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Polarization Scanner Progress Report

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Addendum No. 1 to Technical Memorandum EDL-M420

ERRATA

The following change(s) should be made in the original publication. Each corrected page should be marked "Revised 28 February 1962" in the upper right-hand corner under "EDL-M420."

Page 11: Change first sentence to read "The 1-mil thickness is much greater than a skin depth at S-band, but much less than a skin depth at audio frequencies."

EDL-M420

ELECTRONIC DEFENSE LABORATORIES

P. O. Box 205

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TECHNICAL MEMORANDUM
No. EDL-M420
5 February 1962

POLARIZATION SCANNER PROGRESS REPORT

Bernard J. Lamberty

Approved for publication . . . . N. J. Gamara
Manager
Antenna Department

Prepared for the U.S. Army Signal Research and Development Laboratory under Signal Corps Contract DA 36-039 SC-87475.

SYLVANIA ELECTRIC PRODUCTS INC.

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POLARIZATION SCANNER PROGRESS REPORT

Bernard J. Lamberty

1. ABSTRACT.

This is a report of progress in developing a polarization scanner for use with an existing S-band conical scanning antenna. An objective was to provide as simple a system as possible, both in terms of modification to an existing position tracking system and in terms of operational complexity. A block diagram of one such system, using a ferrite rotator, is presented, and preliminary experimental results are described. Some difficulties were encountered, chiefly due to operation at S-band. Use of a ferrite rotator appears to be more feasible for use at X-band.

Another system involving peak-holding techniques was investigated. This system was used successfully to track a moving light source. The success achieved shows that the peak-holding technique could be used for polarization scanning of microwave signals.

2. INTRODUCTION.

An objective of the work reported herein was to develop a polarization scanner for use with an existing S-band,conical-scanning position-tracking antenna system. Consequently, an attempt was made to develope as simple a polarization scanning system as possible, involving a minimum of modifications to existing position-tracking equipment. In a previous report[1] several methods of analysis and synthesis of polarization of electromagnetic waves were suggested. Among these was an analog system, using three receiver channels, and a system using a ferrite polarization rotator. In later reports, the analog method was described in detail[2] and evaluated experimentally.[3]

The analog method, although technically satisfactory, is considered to be too complex to satisfy the objectives of simplicity and compatibility. Therefore, an investigation was made of less complex systems. This

2. Continued.

report includes a description of progress on an experimental model using a ferrite polarization rotator. An additional method using peak-holding techniques, is suggested. As in the analog method, these methods are only concerned with determining the orientation angle of the incident wave, and then synthesizing this parameter in a linearly polarized antenna of a position-tracking system. Axial ratio and sense of rotation are not determined. A disadvantage of the methods described herein, that was not encountered in the analog method, is the requirement that the incident wave be CW or have a high pulse repetition frequency.

The following section presents a qualitative descritpion of a polarization scanning system using a ferrite rotator. In subsequent sections, the scanning system is analyzed in greater detail, and its incorporation into a specific position-tracking system is described. Results of preliminary experimental data are presented.

The peak-holding method and results of some early experiments are also described.

2.1 The Polarization Scanning System Using a Ferrite Rotator.

A block diagram of a polarization scanning system, using a ferrite polarization rotator, is shown in Figure 1. A conical feed horn and a circular waveguide, both of which support electronmagnetic waves of any polarization, are connected to a ferrite device which can rotate the polarization ellipse of an incident wave. The angle of rotation is a function of the magnetic field in the ferrite, which is in turn related to the magnitude of a magnetizing current. Broadband designs of such a device have been reported at X-band.[4] The ferrite polarization rotator is terminated in rectangular waveguide. If an arbitrarily polarized wave is incident on the conical horn, and the magnetizing current is varied, the orientation angle of the polarization ellipse is rotated in the waveguide. When the orientation angle is normal to the wide dimension of the rectangular waveguide, maximum signal is present at the output. Conversely, when the orientation angle is parallel to the wide dimension, minimum signal is present at the output. The magnitude of the magnetizing current producing minimum output from the rectangular waveguide is then a measure of the polarization orientation angle of the incident wave.

A sweep generator provides the ferrite with a sawtooth magnetizing current. If used with a broadband ferrite rotator, the sawtooth current waveform produces 180-degree continuous polarization rotation at all frequencies in the band of operation. Polarization rotation is linear in

