A Low-Loss Time-Delay Phase Shifter Controlled by Piezoelectric Transducer to Perturb Microstrip Line

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***Abstract*—This paper presents a new time-delay phase shifter using a piezoelectric transducer (PET) on microstrip line with computational and experimental results. Dielectric perturbation changes the line capacitance and propagation constant of the microstrip line. The phase of the microstrip line is varied, but insertion loss is not much affected. A maximum phase shift of 460° with respect to the unperturbed condition has been achieved with an increased insertion loss of less than 2 dB and a total loss of less than 4 dB up to 40 GHz, using the dielectric perturbation controlled by PET. The proposed phase shifter should have many applications in antenna beam steering and in other microwave and millimeter-wave circuits.**

***Index Terms*—Phase shifter, piezoelectric transducer, transmission line perturbation.**

I. Introduction

A WIDE-BAND and low-loss phase shifter is one of important components in microwave and millimeter-wave systems. Common applications are beam steering and beam forming for antenna array, timing recovery circuits, phase equalizers for data channels, etc. Published results on monolithic microwave integrated circuit (MMIC) [1], [2], ferroelectric [3], solid-state [4], and photonically controlled [5] phase shifters were narrowband, lossy, or providing small phase shift.

Recently, a new phase shifter was presented using dielectric image-line perturbation at Ka-band [6]. This idea can be improved by replacing the image line with microstrip line. The use of microstrip line is especially useful because of its quasi-transverse electromagnetic (TEM) mode without cutoff frequency, easy fabrication, no waveguide transition required, and possible use of microelectromechanical system (MEMS) structures. In addition, this paper proposes a new method of a piezoelectric transducer (PET)-controlled dielectric layer to perturb the electromagnetic fields of microstrip line. The dielectric perturber attached to the PET can be easily moved in the z-axis direction, as shown in Fig. 1(a). The deflection of the PET may be varied linearly under an applied voltage [7].

II. Design and Experiments

The new phase shifter of Fig. 1(a) can be analyzed using a configuration in Fig. 1(b) which consists of a microstrip line substrate (dielectric constant of ε_{r1}), air gap (ε_{r2}), and perturber

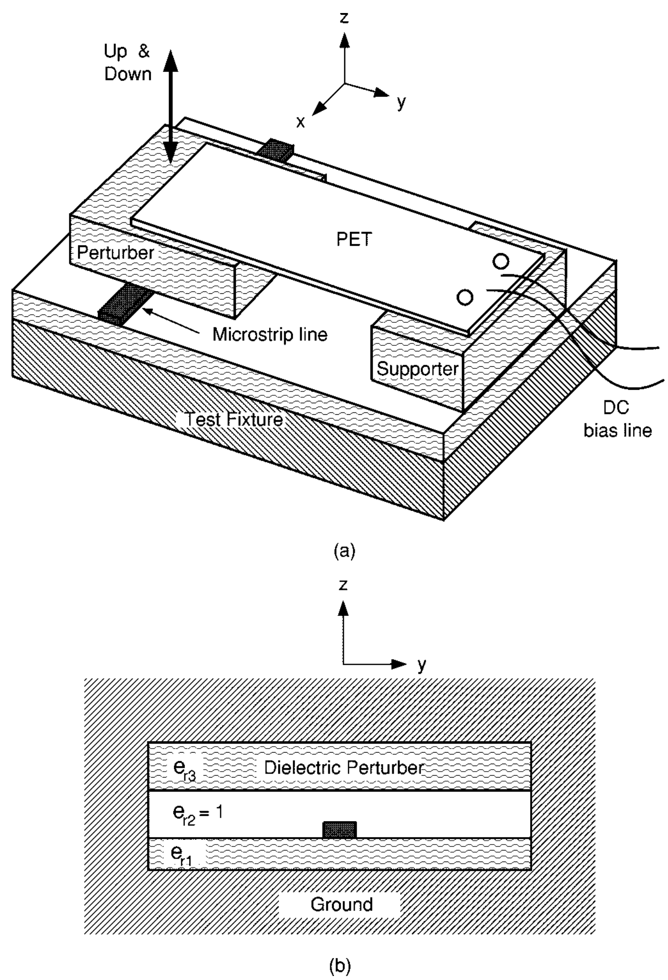

Fig. 1. (a) Configuration of phase shifters using dielectric perturbation controlled by piezoelectric transducer (PET) on microstrip line and (b) configuration for the variational calculation with microstrip line (ε_{r1}), air gap (ε_{r2}), and dielectric perturber (ε_{r3}).

