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September 1968

Azimuth and Elevation Direction Finder Techniques

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1 April - 30 June 1968

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ABSTRACT

During this reporting period all efforts have been directed towards the design and development of individual components. The components to be discussed are the broadband hybrids and phase shifters which may be employed with either bifilar or quadrafilar spirals and the electromechanical switch required for the azimuth - elevation direction finder. Typical experimental data is presented for engineering models of the above components. The data processing equipment has been received from the supplier and is now being evaluated and debugged.

FOREWORD

This report was prepared by The University of Michigan Radiation Laboratory of the Department of Electrical Engineering under Contract DAAB07-67-C-0547. This contract was initiated under United States Army Project No. 5A6 79191 D902-05-11 "Azimuth and Elevation Direction Finder Techniques". The work is administered under the direction of the Electronics Warfare Division, Advanced Techniques Branch at Fort Monmouth, New Jersey. Mr. S. Stiber is the Project Manager and Mr. E. Ivone is the Contract Monitor. This report covers the period 1 April through 30 June, 1968.

The material reported herein represents the results of the preliminary investigation into the study of techniques for designing broadband circularly polarized azimuth - elevation direction finder systems.

The authors wish to express their thanks to Messrs. A. Loudon, E. Bublitz, K. Jagdmann and W. Henry for their efforts in the experimental work that has been performed during this reporting period, and M. Gurney for his efforts in the mechanical design of the switch.

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I

INTRODUCTION

An amendment, extending the present contract to 30 November 1968 has been formalized.

During this, the fourth quarter, efforts have been continued toward the design and fabrication of components required for the azimuth - elevation direction finder (DF) being developed by the Radiation Laboratory of the University of Michigan. The function of the azimuth - elevation DF system is to collect the relative signal levels from each of the antennas (17) associated with the DF system. The above data is evaluated and the pointing direction (associated with each antenna) of the incoming signal is computed and optically displayed by the data processing equipment. As a design goal the accuracy of the system is to be $\pm 2^{\circ}$ in azimuth and $\pm 5^{\circ}$ in elevation.

A thorough discussion of the theory of the DF system and the components associated with it have been presented in the first and second quarterly reports (ECOM-0547-1 and 2). Therefore, this report will again be restricted to the experimental results (as was the case in ECOM-0547-3) that have been obtained during this reporting period.

Efforts have been continued to be expended on the development of a balun that may be employed with either a bifilar planar spiral or a quadrafilar log conical spiral. Previously it has been noted that the quadrafilar antenna has been selected because it exhibits the required pattern characteristics to ensure accurate directional predictions over the 5:1 frequency band (600 - 3000 MHz). However, consideration is also being given to the feasibility of employing a flat planar bifilar spiral. The balun networks required for either of the above antenna configurations are similar and only a slight modification is required to use the same balun with a bifilar or a quadrafilar antenna. The balun network for the bifilar spiral consists of one broadband hybrid and one broadband 90° phase shifter. For the quadrafilar the balun consists of 3 hybrids and one 90° phase shifter. The present status of the development of these components is discussed in Chapter II. The design and development of a single pole 17 throw broadband electromechanical switch has continued during this quarter and the deliverable model of the switch is now being manufactured. The switch is designed to operate at several rotational rates (10) in the 1-1000 rpm range. The circuitry associated with the electromechanical switch to alert the computer as to when data is or is not to be collected has been designed and a model fabricated to be installed in the system. The present status of the switch and its associated components is discussed in Chapter III.

Chapter IV discusses the status of the data processing equipment and its associated equipment which has been supplied by the S. Sterling Company.

II

BALUN SYSTEM FOR ANTENNAS

Articles in the open literature on broadband coaxial couplers have stressed the need for extremely high mechanical tolerances to be associated with the center conductor width, overlap and separation between the stripline and ground planes. Earlier experimental work (at this laboratory) with the stripline couplers and the 90° phase shifter, required for the balun system, was conducted employing crude tolerances for the above item. Although the results were not outstanding, the components exhibited predictable responses. To evaluate the effect of tolerances, a stripline coupler was etched from a 4:1 scale drawing. The drawing was photo-reduced and a coupler was etched using the photo negative. This coupler was tested to determine the effect of employing tighter tolerances in printing the conducting filaments and assembly of the coupler. Preliminary data showed that the coupler's electrical characteristics were quite similar to the coupler employing crude tolerances and made from brass shim stock. The major difference appears to be in the isolation of port 4, which is a non-coupled port. But even here the two sets of data did not differ significantly. Time does not permit a detailed study of the effect of tolerances on the overall coupler performance but at present there is an indication that tolerances are not as critical as one might expect from reading reports in the literature.

Pictures of broadband couplers generally show them to have 45° miter joints at the interesction of the quarter wavelength sections of the coupler. The reason given for using the 45° miter bends is that it reduces the reflections from the junction and improves the overall coupler performance. In our work with these couplers, using both the sharp 90° transition and the mitered 45° transition, we have found the 45° transition reduces the coupling of the stripline coupler. This reduction in coupling is believed to be due to the orthogonal component of currents in the mitered section.

This reduction in coupling is especially evident in the center conductor which has a higher coupling coefficient. Therefore, the overlap that is required to give a particular coupling with a 90° transition must be increased to give the same coupling when one is using 45° mitered transitions. Reflectometer data and the coupling data do not show a great increase in performance by using the 45° mitered joints over the 90° transitions. Impedance discontinuities of the 90° cross overs can be greatly reduced by staggering the cross over such that a more nearly constant line width is maintained through the transition. This means that the transition point on one side of the stripline is displaced from the transition point on the other side of the line to maintain a constant or more nearly uniform line width across the transition.

The phase shifter that is required in the balun network has been fabricated from Rexolite 2200 material and has been checked over the 5:1 operating band. The reference line for the phase shifter was constructed from 0.141 coaxial line instead of using a stripline section of 50 Ω stripline as will be used in the final model.

Since the individual components of the balun were mounted in separate packages for individual testing, it was necessary to connect these components with coaxial cable for testing of the engineering model of the balun network. This is undesirable since the cabling involves extra connectors and loss that would not be present in the final version of the balun network. The average phase of the two tandem (8 and 10db) couplers was 83°, instead of 90°. This difference was due to the total coupling coefficient of the tandem coupler being lower than the design value of -3.0db.

