THE UNIVERSITY OF MICHIGAN
OFFICE OF RESEARCH ADMINISTRATION
ANN ARBOR

STUDY AND INVESTIGATION OF A UHF-VHF ANTENNA

Quarterly Progress Report No. 7
Period Covering October 1, 1961 to January 1, 1962

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ABSTRACT

The theoretical and experimental work accomplished to date is reviewed.

Theoretical work to date is discussed in relation to the particular antenna characteristics which are emphasized in each particular study. It is noted that two of the studies are basic and include information on almost all of the characteristics. These two studies are the rectangular, cavity-backed, slot antenna and the ferrite biconical antenna.

The experimental data on six different antenna models are shown. The data indicate that it is possible to reduce the size of an antenna with ferrite loading by a factor of two or three without serious deterioration of other characteristics. Because of the losses in the ferrite powder used, certain reservations must be placed on this tentative conclusion.

1. REPORTS, TRAVEL, AND VISITORS

During this period no reports were issued and no one visited the project. A trip was made to Wright-Patterson Air Force Base on December 8, 1961 to discuss project matters. Cooley Electronics Laboratory personnel present were CEL Director Dr. B. F. Barton, Professor John A. M. Lyon, and Mr. A. T. Adams. As a result of the discussion, a proposal was submitted covering a six-month extension of the present contract.

2. FACTUAL DATA

2.1 Review of Work Accomplished to Date on Project 03667

A review of work accomplished to date is outlined below, together with plans for future work.

The project has been concerned generally with the possibilities of improvement of antenna characteristics through the use of ferrite and ferroelectric materials. Some of the characteristics which might be improved are:

I size
II efficiency
III directivity
IV aperture
V bandwidth
VI impedance
VII scanning
VIII power capacity
IX weight
X cost

Of the above characteristics, attention has been concentrated in our research on characteristics I through VI with special emphasis on I and II.

Although we have not yet concentrated on scanning effects because of the complexity of analysis, this area may eventually turn out to be very important.

In order to investigate completely the question of possible improvement of antenna characteristics, it would, of course, be necessary to analyze all types of antennas, since no general mathematical model of the generalized radiator exists. Since it is impossible within the framework of the present contract to analyze a great many classes of antennas, theoretical and experimental work has been concentrated on several types of antennas, each of which may be expected to demonstrate the effect of ferrite loading on one or more of characteristics I through VI. It is to be expected, moreover, that the results of the analysis and experimentation will permit some general conclusions concerning the effects and usefulness of ferrite loading. The work completed to date and the work planned for the next eight months will be discussed below with reference to characteristics I through VI.

I. Size

Since wavelength in ferrite is inversely proportional to $\sqrt{\mu\epsilon}$, the use of ferrite materials offers the possibility of reduction in size of antennas. This possibility is being investigated at present both analytically and experimentally. Experiments show that the operating frequency of several classes of antennas (loops, spirals, rectangular and ridge cavities) are lowered by the use of ferrite loading. Limited data also indicate that the other characteristics of the antennas, such as beam pattern, bandwidth, etc., are not seriously impaired, although there is a definite need for better ferrite material before definite conclusions can be drawn. The pertinent data are indicated in Section 2.2.

We have chosen several analytical models to investigate the possibilities of size reduction. These models are discussed below.

(a) Rectangular-Waveguide Radiators. This type of antenna has been analyzed in a previous report (QPR No. 5). Dominant mode aperture fields were assumed and surface currents were neglected. The results predict little change in beam patterns, even with a 10:1 size reduction. Because of the assumptions involved, it was felt that a more accurate solution was necessary. This led to the somewhat similar problem of the rectangular-cavity slot antenna.

(b) The Sectoral-Horn Radiator. This problem was investigated, using the same assumptions as those in (a). This antenna was chosen in order to bring out the effect of ferrite loading and size reduction on a highly directive antenna. The results from the computer are being evaluated.

(c) The Double-Taper-Horn Radiator. An analysis of this problem was initiated in order to investigate the effects of ferrite loading on an antenna which is highly directive in both the E and H planes, using the same assumptions as those in (a) and (b). After the formal mathematical analysis was completed, work on this problem was terminated due to the priority of other work. If future work indicates that this problem is significant, computer studies will be initiated.

(d) Rectangular-Cavity Slot Antenna. This type of antenna is being analyzed at present utilizing a variational technique. It is expected that this procedure will give definite answers as to the change in characteristics such as impedance, beam pattern, efficiency, and possibly aperture when the size is reduced with ferrite loading. Part of this work will be included in the next Quarterly Report.

(e) Infinitesimal Dipole in a Spherical Ferrite Medium. Our study of an infinitesimal dipole immersed in a spherical ferrite medium has indicated that the radiation resistance is increased by large factors at resonant points. Consideration of a similar problem which represents a perturbation of the infinitesimal dipole case shows that the efficiency also increases (Fig. 1) by the same factor. However this increase in efficiency has been obtained at the expense of a sphere of ferrite which is very large compared to the original dipole antenna. This makes it difficult to discuss the relative merits of the loaded and unloaded dipoles. It would be somewhat easier to compare the two antennas if the ferrite diameter were no larger than the length of the antenna. This suggests the biconical analysis of Polk.

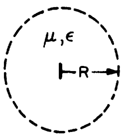
(f) Biconical Antenna. This antenna has the advantage that it can be analyzed exactly by separation of variables. Polk has solved this problem to determine the impedance at the antenna terminals (Fig. 2).

A preliminary analysis involving the assumption of dominant mode fields and lossy ferrite has been made. There are a number of useful additions that might be made to the work done so far. A perturbation of the problem introducing conductor losses on the order of those of silver would permit the evaluation of the efficiency. The inclusion of ferrite losses would be informative concerning the types of ferrite materials required for useful results. The evaluation of far fields would allow evaluation of the directivity. Professor H. Meinke has pointed out in a letter to Mr. E. M. Turner that a complete evaluation of the efficiency of an antenna must include conductor losses in

Consider two Hertzian dipoles with identical current moments, one of which is surrounded by a spherical ferrite medium.

Original Problem

(a) 

(b) 

current moment = G_0 .

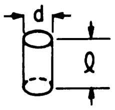
The radiated fields have been calculated for both cases (QPR No. 2, pp. 2-19).

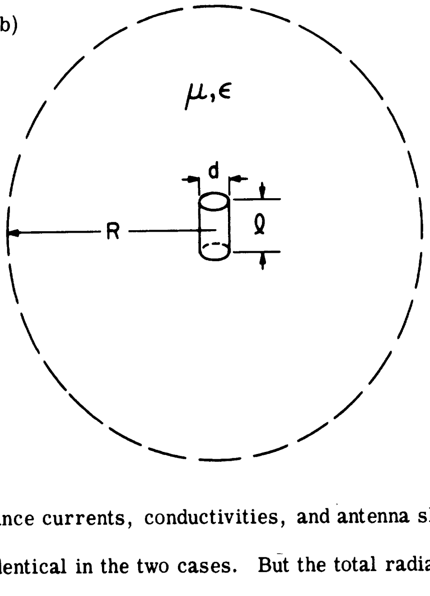
The ratio $\dfrac{\text{radiation resistance (Case No. 2)}}{\text{radiation resistance (Case No. 1)}} = \dfrac{\text{total radiated power (Case No. 2)}}{\text{total radiated power (Case No. 1)}}$

(since the current moments are equal) increases at resonant points to large values. This means, that, with identical current moments, the radiated power is much greater in Case No. 2.

Now consider a small perturbation of the above case. Assume the length and diameter of the antennas are small but finite. Assume that losses in the antenna conductor are small but finite. Assume that fields and current moments are the same as in the ideal case. Then, if the antennas have identical lengths, the currents will be identical.

Perturbation of Original Problem

(a) 

(b) 

surface
current
densities
and conductivities
identical in Cases (a) and (b)

Since currents, conductivities, and antenna shapes are identical, losses in the metal will be identical in the two cases. But the total radiated power in Case No. 2 is greater by a certain factor. Therefore the efficiency in Case No. 2 is also greater by the same factor.

Fig. 1. Efficiency of ferrite-loaded dipoles.