(ε_{r3}). To calculate the capacitance of perturbed microstrip-like transmission lines, the variational method was used [8]. The capacitance variations correspond to variations in effective dielectric constant, characteristic impedance (Z_c), propagation constant, or phase shift [6]–[9].

The substrate used for the microstrip line is RT/Duroid 6010.8 with a dielectric constant of 10.8 and height of 25 mil. The microstrip line has a length of 3 in and a width of 22 mil. The dielectric perturber used has a dielectric constant of 10.8, height of 50 mil, and length of 1 in. From the variational analysis, phase shift was calculated at 10 GHz, as shown in Fig. 2. Calculated results are confirmed with measurements using a dielectric disc perturber regulated by a micrometer. Most phase shift occurs

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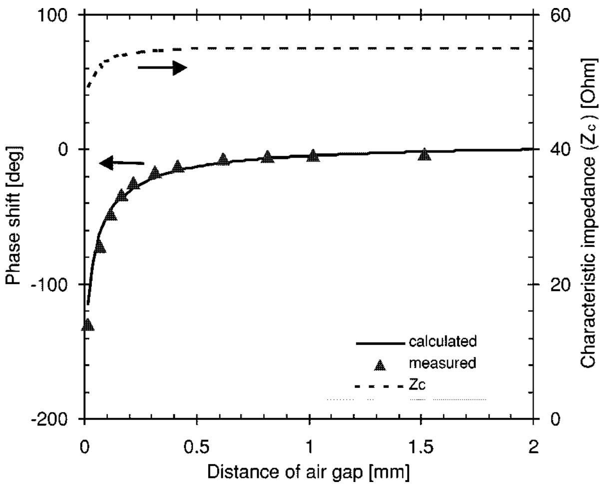

Fig. 2. Calculated and measured data using dielectric perturbation supported by micrometer.

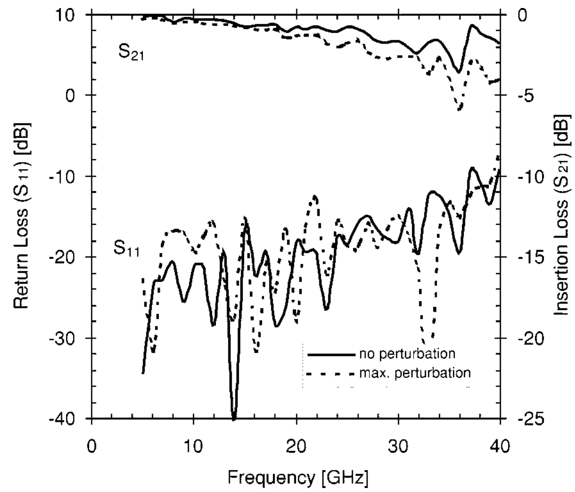

Fig. 3. S-parameters variation on the microstrip line with and without dielectric perturbation controlled by PET.

within 0 to 0.5 mm (about 20 mil) of air gap distance. The variation of Z_c versus the distance of air gap is also shown in Fig. 2. The microstrip line width of 22 mil is designed for a high Z_c of 55 Ω to compensate for the decreased Z_c by dielectric perturbation. At maximum perturbation, i.e., when the dielectric perturber is placed on the microstrip line, Z_c is close to 50 Ω.

Because the phase shift is proportional to the length of perturbed line, the perturber's dielectric length was increased from 1 to 1.8 in to achieve more phase shift for the next experiment with the PET-controlled phase shifter. The PET has a size of 2.75 in (length)$\times$1.25 in (width)$\times$0.085 in (thickness including a supporter) with a composition of lead zirconate titanate. Thru-reflect-line (TRL) calibration was used to remove the coaxial connector-to-microstrip-line transition effect for S-parameters measurement of HP8510. But an imperfect calibration caused a fluctuation in the insertion loss (S_{21}) near 35 GHz, as shown in Fig. 3. Except the fluctuation of S_{21}, the maximum perturbation added loss is about 2 dB, and thus total loss is less than 4 dB up to 40 GHz. The return loss (S_{11}) is less than -15 dB over all the frequency range and about -10 dB near 40 GHz. The magnitude of S-parameters is not much affected by the dielectric perturbation.

