An Electronic Scan Using a Ferrite Aperture Luneberg Lens System*

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Summary—Beam displacements up to ±30° have been observed in the radiation patterns from various ferrite-loaded waveguide apertures in transverse magnetic fields. The apertures are used as feeds for Luneberg lenses, and electrical lobing of narrow pencil beams is accomplished. The proposed use of a square waveguide ferrite-filled feed for a sequential lobing system is described.

Introduction

UNTIL recently, attempts to apply ferrites to the problem of electronic scanning have been limited to their indirect utilization as electrically variable phase shifters in corporate or sequential structure arrays,[1,2] A direct approach to the problem has been studied by Angelakos and Korman,[3] who have investigated the far-field radiation patterns from a ferrite-filled rectangular aperture at X band. They found that shifts in far-field beam maxima up to ±30° can be obtained by application of a transverse magnetic field. Wheeler[4] has reported the beam scattering from magnetized ferrite spheres in cylindrical waveguide apertures for possible application to an electronic conical scan.

At Convair, we have restricted our immediate goal to the development of a passive electronic tracking system with the following consequent simplifications:

1) Electrical beam lobing of the pencil beam is restricted to small squint angles (less than 3°).
2) The nonreciprocity of the Cotton-Mouton effect for the ferrite-filled aperture can be neglected.
3) The nonlinear behavior of ferrites at high power is not relevant.

In this paper, it is proposed that the electronic tracking be based on a sequential lobing system. This leads to use of waveguide geometries having lower symmetry than that required by a conical scanner.

Evaluation of Waveguide Apertures Containing Ferrites

We have studied the shift in the beam maxima of the far-field radiation patterns as a function of applied magnetic fields at ferrite-loaded apertures for three configurations.

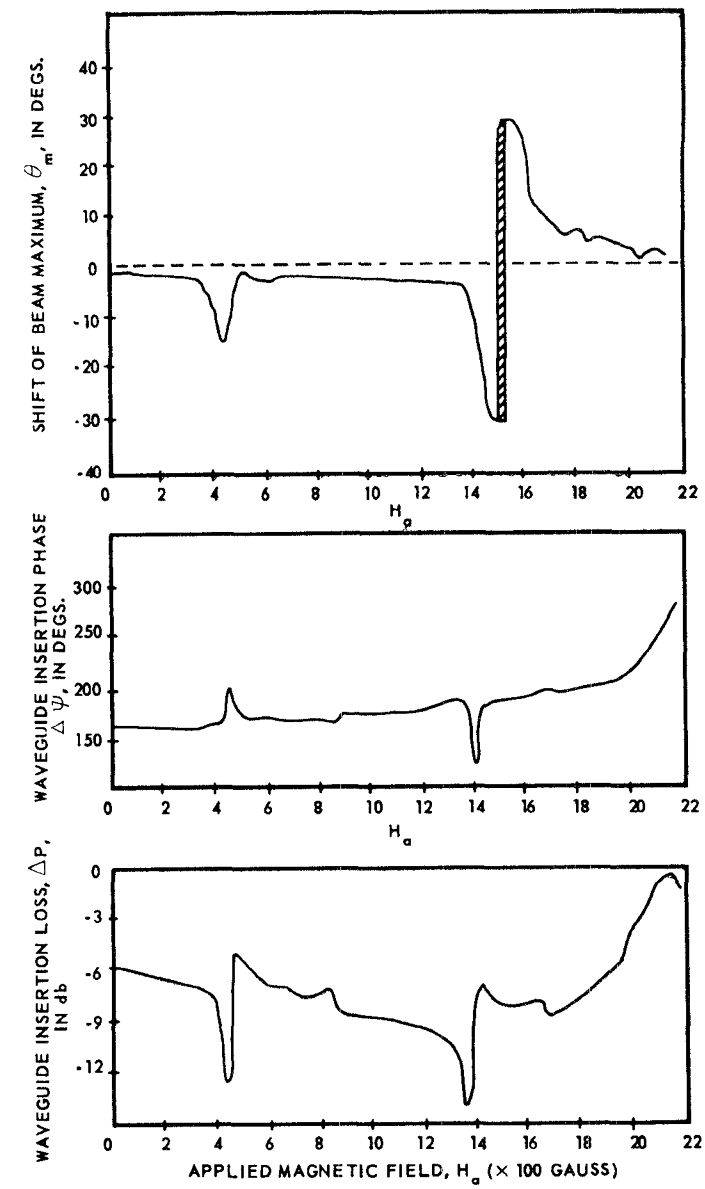

Fig. 1—Comparison of beam swing, θ_m, and waveguide characteristics for ferrite-filled rectangular guide.

