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ABSTRACT

During this reporting period efforts have continued in the design and development of the quadrafilar balun, and the assembly of the components of the DF system has been 90 percent completed. Preliminary tests that have been conducted on the quadrafilar balun have shown that the amplitude variation is well behaved. However, there is some undesirable phase discrepancies in the network. In addition to these tests a preliminary evaluation of the DF system has been conducted. The results of the preliminary tests show that the system is able to direction find with an accuracy of $\pm 5^{\circ}$ in both the azimuth and elevation directions.

FOREWORD

This report was prepared by The University of Michigan Radiation Laboratory of the Department of Electrical Engineering under Contract DAAB07-67-C0547. 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 of 1 July through 30 September, 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. E. Bublitz and W. Henry for their efforts in the experimental work that has been performed during this reporting period, and to M. Gurney for his efforts in the mechanical design of components that are associated with the azimuth - elevation antenna system, and also to M. Wright for her contributions in the preparing of the many graphs presented in this report.

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I

INTRODUCTION

During this, the fifth quarter, the design, fabrication and assembly of components required for the azimuth - elevation direction finder (DF) being developed by the Radiation Laboratory of The University of Michigan have continued. The function of the azimuth - elevation DF system is to collect the signals received by each of the antennas (17) associated with the DF system. The above data is evaluated by a computer and the direction 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 and 4) that have been obtained during this reporting period.

An experimental model of the 5:1 frequency band (600 - 3000 MHz) quadrafilar balun has been fabricated and evaluated. The results of this evaluation show that the balun has a phase discrepancy associated with it suggesting that additional adjustments should be made to one of the components of the balun network. A few preliminary pattern measurements have been made employing the quadrafilar log conical spiral. Pattern results were not as well behaved as had originally been anticipated because of the phase behavior of the balun. It is also felt that to optimize the pattern characteristics of the log conical spiral it would be necessary to investigate the effect of the shape factor and the wrap angle associated with the filaments used in its construction.

The DF system has been assembled and is now being evaluated on one of the antenna ranges at The University of Michigan. Preliminary measurements show that the azimuth - elevation direction finder is capable of computing angular information with an accuracy of $\pm 5^{o}$ in both azimuth and elevation planes. A better accuracy figure may be obtained after some improvements are made in the range geometry.

At the present time the antenna system for the azimuth - elevation direction finder consists of 17 flat planar spirals that were designed and built on a preceding contract associated with azimuth - elevation direction finder techniques (Contract DA 28-043 AMC-01499 (E)). Data is presented to demonstrate the operating characteristics of the cavity backed spiral over the 600 - 3000 MHz range, using both the modified Duncan - Minerva balun and a broadband stripline balun. Because of the poor operating characteristics of the cavity backed spirals much of the data collected has been restricted to a frequency of 1.6 GHz where the cavity backed spirals are well behaved.

Some data processing techniques have been considered on a preliminary basis. Further effort should be expended on data processing to optimize the accuracy of the system.

II

AZIMUTH - ELEVATION DF ANTENNA SYSTEM

During this period the design and development of the quadrafilar spiral balun has continued. An engineering model of the quadrafilar balun has been constructed and tested. Amplitude and phase variations are shown respectively in Figs. 2-1 and 2-2. In Fig. 2-1 it is shown that the amplitude variation at the four ports is small although the phase data (Fig. 2-2) is not well behaved.

The phase variations associated with port 2 relative to port 1 theoretically should have been 90^{o}, $\pm 10^{o}$, and the data of Fig. 2-2 shows that this phase variation over a major portion of the band was within these limits. However, at a frequency of 2.0 GHz the phase has a discrepancy of approximately + 30^{o}. The cause of this variation is not understood and the problem will require further study. However, of greater concern is the data for ports 1-3 and 1-4 which have a larger discrepancy associated with them. It is of interest to note that the data for ports 1-3 relative to that for ports 1-4 shows phase differences of approximately 90^{o} over the 5:1 frequency band which is desirable. The fact that the data for ports 1-2 agrees well with the expected 90^{o} phase variation suggests that the three 3dB hybrids shown in Fig. 2-3 are operating as expected. This conclusion is further substantiated because the amplitude variations at the four ports are also well behaved as shown in Fig. 2-1. The linear slope associated with the curves of ports 1-3 and 1-4 relative to the data of 1-2 suggests that the broadband 90^{o} phase shifter is not functioning properly. Because the two curves for the ports 1-3 and 1-4 vary in a linear fashion it suggests that the reference line of Fig. 2-3 is of the wrong length. If the broadband phase shifter were properly etched it is very probable that the curves of ports 1-3 and 1-4 relative to 1-2 would not have exhibited the linear phase discrepancy apparent in Fig. 2-2.

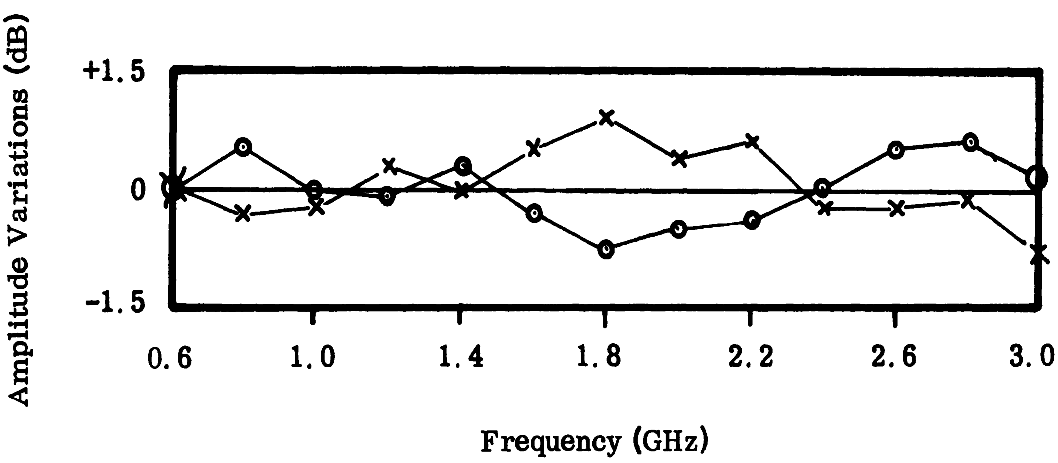


FIG. 2-1: Quadrafilar Output Amplitude Variations.

o—o Port 1 - 4 x—x Port 2 - 3

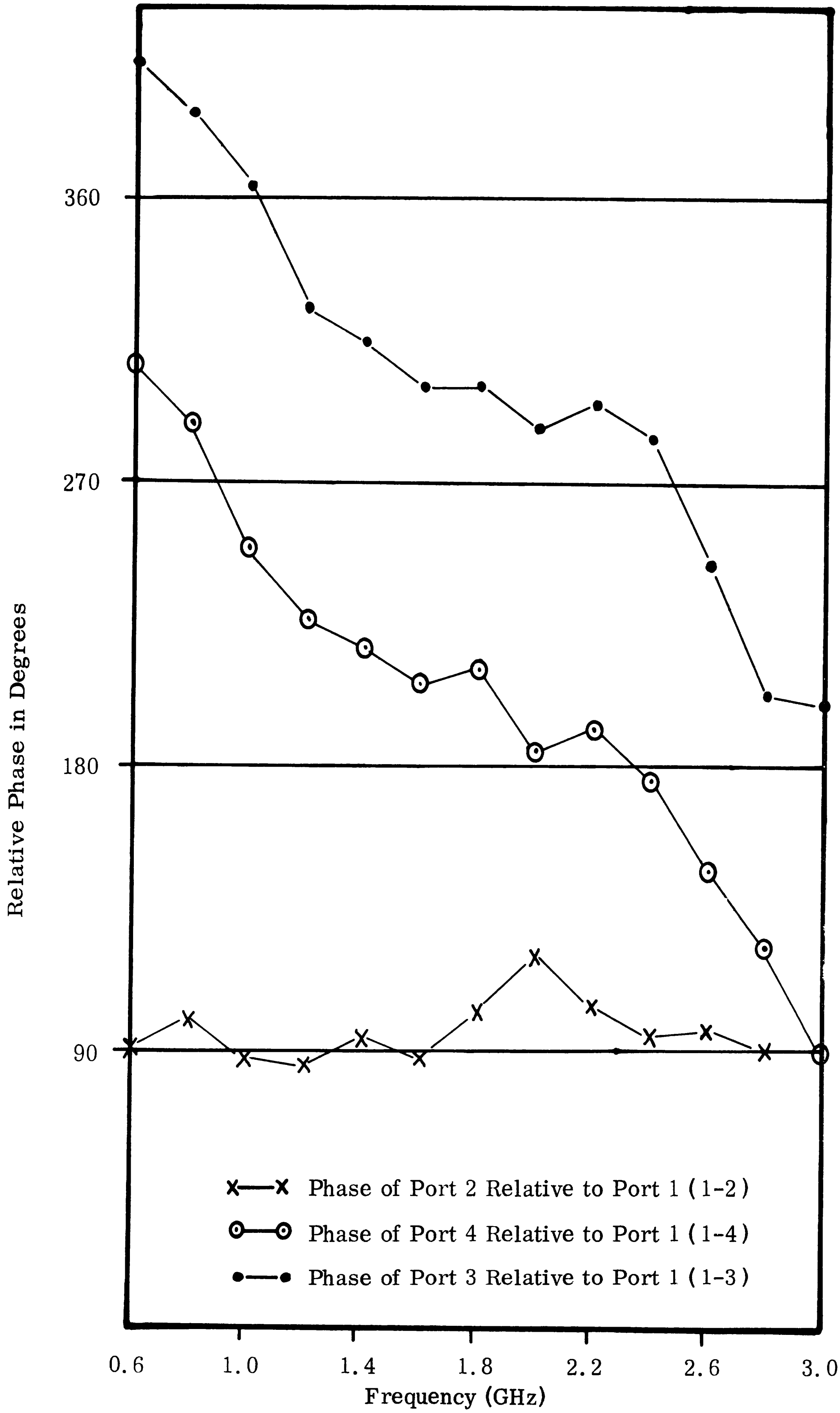


FIG. 2-2: Phase Relationship Between the Four Ports of the Quadrafilar Balun vs. Frequency.

It is believed that the faults in the balun indicated by the data of Figs. 2-1 and 2-2 were not serious and can be corrected with some additional effort. However, because of the lack of time and funds available in the present contract, further work on the balun and antenna network for the quadrafilar configuration has been discontinued and the remaining time and funds will be devoted to the evaluation of the DF system.

The quadrafilar balun is shown in Fig. 2-3. This balun consists of three broadband 3dB directional couplers and a broadband 90^{o} phase shifter. For the purposes of this program, broadband is defined to be a 5:1 frequency band that covers the range of 0.6 - 3.0 GHz. To minimize coupling between adjacent components, it is necessary to use screws throughout the balun network as can be seen in Fig. 2-4. For this particular balun configuration, a total of approximately 600 screws were required to minimize coupling between components. Spacing between the screws must be $\lambda/8$ or less at the highest frequency of interest. It has been found that the spacing between the screws and the stripline center conductor can be as small as $\lambda/8$ at the highest frequency of interest without affecting the impedance characteristics of the stripline.

Pattern data for the quadrafilar spiral antenna has not been encouraging. The cause for the poor pattern behavior is believed to result both from the poor phase response of the balun network and the inaccuracies associated with the winding of the quadrafilar spiral elements. A further discussion of the quadrafilar spiral will be presented in the recommendation of this report.

