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デュアルブラッググレーティングを用いた往復逓倍光変調によるミリ波の発生

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あらまし　往復逓倍変調による60GHz帯ミリ波信号の発生を行った。1つの光位相変調器と2つの光フィルタを用いて5GHzの電気信号から60GHzで変調された光信号を得た。さらに、ベースバンド信号による変調も同時に実現した。

キーワード　光変調器，共振，非対称T型電極，導波路，インピーダンス整合

Millimeter-wave generation by using reciprocation optical modulation with dual-FBG

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Abstract　We demonstrated millimeter-wave generation by using reciprocating optical modulation. A lightwave modulated by V-band millimeter-waves was obtained from a 5 GHz electric signal, and was also modulated by a baseband signal, using an optical phase modulator and two optical filters.

Key words Modulation, Modulators, Analog optical signal processing

1 Introduction

Optical modulation in the millimeter-wave, or micro-wave band, is a key technology for radio-on-fiber systems [1]. Traveling-wave optical modulators are often used to obtain broad-band optical response up to the millimeter-wave region [2]. Resonant-type modulators can also be used to obtain effective optical modulation in a particular band [3, 4]. However, because the modulation efficiency at a high frequency is very small, large-amplitude electric signals must be applied to the optical modulator. Recently, we proposed a novel technique that enables obtaining high-order optical harmonics effectively by using two optical filters placed at the optical input and output ports of an optical modulator [5]. By using this technique, called reciprocating optical modulation (ROM), we can generate a lightwave modulated by a rf signal whose frequency is an integer multiple of that of an electric rf signal applied to the modulator. Thus, we can reduce the frequency of the electric signal in circuits driving the modulator. In ROM, some of the sideband components are fed to the optical modulator again, to effectively generate specific sideband components. The desired sideband components are taken out from the modulator, without recycling for harmonic generation. This is in contrast to mode-lock lasers and optical comb generators, where all generated sideband components are recycled into the modulators regardless of the optical frequency [6]. Thus, the desired sideband components are effectively enhanced, without spreading the optical power over undesired sideband components. Because the difference between optical frequencies of generated sideband components corresponds to the millimeter-wave band, we can generate a millimeter-wave by feeding the output lightwave to a high-speed photo detector. In addition, the intensity of the millimeter-wave can be modulated by feeding a baseband signal to the optical modulator. Thus, we can perform optical subcarrier generation and baseband modulation, simultaneouly, by an optical modulator and two optical fllter, without using any electrical mixing devices.

2 Principle of operation

Our system consists of two optical filters and an optical modulator mounted between them. A schematic diagram is depicted in Fig. 1. A Iightwave is input into the modulator through one of the filters (input filter, henceforth) and comes out from the other filter (output filter). The input filter is a narrow-band optical filter, which transmits an unmodulated input lightwave from a light source, and reflects lightwaves in a specific optical frequency range. The output filter is a band-rejection filter, whose center wavelength equals the wavelength of the input lightwave. The unmodulated input lightwave, whose frequency is f_0 , passing through the input filter is modulated by the optical modulator. The output lightwave of an optical phase modulator can be expressed by

$$\sum_{n=-\infty}^{\infty} J_n(\Delta\phi)\exp[\mathrm{i}2\pi f_n], \quad f_n = f_0 + n f_m \tag{1}$$

where f_{m} is the frequency of the electric sinusoidal rf signal applied to electric ports of the optica1 modulator. $\Delta\phi$ denotes the amplitude of the induced phase shift of the lightwave at the modulator. j_{n} is the first kind Bessel's function of n-th order. Consider that several components of the generated harmonics are in the reflection bands of both the input and the output filters, and we call these components intermediate lightwaves. The intermediate lightwaves reflected by the output filter are modulated again and reflected by the input filter. The reflected lightwaves go through the modulator. Thus, the intermediate lightwaves are confined between the two filters, and are modulated several times by the modulator, with the result that the high-order harmonics can be effectively obtained. These two filters have two purposes. They both send the intermediate lightwaves back to the modulator. Additionally, the input filter leads the unmodulated lightwave from the light source into the modulator, while the output filter extracts the desired spectrum components.

