, the influencen of operating parameters including bias voltage, data signal power, and wavelength on conversion performance were studied in detail. It's found that the proper setting bias voltage can optimize receiver sensitivity of the converted signal for two operating conditions and delayed interferometer can introduce nearly 2.0 dB sensitivity gain under -3.0 V bias voltage.

Key words: Electroabsorption modulator; Delay-line interferometer; Cross-absorption modulation; Wavelenght conversion; Extinction ratio
OCIS Codes: 230.4110; 230.7405; 060.4080

0 Introduction

All-optical wavelength conversion[1] is a key technology in dynamic optical network in the future and can be employed in optical routers to avoid wavelength blocking and improve network feasibility and scalability[2]. All optical wavelength converters have been demonstrated using various nonlinear materials, such as semiconductor Optical Amplifiers (SOAs)[3-6], highly nonlinear fiber[7-8] or photonic crystal fiber[9-10], Electroabsorption Modulator (EAM)[11-14] etc. All optical wavelength converter based on SOAs have been

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studied extensively. However, an SOA has a long gain recovery time of more than a few tens of picoseconds, even if its gain is clamped by means of internal (i. e., self-lasing light) or external assist light. Therefore, pattern effect[15] is not negligible in case of high bit rate. The nonlinear fiber based converter can provide ultrafast nonlinearity response with magnitude of femtosecond, and it has been demonstrated at rates up to 640 Gbit/s[7]. However, fiber based converters is sensitive to environment perturbation and is polarization-sensitive if no diversity scheme is applied. The EAM based converters using cross absorption modulation (XAM) are promising because short absorption recovery time[12] under high reverse bias voltage and stable, polarization-insensitive operation.

In our paper, wavelength conversion assisted by Delayed Interferometer (DI) structure is experimentally studied by comparing two cases of without DI structure and with DI structure. Furthermore, optimization of operation condition is investigated thoroughly by considering the influence of EA bias voltage, data signal power, and DI structure parameters on conversion performance.

1 Experimental setup

The experimental setup is shown in Fig. 1. The 1 547 nm Continue Wave (CW) light is modulated by electroabsorption modulator (EAM-I) driven by 10 GHz clock to generate 10 GHz pulse trains with pulse width around 20 ps. The 10 GHz pulse train is encoded with a PRBS of $2^{31}-1$ by $LiNbO_3$ modulator. The encoded pulse train is amplified by the following Erbium Doped Fiber Amplifier (EDFA) and then injected into reverse-biased EAM-II as pump light after passing the circulator. The anther CW light at wavelength tunable from 1 535nm to 1 565nm, emitting from tunable Distributed Feedback (DFB) laser, is injected into EAM-II from the opposite direction as probe light. When propagating through EAM, the probe CW light is modulated because of the transmission change induced by the data pump light through electrical screening effect of optical generated carriers. Therefore, the information is transferred from the data pump wavelength to the probe wavelength. After the band pass filer centered at the probe light wavelength, the converted signal can be obtained. It's noted that the converted signal is chirped because of the refractive index of EA materials vary accompanying with the transmission change induced by the pump light. The converted signal has the two modes for next step. One is "no DI" mode that the converted signal is measured directly, and the other is "with DI" mode that after firstly passing DI structure, the converted signal is then measured. The detailed DI structure is shown in inset figure, consisting of birefringent crystal with Different Group Delay (DGD) of 8 ps, polarizer, PC_1 used for polarization adjustment, PC_2 used for polarization adjustment and phase bias adjustment. The measurements include waveform monitoring, optical spectrum monitoring, Bit Error Rate (BER) testing. In our experiments the power of the probe light is fixed at 6. 3 dBm.