Figure 2-1 is a graph of the phase of the 90° hybrid formed by the tandem 8.3db couplers. A total phase of the tandem 8.3db couplers varies from a high of 94° to a low of 65° but has a majority of the values near the average of 83°. Figure 2-2 is a graph of the phase shift through the total balun system consisting of the tandem couplers and the 90° phase shifter. The maximum phase shift between the two arms of the

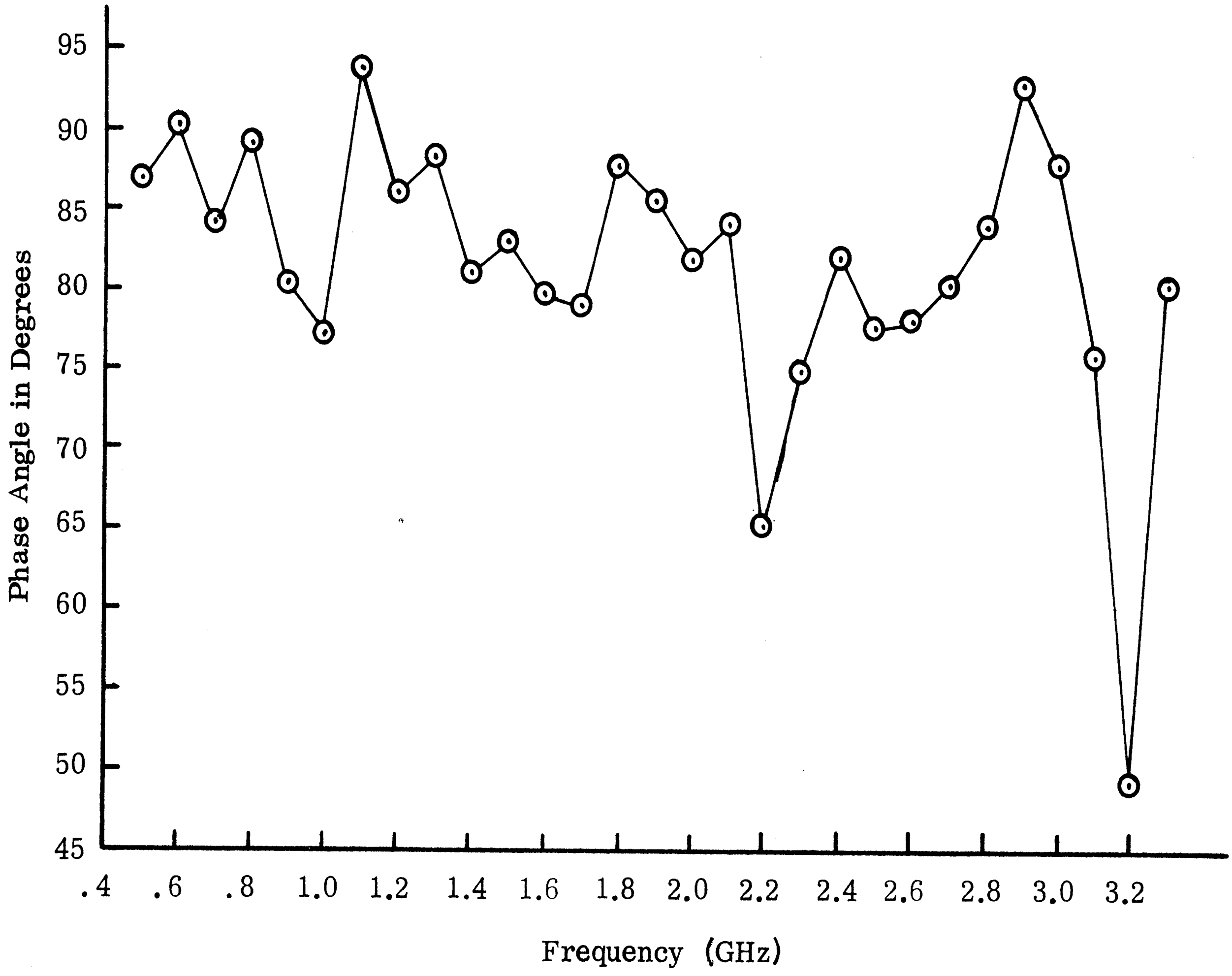

FIG. 2-1: Phase Angle Between Output Terminals of Tandem 8.3 db Couplers.

