STUDY AND INVESTIGATION OF UHF-VHF ANTENNAS

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ABSTRACT

This first quarterly report describes the effort devoted to the four listed tasks of this project. The largest part of the effort has been devoted to two of the tasks; (1) the conical spiral antenna or the log conical spiral antenna, as frequently called; (2) array antennas utilizing loading effects on elements. The remaining tasks (3) endfire ferrite rod antenna and (4) new antenna types at 30 MHz are covered very briefly. These last two tasks have just been initiated.

In addition, some effort has been devoted to electrical properties of material and the measurement of these properties. This information on properties of material will be helpful for the ferrite loading involved in the four numbered tasks. Some data are also included on the power level limitations of ferrite loaded rectangular slot antennas.

I
INTRODUCTION

During this report period, effort was spent upon each of the four tasks included in the contract. Considerable work was done in the area of log conical loaded antennas and in arrays utilizing ferrite elements. The remaining tasks involving end-fire ferrite rod antennas and new types of antennas down to 30 MHz are discussed very briefly, since work has only recently been initiated. Additional work is described which is a background for all of the tasks. This work involves the properties of loading materials and the measurement of such properties.

The results on log conical antennas are encouraging. This type of antenna has been under study for some time by personnel on this project with respect to loading with dielectric materials. Now such studies are being extended to loading with ferrite materials. Some progress has been made relative to the attainment of the parameter values listed in the specifications for this type of antenna. The study of the antenna using both transmitting and receiving modes simultaneously has just been started. Various conditions under which there may be error due to intermodulation are now being considered. A complete resume of analytical studies of the loaded helix will be emphasized in a future report. These studies are important for understanding the operation of the ferrite loaded log conical antenna.

The use of dielectric rod antennas as endfire radiators has been surveyed. The criteria for design of dielectric rods are being extended into criteria for ferrite rods. A detailed comparison of the operation of ferrite rod and dielectric rod radiators is under way.

The use of individual ferrite loaded slots as elements in an array has been attempted. Although one design has been completed, the necessity for modifying the laboratory and the range have delayed experimental verification of the initial design of this array. However, a brief description of an array using such loaded slots is given.

Considerable effort has been given to the study of the interdigital array antenna. A comparison is being made with a somewhat similar array of elements as available from a commercial supplier. This experimental check has not been completed. The analysis of the interdigital array is not presented in this report, since major steps in the analysis are yet to be made.

The influence of ferrite loading on the power capability of ferrite loaded rectangular slots is given in some detail. The electrical characteristics of ferrite material are very much temperature dependent. At elevated temperatures, there can be sufficient deterioration of the electrical characteristics so that the efficiency as a radiator of electromagnetic energy is markedly lower. The deterioration of the radiation efficiency occurs at a temperature considerably lower than that required to permanently change the material. Nevertheless, such a restriction may be of great importance for antennas used on aerospace vehicles during the re-entry period.

II
FERRITE LOADED ANTENNA

2.1 A Bifilar Complementary Helical Antenna

A bifilar complementary helix (or narrow gap helix) was constructed and its property as an antenna was investigated. The specification of the antenna is as follows:

Diameter	: 13 cm
Length	: 40 cm
Gap Width	: 0.1 cm
Pitch Angle	: 10^{o}
Construction	: Bifilar, balanced or unbalanced feed.

2.1.1 The Radiation Pattern

The radiation pattern is shown in Fig. 2-1 where it is seen that the unloaded antenna has good patterns from 600 MHz up to around 900 MHz, which is quite comparable to the equivalent wire helix (its dual)

The radiation pattern of a loaded case is also shown. The EAF-2 ferrite shell of 1/2" thick was loaded inside and under the gap. The radiation pattern indicated in Fig. 2-1 seems to give a useful frequency range from 450 MHz up to around 700 MHz, which gives about 0.75 reduction in the resonant frequency. This is also very close to the value obtained from its dual.

2.1.2 The Near Field Amplitude

The complementary antenna was placed inside an anechoic chamber for the near field amplitude measurement. Since it is a dual of the wire helix, an E-probe was used instead of the H probe that was used in the wire helix measurement. The E-probe was made from a 0.084 cm coaxial line, the length of the protruding inner conductor was 0.4 cm, which is bent 90^{o} with respect to the feeding coaxial line; and a small disk of 1.2 cm diameter was attached to the outer conductor and

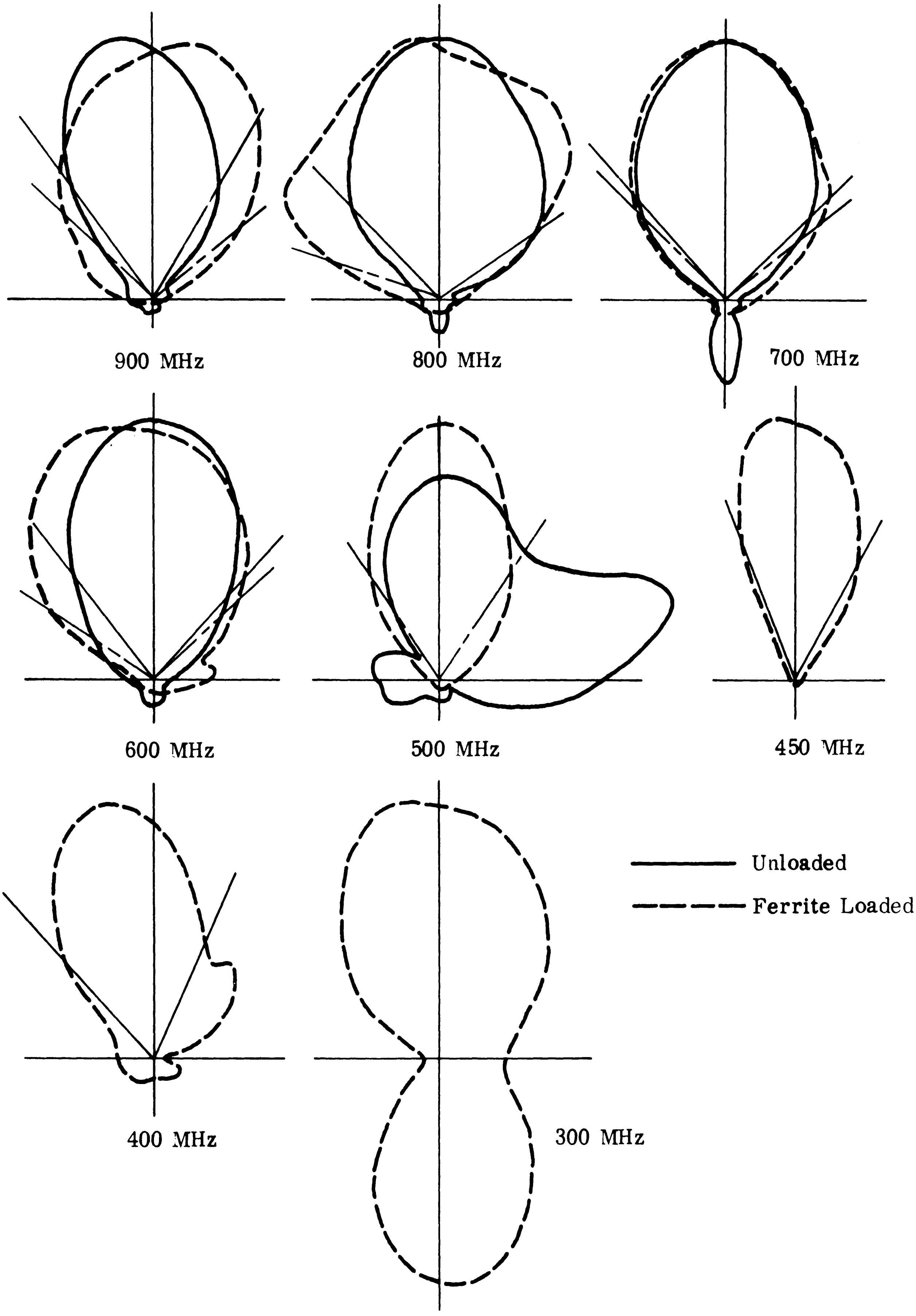


FIG. 2-1: RADIATION PATTERNS OF A COMPLEMENTARY HELICAL ANTENNA

perpendicular to the protruded inner conductor. This unbalanced probe was then placed $\lambda/10$ above the antenna with its inner conductor parallel to the axial direction of the antenna.

The near field amplitude is shown in Fig. 2-2. The general shape and the trend is very similar to those of the wire helix previously taken and discussed (Lyon et al, 1966). The best near field pattern is at 600 MHz (which also gives best far field pattern).

The near field amplitude was also taken with 1/2" shell loading of K-10 dielectric, as shown in Fig. 2-3 which seems to indicate the best near field pattern at 700 MHz. This is a somewhat confusing and strange result. However, since the radiation pattern is not yet available for this type of loading, it is too early to draw any conclusion.

2.1.3 The Measurement of the Phase Velocity Along the Gap.

The phase velocity along the gap can be measured accurately if the phase shift along the axial direction is measured by a typical phase measurement arrangement. However, it is a very time consuming and painstaking measurement. Therefore, a very crude and easy method was devised. The set-up is shown in Fig. 2-4. The antenna is fed through a PRD standing wave detector with a standard VSWR measurement set-up. The shorting copper ring was moved to obtain a minimum reading on the amplitude meter. Then the ring was moved to obtain a second minimum. The distance between the two minima was recorded for several trials and the average value taken. This should be a halfwave length along the axial direction. This value was then converted to the distance along the gap by dividing by the sine of the pitch angle. With the frequency known, it is then possible to obtain a phase velocity along the gap for different types of loadings at different frequencies. The measurement at or near the resonant frequency is very difficult (if not impossible) because most of the energy is radiated before traveling too far down the helix. Therefore, the phase