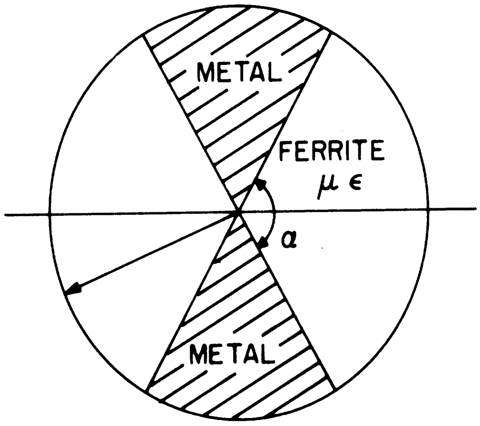


Fig. 2. Imbedded biconical antenna.

order to evaluate the ratio of radiation resistance to loss resistance. In the case of the infinitesimal dipole this can be done by the simple argument outlined in Fig. 1. However, in the case of a finite biconical antenna it would be necessary to make a separate calculation such as the perturbation calculation suggested above. Professor Meinke also points out that the antenna bandwidth can be evaluated in terms of R_s/X and $R_s/\frac{dX}{d\omega}$. In the case of the biconical antenna, these quantities could be calculated. Thus the biconical antenna becomes a very basic problem.

(g) Diffraction Studies. The results of several diffraction studies show a resonant power-gathering effect for spherical and cylindrical ferrite geometries. This effect implies the possibility of greatly increased apertures for ferrite loaded structures.

(1) Isotropic Ferrite Sphere. The problem of diffraction of a plane wave by an isotropic ferrite sphere was investigated. A resonant power-gathering effect was observed. At isolated points the power density was observed to be greater than that of the incident

plane wave by factors greater than 1000. Extensive calculations and computer results were compiled on the properties of the internal and external fields. A paper was presented on this subject at the University of Illinois Antenna Symposium and preparations are being made for further publication.

Problem (1) was also solved with losses in the sphere, but the computer program is in need of minor corrections before consistent results are achieved. It is likely that some further conclusions could be reached on this problem by reciprocal relationships with the infinitesimal dipole problem.

(2) Infinitely Conducting Sphere Embedded in Ferrite Sphere. An extension of the previous problem was made to include an infinitely conducting sphere internal to and concentric with the ferrite sphere. Computer results showed that the frequencies of resonance were shifted slightly.

(3) Lossy Inner Sphere Embedded in Lossless Ferrite Outer Sphere. A further extension of the problem was made to include a lossy sphere internal to and concentric with the lossless ferrite sphere. This arrangement permitted a formal integration of the total losses, which was evaluated on the computer and shown to be very much greater than the power incident upon the same cross-section area in free space by factors greater than 500. A small amount of additional computer work would permit a complete plot of the power flow in and around the lossless ferrite sphere.

(4) Diffraction of a Plane Wave by an Infinitely-Long Ferrite Cylinder. A resonant power-gathering effect was observed similar to that noted in the problem of the ferrite sphere. The total power

passing through a unit length of the cylinder at resonance was found to be greater than the amount of power passing through the same area in free space by factors greater than 15. More computer work would permit a complete plot of the power flow in and around the cylinder at resonance. In addition, it would be desirable to get some idea of the wave impedance at different points in and around the cylinder.

(5) Diffraction of a Plane Wave by an Infinitely-Long Magnetized Cylinder. This problem has been solved formally. The total power passing through the cylinder has been expressed as a function of the magnetizing field, the permeability, the permittivity, and the radius of the cylinder. A computer program is being prepared to evaluate the total power.

(6) Diffraction of a Plane Wave by a Ferrite Prolate Spheriod. Some initial work has been done on this problem, and a method of solution has been outlined. Work on this problem has been suspended due to priority of other work.

The next step in these diffraction problems is to finish off the formal diffraction calculations as soon as possible and to start working toward a realization of these greatly increased apertures. This would involve (1) a study of collecting structures utilizing ferrite spheres or cylinders, and (2) a study of structures utilizing other forms of ferrite which might be expected to exhibit the same resonant power-gathering effect. It is possible, for instance, that Polk's biconical ferrite antenna might exhibit the same phenomenon.

II. Efficiency

The following types of mathematical models, discussed under

(I) Size, will yield information on efficiency:

- (a) rectangular-cavity slot antenna
- (b) biconical ferrite antenna

III. Directivity

The following types of mathematical models will yield information on directivity:

- (a) rectangular-waveguide radiator
- (b) sectoral horn
- (c) rectangular-cavity slot antenna
- (d) biconical ferrite antenna
- (e) ferrite, prolate-spheroidal, constant-current-line-source antenna. Work on the problem will probably be limited to a preliminary analysis.

IV. Aperture

The following studies could yield information on aperture:

- (a) follow-up work on diffraction studies upon cylinder and sphere
- (b) diffraction of a plane wave by:
  - (1) rectangular-cavity slot antenna
  - (2) ferrite biconical antenna

These possibilities, under (b), have not yet been investigated.

V. Bandwidth and VI. Impedance

The following studies will yield information on bandwidth and impedance.

- (a) rectangular-cavity slot antenna
- (b) ferrite biconical antenna

The experimental work to be carried out on the models shown in this Quarterly Report will in general yield information primarily on size reduction characteristics and directivity. With improved ferrite material, reliable information will be obtained on bandwidth and impedance. In addition, it is expected that, with good ferrite material, efficiency and aperture will be measured on a few selected models.

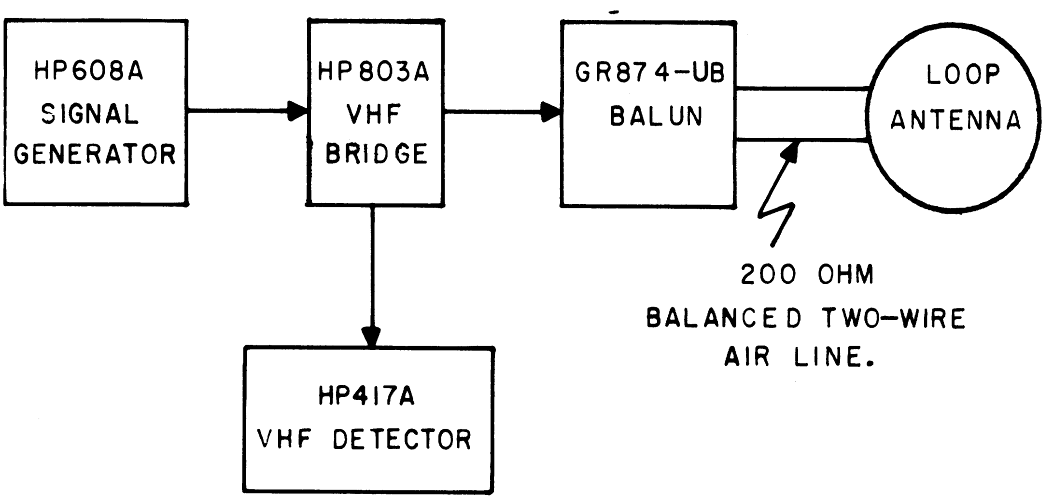
In the above discussion, two of the mathematical models stand out as being capable of yielding information on all of the pertinent characteristics. They are: (1) the rectangular cavity-slot antenna, and (2) the ferrite biconical antenna. The emphasis in these two models differs somewhat. One would expect, for instance, that the biconical would yield more striking effects in efficiency. The solution of the rectangular-cavity slot antenna is under way and it is expected that some work will be done on the biconical in the near future. The complete solution of these two basic problems would provide answers to many of the basic questions posed by the project.

2.2 Experimental Results

2.2.1 Measurements on Loop Antennas.

Initially a simple loop antenna was constructed and its impedance properties measured with and without a spherical ferrite core. Details of construction and measurement data were reported in QPR No. 4 (pp. 27-32). The impedance measurement circuit is shown in Fig. 3. The ferrite core arrangement is shown in Fig. 4. The impedance results are shown in Fig. 5.

