1.3: FERROELECTRIC PHASE SHIFTERS FOR VHF AND UHF*

MARVIN COHN and ANDREW F. EIKENBERG

Electronic Communications, Inc., Timonium, Maryland

An electric field controlled ferroelectric phase shifter has been developed which provides a differential phase shift of approximately 100° per centimeter at a frequency of 200 Mc/s. The attenuation varies from 1.1 to 1.5 db per centimeter. The phase shifter, shown in Figure 1, was constructed in dielectric loaded parallel plane waveguide [1] in which the dominant TE_{10} surface wave mode is excited. This transmission line is inherently suited to the construction of devices requiring control by a uniform electric field. As shown in Figure 1, the surface wave is launched onto and collected from the ferroelectric loaded line by means

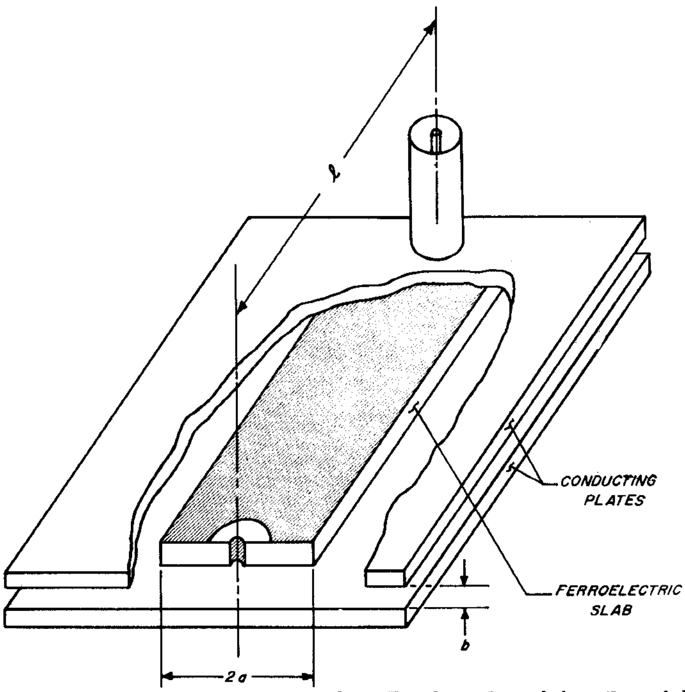

Fig. 1. View of the ferroelectric loaded parallel plane phase shifter. Part of the upper conducting plate is removed and only one of the two coaxial ports is shown.

---

*The research reported in this paper was sponsored by the Electronics Research Directorate of the Air Force Cambridge Research Laboratories, Office of Aerospace Research, U. S. Air Force, under Contract No. AF 19(604)-8379.

of a coaxial line feeding through the upper plate. The center conductor traverses the space between the parallel plates and contacts the lower plate. Prior analysis [2] has shown that this method of surface wave launching is extremely efficient and broadbanded when the dielectric constant (K) of the dielectric slab is very high. In addition it has been found that if the dielectric constant is very high, as it is in the case of ferroelectric materials (K>1000), then the launching efficiency is independent of the dielectric constant. Thus changes in the dielectric constant due to electric field and temperature changes do not affect the launching efficiency. It has been analytically and experimentally determined that the impedance of the ferroelectric loaded parallel plane waveguide is very low compared to the impedance of the unloaded parallel plane regions beyond the extremities of the ferroelectric slab. Hence, very little power radiates from the ends of the slab.

An analysis has been performed to determine the differential phase shift ($\Delta\phi$) of this structure as a function of the dielectric constant (K), change of the dielectric constant (ΔK), free space wavelength (λ_o), and the length (ℓ) and width (2a) of the ferroelectric slab. The results of this analysis are shown in graphical form in Figure 2. Curves of the attenuation due to the dielectric loss (α_d) as a function of the dielectric loss tangent (ϕ_d) and the other previously defined geometric and electrical parameters are shown in Figure 3. Measurements were made of the dielectric constant (K) and dielectric loss tangent (ϕ_d) as a function of

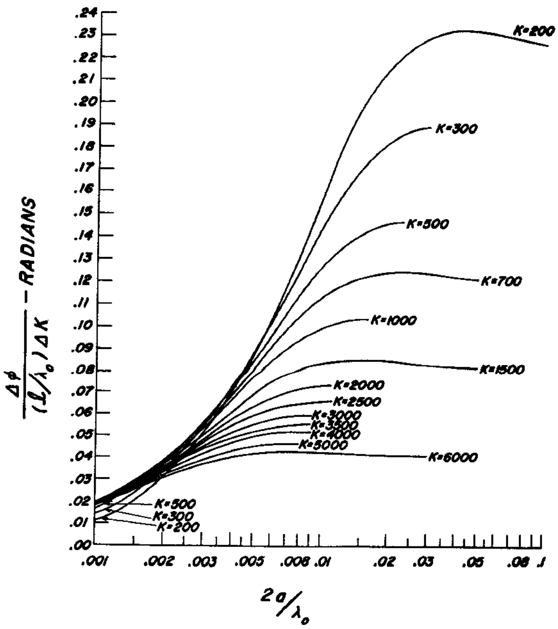

Fig. 2. Normalized phase shift due to a change of the dielectric constant (ΔK), as a function of the normalized width ($2a/\lambda_o$) and dielectric constant (K) of the ferroelectric slab.

