IEEE Transactions on Microwave Theory and Techniques, vol. MTT-26, no. 9, September 1978

SOME EXPERIMENTS ON DESIGN PRINCIPLE OF BROADBAND ELECTROOPTIC MODULATORS

Eikichi Yamashita, Member, IEEE, Kazuhiko Atsuki,
Hidenori Hosokawa, and Kazuo Nagata
University of Electro-Communications
Chofu-shi, Tokyo, Japan 182

Abstract. An experimental modulator was fabricated to test a design principle of broadband traveling-wave electrooptic light modulators proposed in a previous paper. The measured value of modulation bandwidth, 10 GHz, appears to confirm the design principle.

INTRODUCTION

One could transmit enormous amounts of information in a future laser communication system using single-mode optical fibers. Horton [1] suggested a future high data rate system that has 40 - 50 GHz signal bandwidth.

The traveling-wave type light modulator using electrooptic crystals, among others, has been considered as the most broadband modulator but it still has a bandwidth limitation for lack of broadband impedance transformers as discussed by Kaminow et al in 1966 [2] and Chen in 1970 [3].

We proposed a design principle for broadband traveling-wave electrooptic light modulators in a previous paper [4]. This was based on the computer search of modulator structures that satisfy two conditions, the velocity matching and impedance matching, simultaneously.

This technical note reports some experimental results on a traveling-wave electrooptic modulator designed by the above principle.

ESTIMATION OF MODULATION BANDWIDTH

The modulation bandwidth, M.B., of a traveling-wave electrooptic modulator is limited by the difference between the light velocity, v_ℓ, and the modulation wave velocity, v_m. It was given by Kaminow [2] as

$$M.B. = \frac{v_m}{4L}\left|\left(1-\frac{v_m}{v_\ell}\right)^{-1}\right| \quad (1)$$

where L is the length of the modulator. It should be noted that this expression has assumed no reflection and no velocity dispersion of modulation waves in the modulator.

When the matching of the characteristic impedance between the modulator and outside circuits is not considered, the modulation bandwidth is limited by the resonance effect in the modulator. That is

$$M.B. = \frac{v_m}{4L} \quad (2)$$

Most of inhomogeneous transmission lines for modulation waves have the velocity dispersion, to some extent, at high frequencies. The velocity dispersion effect is another important factor to limit the modulation bandwidth. Instead of the expression (1), we have to find the root, f, of an equation

$$f = \frac{v_m(f)}{4L}\left|\left(1-\frac{v_m(f)}{v_\ell}\right)^{-1}\right| \quad (3)$$

to estimate the bandwidth, where $v_m(f)$ is the modulation wave velocity as a function of frequency.

DESIGN OF BROADBAND MODULATORS

The design procedure to obtain a broadband modulator should be as follows:

(1) select a broadband transmission line structure,
(2) satisfy the impedance matching condition and velocity matching condition, at least at low frequencies, simultaneously.

The microstrip line is known as a broadband transmission line. When an anisotropic crystal as $LiNbO_3$ is used as the substrate of a microstrip line, its transmission characteristics can be analyzed within the TEM approximation if the crystal axes are properly oriented [5].

However, the results of the analysis of a microstrip line as shown in Fig.1 based on the method [5] indicate that the simultaneous satisfaction of the impedance matching condition and the velocity matching condition is impossible. Though the characteristic impedance could be varied easily by changing w/h_1, the velocity of modulation waves could not be matched to the light velocity because of the high dielectric constant of $LiNbO_3$.

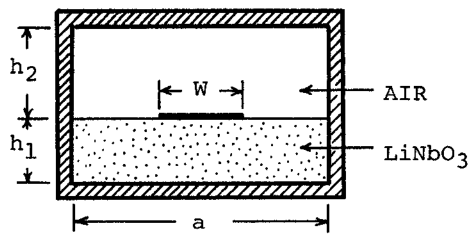

Fig.1 Microstrip line structure as a traveling-wave modulator.

