ELSEVIER

Physica C 372–376 (2002) 360–363

PHYSICA C

www.elsevier.com/locate/physc

Design and performance of high gain superconducting booster circuit for $LiNbO_3$ optical modulator

Keiji Yoshida [a,*], Yuji Mukaiyama [a], Haruichi Kanaya [a], Yutaka Kanda [b]

[a] *Department of Electronics, Graduate School of Information Science and Electrical Engineering, Kyushu University, 812-8581 Fukuoka, Japan*
[b] *Department of Electronics, Fukuoka Institute of Technology, 811-0295 Fukuoka, Japan*

Abstract

Design and performance of a $LiNbO_3$ (LN) optical modulator for subcarrier optical transmission employing a high gain superconducting booster circuit have been studied. Based on a new design theory for the high gain booster circuit, we designed a voltage amplifier with center frequency of 10 GHz, bandwidth of 5 MHz, and the voltage gain of 33 dB using an electromagnetic wave simulator. A preliminary experiment with YBCO electrode on MgO substrate flip chip bonded on LN optical waveguide has also been made.

Keywords: Superconducting microwave device; $LiNbO_3$ optical modulator; High-T_c superconducting transmission line

---

1. Introduction

We have been studying the applications of superconducting transmission lines to traveling-wave-type $LiNbO_3$ (LN) optical modulators with broad bandwidth [1]. Recently, subcarrier optical transmission systems in which microwave or millimeter-wave signals are carried through optical fibers by intensity-modulated lightwave (radio on fiber) has been studied intensively [2]. Resonant type optical modulators are suitable for this purpose [3], and preliminary experiments using YBCO films have been made [4,5]. In our previous paper [6], we proposed a new design theory of high gain booster circuit for a LN optical modulator, which is necessary to amplify the signal voltage applied to the LN optical waveguide.

In this paper we study the gain of the booster circuit using the circuit model with coplanar waveguide (CPW) transmission lines (transmission line model), design the practical device with the voltage gain of 33 dB by the electromagnetic wave (EM) simulator. A preliminary experiment is also made.

2. Design of the optical modulator with transmission line model

In Fig. 1 we show the schematic figure of the LN optical modulator with the high gain booster

---

[*] Corresponding author. Fax: +81-92-642-3971.
E-mail address: yoshida@ed.kyushu-u.ac.jp (K. Yoshida).

0921-4534/02/$ - see front matter © 2002 Elsevier Science B.V. All rights reserved.
PII: S0921-4534(02)00669-X

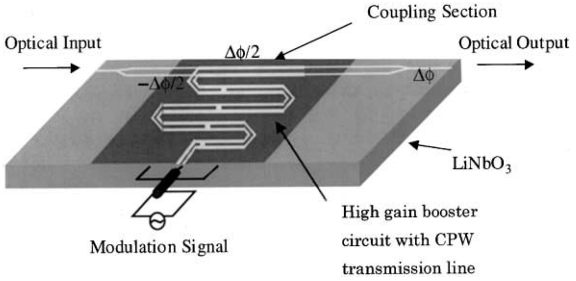

Fig. 1. Schematic of the high gain booster circuit for the Mach–Zehnder type LN optical modulator.

circuit made of superconducting CPW transmission lines. The signal voltage is applied to the Mach–Zehnder type optical waveguide via the standing-wave voltage occurring in the CPW which is short circuited at the end terminal [6].

In the presence of the standing voltage $V(x)$, the expression for the induced total optical phase difference $\Delta\phi(t)$ at the output end of the push–pull type optical modulator can be calculated as [6]:

$$\Delta\phi(t) = \frac{\pi}{V_\pi}\frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)V_{\mathrm{i}}(\omega)\mathrm{e}^{\mathrm{j}\omega t}\,\mathrm{d}\omega \tag{1}$$

with

$$F(\omega) = \frac{1}{V_{\mathrm{i}}(\omega)l}\int_{0}^{l} V(x)\mathrm{e}^{\mathrm{j}(n_0/c)x}\,\mathrm{d}x \tag{2}$$

where $V_\pi = \lambda d/2\Gamma n_0^3\gamma_{33}l$ is the half-wavelength voltage; λ, the light wavelength; n_0, the refractive index of LN; γ_{33}, the electrooptic coefficient; Γ, the overlap integral; d, the spacing between signal and ground electrodes; $F(\omega)$, referred to as the normalized modulation depth, where $V_{\mathrm{i}}(\omega)$, the Fourier transform of the incident voltage.

In Fig. 2(a) we show the example of the input voltage waveform $v_{\mathrm{i}}(t)$ with amplitude shift keying (ASK) modulation signal, and the output phase differences $\Delta\phi(t)$ calculated by Eqs. (1) and (2) for the cases of $A = 1$ (0 dB) and $A = 45$ (33 dB) are shown in Fig. 2(b) and (c), respectively. The type of the filter was Chebyshev one with $n = 3$, $\omega_0/2\pi = 10$ GHz, $w = 0.05\%$ and the ripple of the insertion loss Ar $= 0.01$ dB. It is shown that designed voltage gains are confirmed, indicating that a low driving-voltage optical modulator is possible by designing a large voltage gain.