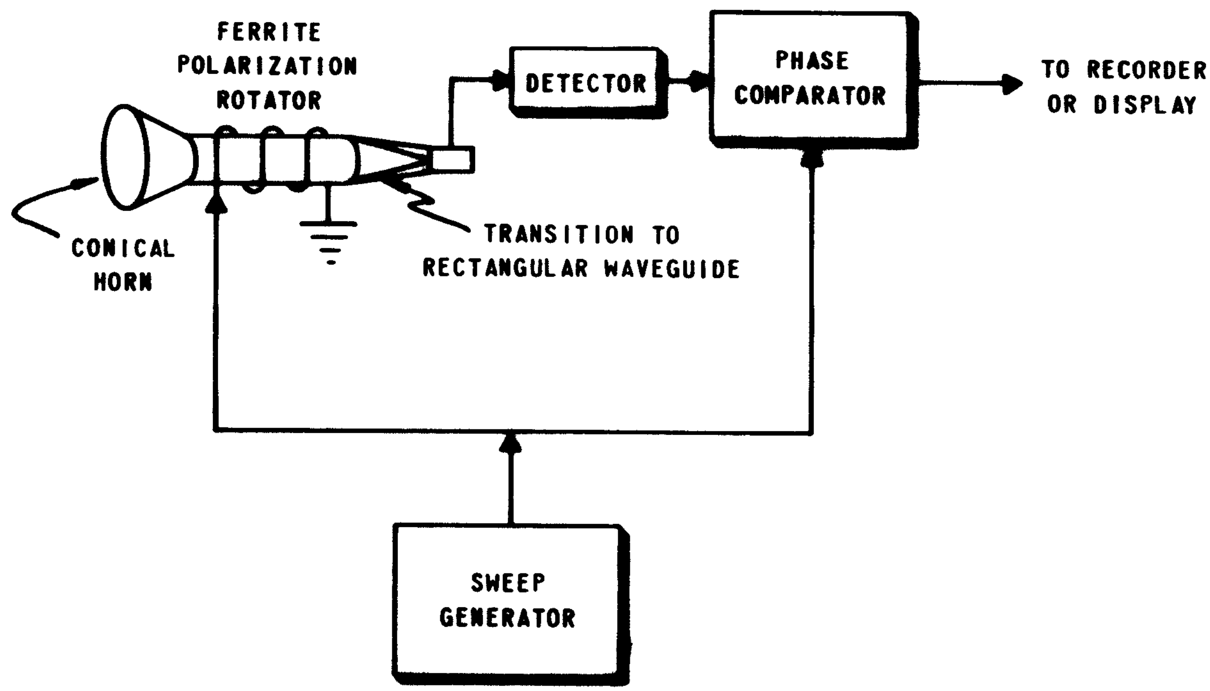


Figure 1

A Polarization Scanning System Using a Ferrite Rotator -- Block Diagram

2.1 Continued.

time, resulting in modulation of the received CW in the rectangular waveguide. The resultant waveform resembles a carrier which is amplitude-modulated by a rectified cosine signal. The modulation is 100 per cent for linearly-polarized incoming waves and zero per cent for circularly-polarized waves. The relative time position of the minimum value of the modulated wave with respect to the flyback of the sawtooth magnetizing current waveform is a measure of the original orientation angle of the incoming wave. Phase comparison is made at the detector output where the waveform is half of the modulation envelope. These waveforms are illustrated in Figure 2 for a linearly-polarized incoming signal. The polarization orientation angle of the incoming wave is given by:

$$\chi = 180 \frac{a}{t} = 180\ af,$$

where χ = the polarization orientation angle, in degrees ($\chi = 0$ corresponds to orientation parallel to the broad face of the terminating rectangular waveguide),

a = the time from flyback to minimum detector output, in seconds,

t = the period of the sawtooth, in seconds,

f = the frequency of the sawtooth in cps.

This method is applicable to CW-type signals or pulse-type signals having a high PRF. If pulse-type signals are received, the frequency of the magnetizing sawtooth current should be about one-tenth of the PRF so that several pulse bursts may be compared on each sweep. If the signal PRF is low compared to the sawtooth frequency, signal polarization or magnitude may change appreciably between pulses. The problem of slow sweep rate is compounded where azimuth and frequency scan (scan-on-scan) is necessary in addition to polarization scan.

Orientation of a linearly-polarized transmitting or tracking antenna can be achieved by using the displacement in time information between flyback of the magnetizing current and the minimum signal from the detector output. Rotation of polarization of a linearly-polarized antenna, in the polarization synthesis portion of the system, can be accomplished either by mechanical means or by another ferrite rotator.

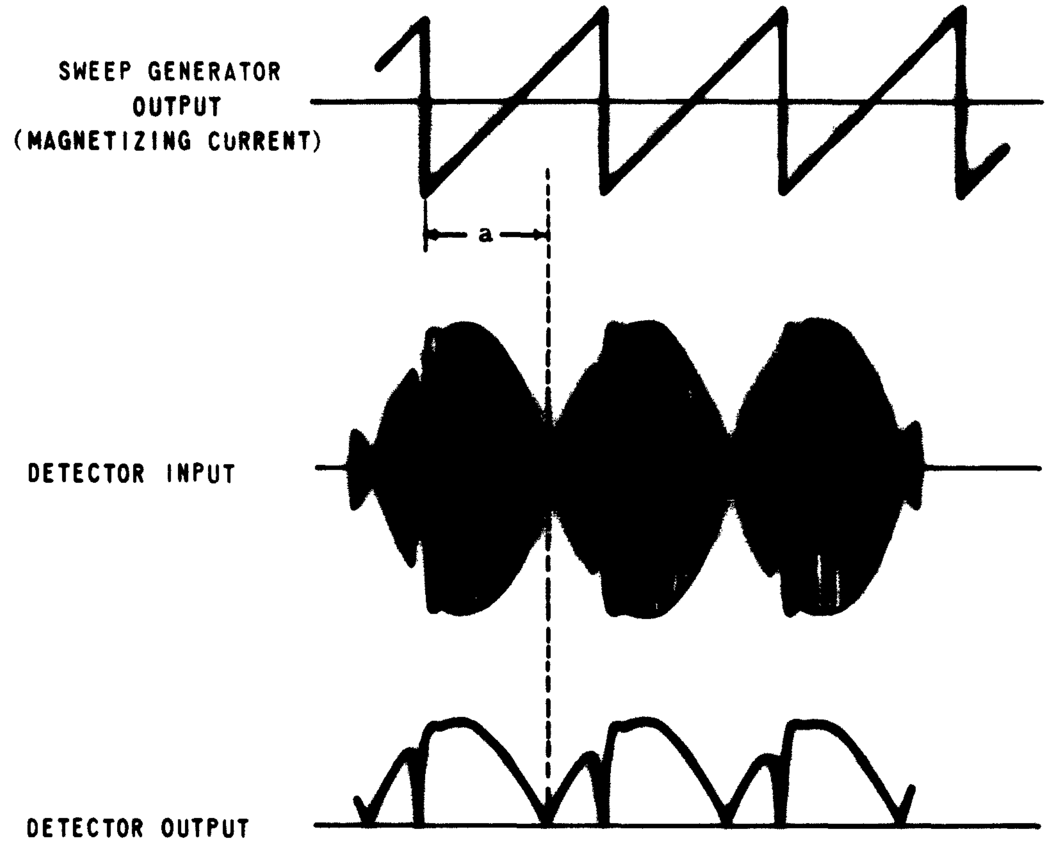


Figure 2

Waveforms for Orientation of Angle Analysis of a Linearly-polarized Incident Wave

2.1 Continued.

Minimum output from the rectangular waveguide is used as a reference since its position is easier to determine than that of maximum output. For a small input signal condition, referencing may be required on the maximum output since the minimum may be obscured by noise.

2.2 Polarization Scanning using Peak-holding Techniques.

An alternate method of referencing to the maximum output value, using peak-holding techniques, is also being investigated. The peak-holding method adjusts the polarization of the receiving antenna so that the received signal is continuously maximized. The controlling adjustment can be either electromechanical or purely electrical, as in the ferrite rotator method.

An experimental model using the peak-holding technique was constructed for automatic tracking of a light source by a photo-sensitive cell mounted on a single-axis antenna control system. The basic principles of this system are applicable to a polarization control system at lower frequencies. Preliminary experiments were successful.

