VII-6 FERROELECTRIC PHASE SHIFTERS

R. Das

Loral Electronic Systems

A diagram of the microstrip ferroelectric phase shifter[1,2] is shown in Fig. 1(a). The nominal thickness of the ferroelectric material is 10 mils. As the dielectric constant of the ferroelectric is very high, the impedance of the microstrip line (~15 mils wide) is comparatively low. For matching purposes quarter-wave transformers of TiO_2 were used. A ceramic ferroelectric material containing 68.5 per cent $SrTiO_3$ and 31.5 per cent $PbTiO_3$ (PS 68.5)* was used in the experiments. For a TEM-mode propagation the insertion phase of a transmission line of length 1 is given by $\beta 1$. Fig. 2 shows the insertion phase of one of the units as measured with a phase discriminator. The total insertion phase at 3.05 Gc/S is 4.434λ. Substracting the insertion phase of the connectors and the quarter-wave transformers the insertion phase of the ferroelectric material alone is 3.486λ. On the application of a biasing voltage, the differential phase shift is given by

$$\Delta\phi = (\beta_1 - \beta_2) \tag{1}$$

where β_1 and β_2 are the phase constants without and with bias respectively.

or

$$\Delta\phi = \frac{2\pi\ell}{\lambda_0}\sqrt{\epsilon_1}\left[1 - \sqrt{\frac{\epsilon_2}{\epsilon_1}}\right] \tag{2}$$

where λ_0 is the free-space wavelength and ϵ_1 and ϵ_2 are the values of the dielectric constant with zero bias and with a bias voltage respectively. The insertion loss is

$$a_d = 27 \tan\delta \qquad \text{db}/\lambda \tag{3}$$

where $\tan\delta$ is the loss tangent of the material.

The differential phase shift of the phase shifter was measured in the bridge shown in Fig. 3. The biasing and microwave circuits were isolated with the help of 0-db couplers, which consist of two 3-db couplers. The opposite ports of the 0-db couplers are d-c coupled while microwave energy is coupled through diagonal ports only. A null was obtained by adjusting the attenuator and the line stretcher. The position of the null is shifted on the application of a d-c bias. From the shift of the position of the line stretcher for the null, $\Delta\ell$, the differential phase shift is calculated

$$\Delta\phi = 2\beta\Delta\ell \tag{4}$$

where β is the free-space phase constant.

Fig. 4 shows the differential phase shift as a function of d-c bias voltage for 2.9, 3.05 and 3.1 Gc/s. The insertion loss of the unit was 6.5 db at 2.9 and 3.05 Gc/s and 6.8 db at 3.1 Gc/s. The VSWR from either direction varied between 1.2 and 1.9. From the known length of the ferroelectric material, the dielectric constant and its change as a function of the d-c bias voltage were calculated from Figures 2 and 4 for 3.05 GC/s. Fig. 5 shows the calculated dielectric constant of PS 68.5 as a function of the bias voltage. The differential phase shift was measured with cw microwave power up to 1 watt. The differential phase shift decreases with increasing cw microwave power primarily because of heating of the ferroelectric material.

To visually observe the differential phase shift as a function of the biasing voltage, a cw microwave source was used. The phase shifter was swept with 60 c/s voltage. The ouput of the bridge detector and a fraction of the 60 c/s sweep voltage were fed respectively to the vertical and horizontal amplifiers of an oscilloscope. The resultant pattern is shown in Fig. 6. The line on the top shows the biasing voltage and the curve shows the out-of-balance voltage due to the differential phase shift. By proper calibration the differential phase shift due to any bias voltage can be detained from the curve. This curve (Fig. 6) shows that the difference in the phase shift for a particular voltage for increasing or decreasing sense is rather small. This means that the dielectric hysteresis is nearly absent.

The dielectric constant of the ferroelectric material and as such the VSWR is a function of the bias voltage as well as the operating temperature. Some impedance compensation can be obtained by making the transformer of a material whose dielectric constant is also dependent on the temperature and the bias voltage. Fig. 1(b) shows such an arrangement. The quarter-wave transformers are also made of the same material as the phase shifter. This avoids the difficulty of aligning the transmission line of the three pieces (Fig. 1(a)).

