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THESIS

DESIGN, CONSTRUCTION AND TESTING OF A PROTOTYPE FIN-LINE MAGIC-TEE AND FIN-LINE MONOPULSE SYSTEM SUITABLE FOR MILLIMETER-WAVE APPLICATIONS

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December 1985

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Design, Construction and Testing of a Prototype Fin-Line Magic-Tee and Fin-Line Monopulse System Suitable for Millimeter-Wave Applications

by

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ABSTRACT

This thesis describes a fin-line 180 degree hybrid (magic-tee) that is suitable for use in monopulse radar antennas at microwave and millimeter-wave frequencies.

The three-dimensional junction of a waveguide magic-tee is replaced with fin-line slots, coupled fin-line slots and microstrip lines mounted in a waveguide fixture. The planar geometry on the substrate provides significant reduction in size and eliminates the waveguide ratrace that is associated with conventional hybrids. Ports one and two are flared into fin-line horns to produce a fin-line monopulse system. Suggestions for further development of the fin-line magic-tee and monopulse system are presented.

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I. INTRODUCTION

A. BACKGROUND

This thesis describes the successful design, construction and testing of both a fin-line magic-tee and monopulse system. Each of these units is probably the first devices of their type constructed.

There are two main categories of magic-tees: the conventional waveguide hybrids, and the new planar devices [Ref. 1: pp. 259-261]. The fin-line magic-tee, developed in this thesis, is in the latter category.

The 180 degree hybrid, or magic-tee, is a passive four port device. It is an essential part of many microwave components, including balanced mixers, single-sideband modulators, frequency multiplexers, linear phase shifters, constant impedance filters, IFM (instantaneous frequency measurement) receivers, interferometers, duplexers and monopulse radar comparators [Ref. 1: pp. 259-261 and Ref. 2: pp. 16-18]. While many of these applications use only one hybrid, monopulse antennas contain a complex network of magic-tee comparators.

Monopulse comparator networks require exact symmetry between numerous sections of transmission lines for proper operation. Unbalanced phase shifts of only a few degrees, due to uneven lengths of transmission line, destroy the target tracking capability of the system [Ref. 3].

Waveguide comparator networks, with bolted together flanges or soldered connections, have difficulty achieving these exacting lengths at millimeter-wave frequencies. This effect limits most of the current monopulse radars to frequencies well below the millimeter-wave band [Ref. 3].

Another limitation of the waveguide hybrid occurs because three of the four ports are on mutually orthogonal axes. It is this three dimensional shape that produces the complex waveguide ratrace and intricate network of soldered flanges in conventional monopulse antennas [Ref. 2: pp. 10-17 and Ref. 3].

Unlike the waveguide magic-tee, all four ports of the new hybrids are in the same plane. This two dimensional geometry greatly simplifies the interconnections between the numerous comparators in a monopulse antenna system. With the planar magic-tees, the confusing and costly maze of waveguide discussed above can be eliminated.

In addition to the fin-line magic-tee designed in this thesis, two other types of planar magic-tees have recently been developed [Ref. 3 and Ref. 4: pp. 523-528]. However, only one of these new hybrids is designed as a monopulse comparator [Ref. 3].

The fin-line magic-tee developed in this thesis and the new fin-line horn antenna developed in a parallel thesis [Ref. 5] are designed to be computer manufactured as a single unit. This combination of fin-line horns and fin-line magic-tees constructed in an integrated unit, is hereafter called a fin-line monopulse system, or a fin-line monopulse comparator. Fin-line monopulse systems, operating at millimeter-wave frequencies, can potentially be mass produced for a few hundred dollars each.

B. RELATED WORK

1. Slotline Magic-Tee

Mr. M. Aikawa and Mr. H. Ogawa [Ref. 4: pp. 523-528] introduced a slotline magic-tee. The fin-line magic-tee developed in this thesis (Fig. 1) is similar to two of these slotline hybrids placed back to back in a waveguide fixture.

There are five major differences between the fin-line magic-tee developed in this thesis and the slotline magic-tee described in Reference 4.

First, the fin-line hybrid is essentially two slotline hybrids in parallel with each other. This configuration significantly changes the impedance characteristics of the circuit.

Second, the waveguide fixture that surrounds the fin-line device, changes all of the impedances as a function of frequency.

Third, the unique microstrip to coaxial transition used in the fin-line device does not have a counterpart in the slotline magic-tee. The purpose of this transition is to maintain a fairly wide bandwidth at the point where the microstrip passes through the waveguide wall.

Fourth, the slotline hybrid uses a tapered section to transition from the main loop to the coupled slot area. In the corresponding portion of the fin-line magic-tee, each section of microstrip maintains a constant width up to the point where the two sections join.

Finally, all of the bends in the slots of the fin-line magic-tee are computer designed to keep incidental reflections as low as possible.

2. Planar Waveguide Comparators

The system described by Syrigos, Crossland and Van Wyck [Ref. 3] is not related to this thesis at all. However, it does meet part of the objectives of this work by utilizing a totally different design and manufacturing concept.

3. Fin-Line Horn Antenna

The fin-line horn antenna was perfected by LCDR Mumtaz-ul-Haq [Ref. 5]. Haq discovered that a substantial amount of the electric field can be launched between the parallel fins. This undesirable effect can be successfully controlled by making the horn fins half of a wavelength wide and shorting the exposed edges together with copper tape. This short reflects another short across the edges of the fin-line slots. The reflected short seals the gap between the fins and keeps the electric field in the slots.

The parallel slots leading to ports one and two (Fig. 1) are separated by a quarter wavelength. Each slot appears as an open to the other slot, reflecting back a short a quarter of a wavelength away. The reflected short seals off the two slots, thereby preventing inadvertent coupling. This concept is a direct result of the applied research performed by Haq [Ref. 5].

C. PURPOSE

The first objective of this work is to design, build and successfully test a fin-line magic-tee at 10-GHZ. This includes the design and construction of a suitable fixture to hold the magic-tee. The final magic-tee is to be integrated with two fin-line horn antennas [Ref. 5], to form a two dimensional fin-line monopulse system (only one difference channel).

The second objective is to produce reasonable sum and difference antenna patterns from the combined one piece unit. This integrated unit is intended to be the prototype of a millimeter-wave fin-line monopulse system that has both azimuth and elevation difference channels.

The third and most important objective is to computerize the design procedure. This will insure the ability to accurately and quickly reproduce these devices at a future date.

The final objective of this research is to recommend possible improvements for the fin-line magic-tee and fin-line monopulse system. Specific recommendations for expanding the fin-line monopulse system into a three channel (sum channel, azimuth channel and elevation channel) monopulse system are required.

II. THEORETICAL PRINCIPLES

The design of the fin-line magic-tee and monopulse system is based on established microwave principles. These theoretical concepts are discussed in this chapter.

A. WAVEGUIDE MAGIC-TEE

The theoretical properties of a waveguide 180 degree hybrid are illustrated in Figures 2 and 3. An input at any one of the four ports is equally divided with half of the power coupling into two orthogonal ports. In phase signals at ports one and two combine in the H-plane arm and cancel in the E-plane arm. Out of phase inputs at ports one and two produce the opposite results. There is complete isolation between ports one and two and between ports three and four. The reverse of these conditions is also true. The 180 degree phase shift depicted in Figure 3 can occur in either S23 and S32 as shown, or in S13 and S31 [Ref. 6: pp. 190-191].

B. MONOPULSE ANTENNAS

The typical monopulse radar antenna contains four identical antenna elements, which are interconnected with three or more magic-tees. The signals to and from the four elements are added and subtracted in various combinations to produce three system ports.

All four of the antennas are summed together in phase to produce the sum channel. This signal is connected to the radar via a T/R (Transmit/Receive) Device.

The two difference channels are the radar's source of target tracking information. The elevation port produces the difference between the upper and lower antennas while the azimuth port produces the difference between the left and right antennas. If a monopulse antenna system is pointing exactly at a target, there will be a strong signal in the sum channel and absolutely no signal in either the elevation or azimuth channels. The null in the difference channels is the result of shifting two identical signals 180 degrees from each other and then adding them together. The phase shift and addition occur within the magic-tees.

