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STUDY AND INVESTIGATION OF A UHF-VHF ANTENNA

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ABSTRACT

The experimental ferrite loading of log conical antennas in a recessed cavity, and a free-standing log conical and helical antenna, reduced the size of the loaded antenna by at least one-half. The corresponding efficiencies of the ferrite-loaded antennas were approximately 25 percent of the unloaded antenna efficiencies. Temperature measurements of permeability show greatly increased losses above 200°C. A preliminary study of a helix with ferrite loading is described.

1. REPORTS, TRAVELS AND VISITORS

This project was visited on 15 and 16 July 1964 by Mr. E. M. Turner, Technical Manager, Antenna and Radome Group, and Mr. O. E. Horton, Project Engineer and Contract Monitor, Antenna and Radome Group, and both from the Electromagnetic Environment Branch of the Air Force Avionics Laboratory, WPAFB, Ohio. Various future objectives for this project were discussed.

2. PERIOD ACTIVITIES

2.1 Ferrite-Loaded Log Conical Spiral

In continuing the studies of the log conical spiral antenna, a new spiral antenna was made together with a new cavity. The metal cavity differs from the one previously used in that it is a machined cavity. These improvements have been made to remove some of the inconsistencies in previously recorded experimental data. In Fig. 1 is shown the log conical spiral antenna together with the empty cavity. This combination of log conical spiral antenna together with cavity and cover plate was used for radiation pattern, VSWR, and efficiency tests. Figure 2 shows the VSWR curves for this antenna with and without loading. The inset in Fig. 2 indicates the arrangement of the antenna in the cavity with and without ferrite. Figure 3 shows a number of radiation patterns taken on this log conical spiral antenna as mounted in the machined metal cavity; both ferrite-loaded and unloaded cases are shown. It should be remarked that the studies indicate that the use of ferrite has lowered the low frequency limit of this antenna. Furthermore, this lowering has taken place while keeping the antenna operating in the usual axial beam mode. It is well known that antennas of this type degenerate at the low frequency end of the range as the operation passes from an axial beam to a split beam mode. Measurements on this antenna utilizing ferrite and the metal cavity indicate an efficiency of 13 percent at 400 Mc. It is apparent that the cavity imposes a severe restriction upon the operation of the log conical antenna. The cavity was designed entirely for convenience in mounting and no design computations or provisions were made for the effects of the cavity upon the radiation pattern. Certainly a more practical construction would involve a greater diameter cavity.

Figure 4 shows two log conical spiral antennas. The smaller antenna on the right was used with powdered ferrite filling the entire conical structure inside the active metal conductors. The powdered ferrite material was retained by a thin sheet of polyethylene plastic over the conductors of the smaller log conical spiral and completely filled all space inside the spiralled conducting elements. Actually, the ferrite extended just outside the conducting elements, since the supporting wood structure extends approximately 1/8" beyond the metal conductors. The VSWR of the two antennas shown in Fig. 4 is shown in Fig. 5. The inset in Fig. 5 shows two antennas, one air-loaded and one ferrite-powder loaded. These two antennas are pictured as the same size; however, their actual relative sizes are shown in

Fig. 4. Figure 6 shows the radiation patterns of these antennas with and without ferrite-loading at various frequencies from 300 Mc through 1000 Mc.

The efficiency of the larger log conical antenna without ferrite as shown on the left of Fig. 4 was compared with that of the small ferrite-filled log conical antenna on the right of Fig. 4. The small ferrite-filled log conical antenna has an efficiency of 23 percent whereas the large log conical antenna which is unloaded has an efficiency of 92 percent. The efficiency values were measured at 400 Mc. The observed decrease in efficiency corresponds to a decrease in lineal dimensions by a factor of approximately 2 and by a decrease in the volume dimensions by a factor of approximately 7. This means that a much smaller antenna of the log conical type utilizing ferrite can be made although there is a decrease of approximately 6db in efficiency. The radiation patterns indicate that except for efficiency the operating performance of the smaller ferrite-filled log conical antenna is at least as good as that of the corresponding air-filled log conical antenna.

2.2. Ferrite-Loaded Helix

A ferrite-loaded helix (see Fig. 7) was constructed in order to test the size reduction obtainable with such a structure. The helix was wound of No. 14 copper wire on a balsa wood cylinder of 4" diameter and 20" length. For a 6-turn helix wound on this core, the pitch angle ψ, defined by $\tan \psi = \frac{\pi \text{ (diameter)}}{\text{(turn-to-turn spacing)}}$ is 14°. As shown in Fig. 7, this structure is loaded around the perimeter of the cylinder, just inside of the helical winding, with 1" x 1/2" ferrite bars. The ferrite bars extend over the total length of the antenna; they are spaced 90^{o} apart around the perimeter of the cylinder. The reason for choosing a moderate pitch angle of 14^{o} was that most of the measurements by other workers had been concentrated in this region, and therefore data were available for comparison. The helix is fed by the center conductor of a type N connector, which is mounted on the axis of the cylinder. Figure 8 shows the measured voltage standing wave ratio for both the unloaded (balsa wood core) and the loaded (ferrite bars embedded in the surface of the balsa wood core) case. The values of VSWR are quite reasonable for both cases, especially when one considers that no attempt was made to obtain a better match between the 50 ohm coaxial feeding line and the helical antenna, by any kind of an impedance transforming network. Generally, VSWR's of about 2.5 are obtained in the useful radiation regions. For the unloaded antenna, the VSWR reaches very high values at 600 Mc and below, whereas for the ferrite-loaded structure this cutoff is reduced to 450 Mc. These high VSWR's establish the absolute lowest possible operating frequency for the helix antenna, since they indicate that at the lower frequencies a very large amount of the input energy is reflected to the generator and therefore is not radiated.

In Fig. 9 radiation patterns are presented for the ferrite-loaded helix from 300 Mc to 1000 Mc. The patterns were taken with the helix being mounted on a

4' x 4' aluminum ground plane. The patterns are quite unidirectional for both E_θ and E_ϕ, with little back radiation except at the low end (300 Mc) where the wave is not properly launched yet and at the high end (800 - 1000 Mc) where the phase velocity along the helix is below that required for a single beam unidirectional pattern.

The beamwidth of the ferrite bar loaded antenna is about 80^o at 400 and 500 Mc, 70^o at 600 Mc and 45^o at 700 Mc; these values compare well with the electrical length vs. beamwidth relationship expected. For this long a helical antenna (.89λ at 500 Mc, 1.07λ at 600 Mc and 1.24λ at 700 Mc) Kraus arrives at beamwidths of approximately 70^o, 60^o, and 50^o, respectively. The unloaded antenna should operate with a well-formed beam for:

$$.77 < C_\lambda < 1.3 ,$$

where C_λ is the helix circumference measured in free space wavelengths. For this 10.1 cm diameter helix, the operating range should be between 727 Mc and 1230 Mc without loading. The ratio of the upper to lower frequency is 1.69, and this is the same ratio as obtained for the ferrite-loaded helix, where $f_{min} = 400$, $f_{max} = 700$ are the two limits. The reduction in the lowest usable frequency then is represented by a factor of 1.8. This is the ratio by which the diameter of the helix has been reduced. The ferrite used was measured to have a $\mu = 6.6$ and $\epsilon = 12.6$ at 300 Mc; at 600 Mc, the μ has most likely declined to about 3 - 4. Assuming $\mu = 4$, one gets $\sqrt{\mu\epsilon} = 7$. The reason for the size reduction not being equal to this ratio lies mainly in the lack of enough ferrite material to be used: only one-third of the perimeter is loaded, and only 16 percent of the total internal volume is loaded with ferrite bars. A size reduction of around 3.5, or one-half that of the theoretical limit indicated by the material parameters, seems quite feasible by using more ferrite inside the antenna.

From the k - β diagram shown in Fig. 10, drawn for a 14^{o} pitch helix, one can deduce over what frequency band the helix could be an effective radiator. The region AB is a linear region and so is BC; however, as pointed out in Ref. 1, the slope AB is suitable for realizing the Hansen-Woodyard radiation condition whereas BC is not. Therefore, the upper cut-off for ka = C_{λ} = perimeter of helix in wavelengths, is located around B, from which point the helix wave velocity V is not increasing sufficiently fast with frequency to maintain a directive beam. Therefore, above this point a breakup of the main lobe occurs.

2.3 Temperature Dependence of Magnetic Properties of Ferrite

The ferrite antenna characteristics as described in Section 2.1 above have been obtained at very low power levels and at room temperature. In anticipation of the use of ferrite antennas at high power levels and possibly high ambient temperatures, studies have been made on the magnetic properties of the ferrite at various temperatures and frequencies. The ferrite used is that previously described in other reports by the following formula:

$$Ni_{.9696}Zn_{.0404}Co_{.03}Fe_{1.84}Al_{.04}O_{4}\ .$$

Figure 11 shows the apparatus used for permeability measurements at elevated temperatures. This equipment provides the means of heating a sample to a specified temperature. The sample is in the form of a toroid which fills a small coaxial cavity. Measurements are taken on the two components of permeability; μ', the relative permeability, and μ'', the relative loss component of permeability, using the techniques of Ref. 2 and 3. Figure 12a through 12c show the variation of these two factors versus frequency for a number of selected temperatures that cover the temperature range from 27^oC through $300^o C$.