3. DESCRIPTION OF THE FERRITE-ROTATOR POLARIZATION SCANNING SYSTEM.

The ferrite-rotator polarization scanning system is intended to scan polarization of an incident S-band wave, while a conical-scanning antenna is tracking the position of its source. The polarization scanning technique, described herein, requires that the rotating beam resulting from conical scan be adjustable to any fixed linear polarization. Such an adjustable polarization has been described by Epis[5] in a report on a novel design of a conical-scanning position tracker. The design described by Epis enables the position-tracking antenna to track a source whose emitted signals have an arbitrary polarization. The ferrite rotator, to be described, extends the position tracking capability to polarization tracking. In the experimental work, the conical-scan system designed by Epis was used for convenience.

Figure 3 shows a system using a ferrite rotator with a conical-scan, position-tracking antenna. Note that the conical horn feeds an offset parabolic reflector so aperture blocking is minimized. The horn, which rotates at 1800 rpm (30 cps), is connected to a circular-waveguide rotating joint. The ferrite polarization rotator and circuitry is attached to the output of the rotating joint, and the ferrite magnetizing sawtooth current waveform is varied at a rate several times greater than 30 cps. Thus,

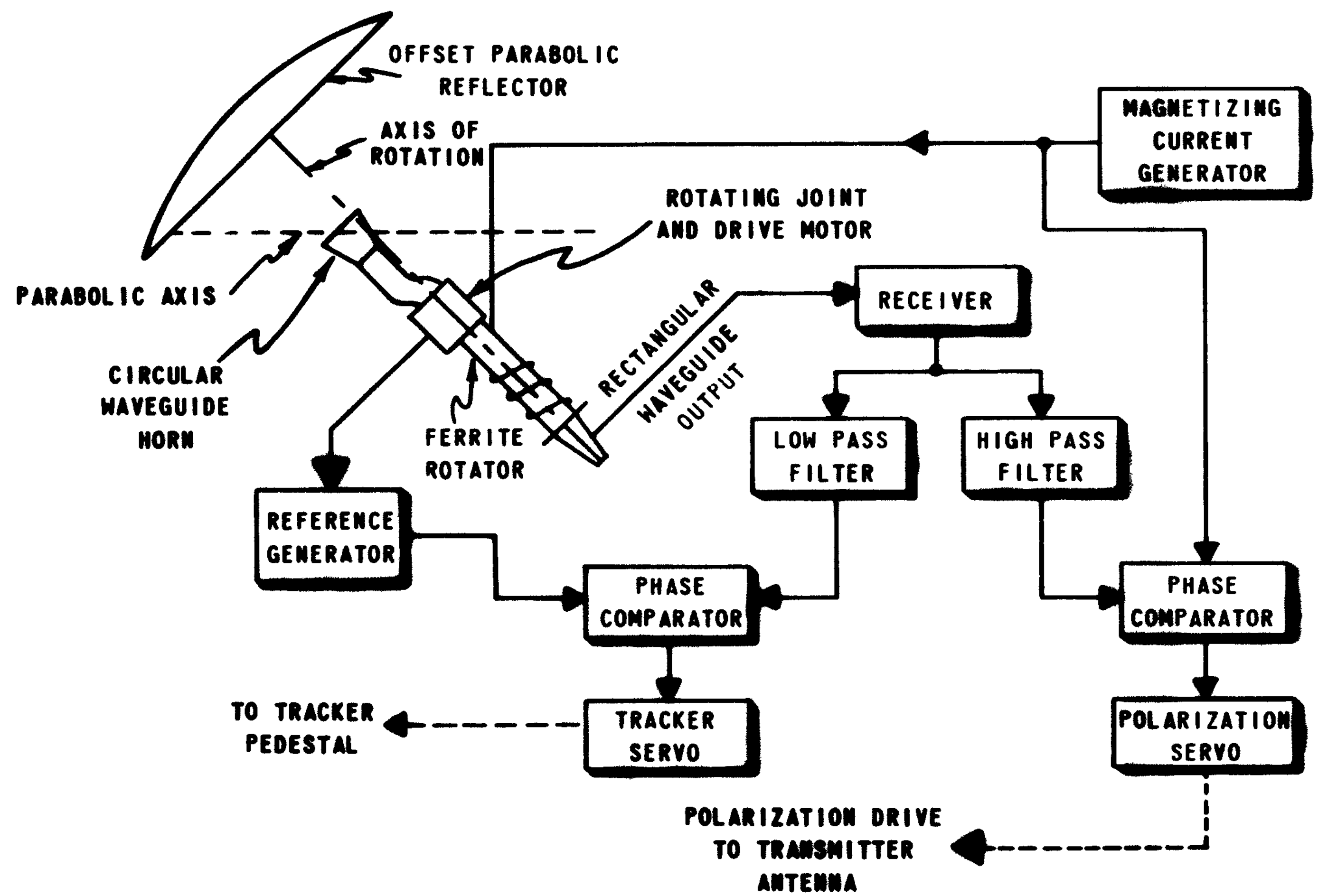


Figure 3

A Ferrite Polarization Scanning Modification to a Conical-scan Position-tracking Antenna -- Block Diagram

3. Continued.

if the position scanner is tracking a steady signal, the input to the ferrite polarization rotator is a fixed polarization signal, amplitude modulated at the position-scanning rate of 30 cps. The amplitude and phase of the 30-cps modulation provide position information about the signal. The task of the polarization analysis circuitry is to extract orientation angle information from this signal without destroying the position information. This is accomplished by means of high and low-pass filters after signal amplification. The output of the high-pass filter contains incident-wave orientation angle information which may be used to control the polarization of another (i.e., transmitting) antenna. The output of the low-pass filter contains position information from the conical scanner which is used to control the tracking-antenna pedestal position.

3.1 Technical Approach and Experimental Program.

Since the modulation frequency of the position tracker is 30 cps, selection of the polarization-rotator sweep frequency must be chosen for least interference with the position tracking. Epis has shown that the signal from a properly-designed conical scanner contains very little energy above the third harmonic of the scanning frequency[6]. This dictates a polarization-scanning frequency above 100 cps which is not an integral multiple of the position-scanning frequency. Choice of scanning frequency is also dictated by other considerations which will be discussed later in this section.