To illustrate the operation of the reciprocating optical modulation, a block diagram of the fifth-order harmonic generation is shown in Fig. 1 . We suppose that the output filter reflects the spectrum components f_0, $f_{\pm1}$,$f_{\pm2}$,$f_{\pm3}$, and $f_{\pm4}$, and that the input filter reflects all spectrum components except for f_0. For simplicity, the amplitude of the electric signal is assumed to be so small that Eq. (1) can be approximated by $j_0(\Delta\phi)$ exp[i2πf_0] + $j_1(\Delta\phi)$ exp[i2πf_{+1}] + $j_{-1}(\Delta\phi)$ exp[i2πf_{-1}]. This system operates in the following steps (See Fig. l). 1) Upper and lower sidebands whose frequencies are f_{+1} and f_{-1}, respectively, are produced by the modulator. 2) The sidebands are reflected by the output filter. 3) The reflected lightwave is modulated again by the the modulator, and the spectrum components f_{+2} and f_{-2} are generated. 4) The input fllter reflects component f_{+2}, f_{+1}, f_0, f_{-1} and f_{+2}, so the modulator generates components f_{+3} and f_{-3}. 5) Spectrum component f_{+5} and f_{-5} are produced from f_{+3} and f_{-3},in the same way as in steps 3) and 4), and passes through the output fllter. Finally, we can obtain components f_{+5} and f_{-5} from the output port of the output filter. Note that the modulator must be able to modulate the backward lightwave in addition to the forward lightwave, in order to carry out step

3). When we use an output filter that reflects the spectrurn components f_0, $f_{\pm1}$, . . $f_{\pm n}$, the component f+(n+1) can be generated through several iterations of the above steps. Thus, if we apply 5 GHz rf signal to the modulator, the lightwave intensity moclulatecl by 60 GHz rf signal can be generated. The intensity of the spectr.al components depends on the difference in the optical phase in successive ROM processes. Thus, we can modulate the intensity of the millimeter-wave by changing the optical phase retardation at the modulator.

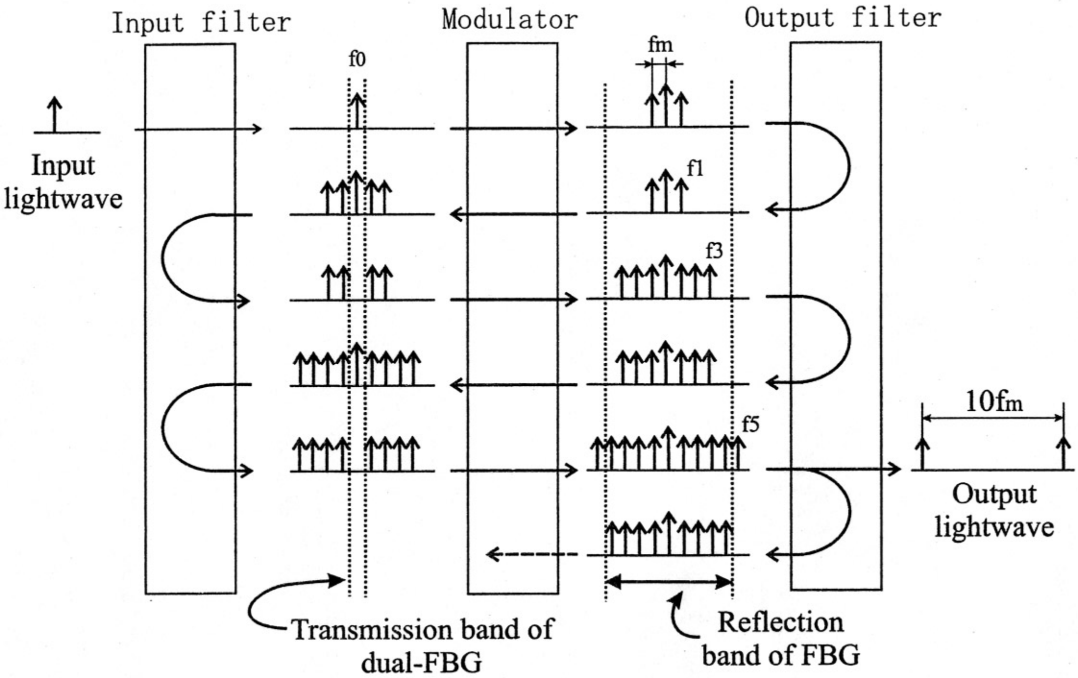

Figure 1: Principle of reciprocating optical modulation.

3 Experimental setup and results

Fig. 2 shows the experimental setup of our ROM system to demonstrate the generation of millimeter-wave. A travelingwave-type optical phase modulator whose halfwave voltage was 7.0 V was placed between an input and an output filter. The input filter was a dual-section fiber Bragg grating (FBG.), consisting of two sections of FBGs whose properties were almost the same. The transmission spectrum profile, which is similar to that of a Fabry-Perot fllter, has very narrow (approx. 2 GHz) transmission bands in the reflection band of one section. The output filter was a tunable FBG whose reflection bandwidth was 50 GHz. The center wavelength of the output filter and the wavelength of the lightwave input from the light source were set to one of the narrow transmission bands of the input filter. Sinusoidal rf electric signals with a frequency of 5.015 GHz and an power of 19.5 dBm were fed to both input and output electric ports of the modulator. The frequency of the rf signal should coincide with the inverse of the round trip time between the two optical filters, to maintain the successive modulation processes in-phase. The phase of the rf signals was trimmed by using delay lines, to eliminate the phase difference between the forward and the backward modulation processes. Fig. 3 shows the spectra of the output lightwave. We found that while in the spectrum generated by the conventional modulation method there were no harmonic components higher than those of the fourth order, in the spectrum generated by ROM, there were high-order harmonic components, especially those of the sixth order. As shown in Fig. 3 (b), effective optical wavelength conversion was achieved by using ROM. The conversion loss is 11.77 dB. Fib. 4 (a) shows the spectra of the generated millimeter waves whose frequencies were 11, 12, 13, and 14 times that of the rf signal source. We also measured the spectrum line width of the