To provide some comparison as to the desirability of employing a well behaved (electrically) balun network, two sets of data are presented for a cavity backed spiral antenna, one fed with a modified Duncan - Minerva balun and the other by a broadband stripline balun network. Typical pattern data is shown in Figs. 2-5 and 2-6. The two

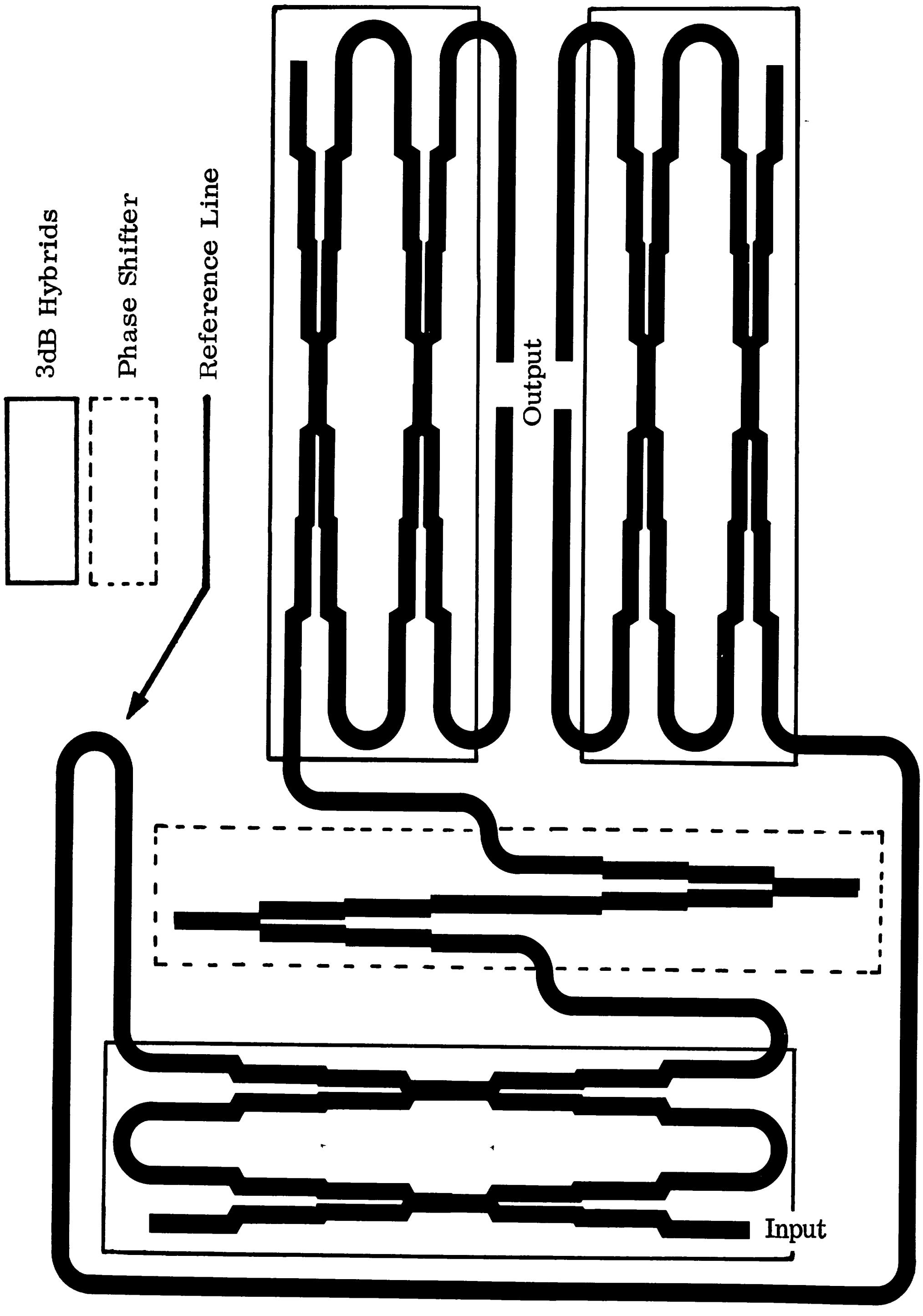


FIG. 2-3: Quadrafilar Balun.

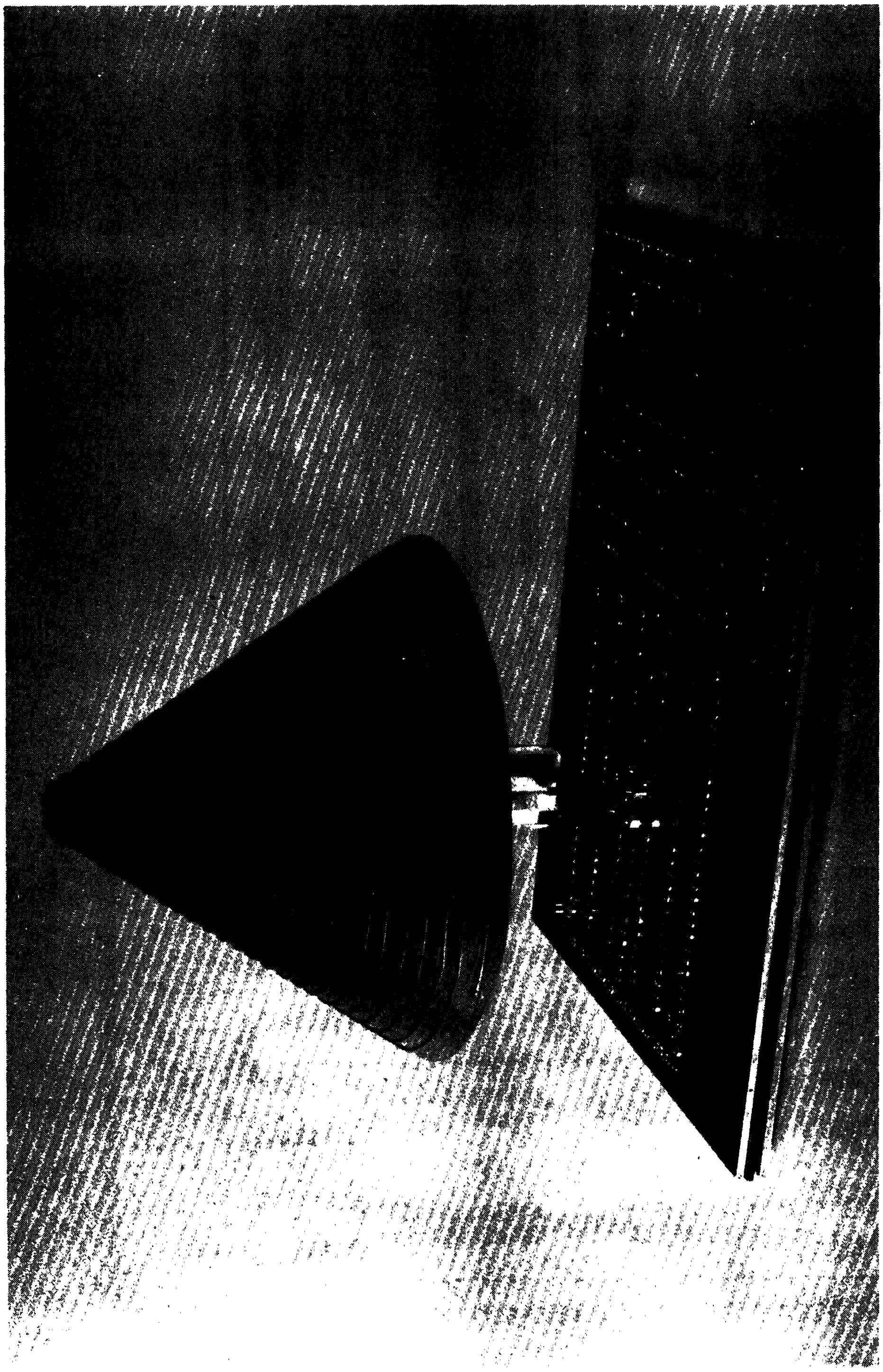


FIG. 2-4: Quadrafilar Spiral and Balun.

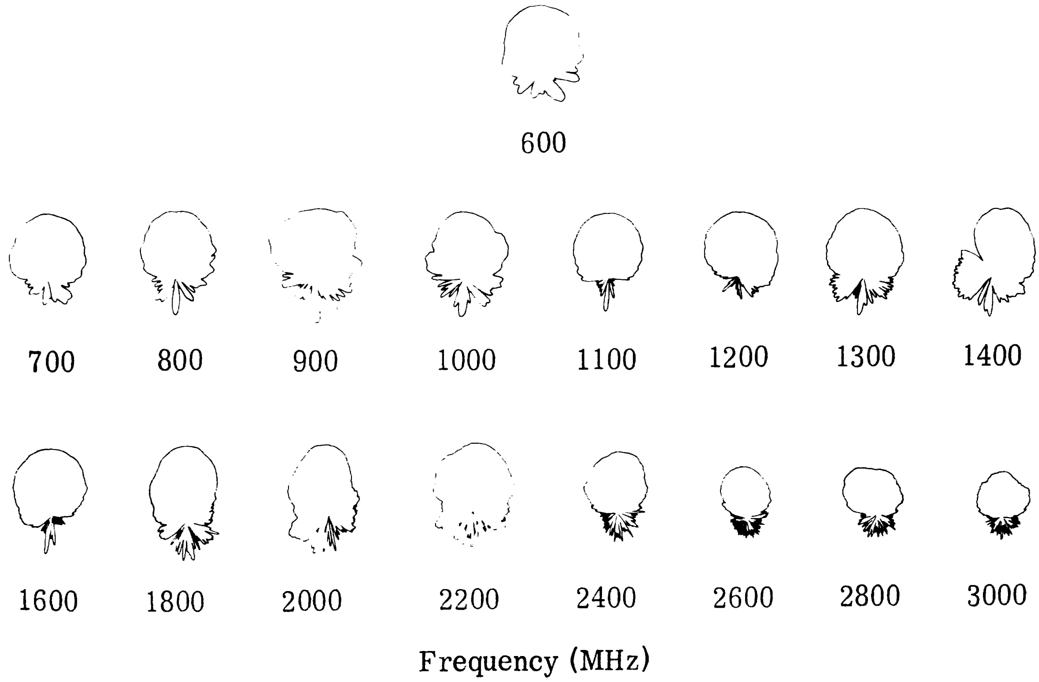


FIG. 2-5: 15 Turn Cavity Backed Spiral with a Duncan - Minerva Balun Mounted at the Zenith of a 6 Foot Hemisphere (E-Plane Patterns for a 5:1 Frequency Band).

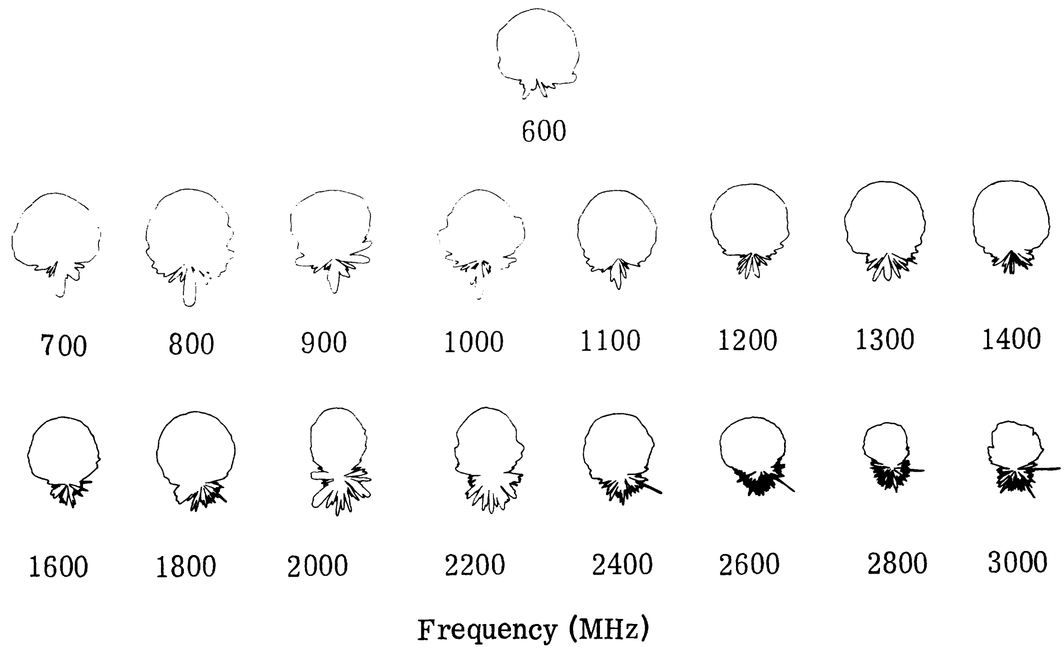
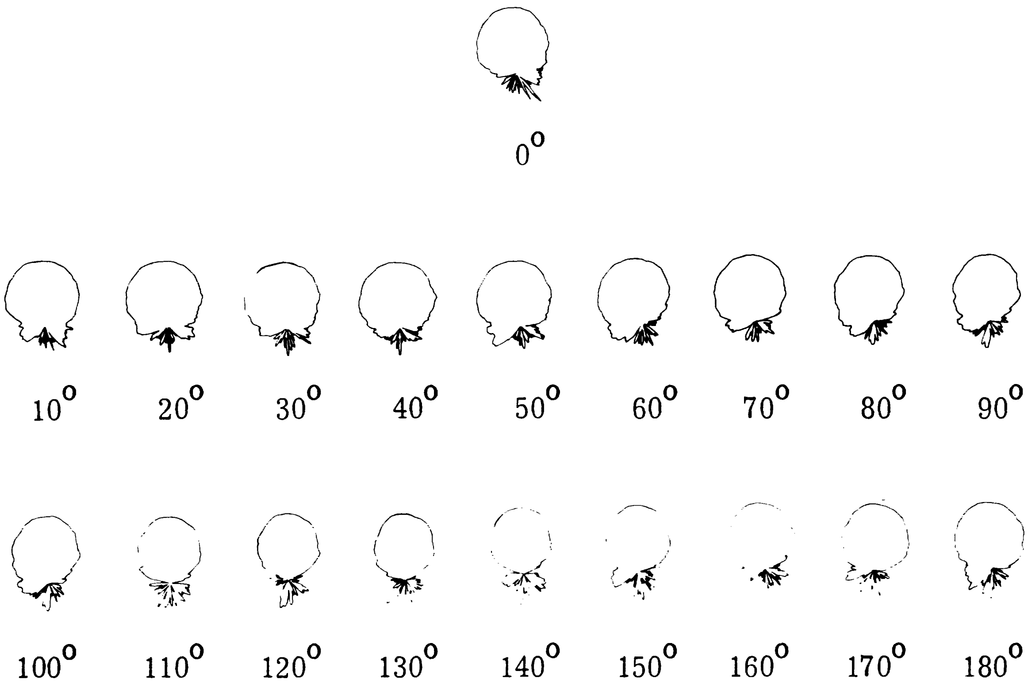


FIG. 2-6: 15 Turn Cavity Backed Spiral with a Broadband Stripline Balun Mounted at the Zenith of a 6 Foot Hemisphere (E-Plane Patterns for a 5:1 Frequency Band).

sets of data noted above were recorded at several frequencies in the 0.6 - 3.0 GHz frequency range. It will be observed from this data that at several frequencies the Duncan - Minerva patterns show some deterioration in comparison with the data for the bifilar stripline case. There are some anomalies noted in the bifilar stripline data and this is felt to be caused by the higher order modes that may be radiated by the bifilar spiral configuration as noted in the first quarterly report (ECOM-0547-1) dated October, 1967.