The ferrite rotator itself is based on the design of a phase shifter reported in Reference 4. The rotator is a quadruple-ridged circular waveguide shown in Figure 4. A ferrite investigated for the S-band application was the Motorola M-052 whose characteristics are summarized in Table 1.

It is difficult to apply an audio frequency magnetic field on the ferrite inside the waveguide. A convenient method of applying the magnetic field is by means of a coil wound around the outside of the waveguide, since its presence will not perturb the propagation of the electromagnetic wave within the waveguide. However, if the current in such a coil is varied at a rapid rate, 100 cps or more to produce polarization scanning, the ferrite rotator becomes a transformer, with the magnetizing current coil acting as the primary winding and the waveguide as a shorted secondary winding. Unacceptably large circulating currents would result when an attempt is made to apply an appreciable magnetic field on the ferrite. Consequently, it was decided to construct the circular waveguide portion of the ridged-waveguide section out of

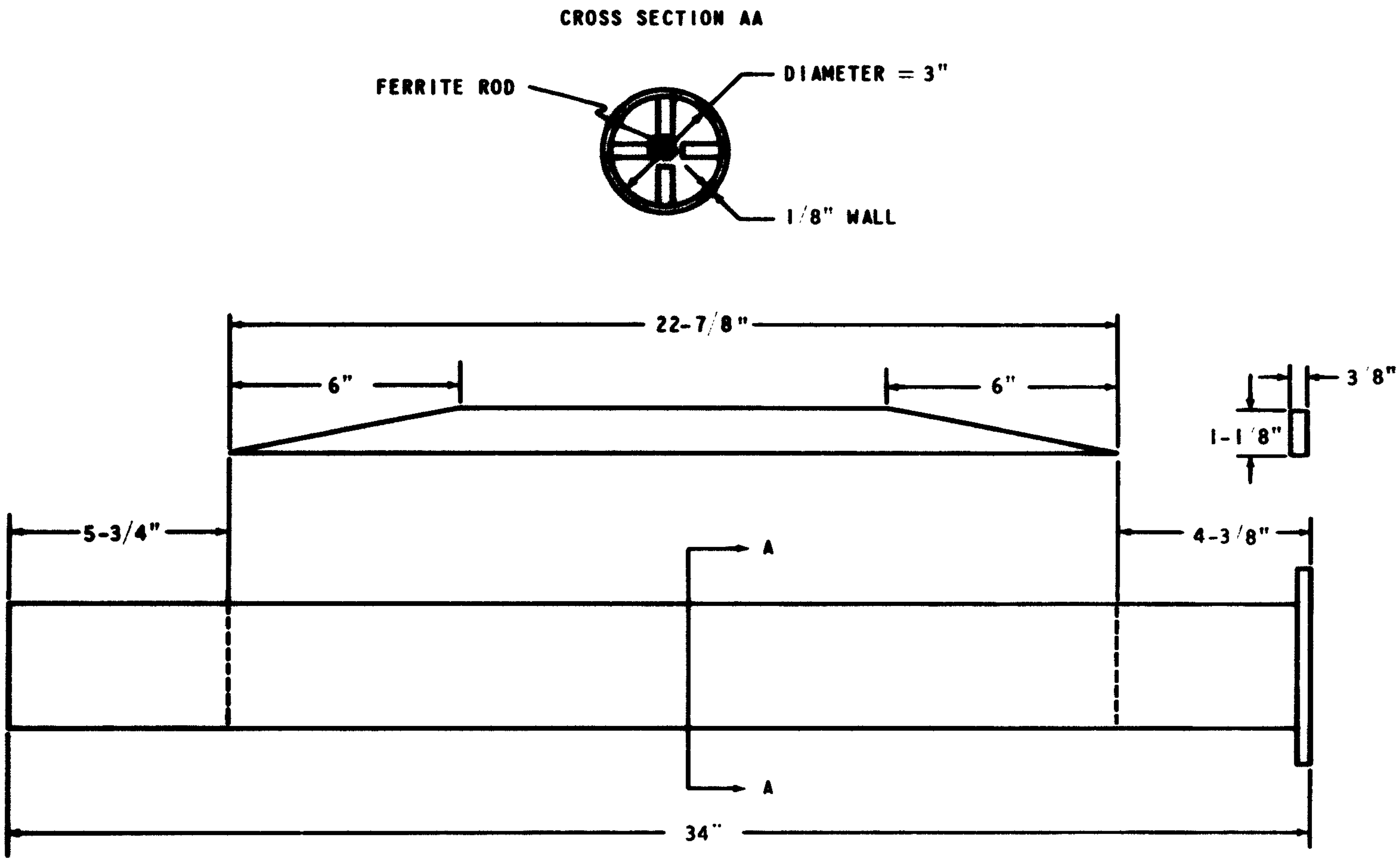


Figure 4

Design Details of a Quadruple-ridged Ferrite Polarization Rotator

TABLE 1

SUMMARY OF APPROXIMATE PROPERTIES OF THE MOTOROLA M-052 FERRITE

Ferrimagnetic resonance line width at 9300 Mc	ΔH	210 oersteds
Effective g-factor at 9300 Mc	g_{eff}	2.27
Saturation magnetization at H_{dc} = 2500 oersteds (20° C)	$4\pi M_s$	3150 gauss
Relative dielectric constant at 20 Mc	ϵ_r	12
Dielectric power factor at 20 Mc	$\tan \delta$	0.002
Curie Temperature	T_e	590° C