An improved shielded, balanced loop was then designed. The details of design are outlined in QPR No. 5 (pp. 18-25). Figure 6 is a close-up view of the loop and its balanced, shielded, two-wire, 200-ohm transmission line. Figure 7 shows the loop, transmission line, and



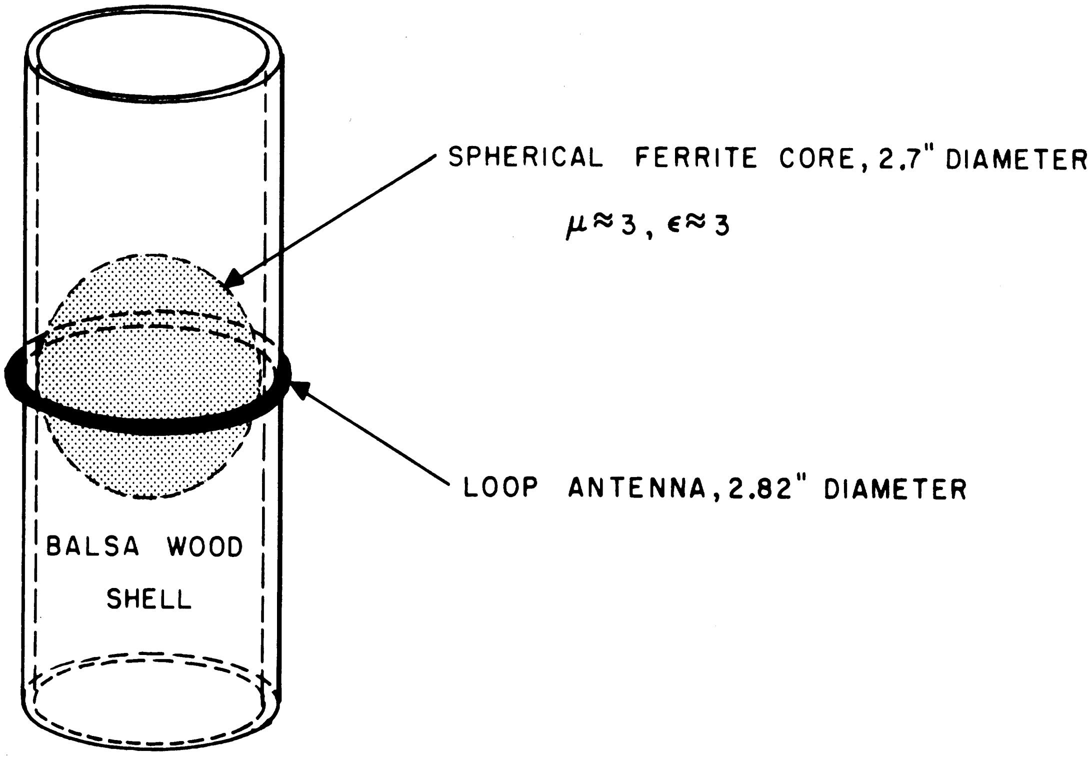


Fig. 4. Ferrite-core loop antenna.

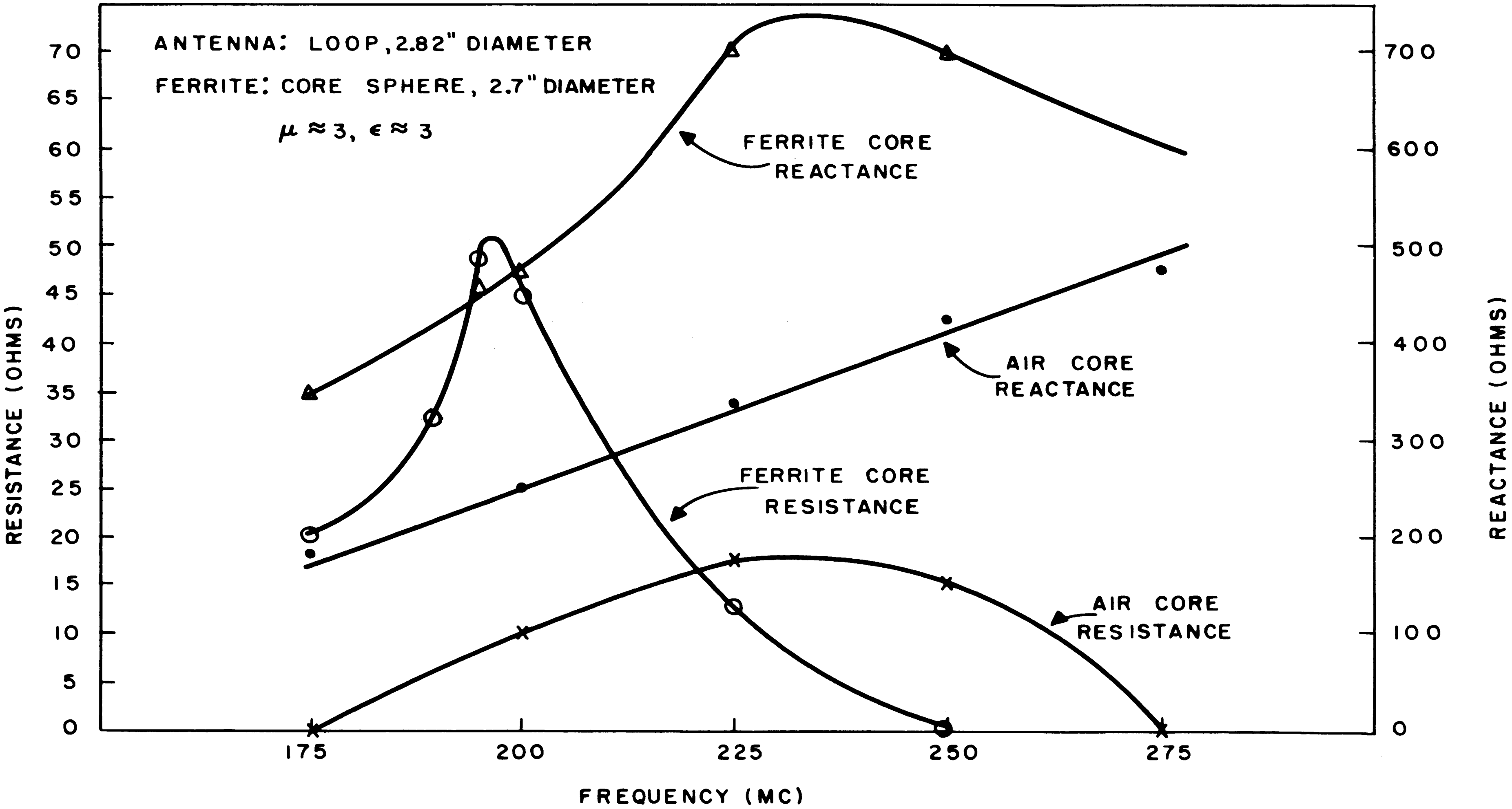


Fig. 5. Impedance at loop antenna.

General Radio Balun. Measurements were made of the impedance properties of this antenna in air as well as immersed in a cylindrical ferrite medium (Fig. 8).

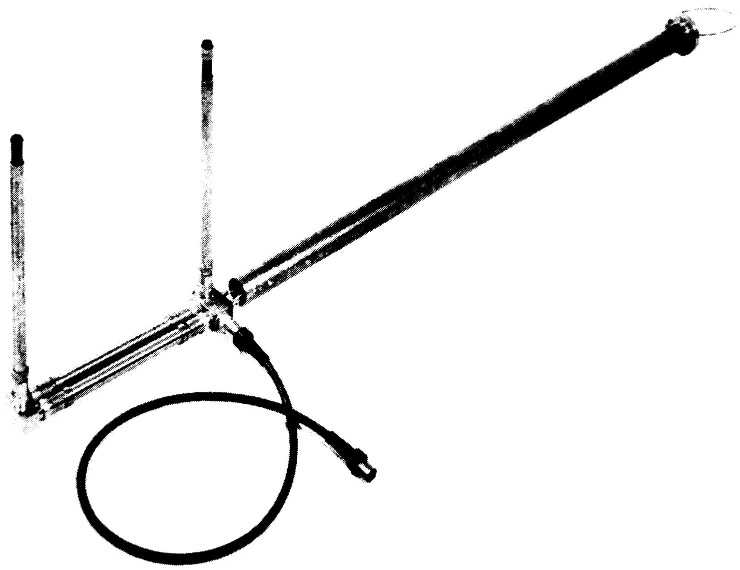
Results of the measurements are shown in Fig. 9. The results show that in the air case resonance (zero reactance) occurs at 350 Mc. A calculation of the resonant frequency in an infinite ferrite medium was made, solving the transcendental equation by the method outlined in QPR No. 5. The result indicated that in an infinite ferrite medium resonant frequency would be reduced to 250 Mc. The data of Fig. 9 show that when the loop was immersed in a cylindrical ferrite medium, resonance occurred at about 275 Mc, so the effect of the finite ferrite cylinder is apparently almost as great as that which would occur with an infinite ferrite medium.

It is noted in Figs. 5 and 9, that the resistive part of the impedance is increased by the ferrite loading. Without a measurement of radiation resistance it is impossible to determine whether or not this increase in radiation resistance gives rise to an increase in efficiency. Further tests will be made in the future with a better ferrite material, and, if justified by the results, a measurement of radiation resistance will be made.

2.2.2 Measurement Apparatus. Figure 10 is a photograph of the coaxial-cavity apparatus for measuring the complex permittivity and permeability of ferrite disk samples. The theory developed for the measurement has been presented in QPR No. 2 (pp. 28-31) and QPR No. 3. The results of measurements and comparison of data with other measurement methods were presented in QPR No. 5 (p. 35). The work on this measurement apparatus is now complete. The cavity will be used from

Fig. 6. Shielded, balanced loop antenna.