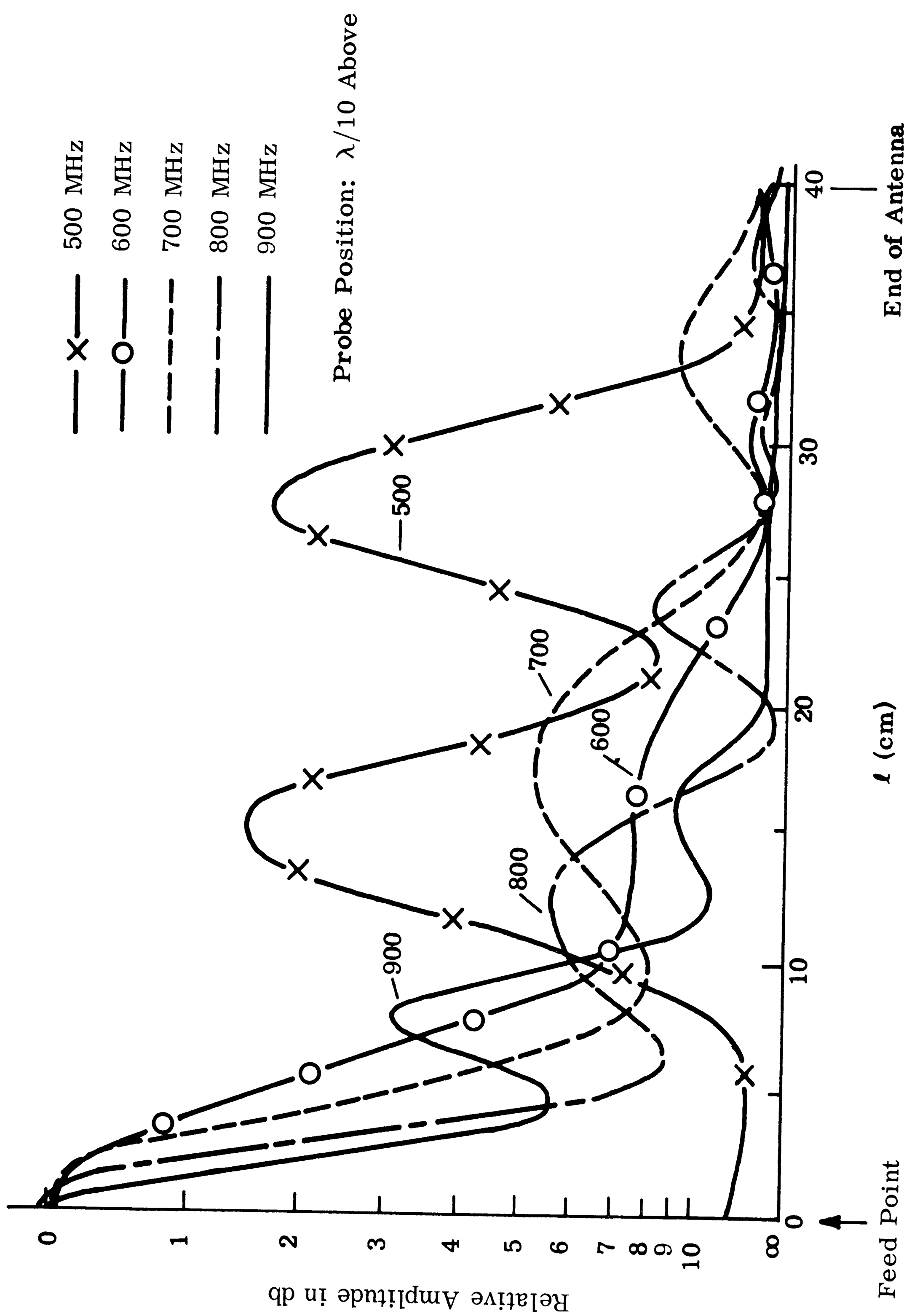


FIG. 2-2: NEAR FIELD AMPLITUDE OF A COMPLEMENTARY HELICAL ANTENNA WITHOUT LOADING.

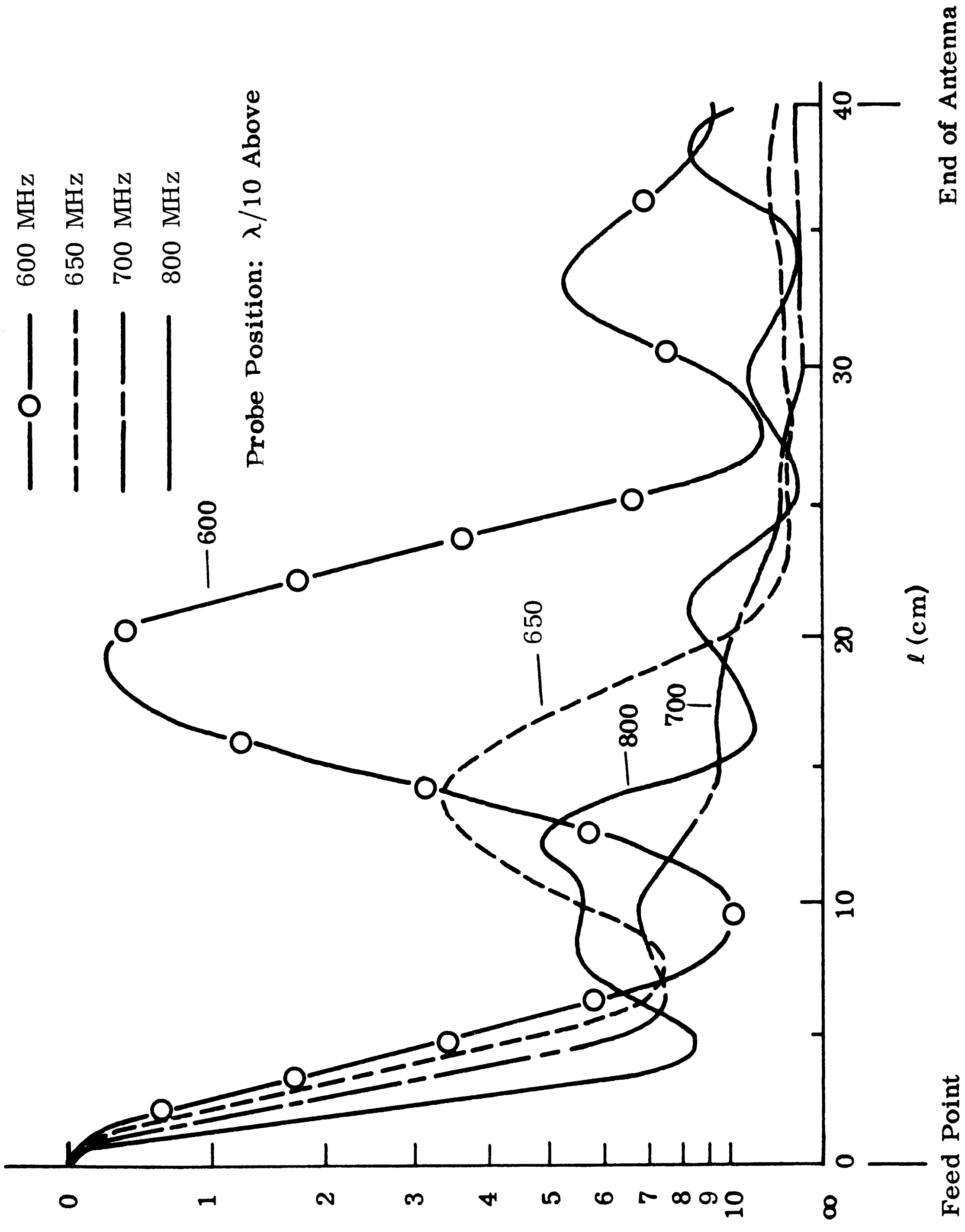


FIG. 2-3: NEAR FIELD AMPLITUDE OF A COMPLEMENTARY HELICAL ANTENNA WITH DIELECTRIC LOADING.

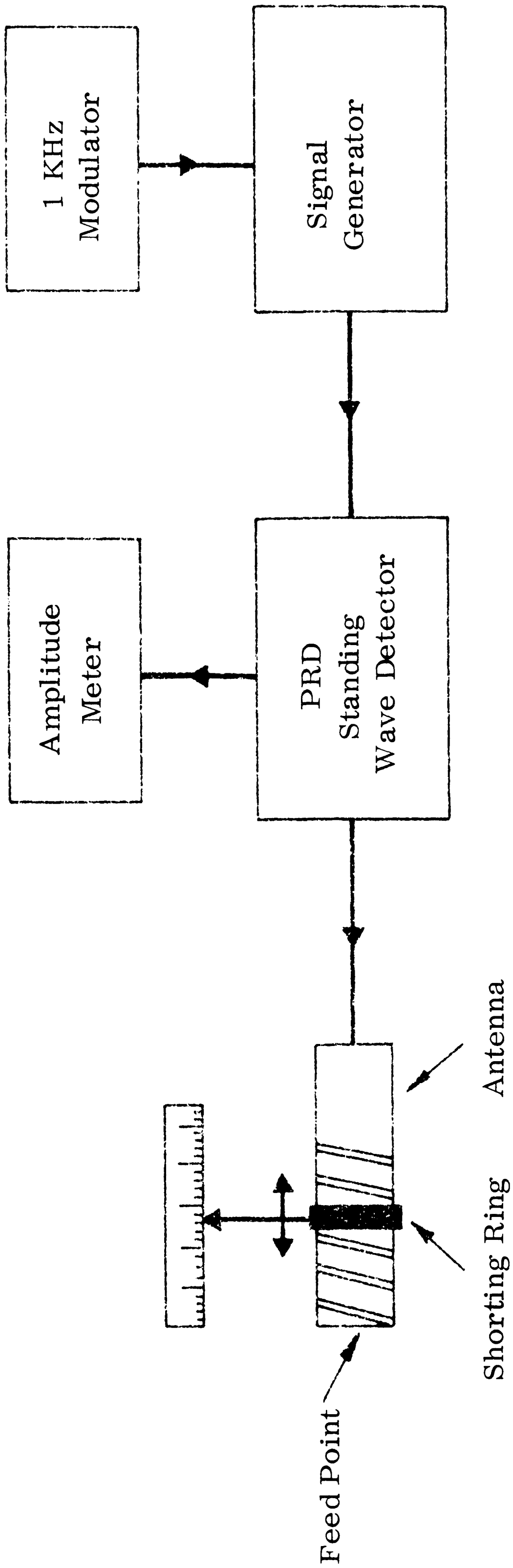


FIG. 2-4: SET-UP FOR THE PHASE VELOCITY MEASUREMENT.

velocity at the resonant frequency must be obtained approximately by extrapolating the results of other frequencies. The measurement was taken for the unloaded, the metal (cylinder of 4" diameter) loaded, the K-10 dielectric shell (1/2" thick) and the EAF-2 ferrite shell (1/2" thick) loaded cases. The results are shown in Fig. 2-5. The resonant frequency can be read out from the intersection of the zero phase shift axis and the straight lines connecting measured points, i.e. 630 MHz for the unloaded, 650 MHz for the metal loaded, 500 MHz for the K-10 dielectric loaded and 520 MHz for the ferrite loaded cases.

2.2 Ferrite Rod Antennas

A study has commenced on the use of high quality ferrite material for rod radiators. An attempt is being made to utilize the previously developed theory regarding dielectric rod radiators. It is expected that the analytical and experimental studies will include the HE_{11} mode as well as the two higher modes, TE_{01} and TM_{01} modes. The latter two modes will produce a null in the endfire direction. It is also expected that the study of ferrite rods will use a variety of feed structures. Using a helix as a feed structure, it is expected that a rotating HE_{11} mode can be studied. This mode would correspond to the usual circularly polarized mode of the helix, often designated as the $n = -1$ mode.

Of course, simple circular cylindrical shapes will be studied. In addition, a ferrite panel guide will be used as a radiator excited in the HE_{11} mode with a vertical polarization. This and other shapes that make use of the image properties of ferrite on a metal sheet will be explored.