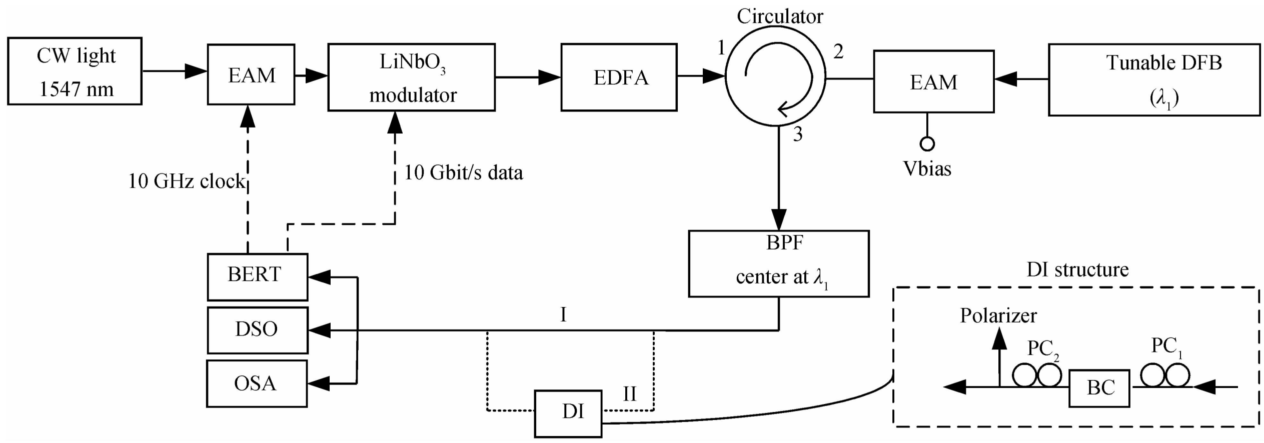


Fig. 1 The experimental setup of wavelength conversion using EA

2 Results and discussion

The "no DI" mode is implemented firstly and the wavelength conversion performance dependence on bias voltage in this mode is presented. The wavelength of the probe light is set at 1 564 nm. The average power of data signal is fixed at 18. 2 dBm and EA reverse bias voltage is tuned from 3. 16 V to 2. 25 V. The corresponding measured waveforms are shown in Fig. 2. With the decrease of bias reverse voltage, the extinction ratio (defined as the ratio between the level of the spaces and the marks) of the converted signal is degraded. The main reason for degradation is that at low reverse voltage the available maximum extinction ratio is lower compared with the situation at high reverse voltage assuming that the data signal has enough high power for achieving absorption saturation. Meanwhile, due to slow absorption recovery at lower reverse voltage, the switching window induced by pump light becomes wide and begins to spread into the next time slot. This can lead to obvious crosstalk between the adjacent bits.

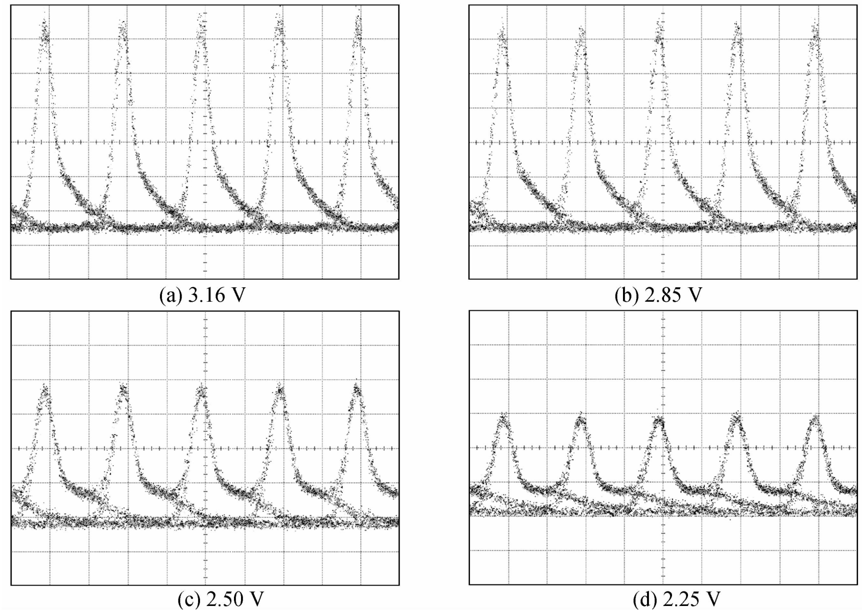


Fig. 2 The waveforms of the converted signal at different bias voltage (50ps/div)

The receiver sensitivity (measured when the optical receiver power is BER=1e-10) of the converted signal at different bias voltage is shown in Fig. 3. The receiver sensitivity increases with the decrease of bias reverse voltage according to the basic tendency of the curve. However, the slight reduction of the receive sensitivity when bias reverse voltage varies from 3.2 V to 3.0 V, is due to that at too high reverse bias voltage of 3.16 V, the obtained extinction ratio become low because more higher power are required for achieving absorption saturation and the obtained Optical Signal to Noise Ratio (OSNR) is lower due to the too large loss. Therefore, the optimum bias voltage of 3.0 V exists for optimizing wavelength conversion performance. When the data signal power is tuned to another value, the optimum bias voltage will vary correspondingly. However, the curve shapes of the sensitivity as a function of reverse bias voltage remain similar.