Fig. 7. Loop antenna with General Radio Balun.



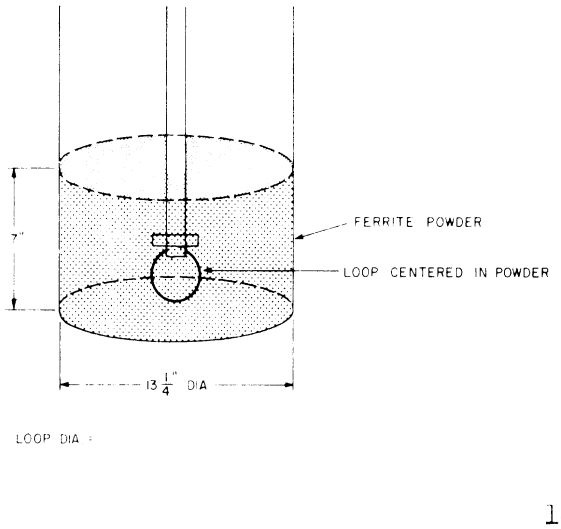


Fig. 8. Ferrite loading for shielded, balanced-loop antenna.

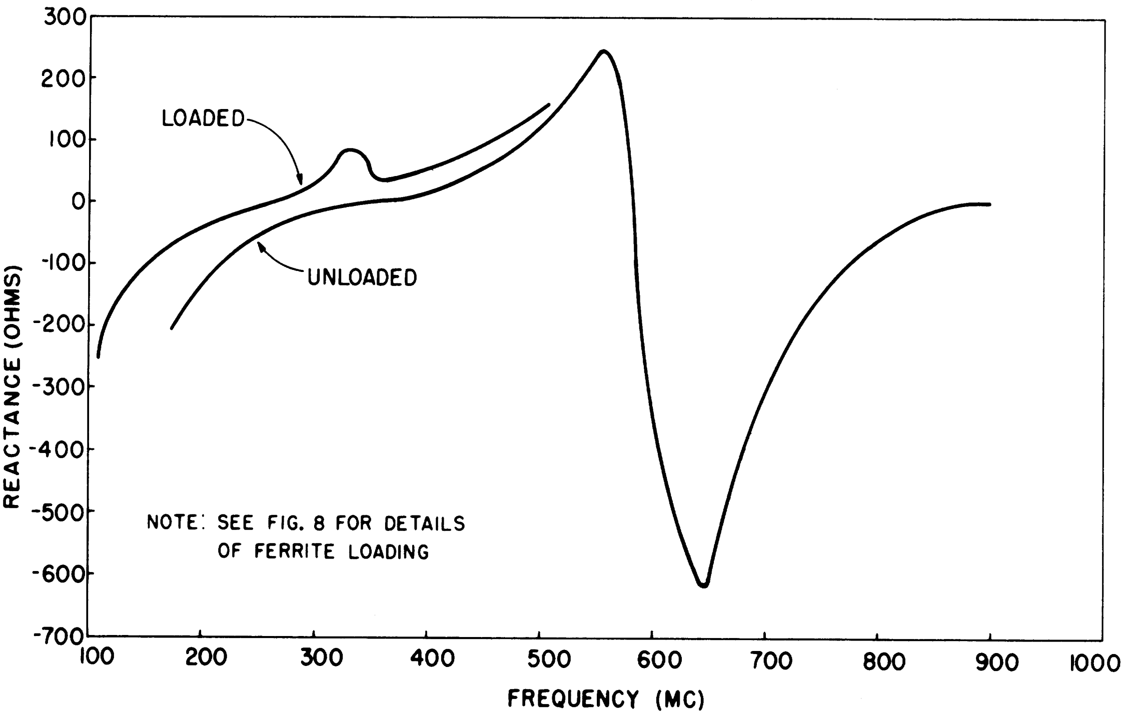


Fig. 9(a). Reactance of a shielded, balanced-loop antenna, loaded and unloaded.

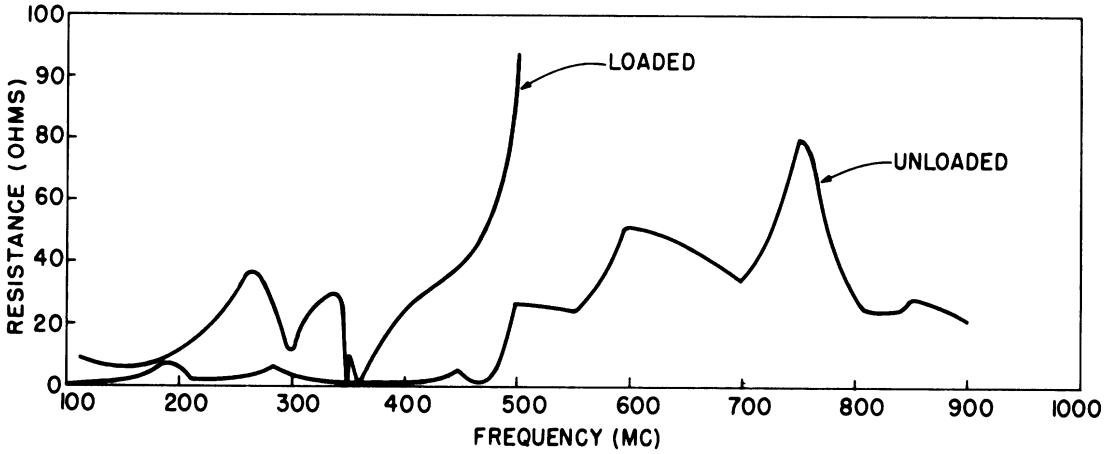


Fig. 9(b). Resistance of a shielded, balanced-loop antenna, loaded and unloaded.

time to time to evaluate ferrite samples received.

2.2.3 Rectangular-Cavity Slot Antenna. A rectangular-cavity slot antenna was constructed. A ball probe feed was used. The probe size, probe position, and short position were varied for optimum impedance and bandwidth characteristics. This rectangular cavity-slot antenna is shown in Figs. 11 and 12. A balsa-wood cap is used to hold the ferrite in place.

The VSWR was measured with and without the ferrite loading. The probe and short configuration were varied in both cases. The optimum arrangements of probe and short positions were identical for the loaded and unloaded cases. The data for the loaded and unloaded cases are shown in Fig. 13. A comparison of the bandwidth in the loaded and unloaded cases can be made from the data of Fig. 13. In the unloaded case, the bandwidth as determined by a VSWR of 2.0 is $\frac{220}{770} = 28.6$ percent. In the loaded case, the bandwidth as determined by a VSWR of 2.0 is $\frac{150}{300} = 50$ percent. Using a VSWR of 1.5 to determine bandwidth, the bandwidths in the unloaded and loaded cases are, respectively, 15.7 percent and 13.6 percent.

Beam patterns taken for the loaded and unloaded cases show good agreement with the theoretical predictions of the theory developed in QPR No. 5 (pp. 26-34). Figures 14 and 15 show the results. Good agreement is obtained between experimental and theoretical H-plane patterns. The E-plane patterns were unsatisfactory because the height of the radiator above the ground plane changed during the rotation. Accordingly, changes are being made in the equipment to permit more reliable H-plane patterns.

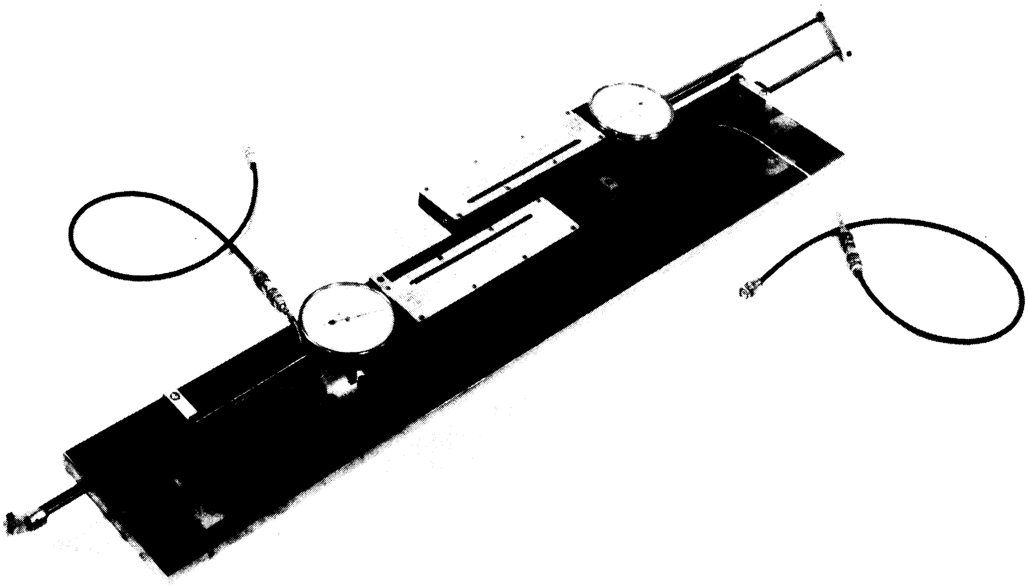


Fig. 10. Measurement apparatus.