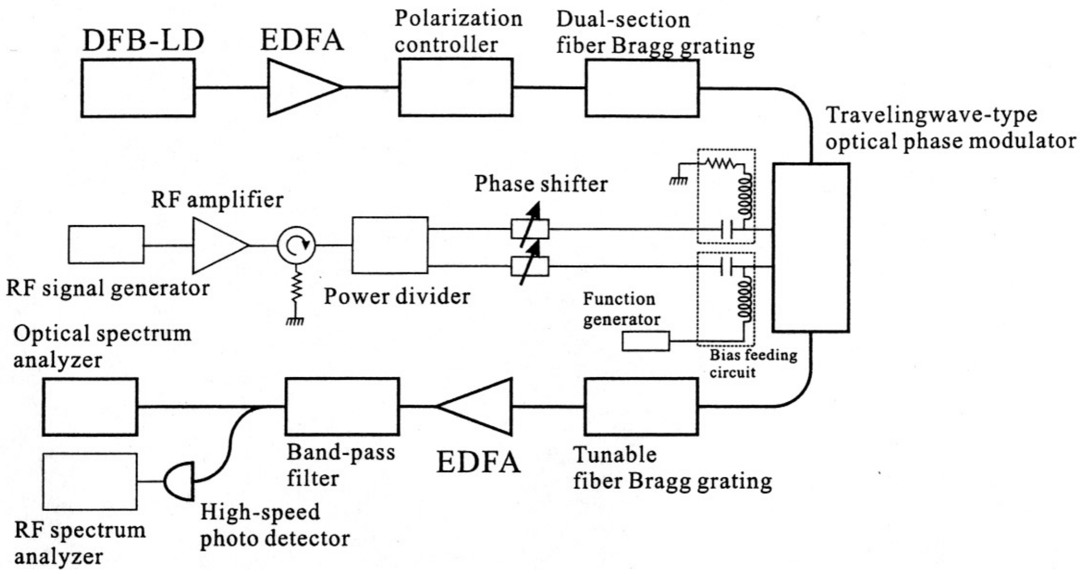

Figure 2: Experimental setup

millimeter-wave of 12th-order (60.180 GHz) with the resolution bandwidth of 300 Hz. The line width was smaller than the resolution and was expected to be less than 300 Hz. In addition, we performed intensity modulation of the millimeter-waves by applying a baseband signal to the optical phase modulator via a bias feeding circuit as shown in Fig. 2. Although only one optical phase modulator was used in our ROM system, we achieved modulation by a millimeter-wave and by a baseband signal simultaneously, as shown in Fig. 4 (b). The bandwidth for the baseband modulation was limited by the frequency response of the bias circuit and the round trip time between the two optical fllters. However, this can be overcome by integrating these optical and electrical components to a small monolithic device.

4 Conclusion

We demonstrated generation of millimeter-waves in V-band, for radio-on-fiber systems by using the reciprocating optical modulation. Optical conversion loss at the modulation process was 11.77 dB, for the sixth order harmonic. The spectrum line widths of the millimeter-waves were smaller than 300 Hz. We also demonstrated generation of a millimeter-wave intensity modulated by a baseband signal, without using any optical or electrical intensity modulators.