Figure 13 shows another type of presentation of the magnetic measurement information on materials at elevated temperatures. At any given temperature the magnetic Q can be obtained by taking the ordinate of the top curve which is the real component of relative permeability and dividing this by the ordinate from the bottom curve at the same temperature and the same frequency. The ordinate from the bottom curve is the imaginary component of relative permeability which corresponds to the loss factor of relative permeability. From these measurements of characteristics it is apparent that the temperature may impose a severe restriction on the use of ferrite antennas. For example, the heating problem of aerospace vehicles upon reentry will also pose a severe temperature problem on a ferrite antenna unless special provisions were made to shield the ferrite material from such high temperature sources. It is possible that ablative material could be used to protect antennas upon reentry vehicles. However, this is not a subject of investigation of this activity.

3. FUTURE RESEARCH EFFORT

3.1 Ferrite-Filled Rectangular Slots

It has been shown that magnetic bias can control the incremental permeability of the ferrite, and thus the resonant frequency of an antenna. Important work remains to be done upon the use of magnetic bias on the ferrite-filled rectangular slot. New arrangements of the magnetic field will be tried. The D-C magnetic field might also be achieved by a bias coil or by using the R-F feed as a D-C feed for polarizing purposes.

3.2 Log-Periodic Conical Antenna

Other loadings of this antenna, particularly with layers rather than complete cones of ferrite, will be measured. Also, magnetic bias will be tried with this type of antenna at an early date. Currently it appears that it would be possible by having an internal coil along the axis of the ferrite cone which is used inside of the cone formed by the active conductors. Such an interior coil would be used to provide a magnetic field. This magnetic field could be made fairly strong because no part of the magnetic field would be through air other than the air spaces which are between ferrite particles.

3.3 High-Power Tests

Currently, plans are being made to provide a power supply of at least 10 watts and perhaps as high as 1 kw for use with various types of antennas such as the log conical, the spiral equiangular and the ferrite-filled rectangular slot. All of these antennas will have ferrite loading, and an attempt will be made to raise the power transmitted high enough so that the limitations of electric field breakdown may be apparent. With a 10-watt source, it is not likely that the ferrite will be heated sufficiently to provide additional information upon operation at high temperatures. It is anticipated that the high temperatures will be provided by a high ambient temperature or by using heaters which have no function as radiators of R-F energy. The power supply of modest wattage is chosen in order to study the effects of voltage breakdown.

4. SUMMARY AND CONCLUSIONS

The low frequency limit of a log conical antenna backed by a ground plane or recessed in a cavity has been greatly lowered by ferrite loading. This means an actual increase in the bandwidth of these antennas. Another way of stating this result is that a ferrite-loaded log conical antenna may be one-half the size of the equivalent air antenna. The loading results in a drop of efficiency to 13 percent for the cavity antenna and 23 percent for the free-standing log conical antenna. The operating range of a ferrite-loaded helix was similarly lowered by a factor of two using only partial loading.

The temperature dependence of ferrite was found to be very critical. Operation hotter than 200°C may not be feasible.

5. REFERENCES

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2. George T. Rado, "Magnetic Spectra of Ferrites," Rev. of Mod. Phys., Vol. 25, No. 1, 1953, p. 81.

3. Benjamin Lax and Kenneth J. Button, Microwave Ferrites and Ferrimagnetics, McGraw-Hill, 1962, p. 442.

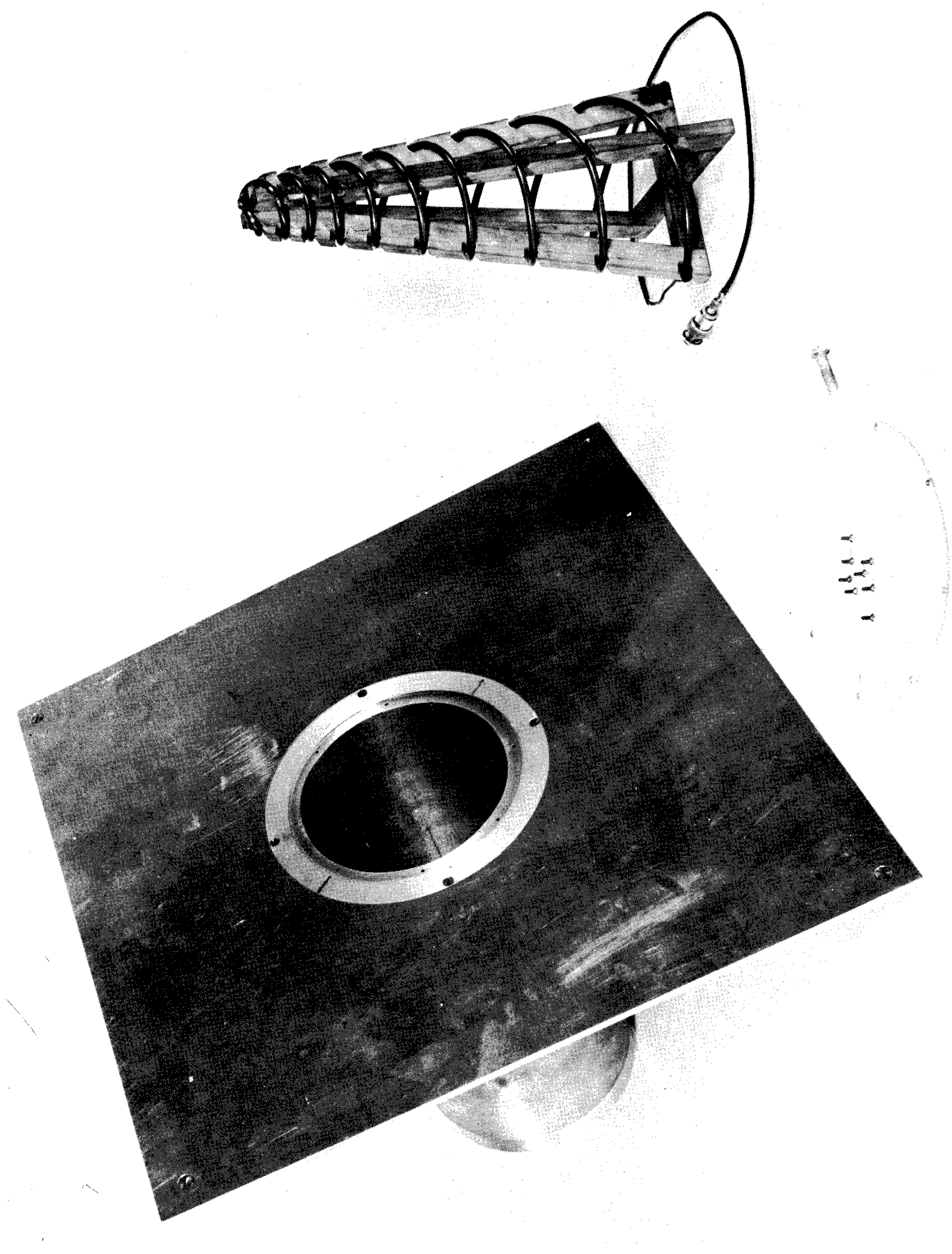

FIG. 1. Log Conical Spiral Antenna with Cavity.