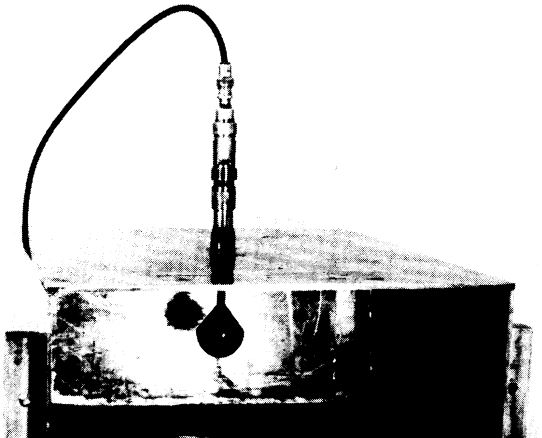


Fig. 11. Rectangular-cavity slot antenna without flange.

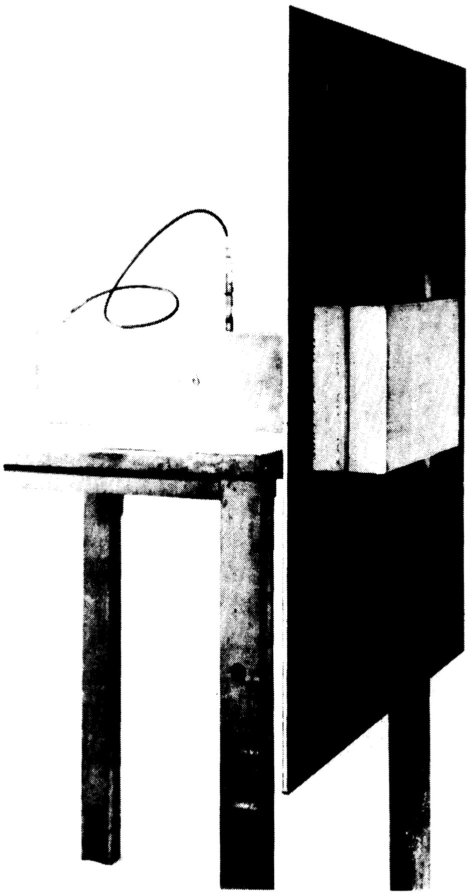


Fig. 12. Rectangular-cavity slot antenna with flange.

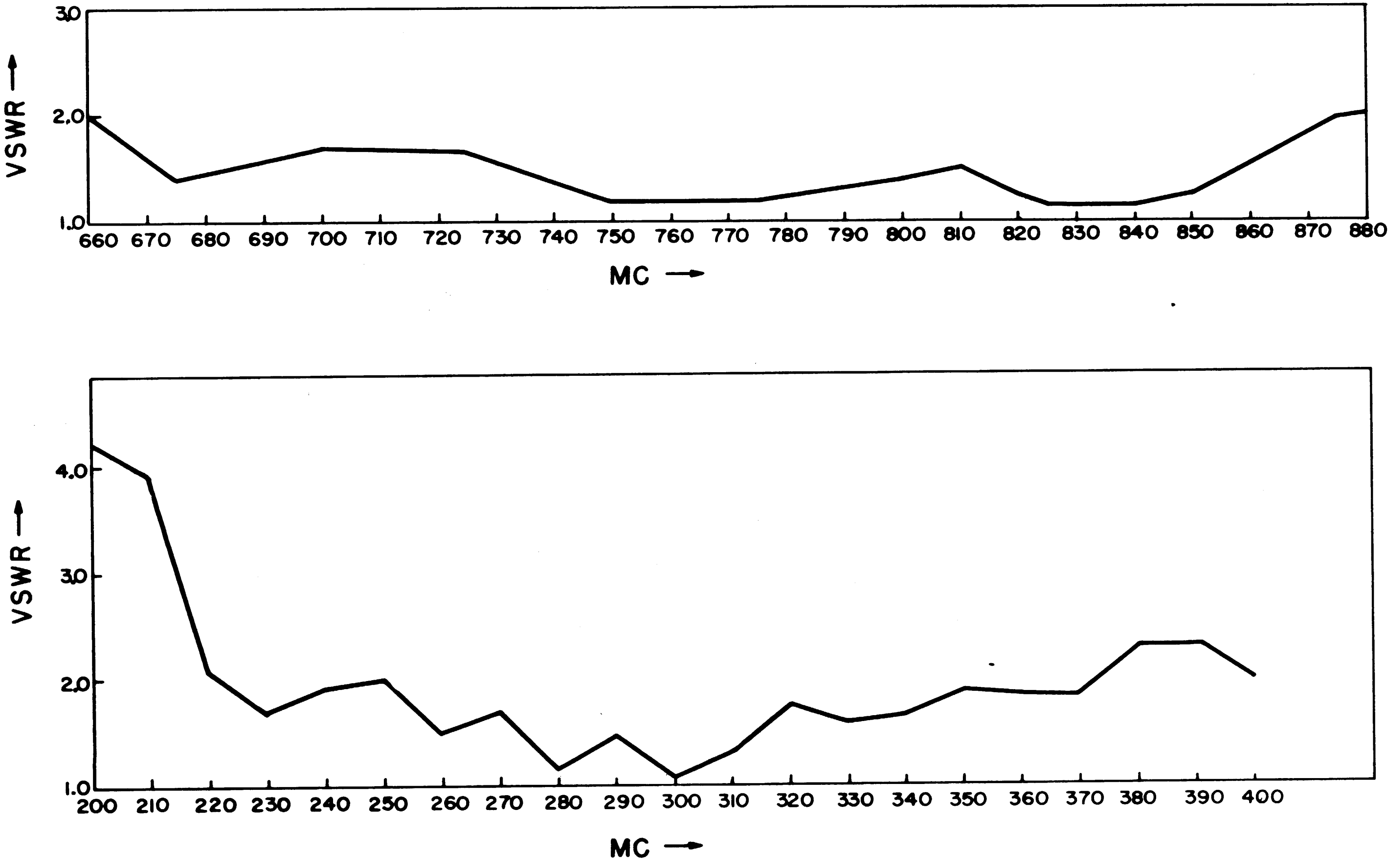


Fig. 13. VSWR of rectangular-cavity slot antenna;
(a) unloaded, (b) ferrite loaded.