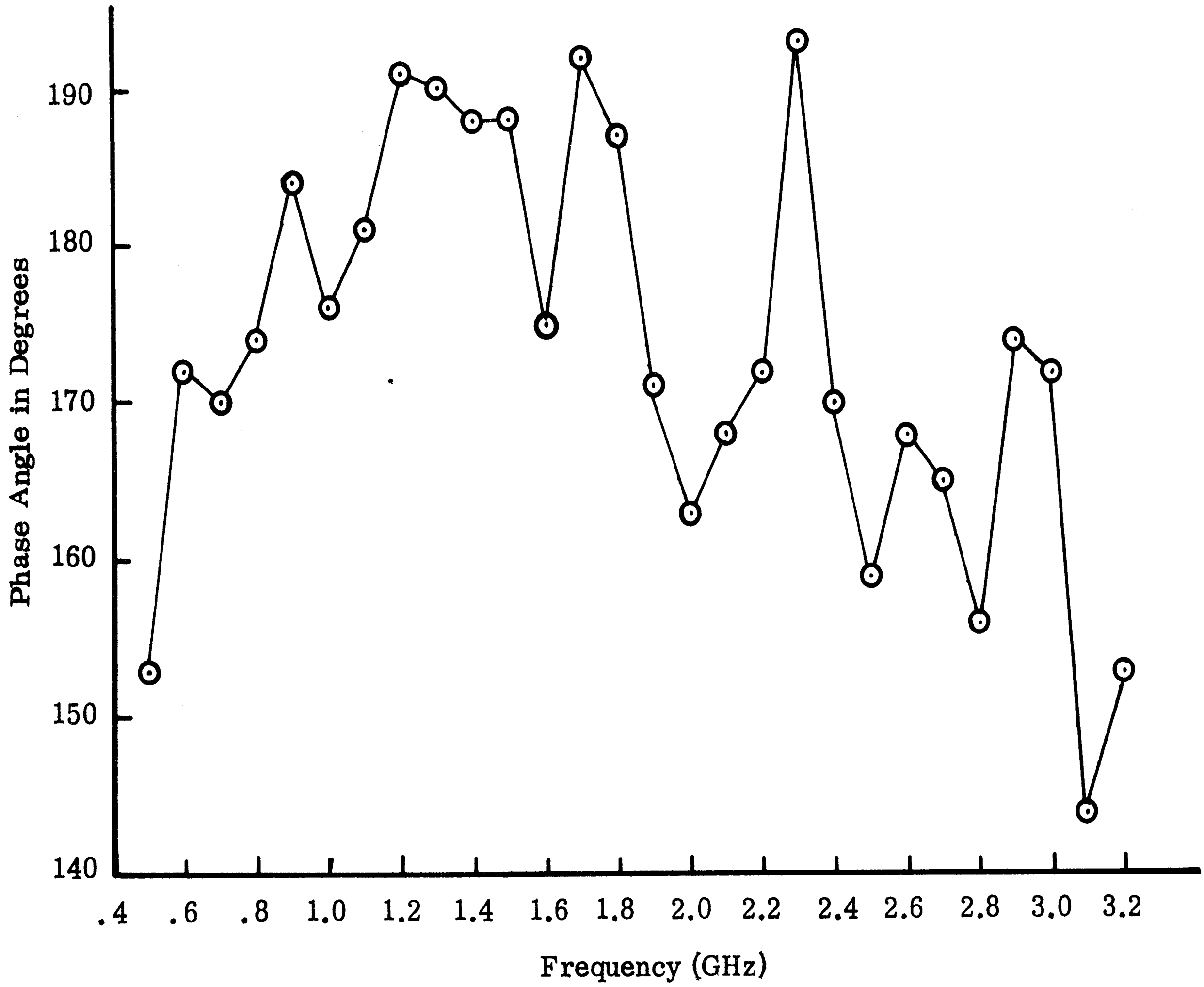

FIG. 2-2: Phase Angle Between Output Terminals of the Stripline Balun.

output is 191° with a minimum value being 156°. Average value of the phase shifter across the band is 175° which reflects the fact that the tandem couplers do not have a true 90° phase shift. The phase in this case was measured by terminating the line with a 10db precision load in front of the connection to a tee while the second terminal was connected to a 50 Ω load. Table 2-1 is a measure of the output power of the two balanced outputs from the balun system. In this measurement one of the balanced outputs was taken at a reference and the db ratio was taken of the second output. In this case the average unbalance between the two ports is 0.34db with a maximum deviation between the ports of 0.9db.

A reflectometer was used to measure the reflection coefficient of the assembled balun with the matched outputs terminated in 50 Ω loads. The 50 Ω loads were then removed and the balun system outputs were coupled to the windings of a cavity backed bifilar spiral and the reflection coefficient was again measured across the band. The reflection coefficient did show an increase when coupled to the cavity backed spiral but it was not as severe as we had earlier expected as the VSWR remained well below 3:1. Oscillations of the reflection coefficient increased with frequency but did not show the erratic variations that were expected. Unfortunately the remaining time does not permit the checking of the phase and amplitude of the balun across the frequency band with mismatched terminations such as found with the spiral antenna which typically has a balanced impedance of 150 Ω between elements. Feeding the antenna with 50 Ω stripline baluns would give a 1.5:1 mismatch at each terminal.

Patterns for a cavity backed spiral with a stripline balun were collected over a 3:1 band from 1 to 3 GHz. These patterns indicated an improvement over a similar spiral with a modified Duncan-Minerva balun. The patterns were taken for two linear orthogonal polarizations. More patterns are required to check the axial symmetry of an antenna with a stripline balun. However, the patterns apparently show some moding still existing in the cavity backed spiral at the higher frequencies. It was not expected that the stripline balun would stop this moding as this is a property of the antenna geometry and not a problem in the feed amplitude and phase.

TABLE 2-1

Relative Power Division of Balun

Frequency (GHz)	Ratio of Terminal Voltages (Per cent)	Ratio of Terminal Power (db)
1.0	97.2	.24
1.1	95.2	.43
1.2	96.8	.28
1.3	95.2	.43
1.4	96.8	.28
1.5	95.2	.43
1.6	95.6	.39
1.7	90.0	.92
1.8	93.6	.58
1.9	92.4	.68
2.0	94.0	.54
2.2	96.4	.32
2.4	101.6	-.14
2.6	105.6	-.47
2.8	98.8	.10
3.0	94.8	.46

III

ELECTROMECHANICAL SWITCH

The electromechanical switch consists of two parts; first, the drive unit, and second the switch junctions. The drive unit consists of a 1/8 horsepower Bodine motor, drive pulley, multiple gear reduction assembly, and a precision spindle. The drive motor and belt drive assembly provide the necessary driving power and speed for the system. The multiple gear reduction assembly provides several choices of switching speeds that range from 1000 rpm to 1 rpm (10 steps). The multiple gear reduction unit has been purchased from Geartronics and is a medium duty (model 2600 series) system that is rugged enough to provide the necessary drive to the switch rotor. The precision spindle has been purchased from Gilman. The spindle has negligible end play and less than 0. 001 inch run out. (These specifications are important to ensure the 0. 004 inch spacing required between the rotor and stator of the switch Additional expense was incurred in the purchase of the spindle since pre-loaded bearings were placed both in the forward and rear section of the spindle to minimize run out in the spindle. The spindle also has a fine adjustment that will aid in adjusting the spacing between the switch stator and rotor.

The electrical portion of the electromehcanical switch consists of two items: one, the capacitive coupling ports (17 inputs and 1 output), and two, a transmission line which is to be fabricated from stripline and will interconnect the switching port to the rotary joint. A photograph of a switching port is shown in Fig. 3-1. These are engineering models that were used to determine the final electrical characteristics of the capacitive coupled ports. VSWR data has been obtained over a 5:1 frequency band (0. 6 to 3. 0 GHz), and is shown in Fig. 3-2. It will be observed that the VSWR of the switch is less than 2:1 in the frequency range of 0. 6 GHz to slightly above 2. 8 GHz.