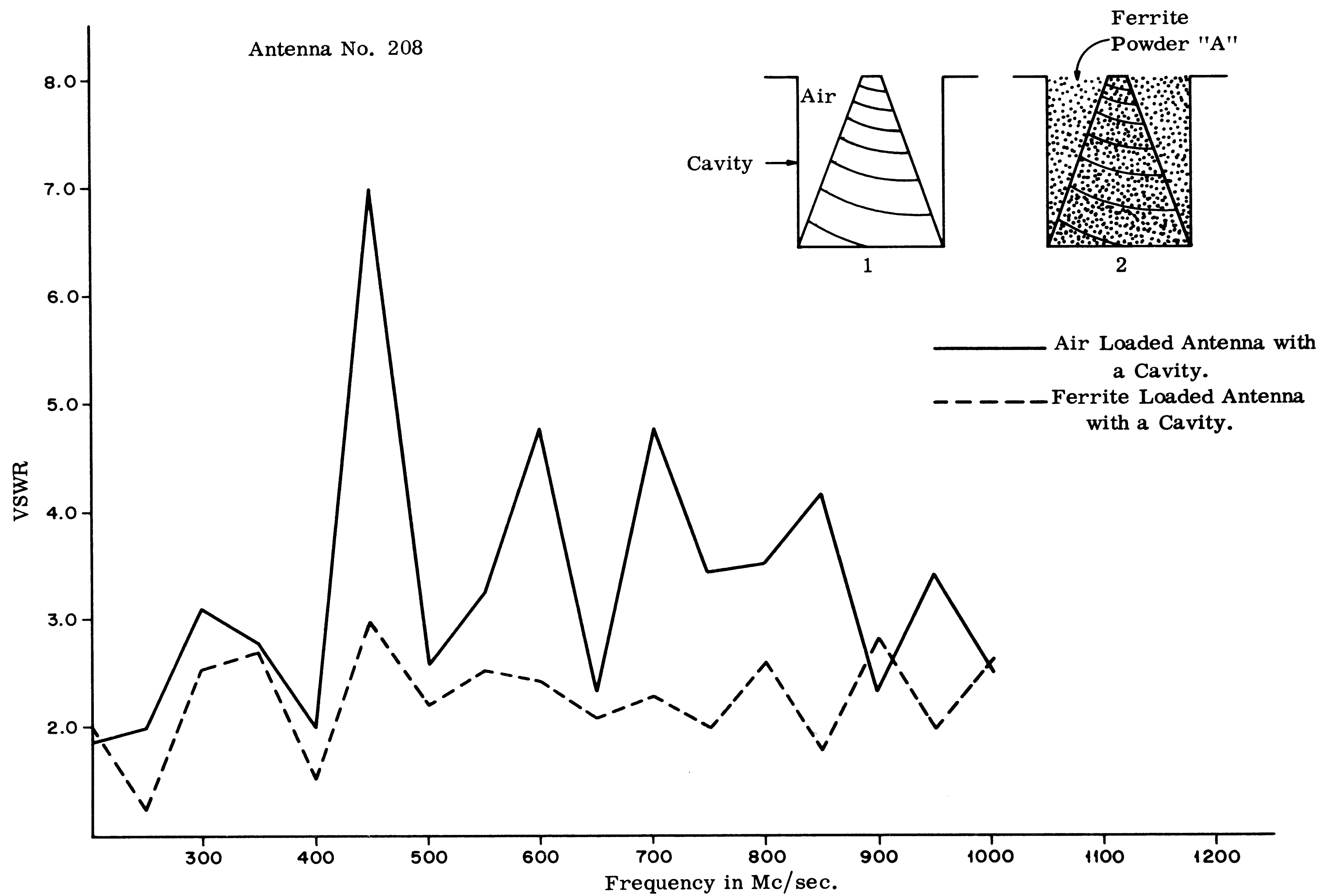

FIG. 2. VSWR vs. Frequency.

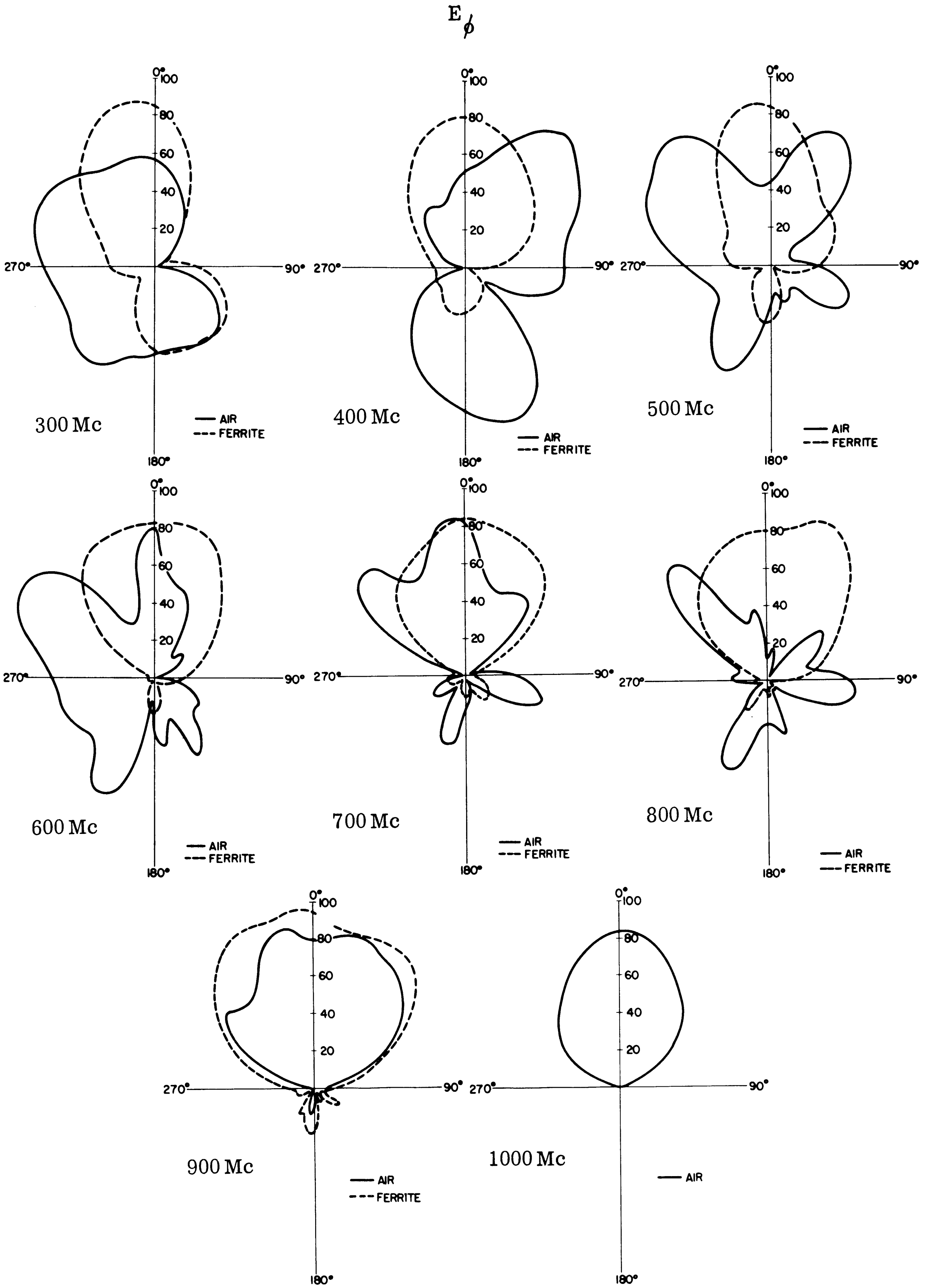

FIG. 3a. Radiation Patterns with Cavity, E_ϕ .

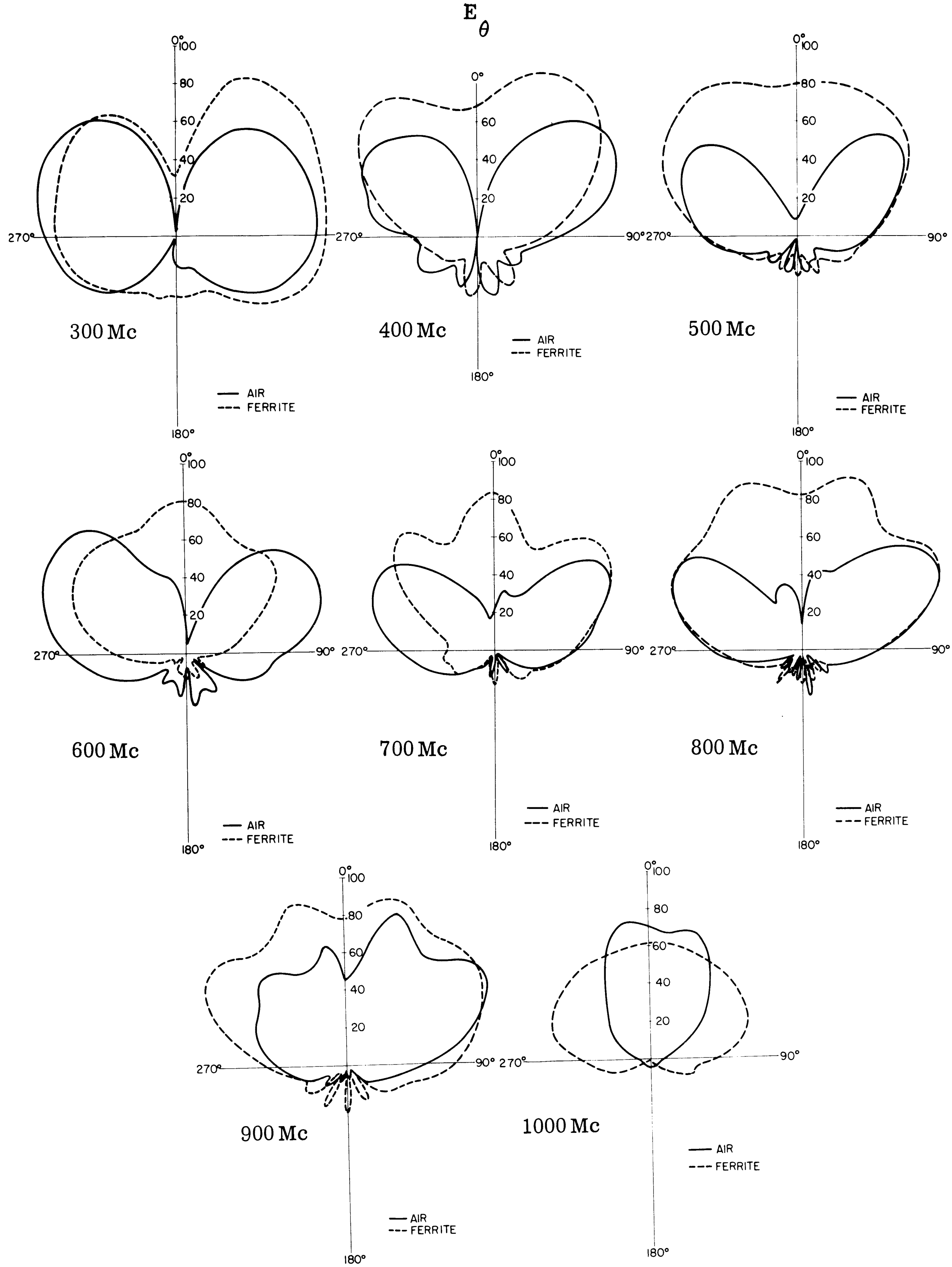

FIG. 3b. Radiation Patterns with Cavity, E_θ .