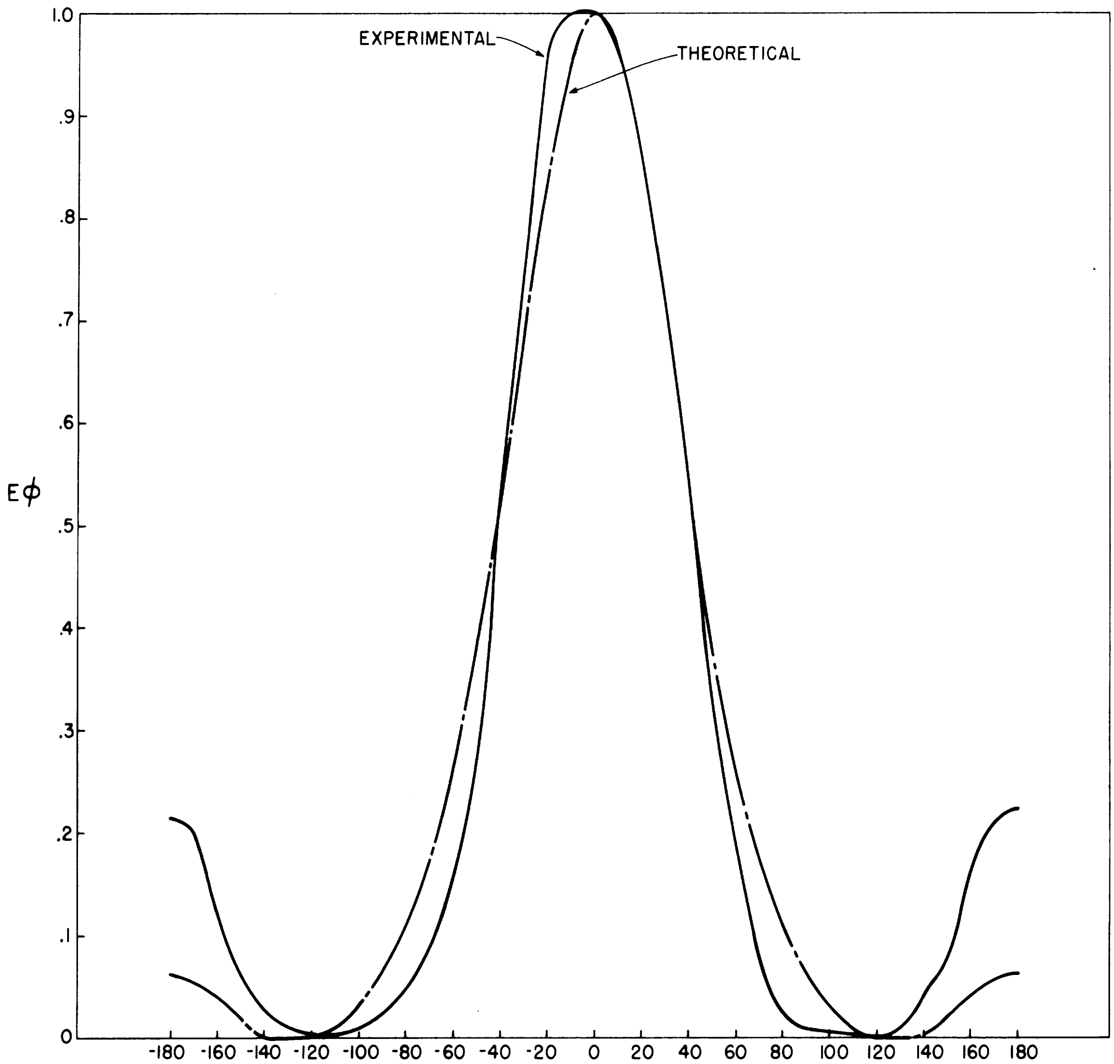


Fig. 14. Rectangular-cavity slot antenna H-plane patterns; unloaded; theoretical and experimental.

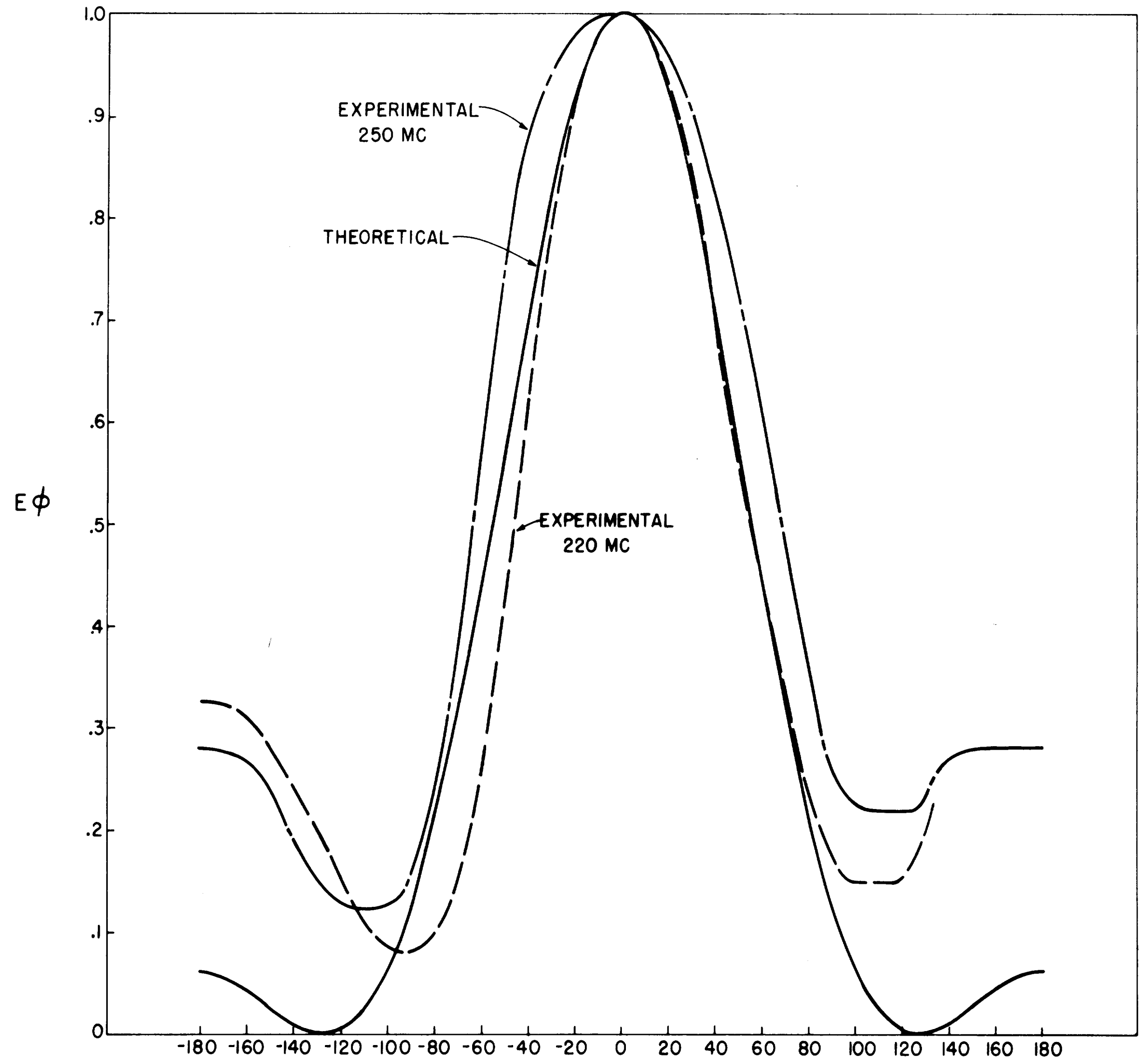


Fig. 15. Rectangular-cavity slot antenna H-plane patterns; ferrite loaded; theoretical and experimental; $\mu = \epsilon = 3$.

Note: The theoretical curve was plotted for a given value of λ/λ_c. Since cutoff depends on μ and ϵ, which can only be determined within 5 or 10 percent accuracy, λ_c is not known exactly. The two frequencies of 220 and 250 Mc represent upper and lower bounds on the correct frequency to correspond with the theoretical data.

2.2.4 Ridged-Cavity Slot Antenna. A ridged-cavity slot antenna was constructed and tested with and without ferrite loading. This antenna is shown in Figs. 16 and 17. A balsa-wood cap is placed over the slot. The slot measures 2-1/8 x 4-1/4 inches. Experimental measurements of impedance on this antenna have yielded favorable results. The measurements in air (Fig. 18) indicate a very-well-matched broadband device. The measurements with ferrite powder (Fig. 19) are very encouraging. Because of the losses in the powder it is difficult to estimate the bandwidth which would result from the use of a lossless structure. Considerable work remains to be done on this antenna, including beam pattern measurements, further optimization of the feed structure using lossless powder, and, finally, use of ferrite in solid form to reduce the operating frequency to about 100 Mc.

2.2.5 Spiral Antenna. Preliminary measurements on a cavity-backed spiral antenna obtained from Wright AFB indicate that the lowest frequency of operation was reduced from 600 Mc to about 300 Mc. Impedance data are shown in Fig. 20.

2.2.6 Disk Antenna. A disk antenna which is omnidirectional in the horizontal plane has been constructed (Fig. 21). Preliminary impedance measurements in air show that the VSWR is under 2.0 between 1150 and 1350 Mc, a bandwidth of about 12 percent. Further work will be done on optimizing the feed structure and testing this antenna with ferrite loading.