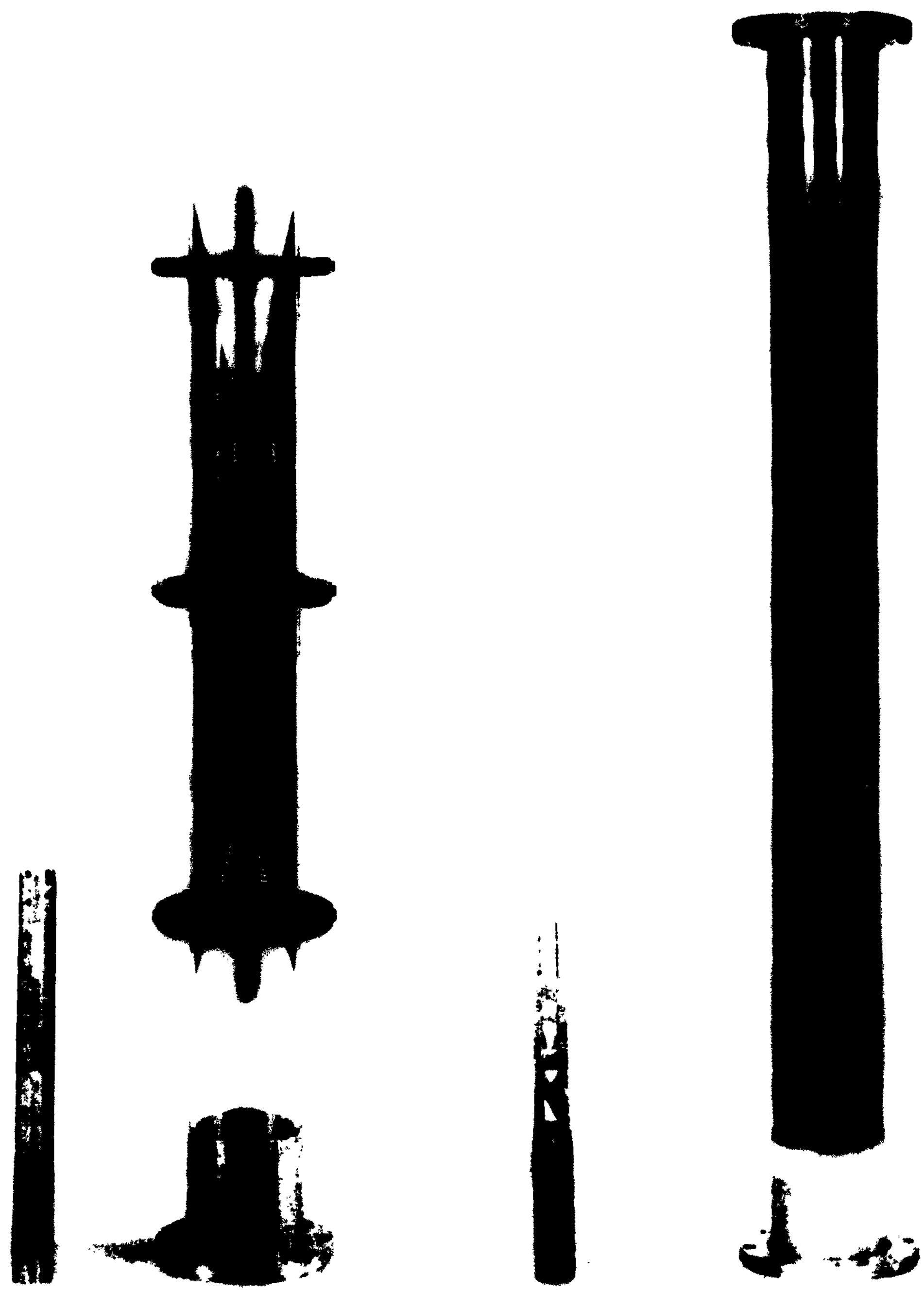
3.1 Continued.

Plexiglas, to insert metal ridges, and to plate the inside of the section with about 1-mil (0.001 inch) of copper. The 1-mil thickness is much less than a skin depth at S-band, but much greater than a skin depth at audio frequencies. Thus, the waveguide propagates electromagnetic waves at S-band, but is transparent to the audio frequency megnetizing current. (1-mil of copper is equal to the skin depth at about 100,000 cps.)[7] Figure 5 is a photograph of the Plexiglas section before and after plating.

The characteristics of plated Plexiglas waveguide were evaluated in an experimental program. Short circular-waveguide sections were constructed of Plexiglas. One was plated with 1-mil copper and another with a thin layer of silver impregnated epoxy. Insertion loss was measured, and the results of these measurements are shown in Figure 6. Figure 6 shows that an average insertion loss of about 0.1 db was measured over most of the frequency band for the copper-plated Plexiglas.

Next, both an unplated Plexiglas circular-waveguide section and a Plexiglas section plated with 1-mil copper were wound with several hundred turns of insulated wire to simulate the magnetizing current coil on the full-size ferrite rotator. Magnitude of input impedance was measured on the coils of both waveguide sections over the audio frequency range, and was found to be nearly identical in both cases (Figure 7). A secondary coil was then wound around a smaller phenolic tube. This coil sampled the magnetic field produced by a current in the primary coils along the axis of the waveguides of both the plated and unplated waveguide sections (Figures 8(a) and 8(b)). The magnetic field was sampled at several audio frequencies to determine whether the plated waveguide caused appreciably more shielding of the field than the unplated waveguide. Results of the test are given in Figure 9. Figure 9 shows the ratio of primary to secondary voltage, as a function of axial position of the secondary coil at several frequencies from 30 to 5000 cps. This figure shows that the shielding effects of the 1-mil copper plating are negligible up to 5000 cps, as predicted from theory. In fact, differences noted between the plated and unplated sections in Figure 7 and 9, may be attributed to differences in the two primary coils themselves.

Many difficulties were encountered in plating the Plexiglas circular-ridged waveguide. A satisfactory component has been fabricated, and will be evaluated in the near future. In the interim, an all-metal, quadrupally-ridged waveguide was constructed and tested with static currents applied to the magnetizing coils. The purpose of the tests