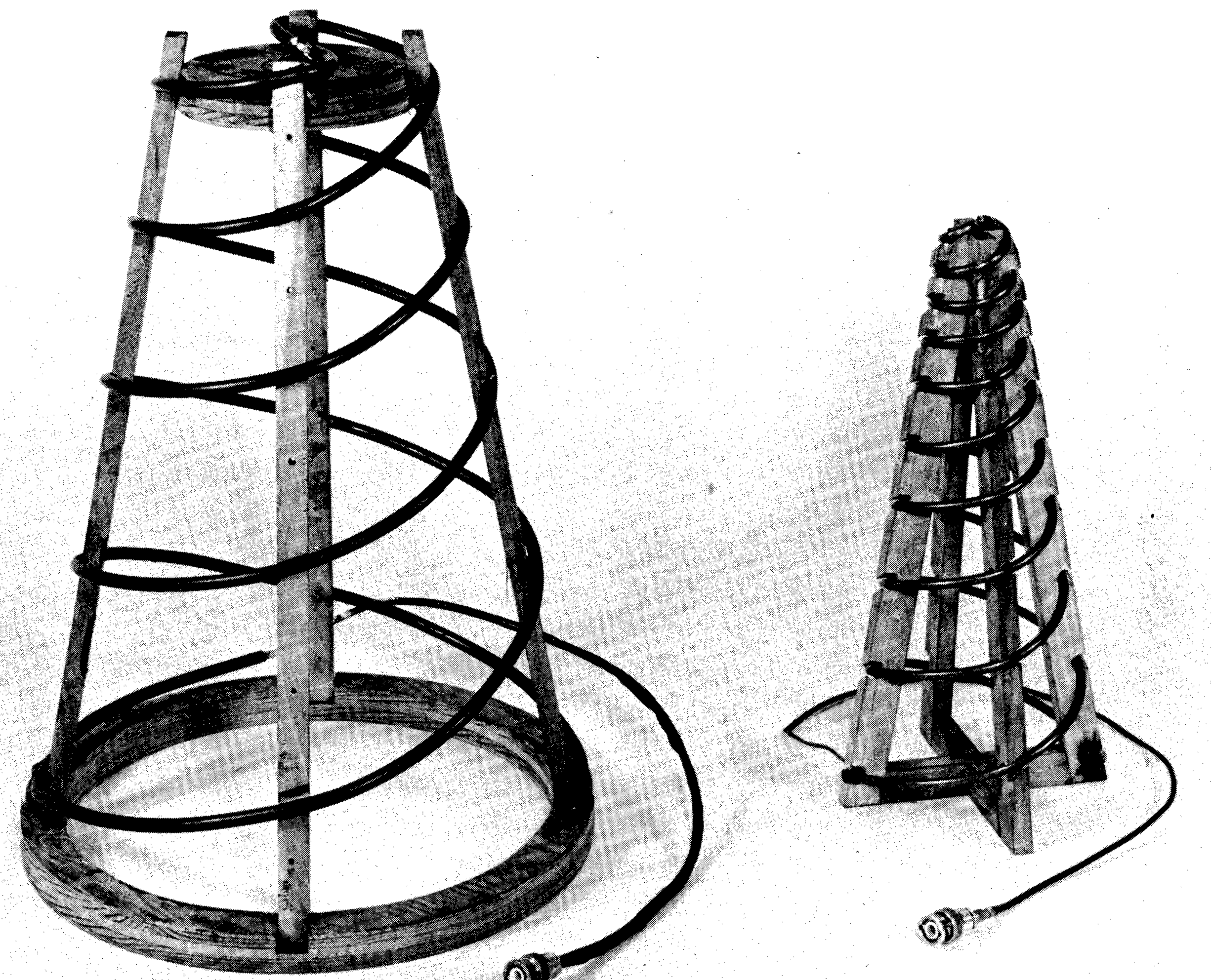

FIG. 4. Large and Small Log Conical Spiral Antennas.

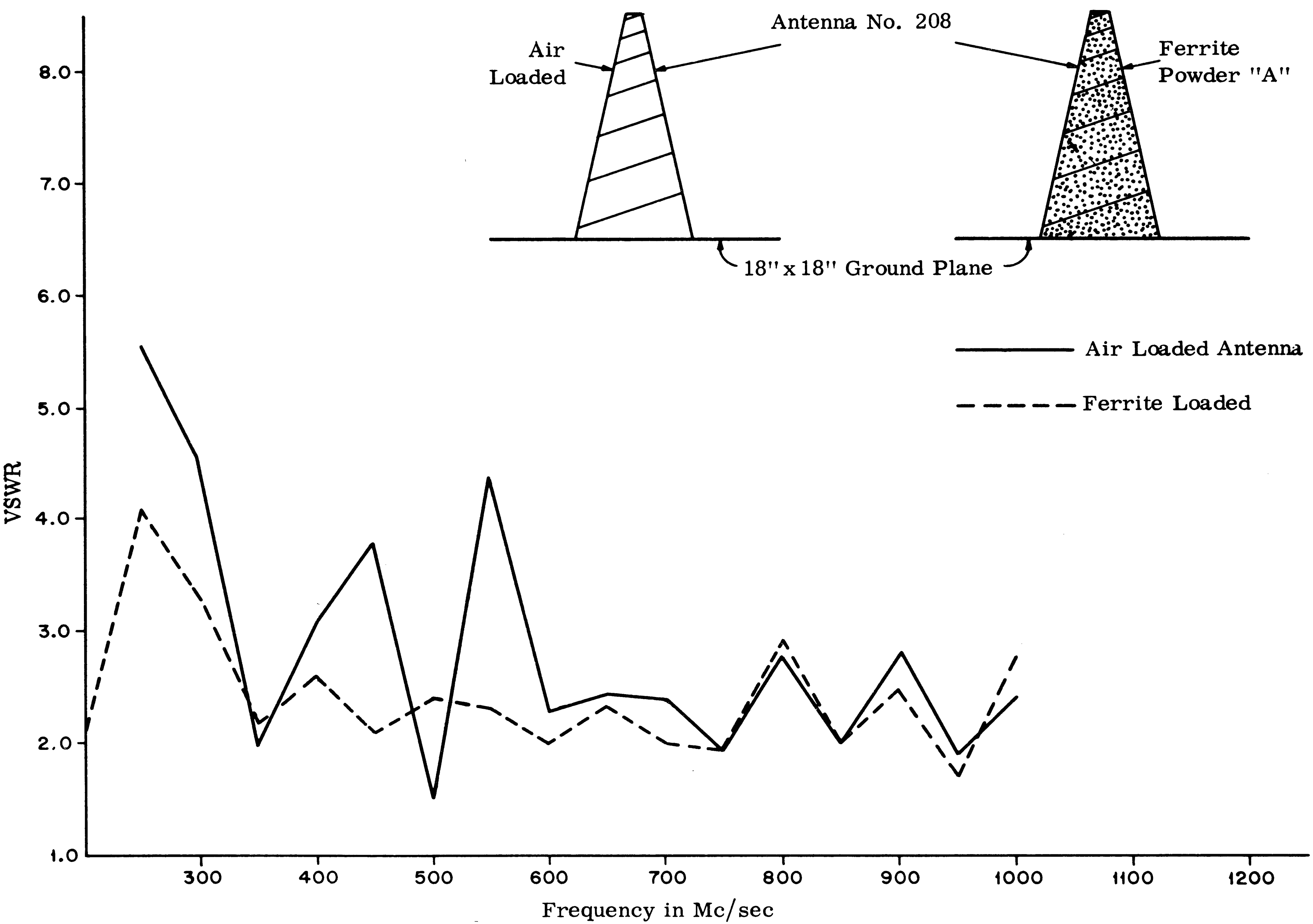

FIG. 5. VSWR vs. Frequency.