Some analysis will be made of traveling wave antennas utilizing ferrite rods. It is expected that the field analysis commonly available for the dielectric rod for the HE_{MN} mode will be extended to include the effects of permeability as well as permitivity. The determinantal equation obtained by matching tangential components at the cylindrical interface of ferrite and aid should be solvable utilizing a computer.

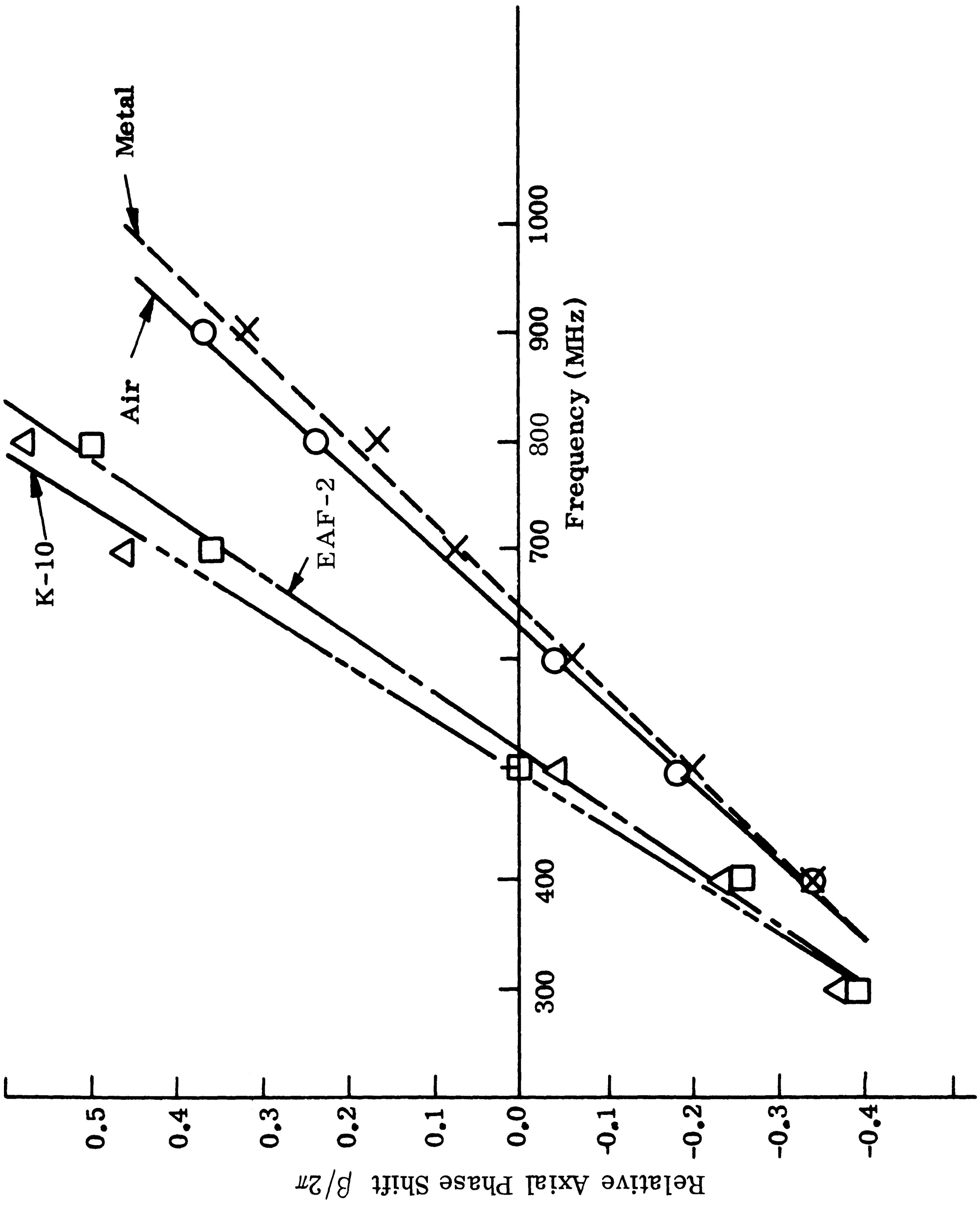


FIG. 2-5: AXIAL PHASE SHIFT OF A COMPLEMENTARY HELICA ANTENNA WITH VARIOUS LOADINGS.

It is expected that the loss characteristics of the ferrite will be incorporated in this solution.

In studying ferrite rod radiators, the effect of metal walls and plates in the vicinity of the ferrite material will be thoroughly studied. Also, the use of hollow shells of ferrite instead of solid ferrite rods will be considered.

2.3 Loaded Antennas Types For 30 MHz Operation

Considerable planning has been done during this period so that antenna measurements may be performed down to 30 MHz. This group has available a ground reflection range located near Hangar No. 2 at Willow Run Airport. This range operates reasonably well down to 50 MHz at present. It appears feasible to extend this range down to 30 MHz with some alterations. This range is used on a time sharing basis and its location is somewhat inconvenient.

At the present time, this group is setting up a new UHF-VHF range on the roof of the Fluids Building on the North Campus of The University of Michigan. This range is designed to operate down to 100 MHz.

In addition, a feasibility study is under way to use a large tract of flat land near the Fluids Building for a ground reflection range operating from 20 to 100 MHz. Such a use of land must be compatible with other activities of the university. Careful scrutiny is being given to the plan. It is expected this plan will be approved by the University Administration. If this range can be built, it will enable data to be taken more conveniently in the lower VHF range than would be possible at the Willow Run range.

At the present time, consideration is being given to loading both a log conical helix and a log periodic dipole antenna with toroids of Q-3 ferrite. The idea is that the toroids would act as lumped inductances for the transmission mode of each antenna and also tend to shorten the length of the radiating elements. Hence, the physical dimensions of the antenna would be reduced. Q-3 is an excellent material for these experiments since it has a high permeability and has a high Q_m below 200 MHz.

III
ARRAYS

3.1 Interdigital Array Antenna

The exploratory experiments conducted have shown the feasibility and some significant advantages of the interdigital array antenna. The structure is interesting for the following reasons:

1) A compact, flush mount is possible.
2) The construction and feed are simple.
3) The antenna is wideband and relatively high gain.
4) The elements may be loaded.

The theoretical investigation has been under way. A systematic experiment on a uniform interdigital array is expected to continue along with the theoretical analysis.

3.2 Ferrite Loaded Slot Array

3.2.1 Theory

The preliminary design and test procedures are discussed in detail in previous report (Lyon et al, 1966). The brief theory of the ferrite loaded slot array is given below. The usual symbols for array analysis will be used throughout:

$$R(\theta, \phi) = E(\theta, \phi) S(\theta, \phi) \; .$$

$R(\theta, \phi)$ - antenna pattern.

$E(\theta, \phi)$ - element pattern.

$S(\theta, \phi)$ - array factor.

On a power basis this is:

$$\left|R(\theta, \phi)\right|^2 = \left|E(\theta, \phi)\right|^2 \cdot \left|S(\theta, \phi)\right|^2 \; .$$

These relations are true for a "parallel array"; which is defined as an array where any element can be made to coincide with any other element by translation without rotation.

It is generally assumed that the "magnetic current" distribution in a radiating slot is sinusoidal (analogous to sinusoidal electric current distribution on a dipole). This assumption is supported by experiments (Adams, 1964). Note that the slot antenna is a magnetic dipole (analogous to electric dipole) having $H_\theta(\theta)$ and $E_\phi(\theta)$ fields.

At resonance, the slot antennas used are half wave magnetic dipoles and the fields of each dipole are given by:

$$H_\theta(\theta) = j \frac{N_o(\max) e^{-jkR}}{\eta_o, 2\pi R} \left[\frac{\cos(\frac{\pi}{2} \cos\theta_n)}{\sin\theta_n} \right]$$

$$E_\phi(\theta) = j \frac{V_o(\max) e^{-jkR}}{2\pi R} \left[\frac{\cos(\frac{\pi}{2} \cos\theta_n)}{\sin\theta_n} \right]$$

The slot can radiate only on one side of the ground plane, hence the pattern for $E_\phi(\theta)$ and $H_\theta(\theta)$ is a half of the usual "doughnut" pattern.

3.2.2 Co-ordinate Transformations

In the x-z plane $\theta = \frac{\pi}{2} - \theta_x$

$$H_\theta(\theta) = K \left[\frac{\cos(\frac{\pi}{2} \sin\theta)}{\cos\theta} \right]$$

$$E_\phi(\theta) = K \left[\frac{\cos(\frac{\pi}{2} \sin\theta)}{\cos\theta} \right]$$

Therefore,

$$E(\theta, \phi)^2 = K'' \left[\frac{\cos^2(\frac{\pi}{2}\sin\theta)}{\cos^2\theta} \right]$$

For array factor calculations in the x - z plane; a Dolph and Tschebycheff distribution was assumed. Thus:

$$S(\theta_1 \phi) = S(\theta_n) = 2(A_o + A_1 \cos\psi + A_2 \cos 2\psi)$$

where

$$\psi = kd\cos\theta_n = kd\sin\theta \quad (\text{ in } x - z \text{ plane})$$

(see Figs. 3-1 and 3-2)

The amplitude coefficients turn out to be:

$$2A_0 = 6.02$$

$$2A_1 = 9.5$$

$$2A_2 = 4.48$$

See the final report of the previous contract (Lyon et al, 1966) for the calculations (Kraus, 1950).

In the following Table III-1 the far field pattern is predicted in the tabular form for several values of θ. The steps in the calculations are included.

As far as the loading of the waveguide slot array is concerned, it has been already established that the length of the array is unchanged though the cross section of the waveguide is reduced to a considerable extent, by approximately $\frac{1}{\sqrt{\mu_r \epsilon_r}}$, through the use of the loading material.