The radar return from a target that is slightly left of the monopulse antenna's extended center line reaches the left elements of the antenna before it reaches the right elements. This produces a slight phase shift due to the difference in arrival times at the left and right elements. Complete cancellation does not occur in the difference channel with this configuration. The resulting difference signal increases in amplitude and shifts in phase as the target gets farther away from the antennas extended center line. There is also a 180 degree phase shift in the difference channel as a target crosses the antenna's extended center line [Ref. 7: pp. 10-29].

Since the null in the difference port can only occur with exact target/antenna alignment, it signifies the exact center of both the sum and difference antenna patterns. Therefore, a target that produces a strong return in the sum channel and no return in one of the difference channels is on a plane that bisects the two antennas which develop the difference signal. When this information is combined with range data, the target's location is limited to an arc on the plane that bisects the two halves of the antenna. The point where the elevation and azimuth arcs cross is directly in front of the antenna. The line between the monopulse antenna and this point is commonly referred to as the boresight of the antenna.

If the outputs of the difference channels are monitored while a target is within the main beam of the sum pattern, the target can be classified as exactly centered, a little left or right, a little high or low, or any combination of these directions.

Skolnik [Ref. 7: pp.10-28] defines an amplitude comparison monopulse system as one that compares the amplitude of the difference channel with the amplitude of the sum channel. This information is used to determine how far a target is away from the antenna's boresight. The phase (+/- only) of the difference signal is used to determine which side of boresight the target is on.

This technique was initially called simultaneous lobing since all of the radiation lobes are sampled during each and every pulse. The ability to obtain a complete tracking solution in only one pulse led to the current designation of monopulse [Ref. 7: p. 10].

Earlier tracking radars such as conical scanning and lobe switching systems required numerous radar returns to obtain the same information. The accuracy of these systems is often degraded by pulse to pulse amplitude variations. Monopulse radars, which are free of this distortion, have achieved tracking accuracies of 0.003 degrees [Ref. 7: p. 10].

Two popular forms of amplitude comparison monopulse antennas are illustrated in Figures 4 and 5.

C. THEORETICAL ANTENNA PATTERNS

The far field effect an antenna has on the environment is a direct result of the current distribution across the face of the antenna and can be represented mathematically with a specialized Fourier Transform [Ref. 8: pp. 345-369 and Ref. 9: pp. 170-195]. This technique is used to develop computer simulations of actual sum and difference patterns. The simulated patterns are used to illustrate the theoretical properties of a monopulse system.

The first step in predicting a theoretical monopulse antenna pattern is to obtain the element pattern by taking the Fourier Transform of the current distribution across the face of one of the elements. The second step is to determine the array or group pattern by taking the Fourier Transform of the entire array, assuming that each antenna element is a delta function. The final step is to multiply the element pattern with the array pattern.

An actual E-plane antenna pattern from one of the fin-line horns of Reference 5 is closely simulated by adding 20% of a sin(x)/x pattern, to 80% of sin(x)/x squared pattern (Fig. 6). This simulation is used as the predicted element pattern.

The group pattern is obtained by taking the trivial transformation of two delta functions. This results in a cosine function for the sum pattern and a sine function for the difference pattern. These theoretical group patterns with an element spacing of one wavelength are illustrated in Figures 7 and 8.

The multiplication of the simulated element and group pattern is done in a short Basic program on an HP-9845B Computer. The theoretical sum and difference patterns computed in this program are shown in Figures 9 and 10, respectively.

D. SLOTLINE CHARACTERISTICS

Slotline consists of a narrow slot in a thin plating of metal foil adhered to one side of a thin layer of dielectric. The other side of the supporting substrate is void of metal. The electric field is guided between the edges of the slot. The impedance of the slot is directly proportional to the width of the slot. A detailed analysis of slotline properties is presented by Gupta, Garg and Bahl [Ref. 10: pp. 195-228].

E. FIN-LINE CHARACTERISTICS

The bilateral fin-line illustrated in Figure 11 has one straight slot on each side of the dielectric. The fin-line magic-tee uses a similar, but more complex configuration which has two slots on each side of the dielectric. The slots in the magic-tee have a mixture of straight, angled and curved sections which join together in a 180 degree bend (Fig. 1). Both of these designs are formed by suspending dual sided slotline in the E-plane of a section of waveguide. As such, they are essentially shielded slotline. As is the case with slotline, the impedance of fin-line is directly proportional to the width of the slot. The detailed properties of fin-line are discussed by Sharma and Hoefer [Ref. 11: pp. 350-355] and Meier [Ref. 12: pp. 1209-1215].

F. EVEN AND ODD MODES IN COUPLED SLOTS

Two identical and parallel slots in either slotline or fin-line are considered coupled if the impedance and electrical length of one slot is effected by the proximity of the other slot. Coupled slots are the key to the operation of both the slotline magic-tee discussed in Reference 4 and the fin-line magic-tee developed in this thesis.

Knorr and Kuchler [Ref. 13: PP. 541-547] define two dominate modes in coupled slots: even or odd. The even mode exists when the electric fields within the two slots are in phase with each other; whereas, the odd mode exists when the two electric fields are out of phase with each other.

In the even mode, the magnetic fields which surround each slot couple together smoothly to form one continuous magnetic field. In this configuration, the fields aid each other and produce a coupled impedance which is lower than the uncoupled impedance [Ref. 10: p. 352].

As the slots are brought closer together, the coupling increases. This effect causes the even mode impedance to decrease. In the limit when the separation between the slots vanishes, each slot has half of the impedance of the new slot which is twice as wide as each of the original slots. At the other limit when the distance between the slots is infinite, each slot retains its uncoupled characteristics [Ref. 10: p. 355].

In the odd mode, the magnetic fields oppose each other and do not join together smoothly. Because of this opposition, the odd mode impedance is higher than the uncoupled impedance. As the two slots are brought closer together, the opposition between the two magnetic fields and the odd mode impedance increase [Ref. 10: p. 352].

In the limit, when the separation between the slots vanishes, there is complete opposition between two equal and opposite magnetic fields. In this condition, the odd mode impedance of each slot is exactly twice the uncoupled impedance of one of the original slots [Ref. 10: p. 355].

The electrical length of coupled slots is longer than the uncoupled length in the even mode and shorter than the uncoupled length in the odd mode. These differences become larger as the two slots are brought closer together [Ref. 13: pp. 543-545].

G. MICROSTRIP CHARACTERISTICS

The microstrip that is used in this thesis is composed of a narrow center conductor with dielectric material and a ground plane on both sides. If the two ground planes are bent around the center conductor until they touch, it will resemble coaxial cable. This dual sided microstrip, defined as "triplate line" by Reference 6, and coaxial cable both operate in the TEM mode [Ref. 6: pp. 38-61].

H. MICROSTRIP TO SLOTLINE TRANSITIONS

A simple and effective transition from slotline to microstrip is presented by Knorr [Ref. 14: pp. 548-553]. With this technique an open length of microstrip on one side of a section of dielectric overlaps a shorted slot on the other side of the same substrate at a 90 degree angle. The portion of the slot that extends past the microstrip, and the portion of the microstrip that extends past the slot are exactly one quarter of a wavelength long. At the junction there is a reflected short in the microstrip and a reflected open in the slot. This procedure is used in both the fin-line magic-tee and the fin-line monopulse system.

With thin substrates and high dielectric constants, the power transfer through this type of transition is close to 1:1 [Ref. 14: pp. 548-553]. The fin-line magic-tee and the fin-line monopulse system developed in this thesis are made from Epsilam-10 which is 0.025 inches thick and has a dielectric constant of 10.2. The return loss of these transitions is minimal.

I. IMPEDANCE MATCHING

A quarter wave length impedance matching technique is used in the fin-line magic-tee. This procedure joins two slots of unequal impedances together with a quarter wave length matching section. The impedance of the center matching slot is equal to the square root of the product of the two original impedances.

If the original impedances are called Za and Zb, and the matching section is called Zo, the relationship becomes Zo equals the square root of Za times Zb.

This relationship is easily visualized on a normalized Smith Chart. Zo is the center of the chart and Za is somewhere to the left of center on the real line. Traveling a quarter of a wave length through the matching section of impedance Zo is represented on the Smith Chart by a half circle of radius Za, which is centered at Zo. The end of this half circle will be on the real line to the right of Zo. If the algebraic relationship discussed above is maintained, this point will be Zb.