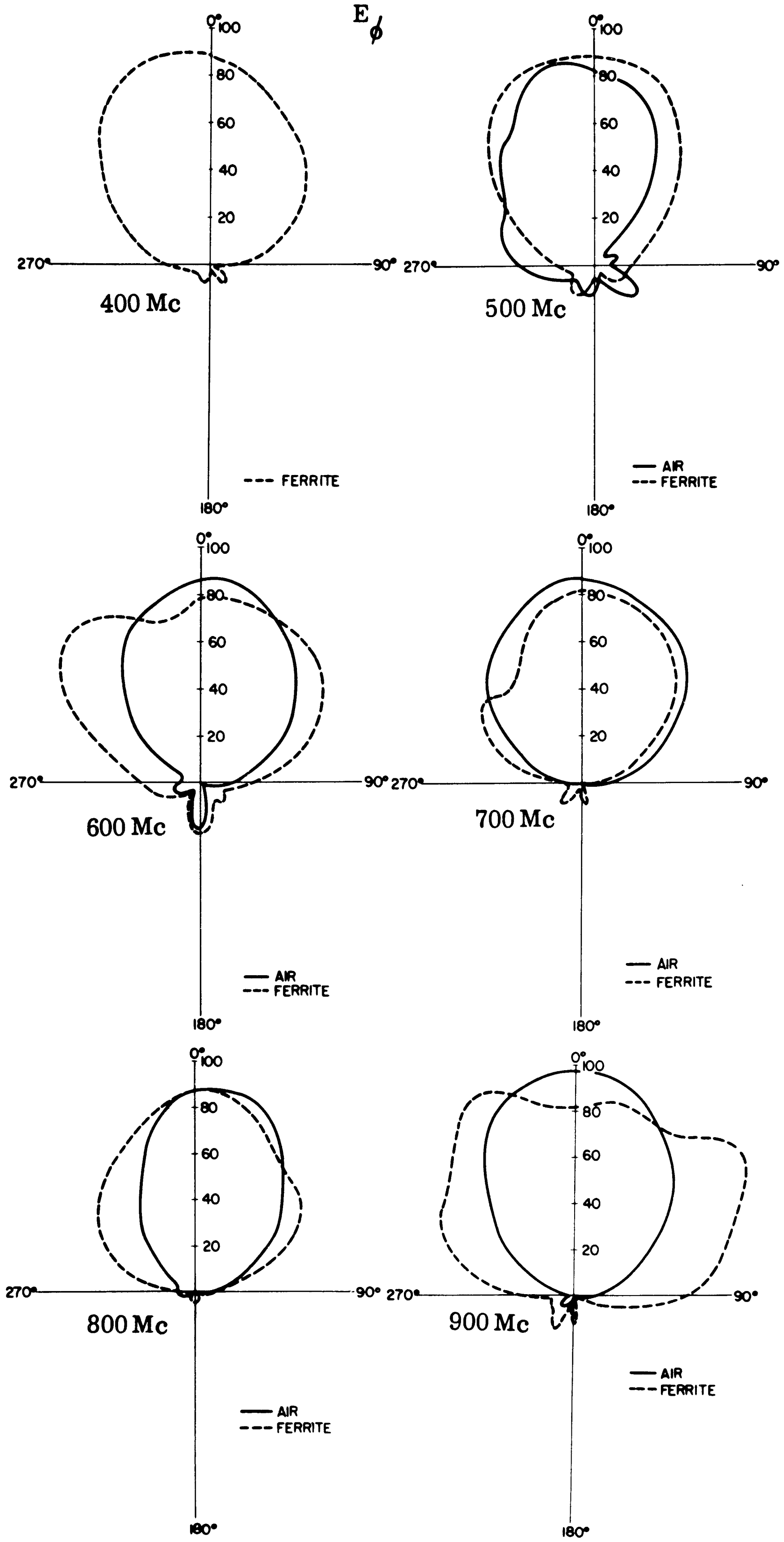

FIG. 6a. Radiation Patterns without Cavity, E_ϕ .

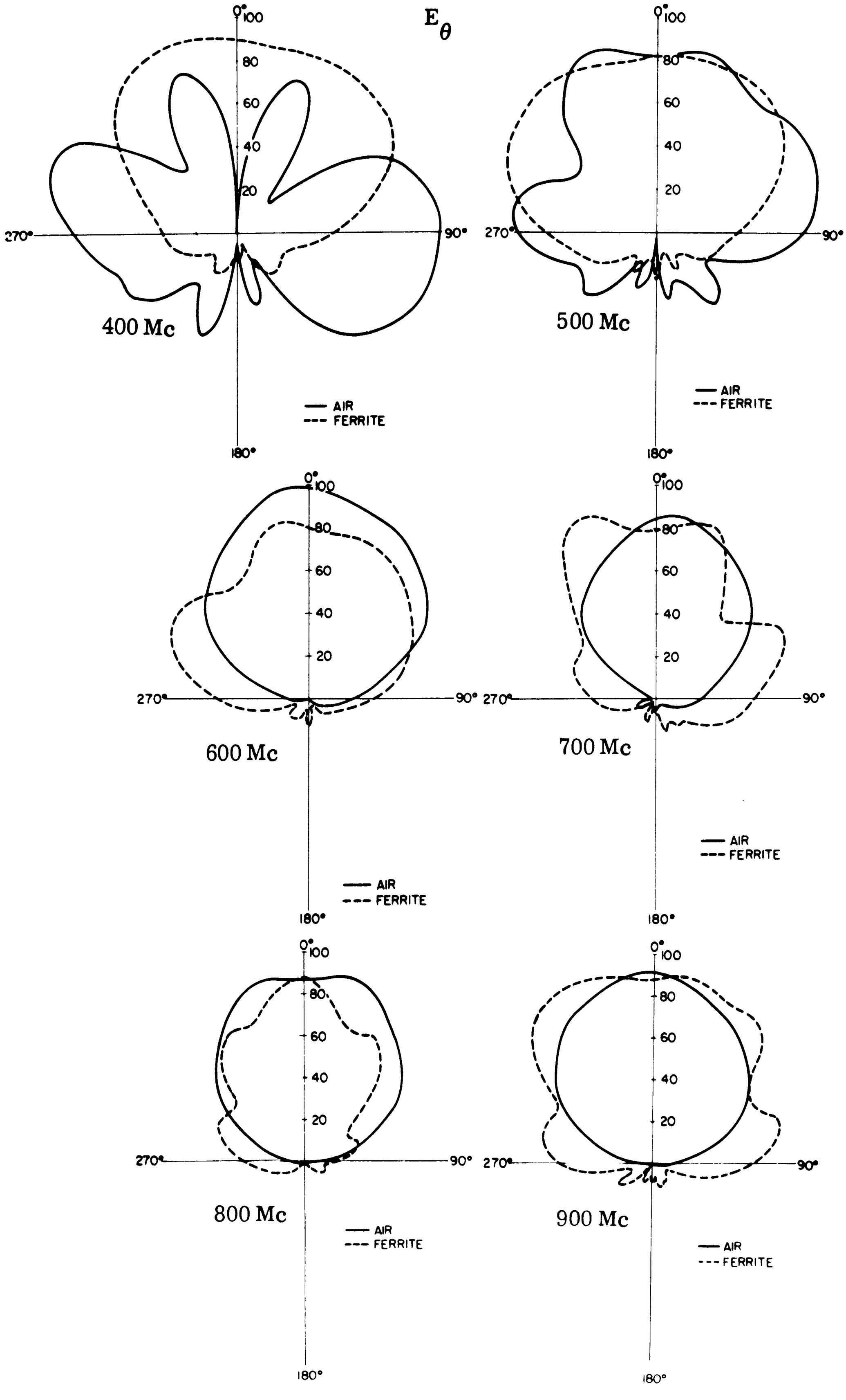

FIG. 6b. Radiation Patterns without Cavity, E_θ .

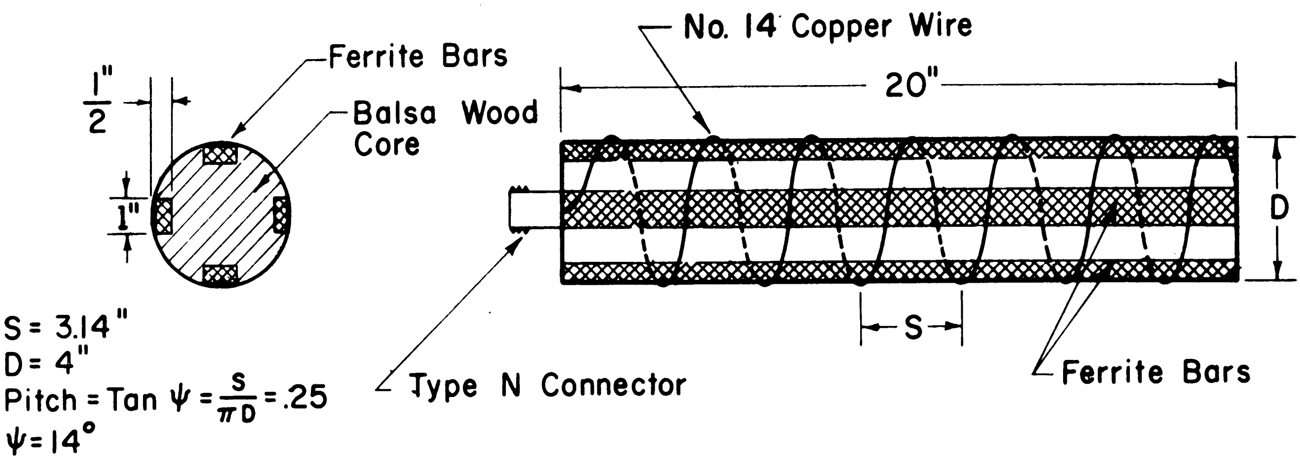

FIG. 7. Helix Antenna Loaded with Ferrite Bars.

