A High-Power Coaxial Ferrite Phase Shifter*

An *L*-band, reciprocal, coaxial, ferrite phase shifter with a low insertion loss, excellent high-power stability at peak power levels up to at least 300 kw, and a figure-of-merit in excess of 1000 has been developed. These characteristics were achieved by using longitudinal biasing fields considerably greater than the field required for resonance.

The motivation for this work stems from the need for improving the high-power characteristics of microwave ferrite phase shifters which are used as scanning elements in phased array antennas for radar transmitters.

An ideal phase shifter for this application would combine good high power stability and a high figure-of-merit (ratio of total phase shift in degrees to the peak insertion loss in db over the range of biasing fields employed) with small control power requirements and an ability to be rapidly switched from one phase shift setting to another. A number of designs have been explored in order to effect some compromise among these requirements. In recent years principal emphasis has been placed on light-weight, easily switched devices which produce the required phase shift upon application of only a very small biasing field. Most notable among these is the Reggia-Spencer phase shifter[1] which has been scaled for operation over a very wide range of frequencies.[2]

But low-field devices, by their nature, suffer from the proximity of the subsidiary absorption.[3] To some extent the threshold power can be controlled by a suitable selection of material, but it is generally conceded that the highest possible figure-of-merit is incompatible with a high threshold, at least with materials that are now available. Judging by our own experience, a light-weight ferrite phase shifter having an acceptable figure-of-merit (~several hundred deg/db) will usually have a threshold peak power of the order of a few tens of kilowatts. Higher threshold powers may be obtained by reducing the figure-of-merit. At *L*-band frequencies the problem is further complicated by the presence, in most materials, of rather excessive low field losses; the low field region thus becomes still less attractive.

The nature of the compromise among the phase shifter characteristics can be greatly altered, and low field losses avoided, by operating on the high-field side of resonance. Here the requirements of low control power and light weight must be relaxed, but one need no longer sacrifice figure-of-merit in order to achieve high power stability. The reason for this lies in the fact that the operating region is now far removed from subsidiary resonance and no instability from this source is predicted to within the approximation employed by Suhl,[4] as long as[5]

$$4\pi\gamma M_s < \omega.$$

The saturation of the main resonance, however, can introduce an appreciable variation in insertion loss with RF power level if the biasing field is not sufficiently great.

In order to explore the possibilities for above-resonance operation at microwave frequencies,[6] we have designed and constructed a ferrite phase shifter in a fully-loaded coaxial geometry for operation at 1350 Mc over a 10 per cent band. The propagation characteristics of such a structure have been analyzed by Suhl and Walker[7] to the extent that the coaxial line can be approximated by a pair of parallel planes. Their results show that the transmission line is cut off over the range of biasing fields,

$$\frac{\omega}{\gamma} - 4\pi M_s < H < \frac{\omega}{\gamma}.$$

Thus the region $H > \omega/\gamma$ is our present concern.

The device, shown schematically in Fig. 1, consists essentially of a $\frac{7}{8}$-in coaxial line fully loaded with TT 1-103, a magnesium manganese ferrite-aluminate.[8] We have found that a longitudinal magnetic field of 900 oe, well above ω/γ (480 oe), is sufficient to reduce the insertion loss of an 18-in length of line to about 0.2 db. This low loss implies that the material has a low dielectric loss tangent.

We should also note that the matching requirements are less stringent than those encountered in low field operation, because here the effective microwave permeability is greater than unity. The characteristic impedance of the ferrite loaded line is thus brought closer to that of the empty line.

In Fig. 2 the electrical characteristics of the phase shifter are shown vs applied dc field. The phase shift and figure-of-merit are given by the same curve with the 0.2-db insertion loss quoted above being the scale factor between the two sets of ordinates.

