

A Novel Photonic Vector-Sum Phase Shifter Using Polarization Maintaining Fibers

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Abstract

We propose and demonstrate a novel photonic phase shifter based on vector summation technique using polarization maintaining fibers (PMF). The phase change is achieved by controlling the modulator bias point and the polarization state of the signal injected into PMF. By controlling PMF length, 2π phase change is possible at microwave and millimeter wave frequencies.

I. Introduction

Recently, phased array antennas which can improve the system performance in space based mobile communication systems or satellite mobile communication systems [1], have been studied extensively. Especially, optically controlled phased array antennas are attracting the interest of many research groups due to many advantages, such as low loss, light weight, broad bandwidth, and high flexibility, compared with electrically controlled systems. One of the key components in the system is the photonic based RF

phase shifter.

Photonic phase shifters are based either on time delay or phase control. Time delay systems have the advantage of wide bandwidth, but they are complex; phase control systems are simpler than time delay systems, but they have small bandwidth [2].

Several methods have been proposed and successfully demonstrated for photonic RF phase shifters based on the phase control system using Mach-Zehnder modulator [3] and polymer materials [4-5]. However, these methods can not achieve the phase change without amplitude variation. To overcome this

problem, vector sum technique is used, but current methods require several modulators [2], or variable attenuators and optical delay lines [6].

In this paper, a new photonic phase shifter based on vector sum technique is proposed and demonstrated using polarization maintaining fibers (PMF). This phase shifter requires only one polarization controller instead of several attenuators and one modulator and two PMFs instead of several modulators. The phase change is achieved by controlling the modulator bias point and the polarization state of the signal injected into PMF. We measured 2π phase change at the millimeter wave frequency of 30GHz.

II. Theory and operation principle

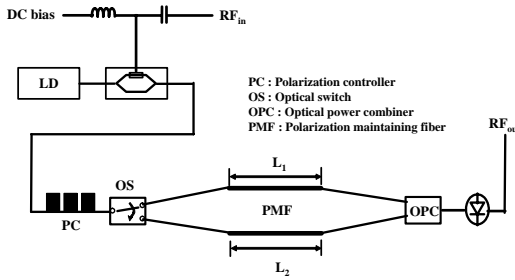


Fig. 1: Configuration of proposed photonic phase shifter

Fig.1 shows the configuration of the proposed scheme. As shown in the figure, the laser output signal is intensity modulated by the electro-optic modulator

and feeds into upper or lower PMF by an optical switch. The output optical intensity of the modulator is,

$$\frac{I}{2} [1 - \cos(\frac{\pi}{V_\pi}(V_m \sin(\omega t) + V))]]$$

, where V_m is the RF zero-to-peak voltage, V is the bias voltage applied to the modulator electrode, V_π is the bias voltage to produce π phase shift and I is input optical intensity.

At the front of PMF, the power of the modulated signal is transferred to two orthogonal polarization modes, fast and slow modes. If the angle between fast axis and input linear polarization is θ ($0^\circ < \theta < 90^\circ$), the power to be coupled to fast mode and slow mode is $\cos\theta$ and $\sin\theta$, respectively. Therefore, the coupled power to each mode can be controlled by the polarization controller.

If the differential group delay (DGD) of the PMF is τ , the photo current at the RF frequency is proportional to,

$$\begin{aligned} & J_1\left(\frac{\pi V_m}{V_\pi}\right) I \sin\left(\frac{\pi V}{V_\pi}\right) (\cos(\theta) \sin(\omega t) + \\ & \sin(\theta) \sin(\omega t + \omega \tau)) \\ & = A \sin(\omega t + \varphi) \end{aligned} \quad (1)$$

where

$$A = J_1\left(\frac{\pi V_m}{V_\pi}\right) I \sin\left(\frac{\pi V}{V_\pi}\right) \sqrt{1 + \sin 2\theta \cos(\omega \tau)}$$

$$\text{and } \varphi = \tan^{-1}\left(\frac{\sin \theta \sin(\omega \tau)}{\cos \theta + \sin \theta \cos(\omega \tau)}\right).$$

As shown in Eq (1), there is a vector sum between two sinusoidal oscillations, $\cos(\theta) \sin \omega t$ and $\sin(\theta) \sin(\omega t + \omega \tau)$. If the

value of $\omega\tau$ is $\pi/2$ or $3\pi/2$, the amplitude (A) of the detected RF signal is always constant, and the phase of the signal (φ) is linearly proportional to θ . At a fixed value of $\omega\tau$, $\pi/2$ or $3\pi/2$, the phase of the detected photo currents depended on θ and V is shown in TABLE I. In the TABLE, V_I is the linear bias point of the modulator.

TABLE 1

$\omega\tau$	$\frac{\pi}{2}$	$\frac{3\pi}{2}$	$\frac{\pi}{2}$	$\frac{3\pi}{2}$
V	V_I	V_I	$V_I + V_\pi$	$V_I + V_\pi$
φ	θ	$\pi - \theta$	$\pi + \theta$	$2\pi - \theta$

III. Experiment and results

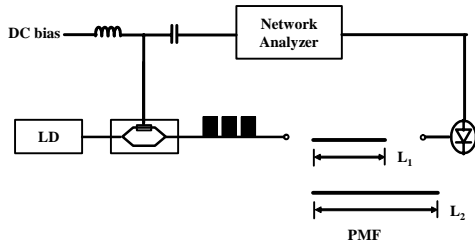


Fig. 2: Experimental setup

Fig. 2 shows the experimental setup for demonstrating the proposed photonic phase shifter. The RF phase of the detected signal is measured by network analyzer (HP8719ES) by changing the polarization state of the input signal injected into PMF and the modulator bias point. The RF frequency and PMF length should be determined so that the value of $\omega\tau$ is $\pi/2$ for L_1 and $3\pi/2$ for L_2 . In the

experiment, PMF length of L_1 of 11.7m and L_2 of 35.1m are used.