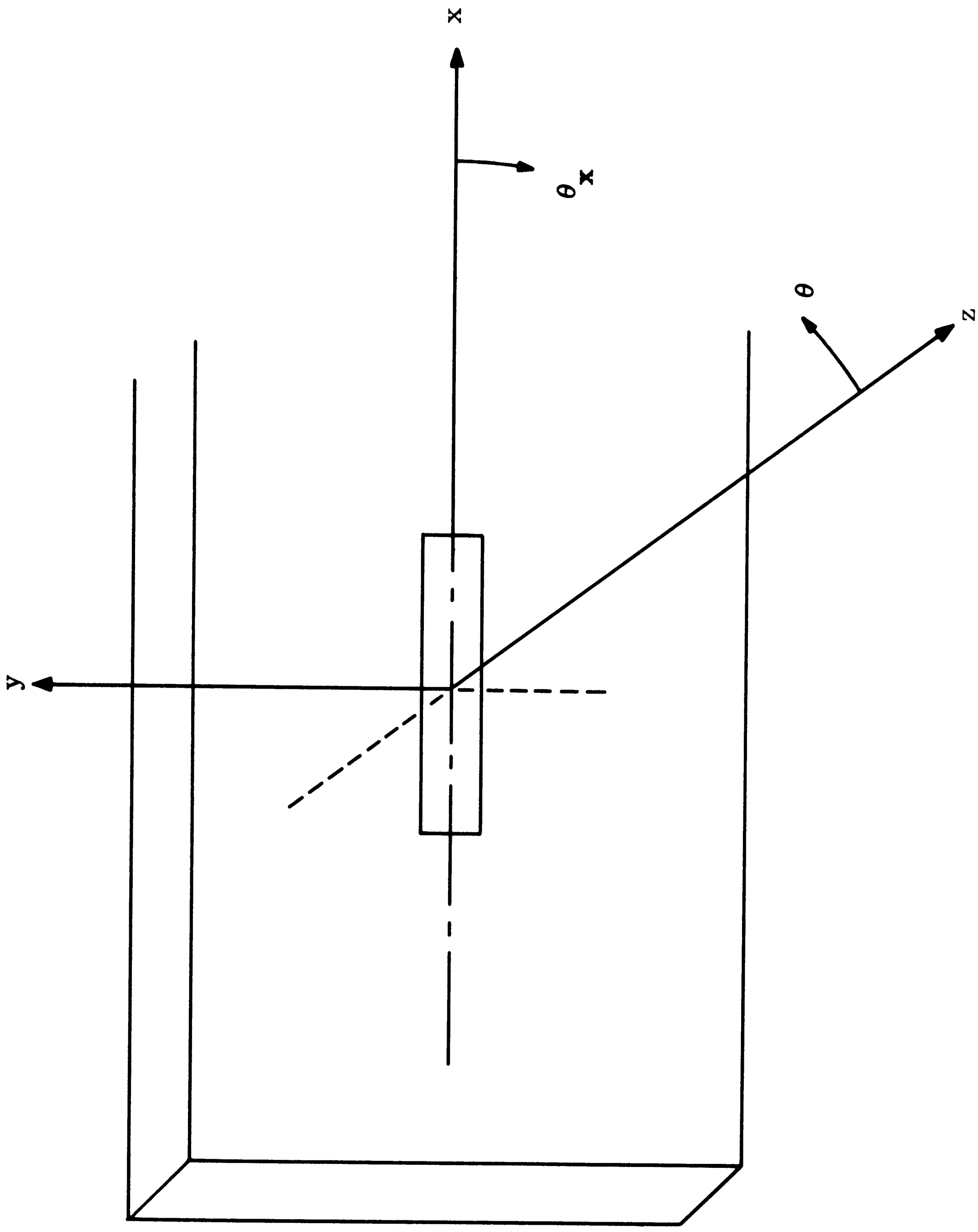


FIG. 3-1: WAVEGUIDE SLOT COORDINATES

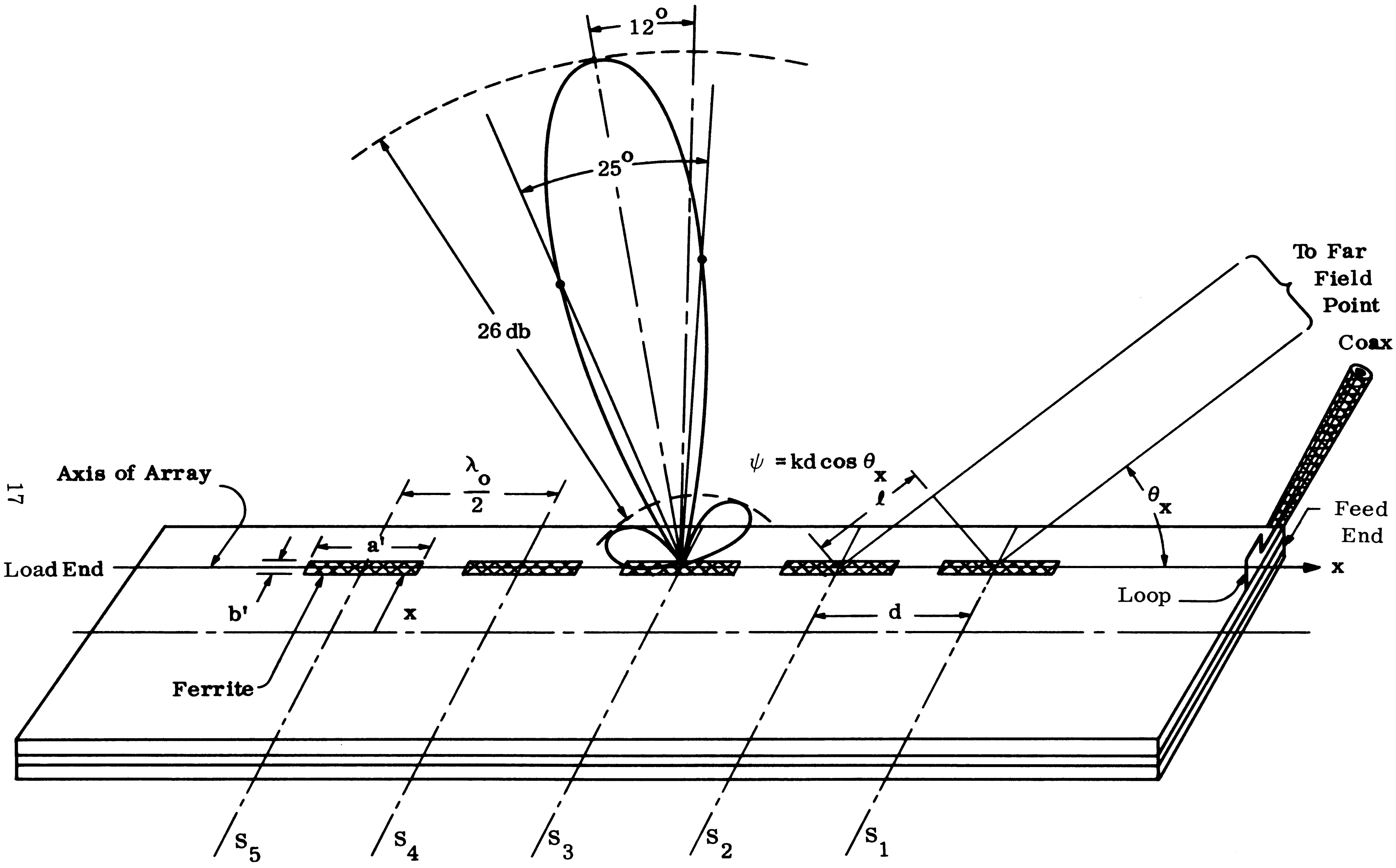


FIG. 3-2: SIMPLIFIED FINAL CONFIGURATION OF ARRAY WITH SHUNT SLOTS.

TABLE III-1

$$S(\theta) = 6.02 + 9.5\cos(\pi\sin\theta) + 4.48\cos(2\pi\sin\theta)$$
$$= 6.02 + 9.5\cos(\pi\sin\theta) + 4.48\quad 2\cos^2(\pi\sin\theta) - 1$$
$$= 1.57 + 9.5\cos(\pi\cos\theta) + 8.96\cos^2(\pi\sin\theta)\ .$$

$$|S(\theta)|^2 = 2.37 + 29.22\cos(\pi\sin\theta) + 117.8\cos^2(\pi\sin\theta) + 170\cos^3(\pi\sin\theta)$$
$$+ 80.35\cos^4(\pi\sin\theta)\ .$$

θ (Degrees)	$\dfrac{\cos^2(\frac{\pi}{2}\sin\theta)}{\cos^2\theta}$	$\sin\theta$	$\cos\theta$	$x = \cos(\pi\sin\theta)$	x^2	x^3	x^4	$\|R(\theta)\|^2$
10	0.955	0.1737	0.9848	0.855	0.73	0.625	0.534	251
12	0.939	0.2079	0.9782	0.794	0.63	0.5	0.397	203
12.5	0.934	0.216	0.976	0.78	0.609	0.475	0.37	199.3
15	0.891	0.2588	0.9659	0.687	0.471	0.324	0.223	133.2
20	0.835	0.342	0.9397	0.477	0.227	0.109	0.05	55
30	0.667	0.5	0.8660	0	0	0	0	1.572
45	0.394	0.707	0.707	-0.614	0.377	-0.232	0.142	0.205
60	0.1729	0.8660	0.5	-0.92	0.846	-0.779	0.715	0.06
80	0.02275	0.9848	0.1737	-1	1	-1	1	0.0273
90	0	1	0	-1	+1	-1	+1	0

Other workers (Jones 1965 and Cheo 1965) have studied waveguide loaded with a dielectric material and the slots cut in the broad face of the waveguide with the goal of achieving a very directive beam pattern with a very low side lobe level. The frequency used (Jones 1965) was around 5.4 GHz for an array of 7 slots in the broad face of waveguide loaded with a dielectric material. A power pattern had a 16^{o} half power beamwidth and 22 db side lobe level. The slots were not loaded with material.

Oliner's formulas are used here for calculating individual slot properties with certain modifications to take into account the magnetic characteristics of the loading material. In addition, the slot is filled with the ferrite. This problem differs from that of Jones and Cheo as follows:

1) The operating frequency is much lower (200 MHz).

2) The slots are loaded with ferrite.

3) The goal is to determine the efficiency of the system.

The design has only five slots. This is because at 200 MHz, the length of the array is quite large and it would be very cumbersome to handle longer lengths. The distance between the slots, for either a loaded or unloaded waveguide array, has to be approximately $\lambda_0/2$. It should be possible to achieve a 25^{o} half power beamwidth and 26 db side lobes with the present design.

The design of (an individual) slot proceeds in much the same way as given by Oliner for an air filled waveguide, except for the modification of the wave number (Cheo 1965).

$$k_\epsilon = \sqrt{\epsilon_r k_0^2 - (\frac{\pi}{a})^2} \quad \text{was modified to} \quad k_{\mu\epsilon} = \sqrt{\mu_r \epsilon_r k_0^2 - (\frac{\pi}{a})^2}$$

A slot can be considered as an impedance in the waveguide. The impedance is either a shunt or series impedance depending upon the location and orientation of the slot with respect to the central line of the waveguide. (The slots are in the broad wall of the guide, Fig. 3-3)

Use is made of shunt type slots. The design is based on Oliner's formulas in which the thickness of the wall of the slot is a very important and critical factor in determining slot impedance variations. The Oliner formulas are for an air filled waveguide with air filled slots. The modification of these formulas for a dielectric loaded waveguide has been suggested (Kay 1956) and verified (Larson et al, 1966). These references considered unfilled slots.

In this work the slots are filled flush with ferrite. This appears to be a way of achieving negligible coupling between elements. The filling of slots with ferrite reduces the resonant length of the slot to almost one third of that for an unfilled slot. Since the distance between two neighboring slots is fixed at $\lambda_0/2$, loading of the slots increases the edge to edge distance between two neighboring slots, and thus the mutual coupling, which is a function of this distance, is reduced considerably.