The proof of this relationship is based on the fact that all of the points on the left half of the real line of a Smith Chart are the reciprocals of the equal distance points on the right side of the real line. Therefore, as long as Za and Zb are on different sides of the real line and equal distance from the center, their product is unity. Since the center of a normalized Smith Chart is Zo which has a value of 1.0, the algebraic relationship discussed above produces a perfect impedance match.

III. FIN-LINE MAGIC-TEE

The fin-line magic-tee is designed to mate with two fin-line horns from Reference 5 to form a fin-line monopulse antenna. To provide a smooth transition between the magic-tee and the horns, a bilateral fin-line magic-tee enclosed in a waveguide fixture is developed. The dielectric is Epsilam-10 which has a thickness of 0.025 inches and a dielectric constant of 10.2.

A. ENGINEERING APPROXIMATIONS

Four major engineering approximations are used in the design of the magic-tee. These approximations greatly facilitate the design process without introducing significant inaccuracies.

1. Parallel Circuit Approximation

An extensive search of the current literature failed to turn up design data for a complex fin-line structure with coupled bilateral fin-line slots at a dielectric constant of 10.2. Therefore, the bilateral fin-line is modeled as two identical unilateral (one sided) circuits in parallel.

Sharma and Hoefer [Ref. 11: pp. 350-355] compared the properties of bilateral fin-line and unilateral fin-line with dielectric constants of 2.22 and 3.0. An 80 ohm, 0.050 inch thick section of bilateral fin-line has 57% of the impedance of a similar section of 0.025 inch thick unilateral fin-line. Changing the dielectric constant to 3.0 drops the ratio to 55%. The same comparison with 0.025 inch thick, 200 ohm unilateral fin-line produces an 84% ratio at a dielectric constant of 2.22 and a 73% ratio with the 3.0 dielectric constant.

At a dielectric constant of 10.2, the low impedance slots should closely fit the parallel circuit model. There may be a slight error for the largest unilateral impedance in the fin-line magic-tee, which is 200 ohms. However, this error should be minimal.

2. Fixtures Effect on Impedance

Kuchler [Ref. 15: p. 103] compared the impedances of shielded and unshielded slotline with a dielectric constant of 20. Between 10- and 12-GHZ for a dielectric thickness of 0.050 inches, the shielded and unshielded impedances are almost indentical. The impedance of the shielded slot is constant to 6-GHZ. The impedance of the unshielded slot is approximately 10% lower at 6-GHz than it is at 12-GHZ.

The quarter wavelength impedance matching technique discussed in Chapter Two is the only type of impedance matching used in the fin-line magic-tee. This technique's simple algebric relationship will factor out any uniform change in impedance. Therefore, the fixture should not effect the impedance matching between the slots. There may be a slight mismatch between the slots and the microstrip leads, but this mismatch should be minimal [Ref. 15: p. 103].

Based on the first two engineering approximations, all of the impedances in the fin-line magic-tee are calculated as slotline impedances with a dielectric thickness of 0.025 inches. All of the slotline impedances are exactly twice the desired bilateral fin-line impedances.

3. <u>Length of the Coupled Slots</u>

The electrical length of coupled slots is different in the even and odd modes [Ref. 13: pp. 541-547]. The actual length of the coupled slots in the slotline magic-tee [Ref. 4: p. 527] is the average of the even and odd mode quarter wavelengths.

Knorr and Kuchler [Ref. 13: pp. 544, 545] graphed the even and odd mode wavelengths for dielectric constants of 11.0 and 16.0. On both of these graphs, the average of the even and odd mode wavelengths is 97% of the uncoupled electrical length. This percentage holds for a very wide range of slot separation distances, including the separation that is used in the fin-line magic-tee.

The length of the coupled slots in the fin-line magic-tee is designed to be 97% of the value of a similar section of uncoupled slotline.

4. <u>Dielectric Termination within the Fixture</u>

Due to the complex geometry of the fin-line magic-tee (Fig. 1) the conventional configuration for the bilateral fin-line shown in Figure 11 is not feasible. The fin-line magic-tee uses a 0.02 inch groove in the fixture wall to support the dielectric. This groove shorts and electrically seals the edges of the fins.

B. EQUIVALENT CIRCUIT

The fin-line magic-tee is similar to two slotline magic-tees placed back to back and mounted in a waveguide fixture [Ref. 4: pp. 523-527]. The equivalent circuit for the fin-line magic-tee is similar to the circuit shown for the slotline magic-tee on page 525 of Reference 4. The fin-line device is represented by two of these circuits connected in parallel. The fin-line version is surrounded by a shield.

1. Theoretical Operation

An actual 1:1 scale drawing of the fin-line magic-tee is illustrated in Figure 1. With the exception of port three, the entire magic-tee is symmetric about an axis that extends through the center of the port four microstrip line. The theoretical operation of the fin-line magic-tee is identical to the operation of the slotline magic-tee [Ref. 4: pp. 523-527].

The microstrip leads from all four ports use the microstrip to slot transition technique discussed in Chapter Two. The short in the loop caused by the port four microstrip effectively isolates ports one and two. Ports three and four are isolated from each other by the 3/4 of a wavelength distance between the short in the loop and the short caused by the port three microstrip.

Two signals that enter the coupled slots in the even mode will couple into port three. There will be a slight phase shift between the two signals in the port three microstrip line. This error is inherent in the design of the device and can only be minimized by keeping the slot separation as small as possible. The even mode signals cancel at port four due to the loop geometry.

Two signals that enter the coupled slots in the odd mode will be out of phase at port three but will couple in phase at port four. The theoretical operation of the fin-line magic-tee is identical to the scattering matrix for the waveguide magic-tee (Fig. 3).

2. <u>Theoretical Impedance Matching</u>

The unilateral impedances in the fin-line magic-tee are 200 ohms in the loop, 100 ohms in the slots that connect to ports one and two, and 70.7 ohms and 141.4 ohms for the even and odd mode in the coupled slots, respectively. These reduce to bilateral impedances of 100 ohms, 50 ohms, 35.4 ohms and 70.7 ohms, respectively. These bilateral values are identical to the impedances listed for the "case three" slotline magic-tee [Ref. 4: p. 527]. A detailed discussion of the theoretical impedance matching in the slotline magic-tee is presented by Aikawa and Ogawa [Ref. 4: pp. 524-527].

There are four basic relationships that require impedance matching within the magic-tee. The paths from port three to ports one and two and from port four to ports one and two must be matched in the even and odd modes. In all of these cases the coupled slots act as a quarter wavelength matching section. The impedance matching problem either reduces to three series impedances of 100, 70.7 and 50 ohms. or 50, 35.4 and 25 ohms. In all cases, the impedance of the coupled slots is the square root of the other two impedances.

C. SLOT IMPEDANCE AND ELECTRICAL LENGTH

1. Uncoupled Slots

Cohn [Ref. 16: p. 1092] graphed slotline impedance and effective wavelength for dielectric constants of 9.6 and 11.0. The data points on Figure 12 and 13 are extrapolated from Cohn's graphs for a dielectric constant of 10, a dielectric thickness of 0.025 inches and a frequency of 10-GHZ. All of the slot widths and electrical lengths in the fin-line magic-tee are derived from this information.

2. Coupled Slots

As discussed in Chapter Two, the odd mode impedance of coupled slots with no separation is equal to twice their uncoupled inpedance. Their even mode impedance with no separation is one half of the uncoupled impedance of the new larger slot [Ref. 10: p. 355].

Knorr and Kuchler [Ref. 13: pp. 544, 545] graphed the even and odd mode impedances of coupled slots for dielectric constants of 11 and 16. A normalized version of this information is plotted in Figure 14 for a dielectric thickness of 0.025 inches and a frequency of 10-GHZ.

The normalization in Figure 14 is non-standard. The normalizing impedance is the slot impedance for S/D (slot separation/dielectric thickness) approaching infinity. The minimum value of zero is equivalent to the even mode impedance with no slot separation. This correlates to half of the uncoupled impedance of a slot that is twice as wide as the original slots. The center value of 1.0 represents an infinite slot separation. This is equivalent to the uncoupled impedance of each slot. The maximum value of 2.0 is the same as the odd mode impedances with zero slot separation. This corresponds to twice the impedance of the uncoupled slots.

The width of the coupled slots and the separation between the coupled slots are determined by trial and error. During this process impedances from Figure 12 are assigned to the normalized values of zero. 1.0 and 2.0 shown in Figure 14. The curve for a dielectric constant of 11.0 is used in this procedure. Based on the comparison between the curves for dielectric constants of 11.0 and 16.0 (Fig. 14). little error will be induced by this approximation.

