TABLE I
COUPLING FOR VARIOUS APERTURE LOCATIONS

Large		Small		Constant	
$C_1^-(+)$	$C_2^{\pm}(+)$	$C_1^-(-)$	$C_2^+(-)$	$C_3^-(\pm)$	$C_1^+(\pm)$
$C_3^+(+)$	$C_4^+(+)$	$C_4^+(-)$	$C_4^-(+)$	$C_\alpha^-(\mp)$	$C_\beta^-(\pm)$
$C_5^-(-)$	$C_6^{\pm}(-)$	$C_8^-(-)$	$C_8^+(+)$		
$C_7^+(-)$	$C_8^+(-)$	$C_\alpha^+(+)$	$C_\beta^+(-)$		
$C_4^-(-)$	$C_8^-(+)$	$C_\gamma^+(+)$	$C_\gamma^-(-)$		
$C_\alpha^+(-)$	$C_\beta^+(+)$				

variation since the susceptibility χ_{lm} is an odd function of the applied magnetostatic field.

The directivity is defined as the ratio in decibels of the power coupled in a particular direction in the secondary arm for an incident wave in the forward and backward directions, respectively, in the primary arm. Thus, we obtain in db

$$D = |C^+ - C^-|. \quad (3)$$

The coupling defined here is the negative of the standard definition. This is done so that an increase in coupled power corresponds to an increase in the ordinate of the curve of coupling vs magnetostatic field or frequency.

It is interesting to note, by inspection of (1) or (2), that the power coupled in one direction can be made independent of the magnetic susceptibilities by a proper choice of the hole location. Moreover, the susceptibilities can be made much larger than unity and can be controlled by the applied magnetostatic field. For a spherical ferrite sample, the maximum value of the susceptibility is inversely proportional to the reduced damping constant.[11] For ordinary microwave ferrites, this results in a maximum increase in coupling of about 20 db. The aperture locations in the cross-guide coupler and in the collinear coupler for which the coupling is significantly affected by the magnetostatic field are shown in Figs. 1 and 2, respectively. Information concerning the coupled power for some of the various aperture locations is given in Table I. The notation $C_i^-(+)$ means the coupling in the negative direction, aperture location i, and a positive value of the applied magnetostatic field. Thus, the sense of the magnetostatic field is indicated by the plus or minus sign inside the parentheses.

EXPERIMENTAL RESULTS

Curves of coupling vs the magnitude of the magnetostatic field for the cross-guide coupler, aperture location 1, and a Ferramic R-1 sphere are given in Fig. 3(a). Using (3), the directivity of the coupler for a positive magnetostatic field of 3 kilo-oersteds is 26 db. The coupling is -37 db. Curves of coupling vs the magnitude of the magnetostatic field for the collinear coupler, aperture location α and a Ferramic R-1 sphere are given in Fig. 3(b). The directivity for a negative magnetostatic field of 3 kilo-oersteds is 27 db. The coupling is -37 db. Another aperture location is γ, the centered hole. The coupling curves for this are shown in Fig. 3(c). An interesting characteristic is that the directivity is about 26 db with no

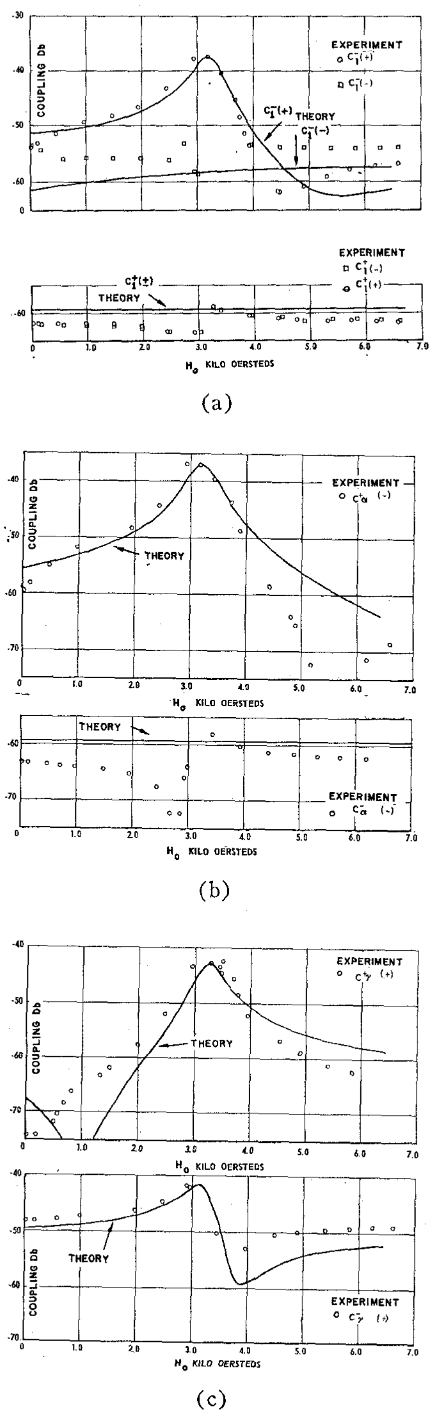

Fig. 3—Comparison of theory and experiment for coupling with Ferramic R-1 sphere of 0.124-inch diameter. Theoretical values for $\lambda_1=0.08$, $R=1.278$, $E=0.813$, $C'=0.816$: (a) cross-guide coupler, aperture location 1; (b) collinear coupler, aperture location α; (c) collinear coupler, aperture location γ.