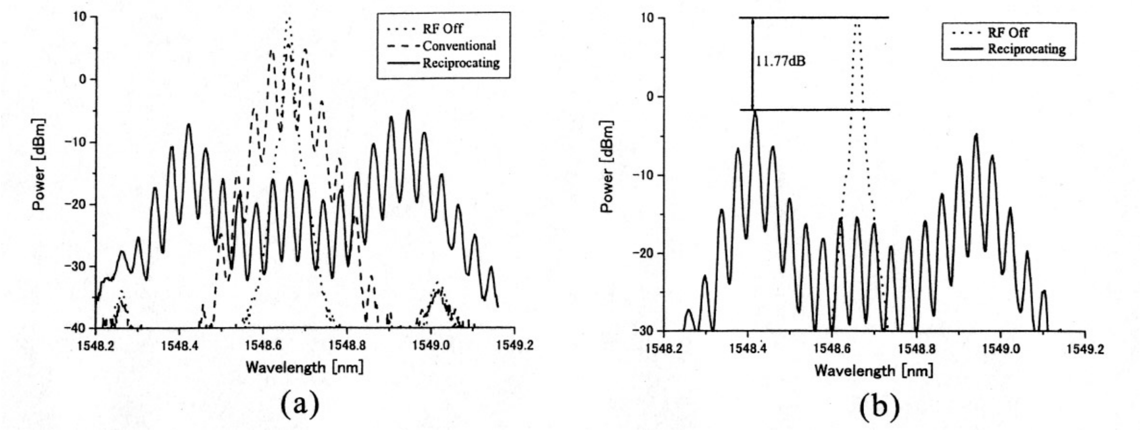

Figure 3: Optical spectra of output lightwaves. Solid lines and dashed lines denote, respectively, spectra generated by ROM and those generated by conventional optical phase modulation. In conventional modulation, the backward rf electric signal is turned off and the reflection band of the output fllter is tuned to let all harmonic components out of the band. Dotted line shows unmodlated lightwave spectrum at the output port of the output filter, obtained by turning off the rf signal. The output filter is the same as in conventional modulation. (a):The phases of rf electric signal and lightwave are adjusted to maximize the generated millimeter-wave. (b):The phases are adjusted to maximize +6th-order harmonic component.

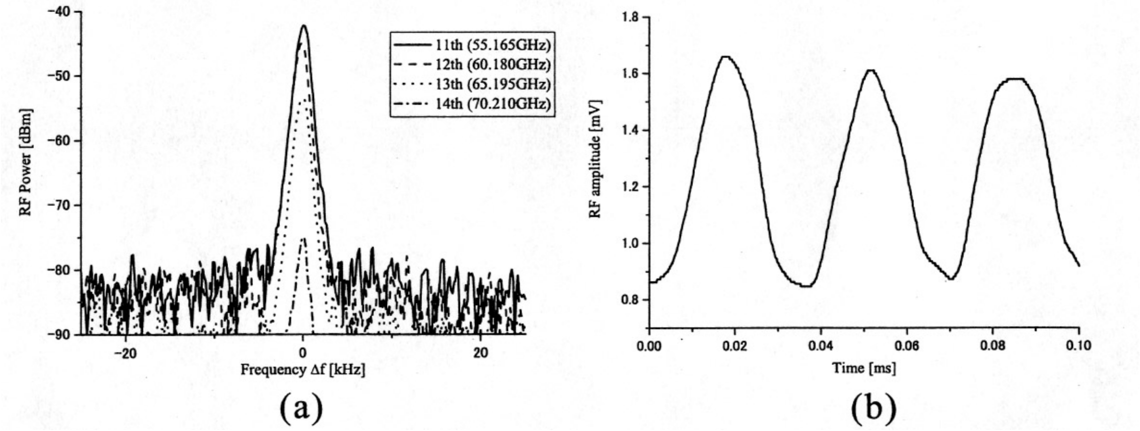

Figure 4: Electric signal obtained by photo detector. (a):Electric spectrum of the generated millimeter-wave, where resolution bandwidth of the spectrum analyzer (1 KHz) is dominant in bandwidths of measured spectra. (b):Intensity of 12th-order signal modulated by a baseband signal with a frequency of 30 KHz and a rms amplitude of 1.12 V.

References

[1] C. Lim, A. Nirmalathas, D. Novak and R. Waterhouse, "Optimisa,tion of baseband modulation scheme for millimetre-wave fibre-radio systems" , *Electron. Lett.*, Vol. 36, pp.442-443, March 2000

[2] K. Noguchi, O. Mitomi and H. Miyazawa, Millimeter-wave Ti : $LiNbO_3$ opitcal modulators, J. Lightwave Tech*nol*. **16**, 615-619 (1998)

[3] T. Kawanishi, S. Oikawa, K. Higuma, Y. Matsuo and M. Izutsu, $LiNbO_3$ resonant-type optical modulator with double-stub structure, *Electron. Lett*. 37, 1244-1246 (2001)

[4] T. Kawanishi, S. Oikawa, K. Higuma, M. Sasaki and M. Izutsu, Design of LiNb03 optical modulator with an asymmetric resonant structure, (to be published in IEICE Trans. Electron E85-C)

[5] T. Kawanishi, M. Sasaki, S. Shimotbsu, S. Oikawa and M. Izutsu, Reciprocating Optical Modulation for Harmonic Generation, *IEEE Photonics Tech. Lett* **13**, 854-856 (2001)

[6] K. S. Abedin, N. Onodera, and M. Hyodo, "Higher Order FM Mode Locking for Pulse-Repetition-Rate Enhancement in Actively Mode-Locked Lasers: Theory and Experiment", *IEEE J. Quantum Electron.*, Vol. 35, pp.875-890, June 1999