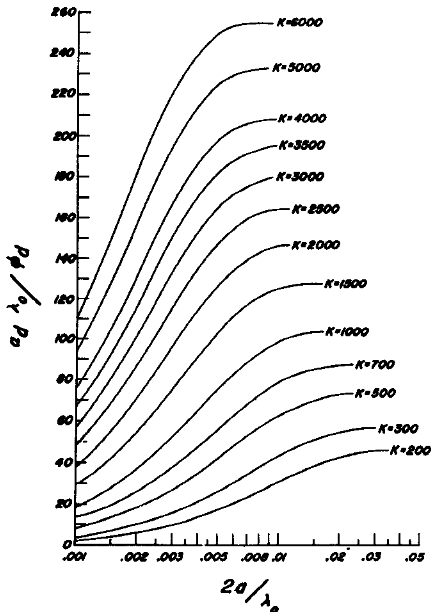

Fig. 3. Normalized attenuation, in nepers per meter, $(\alpha_d \lambda_o/\phi_d)$ as a function of the normalized width $(2a/\lambda_o)$ and dielectric constant (K) of the ferroelectric slab. ϕ_d is the dielectric loss tangent of the ferroelectric material.

applied dc electric field on a ceramic mixture consisting of 35 per cent $PbTiO_3$ and 65 per cent $SrTiO_3$. The measured properties, which are shown in Figure 4, can be used in conjunction with the curves of Figures 2 and 3 to predict the phase shift and insertion loss of this type of phase shifter as a function of the applied dc electric field. Curves of the predicted performance are shown on Figure 5 for comparison with the actual measured performance. A figure of merit (M) for this phase shifter is the ratio of the differential phase shift $(\Delta\phi)$ produced in a line of length ℓ to the losses incurred in this length of line. Analysis shows that the figure of merit is given by the following equation:

$$M = \frac{\Delta\phi}{\alpha_d \ell} = \frac{\Delta K}{K\phi_d} \left(\frac{\text{radians}}{\text{neper}}\right) = 6.6 \frac{\Delta K}{K\phi_d} \left(\frac{\text{degrees}}{\text{db}}\right)$$

The above figure of merit can be used for comparative evaluation of various ferroelectric materials for application to phase shifters.

Gold electrodes were baked onto the portions of the ferroelectric slab which are shaded in Figure 1. The high voltage electrode consists of the lower surface of the slab (not shown) and the surfaces of the half holes at the end of the slab. The gold electrode on the upper surface is maintained at ground potential. The half annular regions on the upper surface, which are not covered by gold, butt up against the coaxial lines of the

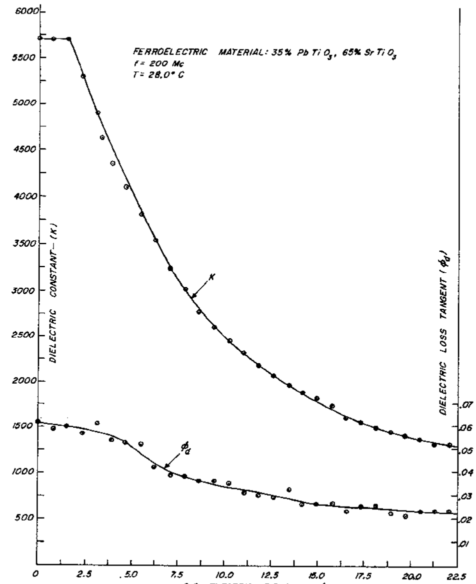

Fig. 4. Measured dielectric constant and loss tangent of a ceramic mixture of 35% $PbTiO_3$ - 65% $SrTiO_3$ as a function of applied dc electric field.

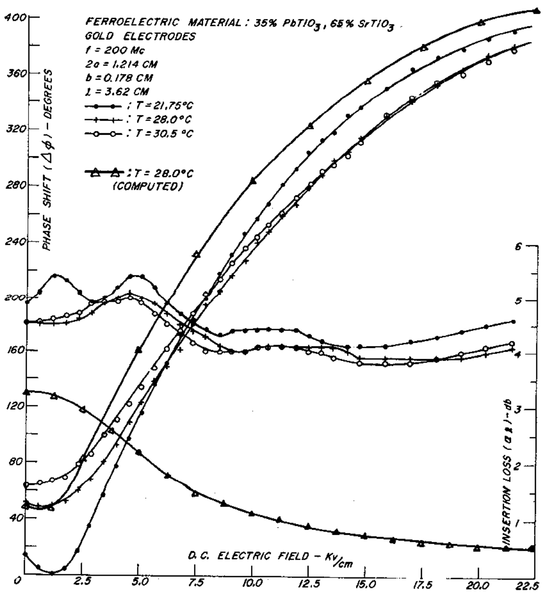

Fig. 5. Measured phase shift ($\Delta\phi$) and insertion loss ($\alpha\ell$), as a function of the applied dc electric field and ambient temperature.