It is clear from the figure that two feet of loaded line is sufficient to produce 360° of phase shift with a change in biasing field of about 500 oe. A figure-of-merit of more than 1000 may be obtained without difficulty. Most important, however, is the fact that this figure-of-merit does not deteriorate with the application of high power. In fact, up to the highest peak power used (~300 kw),[9] no instability was observed over the range of biasing fields shown in Fig. 2.

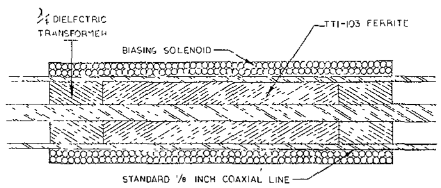

Fig. 1—Diagram of experimental coaxial ferrite phase shifter.

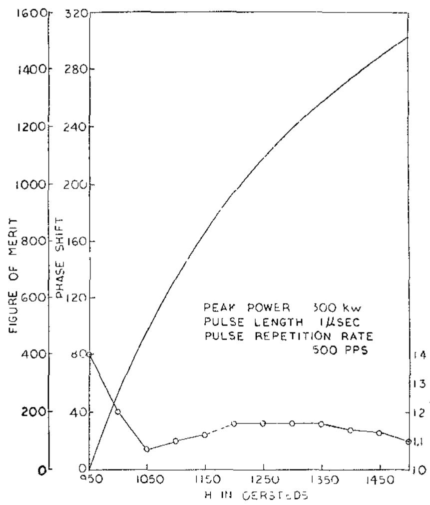

Fig. 2—Phase shift, figure-of-merit and VSWR vs dc field for TT1-103 in a $\frac{7}{8}$-in coaxial geometry. Length = 18-in, frequency = 1.35 kMc.

In installations where the large coil weight would not be a major disadvantage and where power and cooling could be provided for the permanent biasing and switching fields, the device described has important advantages. First, the high power stability represents an improvement of at least an order of magnitude over a comparable low-field device. Second, the phase shifter exhibits a very low insertion loss and the RF heating of the ferrite should, as a consequence, be relatively small. Third, the phase shift settings are not disturbed by hysteresis effects, and hysteresis heating by the switching operation is reduced to negligible proportions. In fact, since the magnetization is virtually independent of the biasing field, the presence of the ferrite should have little or no effect on the switching operation.

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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] R. S. McCarter and E. F. Landry, "K_a-band ferrite phase shifter," IRE Trans. on Microwave Theory and Techniques, vol. MTT-9, p. 271; May, 1961.

[3] J. F. Ollom and W. H. von Aulock, "Measurement of microwave ferrites at high signal levels," IRE Trans. on Instrumentation, vol. I-9, pp. 187–193; September, 1960.

[4] H. Suhl, "Theory of ferromagnetic resonance at high signal powers," *J. Phys. Chem. Solids*, vol. 1, pp. 209–227; April, 1957.

[5] P. C. Fletcher and N. Silence, "Subsidiary absorption above ferrimagnetic resonance," *J. Appl. Phys.*, vol. 32, pp. 706–711; April, 1961.

[6] An above-resonance UHF phase shifter using a stripline geometry was reported on by Johnson (see below) and his results show no instability up to peak powers of 10 kw except in the immediate neighborhood of resonance.

C. M. Johnson, "Ferrite phase shifter for the UHF region," IRE Trans. on Microwave Theory and Techniques, vol. MTT-7, pp. 27–31; January, 1959.

[7] H. Suhl and L. R. Walker, "Topics in guided wave propagation through gyromagnetic media, part III—perturbation theory and miscellaneous results," *Bell Sys. Tech. J.*, vol. 33, pp. 1133–1194; September, 1954.

[8] Trans.-Tech., Inc., Gaithersburg, Md.

[9] This power level greatly exceeds the rating for a standard $\frac{7}{8}$-in coaxial line. However, it was desired that the level be increased until instabilities appeared in the ferrite. In the neighborhood of 300 kw, arcing occurred in the waveguide-coax transitions.