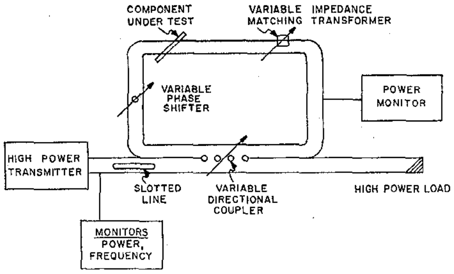

Fig. 1—Resonant ring circuit.

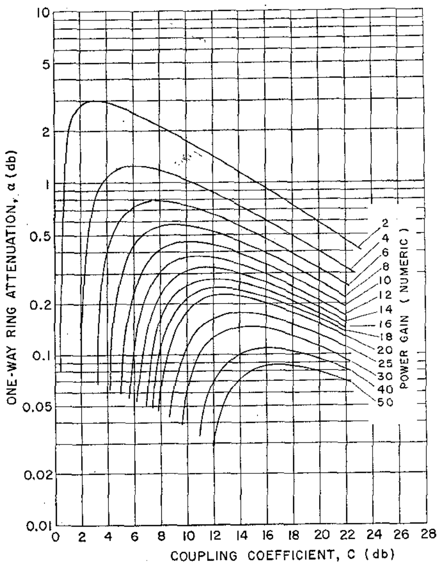

Fig. 2—Resonant ring characteristics with power gain as the parameter.

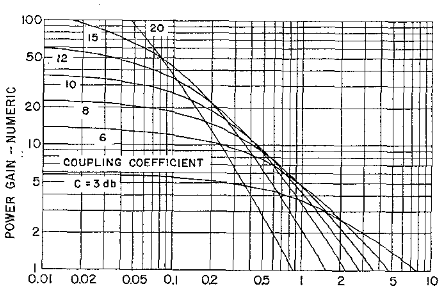

Fig. 3—Resonant ring power gain with coupling coefficient as the parameter.

components. This is because maximum electric fields do not occur at the same location as the maximum magnetic fields. To overcome this doubt, a resonant ring circuit can be employed[1,2,3] (see Fig. 1). In this circuit, the waves are ideally unidirectional and it is possible to obtain "power-level multiplication" of 10 to 50 times the transmitter output. The amount of multiplication depends on the value of the directional coupler and is very sensitive to the attenuation in the ring circuit.[2,3] The purpose of this brief paper is to illustrate these dependences in convenient graphical form.

If the ring circuit is properly matched in impedance[4] and the phase shifter is adjusted for resonance condition, the power "multiplication" or gain PG is given by

$$PG = \left[\frac{C}{1 - k\sqrt{1 - C^2}}\right]^2,$$

where

C = voltage coupling coefficient of the directional coupler, less than unity,

$k = 10^{-\alpha/20}$, a voltage ratio less than unity, and

α = one-way attenuation around the ring, in db.

This power gain equation is plotted in Figs. 2 and 3. For example, if a power gain of 20 is desired and the ring circuit attenuation is 0.2 db, either an 11- or 16-db coupler is needed.

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Reciprocal Ferrite Phase Shifters*

On Higher Order Modes

The Reggia-Spencer phase shifter[1] has been the subject of a great deal of investigation[2–4] because of the large amounts of phase shift possible with a relatively simple construction.

Rizzi and Gatlin[5] have proposed a model which qualitatively explains most of the observed phenomena associated with this type of phase shifter. Their explanation centers about the fact that only large amounts of phase shift are observed when the ferrite exceeds a critical diameter given by

$$d > \frac{C}{1.706f\sqrt{\epsilon}}, \qquad (1)$$

* Received by the PGMTT, November 13, 1959. The research reported herein has been sponsored by the Electronics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command, under Contract AF19(604)-3467.

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

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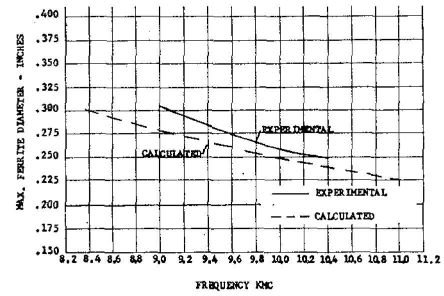

Fig. 1—Calculated and experimental curves of maximum diameter for suppression of higher-order modes as a function of frequency for RG 52/u waveguide. Device uses R-1 ferrite.