Because of the poor pattern response at several frequencies in the 0.6 - 3.0 GHz band for the Duncan - Minerva cavity backed spiral configurations, evaluation of the azimuth - elevation DF system has been limited to a frequency of 1.6 GHz. This frequency was chosen because of the well behaved pattern characteristics as a function of antenna orientation. Typical ellipticity data is shown in Fig. 2-7 for a cavity backed bifilar spiral fed with a Duncan - Minerva balun. Additional data has been recorded for spiral elements located at $\theta = 40^o$ and 80^o and is shown in Fig. 2-8. The θ angles of 40^o and 80^o were selected because two rings of 8 antenna elements each were located at $\theta = 40^o$ and 80^o. This data is shown to demonstrate the pattern characteristics of the spirals when located unsymmetrically on the hemisphere surface.

The 17 antennas associated with the antenna system of the azimuth - elevation direction finder are mounted on a non-metalized fiberglas surface possessing a hemispherical contour 6 feet in diameter. The gain of the Duncan - Minerva cavity backed spiral antennas measured at 1.1 and 1.6 GHz has been found to be approximately 3dB above a linearly polarized isotropic source. If the antennas are assumed to be reasonably well behaved insofar as the ellipticity is concerned, an additional 3dB may be added to the linearly polarized gain suggesting a gain of approximately 6dB above a circularly polarized isotropic source. However, no measurements have been made to confirm this assumption.



(1600 MHz)

FIG. 2-7: Ellipticity Data at 1.6 GHz for 15 Turn Cavity Backed Spiral Mounted at the Zenith of a 6 Foot Hemisphere (Duncan - Minerva Balun).

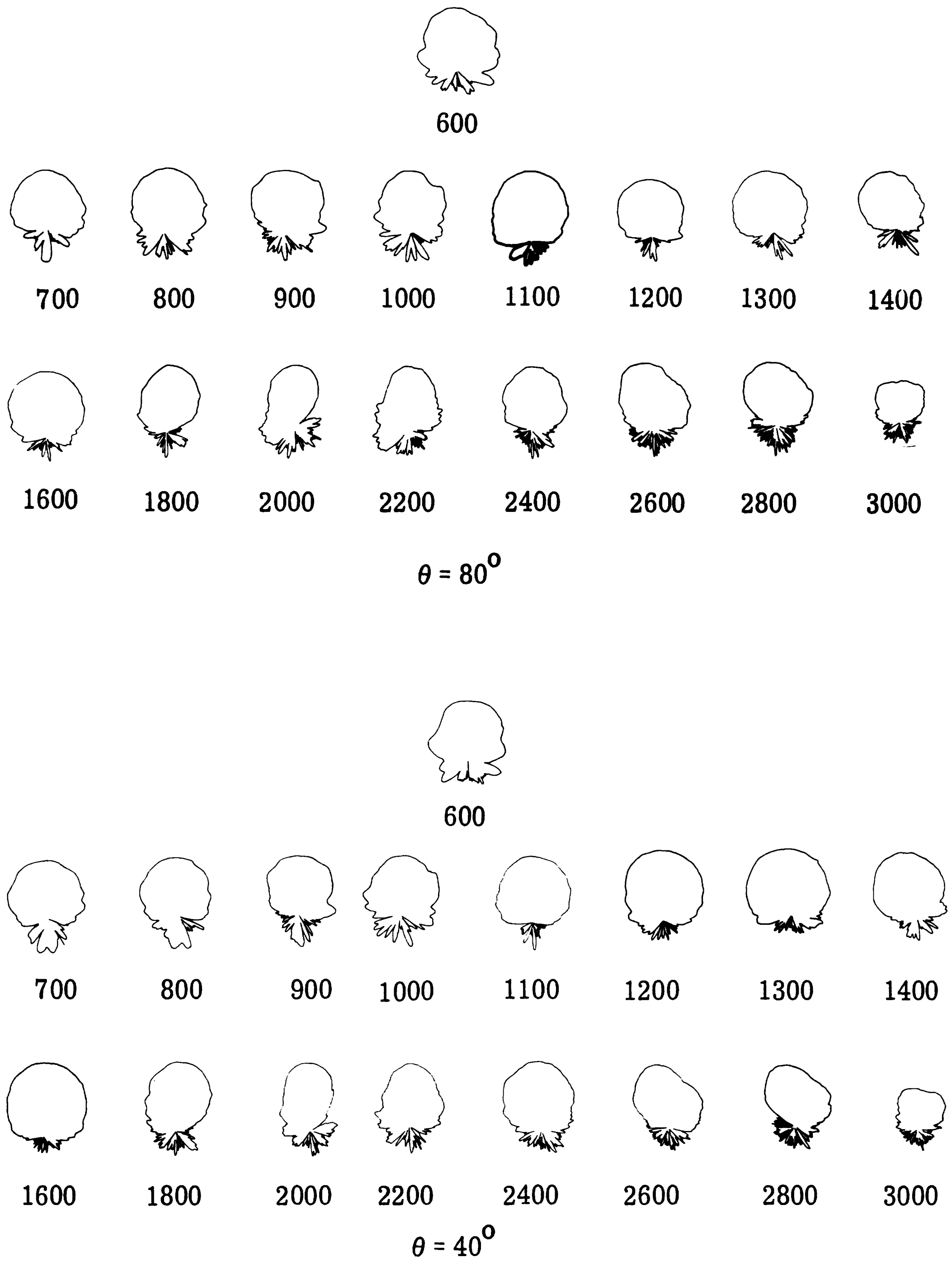


FIG. 2-8: E-Plane Pattern Data of a 15 Turn Cavity Backed Spiral Positioned Non-Symmetrically on a Dielectric 6 Foot Hemisphere (Frequency = MHz).

III

ELECTROMECHANICAL SWITCH

The electromechanical switch has been fabricated and tested and is presently being employed with the DF system to collect DF data. The photo-diodes for the switch have been installed which provide the interrupt information to the computer to designate which antennas are being interrogated as a function of time. A few problems were encountered with the interrupt circuit necessitating some modifications to the pulse circuitry associated with the photo-diodes. These problems appear to have been corrected and the circuitry is now being wired for delivery.

The VSWR characteristics of the switch are shown in Figs. 3-1 and 3-2. The data of Fig. 3-1 is for maximum coupling between one of the antenna switching ports and the output port. It will be observed that at approximately 2.4 GHz the unit exhibits a high VSWR. This may be explained as follows: each switching port has associated with it a characteristic impedance. A similar impedance is associated with the rotary junction because both coupling junctions are mechanically identical. The transmission line or stripline interconnecting the rotary joint and switching port has a length that results in an addition of the impedances to produce a high VSWR at 2.4 GHz.

The data of Fig. 3-2 is for the case when the switch is rotated to a position where the switching port is adjusted for half coupling. Here again it will be noted that the VSWR characteristics are quite well behaved across the wide band of frequencies, however, a high VSWR is noted at the high end of the frequency band.

The loss through the switch has been checked at several frequencies in the operating band and found to be 0.5dB or less.

To protect the switch from dirt and dust during field operation, a dust cover has been attached to enclose the switch rotor and precision spindle employed to accurately adjust the spacing between the rotor and stator of the switch. It is recommended that this cover be kept in place at all times and only be removed in the case of emergency or malfunctioning of the switch. It will also be recalled that the spacing between the rotor and stator of the switch is approximately 0.004 inches and therefore it is extremely important that the switch be handled with care to minimize the possibility of changing the spacing between the stator and the rotor.

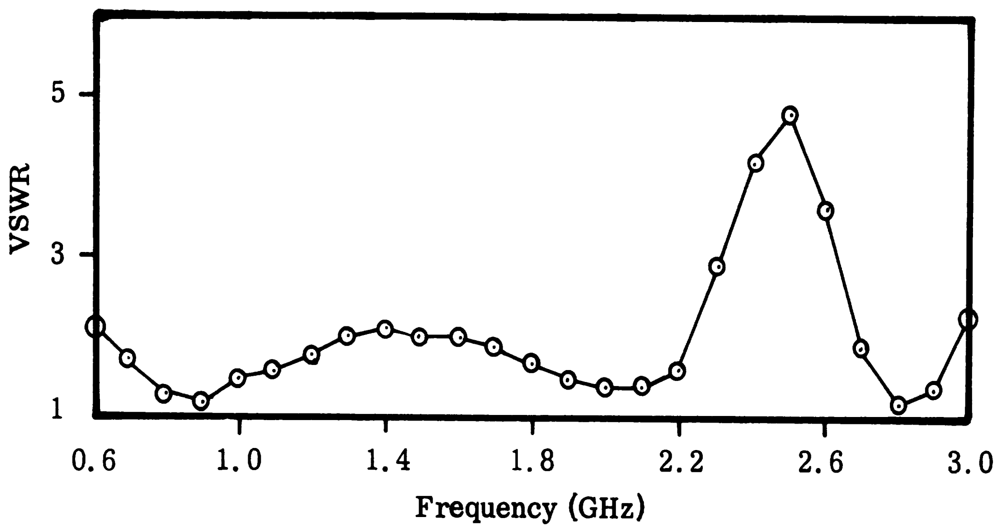


FIG. 3-1: VSWR Characteristics for Maximum Switch Coupling.

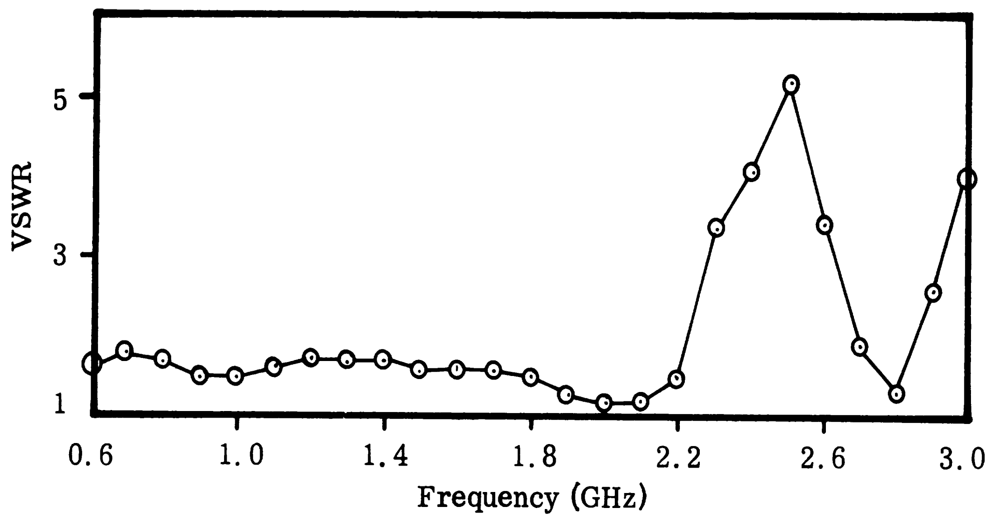


FIG. 3-2: VSWR Characteristics With Switch Adjusted for One Half Coupling.

IV

DATA CONVERSION SYSTEM

Below is a brief description of each of the components that make up the data conversion system (Fig. 5-1) employed with the azimuth - elevation direction finder. Each of these components will be described more completely in the operator's manual now being prepared.

4.1 Hewlett-Packard 450A Video Amplifier (Not Shown in Fig. 5-1)

The output from the receiver is passed through this amplifier and then to the memory voltmeter. A switch on the front panel allows the selection of either 20dB or 40dB gain. A DC restoring network has been added to the amplifier so that its output is always positive.

4.2 Micro Instruments 5201-B-1 Memory Voltmeter

The memory voltmeter (peak detector) is used to detect the highest signal level picked up by each of the antenna elements as the antenna switch passes by the corresponding switch position. It is capable of registering all signals from DC to pulses as short as 50 nanoseconds. The voltmeter is activated by the computer during the time when the antenna switch is coupling one of the elements to the receiver. At the end of this period, the voltmeter output continues to record the magnitude of the largest signal present during the interval.

4.3 Texas Instruments 848 Analog to Digital Converter

The analog to digital converter (A/D) transforms the voltage output of the memory voltmeter into a digital form acceptable to the computer. On command from the computer, the converter samples the voltmeter output and forms the digital representation of it. This process takes about 29μsec after which the computer may read the result into its memory.

4.4 Varian 620I Computer

The computer function is to control and coordinate the whole system. It can turn the memory voltmeter on and off, trigger the A/D converter, read data from the A/D converter and display results (angles) on the NIXIE tube registers. Also, it has interrupt lines from the antenna switch and A/D converter which allow these devices to interrupt the normal operation of the computer to inform it that some external event has occurred. Available for use by the computer is a clock which can be turned on and off, and which interrupts at 100 μsec intervals after it is turned on. Also connected to the computer is a model 33ASR teletype through which the operator can communicate with the computer either by the use of the keyboard or punched paper tape. Likewise the computer can punch or print information for the operator. The core memory of the 620I has 4096 words, each 16 bits long and a full cycle time of 1.8 μsec.

4.5 Other Equipment

In addition to the components described above, the main equipment rack also houses logic circuitry which interfaces the computer with the various external devices and contains the 100 μsec clock. The NIXIE tube displays, along with their high voltage power supply, and some logic cards are mounted on the front panel. In back is a separate power supply used to run the logic circuits.