Fig. 4 shows how S_{21} of the microstrip line with PET-controlled perturber exhibits a phase shift from -460° to -20° at 40 GHz with respect to the unperturbed condition. The amount of phase shift depends on PET deflection which is controlled by varying the applied voltage from 0 to 90 V. A null-response region of flat phase shift from 0 to 15 V may be due to imperfect alignment of the PET plate at this level of deflection. About 15 V is needed to overcome this effect. The phase difference between four frequency curves is not the same, but smaller at higher frequencies. The reason is that as the effective dielectric constant gradually increases from 7 at 1 GHz to 9 at 40 GHz, the perturbed amount of effective dielectric constant becomes smaller at higher frequencies.

III. Conclusion

A new analog phase shifter using perturbed microstrip line controlled by piezoelectric transducer (PET) has been successfully demonstrated. The theoretical results agreed well with measured data. The proposed phase shifter showed very low loss over ultrawide bandwidth up to 40 GHz. The new phase shifter should be useful for beam steering and beam forming of an array antenna and for other microwave and millimeter-wave circuit applications.

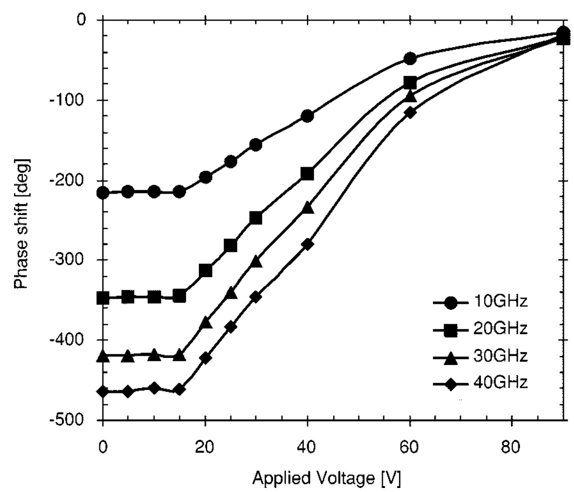

Fig. 4. Phase shifts at four different frequencies using dielectric perturbation controlled by PET on microstrip line.

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References

[1] S. Lucyszyn and I. D. Robertson, "Synthesis techniques for high performance octave bandwidth 180° analog phase shifters," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 731–740, Apr. 1992.

[2] A. S. Nagra and R. A. York, "Distributed analog phase shifters with low insertion loss," *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 1705–1711, Sept. 1999.

[3] J. B. L. Rao, D. P. Patel, and V. Krichevsky, “Voltage-controlled ferroelectric lens phased arrays,” *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 458–468, Mar. 1999.

[4] C. S. Lee and J. M. Tran, “Coplanar waveguide semiconductor phase shifter,” *Microwave Opt. Technol. Lett.*, vol. 10, no. 2, pp. 100–102, Oct. 1995.

[5] S.-S. Lee, A. H. Udupa, H. Erlig, H. Zhang, Y. Chang, D. H. Chang, D. Bhttacharya, B. Tsap, W. H. Steier, L. R. Dalton, and H. R. Fetterman, “Demonstration of a photonically controlled RF phase shifter,” *IEEE Microwave Guided Wave Lett.*, vol. 9, pp. 357–359, Sept. 1999.

[6] M.-Y. Li and K. Chang, “New tunable phase shifters using perturbed dielectric image lines,” *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 1520–1523, Oct. 1998.

[7] R. C. Buchanan, Ed., *Ceramic Materials for Electronics*. New York: Marcel Dekker, 1986.

[8] B. Bhat and S. K. Koul, “Unified approach to solve a class of strip and microstrip-like transmission lines,” *IEEE Trans. Microwave Theory Tech.*, vol. 30, pp. 679–686, May 1982.

[9] K. Chang, *Microwave Solid-State Circuits and Applications*. New York: Wiley, 1994.