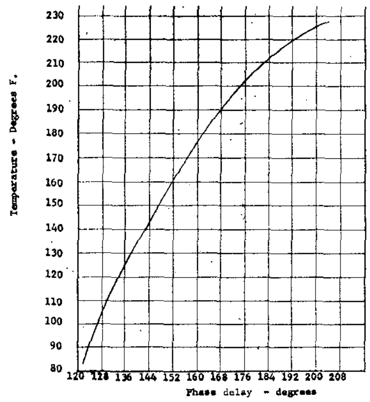

Fig. 2—Change of phase length with temperature using constant bias current of 85-ampere turns. RF frequency, 10.0 kmc. R-1 ferrite 0.250 diameter.

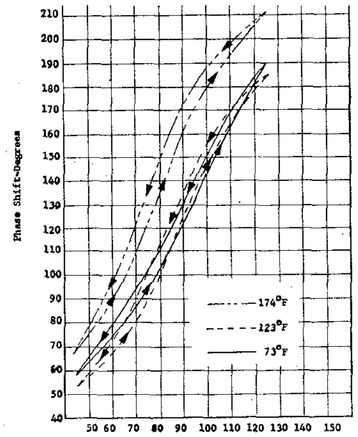

Fig. 3—Phase modulation characteristic of the phase shifter using an 85-ampere turn bias for various temperatures. RF frequency, 10.0 kmc.

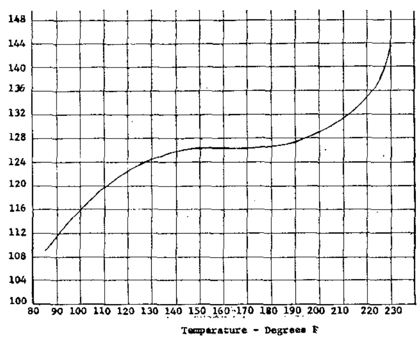

Fig. 4—Peak-to-peak phase modulation as a function of temperature with a constant bias of 85 ma, and a modulation current of ±60 ma at 500 cps.

where

C = velocity of light,
f = frequency,
ϵ = dielectric constant.

It is at this diameter that orthogonal TE_{11} modes can propagate in the ferrite acting as a dielectric waveguide. We have observed an additional phenomena which can also be explained by this dielectric waveguide model. This effect is discussed by Weiss[4] and is associated with the large amount of periodic loss which occurs as one increases the microwave frequency above a critical value. I believe a simple explanation of this behavior can be attributed to the excitation of the next higher order mode, the TM_{01}. This mode can only propagate in the ferrite region and is not matched to the rectangular waveguide by the transformer that matches the TE_{11} mode. Multiple reflections, therefore, occur between the ferrite ends with periodic losses resulting. In a similar manner to that used by Rizzi and Gatlin, the frequency at which this mode propagates is computed by

$$f > \frac{C}{1.309\, d \sqrt{\epsilon}}. \qquad (2)$$

The dashed curve in Fig. 1 has been calculated using this relationship with $\epsilon = 13$. Also presented is an experimental curve obtained with R-1 ferrite. The two curves show a general agreement. Some of the differences in the two curves can be possibly explained by the value of ϵ used as well as the effect of the waveguide height. Since all the microwave energy is not trapped to the ferrite, especially at low applied fields, a reduction in the narrow dimension should raise the frequency at which the TM_{01} mode can propagate. We have experimentally observed the above to be true.

On Temperature Sensitivity

The temperature sensitivity of the Reggia-Spencer phase shifter has been of concern in those applications which require precise phase control or phase modulation. In applications that require both phase advances and delays, bias currents are required because of the reciprocal nature of the phase shifter. The phase delay, as a function of temperature at a bias point of 85 ampere-turns for R-1 ferrite 1.4 inches long with 0.6-inch conical tapers, is shown in Fig. 2. It can be observed that over very large temperature ranges as much phase shift can be obtained from this effect as from applied magnetic fields.

The type of phase modulation characteristics obtainable about the 85-ampere-turn bias points as a function of temperature, is shown in Fig. 3. These curves are plotted on a relative basis; *i.e.*, they all use the same zero field phase-shift value. Note that the peak-to-peak phase shift is quite constant. This is illustrated by Fig. 4, which indicates the variation in the peak-to-peak phase shifts as a function of temperature. There is a fairly large range of temperature possible with little change in phase modulation characteristics. Threfore, if one desires to use these devices as phase modulators it is possible to do so with little change in the index of modulation with temperature.

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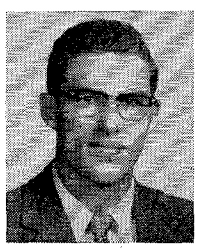

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