V
DF TEST RESULTS

A photograph of the data conversion equipment is shown in Fig. 5-1. The complete system has now been assembled and is being evaluated at the Radiation Laboratory of The University of Michigan. A block diagram of the system is shown in Fig. 5-2. Initial data that has been collected for the azimuth - elevation direction finder have some system errors associated with it. The prime system error is the inaccuracy associated with the alignment of the azimuth - elevation DF antenna system. Initial data is being collected for a frequency of 1.6 GHz. The pointing errors for the present data appear to be in the range of $\pm 5^{o}$ for both azimuth and elevation. At the present time data is being collected to determine the system repeatability.

Initially the azimuth - elevation DF antenna was oriented such that data would be presented for a constant azimuth angle ($\phi = 90^{o}$ or 270^{o}) while the elevation angle was varied through 180^{o}. To aid in the understanding of the azimuth - elevation angular data, a coordinate system is shown in Fig. 5-3. A typical set of azimuth data that has been obtained from the azimuth - elevation system is shown graphically in Fig. 5-4. The data of Fig. 5-4 shows the calculated azimuth information as a function of elevation angle at a frequency of 1.6 GHz. Ideally the azimuth data should read either 90^{o} or 270^{o} depending upon which side of the hemisphere (east or west) data is being collected from. It will be observed that the data near the pole position of the hemisphere (i.e., data looking straight above the hemisphere, $\theta = 0^{o}$) is of least accuracy. However, if one considers that the elevation data is accurate to within $\pm 5^{o}$, this is a rather small solid angle over which the ambiguity exists.

A cause for the errors near the polar region ($\theta = 0^{o}$), is the inaccuracies or imperfections associated with radiation patterns of the antenna. Further, it is to

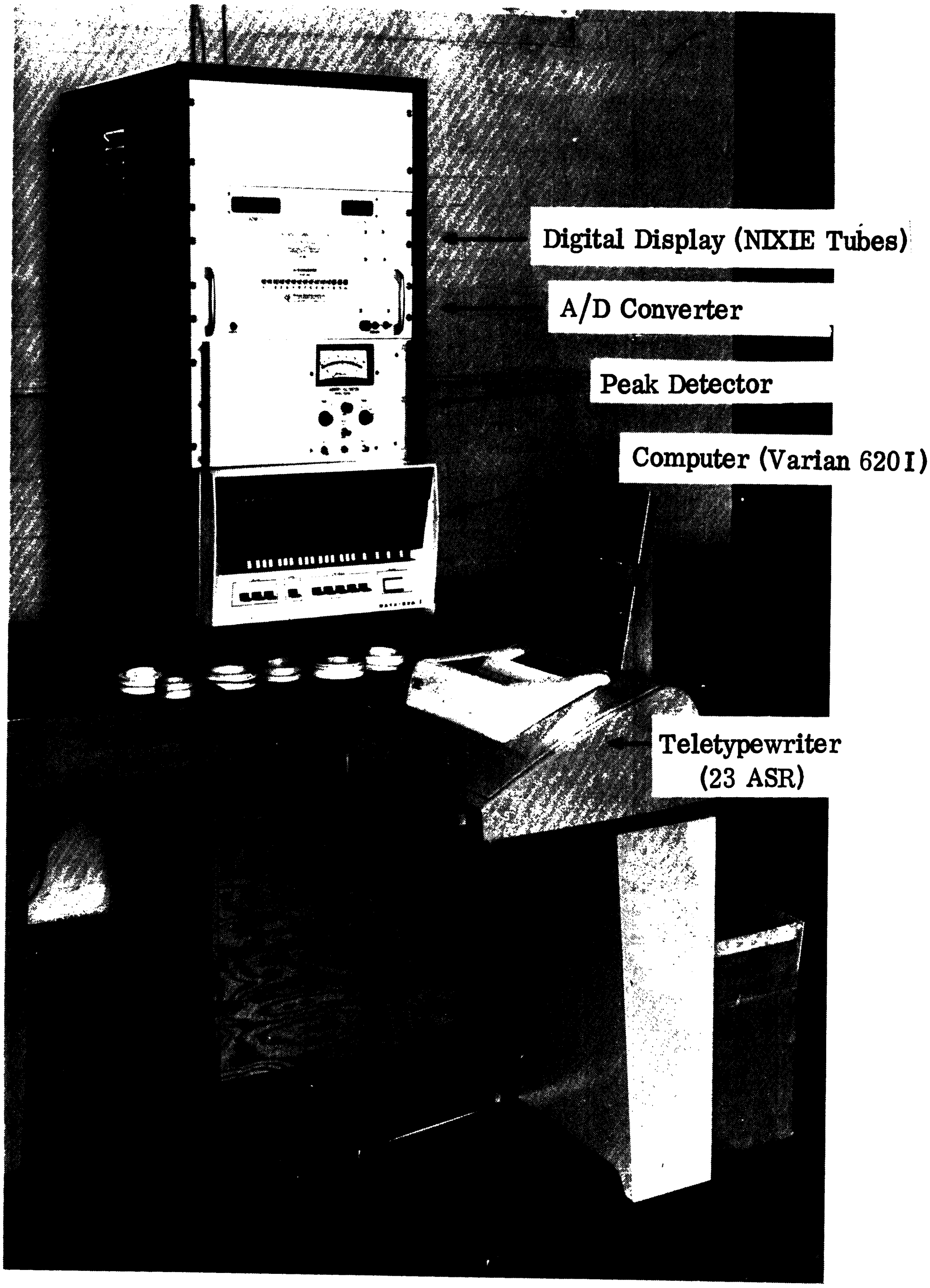


FIG. 5-1: Data Conversion Equipment.

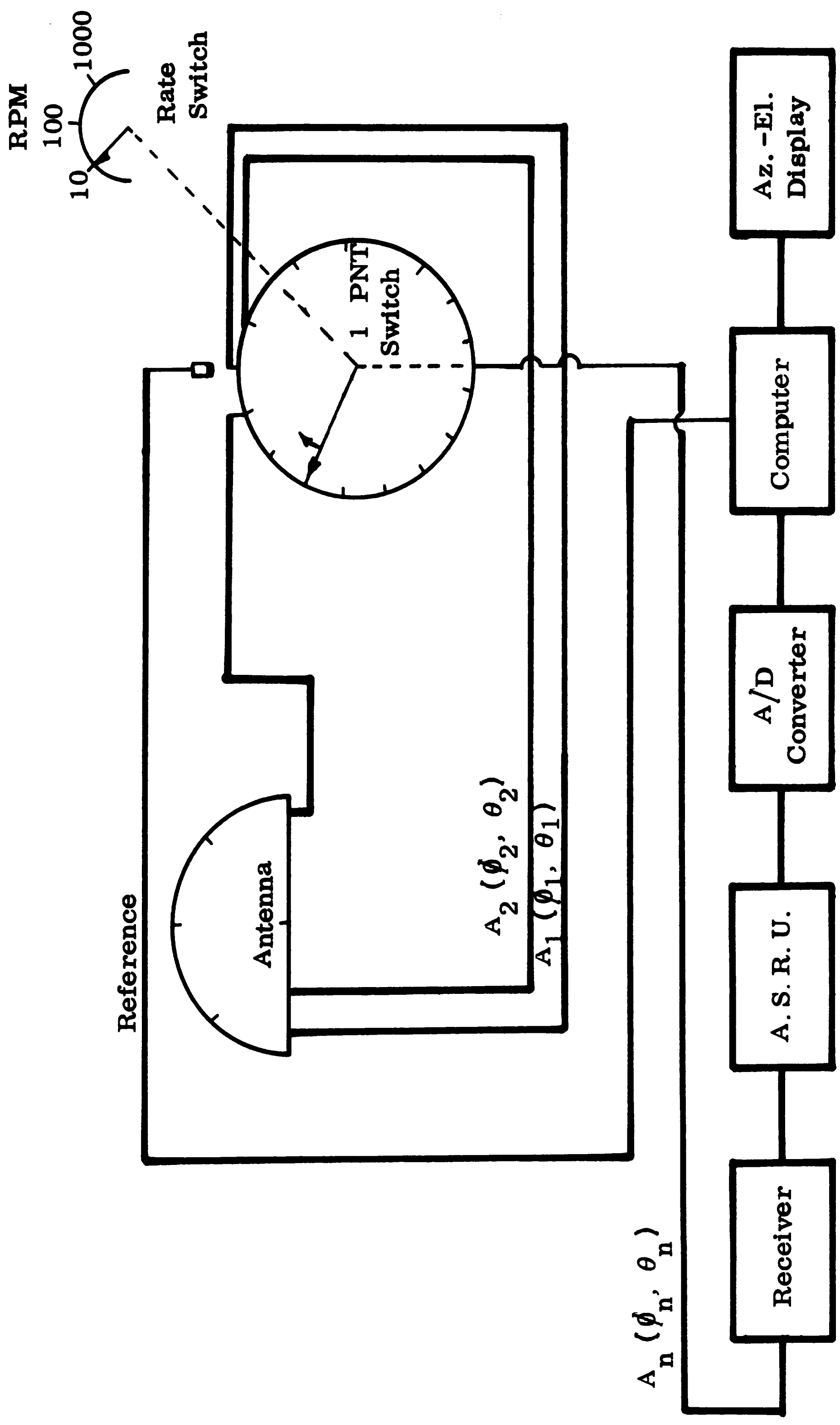


FIG. 5-2: Azimuth - Elevation System Block Diagram.

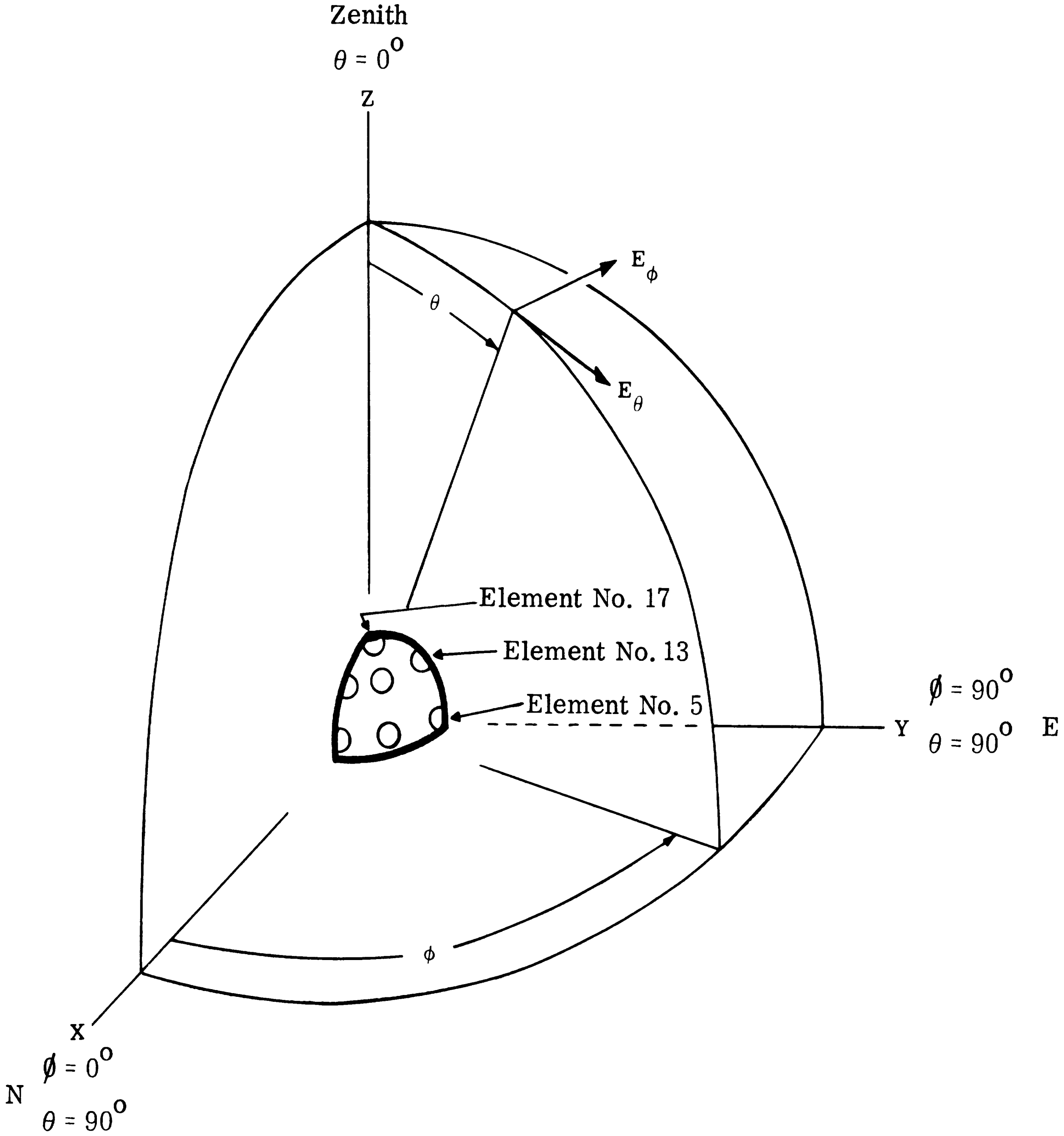


FIG. 5-3: Azimuth - Elevation Coordinate System.