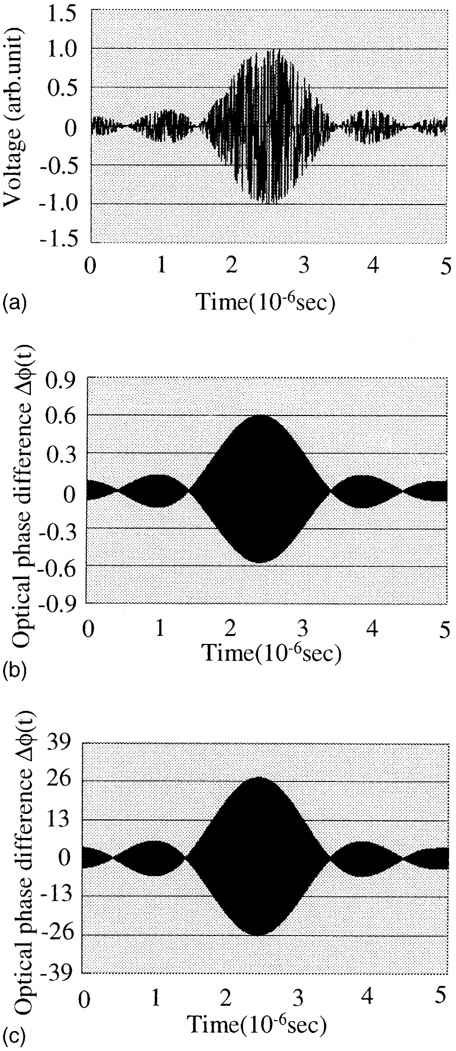

Fig. 2. Time domain characteristics of the optical modulator, (a) input voltage waveform $v_{\mathrm{i}}(t)$ of ASK signal, (b) output optical phase difference in the case of the voltage gain of $A = 1$ (0 dB), (c) output optical phase difference in the case of the voltage gain $A = 45$ (33 dB).

3. Simulated performance of the practical optical modulator

In this section we show the design and performance of the practical optical modulator using EM simulator. In Fig. 3(a), we show the configuration of the booster circuit made of meander CPW transmission lines. The length of the half-wavelength resonator and the geometry of inverters are

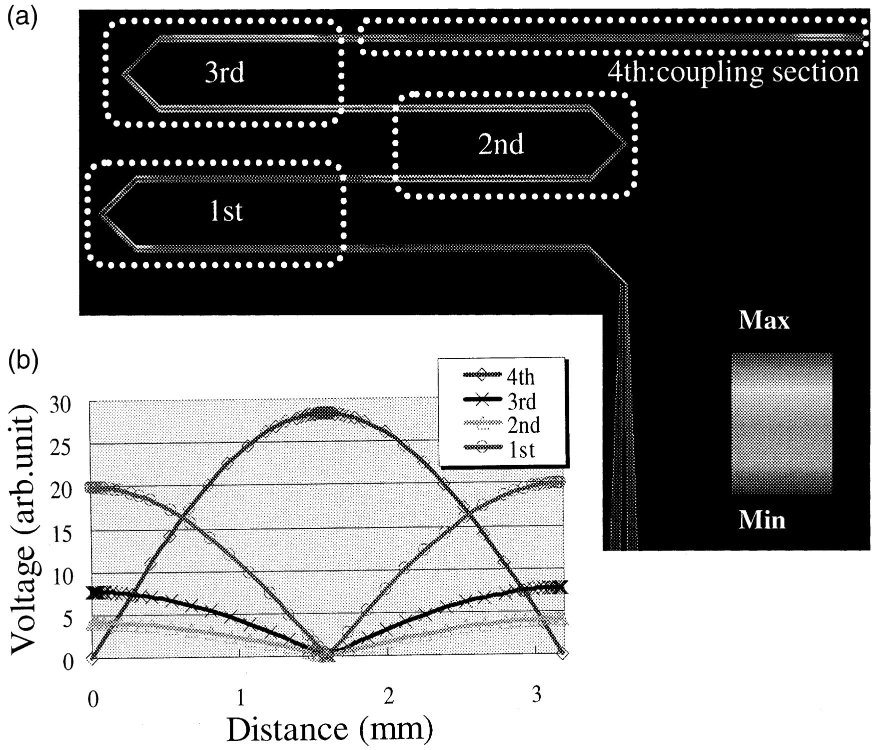

Fig. 3. Booster circuits designed by EM simulator, (a) configuration of the booster circuit made of meander CPW transmission line, where spatial distribution of the standing-wave voltage by EM simulator is shown, (b) spatial distribution of the standing-wave voltage expected from the transmission line model.

decided in the same manner as described in [7]. In Fig. 3(b) we show the spatial distribution of the amplitude of the standing-wave voltage calculated by the EM simulator and the transmission line model, respectively.

In Fig. 4, we compare the group delay of S_{11} calculated from the circuit model with that calculated from EM simulator. A reasonable agreement is obtained for both cases, demonstrating the validity of the present design theory for the high gain booster circuit.