First, an arbitrary value for the uncoupled impedance is chosen. To illustrate this procedure, an initial value of 100 ohms is used for the uncoupled impedance. The normalized impedance of 1.0 (Fig. 14) is assigned this value (100 ohms). The normalized impedance value of 2.0 (Fig. 14) is set equal to twice this value (200 ohms).

Second, the slot width (0.4340 millimeters) for this arbitrary impedance (100 ohms) is obtained from the 0.635 millimeter curve in Figure 12. The impedance (132.2 ohms) of a slot twice this wide (0.8680 millimeters) is also calculated from Figure 12. The normalized impedance of zero (Fig. 14) is set equal to half of this value (66.15 ohms).

Third, the impedances in Figure 14 are now scaled for a dielectric constant of 10. The lower portion of the graph is linear from 66.15 ohms (normalized value of zero) to 100.0 ohms (normalized value of 1.0). The upper portion is linear from 100.0 ohms (normalized value of 1.0) to 200.0 ohms (normalized value of 2.0). On this scaled version of Figure 14, an S/D is picked that corresponds to an odd mode impedance of 141.4 ohms. If the correct value is selected for the uncoupled impedance (step one), the even mode impedance will be the required 70.7 ohms. In this example, the normalized odd mode impedance of 1.414 corresponds to an S/D of 0.5613 and a normalized even mode impedance of 0.4174 (Fig. 14). This equates to an actual even mode impedance of 80.28 ohms.

Fourth, this process is repeated until the scaled version of Figure 14 produces an odd mode impedance of 141.4 ohms and an even mode impedance of 70.7 ohms for the same S/D. There is only one uncoupled impedance (Fig. 12) and one S/D (Fig. 14) that produce this relationship for each specific dielectric constant.

For Epsilam-10, the uncoupled impedance that matches this criteria is 92.3 ohms. The actual slot width is 0.0134 inches (0.3401 millimeters). The correct S/D is 0.4187. The normalized impedances are 0.3383 for the even mode and 1.5320 for the odd mode. The actual distance between the slots is 0.0105 inches (0.2659 millimeters).

The last step is to determine the slot wavelength from the 0.635 millimeter curve in Figure 13. The proper value for an S/D of 0.4187 is 0.5132 times the free space wavelength (Fig. 13). As discussed in the engineering approximations section, 97% of a quarter wavelength is used for the length of the coupled slots. This value is 0.1470 inches (3.7335 millimeters).

All of these calculations are done on two foot by three foot computer generated replicas of Figures 12, 13 and 14. The values are picked off of these large charts with calipers.

D. FIXTURE DESIGN AND ASSEMBLY

The fixture for the magic-tee is used to hold the fin-line monopulse system. A 1:1 scale drawing of the original version of the fixture is illustrated in Figure 15.

The fixture is constructed from WR-90 copper waveguide. The two mirror image halves have 0.020 inch deep and 0.025 inch wide grooves in all three of the edges of the joining seam.

The two sections of dielectric are placed into these grooves. Then the microstrip launchers for ports three and four are set into place and soldered to the microstrip leads. Only one of the mirror image sections of dielectric is etched with microstrip. The other piece is void of metal on the inside.

After the two launchers are soldered in place, the fixture is bolted together. At this point, the launchers for ports one and two are attached.

The original design used OSM 2070-5029-02 launchers for all four ports. With this design, the launchers are held in place by the fixture when it is bolted together. The launcher is not screwed into the fixture. This arrangement does not provide a satisfactory electrical contact between the fixture and the launchers.

The fixture was modified to accept OSM 2052-1658-02 two hole flange mount jacks. The flange mounted jacks are attached to the fixture with small screws. This configuration provides good electrical continuity between the fixture and the connector.

E. FIN-LINE MAGIC-TEE DESIGN

1. Slotted Side

The length of the loop is 3/4 of a wavelength from the port three microstrip to the port four microstrip. The width of the loop slot and the separation between the two halves of the loop are operator adjustable variables. The computer program (Appendix A) calculates the length of the portions of the loop, and adjusts the length of the straight section in the loop to keep the overall length equal to 3/4 of a wavelength.

The top and bottom lengths of the coupled slots are vastly different. The calculated quarter wave length is equal to the average of these two lengths.

All of the bends in the slots are constructed in the same manner. A line extending through a bend from corner to corner will bisect the angle of the bend. In this manner, the corners in a 90 degree bend are offset from each other by 45 degrees. In a 45 degree bend, the offset angle is 22.5 degrees. This arrangement insures that the slotwidth in the bend is at least as wide as the slots that lead into the bend.

All of these relationships are calculated by the computer program which draws the magic-tee.

The slots that lead to ports one and two are spaced wide apart for the first two magic-tees and closely together for the third magic-tee and for the fin-line monopulse system. In magic-tees one and two, the slots are 0.01 inches from the edge of the fixture.

In the third magic-tee and the fin-line monopulse system, the distance from the slots to the fixture groove is twice as large as the distance between the slots. At 11.4-GHZ these distances are one half and one quarter of a wavelength, respectively. The half wavelength short and the quarter wave length open effectively seal the edges of the fins within the slot.

2. <u>Microstrip Side</u>

The widths of the microstrip lines are taken from Saad's microstrip impedance graph [Ref. 17: p. 117].

The transitions from microstrip to coaxial cable are unique. The metal foil on the slotline side of the dielectric acts as the ground plane for the microstrip. Near the connectors, this ground plane is parted in a "V" shape (Fig. 1). At the same time the width of the microstrip is flared at a lesser angle. The flare in the microstrip is adjusted to maintain a 50 ohm impedance at every point in the line.

The notch in the ground plane is flared at a 45 degree angle in each direction. The total angle of the notch is 90 degrees. The maximum width of the notch occurs at the inside edge of the fixture. At this point, the width of the notch exactly matches the diameter of the hole in the fixture wall, which exactly matches the outside diameter of the dielectric within the flanged launcher.

The magic-tee dielectric extends through the hole in the fixture and touches the launcher's dielectric. With this alignment, the inside wall of the shield on the coaxial cable transitions smoothly through the launcher to the edge of the ground plane notch.

This microstrip to coaxial cable transition minimizes physical discontinuities that could cause inductive or capacitive reactances [Ref. 18: p. 95]. This lack of reactance maximizes the bandwidth through the fixture wall.

F. MANUFACTURING PROCESS

A simple form of computer aided design is adapted for this project. A BASIC Computer Program, written on an HP 9845B computer (with an HP Graphics ROM), controls an HP 9872C Plotter. The plotter draws the outline of the magic-tee four times the actual size (4:1 scale). The outline is filled in by hand, using black marking pens. The completed drawing is photographically reduced.

The negatives, which are exactly 1:1 scale, are used as etching masks. The negative for the slot side and the negative for the microstrip side are taped to opposite sides of a scrap section of dielectric. The alignment between these two negatives is done on a light table. The phase difference at port four, between signals that originate at ports one and two can be altered by poor alignment.

The section of dielectric that is to be etched is placed between the two negatives during the etching process. The completed etching is hand cut and sanded to fit the fixture.

G. COMPUTER AIDED DESIGN

A simplified version of CAD (Computer Aided Design) is used to draw the outline of the magic-tee and fin-line monopulse system (Appendix A). This process starts by establishing an imaginary "X, Y" Cartesian Grid. Every significant point that defines the drawing is assigned two grid lines. One in the X-direction and one in the Y-direction. The grid line labels start at Xa in the horizontal direction and at Ya in the vertical direction. The origin of the grid is the point where the port three and port four microstrip lines would intersect if extended. The distances between the grid lines are defined by variables. There are numerous points on most of the grid lines, but no two points share the same horizontal and vertical grid line.

Each point which defines the drawing is numbered, starting at one, and assigned its own unique coordinates. If point one lies on the intersection of Xc and Yv, then X1 is set equal to Xc and Y1 is equated with Yv. This procedure is repeated for every point that defines the drawing.

The awkwardness of this approach is more than offset by two key advantages. First, the program that draws the magic-tee is very easy to write. The command MOVE X1, Y1 followed by DRAW X2, Y2 draws a line from point one to point two.