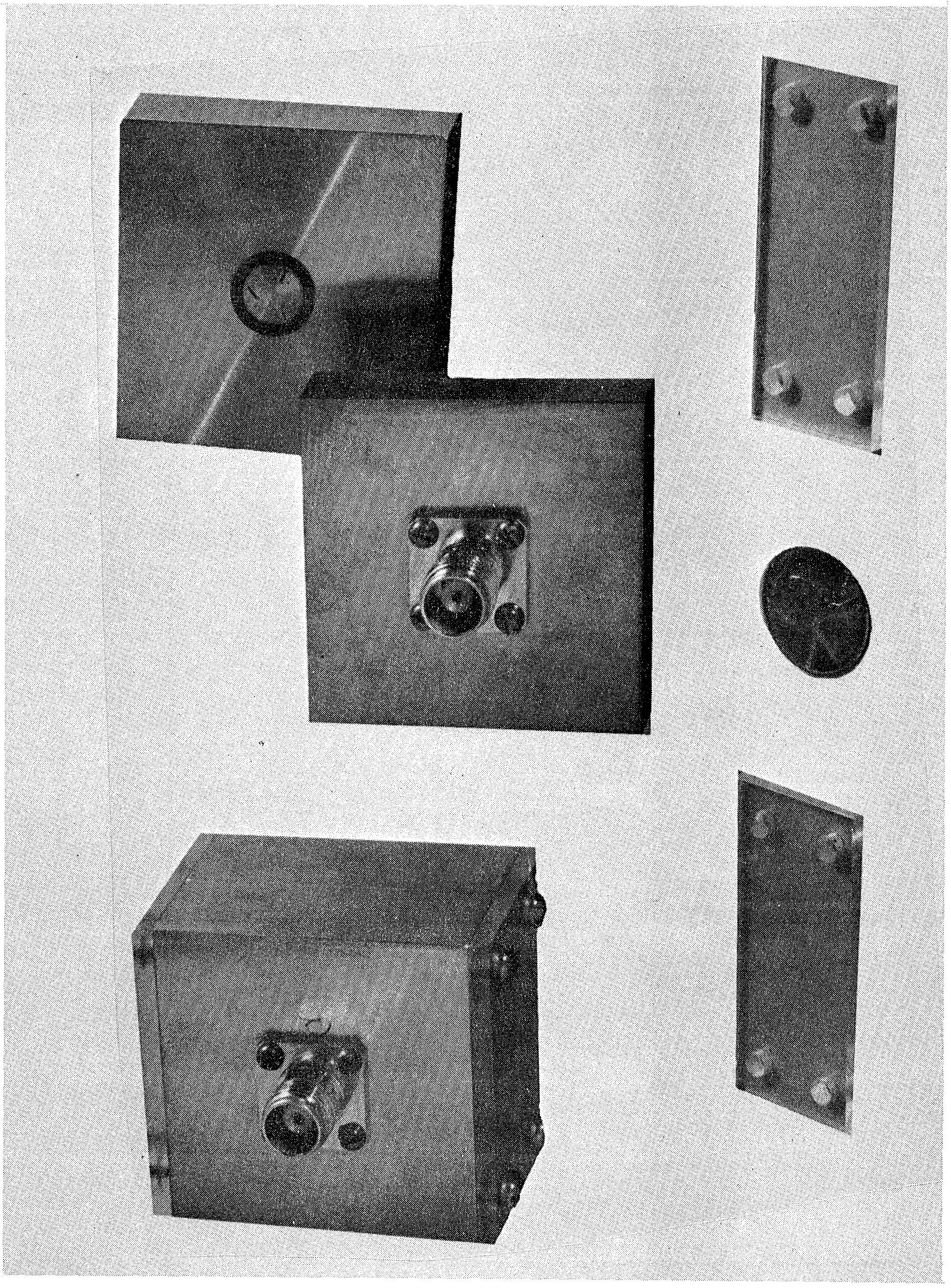

FIG. 3-1: Engineering Models of Capacitive Junction of Electromechanical Switch.

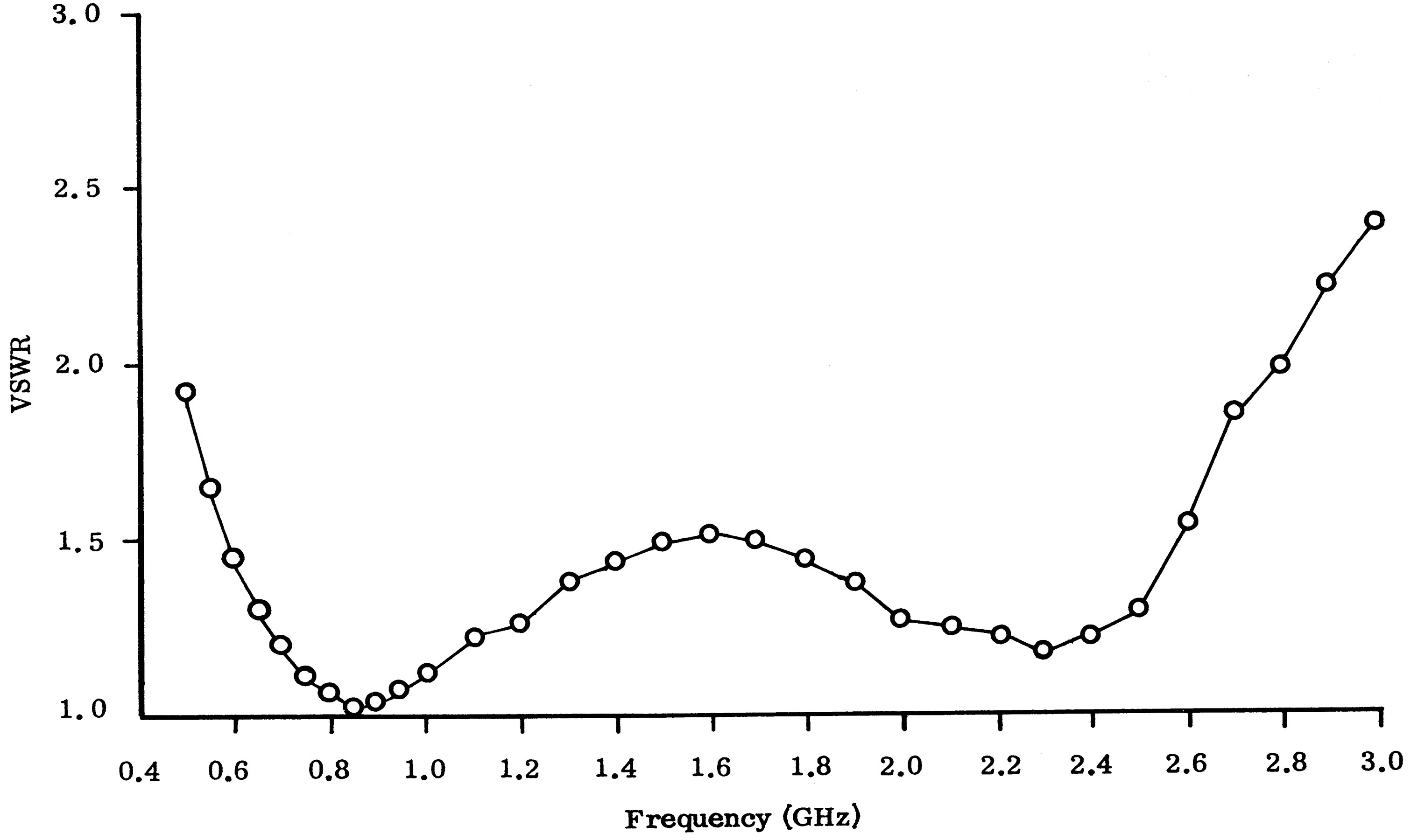

FIG. 3-2: VSWR of a Single Switch Terminal.