The procedure for calculation of slot impedance from Oliner's formula for a dielectric filled waveguide (with unfilled slots) is in the form of a computer program by Maldups and Larson of this laboratory. Modifications have been made to take into account the magnetic character of ferrite. The modified computer program was given the code name "Oliner SLIME IB". Details of the computation effort are shown in previous report (Lyon et al 1966). Design data curves are plotted in (Figs. 3-4, 3-5 and 3-6). Since the mutual coupling between two slots can be neglected, the impedance properties calculated above for an individual slot can be used in determining the power radiated by each slot.

The power radiation required from different slots is then calculated. To achieve this power distribution by the individual slots, appropriate conductance values (symbolizing radiated power) must be chosen. The control variable is the displacement of the slots from the central line of the waveguide. As can be seen from the curves of impedance properties of an individual slot (Figs. 3-4, 3-5 and 3-6), the

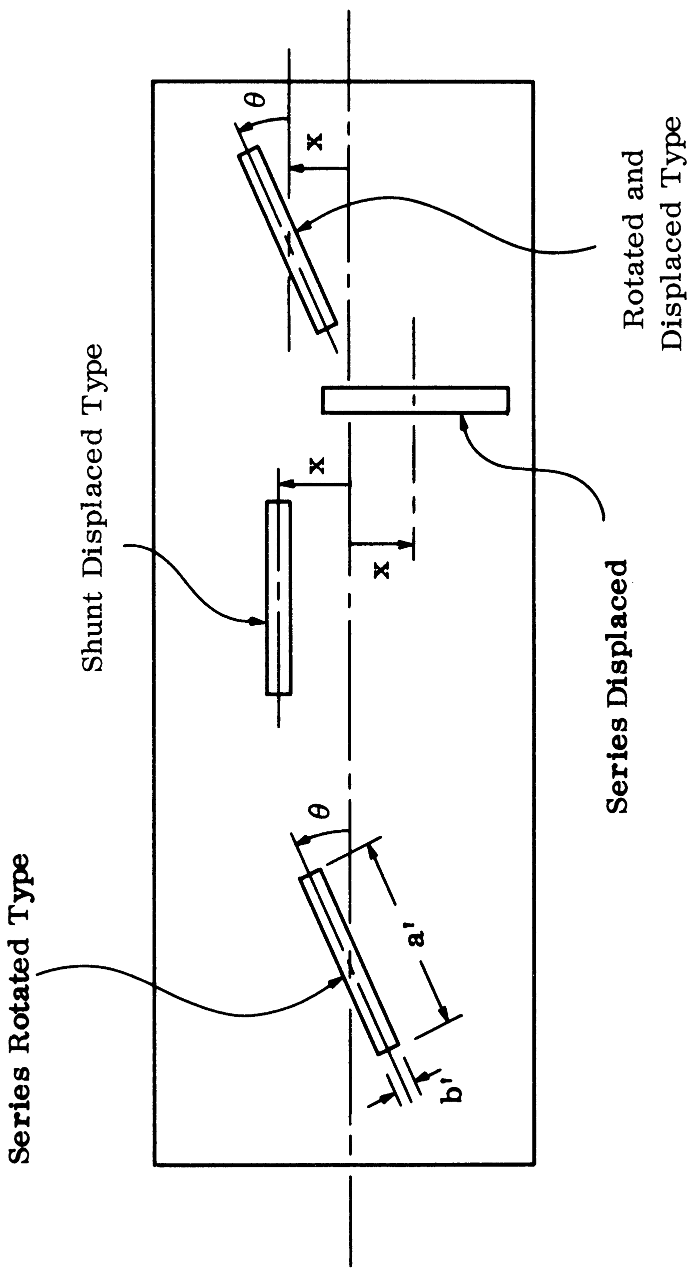


FIG. 3-3: TYPES OF SLOTS AND THEIR PARAMETERS.

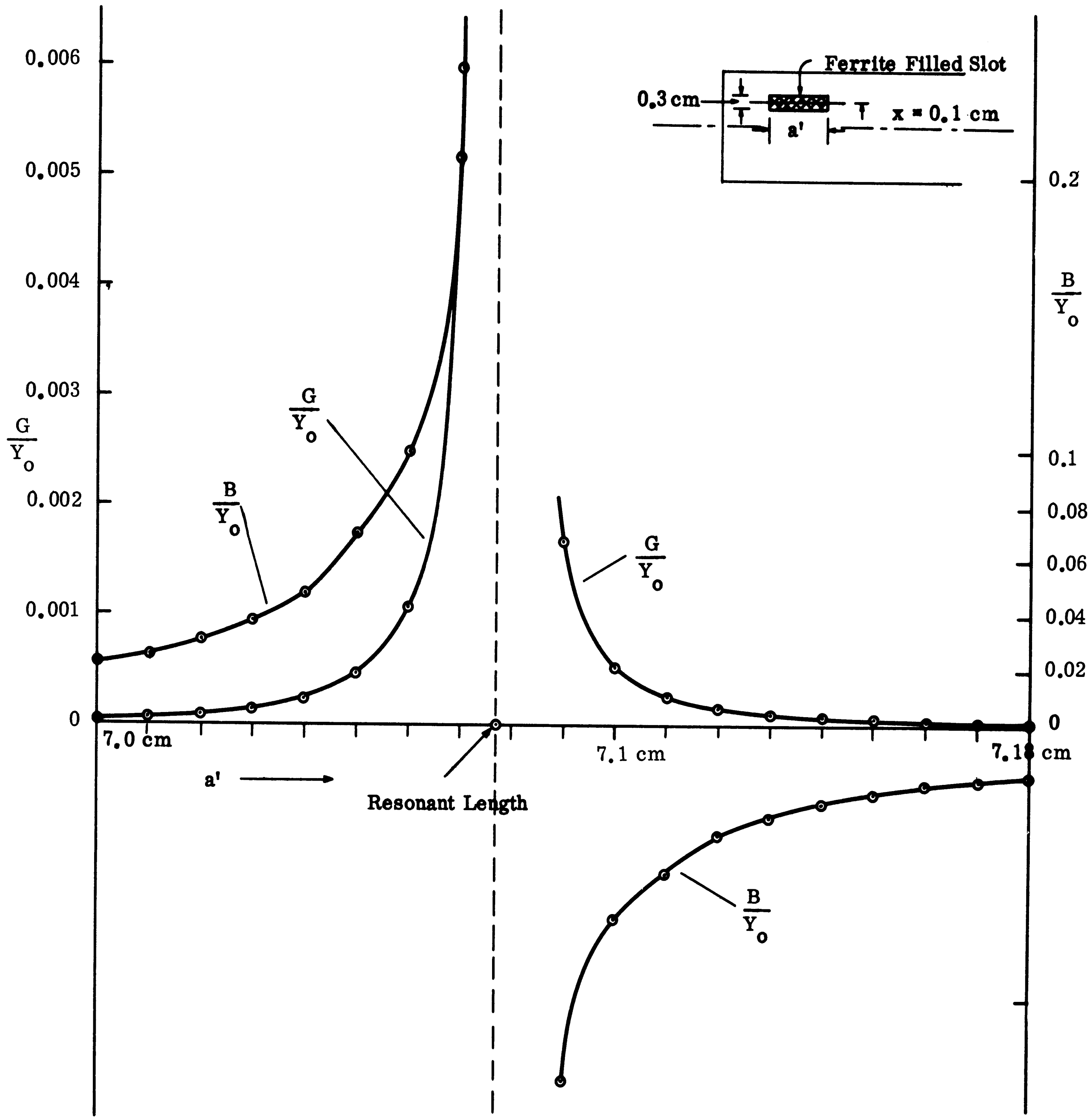


FIG. 3-4: SLOT NOT FILLED WITH FERRITE

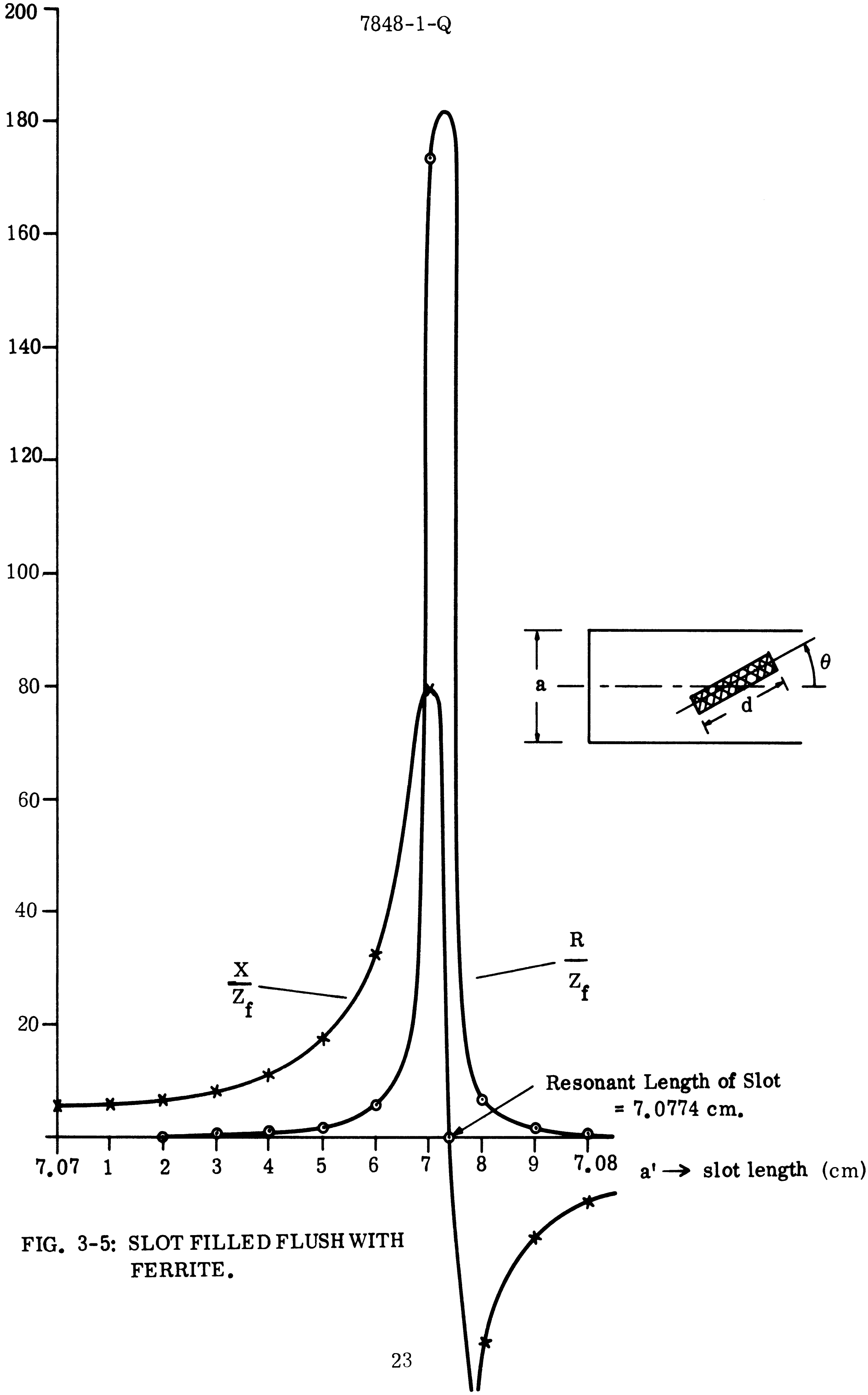


FIG. 3-5: SLOT FILLED FLUSH WITH FERRITE.