applied magnetostatic field which decreases to zero when the magnetostatic field increases to 3 kilo-oersteds. In the cases considered, agreement between theory and experiment is acceptable in a qualitative sense. Unfortunately, the sphere was too large to expect exact quantitative agreement. Coupling curves were also run on a 3-hole coupler using 3 Ferramic R-1 spheres and aperture location α. The center hole was larger than the end holes in order to improve the directivity. The measured coupling curves were similar to those in Fig. 3(b). For a negative applied magnetostatic field of 3 kilo-oersteds, the directivity was 42 db and the coupling was -26 db. For no magnetostatic field, the coupling was -46 db and the directivity was at least 30 db.

CONCLUSIONS

Ferrite directional couplers display several advantages over normal directional couplers, such as nonreciprocal coupling and the electrical control of coupling. The couplers also permit one to obtain fairly good absolute data and quite good comparative data on the characteristics of ferrite materials. Work in this area will be reported at a later date.

ACKNOWLEDGMENT

The author wishes to thank M. L. Fisher for considerable aid in the measurement program.

DONALD C. STINSON
Lockheed Missile Systems Div.
Sunnyvale, Calif.

[11] *Ibid.*, see Appendix.

A Modulator for Microwave Mixers*

A method is described for producing an amplitude modulated wave at an intermediate frequency from the mixing of two cw signals in a coaxial or waveguide system. The method is adaptable to any frequency range in which crystal mixers are used. At least 82 per cent modulation is produced by this method, and the envelope is a square wave. The repetition rate is 0 to 20 kc with presently available commercial components.

One advantage of this system is to provide an ac signal for further amplification. In addition, the frequency and phase of the envelope depends only on the stability of the audio generator and the chopper. This makes the system suitable for use with a phase sensitive detector. Thus, the bandwidth of the detector system can be readily reduced to 1 cps. This system of modulation has been used to replace the swept local oscillator in a microwave attenuation measurement system.

Fig. 1 is a wiring diagram of the modulator. As is well known, the impedance and conversion loss of a crystal depend on the

* Received by the PGMTT, March 19, 1958.

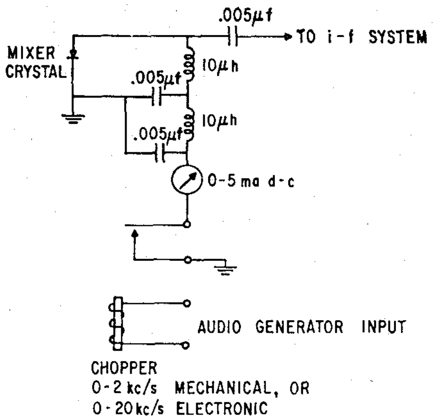

Fig. 1—Circuit diagram of modulator.

amount of rectified current in the crystal. The chopper serves to present alternately a low and a high impedance dc return. This change in crystal current affects the conversion loss to produce a square wave with more than 80 per cent modulation.

The modulator was developed for use in an attenuation measurement system. In this application a primary standard attenuator is in the IF system between the mixer and IF amplifier so that the principal noise source is the input stage of the IF amplifier. The ratio of the fundamental component of signal at 1 kc derived from the chopper modulation to that derived from a swept local oscillator was approximately unity. Thus, in this particular system the signal and noise levels remain unchanged.

In many applications there would be no isolation between the crystal mixer and the IF amplifier. In this type of receiver, the crystal noise is significant. The additional noise introduced by the chopper modulation was measured for 100-cps bandwidth at 1 and 10 kmc. The ratio of noise power with the chopper operating to that produced when the local oscillator was operating cw was 14 db. The ratio of the noise power with the chopper operating to that produced when the local oscillator was swept was 12 db.

The reduction of noise power by use of a phase sensitive detector can be 20 db without materially increasing the time to make an observation. Such a reduction would increase the dynamic range of the attenuation measurement system by 20 db, or increase the sensitivity of a receiver with the IF amplifier connected directly to the crystal by 8 db.

In summary, a method of producing phase-controlled amplitude modulated IF signals from mixing cw signals has been developed for microwave receivers which has been successful in the frequency range 300 mc to 12,000 mc. The principle appears applicable to any frequency range in which crystal mixers are used. For a given signal-to-noise ratio, the dynamic range of a microwave attenuation measurement system can be increased by 20 db through the use of this modulator and a phase sensitive detector without increasing the time constant in the final indicating device.

G. E. Schafer
Natl. Bur. of Standards
Boulder, Colo.

Reciprocal Ferrite Phase Shifters in Rectangular Waveguide*

A recent article by Reggia and Spencer[1] describes a reciprocal ferrite phase shifter for rectangular waveguide. This phase shifter consists of a pencil of ferrite suspended along the central axis of the waveguide by means of a dielectric. The phase is controlled by an applied longitudinal magnetic field. This geometry is shown in Fig. 1. Large amounts of phase shift are produced by this geometry with low insertion loss, and application to antenna beam scanning appears likely, as suggested by Reggia and Spencer.