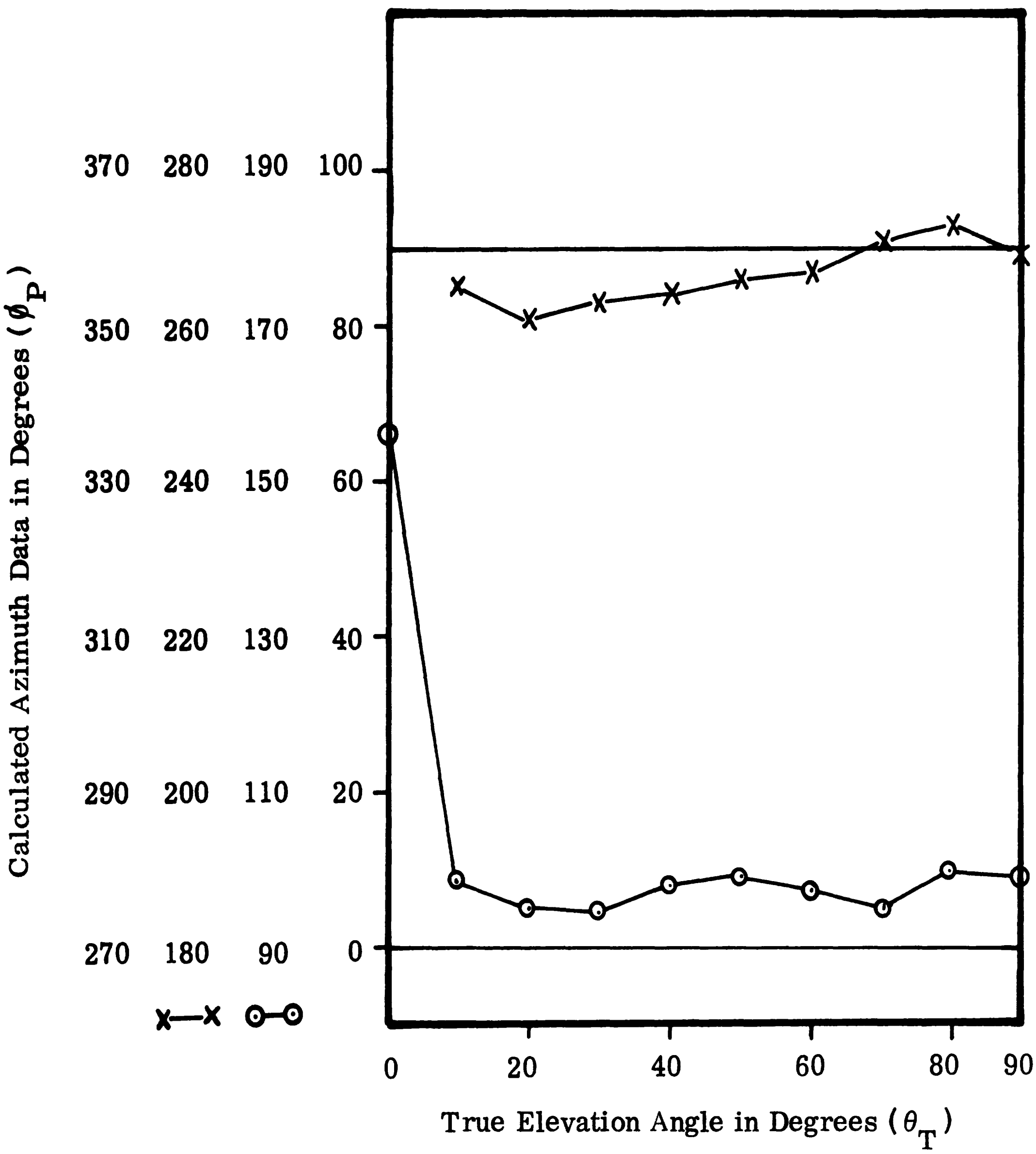


FIG. 5-4: Azimuth Angle as Generated by the DF System as a Function of the True Elevation Angle for $\phi = 90^o$ ⊙—⊙ and $\phi = 270^o$ x—x.

be noted that the errors that have been observed in the polar region had been determined theoretically prior to the tests now being conducted. Again the theoretical work was performed taking into account the inaccuracies associated with the antenna patterns.

One will also observe that there is an increase in the error near the horizon (at elevation angles of $\pm 90^{\circ}$). This error is caused because of the inaccuracy in the positioning of the antenna with respect to the illuminating antenna. Efforts are now being made to improve the position of the antenna so as to be able to more accurately evaluate the accuracy of the azimuth - elevation DF system.

Additional azimuth data has been collected at 1.6 GHz for azimuth angles of 80°, 70°, and 60° and this data is shown in Figs. 5-5 through 5-7. Here one will observe similar errors for the azimuth data as for the data for $\phi = 90^{\circ}$.

Little has been said about the errors present in the elevation data. In the first quarterly report (ECOM-0547-1) dated October, 1967, it was theoretically determined that there would be an error in the elevation data. The cause for the error in the elevation data comes about because of the non-symmetry in the location of antennas in the θ plane of the antenna system, i.e., antenna elements are only employed in the upper hemisphere of the spherical coordinate system. Therefore, since the data employed to calculate the elevation angle are from a non-symmetrical system, the errors noted above are expected. Further, in the first quarterly report (ibid) it has been shown that the errors associated with the elevation angle are predictable and therefore can be corrected for in the computer. As of the present time, we have not inserted the necessary correction factor in the computer since further experimentation will assist in optimizing the correction factor.

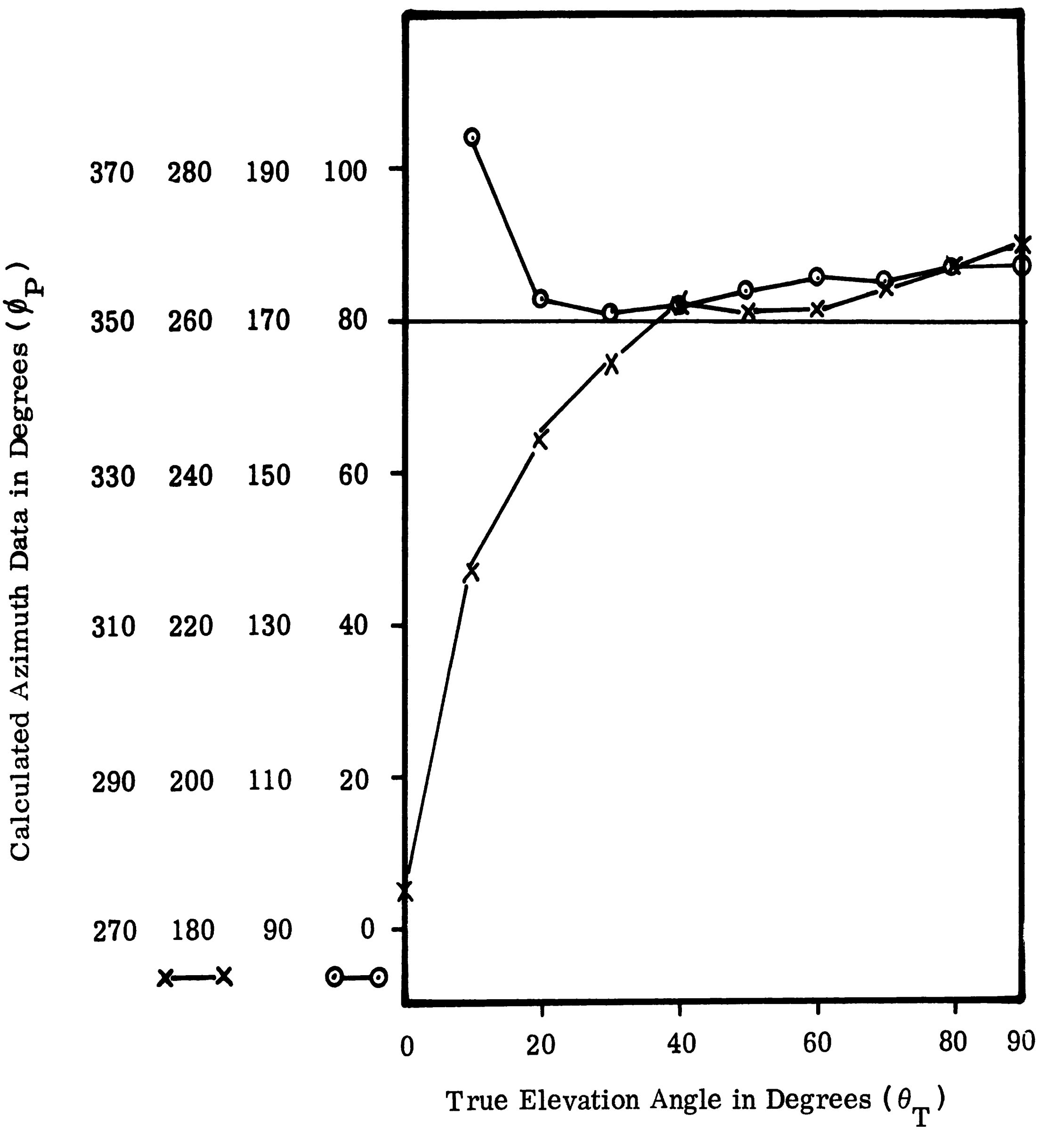


FIG. 5-5: Azimuth Angle as Generated by the DF System as a Function of the True Elevation Angle for $\phi = 80^o$ O—O and $\phi = 260^o$ X—X .

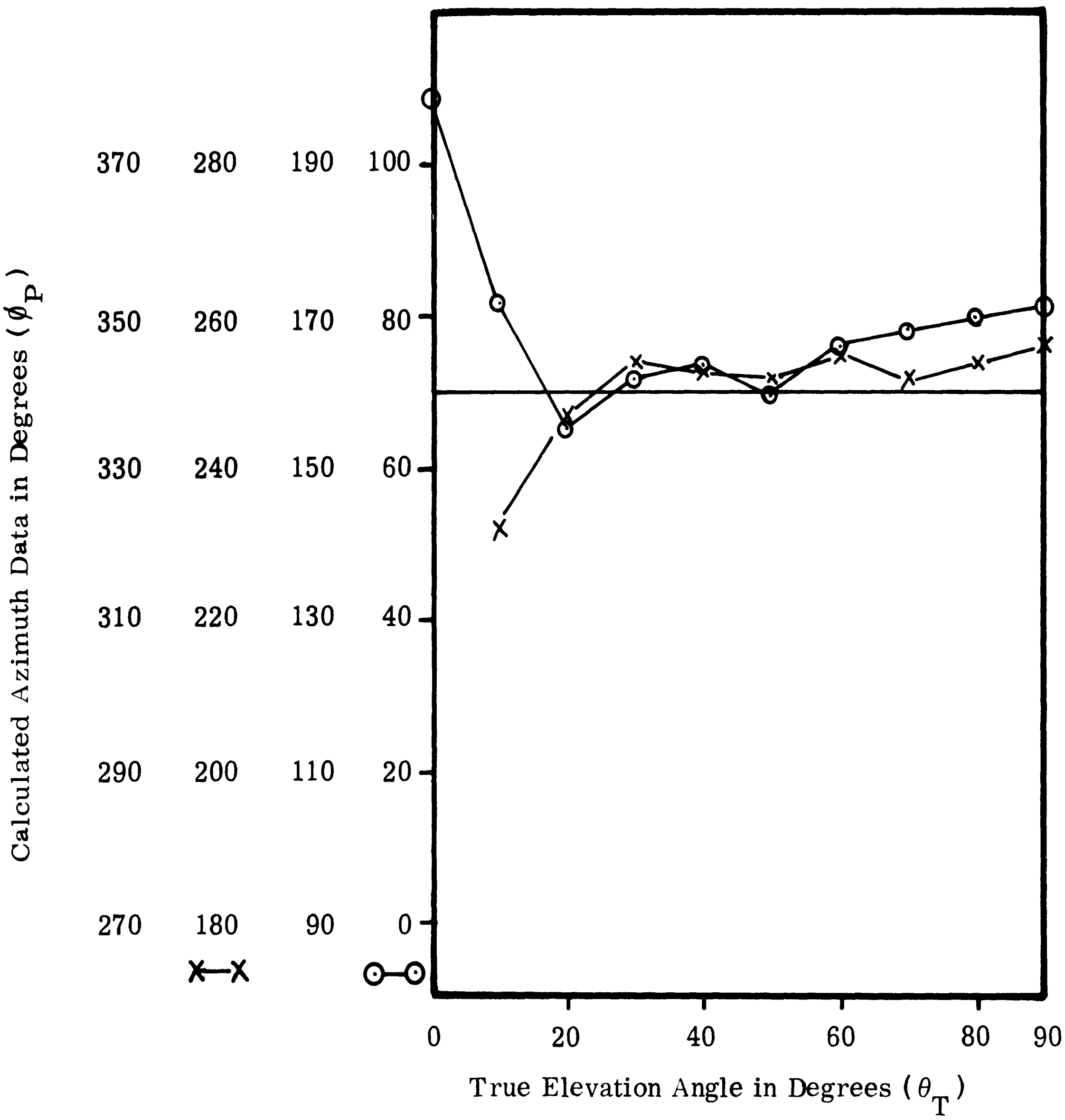


FIG. 5-6: Azimuth Angle as Generated by the DF System as a Function of the True Elevation Angle for $\phi = 70^o$ ⊙—⊙ and $\phi = 250^o$ x—x .