The original geometry of Angelakos and Korman[3] [Fig. 4(a)] was studied for a ferrite sample $\frac{3}{8}$ inch thick (General Ceramics R-1) at a frequency of 9375 mc. Ultrasonic cutting techniques were used for shaping these and subsequent ferrite slabs for precise fit in the waveguide apertures. Beam lobing in the H plane up to ±30° for 60° beamwidths was observed. Fig. 1 (top curve) represents the shift in beam maximum, θ_m,[5] as a

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[1] *Proceedings of Third Symposium on Scanning Antennas*, Naval Res. Lab., Washington, D. C.; April, 1952.
[2] *Record of the Georgia Tech-SCEL Symposium on Scanning Antennas*, Georgia Inst. Tech., Atlanta, Ga.; December 18–19, 1956.
[3] D. J. Angelakos and M. M. Korman, "Radiation from ferrite-filled apertures," Proc. IRE, vol. 44, pp. 1463–1468; October, 1956.
[4] M. S. Wheeler, "Nonmechanical beam steering by scattering from ferrites," this issue, p. 38.
[5] Beam maximum position is defined as the average of the angular coordinates of the 3-db points.

function of applied field, H_a. This curve is in general agreement with the results of Angelakos and Korman for this thickness and frequency. It is shown here only for the interesting correlation with the two lower curves of Fig. 1. These are plots of relative insertion phase, $\Delta\psi$, and insertion loss, ΔP, for the identical ferrite sample in nonradiating waveguide. They were obtained by use of microwave interferometer techniques previously applied to investigation of dielectric constant. Significant changes in ΔP, $\Delta\psi$ occur for those regions of applied field producing large beam swings. This technique has been utilized to determine regions of appreciable beam shift for other thicknesses, frequencies, and ferrite materials without recourse to extensive measurement on the antenna pattern range. In addition, this observed correlation between the curves of Fig. 1 appears to give some credence to the assumption that the field distributions at the aperture plane are approximately those which, in principle, can be found from an analysis of the waveguide problem.[6,7] (This analysis has yet to be carried out for a finite slab filling the guide cross section.)

A second geometry investigated, also in rectangular X-band waveguide was that of the twin slab structure.[8,9] A typical aperture is shown in Fig. 2 (a 24-inch square ground plane is omitted). With this configuration, beam shifts up to 15° in the vicinity of 1500 Gauss were observed. Several variations of this twin slab geometry were studied in detail; the most interesting was one in

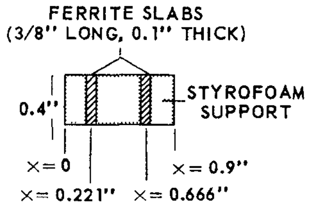

Fig. 2—Typical twin slab aperture.

which the spacing of the slabs was only 0.2 inch, the slab thickness 0.05 inch. In this case, beam shift up to ±35° with a corresponding loss in radiation amplitude of 1.08 db was observed in the neighborhood of 1600 Gauss. In the case of the completely filled aperture, beam shifts of this order have a corresponding loss in radiation amplitude, of at least 5 db and ranging up to 20 db and higher.