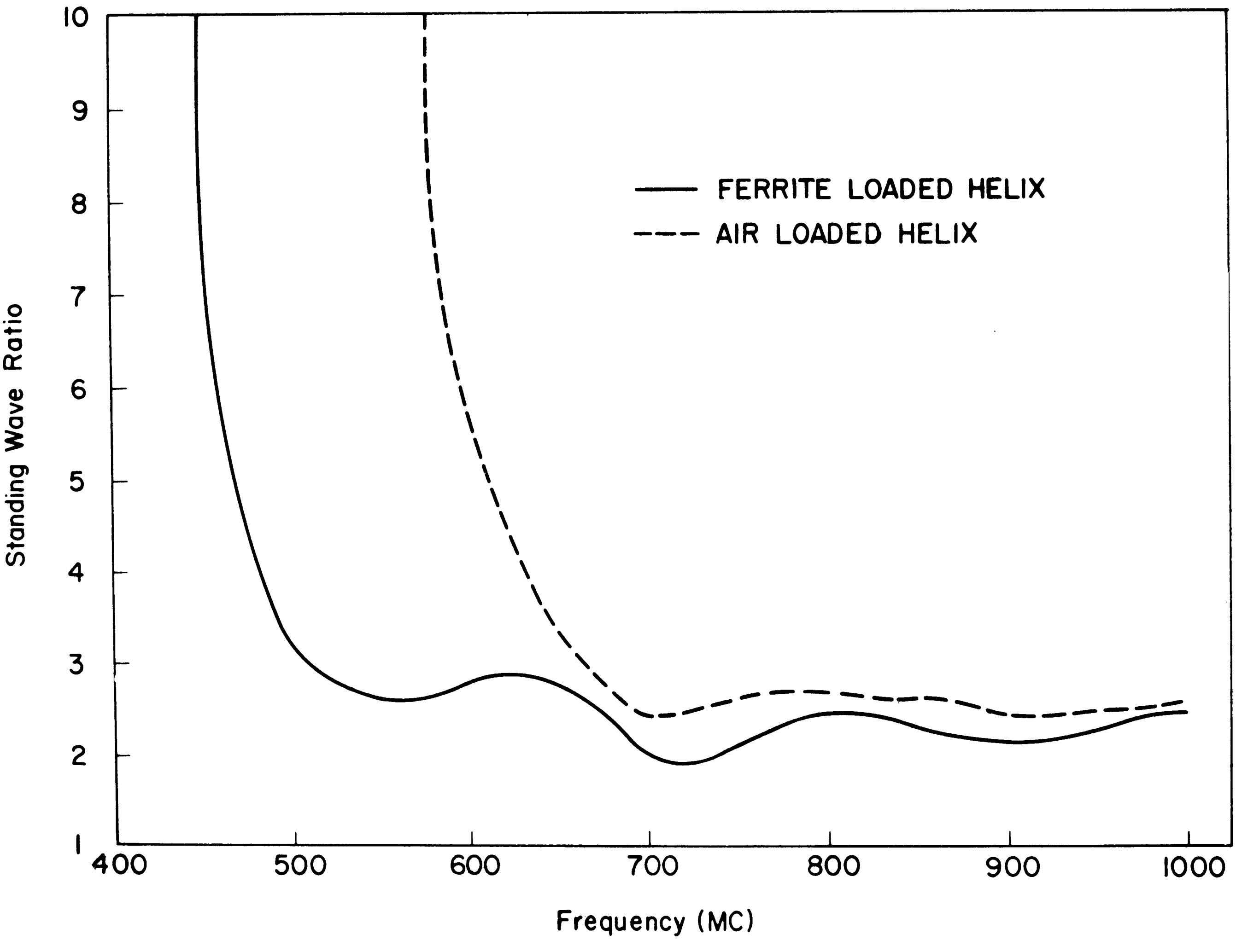

FIG. 8. VSWR for Loaded and Unloaded Helix.

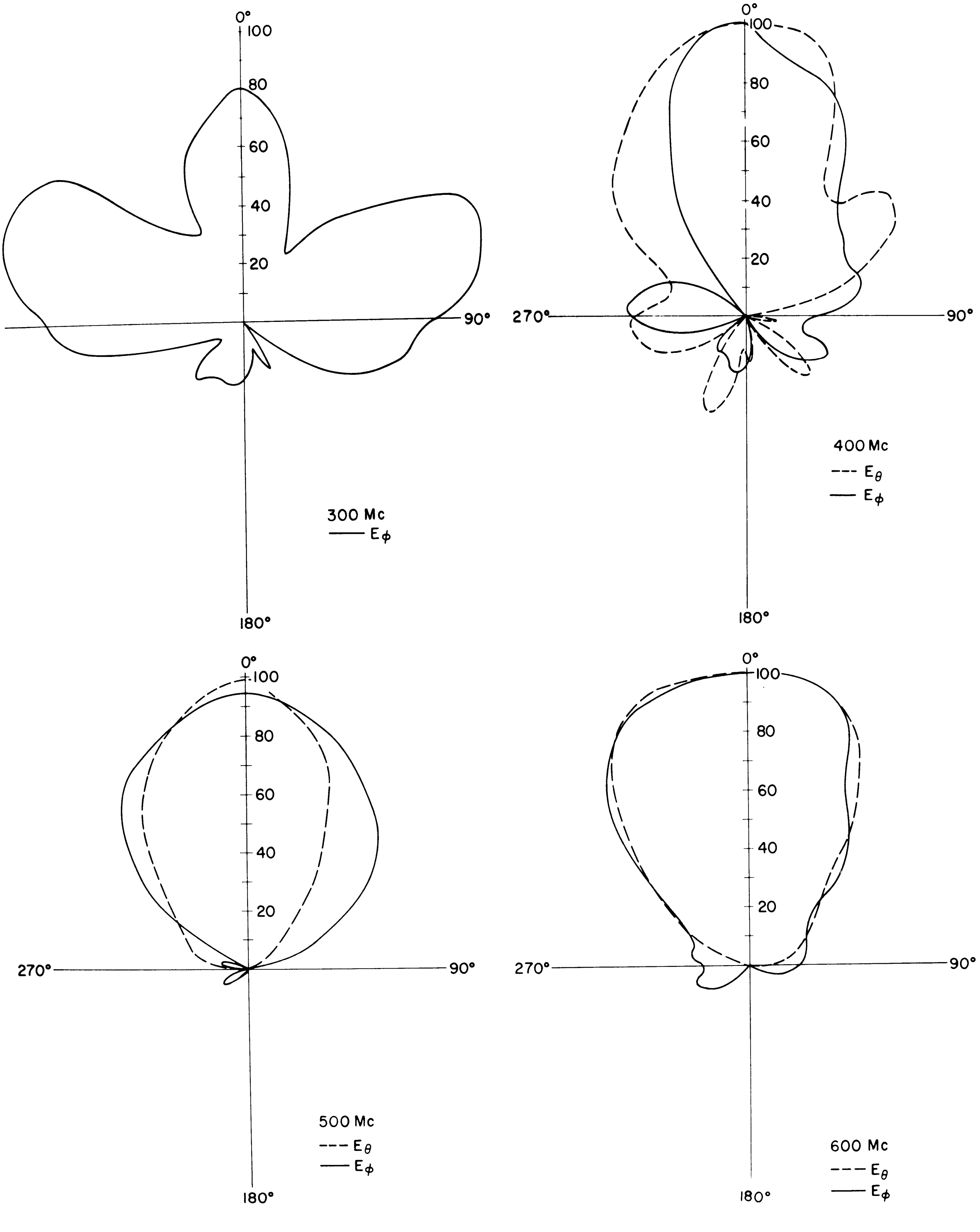

FIG. 9. Radiation Patterns for Ferrite-Loaded Helix.

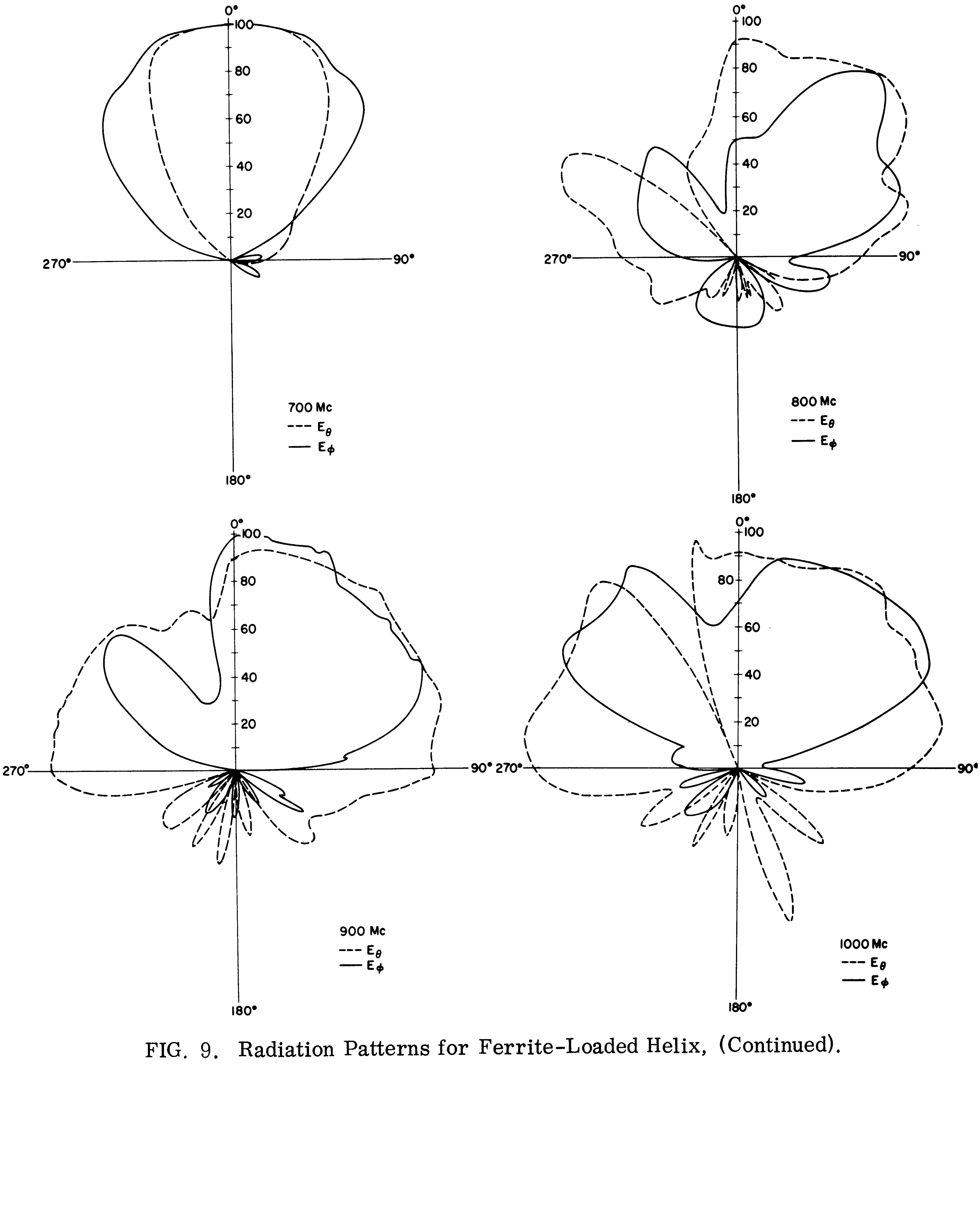

FIG. 9. Radiation Patterns for Ferrite-Loaded Helix, (Continued).

