IEICE Electronics Express, Vol.1, No.8, 217–221

Optical frequency comb generator using optical fiber loops with single-sideband modulation

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Abstract: This paper describes optical frequency comb generation using optical single-sideband modulation technique. We can obtain optical frequency shift using the singnal-sideband modulator consisting of four optical phase modulators, where the frequency shift is precisely equal to that of an rf-signal fed to the modulator. A series of optical spectral components can be generated by using an optical fiber loop having an optical single-sideband modulator.

Keywords: Optical frequency, optical modulation, single-sideband

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DOI: 10.1587/elex.1.217
Received June 11, 2004
Accepted June 18, 2004
Published July 25, 2004

IEICE Electronics Express, Vol.1, No.8, 217–221

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1 Introduction

Expectations are high for multi-wavelength light sources for multiple-wavelength transmission systems and measuring instruments. Various types have recently been presented, including those integrating a number of laser diodes (LDs), supercontinuum light sources utilizing nonlinearity of fibers, mode-locked lasers employing optical fiber loops, and comb generators equipped with a Fabry-Perot light modulator [1, 2, 3, 4, 5]. With integrated LDs, phase relations among spectral components are undetermined, as their optical frequency (or wavelength) accuracy depends on the stability of each LD unit: Hence, the use of a wavelength locker is required to improve the accuracy of the optical frequencies. With respect to mode-locked lasers and Fabry-Perot light modulators, the phase relation is fixed between spectral components, and the frequency intervals are highly precisely constant. Nevertheless, these types of light sources require a more complicated stabilization system to obtain a fixed optical path length, where fluctuation of the path causes large instability in the output optical comb. Meanwhile, supercontinuum sources necessitate the use of a more stabilized mode-locked laser as an input lightwave.

The use of an optical frequency comb generator as a multi-wavelength light source does not necessarily require the determination of the phase relation. Comb generation without phase-locking can be obtained by using an optical fiber loop with an acousto-optic (AO) frequency shifter [6, 7, 8, 9]. The frequency interval, which depends on the frequency of the electric signal fed to the AO frequency shifter, is precisely constant, where the phases of spectral components are not locked. However, the frequency interval is limited by the frequency response of the AO frequency shifter. Recently, we developed an optical frequency shift technique by using an integrated optical single-sideband (SSB) modulator consisting of four optical phase modulators [10, 11], where the frequency difference between the input and output lightwaves equals that of an electric signal fed to the electrode of the modulator. The SSB modulator is comprised of $LiNbO_3$ electro-optic modulators which have high-speed traveling-wave electrodes, so that we can obtain optical frequency shift of large deviation up to 10 GHz or more. In this paper, we investigate an optical comb generator using an optical SSB modulator that

DOI: 10.1587/elex.1.217
Received June 11, 2004
Accepted June 18, 2004
Published July 25, 2004

has a highly precise frequency interval and dispense with complex stabilization control, although with an undetermined phase relation. This setup can be used also for a tunable delay line in an optical packet system [12]. Composed of a fiber loop having an optical SSB modulator, our device allows the modulator to shift optical frequencies to generate optical combs sequentially each time the lightwave circulates in the loop. In the optical SSB modulator, only frequency-shifted elements are generated, with the suppression of original spectral components by circulation. Thus, without optical path stabilization, our device ensure stable operation by only a simple configuration. Although the phase relation between frequency components slowly changes with variations in optical path length, our device can produce a multi-wavelength light signal having an extremely high relative frequency accuracy because the frequency interval is determined by the frequency accuracy of the electrical signal supplied to the modulator.

2 Optical comb generator

Figure 1 shows the setup of an optical comb generator using an optical SSB modulator. The generator is composed of an optical SSB modulator and an optical fiber loop having an optical amplifier to compensate for conversion loss at the modulator. The loop has an input port and an output port, which are realized by using an optical coupler or a fiber Bragg grating. The optical SSB modulator shifts the optical frequency. It is to be noted that modulator output contains almost no frequency components other than those shifted. Shifted elements circulate around the loop, marge with optical elements come from the input port, and then re-input to the optical SSB modulator. In the modulator, both shifted elements and input elements undergo optical frequency shifting at a time. A large number of spectral elements are generated as this process is repeated. The optical frequency interval for each element precisely coinsides with the frequency of the sinusoidal wave signal supplied to the modulator. The phase relation of an element with an adjacent one changes unsteadily with a variation in loop length. However, phase fluctuations do not lead to extreme instability because output from the optical SSB modulator contains few undesired frequency elements, and thus little interference occurs between elements of different number of rotations. In addition, variance in spectral line width due to phase fluctuations is as small as the mechanical vibration frequency of the loop, and is much smaller than the input lightwave spectral line width. The table below compares various optical comb generation technologies. A mode-locked laser and the Fabry-Perot (FP) light modulator are capable of maintaining a determined phase and frequency, making them both competent pulse generation technologies. Nevertheless, they require the use of a stabilization technology, such as feedback control. The LD array needs individual control of a number of light sources at the same a time, where its optical frequency interval depends on the stabilization control accuracy of each light source. The supercontinuum can obtain a stable optical comb for both the frequency interval and phase re-