The VSWR increases to as high as 2.5 at 3.0 GHz. It is conceivable that slight improvements in the VSWR characteristics of the switch could be achieved. However, in the interests of time and costs, it was felt that the present configuration **should be accepted**. It will be observed that the switching ports operate well over more than a 4:1 frequency band having a VSWR characteristic of less than 2:1.

A sketch of the switch capacity junction is shown in Fig. 3-3. It is to be noted that this sketch is not to scale as is obvious when one considers that the center conductor of the coaxial connector has a dimension of 0.080" and the spacing of the capacitive coupling is 0.040". To aid in understanding the operation of the switch one may make an analysis employing transmission line techniques. For the present switch, coaxial connectors are located at the input and output of the capacitive junction, and have a nominal impedance of 50 Ω. The Rexolite region of the switch has a nominal impedance of 100 Ω. The equivalent circuit for the switch is shown in the lower right hand corner of Fig. 3-3. The two inductances are obtained from the Rexolite sections of the switch. The capacitive portion of the switch is obtained between the two metalic discs which are 0.375" in diameter and are spaced 0.040" apart. Since the 100 Ω sections of coaxial line are electrically short (less than $1/16\,\lambda$) at all frequencies of interest, one may plot the impedance characteristics on an impedance chart (e.g., a Smith chart) and determine the inductive reactance as a function of frequency. However, in the case of the capacitive reactance, it is somewhat more difficult (at microwave frequencies) to determine the manner in which the reactance varies as a function of frequency. One of the reasons for the capacitive reactance to be more complicated is because the voltage is not uniformly distributed between the plates, but rather is restricted near the outer edges of the plates due to the skin effect. Because the voltage has a non-uniform distribution and further because this distribution changes as

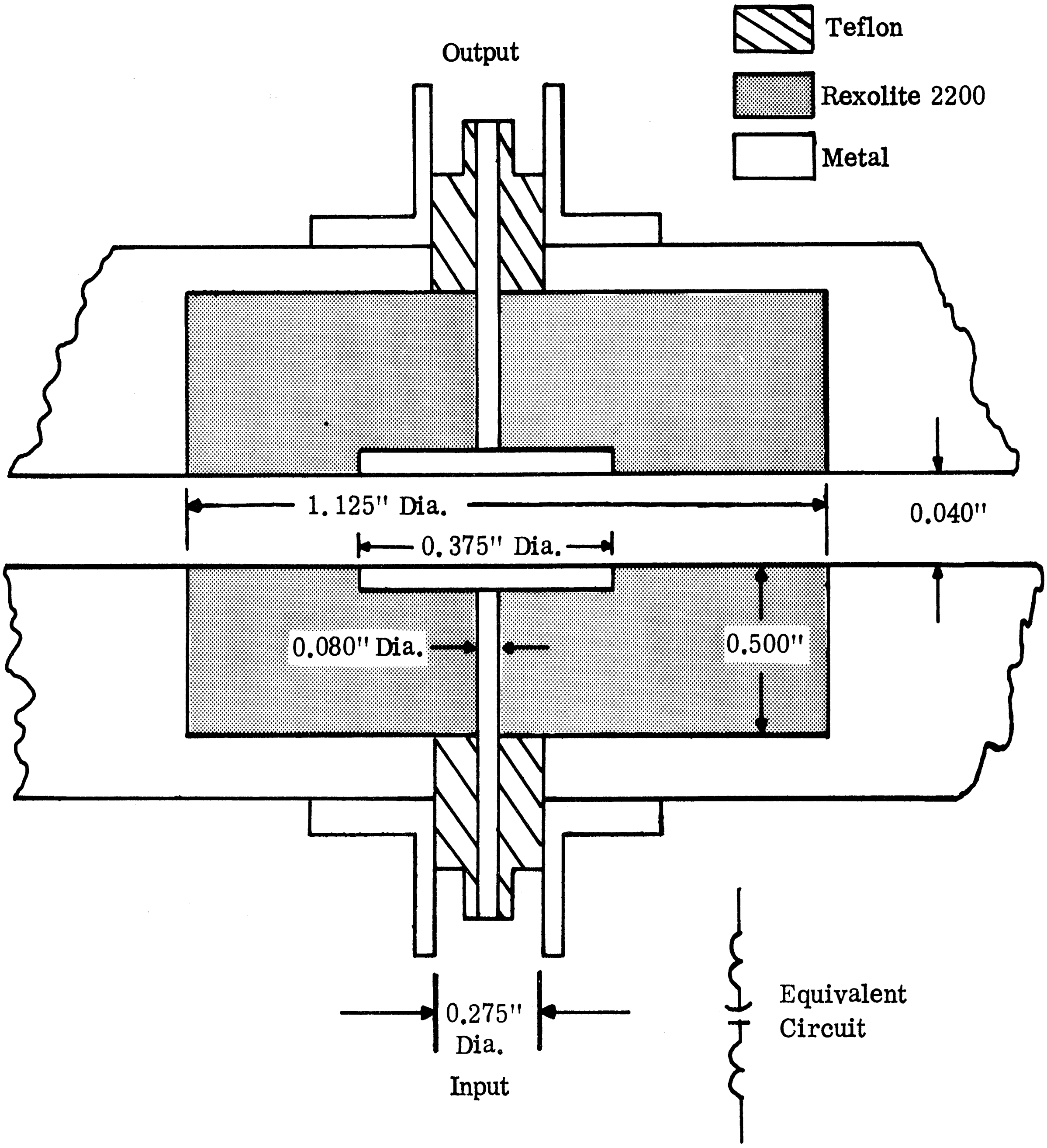

FIG. 3-3: Sketch of Switch Capacitive Junction (Not to Scale).

a function of frequency, the capacitive reactance varies in a non-linear fashion as a function of frequency. To obtain some insight as to the way the capacitive reactance behaves as a function of frequency, a special capacitive junction was fabricated. The capacitive junction was constructed by employing a 50 Ω transmission line and tapering the inner and outer conductors as shown in Fig. 3-4 in such a manner as to obtain the desired capacitive plate diameters while maintaining the 50 Ω transmission line characteristic. Employing this configuration (that of Fig. 3-4), a set of impedance data was plotted and is shown at the top of Fig. 3-4 for the capacitive junction. Had the capacitance remained constant (as in the case at audio frequencies) one would expect the capacitance reactance to have varied in a linear fashion along the resistance impedance circle of one.