2.2.7 Biconical Antenna. Impedance measurements on a ferrite-loaded biconical antenna (Fig. 22) show that the frequency of operation is reduced by a factor of about 2 to 1 with the addition of ferrite loading. Beam patterns have been taken, but evidently the beam

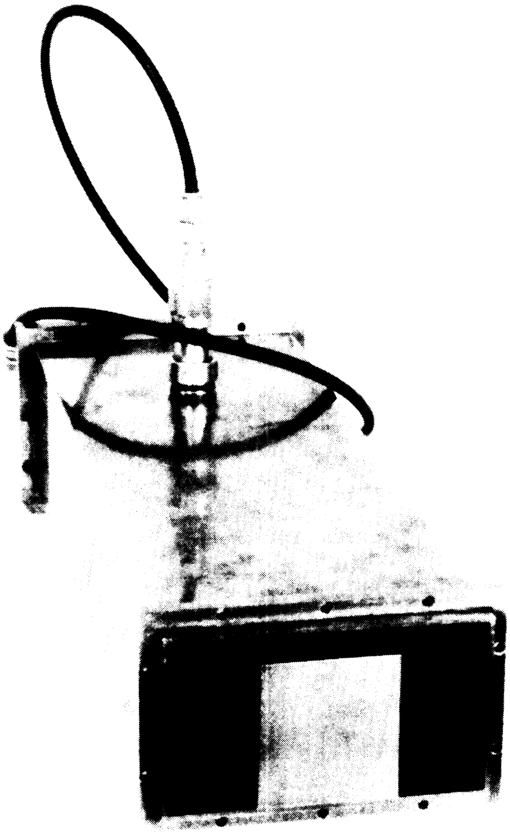
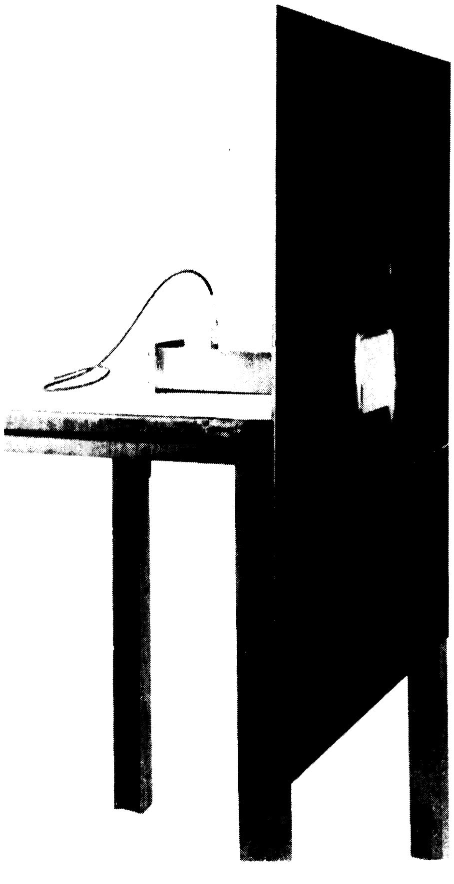


Fig. 16. Ridged-cavity slot antenna without flange.

Fig. 17. Ridged-cavity slot antenna with flange.



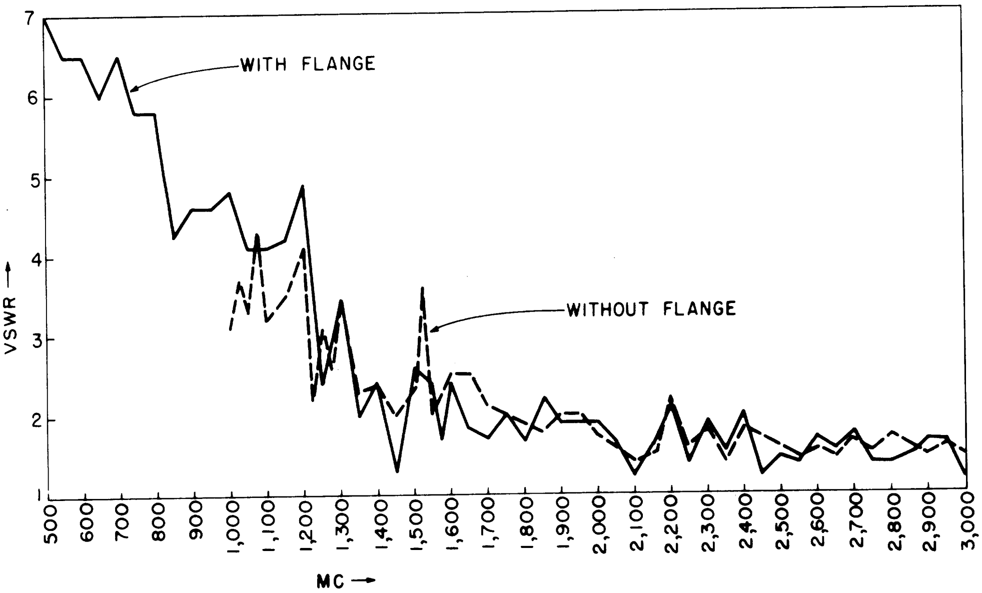


Fig. 18. VSWR of ridged-cavity slot antenna; unloaded.

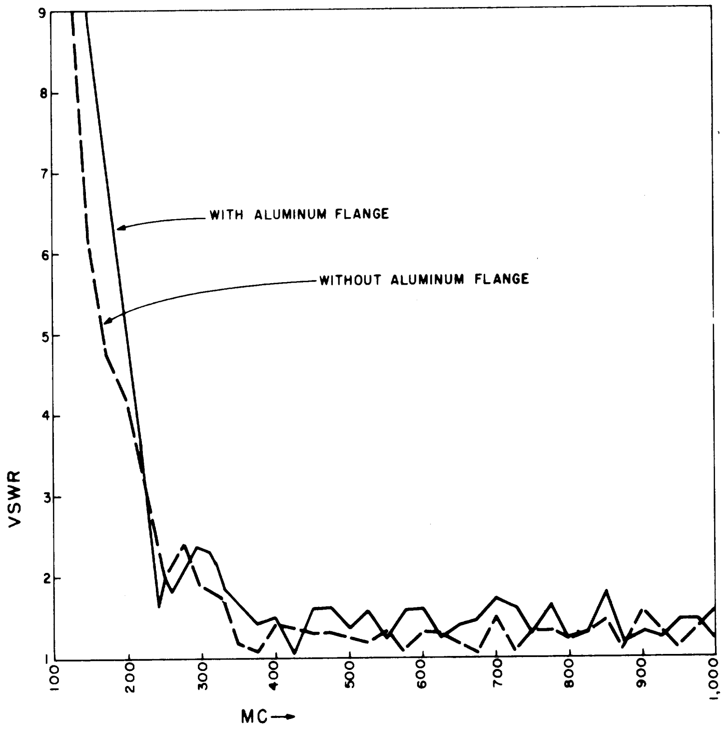
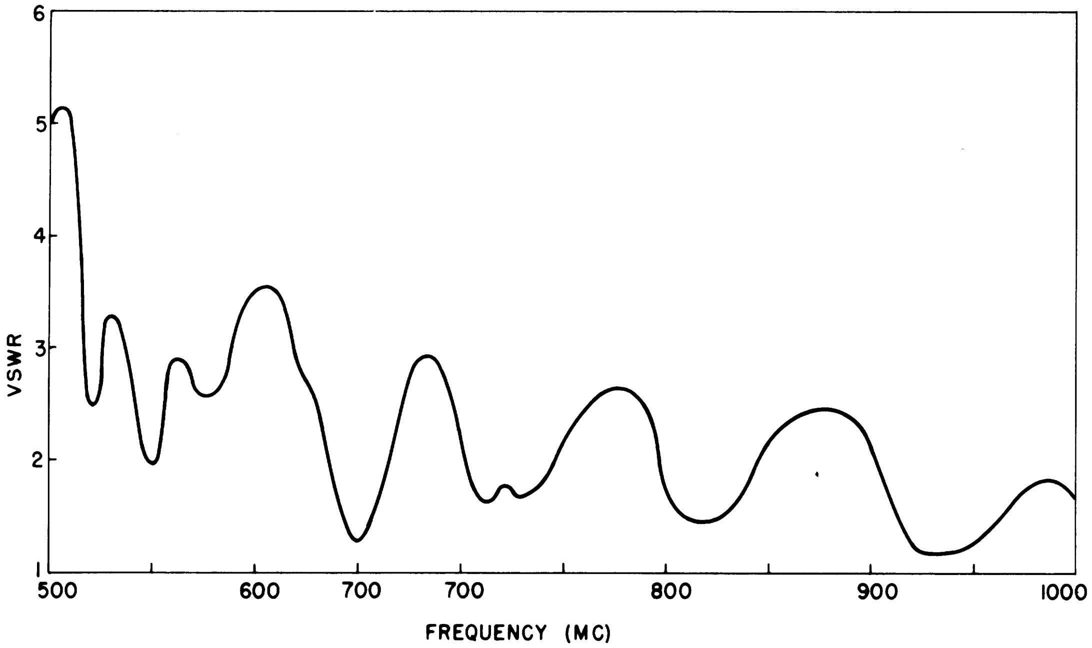
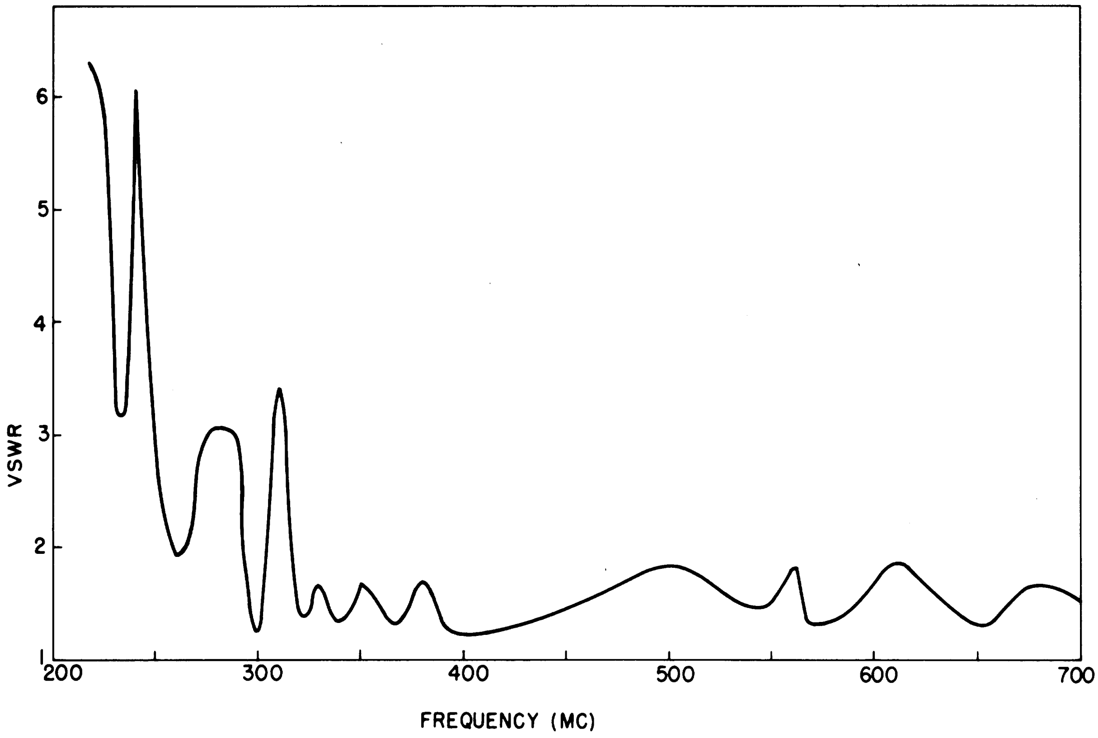