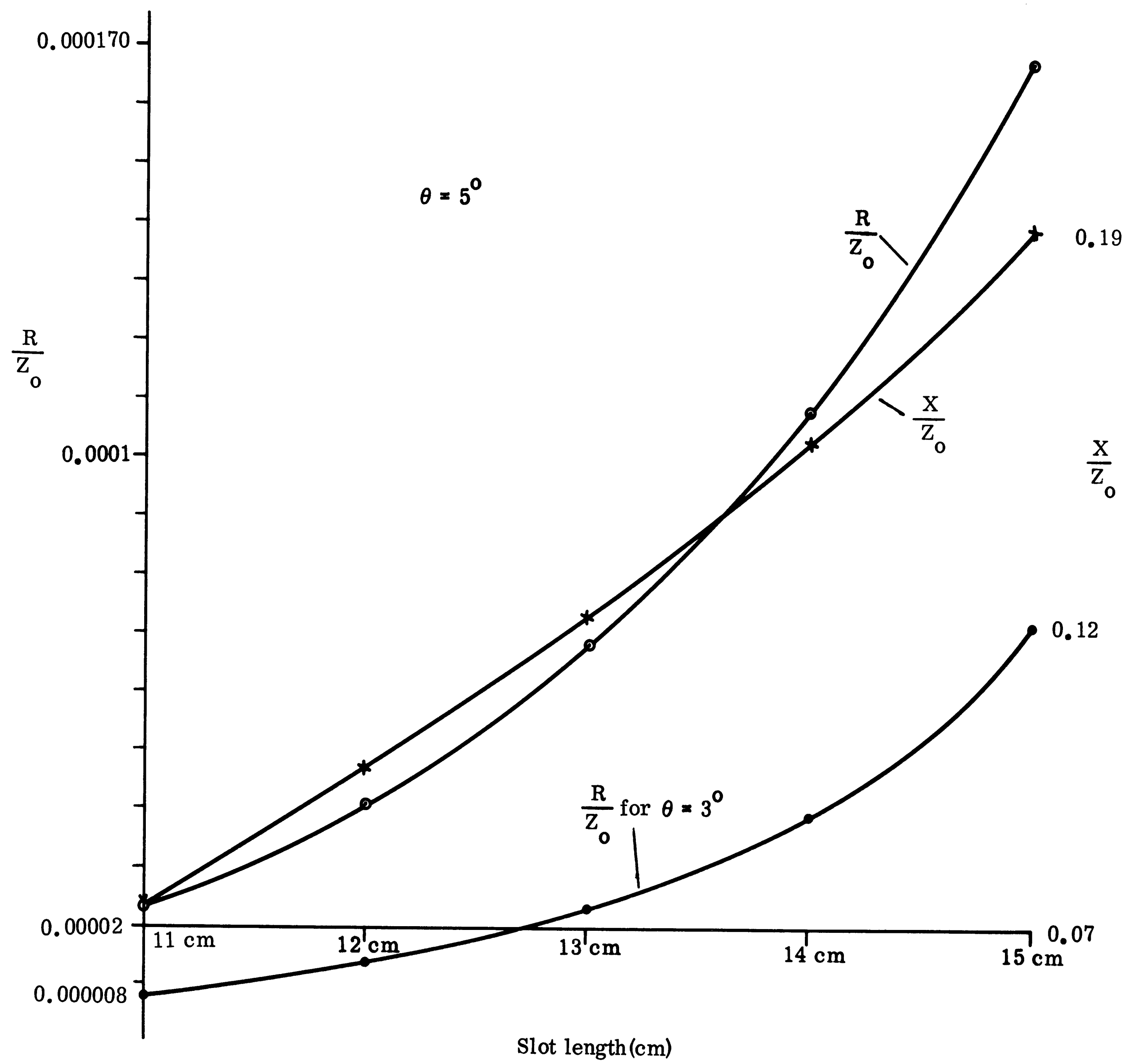


FIG. 3-6: SHUNT SLOT PROPERTIES

conductance is a very sensitive function of the displacement and slot length and it is hardly feasible to achieve the proper displacement within reasonable mechanical tolerances. Another method to control the conductance would be to put the slot on the central line of the waveguide and perturb the field in the guide by means of a screw probe, using one for each slot. This experimental method will be tried. Arguments for this are based on the sketch Fig. 3-7. When the field is unperturbed, the slot does not intercept any current lines, and hence does not radiate. When the field is perturbed, the symmetry of the distribution is disturbed, as shown in Fig. 3-7, and the current lines are no longer parallel to the slot. The slot starts radiating. The depth of the screw will determine the angle of the current lines with the slot, increasing the angle with increased depth and hence increasing radiation. Thus the required power distribution could be achieved. A radiation sensing device will be needed to sense power from the slots.

3.2.3 Experimental Work

The properties of the Q-3 ferrite material were determined for the proper design of the waveguide. A VSWR of 1.95 was achieved by designing an appropriate feed loop and a pattern was taken keeping the other end of waveguide open as an aperture. Attenuation due to ferrite filling was determined for frequencies from 160 MHz to 220 MHz. The experimental set-up is shown in Fig. 3-8. Verification of the calculated impedance and the predicted pattern as well as determination of the efficiency remain to be done.

