High dynamic extinction ratio and pulse modulation of optical signals

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Abstract. The use of a saturable absorber for increasing the extinction ratio at external modulation of optical signals is considered. An erbium doped fiber was used as the saturable absorber in the experiments. A considerable increase in the static extinction ratio (up to 50 dB) was demonstrated. A rather long erbium doped fiber relaxation time (about 10 ms) was a limiting factor in the case of pulse modulation. Ways of overcoming this drawback are discussed.

1. Introduction

Pulsed optical radiation sources are widely used in modern systems of high-precision fiber-optic sensors. The extinction ratio of optical pulses in time multiplexers, interrogators and distributed systems based on coherent reflectometry defines the noise level, dynamic range and sensitivity of the system [1]. One of approaches to optical pulse generation involves the use of a highly coherent DFB laser diode in the CW regime and an external high-frequency integrated optical modulator [2]. Typical values of the electrooptical modulator extinction ratio are in the range 20–30 dB, however, a number of applications require the ratio of about 50–60 dB.

In our work the nonlinear transmission of saturable absorber (with high losses at the lower input power and lower losses at high input power) is used to improve the extinction ratio. An erbium doped fiber was chosen as the saturable absorber because of the required wavelength range (1520 – 1565 nm), lower saturation power, and excellent compatibility with fiber optic systems.

2. Experimental setup

Figure 1 shows an optical scheme of the experimental setup. A DFB laser diode with a central wavelength of 1530 nm and controlled output laser power of up to 20 mW was used as an optical source. The external modulator was a Mach-Zehnder lithium niobate integrated optical modulator with a half-wave voltage of 4 V, modulation bandwidth of about 10 GHz and optical losses of 3 dB. The maximum extinction ratio of the modulator was about 30 dB which was checked in the static regime. To investigate the dynamic extinction ratio, the modulation signal from the waveform generator was fed to the modulator RF input. A special scheme for the flat bottom pulse generation was used [3]. The DC input was used to measure the static extinction ratio and to control the bias at pulse modulation. A section of the erbium doped fiber EDF (HE980 Lucent) of a 3-m length was used as the saturable
absorber. A fiber optic coupler with a 50/50 ratio at the input of the saturable absorber was used to monitor the input power and control the extinction ratio at the modulator output. An optical power meter was connected to the 50% output of the coupler in static measurements. In dynamic measurements, a high frequency photodetector was connected to this output. A WDM fiber optic filter with the central wavelength at 1530 nm and wavelength bandwidth of about 0.1 nm was used to reduce noise and background caused by spontaneous emission at the EDF output. The final extinction ratio was measured by an optical powermeter in the static (DC) regime or by a fast photodetector in the dynamic mode. To observe a very high extinction ratio, a nonlinear signal amplifier with the gain characteristic close to the logarithmic one was designed. The output optical pulse shape was monitored at an oscilloscope (Tektronix TDS 1012C-EDU).

Figure 1. Experimental setup: 1 – DFB laser diode; 2 – Mach-Zehnder lithium niobate integrated optical modulator; 3 – saturable absorber (EDF); 4 – WDM fiber optic filter; 5 – optical powermeter; 6 – fast photodetector; 7 - nonlinear signal amplifier; 8 – oscilloscope; 9 – waveform generator; 10 – DC power supply for biasing; 11 – scheme for pulse bottom formation.

3. Static (DC) regime
At first the nonlinear transmission of the saturable absorber was studied in the static mode. A coarse input power control was performed by changing the DFB laser power, and fine tuning was performed by biasing the modulator. A typical saturation curve is shown in figure 2.
Figure 2. Optical transmission of saturable absorber as a function of input light power (saturation curve)

High losses (high absorption) of about 20 dB were observed at low input light powers. Low losses of about 2 dB were observed when the input light power exceeded the saturation power (~5 mW). The use of the saturable absorber allowed an about 20 dB increase in the extinction ratio as compared with the initial modulator extinction ratio. The extinction ratios for different input light powers are listed in table 1. The maximum static extinction ratio of 47 dB which was close to the sensitivity limit of our measurement equipment was demonstrated.

| Input power | Extinction ratio |
|-------------|------------------|
| 5 mW        | 7000             |
| 10 mW       | 22200            |
| 15 mW       | 37700            |
| 20 mW       | 46100            |
| 27 mW       | 52000            |

4. Dynamic mode at pulse modulation

To investigate the dynamic extinction ratio, the modulation by square shape pulses was used. The pulse duration was 10 ms, the repetition time was 10 ms. The pulse rise and fall time was < 1 µs. The oscilloscope traces of the detected optical pulse after the modulator are shown in figure 3a. A high reproducibility of the modulated signal was observed. The maximum extinction ratio calculated as the ratio between the upper and lower pulse levels with a correction for the nonlinearity of the
transmission characteristic of the nonlinear signal amplifier was about 30 dB, which is in good agreement with the results of static measurements. The oscilloscope traces of the optical pulses after the saturable absorber are shown in figure 3b. The light power at the EDF input corresponding to the upper level of pulses was about 10 mW, which is enough for saturation. A rather long transition process (~10 ms) was observed at the trailing pulse edge. We attribute this transition process to the relaxation of erbium ions excited to the metastable level [4]. Because of a long relaxation time the EDF cannot be used for improvement of the extinction ratio when the modulation frequency is higher than several hundred Hertz. However, for the signal reaching the lowest level (very close to the noise bottom) estimation of the dynamic extinction ratio gives more than 40 dB, which is the evidence of applicability of the suggested approach in the case other saturable absorbers with short relaxation time are used. Semiconductor saturable absorbers can provide nanosecond and even picosecond relaxation times [5]. Acetylene-filled hollow-core photonic crystal fibers with typical relaxation times of several nanoseconds [6] are of particular interest since they provide the all-fiber implementation, like EDF.

![Figure 3. Oscilloscope traces: a) optical pulses at the modulator output; b) optical pulses after saturable absorber](image-url)
5. Conclusions
To summarize, it is shown that the use of a saturable absorber allows one to considerably increase the extinction ratio of an optical pulse.

6. Acknowledgment
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References
[1] Brooks J L, Boslehi B, Kim B Y and Shaw H J 1987 J. Lightwave Technol. 5 1014
[2] Huang S-C, Tsay J-S and Lin W-W 2000 Opt. Eng. 39 2214
[3] Schoenwetter H.K. 1983 IEEE Trans. Instrum. Meas. 32 22
[4] Becker P C, Olsson N A, Simpson J R, 1999 Erbium-Doped Fiber Amplifiers (New York London, Boston: Academic press)
[5] Keller U 1999 “Semiconductor nonlinearities for solid-state laser modelocking and Q-switching,” in Semiconductors and Semimetals vol. 59A, ed A Kost and E Garmire (Boston: Academic Press).
[6] Agruzov P, Shamray A, Miramontes M O, Hernández E H, Stepanov S 2012 Applied Physics B 108 827