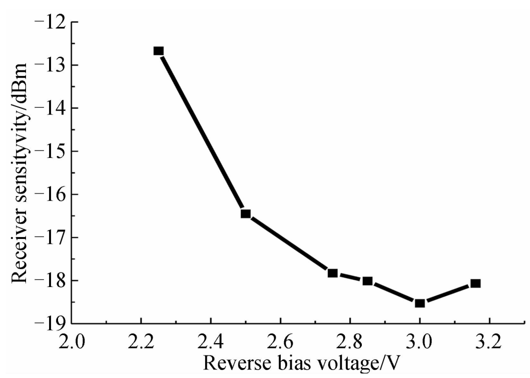
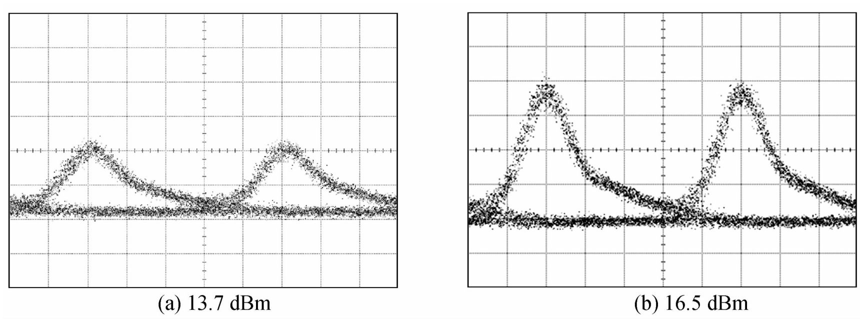
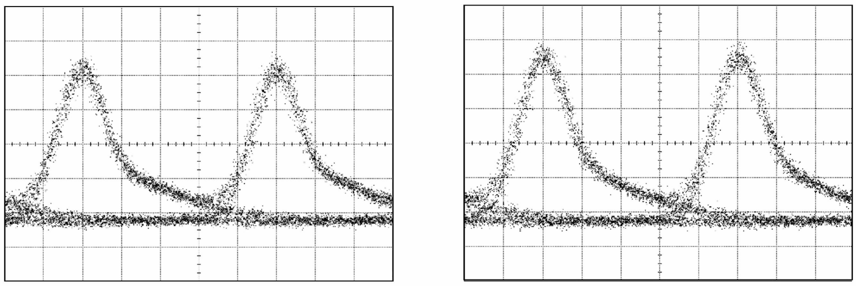


Fig. 3 The receiver sensitivity under different bias voltage

The wavelength conversion performance as a function of the data signal power is also investigated.





(c) 18.0 dBm (d) 19.2 dBm

Fig. 4 The waveforms of the converted signal at different data signal power (20 ps/div)

The wavelength of the probe light is set to 1 557 nm, and the bias voltage is set to 2. 75 V. The data signal power is tuned from 13. 7 dBm to 19. 6 dBm, and the measured waveforms of the converted signals are shown in Fig. 4. It is found that with the increase of the data signal power, the extinction ratio of the converted signal also increases.

The wide-band operation capability of the EAM based wavelength conversion is also confirmed. The data signal power is fixed at 18 dBm and bias voltage is set to 3 V. The probe light wavelength is tuned from 1 535 nm to 1 565 nm and the measured receiver sensitivity is plotted in Fig. 5. It is demonstrated that wavelength conversion is successfully achieved with error-free in around 30 nm range and the difference in receiver sensitivity is less than 1. 5 dB.

The "with DI" mode is investigated in the following section. The wavelength of the probe light is set at 1 557 nm. The average power of data signal is fixed at 18. 2 dBm and EA bias voltage is tuned from 3. 16 V to 2. 25 V. The measured waveforms in two modes are shown together in Fig. 6 for comparison. It is found that in "with DI" mode the pulses have been compressed compared with "no DI" mode, and that at lower bias voltage the trail of the converted signal induced by slow absorption recovery is almost eliminated with help of DI structure. Therefore, it is demonstrated that the DI structure is helpful to suppress the pattern effects induced by the limited response speed.