This paper demonstrates the feasibility of thin ferroelectric phase shifters. The bias voltage is considerably smaller than those previously reported[1,2] for the same values of the differential phase shift. The percentage change of the dielectric constant for a bias field of 7.9KV/cm is 27.3 per cent at 3.05 Gc/s compared to 33 per cent[3] at 1 Mc/s. Assuming the loss tangent of PS 68.5 at 3.05 Gc/s to be 0.065, the value reported[3] for 1.2 Gc/s, the insertion loss of the device, due to dielectric losses alone, is 6.1 db compared to the measured value of 6.5 db. The losses of such devices can be substantially reduced by using low loss materials like $SrTiO_3$, KDP etc. This type of phase-shifters can be used for steering the beam of antenna arrays.

ACKNOWLEDGMENT

It is a pleasure to acknowledge the encouragement of Mr. Paul Howells, Director and the active support of Mr. Paul Van der Esch, Project Director, both of Special Projects Laboratory, Syracuse University Research Corporation.

REFERENCES

1. M. DiDomenico, Jr. and R.H. Pantell, "An X-Band Ferroelectric Phase Shifter" IRE Transactions on MTT, pp. 179-185, May 1962.
2. M. Cohn and A.F. Eikenberg, "Ferroelectric Phase Shifters for VHF and UHF" IRE Transactions on MTT pp. 536-548, November 1962.
3. J.W. Amoss, M.R. Donaldson, L.J. Lavedan, A.L. Stanford, J.E. Pippin, "A Ferroelectric Microwave Switch" IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-13, No. 6, November 1965.

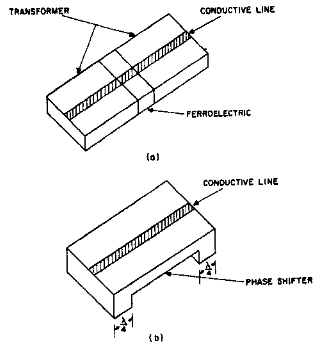

FIG. 1 - Thin Ferroelectric Phase Shifter

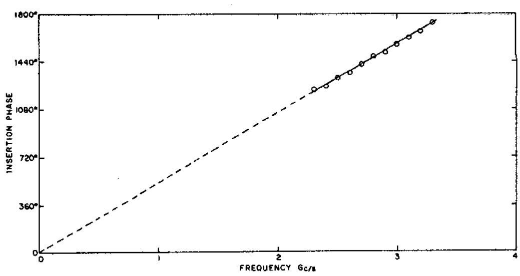

FIG. 2 - Insertion Phase of the Ferroelectric Phase Shifter

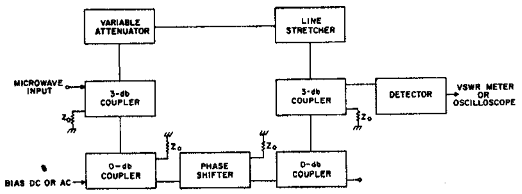

FIG. 3 - Experimental Arrangement for the Measurement of the Differential Phase Shift

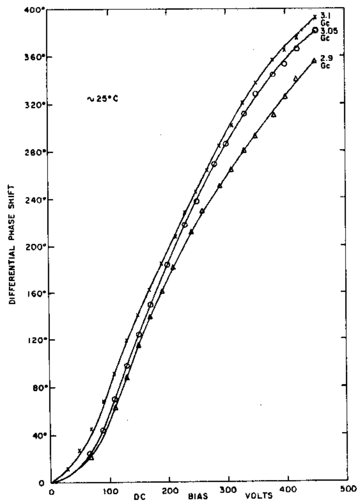

FIG. 4 - Differential Phase Shift as a Function of the Bias Voltage

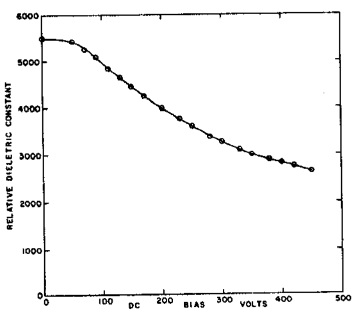

FIG. 5 - Relative Dielectric Constant of PS68.5 as a Function of the Bias Voltage

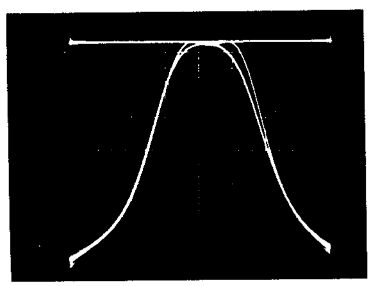

FIG. 6 - Visual Display of Differential Phase Shift versus Sweeping Bias Voltage