(a) Before Plating 61021402 (b) After Plating 61092811

Figure 5

Photographs of Plexiglas Waveguide Sections

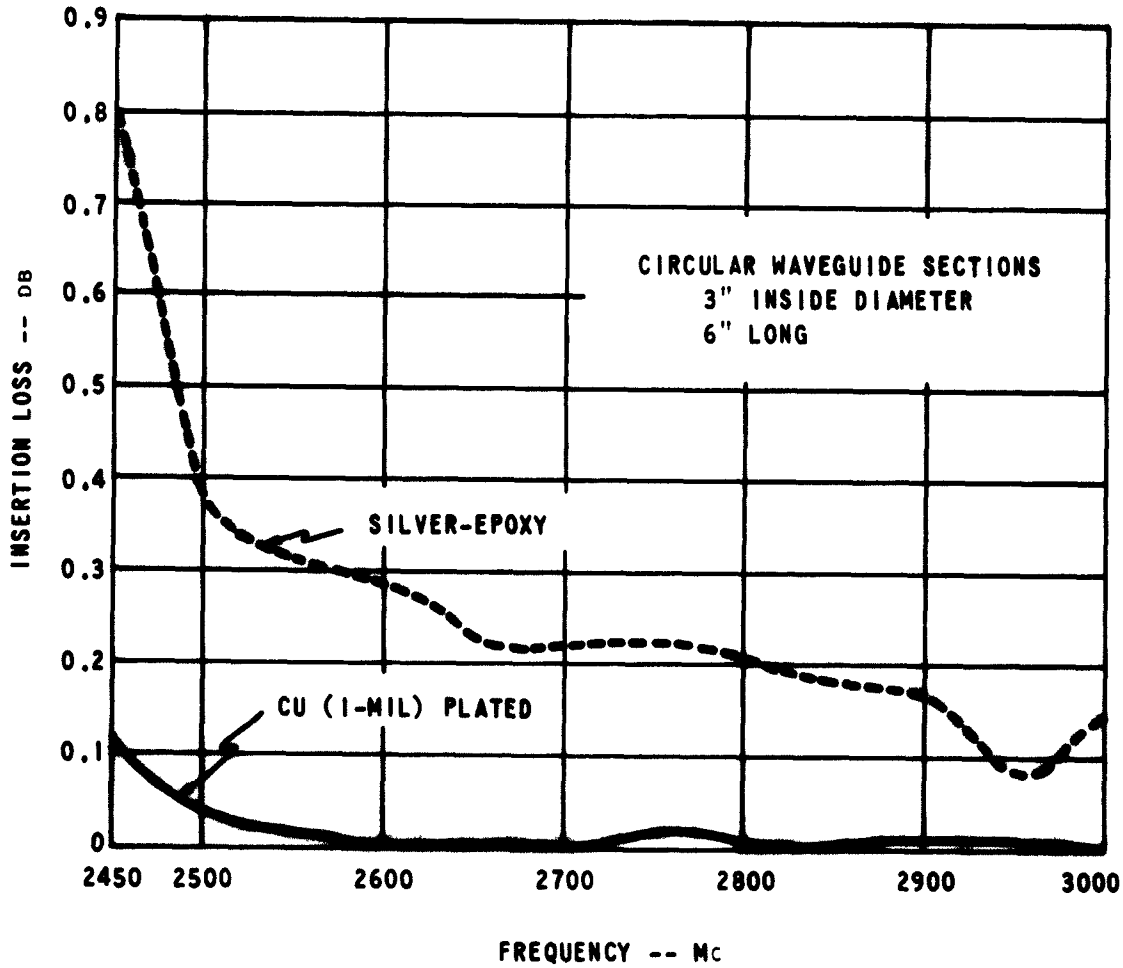


Figure 6

Insertion Loss of Plated (0.001 inch) Copper and Silvered (paint) Rexolite Circular Waveguide Section

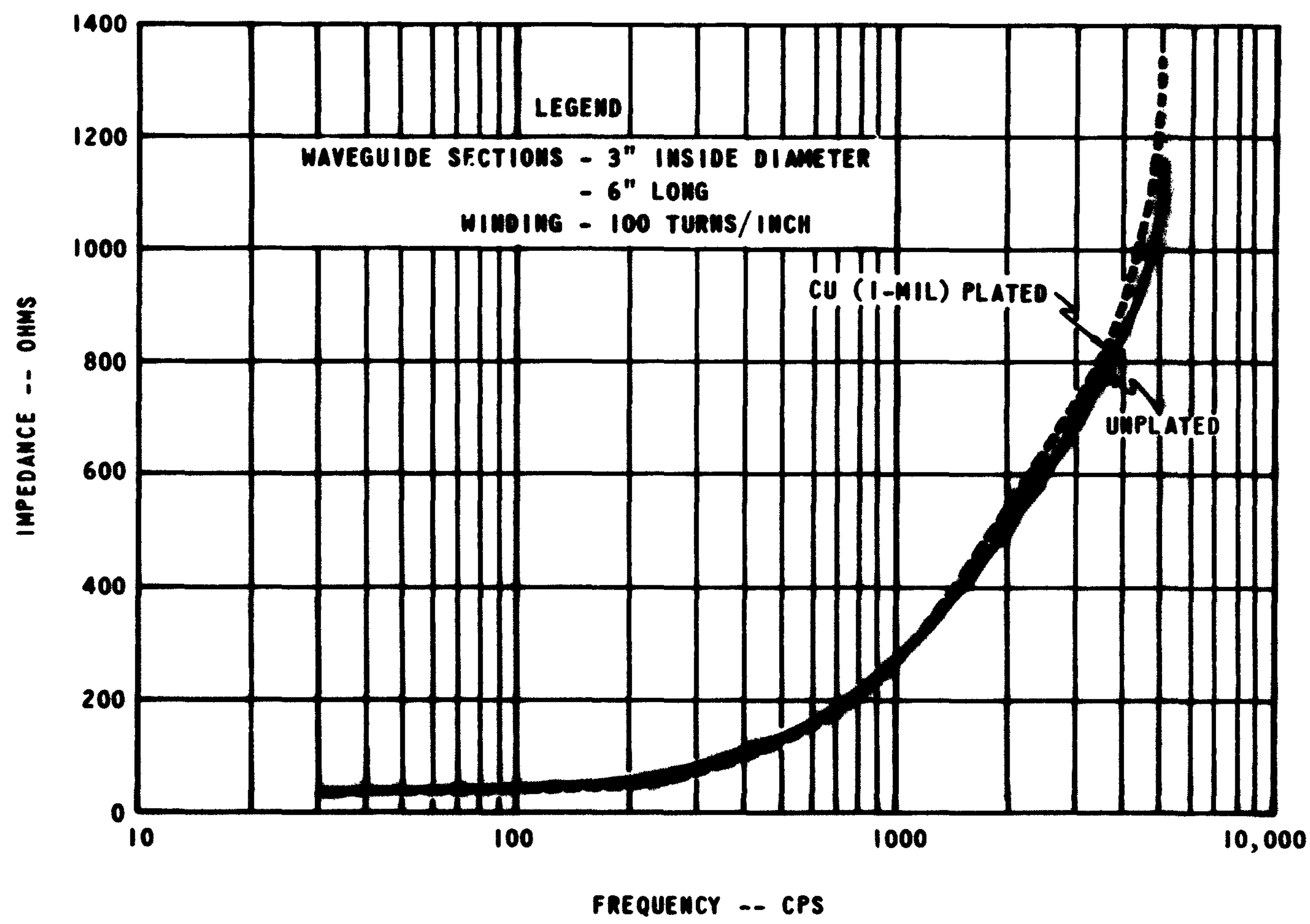


Figure 7

Impedance Characteristic of Solenoid Wound on Plated and Unplated Rexolite Waveguide Sections

