Digital Electrooptic Modulators Synthesized from Directional Couplers

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Abstract - **This paper presents an electrooptic digital modulator synthesized from cascaded directional coupler. For the digital modulator, a nearly perfect cross state and bar state can be obtained in a broad range of modulation voltages that is from 0.03π to 0.28π Volts.**

I. INTRODUCTION

There have been a number of guided wave single mode electrooptic modulators developed for applications in ultra high speed signal processing and in optical communications. Among them are Mach-Zehnder interferometric modulator and directional coupler switch which have been extensively employed to implement switches, modulators and waveguide filters [1][2].

In an analog system, a large modulation range with a linear voltage relationship is needed. In a digital system, it is very desirable to have a tolerable range of voltages to obtain both the cross-state and the bar-state of the output intensity. The alternating $\Delta\beta$ directional coupler switch can provide a cross-state over a range of modulating voltages. On the other hand, it requires an accurate voltage to reach the bar-state due to the presence of the sidelobes.

In this paper we propose theoretically a digital modulator synthesized from cascaded alternating $\Delta\beta$ directional couplers in comparison with a conventional directional coupler.

The sidelobes are reduced from – 9.5 dB to – 38 dB and the voltage tolerance for a 99.9% cross-state output is increased by factor of 9 theoretically. The switching voltage of such a modulator can be as low as the drive voltage of a conventional directional coupler.

II. DIRECTIONAL COUPLERS

Two parameters govern the strength of this coupling process, that is coupling coefficient κ which depends on the dimension, wavelength and refractive indices and the phase mismatch of the propagation constant which is given by;

$$\delta = \Delta\beta / 2 = (\beta_1 - \beta_2)/2 = \pi\Delta n / \lambda_0 \qquad (1)$$

where Δn is the difference between the refractive indices of the waveguides. For a waveguide of length L_0 and if a small phase mismatch, δ is introduced, the power transfer ratio, $\Im = S(L_0)/R(0)$ may be written as a function of δ and is given by;

$$\Im = \left(\frac{\pi}{2}\right)^2 \sin c^2 \left\{ \frac{1}{2}\left[1 + \left(\frac{\delta L_0}{\pi}\right)^2\right]^{\frac{1}{2}} \right\} \qquad (2)$$

where sinc(x)=sin(πx)/(πx). Fig. 1 illustrates the dependence of the power transfer ratio, $\Im$ on the mismatch parameter $\Delta\beta L_0$. The ratio has a maximum value of unity at $\Delta\beta L_0$=0, decreases with increasing $\Delta\beta L_0$, and then vanishes when $\Delta\beta L_0 = \sqrt{3}\pi$.

A dependence of the coupled power on the phase mismatch is the key to making electrically activated directional couplers. Electrical control of $\Delta\beta$ is achieved by the use of the electrooptic effect. An electric field applied wills alters the refractive index by $\Delta n = -\frac{1}{2}n^3 rE$, where r is the Pockels coefficient. This results in phase shift given by;

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$$\Delta\beta L_0 = \Delta n(2\pi L_0/\lambda_0) = -(\pi/\lambda_0)n^3 r L_0 E \quad (3)$$

With two waveguides separated by a distance d, an applied voltage V creates an electric field $E = V/d$ in one waveguide and $-V/d$ in the other, where d is an effective distance determined by solving the electrostatic problem. The result is a net refractive index difference is given by, $2\Delta n = -n^3 r(V/d)$ corresponding to a phase mismatch factor which is proportional to the applied voltage V and is given by;

$$\Delta\beta L_0 = -(2\pi/\lambda_0)n^3 r(L_0/d)V \quad (4)$$

The voltage necessary to switch the optical power for which $|\Delta\beta L_0| = \sqrt{3}\pi$ is given by;

$$V_0 = \sqrt{3}\frac{d}{L_0}\frac{\lambda_0}{2n^3 r} = \frac{\sqrt{3}}{\pi}\frac{\kappa\lambda_0 d}{n^3 r} \quad (5)$$

This is called the switching or modulation voltage.

III. DIGITAL MODULATOR

The proposed digital modulator is shown schematically in Fig. 2. It consists of four cascaded alternating Δβ element couplers. The crossover light of each element coupler serves as the input to the next element coupler. The length, L of each element coupler is chosen to be exact one coupling length, l.

From couple-wave analysis it is known that the crossover optical power of an alternating Δβ coupler is given by [3],

$$P_1 = SS^* = (2A^*B)(2A^*B)^* = 4(AB)(AB)^* \quad (6)$$

where;

S is a complex amplitude of the crossover light,

$$A = \cos\left(L\sqrt{\kappa^2+\delta^2}\right) + j\sin\left(L\sqrt{\kappa^2+\delta^2}\right)/\sqrt{\kappa^2+\delta^2}$$

$$B = \sin\left(L\sqrt{\kappa^2+\delta^2}\right)/\sqrt{\kappa^2+\delta^2}$$

and,

$\kappa = \pi/2l$ is the coupling coefficient,

$\delta = \Delta\beta/2$ is a phase mismatch between the propagation constants β_1 and β_2 in the two waveguides.

It is easily seen from equation (1), that if the device consists of N cascaded element couplers, the overall crossover power is given by,

$$P_N = (P_1)^N . \quad (7)$$

IV. SIMULATION RESULT

Fig. 3 shows a comparison of the proposed design to that of a conventional directional coupler with uniform electrode and to that of an alternating Δβ coupler with $L/l = 1$.