Fig.2 (a) shows a proposed modulator in a previous paper [4] which includes Teflon material near $LiNbO_3$ to decrease the effective dielectric constant without changing the modulation field in the crystal. This structure can be approximately analyzed by requiring that electric fields are almost parallel to the side walls of the crystal.

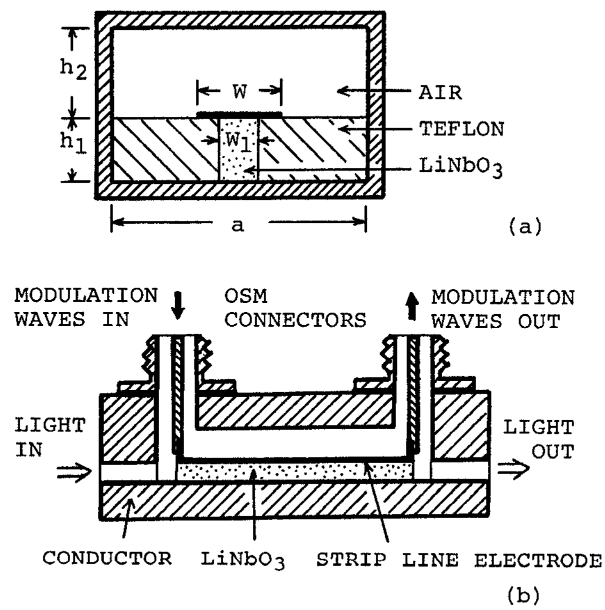

Fig.2 Experimental modulator structure.
(a) Cross-sectional view.
(b) Traveling-wave structure of modulation waves and light.

Manuscript received September 6, 1977;
revised May 15, 1978.

Computed dimensions for satisfying the two conditions simultaneously are as follows:

$a = 3.35h_1$ $h_2 = 2.335h_1$ $w = 0.9h_1$ $w_1 = 0.445h_1$

where

the dielectric constant of $LiNbO_3 = 28.0$

the dielectric constant of Teflon = 2.1

$n = v_0 / v_\ell = 2.24$

the characteristic impedance = 50 ohms.

The approximate estimation of M.B. based on (3) showed 10 GHz.

EXPERIMENTAL RESULTS

An experimental modulator was fabricated in our laboratory to test the above design principle. Its dimensions are as follows:

$a = 6.67$mm $h_1 = 2.0$mm $h_2 = 4.67$mm

$w = 1.82$mm $w_1 = 0.89$mm $L = 40.0$mm

Modulation waves were guided by 50-ohm coaxial cables to the modulator through OSM connectors as shown in Fig.2 (b). A matched load was also connected to the other end of the modulator.

Fig.3 (a) shows the transmission coefficients of the modulator against modulation frequencies except frequencies near 5 GHz at which microwave sources were not equipped in our laboratory. This graph indicates the extent of the impedance matching. The microwave bandwidth of the modulator is seen to be about 12 GHz though some resonances are observed at 1.5GHz and 5GHz.

The microwave power output of about 2 watts from three traveling-wave-tube amplifiers were employed to modulate He-Ne laser light. The spectrum of the phase modulated light was recorded by the Fabry-Perot interferometer method[6]. Fig.3(b) shows the amplitude ratio of side-band waves to carrier waves. This graph indicates the total effect of the velocity matching and the impedance matching. The observed bandwidth, about 10 GHz, appears to support our design principle.