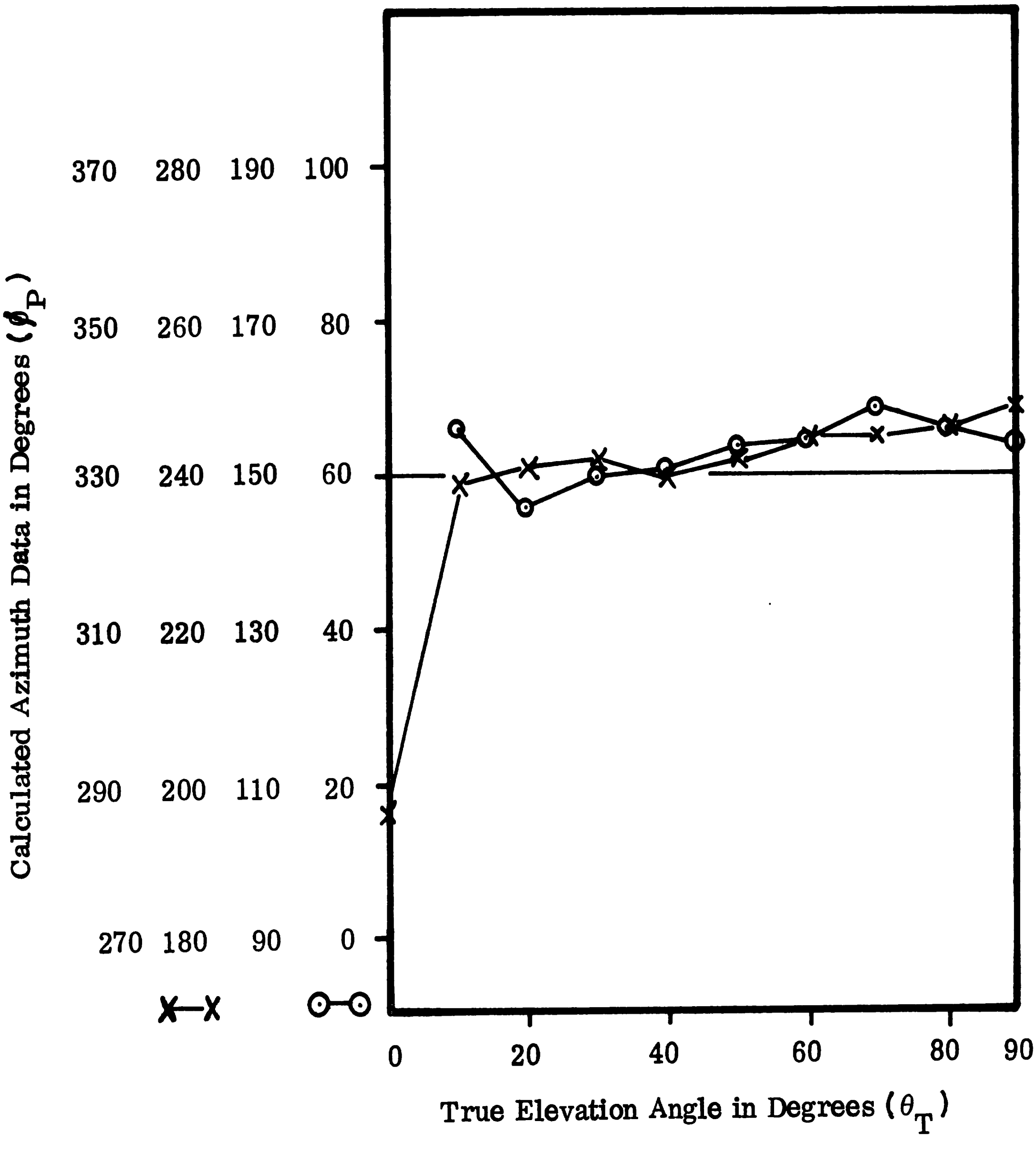


FIG. 5-7: Azimuth Angle as Generated by the DF System as a Function of the True Elevation Angle for $\phi = 60^o$ ⊙–⊙ and $\phi = 240^o$ X–X.

For the purposes of comparison we have included the theoretically computed elevation angle versus the actual elevation angle assuming a cosine antenna pattern for the individual elements in Fig. 5-8. Referring to Fig. 5-8, it is to be noted that the data varies in a piecewise linear fashion such that the correction factor to be inserted in the computer will be a relatively simple expression.

Referring now to the elevation data in Figs. 5-9 through 5-12, it will be observed that the system generated data does not agree with the true elevation data. However, the data does agree well with the theoretical data of Fig. 5-8. Therefore, the system elevation data should be easily corrected for as noted above.

To illustrate the importance of having antenna patterns that are well behaved both as a function of frequency and orientation, an additional set of azimuth - elevation data has been plotted for an azimuth angle of $\phi = 60^{o}$ at a frequency of 1.4 GHz in Figs. 5-13 and 5-14. The reader is referred to the pattern data shown in Fig. 2-5 for a frequency of 1.4 GHz. Here it will be observed there is considerable non-symmetry in the element pattern for this frequency. It is because of this non-symmetry in the element pattern that the large errors shown in Figs. 5-13 and 5-14 are present both in the azimuth and elevation data.

To gain some insight as to how the azimuth - elevation data may vary as a function of frequency, the orientation of the illuminating antenna was held fixed (with respect to azimuth - elevation system) and the data plotted in Fig. 5-15 and 5-16 was collected as a function of frequency. This data was collected for several frequencies in the range of 0.6 - 3.0 GHz. It will be observed that there are some large errors associated with the data as a function of frequency. The cause for the errors is related to the symmetry associated with the antenna element patterns both as a function of frequency and orientation.

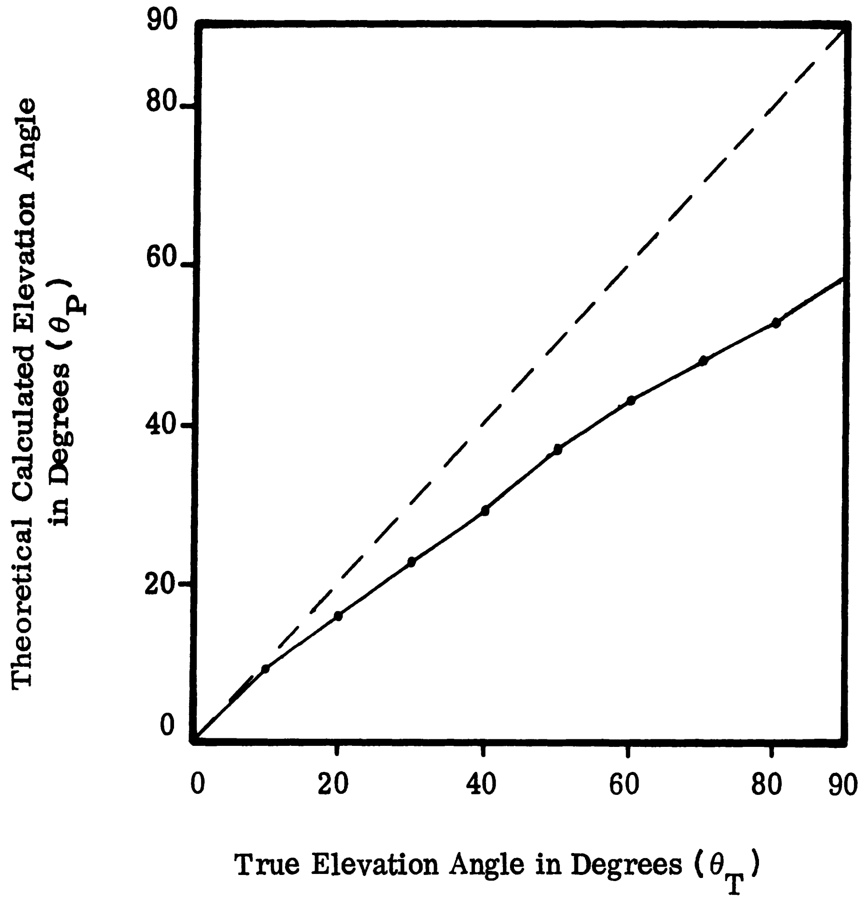


FIG. 5-8: Theoretical Calculated Elevation Angle vs. True Elevation Angle (Assuming a Cosine Element Pattern with Elements Placed at $\theta = 40^o$ and 80^o).

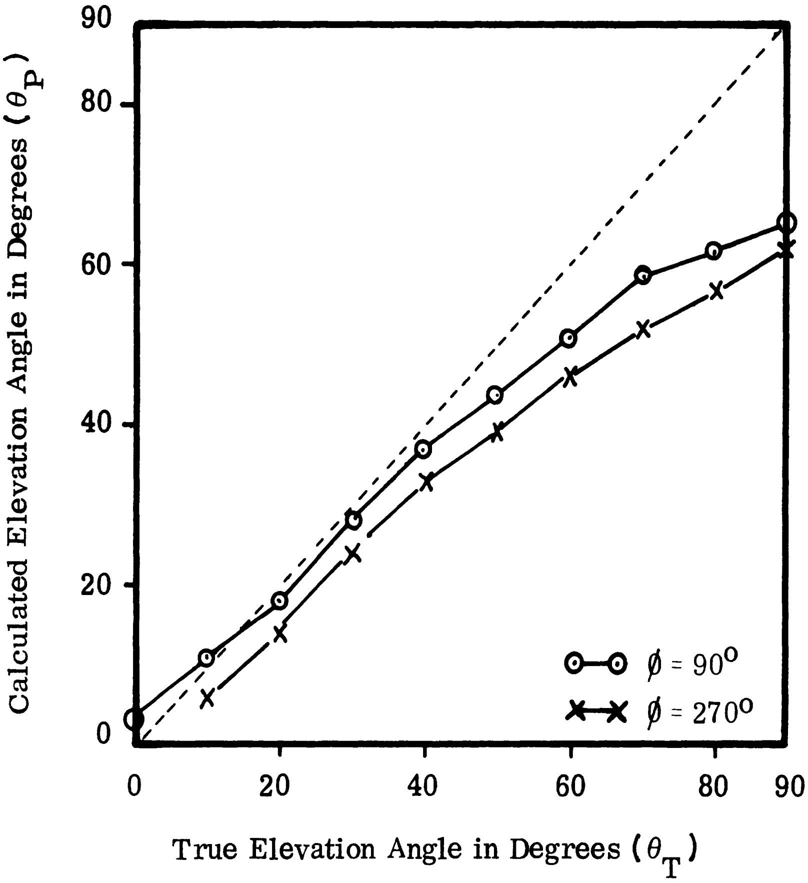


FIG. 5-9: System Generated Elevation Angle vs. True Elevation Angle (Frequency = 1.6 GHz).

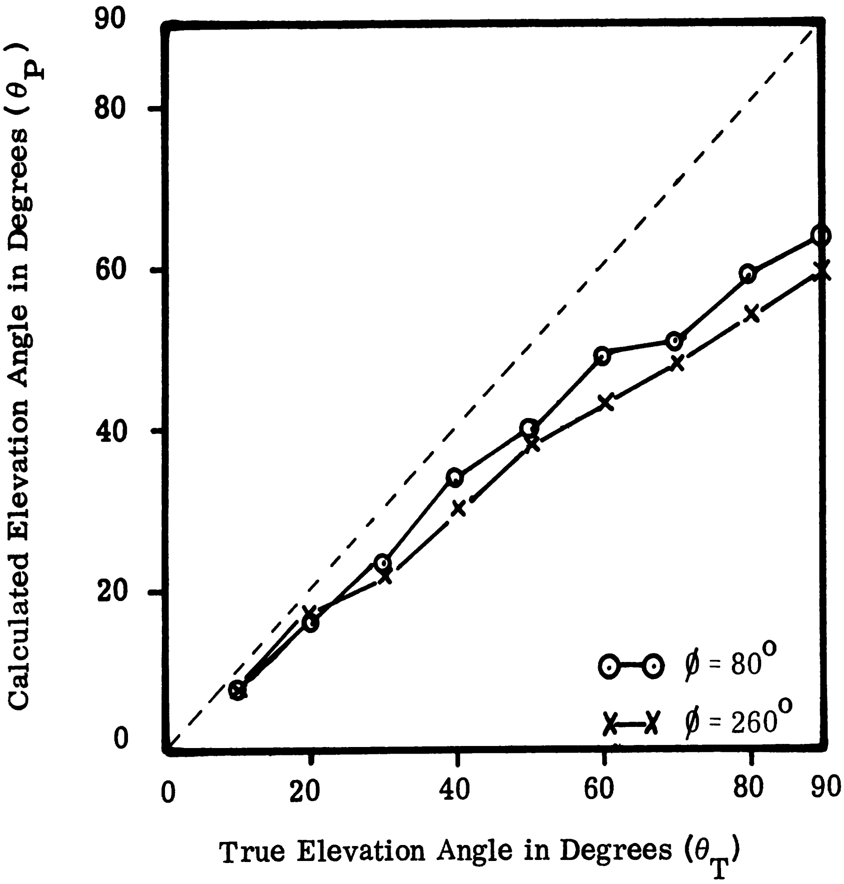


FIG. 5-10: System Generated Elevation Angle vs. True Elevation Angle (Frequency = 1.6 GHz).