The second and perhaps most dramatic advantage occurs when the value of one of the variables is changed. Only one line in the program has to be changed to adjust the width of any slot. All of the grid lines that are affected by this variable are automatically adjusted as the program is executed.

Once the program is written, this approach is faster than roughly sketching new ideas by hand. Accurate scaled drawings showing numerous variations can be completed in a few minutes without the aid of a draftsman or expensive drafting computer.

The computer program adjusts the locations of the numbered points to compensate for half of the thickness of the line that the plotter makes. There is also a few variable fudge factors that the operator can assign to any point in the program to account for anomalies introduced by the plotter. Each finished drawing is measured under a microscope. The variable that adjusts for the width of the plotter's pen and the fudge factors are adjusted at this time.

The same computer program draws the magic-tee, the fin-line horn, and the fin-line monopulse system (Appendix A). The interactive program asks the operator a string of questions. These questions include: Which drawing is to be made?; Which side (slot or microstrip) is to be drawn?; and Is it a rough draft or smooth copy? The lines on the smooth copy take considerably longer to draw but are extremely accurate (Appendix A).

The program can add a scaled three inch ruler to the bottom of the drawing. This ruler is used to check the accuracy of the photo reduction. The ruler was only used on the first photography work order. The precision work accomplished by the Naval Postgraduate School Photo Lab is exemplary.

H. RESULTS

1. Fixture

As discussed above, the original fixture design does not provide sufficient electrical continuity between the launchers and the fixture. The flanged jacks, which attach to the modified fixture with screws, solve this problem.

The soldered joints in the fixture came apart on two occasions. Repair is extremely difficult due to the heat conducting properties of copper. The heat required to fix a seam is sufficient to loosen an adjacent joint.

Due to the flexibility of Epsilam-10, the fixture does not apply enough pressure to make good electrical contact with the port three and four microstrip. This problem is solved by soldering the launcher probes to the microstrip.

2. Magic-Tee Number One

The loop of this magic-tee tapers into the coupled slot region. The second magic-tee does not have this taper. Other than that, the first two magic-tees are identical.

The first magic-tee was destroyed in testing. The soldered connection on port four ripped the microstrip off of the dielectric when the screws that attach the launcher to the fixture were tightened.

Preliminary reflection checks on a scalar analyzer were performed prior to this damage. The reflections for this magic-tee are slightly worse than the similar reflections in the second magic-tee.

3. Magic-Tee Number Two

The slots that lead to ports one and two in this magic-tee are 0.01 inches inside of the fixture wall. The actual scattering matrix for this device is illustrated in Figure 16. The reflections in this magic-tee are quite high.

The phase shifts are almost perfect, except for a slight phase error associated with port four. This is probably caused by improper alignment of the two negatives prior to the etching process.

4. Magic-Tee Number Three

The closeness of the port one and two slots to the fixture wall in the second magic-tee causes an apparent discontinuity where the fixture terminates. These slots were set well inside the fixture on the third magic-tee in hopes of eliminating this discontinuity.

The actual scattering matrix for the third magic-tee is shown in Figure 17. This magic-tee also has near perfect phase shifts. However, the reflections are a little higher than they were for magic-tee number two.

The actual phase and magnitude from 8- to 12-GHZ for each of the 16 points in magic-tee number three's scattering matrix are illustrated in graphical form in Figures 18 to 33.

IV. FIN-LINE MONOPULSE SYSTEM

A. DESIGN

The fin-line monopulse system is a combination of fin-line magic-tee number three and two of the fin-line horns developed by Haq in Reference 5. The horns are driven from ports one and two of the magic-tee. The width of the slot in the horns is the same width as the matching slots in the magic-tee. The half wave length geometry of the fin-line horn and fin-line magic-tee are maintained in the fin-line monopulse system (Fig. 34). The monopulse system is drawn at a 2:1 scale. The HP-9872C Plotter will not accommodate a larger drawing.

All of the exposed edges of the dielectric, except the actual horn openings, are sealed with copper tape. This prevents energy from leaking out of the slots and destroying the antenna patterns.

The distance between the center of the two horns is 30.44 millimeters. At 10.3-GHZ, this distance is equal to 1.05 wavelengths in air and 3.34 wavelengths in Epsilam-10. The antennas use both air and dielectric to propagate the antenna pattern. Therefore, the effective element spacing of the fin-line monopulse system is between the limits of 1.05 and 3.34 wavelengths at 10.3-GHZ.

The E-plane pattern for a single fin-line horn with a dielectric constant of 10.2 is illustrated in Figure 6. The associated H-plane pattern is shown in Figure 35. The extreme width of the H-plane pattern is due to the high dielectric constant of 10.2. Similar horns constructed with a dielectric constant of 2.54, have nearly symmetrical E- and H-plane patterns [Ref. 5]. The monopulse effect of this system is entirely in the E-plane. Therefore, the wide H-plane element pattern will produce a wide H-plane monopulse system pattern.

The gain of each antenna is obtained by comparing the amplitude of the antenna pattern with the pattern from a standard gain horn.

B. RESULTS

The actual E- and H-plane patterns for the monopulse system are shown in Figures 36 and 37 respectively. The gain of the sum pattern is eight dB. This is four dB above the element pattern. A three dB improvement is expected (Fig. 9).

The first nulls in the sum pattern (Fig. 36) are approximately 29 degrees left and right of boresight. The element spacing in the computer simulated sum pattern (Fig. 38) is adjusted until the first nulls occur at plus and minus 29 degrees. The corresponding simulated difference pattern is shown in Figure 39. The effective element spacing that produces this match is 1.60 wavelengths.

The difference port microstrip was torn off of the dielectric during testing. This occurred after the patterns in Figures 36 and 37 were taken. The damage was repaired by soldering a small section of copper foil across the break.

Following this repair, the fin-line monopulse system was tested, in an effort to find the bottom of the difference null. Figure 40 shows the results of this test. The recorder gain is maximum, and the eight dB sum pattern is saturated against the top of the recorder. Yet, the bottom of the difference null is still not visible.

V. CONCLUSIONS AND RECOMMENDATIONS

A. FIXTURE

1. Conclusions

The original fixture design is unsatisfactory. It is too fragile and it does not provide good electrical continuity between the magic-tee and the launchers at ports three and four. The modified fixture, which has screwed on coaxial to microstrip launchers at ports three and four, is marginally effective.

The electrical transistions through the fixture wall at ports three and four do not appreciably restrict the bandwidth of the fin-line magic-tee (Figs. 10-33). Therefore, the holes in the fixture at ports three and four and the notches in the magic-tee's ground plane at ports three and four function reasonably well.

2. Recommendations

Testing should not be resumed until an improved fixture is constructed. Each half of the new fixture should be machined out of a solid piece of metal. All of the launchers which connect to the fixture should be attached with screws. A stiff or semi-rigid dielectric should be used to avoid the necessity of soldering the launchers to the microstrip lines. The microstrip to coaxial transition concept which is used in this thesis should be incorporated in the new fixture design.

B. FIN-LINE MAGIC-TEE

1. Conclusions

The fin-line magic-tee worked better than expected after only three iterations of the developmental process. The phase shifts are very close to the theoretical parameters. However, the dielectric material is too flexible and the reflections at all four ports need to be reduced.

There are four factors that could be causing the high relections. First, as noted in the engineering approximations (Chap. 3), the bilateral fin-line impedance of the loop might be slightly above the desired 100 ohms.

Second, the soldered connections on the microstrip lines at ports three and four probably introduce significant reflections.

Third, the magic-tee is not completely symeteric. The port three microstrip line couples with two slots while the microstrip at port four couples with a single slot.

Fourth, due to the different dielectric constants of air and Epsilam-10, the distribution of the electric field within the dielectric is not the same as the distribution of the electric field in the air. Therefore, the reactive interference in the air is not the same as the reactive interference within the dielectric material. These unmatched reactances probably contribute to the harmonic pattern of reflections observed at all four ports (Figs. 18-33).

2. Recommendations

Future magic-tees should be made out of a stiff or semi-rigid dielectric material. The combination of a stiffer material and a new fixture design should eliminate the need for soldered connections.

Two new magic-tees should be made with unilateral loop impedances of 190 ohms and 195 ohms. Tests of these tees will help identify the proper unilateral loop impedance and check the accuracy of the first engineering approximation.