Employing the data for the capacitive junction and normal transmission line techniques for determining the inductance of the switch, several graphical analyses were made of the capacitive junction to be employed in the electromechanical switch and four junction configurations were fabricated and evaluated further. The final choice (that shown in Fig. 3-3) was a result of this analysis and the VSWR characteristics of this junction are shown in Fig. 3-2. To minimize the design time of the electromechanical switch, all switching ports (18, 17 fixed and 1 rotary) are being fabricated the same and will have the dimensions shown in Fig. 3-3. A drawing of the switch is shown in Fig. 3-5, and an overall drawing of the switch is shown in Fig. 3-6. A photograph of the electromechanical switch and drive assembly is shown in Fig. 3-7.

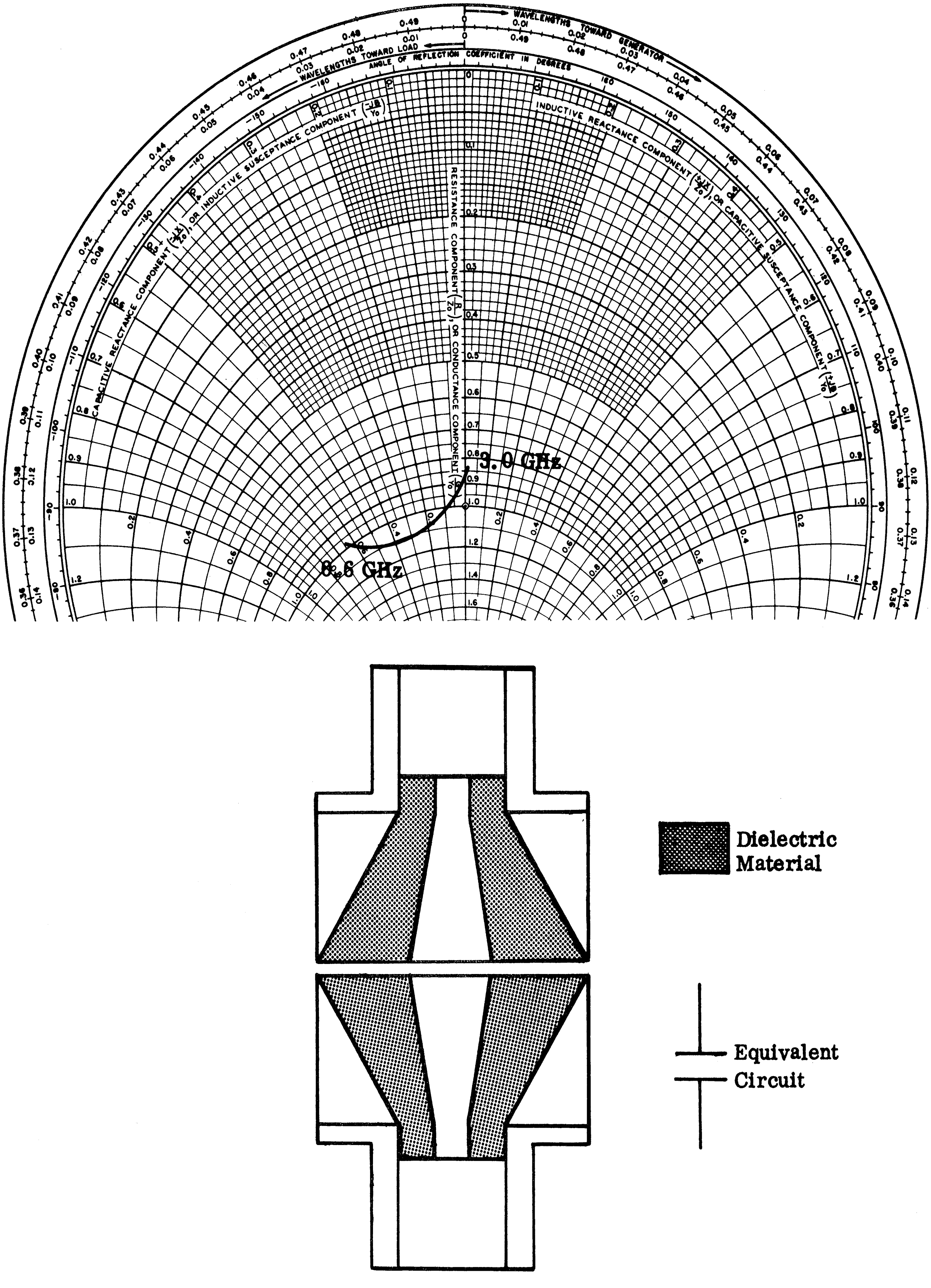

FIG. 3-4: Capacitive Junction Impedance.