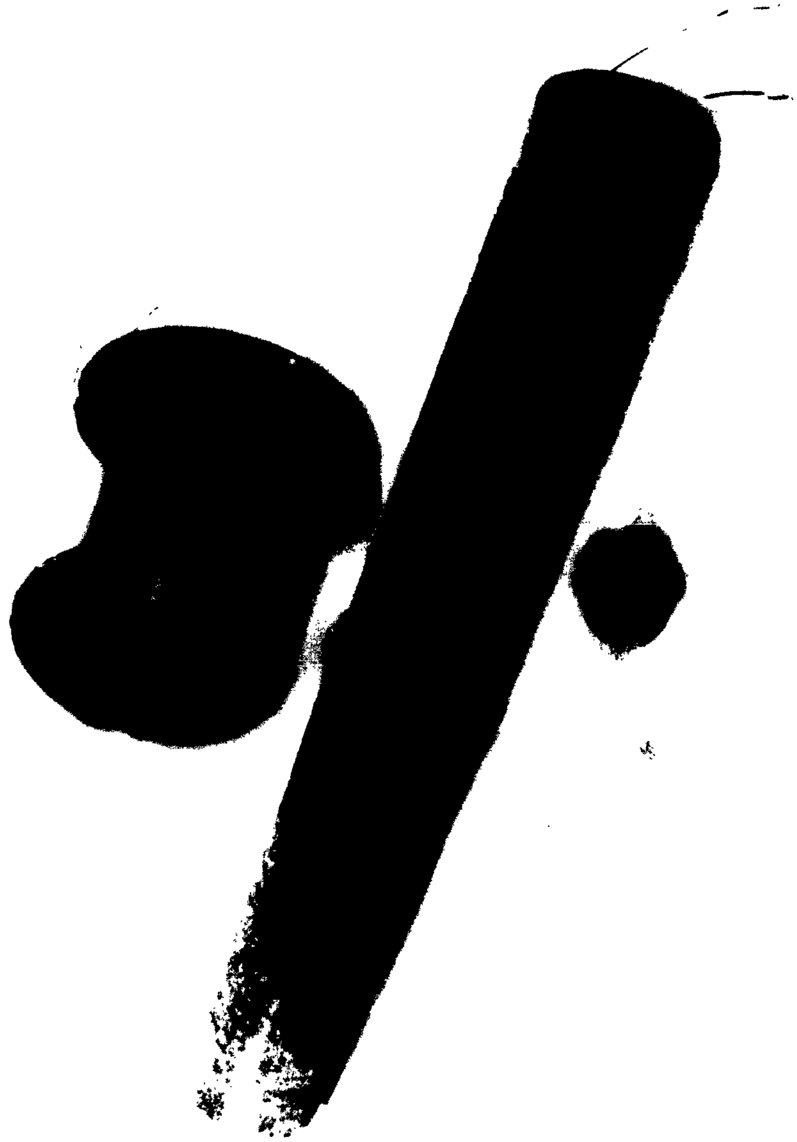


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Figure 8(a)
Photograph of Coil Assembly --
Unassembled Components

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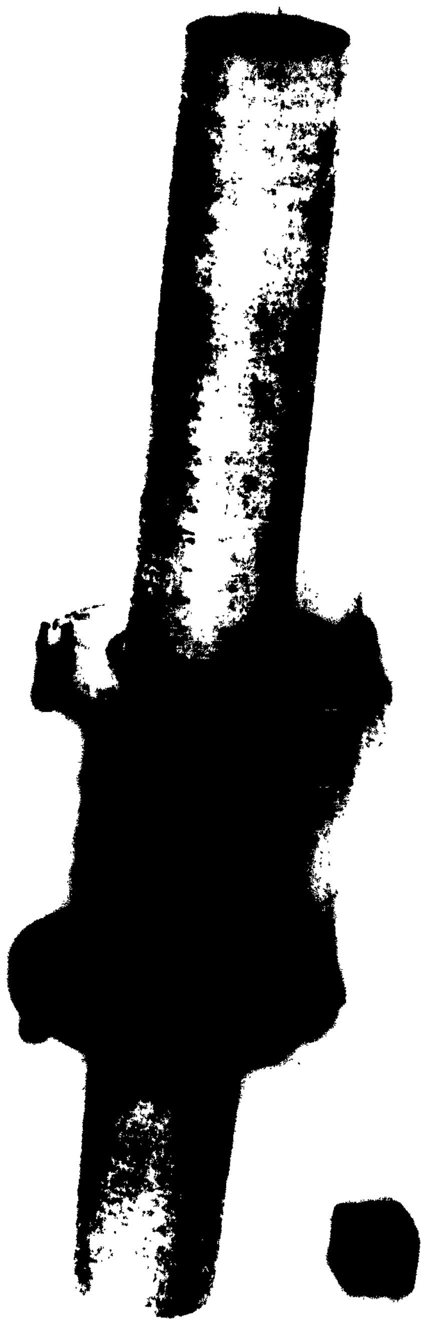