It can be seen from the graph that the alternating Δβ coupler with $L/l = 1$ has a broader range of voltages to achieve nearly perfect cross-state than that of a conventional directional coupler with uniform electrode. Cascading deeply suppresses the sidelobes, therefore makes the bar-state output insensitive to the modulation voltage as long as it is greater than a threshold voltage. Theoretically the first symmetric sidelobes of both the conventional and alternating Δβ couplers are approximately –9.5 dB [4]. For an N-element digital modulator or switch the sidelobes are suppressed to a level that can be written as,

(-) N x 9.5 dB.

Therefore, with N = 4, the first sidelobes are –38 dB.

For a conventional directional coupler a 99.9% output level can be obtained only if the cross-state modulation voltage fall in the range of $|\Delta\beta L(V)| \le 0.03\pi$.

For the proposed digital modulator with N = 4, the same output level can be obtained if the cross-state modulation voltage are within the range of $|\Delta\beta L(V)| \le 0.28\pi$, improved by a factor of 9 approximately.

Digital modulation can also be achieved by choosing an alternating Δβ coupler with more than two sections as an element coupler in the propose structure. Shown in Fig. 4 are relative output power versus voltage characteristic of a four element modulator with its element coupler being 2,3 and 4 section alternating Δβ coupler.

Low switching voltage is very desirable for electrooptic modulator or switch devices. Increasing the number of sections in the element coupler will allow a broader range of voltages to obtain an excellent cross-state but require a higher switching voltage to reach the bar-state. On the other hand, since the switching voltage is exponentially dependent to the device length, by cascading more element couplers, devices with further lowered switching voltage can be obtained at the expense of increasing insertion loss.

V. CONCLUSION

In conclusion, we have successfully demonstrated a digital modulator using alternating Δβ directional coupler and compared to a conventional directional coupler. The digital modulator has a tolerable range of voltages to achieve the cross state and bar state.

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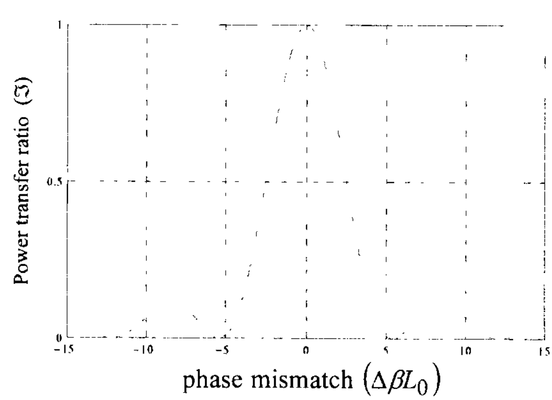

Fig. 1: The dependence of power transfer ratio on the modulation characteristic

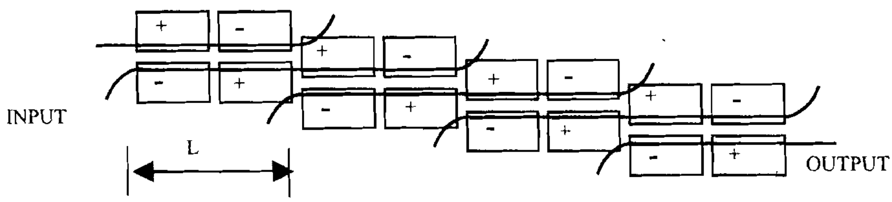

Fig. 2 : Schematic diagram of the proposed digital modulator with four element couplers.

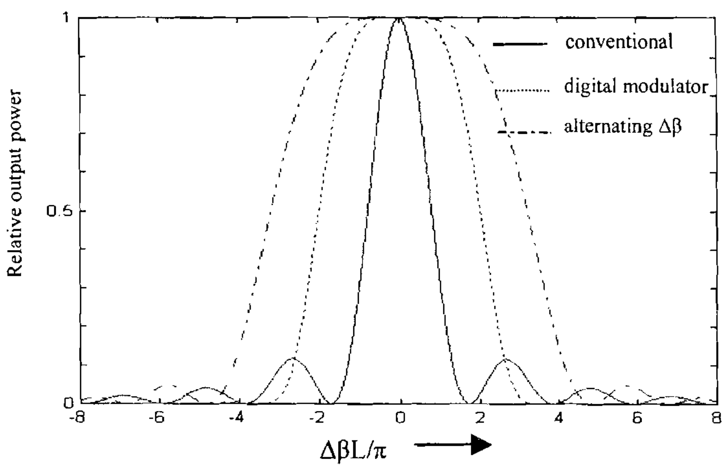

Fig.3: Modulation characteristic of digital modulator in comparison with conventional and alternating $\Delta\beta$ directional couplers

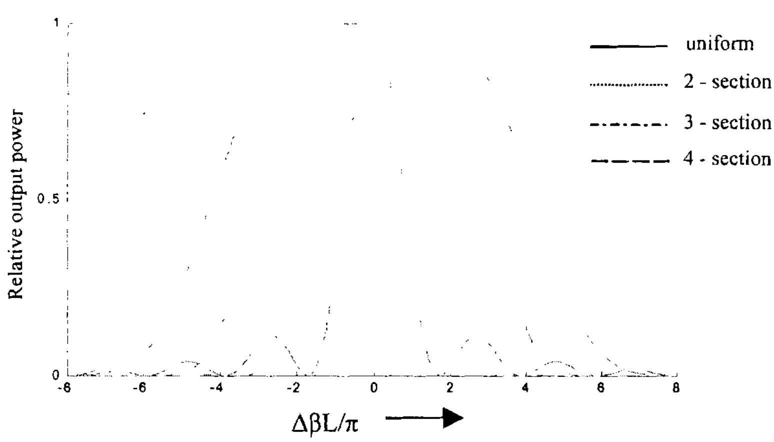

Fig. 4 : Modulation characteristic of digital modulator (N=4) with its element coupler being 2,3 and 4 section alternating $\Delta\beta$