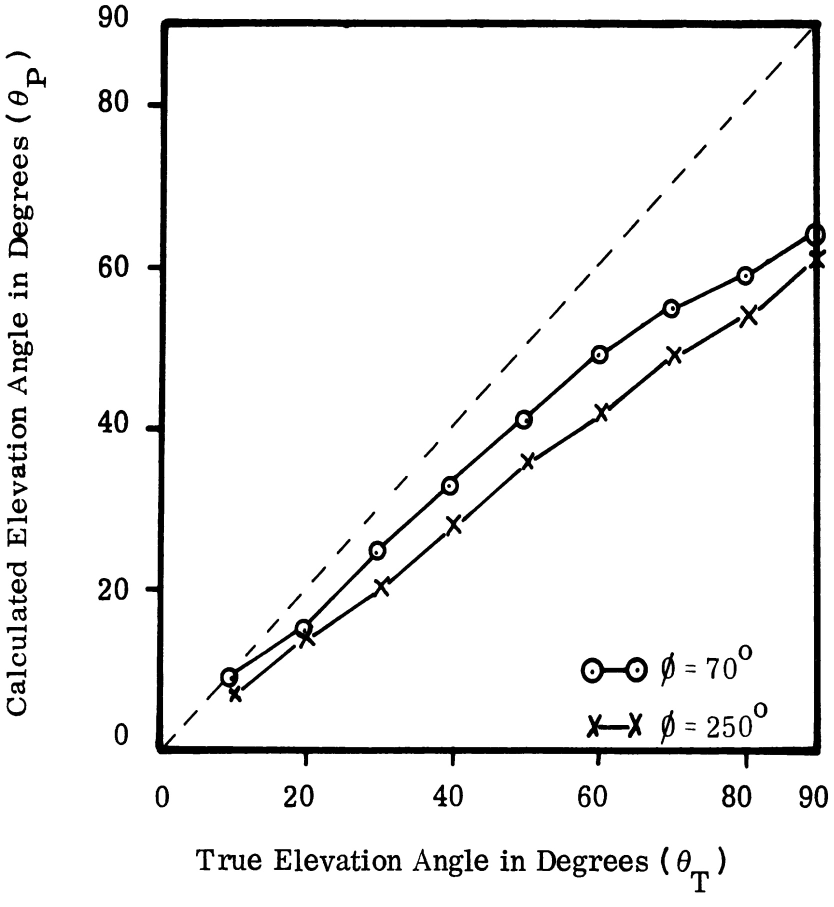


FIG. 5-11: System Generated Elevation Angle vs. True Elevation Angle (Frequency = 1.6 GHz).

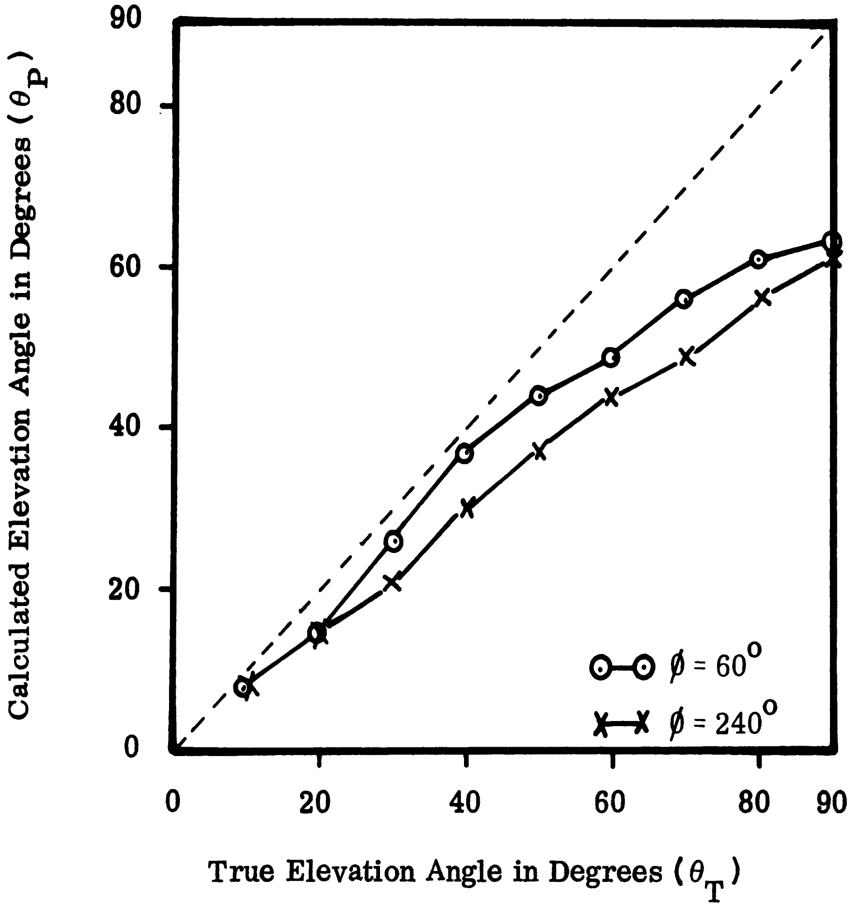


FIG. 5-12: System Generated Elevation Angle vs. True Elevation Angle (Frequency = 1.6 GHz).

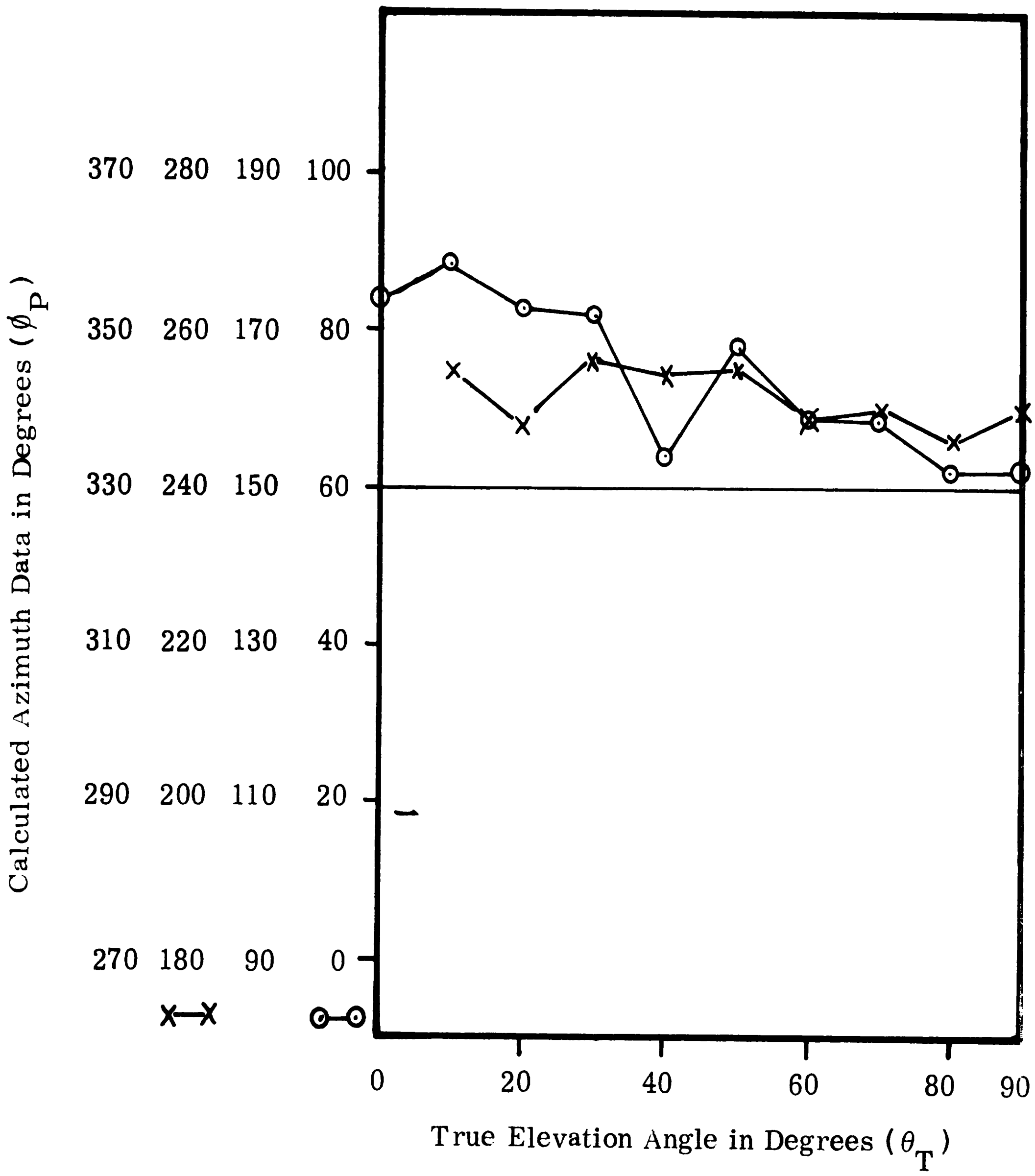


FIG. 5-13: System Generated Azimuth Angle vs. True Elevation Angle (Frequency = 1.4 GHz) for $\phi = 60^o$ ⊙—⊙ and 240^o x—x .

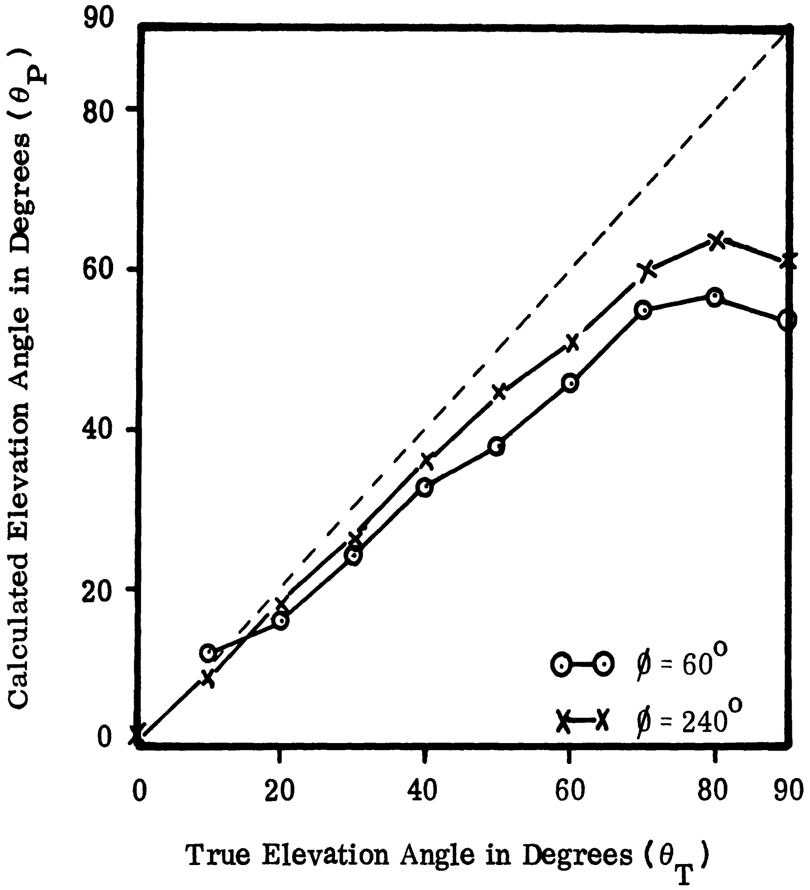


FIG. 5-14: System Generated Elevation Angle vs. True Elevation Angle (Frequency = 1.4 GHz).

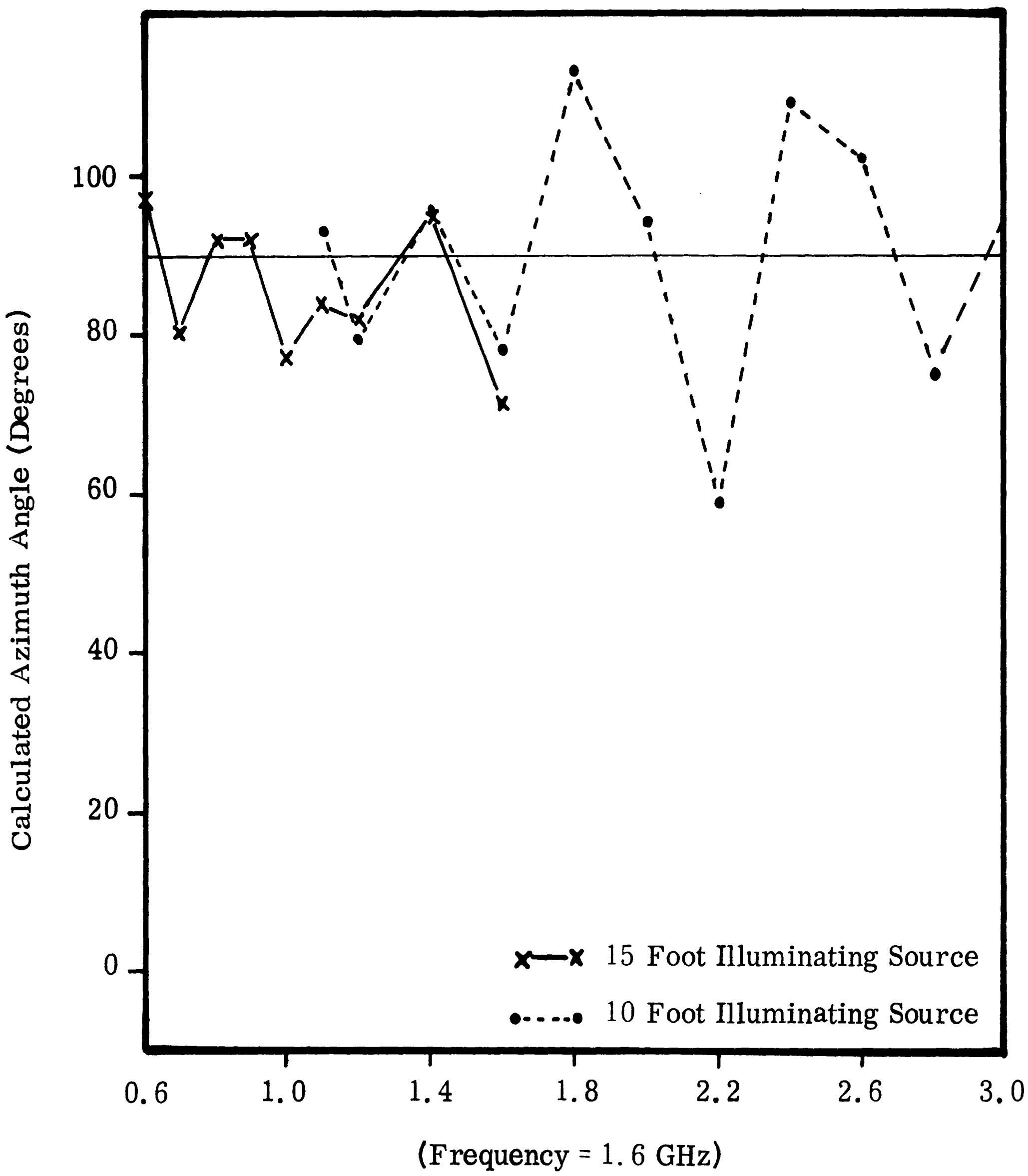


FIG. 5-15: System Generated Azimuth Angle vs. Frequency for a Fixed Azimuth and Elevation of Illuminating Source ($\theta = 90^o$, $\phi = 30^o$).