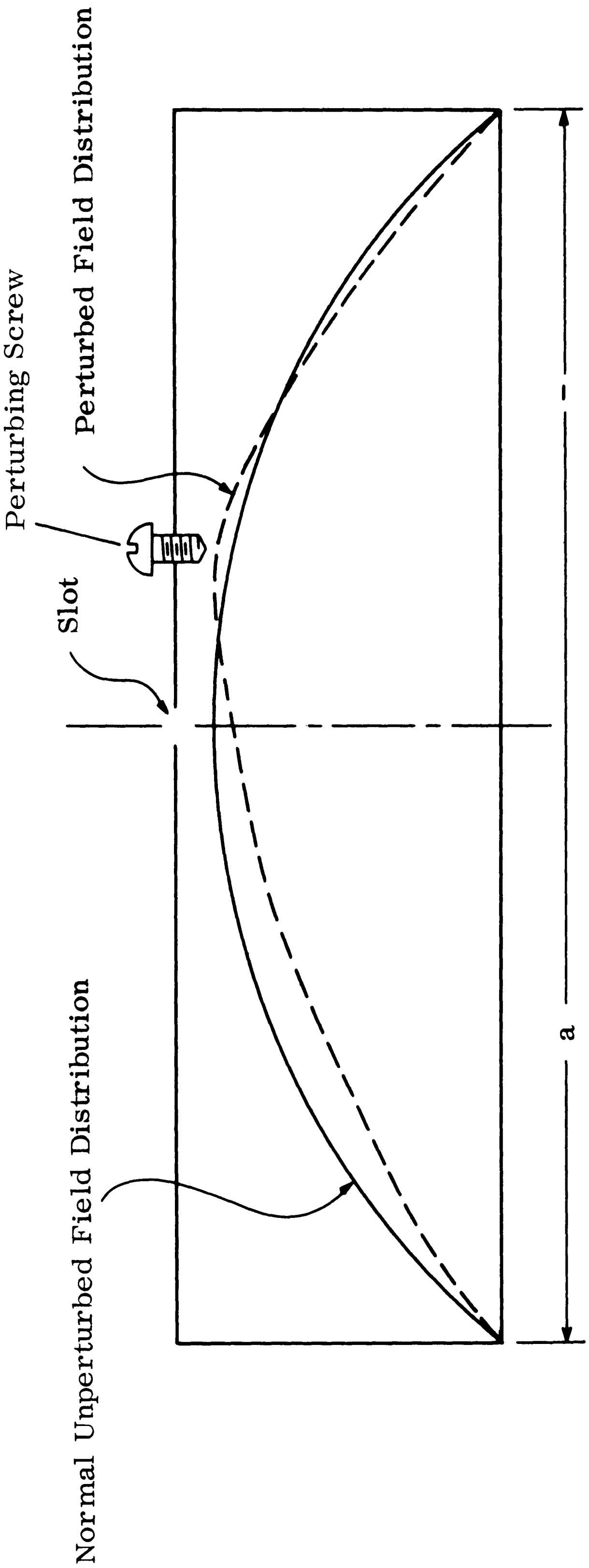


FIG. 3-7: FIELD DISTRIBUTION OF A SLOT

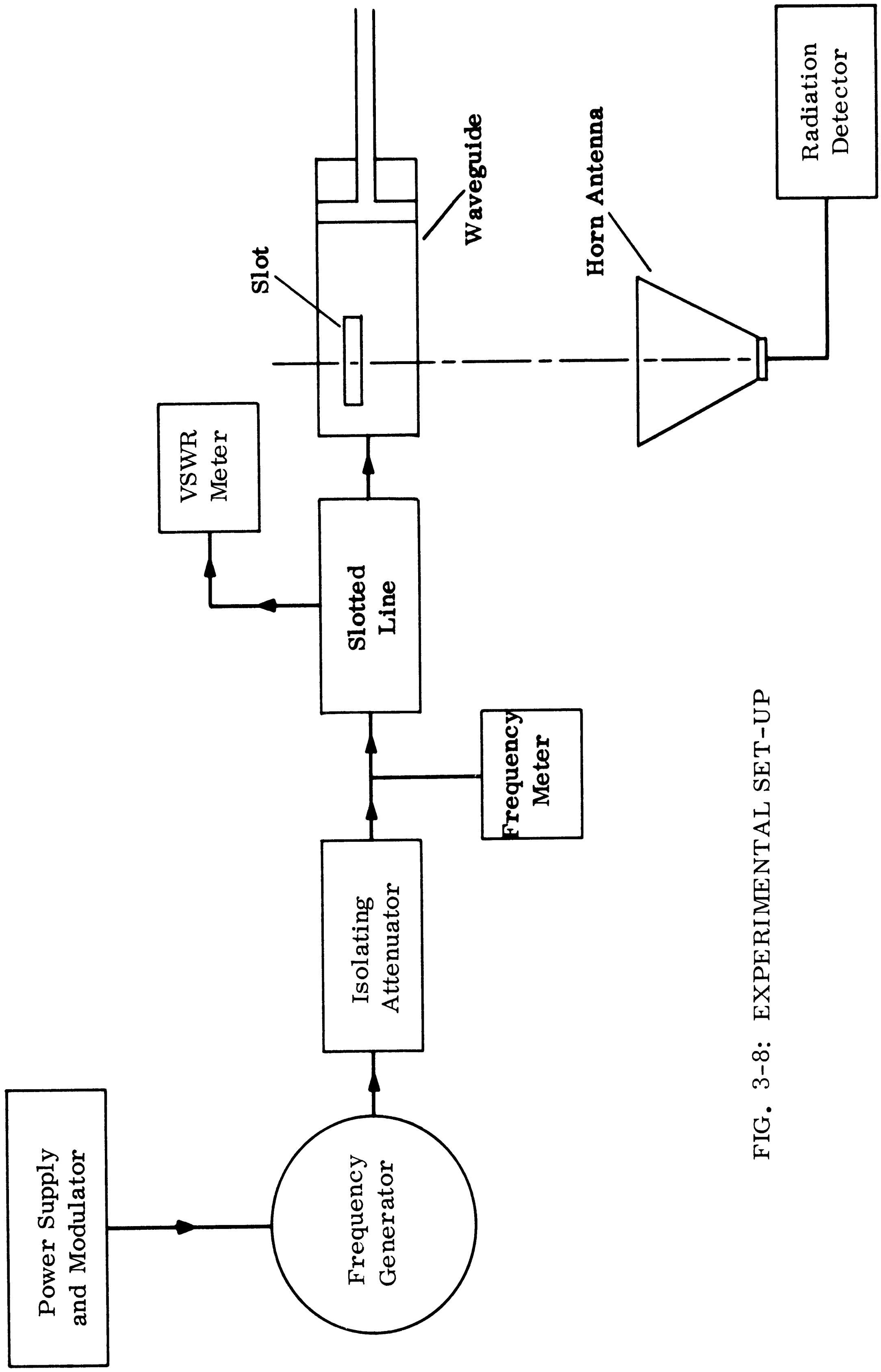


FIG. 3-8: EXPERIMENTAL SET-UP

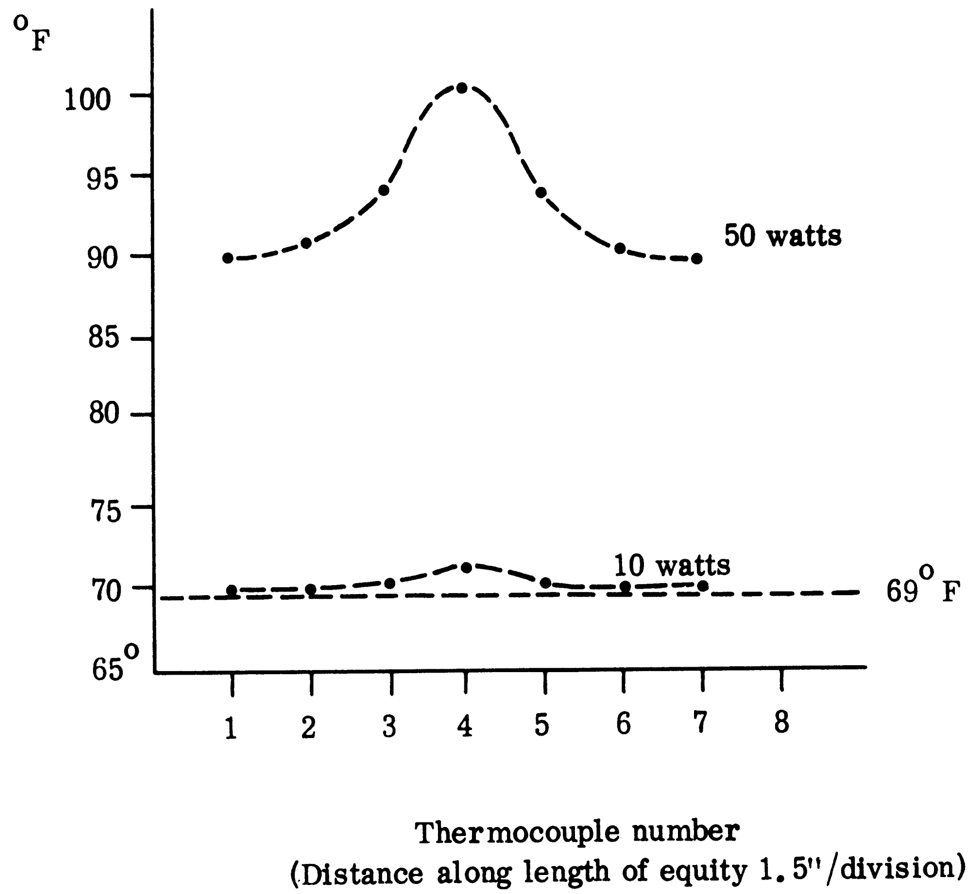
IV
POWER MEASUREMENT OF FERRITE LOADED ANTENNA

4.1 Power Capability of Ferrite Loaded Slot Antenna

Since it is anticipated that ferrite loaded transmitting antennas may be operated at high power input levels, an investigation was made of the limitations which may be imposed on allowable power levels due to excessive heating of the loading material and possible deterioration of its inherent magnetic and electrical properties. As a preliminary investigation, a cavity slot antenna filled with EAF-2-A powdered ferrite was tested at 10, 50, 100 and 150 watt inputs. The temperature distribution was measured by means of a series of thermocouples placed along the broad center line of the cavity (see Fig. 4-1).

The dimensions of the slot antenna tested are 12"x3" backed by a cavity 5" deep. The thermocouples are Copper-Constantan probes inserted 2.5" into the aperture face of the cavity. After a typical temperature versus thermocouple location curve was established (Fig. 4-1), only the thermocouple located at the point of maximum temperature rise (center of antenna) was retained. The rest were removed in order to eliminate the perturbations of the electromagnetic field. The data points for the curves of Fig. 4-1 were taken after thermal equilibrium was reached.

The block diagram of the experimental set-up is shown in Fig. 4-2. This arrangement was decided upon as the most appropriate, after several schemes were tried. The frequency of operation for the tests was 312.5 MHz where the VSWR was 1.16 and 1.47, respectively, with and without thermocouple No. 4 in position. Some of the results of the experiments are shown in Figs. 4-3 and 4-4. Of particular interest is the graph of temperature versus time which appears in Fig. 4-3. This graph corresponds to 150 watts input. The 150 watt curve covers an abrupt



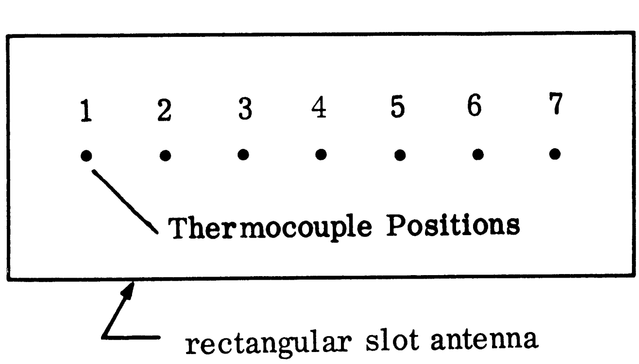
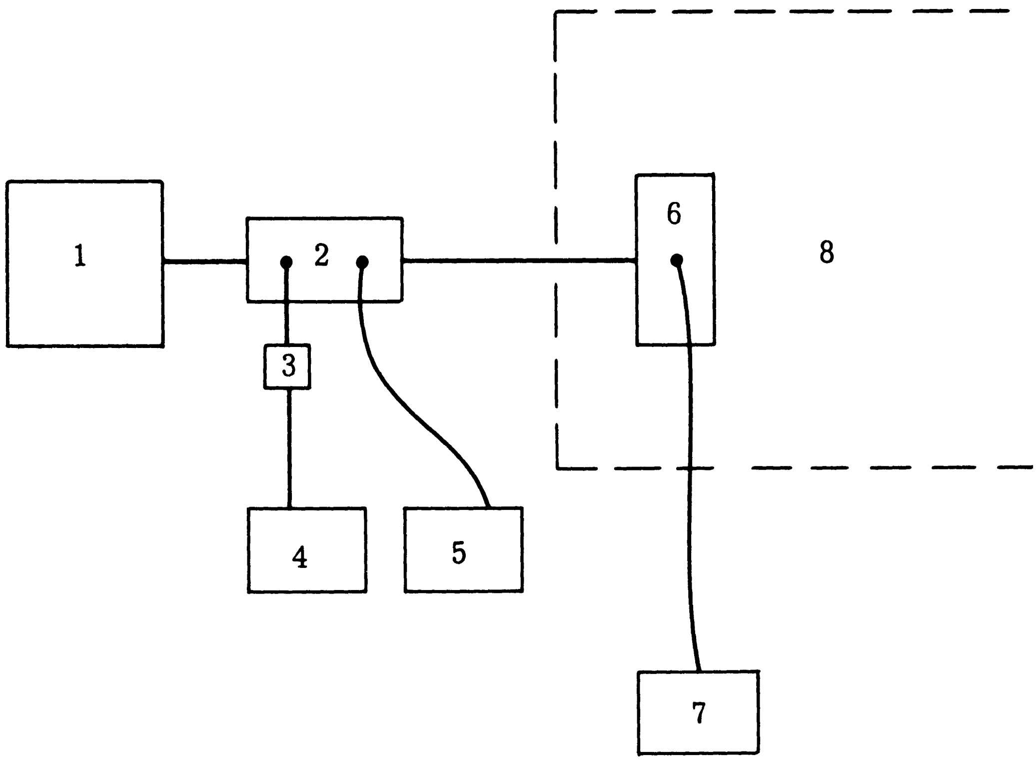


FIG. 4-1: TEMPERATURE VERSUS POSITION IN CAVITY AT THERMAL EQUILIBRIUM



1. High Power transmitter
2. 40 db Directional coupler
3. 10 db Attenuator
4. Incident power meter
5. Reflected power meter
6. Antenna
7. Temperature bridge
8. Anechoic chamber

FIG. 4-2: EXPERIMENTAL SET-UP

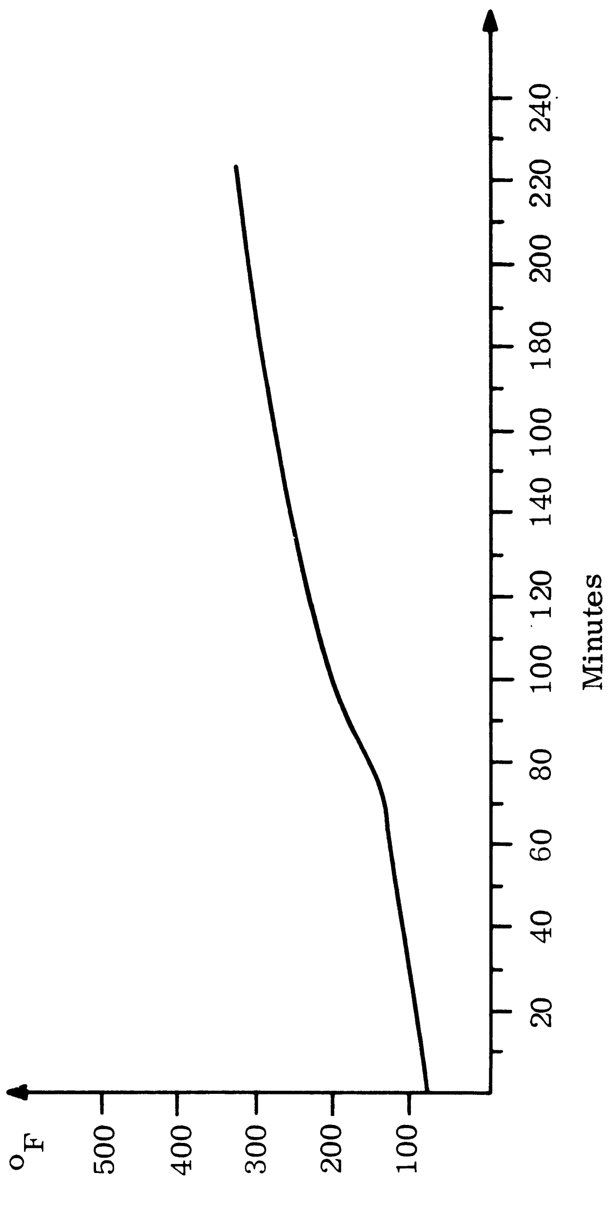


FIG. 4-3: INCREASE IN TEMPERATURE VERSUS TIME (150 watts).