Two sections of dielectric material which are totally void of metal foil can be added to the outsides of the existing two sections of dielectric. In this configuation, the slots will be totally surrounded by the same dielectric constant. This should improve the symmetry of the electric field distribution near the slots. thereby reducing the amount of reflected energy within the magic-tee.

C. FIN-LINE MONOPULSE SYSTEM

1. Conclusions

The performance of the fin-line monopulse system is very satisfactory. The null in the difference pattern is more than 40 dB below the peak of the sum pattern at 10.3-GHZ (Fig. 40). This deep unmeasurable null which exactly splits the main peak of the sum pattern (Fig. 40) is the essence of a good monopulse antenna. The minor problems caused by high reflections should be resolved when the fin-line magic-tee is improved.

The peak in the fin-line monopulse system's difference pattern is approximately nine dB lower than the peak in it's sum pattern (Fig. 36). This difference is approximately three dB more than the corresponding relationship in Skolnik's patterns [Ref. 7: pp. 17-23]. The fin-line comparator's weak difference pattern is probably the result of reflections caused by the large quanities of solder on the port four microstrip line. The shape of the fin-line monopulse system's sum and difference patterns and the exact centering of the difference null are almost identical to Skolnik's illustrations.

Skolnik [Ref. 7: pp. 10-28] shows that the second null in a theoretical sum pattern is not present on an actual monopulse pattern. This effect is roughly reproduced in this thesis (Figs. 36 and 38). The second and third peaks in the simulated sum pattern (Fig. 38) are at 40 and 72 degrees respectively. Corresponding peaks are evident at 50 and 77 degrees on the actual pattern (Fig. 36). The actual pattern is filled in between these two peaks just as Skolnik predicted.

As discussed in Chapter Four, the effective element spacing at 10.3-GHZ is 1.60 wavelengths. This is 152% of the element spacing in air and 48% of the element spacing in the dielectric. These percentages are probably a function of the dielectric constant. Therefore, the effective element spacing of the fin-line monopulse system can probably be controlled by proper selection of the dielectric constant.

2. Recommendations

The fin-line monopulse system should be enlarged to include two orthoganal difference ports. This will make it useful as a target tracking antenna [Ref. 7: pp. 10-23]. The diamond configuration shown in Figure 4 and the square design illustrated in Figure 5 can both be adapted to the fin-line monopulse technique.

a. Diamond Fin-Line Monopulse System

A simple arrangement of four horns connected to three fin-line magic-tees can be constructed using a semi-rigid dielectric material. This configuration will consist of two of the fin-line monopulse comparators developed in this thesis placed side by side. The difference ports of these two comparators will be the elevation and the azmuith ports for the new three port system. The sum ports will connect to the inputs of the third magic-tee. The third magic-tee's sum port will be the system's sum port. The difference port of the third magic-tee will be loaded.

The individual azimuth and elevation comparators will be electrically orthogonal to each other if they are each twisted 45 degrees in opposing directions. The twisting should be confined to the area between the fixture and the horns. In this configuration the two groups of antennas will be orthogonal to each other, yet all three magic-tees will be in the same plane.

b. Square Fin-Line Monopulse System

A dual plane fin-line monopulse system constructed out of semi-rigid dielectric material is illustrated in Figure 41. The dielectric material will have to be flexible enough to bend, yet rigid enough to provide good electrical contact between the microstrip lines and the launchers. This device will require careful engineering to properly align the sheets of dielectric material. Once these problems are solved, mass production should be easy.

D. COMPUTER AIDED DESIGN

1. Conclusions

The computer aided design portion of this thesis is useable, however it should be enlarged to include more of the design process.

2. Recommendations

Figures 12, 13, and 14 should be modified to include a wider range of dielectric constants and dielectric thicknesses. The data in the new versions of Figures 12 and 13 can probably be represented by simple algebraic equations [Ref. 10: pp. 226-228]. The new version of Figure 14 could be approximated by exponential equations. The four step trial and error process presented in Chapter Three and the design parameters for the fin-line horns [Ref. 5] can probably be written in the form of a short computer program.

information should be computerized and added to the existing program (Appendix A).

The improved version of the computer aided design program could ask the operator; What gain/beam width combination is desired for the fin-line monopulse system? The program could then recommend the approriate dielectric constant and prompt the operator to place the paper on the plotting table. When the first drawing is finished, the program could prompt the operator to change the paper. Using this concept, made-to-order monopulse target tracking antennas could be inexpensively mass produced in a matter of days.

E. MEETING THESIS OBJECTIVES

Magic-tees number two and three and the monopulse system satisfy the first objective listed in the introduction. The sum and difference patterns (Figs. 36, 37, and 40) are better than expected for limited iterations of the design process. They meet the second objective. The interactive computer aided design program (Appendix A) satisfies the third objective. The recommendations presented in this chapter fulfill the final objective of this thesis.