Finally, in order to remove the limitation of beam lobing to a single plane, a square waveguide system shown in Fig. 3 has been devised. The square waveguide is operated in either TE_{10} or TE_{01} modes as two independent apertures.[10] The direction of applied magnetic field is synchronized with the appropriate probe

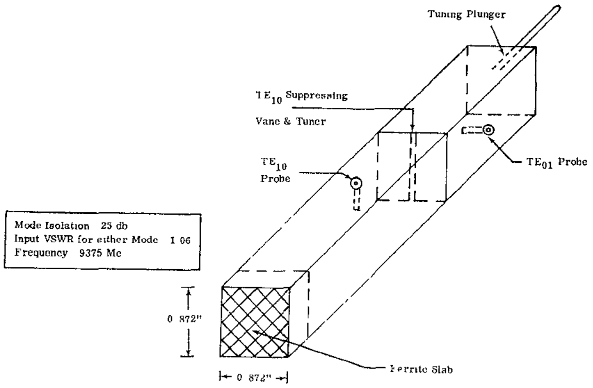

Fig. 3—Square waveguide use as a dual mode feed.

excitation. Mode isolation of about 25 db is obtained with the geometry used.[11] The ferrite slabs investigated do not introduce any observable additional cross-mode coupling. Beam shifts obtained with a single mode were analogous to those observed with the rectangular waveguide, although the details of the $\theta_m(H_a)$ function are quite different.

Electrical Lobing of Pencil Beams

Phase and amplitude determinations of the various aperture electric field distributions have been obtained using a second modification of the microwave interferometer.[12] Ferrite-loaded rectangular and square waveguide apertures have subsequently been used as feeds for a Luneberg lens (see Fig. 5).[13] The Luneberg lens is admirably suited for magnetic scanning since one is not concerned with an aperture blocking problem. The 3-db beamwidth with an 18-inch lens is 4.5°. A typical lobing pattern in the H plane obtained with this system is shown in Fig. 4 (deeper crossovers up to 3 db were obtained with the rectangular feed). In all cases, it was observed that as the squint angle increased, with consequently deeper crossovers, the sidelobe levels also increased. The patterns shown in Fig. 4 constitute a compromise between the opposing requirements of deep crossover and low side lobes. The side lobe increase is considered to be analogous to the coma lobes observed when one attempts large angle off-axis scan of paraboloid reflectors.

A continuous scan in the H plane has been observed with the monitoring equipment of Fig. 5. Rectangular waveguide was used as the feed for a 12-inch Luneberg.

[6] D. B. Medved, Second Bimonthly Progress Report, Convair RSR Project 1002; March 13, 1957.

[7] G. Tyras and G. Held, "Radiation from a Rectangular Waveguide Filled with Ferrite," URSI-IRE Joint Meetings, Commission 6; May 24, 1957.

[8] M. L. Kales, H. N. Chait, and N. G. Sakiotis, "A nonreciprocal microwave component," *J. Appl. Phys.*, vol. 24, p. 816; June, 1953.

[9] B. Lax, K. J. Button, and L. M. Roth, "Ferrite phase shifters in rectangular wave guide," *J. Appl. Phys*, vol. 25, p. 1413; November, 1954.

[10] D. Levine and W. Sichak, "Dual-mode horn feed for microwave multiplexing," *Electronics*, vol. 27, p. 162; September, 1954.

[11] This could be considerably improved by using a tee arrangement with appropriate matching posts.

[12] D. B. Medved, "An Electronic Scan Using a Single Ferrite Aperture," Convair Rep. ZN-309, pp. 19–21; May, 1957.

[13] J. Brown, "Microwave Lenses," Methuen & Co., Ltd., London, Eng., pp. 86–89; 1953.

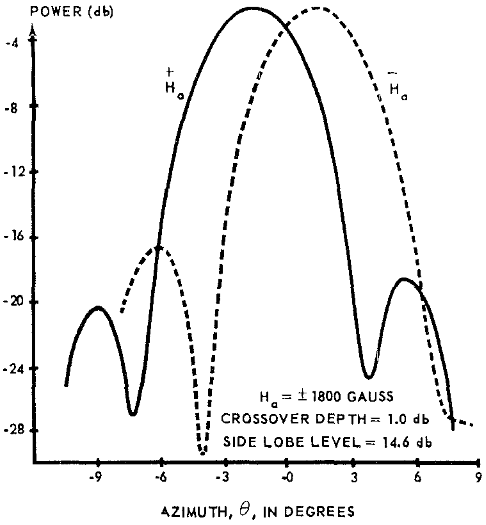

Fig. 4—Beam lobing patterns: 18-inch Luneberg lens fed by square waveguide.