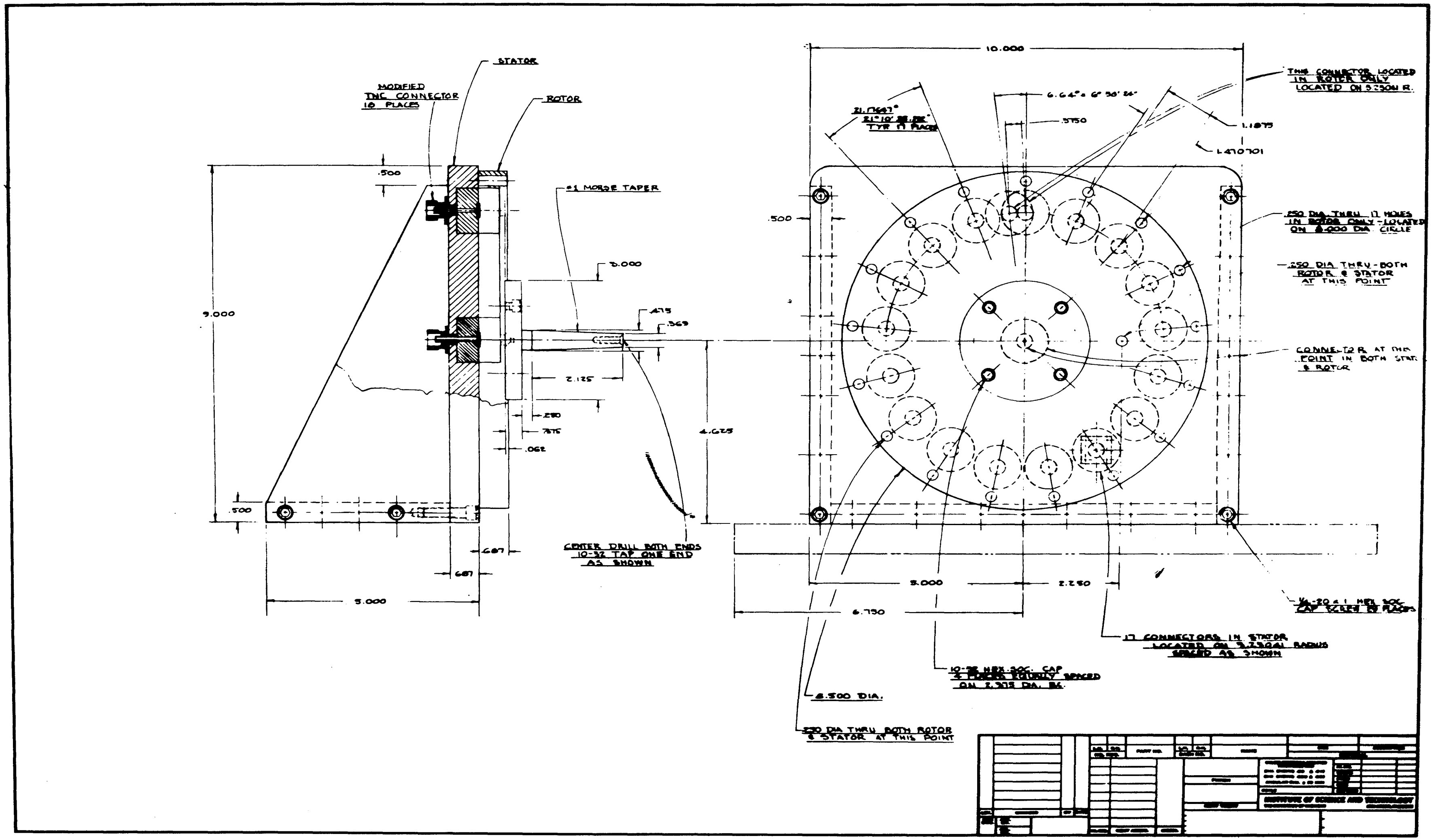

FIG. 3-5: Drawing of Electromechanical Switch.

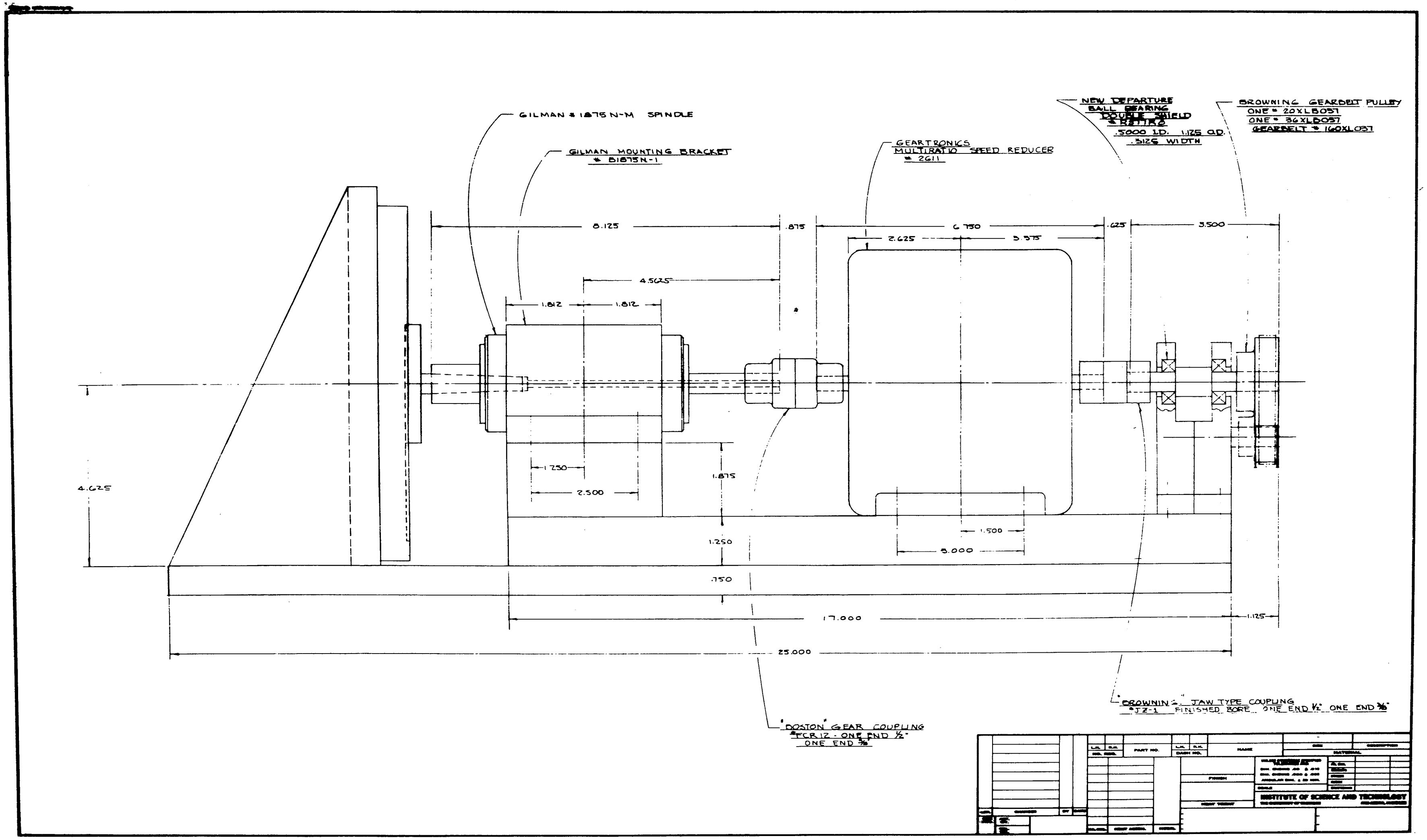

FIG. 3-6: Drawing of Electromechanical Switch Assembly.