For determining the value of τ , the frequency response of PMF having length of 35.1m is measured with two polarization modes excited equally.

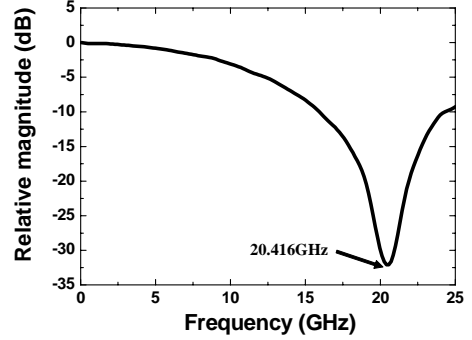


Fig. 3 Frequency response of PMF (35.1m)

The frequency response is shown in Fig. 3. The relationship between τ and the first dip position (f_{dip}) is $\tau = 1/2f_{dip}$. As shown in the figure, the measured value of f_{dip} is about 20.42 GHz, which give the value of 24.40 ps for τ . From this value, the RF frequency that gives $3\pi/2$ for $\omega\tau$ is determined to be 30.63GHz.

Fig. 4 and Fig. 5 show the measured RF phases in the case of L_1 and L_2 , respectively. In the figures, the hollow squares are measured at 6.8V and the solid ones are measured at 2.3V bias point of modulator. In the case of L_2 , the measured data is shifted in the counterclockwise direction about 10° . It is because that L_2 is longer than three times of L_1 .

Fig. 6 shows the continuously changed RF phases. It is measured at a

fixed RF frequency of 30.63GHz and 2.3V modulator bias point with manually changing the polarization state of the injected signal to L_1 by polarization controller. As shown the figure, the RF phase can be changed continuously as the polarization state is varied.

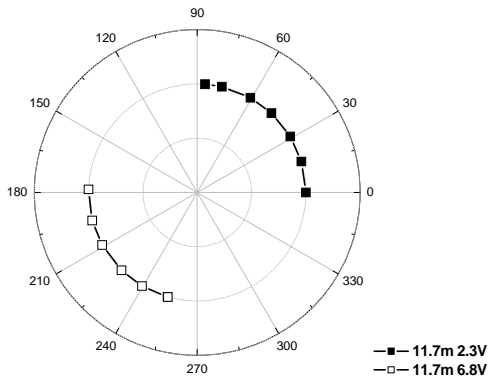


Fig. 4: Measured RF phase in the case of L_1 at the frequency of 30GHz

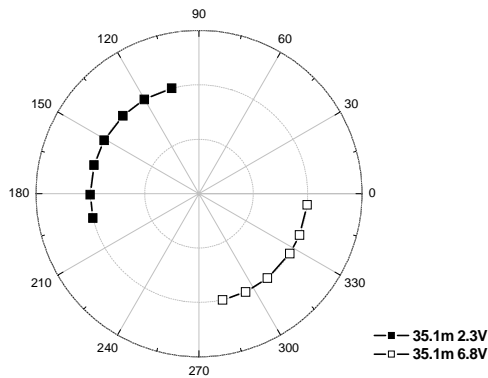


Fig. 5: Measured RF phase in the case of L_2 at the frequency of 30GHz

IV. Conclusion

In this paper, a new photonic phase shifter based on the vector sum technique is proposed and demonstrated using PMFs. The phase change can be

controlled by changing the polarization states of injected signal into PMF and the bias voltage applied to modulator electrode. We successfully demonstrate the photonic phase shifter to control the phase of the input RF signal continuously and fully (2π) at 30.63GHz.

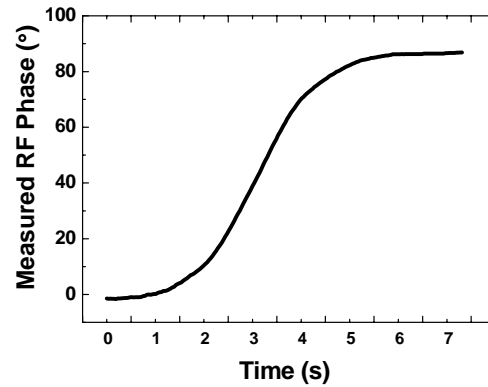


Fig. 6: Continuously changed RF phase

References

- [1]A. Dreher, N. Niklasch, A. Schroth, *IEEE Trans. Microwave Theory Tech.*, **51**, 1815(2003).
- [2]J. F. Coward, T. K. Yee, *IEEE J. Lightwave Technol.* **11**, 2201(1993).
- [3]D. R. Jez, K. J. Cearns, P. E. Jessop, *Micro. Opt. Technol. Lett.*, **15**, 46(1997).
- [4]S. S. Lee, A. H. Udupa, H.R. Fetterman, *IEEE Microwave and Guided Wave Lett.* **9**, 357(1999).
- [5]J. H. Han, *IEEE Photon. Technol. Lett.*, **14**, 46(1997)
- [6]H. Yilmaz, W. Freude, *MWP'03. Technical Digest*, 359(2003)