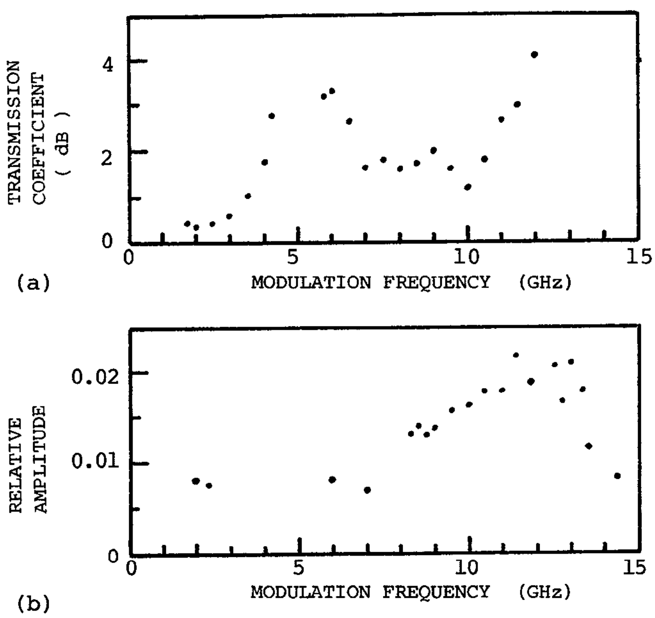

Fig.3 Characteristics of the modulator.
(a) Transmission coefficients.
(b) Relative amplitude of sideband waves to carrier waves

Suggestions for further broadening of the bandwidth are as follows:

(1) The bandwidth can be increased by employing smaller cross-sectional dimensions.

(2) Another transmission line structure to decrease the effective dielectric constant is a parallel-strip line on a thin-film crystal [7]. A theoretical value of the modulation bandwidth for a structure as shown in Fig.4 was estimated as 40 GHz per centimeter length of the modulator assuming no problems in connectors [8].

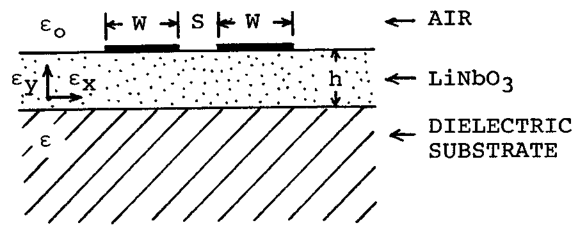

Fig.4 A parallel-strip line structure as a traveling-wave modulator.
$w = 1.34$mm $s = 50\mu$m $h = 18.5\mu$m
$\varepsilon_x^* = 28.0$ $\varepsilon_y^* = 43.0$ $\varepsilon^* = 4.0$

ACKNOWLEDGEMENT

The authors thank Professor T.Okabe for his helpful advice. This work was supported in part by Scientific Research Grant-In-Aid from the Ministry of Education, Japan

REFERENCES

[1] J.B.Horton, "President's message-microwaves of the 70's," IEEE Trans. Microwave Theory Tech., vol.MTT-21, p.746, Dec. 1973.

[2] I.P.Kaminow and E.H.Turner, "Electrooptical light modulators," Proc. IEEE, (Special Joint Issue on Optical Electronics with Applied Optics), vol.54, pp.1374 - 1390, Oct. 1966.

[3] F.S.Chen, "Modulation for optical communications," Proc. IEEE, (Special Issue on Optical Communications), vol.58, pp.1440 - 1457, Oct. 1970.

[4] E.Yamashita, K.Atsuki, and T.Akamatsu, "Application of microstrip analysis to the design of a broadband electrooptical modulator," IEEE Trans. Microwave Theory Tech., vol.MTT-22, pp.462 - 464, April 1974.

[5] E.Yamashita, K.Atsuki, and T.Mori, "Application of MIC formulas to a class of integrated-optics modulator analyses : A simple transformation," IEEE Trans. Microwave Theory Tech., vol.MTT-25, pp.146 - 150, Feb. 1977.

[6] I.P.Kaminow, "Splitting of Fabry-Perot rings by microwave modulation of light," Appl. Phys. Letters, vol.2, pp.41 - 42, 15, Jan. 1963.

[7] E.Yamashita and K.Atsuki, "Distributed capacitance of a thin-film electrooptic light modulator," IEEE Trans. Microwave Theory Tech., vol.MTT-23, pp. 177 - 178, Jan. 1975.

[8] K.Atsuki and E.Yamashita, "Fundamental analysis for broadening the bandwidth of light modulators of optical-waveguide type," presented at the Symposium on Optical Guided-Wave Electronics, Osaka, Nov. 14 - 15, 1977 (In Japanese) and at the Technical Meeting on Optical Circuit Components, Tokyo, Jan. 17, 1978 (In Japanese).