Fig. 19. VSWR of ridged-cavity slot antenna, loaded with ferrite powder.



(a) unloaded



(b) loaded with ferrite powder

Fig. 20. VSWR of cavity-backed spiral antenna.

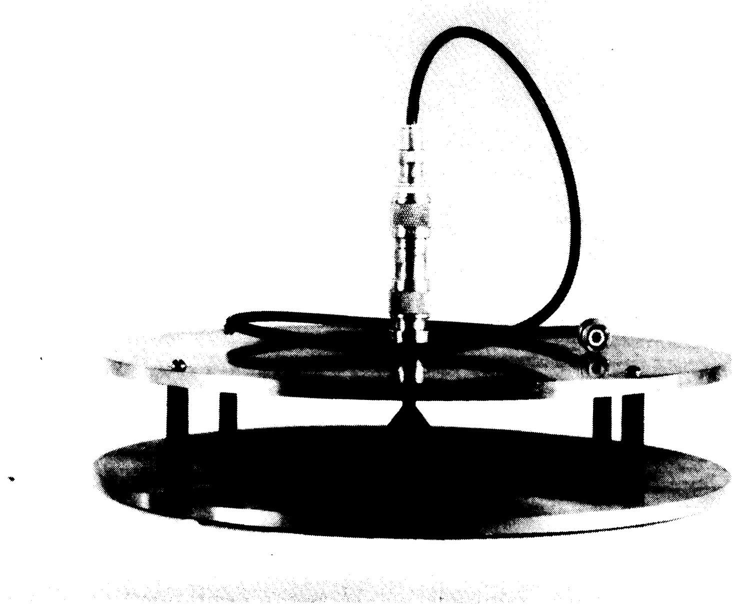


Fig. 21. Disk antenna.

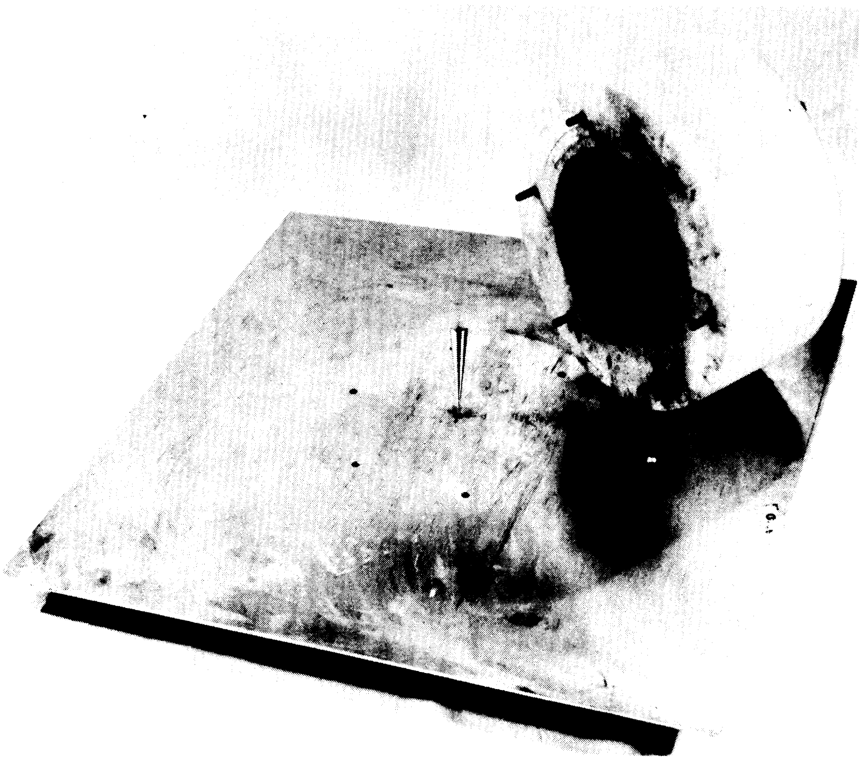


Fig. 22. Biconical antenna.

pattern is very much affected by the size of the ground plane in wavelengths, thus introducing an additional parameter change between the loaded and unloaded cases. There is some indication that the beam pattern is narrowed with the introduction of the ferrite powder. Further tests will be made with a larger ground plane.

2.2.8 Summary of Results. Tests have been made on six different types of ferrite-loaded antennas. Results to date generally indicate that ferrite loading allows reduction in size of an antenna by a factor of 2 or 3 without serious deterioration of other characteristics. Further tests will be required with lossless ferrite powder to fully justify this conclusion. After tests with a lossless powder are completed, several of the more promising models will, if time and funds permit, be loaded with solid ferrite material in order to increase the size reduction factor to somewhere around ten. Likely candidates at present for the final models are the spiral and the ridged cavity-slot antenna.

3. ACTIVITIES FOR THE NEXT PERIOD

During the next period primary emphasis will continue to be placed on experimental work, including further tests on the models discussed in the report in both loaded and unloaded conditions and further optimization of designs with the eventual goal of producing final models. Inquiries are being made into the purchase of better ferrite material, and an order will be placed in the near future.

Theoretical work for the next period will consist primarily of further work on the rectangular-cavity-backed slot antenna (including carrying out the approximation technique to evaluate the aperture fields), the ferrite biconical antenna, and the problem of diffraction of plane waves by a ferrite sphere.

4. SUMMARY

The theoretical and experimental work accomplished to date has been reviewed, and specific plans for the remainder of the contract are outlined. In the review of theoretical work, a list of antenna characteristics is given, and it is shown that most of the theoretical work has been directed toward showing the effect of ferrite loading on five of these antenna characteristics. Each of the theoretical studies is discussed in relation to these characteristics, and the information expected from these studies is outlined. It is noted that two basic problems have the potentiality of yielding definite results on almost all of the characteristics noted. One of these problems, the rectangular-cavity-backed slot antenna, is already under way. It is expected that some work will also be done on the other problem, which is the ferrite-loaded biconical antenna.

The results of experimental work on six different antenna models are shown. Results generally indicate that the size of antennas of the types tested can be reduced by a factor of 2 or 3 with ferrite loading without seriously impairing other characteristics. More complete tests with a lossless ferrite are necessary to completely justify this conclusion, since the losses in our present powder tend to mask many of the effects. Plans for future tests include further optimization and testing of models with a lossless powder, and use of solid ferrite in a few selected models.

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