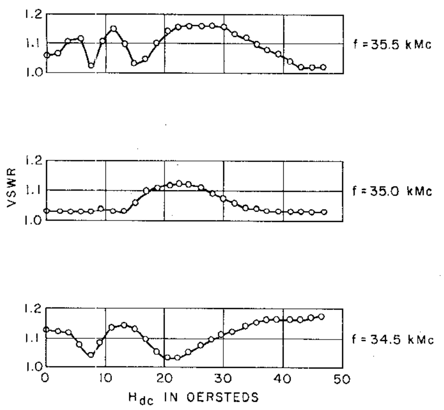

Fig. 1—VSWR characteristics of the prototype ferrite phase shifter.

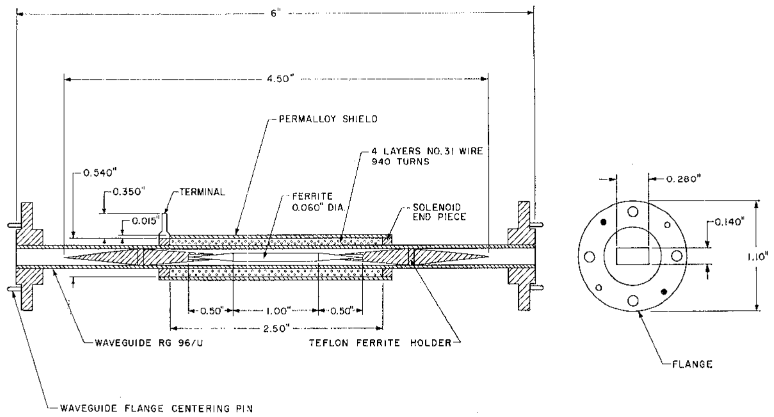

Fig. 2—Assembly drawing of the K_a-band phase shifter.

K_a-Band Ferrite Phase Shifter*

In 1957, Reggia and Spencer[1] utilized a new technique to develop a phase shifter at 9.1 kMc. This letter reports an extension of their technique to K_a-band frequencies. A maximum figure of merit of 1100 degrees of phase shift per db of loss has been achieved at 35 kMc ±500 Mc.

Selection of the Ferrite

For a Reggia-Spencer phase shifter the variation in μ' from zero applied field to saturation determines the amount of phase shift for a given geometry.[2] This difference in μ' generally increases as the saturation magnetization ($4\pi M_s$) increases; hence $4\pi M_s$ should be relatively high. However, materials with a high $4\pi M_s$ have been found to increase the loss of the device at very low applied fields. A practical value is $4\pi\gamma M_s/\omega < 0.5$ or $4\pi M_s < 6250$ oersteds at 35 kMc. In addition, the ferrite should have a small dielectric loss tangent and a narrow resonance linewidth for minimum insertion loss.

A nickel ferrite with a linewidth of 100 oersteds and a $4\pi M_s$ of 5000 gauss was selected because of its availability and superior performance. Other materials with $4\pi M_s$ as low as 3300 gauss were tested and found to yield less phase shift and a lower figure of merit.

Phase-Shifter Design

Two dimensions are critical for a Reggia-Spencer phase shifter. These are: 1) the narrow dimension of the waveguide and 2) the diameter of the ferrite rod. The rectangular waveguide has the function of coupling a TE_{10} mode into and out of the ferrite rod; hence, its narrow dimension must be small enough to prevent Faraday rotation in the ferrite-loaded region. A maximum rod diameter exists beyond which the rod will become a "self-sufficient" dielectric waveguide and Faraday rotation will occur.[2,3]

The investigation of the effects of rod diameter on phase-shifter performance revealed that the figure of merit increases with diameter provided there is no Faraday rotation. However, this advantage is tempered by the impedance-matching problem. The most practical diameter was found to be 0.060 inch for the standard K_a-band waveguide with inside dimensions of 0.280 and 0.140 inch. Faraday rotation occurred for a diameter of 0.065 inch.

Conventional matching techniques, consisting of tapering the ferrite rod and employing tapered dielectric supports, were used to obtain a smooth impedance transformation. The teflon insert ($\epsilon = 2.1$) was designed for the dual purpose of supporting the ferrite rod and providing an intermediate characteristic impedance between the ferrite-loaded section and the empty waveguide. The maximum VSWR of this combination (Fig. 1) varied from 1.12 to 1.17 over the band.

The ferrite and its teflon holders are contained in a 6-inch section of RG-(96)/U waveguide (Fig. 2). The complete assembly weighs approximately 4 ounces and has a maximum cross-sectional dimension of 1.1 inches (Fig. 3).

The coil produces a magnetic field of 187 oersteds per ampere. The value of field strength necessary to produce 360° of phase shift at 34.5 kMc is 35 oersteds.

Phase shift and insertion loss of the device are shown in Fig. 4. These data were taken for a range of field strengths from zero to 47 oersteds at 35 kMc and at 34.5 and 35.5 kMc.

Insertion loss is practically independent of frequency in the range of operation. The loss varies from a low of 0.20 db ±0.05 db at zero field to a maximum of 0.45 db. The frequency sensitivity of phase shift of the device is approximately 0.18° per megacycle.

At the center frequency of 35 kMc the maximum figure of merit is 1100° per db at a phase shift of 490°.

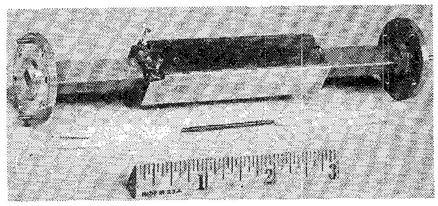

Fig. 3—Photograph of the K_a-band ferrite phase shifter.

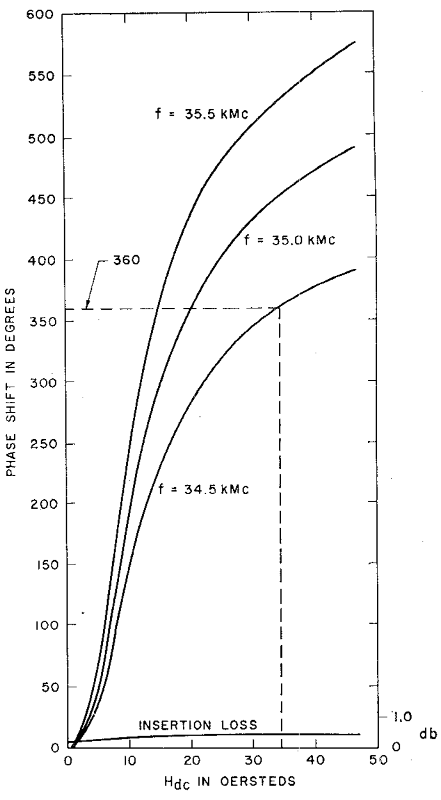

Fig. 4—Phase shift and loss characteristics of the K_a-band ferrite phase shifter.

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[1] F. Reggia and E. G. Spencer, "A new technique in ferrite phase shifting for beam scanning of microwave antennas," Proc. IRE, vol. 45, pp. 1510–1517; November, 1957.

[2] J. A. Weiss, "A phenomenological theory of the Reggia-Spencer phase shifter," Proc. IRE, vol. 47, pp. 1130–1137; June, 1959.

[3] S. A. Schelkunoff, "Electromagnetic Waves," D. van Nostrand Co., Inc., New York, N. Y., Sec. 10.20; 1943.