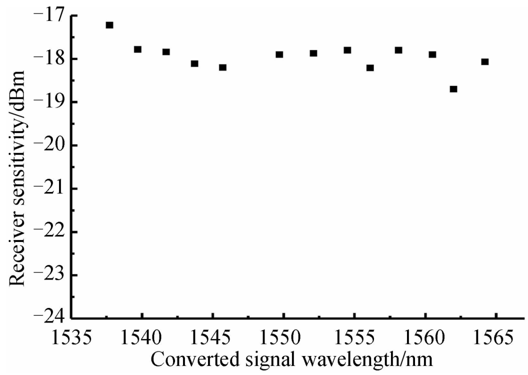
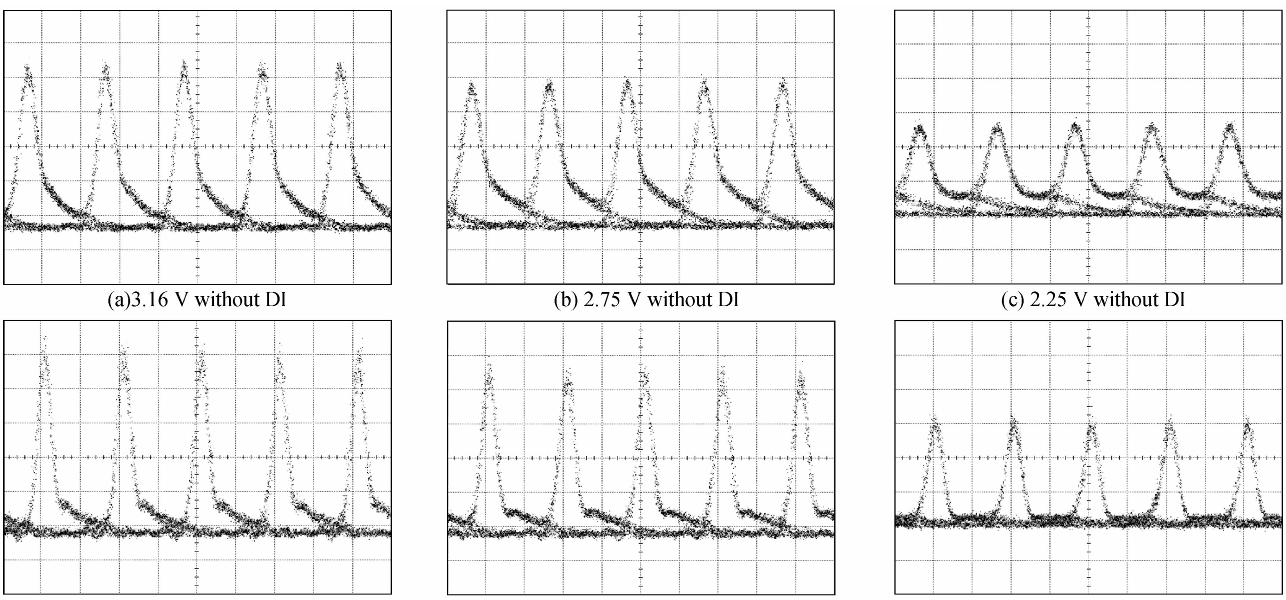


Fig. 5 The wavelength dependence of the receiver sensitivity of the converted signal



(a)3.16 V without DI (b) 2.75 V without DI (c) 2.25 V without DI

(a) 3.16 V with DI (b) 2.75 V with DI (c) 2.25 V with DI

Fig. 6 The waveforms comparisons of two modes

The receiver sensitivity in two modes is also compared in Fig. 7. At lower bias voltage, the receiver sensitivity is improved greatly with DI structure compared without DI because the pattern effect induced by slow absorption recovery is suppressed through the delay interference. However, at relatively high bias voltage, the receiver sensitivity is slightly degraded with DI structure because the OSNR of the converted signal decreases due to insertion loss introduced by the DI structure.

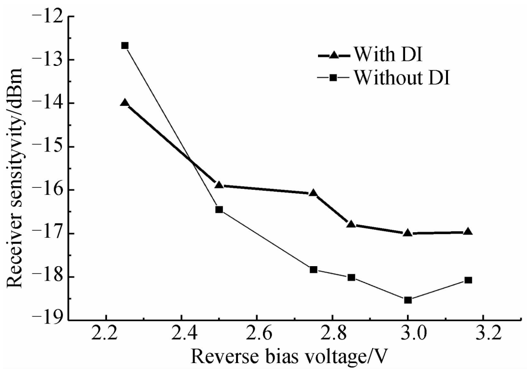


Fig. 7 The receiver sensitivity vs. reverse bias voltage at two modes

3 Conclusions

The wavelength conversion using EAM for Return to Zero(RZ) signals is compared experimentally for two conditions: without DI structure and with DI structure. It is proved that the DI structure can significantly improve the quality of the converted signals in term of pulse shape and high extinction ratio and enhance the receiver sensitivity of the converted signals. The parameters optimization of the bias voltage and data signal power has also been investigated. The results showed that the proper setting of reverse bias voltage can maximize the sensitivity gain of the DI-assisted wavelength conversion compared to no DI case. The experimental results revealed the proposed EAM-based wavelength converter assisted by DI is promising scheme for application in all-optical network.

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