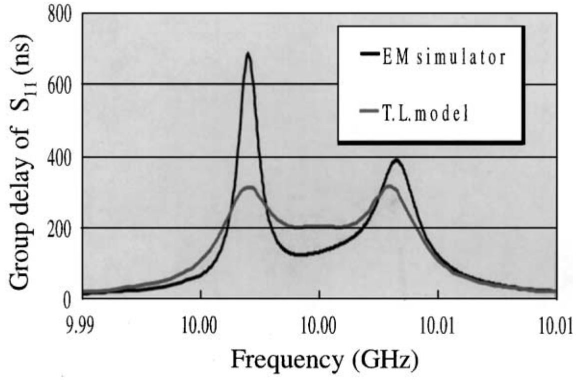

Fig. 4. Group delay of $S_{11}(\omega)$ calculated from the transmission line model and EM simulator for the case of $A = 45$ (33 dB).

4. Preliminary experiment

In order to confirm the proposed design theory we carried out the experiment. In Fig. 5 we show the pattern of the modulation electrode with the meanderline three-pole Chebyshev filter fabricated by a YBCO thin film on a MgO substrate with the dimension of 10 mm × 10 mm. The YBCO electrode on MgO substrate was flip chip bonded onto

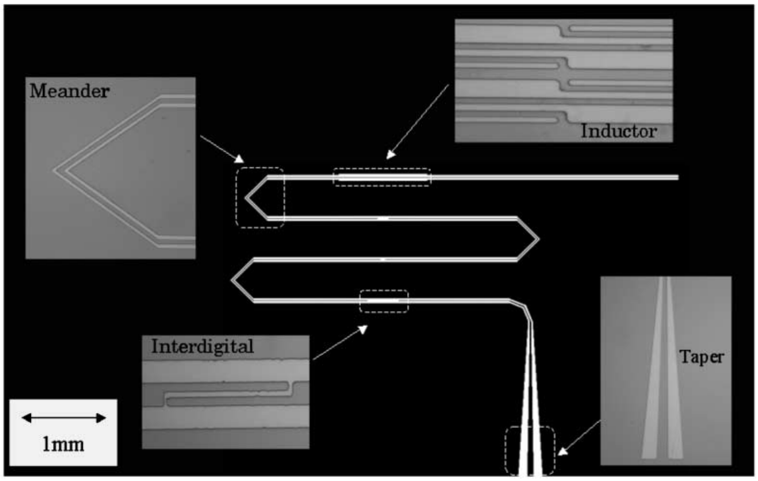

Fig. 5. The experimental pattern of the booster circuit.

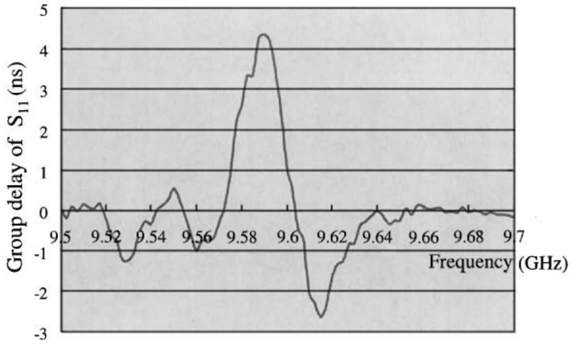

Fig. 6. Group delay of $S_{11}(\omega)$ observed in the experiment.

an optical waveguide in a LN substrate, and was cooled down by a refrigerator [4]. In Fig. 6 we show the observed group delay of S_{11} of the device. The observed data find traces of those expected from theory as shown in Fig. 4.

5. Conclusions

Based on the new design theory for the high gain LN optical modulator, we designed the practical device with the voltage gain of 33 dB by EM simulator, and demonstrated the expected performances. A preliminary experiment of the designed optical modulator using the flip chip bonding of the YBCO thin film on MgO substrate was also made. The application of the present booster circuit to a high speed optical switch is being in progress.

References

[1] K. Yoshida, Y. Kanda, S. Kohjiro, IEEE Trans. Microwave Theory Tech. 47 (1999) 1201.
[2] N. Dagli, IEEE Trans. Microwave Theory Tech. 47 (1999) 1151.
[3] M. Izutsu, H. Murakami, T. Sueta, IEICE Trans. Electron. J71C (1988) 653.
[4] K. Yoshida, H. Morita, Y. Kanda, T. Uchiyama, H. Shimakage, Z. Wang, Inst. Phys. Conf. Ser. 167 (2000) 375.
[5] E. Rozan, C. Collado, A. Garcia, J.M. O'Callaghan, R. Pous, IEEE Trans. Appl. Supercond. 9 (1999) 2866.
[6] K. Yoshida, H. Takeuchi, H. Kanaya, Y. Kanda, T. Uchiyama, Z. Wang, IEEE Trans. Appl. Supercond. 11 (2001) 442.
[7] K. Yoshida, K. Sashiyana, S. Nishioka, H. Shimakage, Z. Wang, IEEE Trans. Appl. Supercond. 9 (1999) 390.