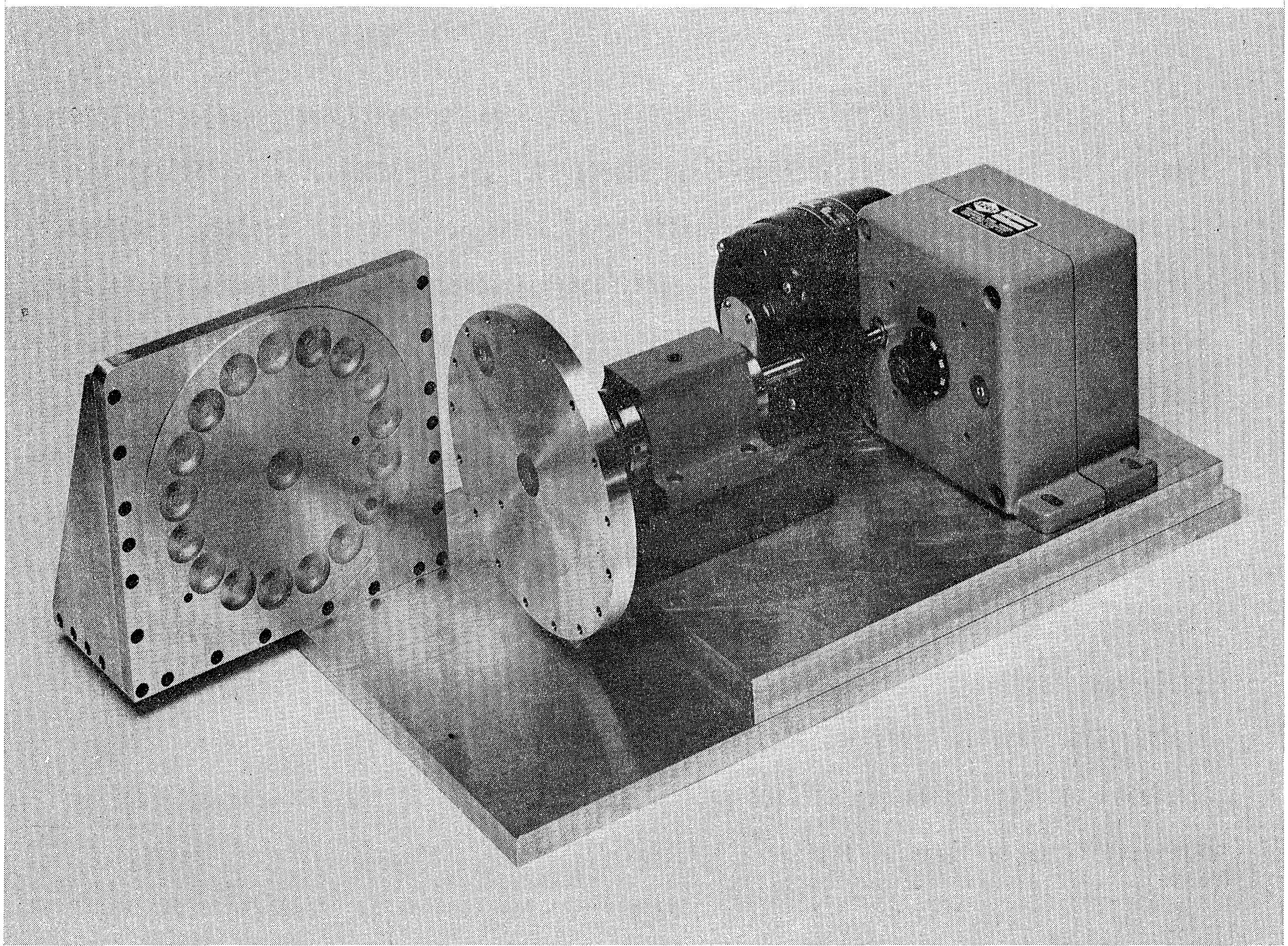

FIG. 3-7: Electromechanical Switch and Drive Assembly.

IV

COMPUTER AND PERIPHERAL EQUIPMENT

The peak reading voltmeter, which is a key component in the signal processing system, has been received and has been modified. At the time of its delivery from the manufacturer, considerable re-wiring was necessary to make the peak reading voltmeter compatible with the computer and analog-to-digital converter. Modification of this wiring has been completed and the peak reading voltmeter has been installed in the cabinet with the computer and peripheral equipment. The whole system has been delivered to the Radiation Laboratory, but upon delivery the programmer discovered a defect in the program interrupt, (a portion of the interfacing inside the computer). The interfacing section of the computer has been returned to the supplier and is at the present being corrected. The remainder of the computer system and peripheral equipment has not been checked and will have to undergo further checking before final acceptance by the Radiation Laboratory. The program has been written for the computer and the computer will be programmed as soon as the interfacing is returned.

V

CONCLUSIONS

The design of the 3db hybrid coupler has been completed and encouraging data has been collected both in regards to coupling and phase shift over a 5:1 frequency band. A stripline balun employing a 3db hybrid and a 90^{o} phase shifter has been assembled and some preliminary pattern data collected from a bifilar cavity backed spiral.

A set of drawings has been completed for the deliverable version of the electromechanical switch and the switch is now in the process of being fabricated. The necessary electromechanical parts have been received and are being prepared for assembly into the rotary switch. Preliminary data on the engineering model of the switch showed that a VSWR of less than 3:1 could be achieved over the 5:1 frequency band, and is less than 2:1 in the 600 MHz to 2.8 GHz range.

The computer and peripheral equipment for the data processing equipment has been received and a program has been prepared. Some difficulty has been encountered with the interrupt circuit, however, this is now being corrected.

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13. ABSTRACT

During this reporting period all efforts have been directed towards the design and development of individual components. The components to be discussed are the broadband hybrids and phase shifters which may be employed with either bifilar or quadrafilar spirals and the electromechanical switch required for the azimuth - elevation direction finder. Typical experimental data is presented for engineering models of the above components. The data processing equipment has been received from the supplier and is now being evaluated and debugged.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Broadband Phase Shifter						
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