APPENDIX A

COMPUTER PROGRAM LISTING

```
10  !                          MSEE THESIS
20  !
30  !           FIN-LINE MAGIC TEE, FIN-LINE HORN AND
40  !                 FIN-LINE MONOPULSE SYSTEM
50  !
60  !                 BY LCDR JAMES W. ROWLEY
70  !
80  !                       AUGUST 1985
90  !
100 !           NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA.
110 !
120 !       (WRITTEN ON AN HP-9845B; WITH AN HP-9872C PLOTTER)
130 !
140 !
150 ! MISC. PROGRAMING INFO:
160 !
170 !
180 ! THIS PROGRAM IS WRITTEN IN "BASIC". THE FOLLOWING RULES APPLY:
190 !
200 !    BUILT IN COMMANDS: THE ENTIRE WORD IS IN UPPER CASE LETTERS.
210 !       DEFINITION OF NON-STANDARD BUILT IN COMMANDS:
220 !          ATN(): RETURNS THE ARC TANGENT OF THE VARIABLE IN THE BRACKETS.
230 !          MSCALE A,B:  PLOTTER IS SCALED IN MILLIMETERS. THE ORIGIN IS
240 !             "A" MILLIMETERS LEFT AND "B" MILLIMETERS UP FROM THE LOWER
250 !             LEFT HAND CORNER OF THE PLOTTING AREA. WHEN "MSCALE" IS
260 !             USED, ALL UNLABLED UNITS IN THE PROGRAM ARE IN MILLIMETERS.
270 !          PLOTTER IS "": COORDINATES THE COMPUTER AND THE PLOTTER.
280 !          DEG: TELLS THE COMPUTER THAT ALL ANGLES ARE IN DEGREES.
290 !
300 !    VARIABLES:  ONE UPPERCASE LETTER FOLLOWED BY NOTHING, OR FOLLOWED
310 !       BY A STRING OF LOWERCASE LETTERS AND/OR NUMBERS. A VARIABLE
320 !       CAN BE UP TO 15 CHARACTERS LONG. IF A VARIABLE IS ENDED IN A
330 !       DOLLAR SIGN ($), IT IS A STRING VARIABLE. DUE TO THE EXTREMELY
340 !       LARGE NUMBER OF VARIABLES IN THIS PROGRAM, THEY ARE DEFINED AND
350 !       ASSIGNED INITIAL VALUES AT THE SAME TIME. THIS PROGRAM DEFINES
360 !       KEY POINTS IN TERMS OF "X" AND "Y" REFERENCE PLANES. THESE PLANES
370 !       ARE DEFINED BY A COMBINATION OF A FEW KEY DIMENSIONS. THIS CHANGE
380 !       OF VARIABLES APPROACH WAS USED TO FACILITATE FUTURE DESIGN
390 !       MODIFICATIONS. A FOLLOW ON PROGRAMER CAN CHANGE ANY ONE OR MORE
400 !       OF THE KEY DIMENSIONS IN THIS PROGRAM AND THE ENTIRE DRAWING WILL
410 !       BE AUTOMATICALLY ADJUSTED. THIS IS A LIMITED APPLICATION OF CAD
420 !       (COMPUTER AIDED DESIGN).
430 !
440 ! STEP ONE: DETERMINE WHICH DRAWING THE OPERATOR DESIRES.
450 INPUT "MAGIC-TEE (TEE); HORN (HORN); OR MONOPULSE SYSTEM (MONO)?",Drawing$
460 IF Drawing$="TEE" THEN 500
470 IF Drawing$="HORN" THEN 500
480 IF Drawing$="MONO" THEN 500
490 GOTO 450 !ASK QUESTION UNTIL PROPER REPLY IS GIVEN.
500 INPUT "DRAW FIN-LINE OR MICROSTRIP SIDE? (F/M),CONT",Side$
510 IF Side$="F" THEN 550
520 IF Side$="M" THEN 550
530 GOTO 500!WRONG REPLY.
540 !
550 INPUT "DRAW RULER AND COMMENTS? (Y/N),CONT",Ruler$
560 IF Ruler$="Y" THEN 600!CHECK FOR PROPER REPLY.
570 IF Ruler$="N" THEN 600
580 GOTO 550 !ASK QUESTION UNTIL PROPER REPLY IS GIVEN.
590 !
600 INPUT "QUICK LINE (1), OR PRECISION LINE (4)",Linenumber
610 IF Linenumber=1 THEN 660
620 IF Linenumber=4 THEN 640
630 GOTO 600!ASK UNTIL VALID REPLY GIVEN.
640 Segmentsize=.04      !DISTANCE BETWEEN THE DOTS, IF A DOTTED LINE IS USED.
650 !
660 ! STEP TWO: ADJUST THE GENERAL LAYOUT OF THE DRAWING.
```

```
670  !
680  ! THIS SECTION CONTAINS REQUIRED COMMANDS FOR COM...ER/PLOTTER
690  ! COORDINATION AND GENERAL COMMANDS AND VARIABLES THAT ARE
700  ! USED TO ORGANIZE THE DRAWING.
710  PLOTTER IS "9872A"  !COORDINATES COMPUTER AND PLOTTER.
720  DEG                 !ALL ANGLES IN THE PROGRAM ARE IN DEGREES.
730  Title$="3"          !THIS WILL BE PRINTED ON THE DRAWING.
740  Flip=1              !-1 PUTS THE SUM NOTCH ON THE OPPOSITE SIDE.
750  Xcenter=82          !CENTER OF DRAWING ON PAGE IN mm FROM LOWER LEFT.
760  Ycenter=95          !CENTER OF DRAWING ON PAGE IN mm FROM LOWER LEFT.
770  MSCALE Xcenter,Ycenter   !POSITIONS THE DRAWING ON THE PAPER,
780  Scale=1             !THE ENTIRE DRAWING IS SCALED TO THIS FACTOR.
790  Mm=Scale            !DEFINES Mm=MILLIMETERS (DRAWN TO SCALE).
800  In=25.4*Scale       !DEFINES In=25.4 MILLIMETERS = INCH (DRAWN TO SCALE).
810  LINE TYPE Linenumber,Segmentsize
820                      ! IF Linenumber EQUALS "1", THE PLOTTER WILL DRAW
830                      ! A REGULAR LINE. IF Linenumber EQUALS "4", THE
840                      ! PLOTTER WILL DRAW A DOTTED LINE WITH OVERLAPPING
850                      ! DOTS. THE DOTTED LINE ELIMINATES PEN OSCILLATION
860                      ! ERRORS, AND PRODUCES A VERY HIGH QUALITY SOLID LINE.
870  !
880  !
890  ! STEP THREE: DEFINE THE DIMENSIONS OF THE DRAWING.
900  !
910  ! "THE FOLLOWING VARIABLES DESCRIBE THE ENTIRE DRAWING. THE REST OF THE
920  ! PROGRAM USES THESE VALUES TO CONSTRUCT THE DRAWINGS.
930  ! ANY CHANGE IN THESE VARIABLES WILL RESULT IN ALL ASSOCIATED PARAMETERS
940  ! IN THE DRAWING BEING ADJUSTED AUTOMATICALLY.
950  !    VARIABLES ASSOCIATED WITH THE MAGIC TEE END IN A "t" SUBSCRIPT.
960  !    VARIABLES ASSOCIATED WITH THE SINGLE HORN END WITH AN "h" SUBSCRIPT.
970  !    VARIABLES ASSOCIATED WITH THE MONOPULSE SYSTEM END IN AN "mh"
980  !    SUBSCRIPT.
990  !
1000 !
1010 ! USER DEFINED VARIABLES:
1020 !
1030 Er=10.2                               !DIELECTRIC CONSTANT. Er IS ONLY USED
1040                                       ! TO CALCULATE THE TEM WAVELENGTH IN
1050                                       ! THE MICROSTRIP LINES.
1060 Lambdazero=26.306*Mm                  !FREE SPACE WAVELENGTH AT 11.4 GHZ.
1070 Lambdad=Lambdazero/SQR(Er)            !TEM WAVELENGTH.
1080 Qucoupledslots=.4990*Lambdazero/4     !QUARTER WAVELENGTH IN COUPLED SLOTS.
1090                                       ! .4990 IS 97% OF THE VALUE FOR A
1100                                       ! SINGLE SLOT THAT IS NOT COUPLED.
1110 Quloop=.6360*Lambdazero/4             !QUARTER WAVELENGTH IN LOOP SLOTS.
1120 Qumicrostrip=Lambdad/4                !QUARTER WAVELENGTH IN MICROSTRIP (TEM).
1130 Quhornslot=.5216*Lambdazero/4         !QUARTER WAVELENGTH IN 100 OHM SLOTS.
1140 !
1150 ! THE FOLLOWING DIMENSIONS ARE EXACTLY MATCHED TO THE SIZE OF THE FIXTURE;
1160 At=.165*In        !WIDTH OF THE NOTCH IN THE COPPER FOIL THAT MATCHES THE
1170                   ! HOLE IN THE FIXTURE THAT CONNECTS THE DEVICE TO THE
1180                   ! COAXIAL LAUNCHER.
1190 Bt=.0230*In       !WIDTH OF THE MICROSTRIP TRANSITION AND OF THE WIDTH
1200                   ! OF THE CENTER CONDUCTOR IN THE COAXIAL ADAPTER.
1210 Ct=.03*In         !THICKNESS OF THE FIXTURE WALL THAT IS BEYOND THE
1220                   ! SUBSTRATE GROOVE.
1230 Dt=.22*In         !DISTANCE FROM CENTER OF DIFFERENCE PORT TO THE EDGE
1240                   ! OF THE DIELECTRIC THAT IS INSIDE OF THE FIXTURE.
1250 Et=.770*In        !LEFT EDGE OF THE SUBSTRATE TO THE CENTER OF SUM PORT.