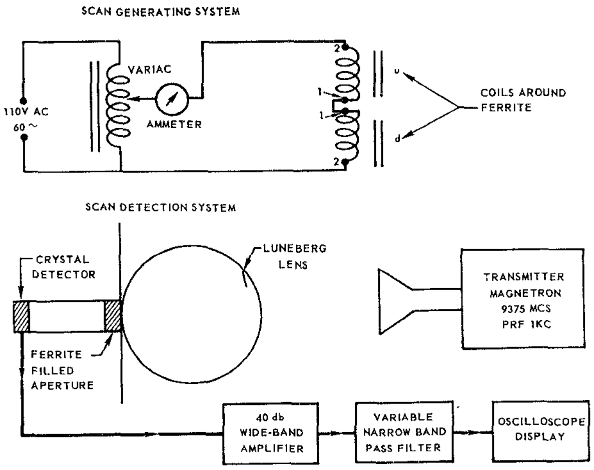

Fig. 5—Method for generation and detection of electronic scan.

Sine wave currents corresponding in peak value to $H_a = 1600$ Gauss were passed through the electromagnet coils at 60 or 400 cycles. The resulting pattern is thus sector-scanned in the H plane at the 60 or 400 cycle rate. An error signal effect is simulated by offsetting the receiver from the line-of-sight axis to the transmitter. The detected signal is amplified, filtered, and displayed on an oscilloscope. Maximum signal was observed at an 8° offset angle.

Sequential Lobing with Square Waveguide

A proposed sequential lobing system using ferrite filled square waveguide as a feed for a Luneberg lens is illustrated in Fig. 6. The square waveguide is operated essentially as two independent sources for TE_{10} and TE_{01} modes. The circles represent positions of beam maxima with appropriate rf E-field polarization indicated by the dashed arrows. Signals detected by the TE_{10} probe (beams 1 and 3) would be fed into an azimuth information channel, whereas tilt coordinate information is supplied by the crossover of beams 2 and 4. In the lower part of the figure, the time variation of electromagnet current necessary to produce the desired lobing sequence is plotted; *e.g.*, current in the coils labeled U-D with rf field corresponding to TE_{10} produces a shift of the beam to the right or left in the azimuth plane, depending on the magnetic field direction.

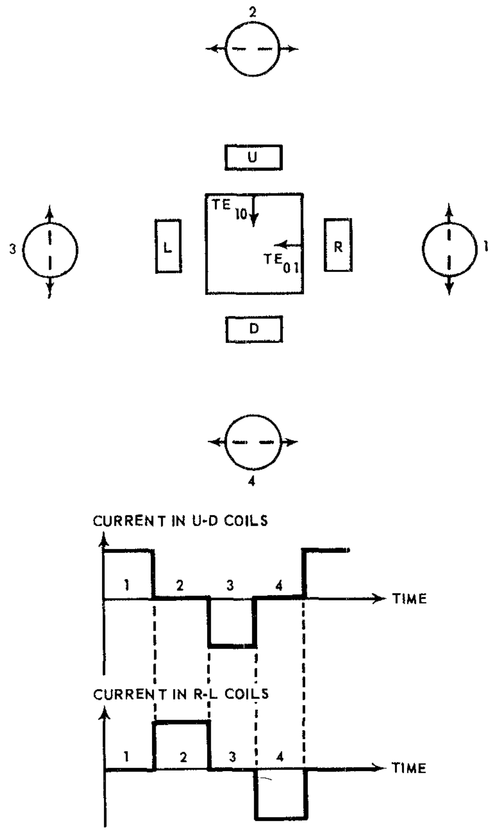

Fig. 6—Sequential lobing using square waveguide aperture.

The polarization sensitivity of the method may seem to present a serious limitation to use of this method. Consider for example, the reflected signal from a wing surface parallel to the E field of the TE_{01} mode. Information on the azimuth coordinates cannot be obtained under these conditions. However, if one considers the equivalent situation for conical scan, neither azimuth nor tilt coordinates can be obtained in the case that the nutating beam is polarized perpendicular to the wing. The difference in the two systems may be paraphrased by a choice of being at least half informed all the time or not informed at all some of the time concerning the target coordinates.

Acknowledgment

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