One of the limitations of the configuration of Fig. 1 is power handling. In this regard it is similar to Faraday rotators in circular waveguide. The ferrite in both instances is suspended by a dielectric in the center of the guide having no contact with the walls. If the ferrite material were to be placed in contact with the waveguide walls, a large amount of heat would be conducted away, thus greatly increasing the power handling ability. In order to investigate this possibility, the configurations shown in Fig. 2 were measured for reciprocal phase shift characteristics. It was found that the geometry used in Fig. 2(a) resulted in a phase advance, while that used in Fig. 2(b) resulted in a phase delay. The results of these measurements taken at 9600 mc are shown in Fig. 3.

A measurement of insertion loss for the three phase shifters showed that the loss of the configuration of Fig. 1 varied from 0.3 db at zero field to about 0.8 db at saturation, while that of Fig. 2(a) stayed constant at a value near 0.1 db for all fields, and that of Fig. 2(b) varied from 0.2 db to 0.6 db at saturation. These loss figures indicate that the figure of merit (degrees of phase shift÷loss) for the design with the ferrites in contact with the narrow walls of the waveguide [Fig. 2(a)] is equal or slightly better than that of the centrally suspended ferrite rod. The amount of phase shift is low for the configuration of Fig. 2(a) when compared to that of Fig. 1. However, additional changes in thickness or height might improve this situation.

The configuration of Fig. 2(a) was subjected to 250 watts of average power resulting in a measured temperature rise at the waveguide wall of only 50°C.

The temperature rise indicated resulted in some additional measurements on the temperature sensitivity of these phase shifters. Measurements were made of phase shift as a function of temperature, and all three designs were found to show large variations. Phase shifts due to temperature variations over the range −20°C to +71°C showed as much change as that due to variation of applied magnetic field. In order to apply these phase shifters to antenna scanning, ovens may have to be utilized to stabilize temperature variations. Another approach that can offer a partial solution relies on controlling the magnetic field in such a way as to compensate for temperature changes.

* Received by the PGMTT, April 2, 1958.

[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.

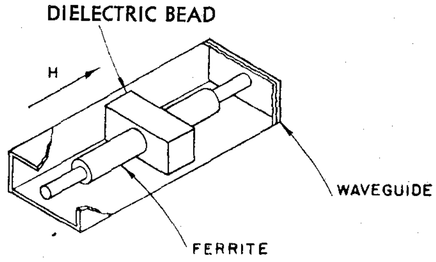

Fig. 1—Phase shifter using a cylindrical rod of ferrite suspended along the axis of a rectangular waveguide.

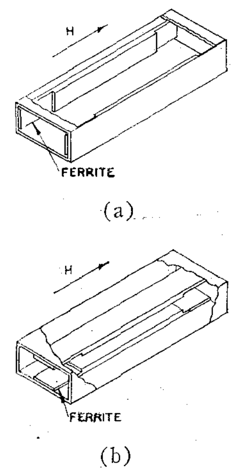

Fig. 2—Reciprocal ferrite phase shifters in rectangular waveguide in which the ferrite is in contact with the waveguide wall.

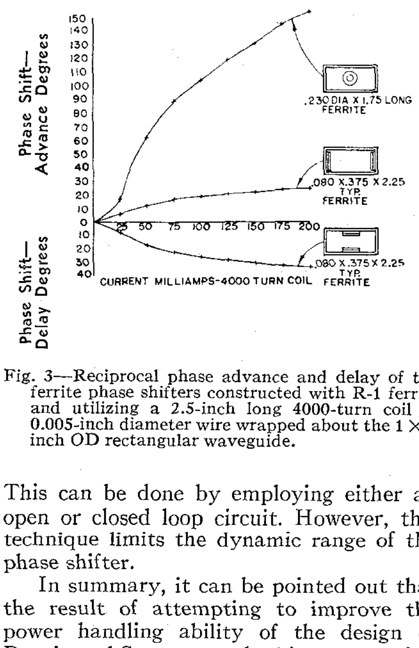

Fig. 3—Reciprocal phase advance and delay of the ferrite phase shifters constructed with R-1 ferrite and utilizing a 2.5-inch long 4000-turn coil of 0.005-inch diameter wire wrapped about the $1 \times \frac{1}{2}$-inch OD rectangular waveguide.

This can be done by employing either an open or closed loop circuit. However, this technique limits the dynamic range of the phase shifter.

In summary, it can be pointed out that the result of attempting to improve the power handling ability of the design of Reggia and Spencer resulted in two new ferrite geometries, one giving a phase advance and the other a phase delay, each with power handling capabilities of at least 250 watts. Additionally, the temperature sensitivity of all three devices may limit their usefulness in antenna beam scanning applications unless they are utilized in a parallel feed system where only relative phase shifts are important, and all the phase shifters have identical geometry.

Alvin Clavin
Rantec Corp.
Calabasas, Calif.