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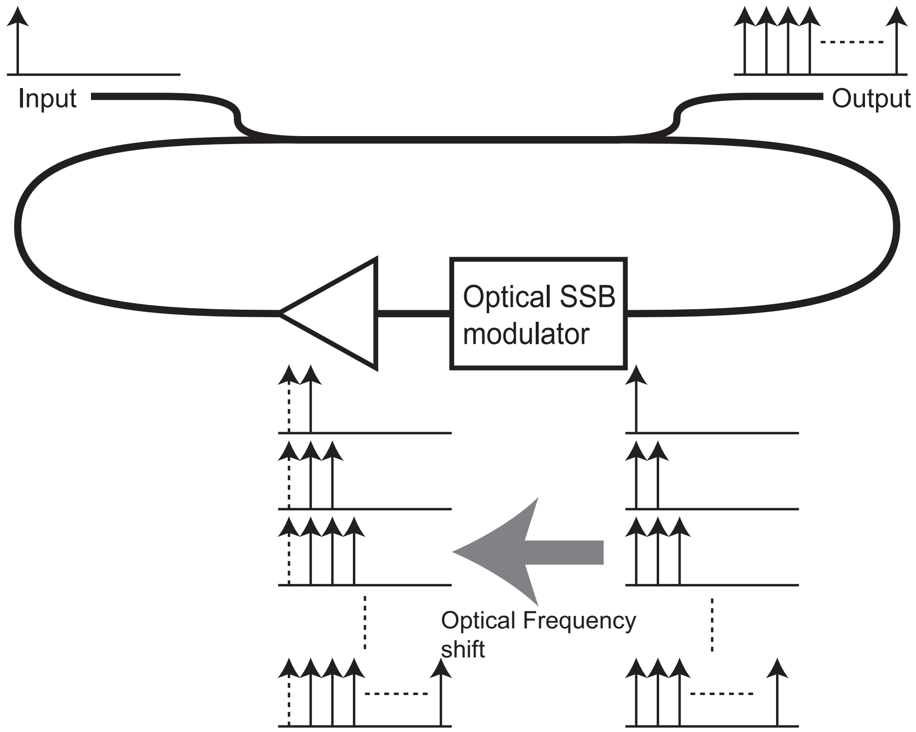

Fig. 1. Optical comb generator using an optical SSB modulator

lation by using a light source that provides phase-modulated continuous light. However, it must employ a special fiber for spectral broadening. On the other hand, the optical comb generator using an SSB loop ensures outputs having an accurately determined optical frequency interval, without the necessity of stabilization control of the optical path length. Thus, this technology can make the device less expensive.

Table I. Comparison of optical comb generation technologies

	Frequency	Phase	Stability
Mode-locked laser	Locked	Locked	Fair
FP optical modulator	Locked	Locked	Fair
LD array	Unlocked	Unlocked	Good
Supercontinuum	Locked	Locked	Good
SSB loop	Locked	Unlocked	Excellent

3 Experimental results

Figure 2 presents an example of output optical spectrum. An input light had a wavelength of 1550 nm and an intensity of 1 mW, and the frequency of the electrical signal supplied to the optical SSB modulator was 10 GHz. The optical loss incurred in wavelength conversion on the optical SSB modulator was compensated for by installing in the loop an optical amplifier of a fluoride

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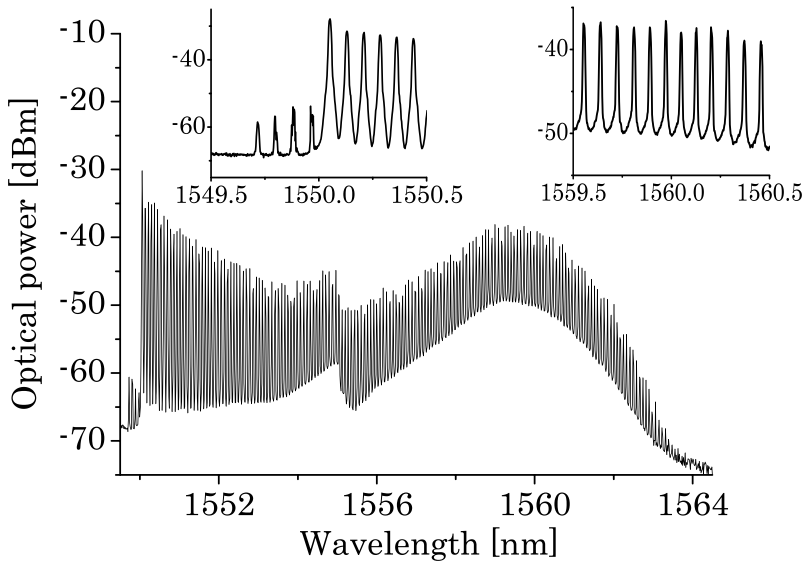

Fig. 2. Outputted optical spectrum

EDF. The wavelength interval was 0.08 nm for 10 GHz. More than 120 rotations were achieved and the generation of optical combs was confirmed over a range of about 10 nm.

4 Conclusion

We investigated an optical frequency comb generator using an optical fiber loop with an optical SSB modulator. The frequency interval can be larger than 10 GHz, which corresponds to the frequency of the electric signal fed to the modulator. Without using any stabilization techniques, we can generate a stable optical frequency comb, where the frequencies of the spectral components were presicely fixed. Thus, a low-cost optical frequency comb generation system can be constructed by an optical SSB modulator, and an optical fiber loop.

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