change of the characteristics of the ferrite at temperatures ranging between $120 - 150^{\circ}$ F. If this change is attributed to the deterioration of μ' and μ'' at these temperatures, then from Fig. 4-4 the power limitation of the ferrite loaded, slot antenna is about 50 watts. However, before any definite conclusions are reached one must determine the exact dependence of μ' and μ'' on temperature for the EAF-2-A powdered ferrite. For this investigation measurements can be taken using modified techniques as given in the references (Rado, 1955 and Lax 1962). Also, measurements for the determination of the performance of ferrite loaded antennas, at elevated temperatures showing any deterioration of radiation pattern or efficiency should be made.

4.2 Loss Tangent, Q_m Determination Method For Lossy Ferrites

The loss tangent and magnetic Q-factor of lossy ferrite materials can be accurately measured by employing a short-circuited coaxial transmission line technique. The short circuited impedance of a coaxial line is given by

$$Z_{sc} = Z_o \tanh \gamma \ell \quad . \tag{4.1}$$

If the line is loaded by ferrite material in a length ℓ_f (as shown in Fig. 4-5) then Eq. 4.1 is modified as

$$Z_{sc} = Z_f \tanh \gamma_f \ell_f \quad , \tag{4.2}$$

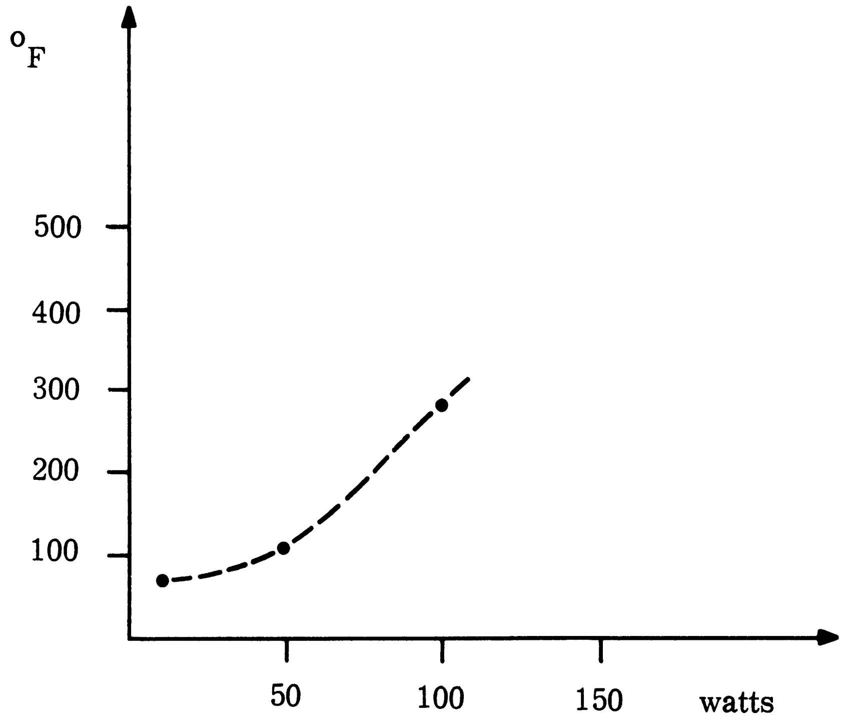


FIG. 4-4: °F VERSUS WATTS

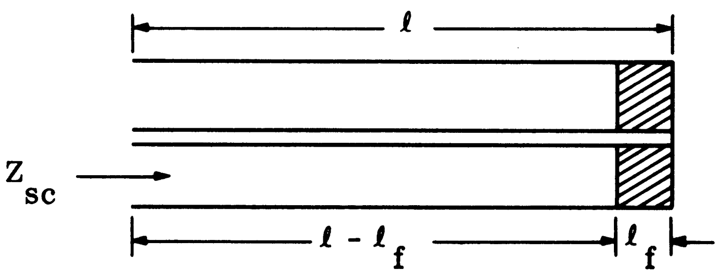


FIG. 4-5: COAXIAL LINE WITH SPECIMEN IN POSITION

where $Z_f = \sqrt{\frac{\mu}{\epsilon}}\, Z_o$, $\gamma_f = \alpha_f + j\beta_f$, α_f = attenuation constant in the ferrite, β_f = phase constant in the ferrite.

Using an impedance bridge, a reference for the shorted air-loaded line is established by employing (4. 1) and a $Z-\theta$ chart. When the ferrite specimen is placed in the line, the readings taken by the use of the bridge are transformed through an $\ell - \ell_f$ rotation in the $Z-\theta$ chart, in degrees. This then gives the correct Z_{sc} for the ferrite material. If the length of the ferrite sample is very small relative to the wavelength $(\ell \leq \lambda/70)$ one can approximate relation (4. 2) by

$$Z_{sc} \cong \sqrt{\frac{\mu}{\epsilon}}\, Z_o \gamma_f \ell_f \quad . \tag{4. 3}$$

Also, for ferrites assuming the lossy component of the permittivity constant negligible and writing $Z_{sc} = R + jX$, one obtains:

$$R + jX = \sqrt{\frac{\mu' - j\mu''}{\epsilon}}\, Z_o \gamma_f \ell_f \quad . \tag{4. 4}$$

From the above relation by squaring both sides, rearranging terms and then separating real and imaginary components one obtains:

$$\mu'(\alpha_f^2 - \beta_f^2) + \mu''(2\alpha_f \beta_f) = (r^2 - x^2)\frac{\epsilon}{\ell_f^2} \tag{4. 5}$$

and

$$\mu'(2\alpha_f \beta_f) - \mu''(\alpha_f^2 - \beta_f^2) = (2rx)\frac{\epsilon}{\ell_f^2} \tag{4. 6}$$

with $r = R/Z_o$, $x = X/Z_o$.

Solving (4. 5) and (4. 6) for μ', μ'' and taking the ratio $\frac{\mu''}{\mu'}$ there results:

$$\tan \delta_m = \frac{\mu''}{\mu'} = \frac{\dfrac{r^2 - x^2}{2rx} - \dfrac{\alpha_f^2 - \beta_f^2}{2\alpha_f \beta_f}}{1 + \left(\dfrac{r^2 - x^2}{2rx}\right)\left(\dfrac{\alpha_f^2 - \beta_f^2}{2\alpha_f \beta_f}\right)} \tag{4.7}$$

Thus the magnetic Q is:

$$Q_m = \frac{1 + \left(\dfrac{r^2 - x^2}{2rx}\right)\left(\dfrac{\alpha_f^2 - \beta_f^2}{2\alpha_f \beta_f}\right)}{\dfrac{r^2 - x^2}{2rx} - \dfrac{\alpha_f^2 - \beta_f^2}{2\alpha_f \beta_f}} \tag{4.8}$$

where the parameters r, x, α_f, β_f can be experimentally measured.

V
CONCLUSIONS

The phase velocity on a helical structure at a given frequency has been shown to be readily attainable through the use of a shorting ring on the complementary helix. As described in the body of the report, the measurements are actually standing wave measurements at the feed-end of the antenna.

The measurements on ferrite loaded log conical antennas are sufficiently encouraging so that all of the objectives for this type of antenna seem to be obtainable at least in part. In now appears that the most difficult part will be the requirements on physical size.

The design study on array antennas using ferrite loaded rectangular slots of small dimensions is encouraging from the consideration of the reduction of mutual coupling due to the small elements. The variation of the port impedance of a phased array will be much improved if the viewpoint expressed here on mutual coupling is substantiated. The interdigital array study has not been carried to the point where a firm evaluation can be made. Similar statements apply to the ferrite rod task and the task for a ferrite loaded antenna operable down to 30MHz.

VI
FUTURE EFFORT

In the near future, possibly by the end of the next quarterly report period, it is anticipated that the analysis of the conical spiral treated as a helix boundary value problem with loading material will be completed. It is planned to present the detailed analysis of this type of antenna.

Arrangements will be made so that the power handling capability of the conical spiral can adequately be tested. Generators, together with amplifiers, capable of producing 100 watts cw power, will be made for a few spot frequencies. It is still hoped that a high power generator capable of delivering in excess of 100 watts, over a frequency range of 200-600 MHz will be made available by the contracting agency.

It is expected that experimental work on the radiation properties of the small slot array with ferrite loading will be available at the end of the next report period. The newly improved range facility should be usable within the next few days to allow this work to proceed.

Work is continuing on the interdigital array and considerable analytical effort is already under way. Some preliminary results of an experimental nature should also be available in the very near future.

The study of endfire ferrite rod antennas for the frequency range from 300-1000 MHz has been initiated. In the next quarterly report, a detailed comparison of ferrite rod radiators with dielectric rod radiators will be made from an analytical viewpoint. It is expected that some of the future experimental work will also give detailed comparisons of these types.

The task involving the feasibility of new types of antennas capable of operating with ferrite loading down to 30 MHz has been barely started. However, the direction of effort will be to consider types on two bases: 1) the utilization of existing types previously good only for higher frequency but with ferrite loading capable of operating at lower frequencies; 2) the creation of entirely new types of antennas which with ferrite will give radiation efficiencies comparable to prevailing efficiencies at frequencies down to 30 MHz. Immediately after a survey of types, it is anticipated that a great deal of experimentation will take place on selected types which offer the greatest promise. It is anticipated that this task will be attacked primarily on an experimental basis.

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13. ABSTRACT

This first quarterly report describes the effort devoted to the four listed tasks of this project. The largest part of the effort has been devoted to two of the tasks; (1) the conical spiral antenna or the log conical spiral antenna, as frequently called; (2) array antennas utilizing loading effects on elements. The remaining tasks (3) endfire ferrite rod antenna and (4) new antenna types at 30 MHz are covered very briefly. These last two tasks have just been initiated.

In addition, some effort has been devoted to electrical properties of material and the measurement of these properties. This information on properties of material will be helpful for the ferrite loading involved in the four numbered tasks. Some data are also included on the power level limitations of ferrite loaded rectangular slot antennas.

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