Figure 8(b)
Photograph of Coil Assembly --
Assembled Components

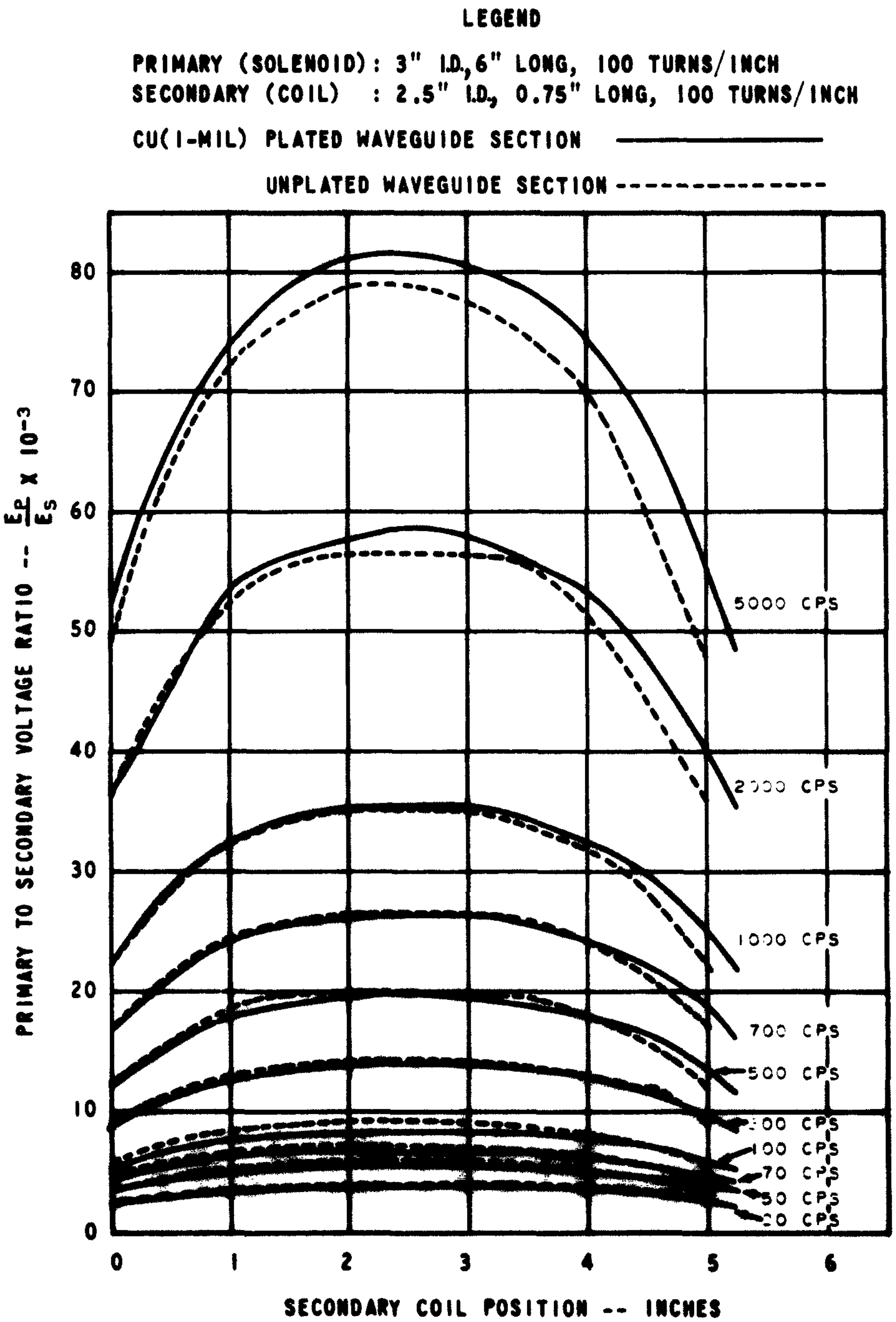

Figure 9

Voltage Ratio of Primary (Solenoid) to Secondary (Coil) as a Function of Axial Position of Coil Assembly

3.1 Continued.

was to determine the phase shift as a function of magnetizing current over the intended frequency range of operation. Unfortunately, the ferrite selected (M-052), produced an extremely high zero-field insertion loss (about 30 db for 12 inches of ferrite rod). An applied field of about 75 oersteds reduced this loss by only 3 db.

Existence of the high zero-field loss is disconcerting. Similar experiments at this laboratory and elsewhere[4] have indicated that such a high loss is not usually encountered. Although the other referenced experiments were performed at X-band, it seems reasonable to expect that ferrite material should be available which would provide satisfactory operation at S-band. Consequently, use of other ferrites for this application is under investigation. Previous experiments have also shown that tolerances in ferrite devices are extremely critical. Tolerance in ferrite devices is also being investigated.

4. SUGGESTIONS FOR FURTHER WORK.

Use of ferrites other than the M-052 will be investigated for the polarization rotator application. Particular attention will be given to those having low zero-field loss.

In this experimental work, the solenoid used to apply the magnetic field to the ferrite had a large air gap. Consequently, use of a shorter coil with a higher number of turns should be investigated to determine if the higher resultant magnetic field intensity, and a smaller piece of ferrite, will be more successful in reducing zero-field loss, and still provide sufficient rotation to waves passing through the polarization rotator.

Effects of ferrite tolerance on operation will also be investigated. Tolerance has been found to be an important factor in other ferrite applications.

Once a satisfactory ferrite-solenoid combination is developed, frequency dependence must be evaluated. Following this, the necessary ac waveforms to produce a linear 180-degree polarization rotation must be determined. and evaluated.

Development of the peak-holding technique will continue.

4.1 Difficulties Anticipated in Future Work.

Two main difficulties are anticipated; both are associated with the intended application of the system in S-band. These difficulties are:

4.1 Continued.

(a) Characteristics of ferrites are not the same at this frequency as they are at higher frequencies. Insertion losses are usually higher and polarization rotation with magnetic field is usually smaller at S-band than at X-band.

(b) The solenoid required to impose a magnetic field on the ferrite has a large air gap. This is the consequence of the large diameter of S-band waveguides. Consequently, it is difficult to apply a magnetic field sufficiently large to cause an adequate polarization rotation.

In spite of these difficulties, the ferrite rotator method for polarization scanning has the great advantage of being simple in design and operation, and should be brought to a successful completion.

5. SUMMARY AND CONCLUSIONS.

The foregoing has been a progress report on a ferrite polarization scanner to be used with an S-band position tracker. Experimental investigations have reached a stage where a further investigation of available ferrites is required.

The proposed method to achieve polarization scanning appears theoretically feasible. However, certain difficulties have precluded an evaluation at this time. These difficulties seem directly related to the attempt to build the system at S-band. The described system could be constructed with relatively little difficulty at higher frequencies, for example, at X-band, but considerably more work is required before satisfactory operation at S-band is achieved.

This report has been concerned with two methods of polarization scanning, namely the ferrite rotator and the peak-holding method. Other methods could also be used; in particular, the analog method. A disadvantage of the analog method, however, is its requirement of three nearly-identical receiver channels for effective operation. The analog system has been evaluated elsewhere.[2] In contrast, the systems described herein are simple, both in terms of operation and in terms of required modifications to the system for which they are intended.

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