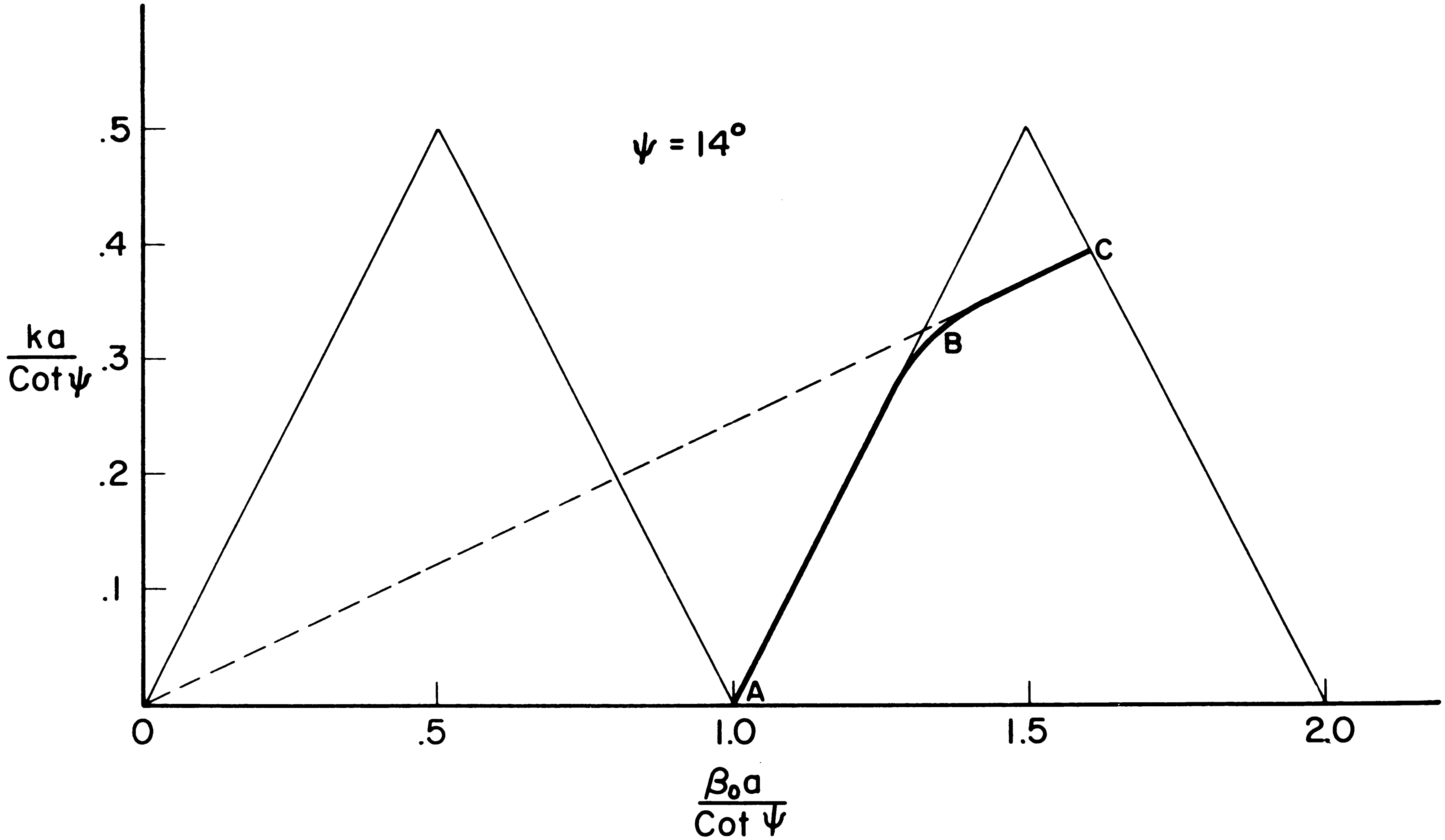

FIG. 10. k - β Diagram for Helix .

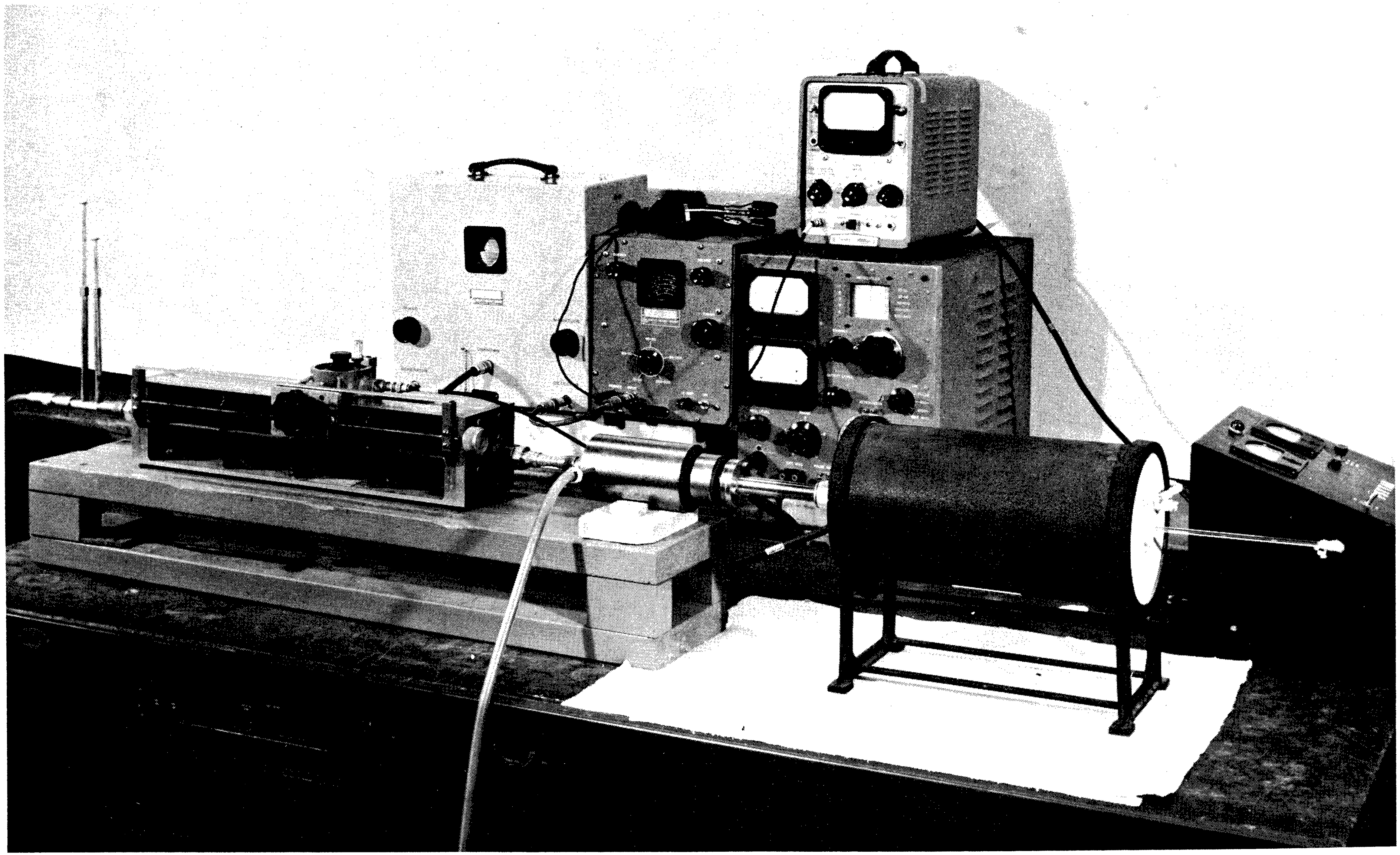

FIG. 11 Permeability vs. Temperature Measuring Equipment .

FIG. 12a.