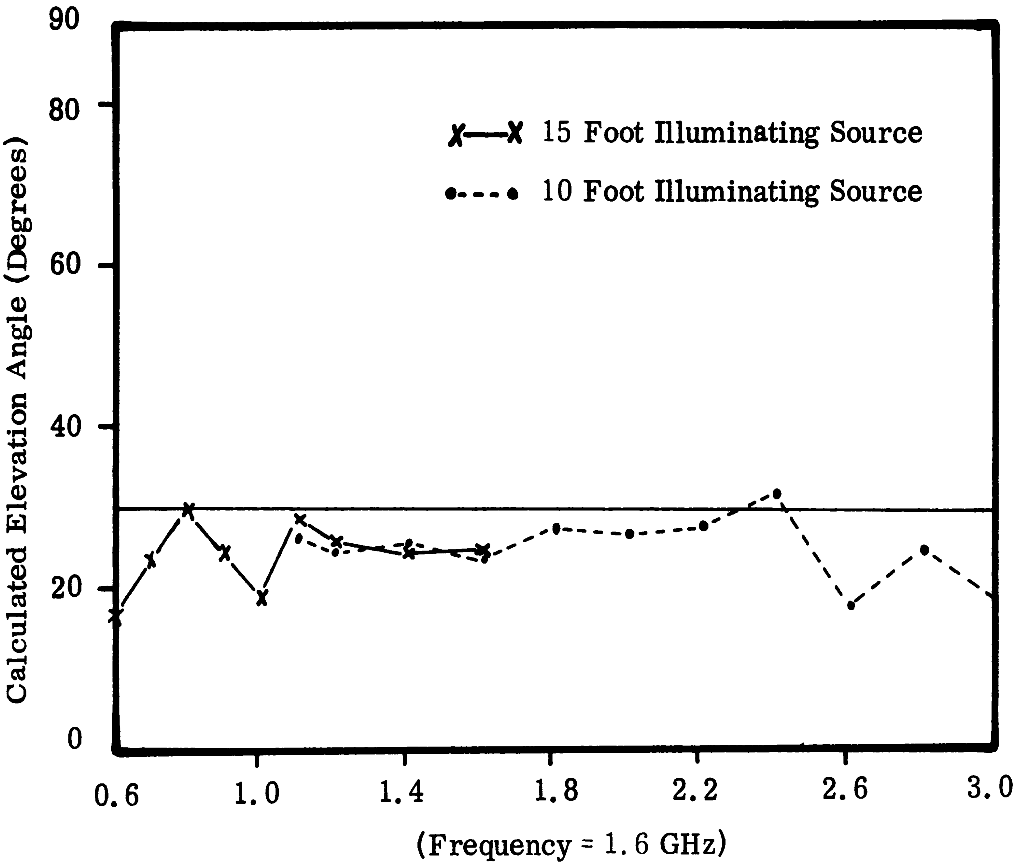


FIG. 5-16: System Generated Elevation Angle vs. Frequency for a Fixed Azimuth and Elevation of Illuminating Source ($\theta = 90^{o}$, $\phi = 30^{o}$).

The data presented above has been collected employing a CW source. In addition, some tests have been made employing pulse data. In this test a pulse width of approximately 4 microseconds duration and a repetition rate of 1000 pulses per second was used. This data agreed well with the CW data presented above.

The results presented above have been collected without benefit of any data processing techniques. Some preliminary work has shown that data processing can improve the accuracy for those cases where the element patterns are not well behaved both as a function of frequency and orientation.

In one of the data processing schemes only a limited amount of the data collected by the computer was processed. This method simply required that the computer scans the data collected from the 17 antennas and determines the maximum signal received, so that the remaining data can be normalized with respect to the pattern maximum. Only data within a specified limit of the pattern maximum is employed in the calculation of the azimuth - elevation angles. Typically, data has been limited to that within 15, 10, and 6dB of the data maximum. Essentially, one is discarding all data below the specified limit. Through this method one hopes to limit the data used by the computer to that region where the antenna element patterns are well behaved both as a function of frequency and antenna orientation.

A second method of processing required the averaging of data. Employing this technique the azimuth and elevation is calculated and stored (in the computer) for several revolutions for the antenna, typically 10 revolutions. This data is then averaged and the average displayed to the operator. The purpose for using this technique is to provide a large number of data points which have random variation due to anomalies in the DF system from which to calculate the azimuth and elevation direction of arrival.

More effort is required to properly evaluate data processing techniques that may be applicable in improving the accuracy and reliability of the data displayed by the DF system.

VI

FLY-BY TESTS

Preparations are now being made to conduct a series of fly-by tests with the azimuth - elevation direction finding equipment. In these tests the aircraft flies in the vicinity of the azimuth - elevation direction finder while radiating a 1.6 GHz CW or pulse signal. The aircraft will be tracked with a NIKE Ajax (Fig. 6-1) skin tracking radar system to provide an accurate azimuth - elevation location of the aircraft as a function of its flying time. At the present time, it appears that the data from the NIKE Ajax system can be placed in a format such that it can be inserted into the azimuth - elevation direction finder computer system and printed out on the teletype along with the azimuth and elevation data from the DF equipment. This will provide a real time comparison between a known azimuth - elevation system (the NIKE Ajax system) and the system under test (Azimuth - Elevation Direction Finder). Presently one of two aircraft are being considered for use. They are a C-131 Air Force aircraft or an Army C-46 aircraft. Either of the aircraft has the capability of being flown at an altitude of 10,000 feet for a minimum of one hour testing time.

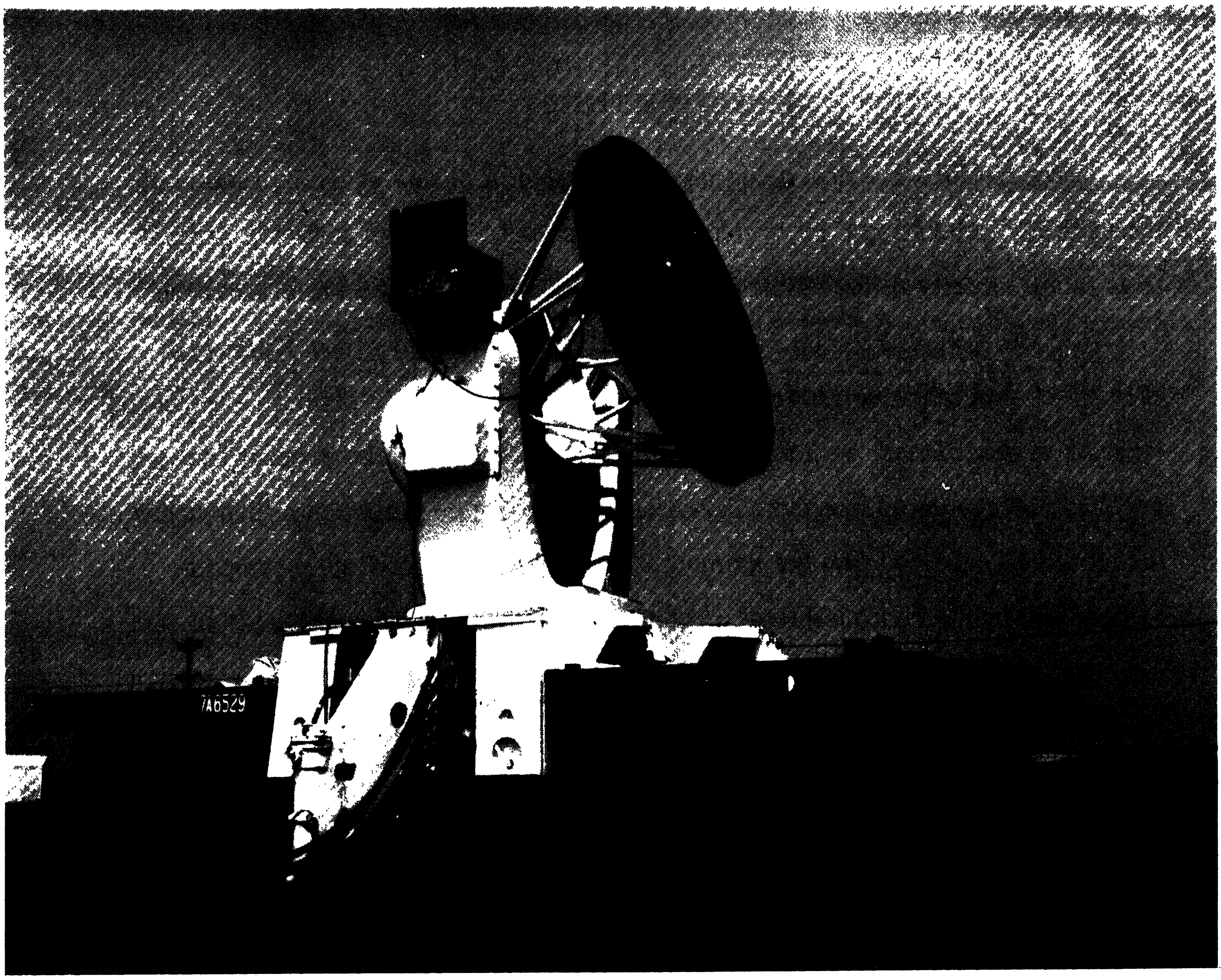


FIG. 6-1: NIKE Ajax Skin Tracking Antenna.

VII

CONCLUSIONS AND RECOMMENDATIONS

The fabrication of the quadrafilar balun network has been completed and the phase data is not as well controlled as desired. However, it is felt that with some additional effort, the balun can be optimized to operate in accordance with the design criteria. It is recommended that this effort (optimization of the balun network) be continued, so as to obtain the proper amplitude and phase characteristics required for the quadrafilar spiral.

As noted in Chapter II, some preliminary radiation patterns recorded for the quadrafilar spiral were unsatisfactory. The cause for the poor pattern characteristics is the improper phase distribution associated with the balun, and the wrap angle of the spiral and perhaps irregularities in the winding of the spiral elements. The present quadrafilar spiral was hand-made and some errors in the manner in which the elements were wound are apparent. Therefore, it is recommended that the study of the quadrafilar spiral configuration be continued so as to optimize the element design, thus enhancing accuracy of the direction finder system. As a part of the optimization of the elements, consideration should be given to the cone angle and material, element conductor and wrap angles. Although several investigators are working with the multifilar spiral configuration, no satisfactory antennas are available commerically.

Because of the unavailability of multifilar spirals, the authors have given consideration to the use of the bifilar cavity backed spirals as advertized by many commercial organizations. However, as a result of extensive discussions with the manufacturers representatives, it has been learned that most of the spirals are inefficient and therefore have low gains. One cause for the poor efficiency associated with commercially available cavity backed spirals is that the manufacturer employs resistive material (microwave absorber, etc.) to minimize moding and to improve the radiation characteristics of the antenna.

A general review of the preliminary results that have been obtained for the azimuth - elevation direction finder substantiate the feasibility of employing the vector analysis technique for direction finding in both azimuth and elevation. Present results show that the system accuracy is $\pm 5^{\circ}$ for both azimuth and elevation planes. The chief limiting factor to the system is the antenna elements. To overcome this limitation additional effort is needed on the optimization of the elements and further consideration on improved data processing techniques is in order.

In the event there is interest in employing the present azimuth - elevation DF system with higher gain elements, it would be desirable to store the element pattern in the computer. It appears that this would require a more sophisticated computer than the one now in use. This is another area of study worthy of future consideration.

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13. ABSTRACT

During this reporting period efforts have continued in the design and development of the quadrafilar balun, and the assembly of the components of the DF system has been 90 per cent completed. Preliminary tests that have been conducted on the quadrafilar balun have shown that the amplitude variation is well behaved. However, there is some undesirable phase discrepancies in the network. In addition to these tests a preliminary evaluation of the DF system has been conducted. The results of the preliminary tests show that the system is able to direction find with an accuracy of $\pm 5^{\circ}$ in both the azimuth and elevation directions.

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