input and output ports. These half annular regions as well as the sides and ends of the ferroelectric slab, which are not covered by gold, are covered with a .001" mylar tape having a silicone adhesive. Application of the mylar tape reduced surface breakdown effects. Gold electrodes were used on these phase shifters subsequent to observing that the insertion loss of phase shifters with silver electrodes increased with time over a period of several months. This aging effect is believed to be due to the migration of silver through the ceramic ferroelectric.

The measured characteristics of a 200 Mc/s ferroelectric phase shifter are shown in Figures 5 and 6. The ferroelectric slab consists of a ceramic mixture of 35 per cent lead titanate and 65 per cent strontium titanate, whose Curie temperature is 28° C.

A good impedance match was obtained through the use of quarter wave transformers at each port which stepped the impedance up by a ratio of 33:1. Double stub tuners were used at each end of the assembly. These tuners were adjusted to provide an intrinsic match at each port via the method described by Tomiyasu [3]. Coaxial dc blocking capacitors were located between the quarter wave transformers and stub tuners, so that the high dc voltage (up to 3900 volts) was constrained to the lower conducting plate and the coaxial center conductors up to the dc blocks. The intrinsic matching was performed at a temperature of 30.5° C and an electric field strength of 4.0 KV/cm. The data of Figures 5 and 6 was taken without readjusting the tuners.

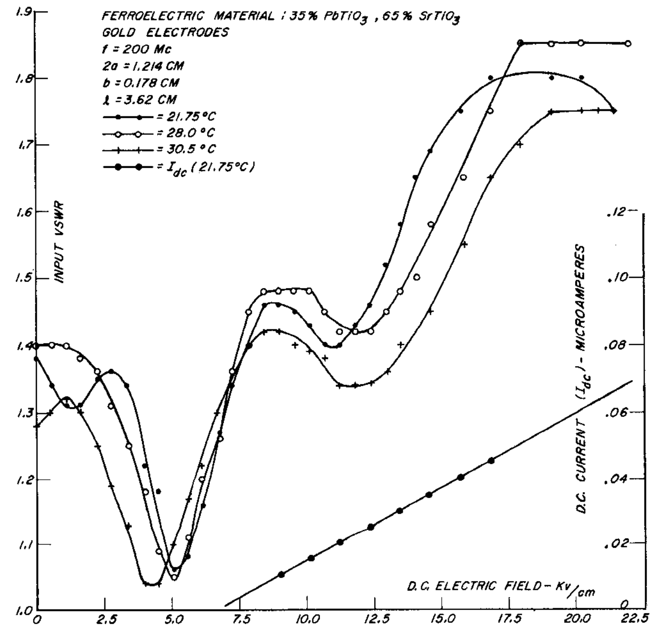

Fig. 6. Measured input VSWR and dc current as a function of the applied dc electric field.

The measured results show that large values of phase shift and reasonable losses can be achieved with compact ferroelectric phase shifters. The losses shown in Figure 5 are those due to dissipation within the phase shifter plus radiation (if present) due to inefficient launching and collecting. An additional 1.1 db loss due to the transformers, dc blocks, and tuners is not included. The intrinsic matching procedure results in moderate values for the input and output VSWR over the range of voltage and temperature checked. The frequently cited temperature sensitivity varied from 8 degrees/^{o} C at the low voltage end to 2.7 degrees/^{o} C at the high voltage end with values in between which were much lower. These figures do not compare unfavorably with ferrite phase shifters in the VHF and UHF region. Since the dc current drawn by these phase shifters is so low, as illustrated in Figure 6, the power required to maintain a constant phase shift is much lower than in a comparable ferrite phase shifter. Calculations of the driver power required to effect a rapid change of phase, show that it too is much less than that for a ferrite phase shifter.

The combination of low holding and driving power requirements and small size are substantial incentives for the development of ferroelectric phase shifters.

---

1. M. Cohn, "Propagation in a Dielectric Loaded Parallel Plane Waveguide," Trans. IRE MTT-7, 202-208 (1959).

2. M. Cohn, E. S. Cassedy, and M. A. Kott, "TE Mode Excitation on Dielectric Loaded Parallel Plane and Trough Waveguides," Trans. IRE MTT-8, 545-552 (1960).

3. K. Tomiyasu, "Intrinsic Insertion Loss of a Mismatched Microwave Network," Trans. IRE MTT-3, 40-44 (1955).