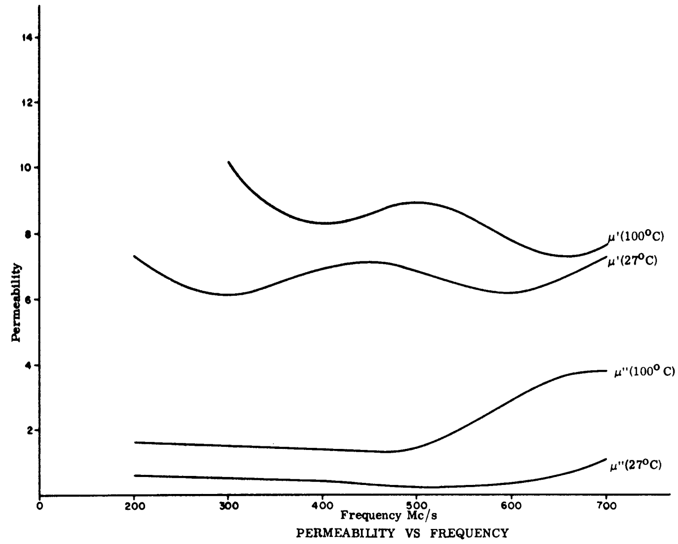

FIG. 12b.

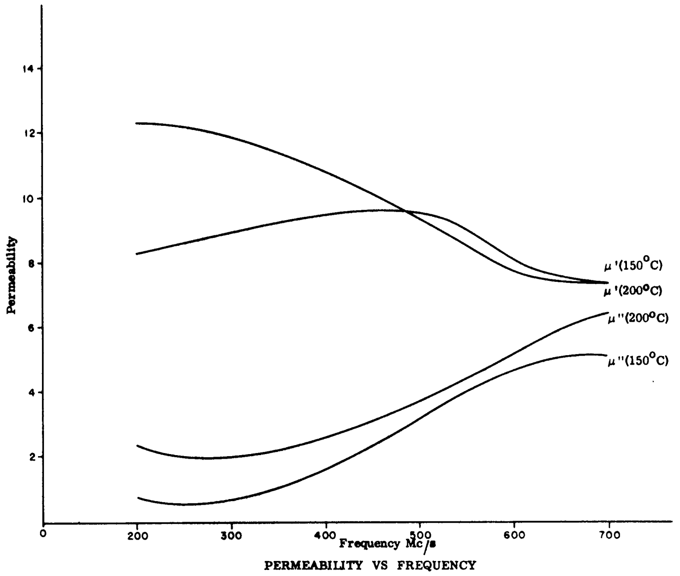

FIG. 12c.

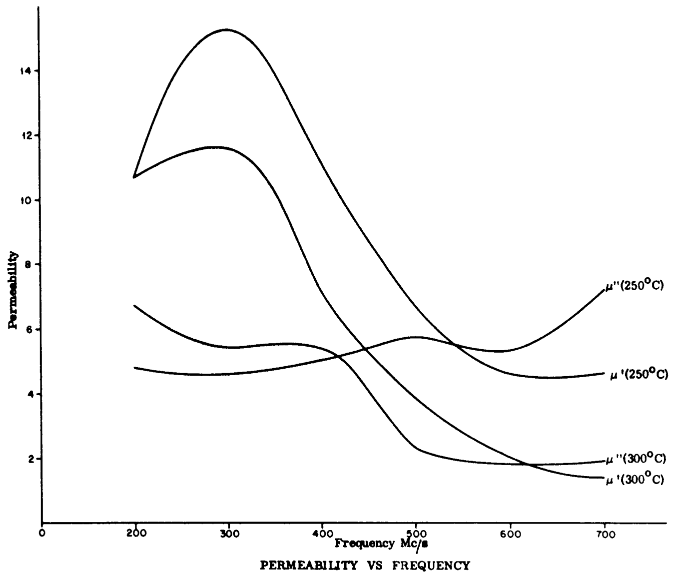

FIG. 12. Permeability vs. Frequency and Temperature.

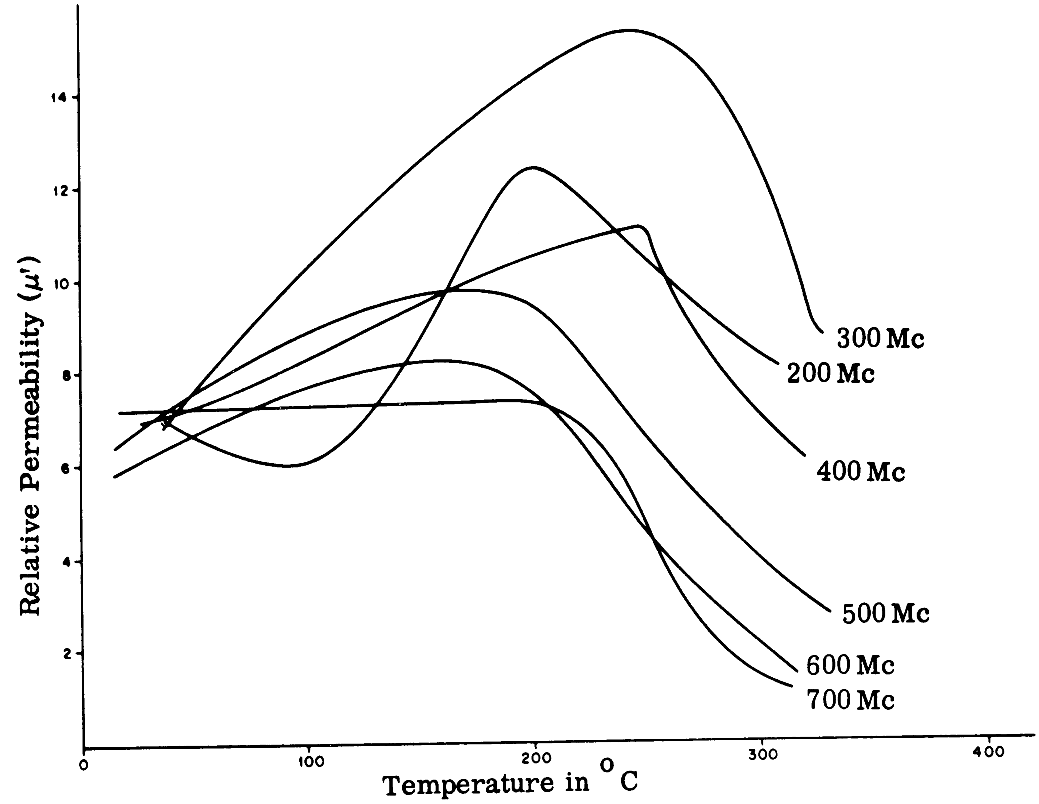

FIG. 13a. Relative Permeability (μ') vs. Temperature for Co_2Z.

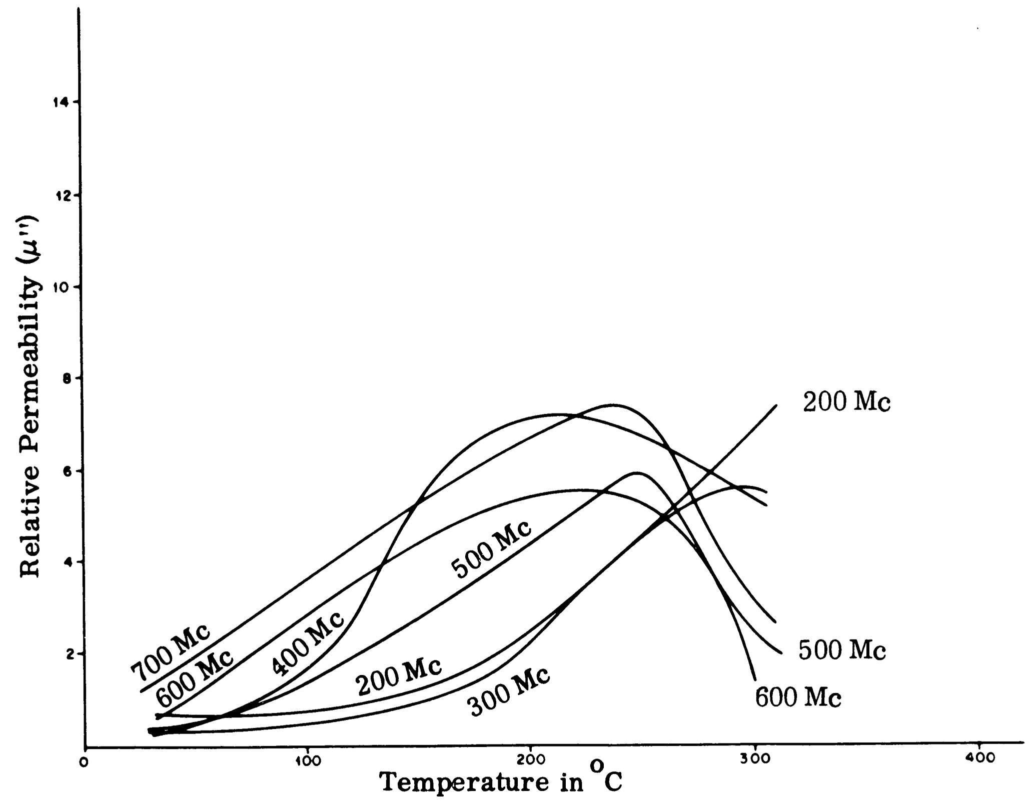

FIG. 13b. Relative Permeability (μ'') vs. Temperature for Co_2Z.