1260                   ! THIS VALUE MAKES THE SUM AND DIFFERANCE PORTS
1270                   ! APPROXIMATELY THE SAME LENGTH.
1280 Ft=1.5*In         !CENTER OF SUM THE PORT TO THE RIGHT EDGE OF THE FIXTURE.
1290                   ! THIS ALLOWS SUFFICIENT ROOM TO MOUNT THE FIXTURE
1300                   ! WHILE TAKING ANTENNA PATTERNS.
1310 Grt=.5*In         !ALLOWS ROOM FOR LAUNCHERS ON RIGHT SIDE OF PORTS 1&2.
1320 Glt=.25*In        !ALLOWS ROOM FOR LAUNCHERS ON LEFT SIDE OF PORTS 1&2.
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1330  !
1340  ! THE FOLLOWING DIMENSIONS DEFINE THE LAYOUT OF THE MAGIC TEE;
1350  ! THREE DIFFERENT VALUES FOR Ht ARE GIVEN. PICK THE APPROPRIATE ONE.
1360  ! Ht=1.3117*Mm !WIDTH OF 160 OHM LOOP SLOT.
1370  ! Ht=1.674*Mm !WIDTH OF 180 OHM LOOP SLOT.
1380  Ht=2.056*Mm          !WIDTH OF 200 OHM LOOP SLOT.
1390  It=.340*Mm           !WIDTH OF THE COUPLED SLOTS.
1400  Jt=.43995*Mm         !WIDTH OF THE 100 OHM "HORN" SLOTS.
1410  Kt=.2086*Mm          !WIDTH OF MICROSTIP.
1420  Lt=.0781*In          !LENGTH OF THE TRANSITION IN THE SUM AND DIFFERENCE
1430                       ! MICROSTIP LINES.
1440  Mt=2.54*Mm           !DISTANCE BETWEEN THE SLOTS IN THE LOOP.
1450  Nt=Ht+Mt/2-(It+Ot/2) !MAKES ANGLE BETWEEN PTS 36,37 AND 38 135 DEGS.
1460  Ot=.266*Mm           !DISTANCE BETWEEN COUPLED SLOTS.
1470  Pt=1.5*Mm            !WIDTH OF THE ISOLATION SLOT.
1480  Qt=.8*(Dt-Jt)        !MAKES THE PARALLEL SLOTS 1/4 WAVELENGTH APART AND
1490                       ! AND HALF A WAVELENGTH FROM FIXTURE WALLS AT 11.4 GHZ.
1500  Rt=.25*In            !DISTANCE BETWEEN FIXTURE AND FIRST CORNER IN SLOTS.
1510  St=.2*In             !DISTANCE FROM FIXTURE TO VERTICAL SLOTS.
1520  IF Rt+.1*In>St THEN St=Rt+.1*In!ALLOWS ROOM FOR LOWER BEND IN THE
1530                                    ! IN THE INPUT SLOTS (OUTSIDE OF FIXTURE).
1540  Tt=.3*In             !SIDE OF 45 DEGREE CUTOUT.
1550  Ut=0*In              !LENGTN OF VERTICAL SLOTS.
1560  Vt=15*Mm             !HALF OF THE SEPARATION BETWEEN THE "HORN" SLOTS.
1570  ! THE NEXT LINE INSURES ADEQUATE SEPARATION BETWEEN THE TIPS OF THE
1580  ! MICROSTRIP THAT EXTENDS FROM PORTS ONE AND TWO.
1590  IF Vt<.35*In THEN Vt=.35*In
1600  Wt=.5*In             !DISTANCE FROM "HORN" SLOTS TO EDGE OF DIELECTRIC.
1610                       ! THIS ALLOWS SUFFICIENT ROOM TO MOUNT THE LAUNCHERS.
1620  !
1630  ! THE FOLLOWING LINES DEFINE THE HORN.
1640  Angleh=9.1 !HALF OF THE HORN ANGLE.
1650  Hh=8                 !Hh*Lambdad=LENGTH OF HORN FLARE (Bh).
1660  !
1670  ! THE FOLLOWING DIMENSIONS ARE USED TO ADD THE MISC. DATA TO THE DRAWING.
1680  Sixteenth=1/16*In  !USED TO BUILD RULER AT THE BOTTOM OF THE DRAWING.
1690  Space=.07*In        !SPACES THE COMMENTS AND RULER AWAY FROM THE DRAWING.
1700  !
1710  !
1720  ! THE FOLLOWING VARIABLES ARE COMBINATIONS OF THE USER DEFINED VARIABLES,
1730  ! AND/OR SHORT VARIABLES THAT REPLACE LONGER MORE DESCRIPTIVE VARIABLES.
1740  !
1750  Bat=Qumicrostrip    !LENGTH OF MICROSTRIP OVERLAPS.
1760  Bbt=Quhornslot      !LENGTH OF HORN SLOT OVERLAP.
1770  !
1780  ! THERE ARE TWO VALUES FOR Bct AND Bdt GIVEN. ONE SET MAKES A TAPERED
1790  ! LOOP, AND THE OTHER SET MAKES A NON-TAPERED LOOP AS INDICATED. PICK
1800  ! THE DESIRED TYPE OF LOOP GEOMETRY.
1810  !
1820  ! TAPERED LOOP:
1830  ! Angle0 IS THE ANGLE USED TO DETERMINE Bct AND Bdt. IT IS ONE HALF OF THE
1840  ! AVERAGE OF THE TWO ANGLES FORMED BY POINTS 20,21,22 AND 36,37,38. Bct
1850  ! AND Bdt ARE USED TO MAKE A SMOOTH TRANSITION AROUND THE CORNERS IN
1860  ! THE LOOP.
1870  ! Angle0=((180-ATN((Ht+Mt/2-It-Ot/2)/Wt))/2+(180-ATN((Mt/2-Ot/2)/Wt))/2)/2
1880  ! Bct=Ht/TAN(Angle0)  !THE OFFSET AT THE RIGHT SIDE OF THE TAPERED LOOP.
1890  ! Bdt=It/TAN(Angle0)  !OFFSET AT EDGE OF TAPERED LOOP.
1900  !
1910  ! NON-TAPERED LOOP:
1920  Angle00=ATN(Wt/(Ht+Mt/2-(It+Ot/2)))  !FOR NON-TAPERED LOOP.
1930  Bct=Ht*TAN(45-Angle00/2) !FOR NON-TAPERED LOOP.
1940  Bdt=Wt/COS(Angle00)-It*TAN(Angle00) !FOR NON-TAPERED LOOP.
1950  !
1960  !
1970  Bet=Jt/COS(45)-It    !OFFSET AT LEFT EDGE OF COUPLED SLOTS.
1980  Bft=Qucoupledslots-Bet/2-Bdt/2  !LENGTN OF THE TOP OF THE COUPLED SLOTS.
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1990 Bgt=TAN(22.5)*Jt    !OFFSET FOR 45 DEGREE BENDS IN 100 OHM SLOTS.
2000 !
2010 !
2020 ! THE FOLLOWING CALCULATIONS MAKE THE CENTERLINE OF THE LOOP 3/4 OF A
2030 ! WAVELENGTH LONG.
2040 Arc=(Mt+Ht)*PI/4-Kt/2 !ARC LENGTN, EXCLUDING PORTION THAT OVERLAPS THE
2050                       ! MICROSTRIP.
2060 Slantpartofloop=SQR((Nt+Bct/2-Bdt/2)^2+((Mt+Ht-Ot-It)/2)^2) !LENGTH OF THE
2070                                                               ! SLANT PART OF
2080                                                               ! THE LOOP,
2090                                                               ! MEASURED ON
2100                                                               ! CENTERLINE.
2110 Flatpartofloop=3*Qwloop-Arc-Slantpartofloop-Bdt/2!ADJUSTABLE PART OF LOOP.
2120 Bht=Flatpartofloop+Bct/2  !THIS MAKES THE LOOP 3/4 OF A WAVELENGTN LONG.
2130 !
2140 Bit=Dt-Qt-It-Ot/2  !LENGTN OF 45 DEC SLOTS (IN THE "X" AND "Y" DIRECTIONS)
2150                    ! THAT ARE INSIDE OF THE FIXTURE.
2160 Bjt=Dt-Qt-Jt       ! DISTANCE FROM CENTERLINE TO INPUT SLOTS (INSIDE OF
2170                    ! OF THE FIXTURE).
2180 Bkt=St-Rt          !LENGTH OF LOWER 45 DEGREE SECTION (IN "X" AND "Y"
2190                    ! DIRECTION) THAT IS OUTSIDE OF THE FIXTURE.
2200 Blt=Vt-Bjt-Bkt-Ut  !LENGTH OF UPPER 45 DEGREE SECTION (IN THE "X" AND "Y"
2210                    ! DIRECTION) THAT ARE OUTSIDE OF THE FIXTURE.
2220 Bmt=2^.5*(Dt-Qt-Jt-Pt/2)-Ot/2  !DISTANCE FROM COUPLED SLOTS TO THE
2230                                ! TIP OF THE ISOLATION SLOT (IN THE "X"
2240                                ! DIRECTION).
2250                                ! (IN THE "X" AND "Y" DIRECTIONS).
2260 Bnt=Pt/2           !LENGTH OF THE VEE AT THE END OF THE ISOLATION SLOT.
2270                    ! Bnt KEEPS THE SLANT PORTION OF  THE ISOLATION SLOT
2280                    ! AND THE HORIZONTAL PART OF THE ISOLATION SLOT
2290                    ! EQUADISTANCE FROM THE 100 OHM SLOTS (INSIDE OF THE
2300                    ! FIXTURE).
2310 !
2320 ! THE FOLLOWING ARE COMBINATIONAL HORN VARIABLES.
2330 IF Drawing$="HORN" THEN 2360 ! USED TO MATCN HORN TO FIXTURE.
2340 Ah=Qt        !WIDTN OF HORNS MATCHES FIXTURE FOR MAGIC-TEE.
2350 GOTO 2370
2360 Ah=Dt-Jt/2  !WIDTH OF HORN STRIP FOR SINGLE HORN.
2370 Bh=Nh*Lambdad  !LENGTH OF HORN FLARE FROM Xoh.
2380 Ch=Ah*SIN(Angleh)  !LATERIAL OFFSET DISTANCE AT END OF HORN.
2390 Dh=Ah*COS(Angleh)  !VERTICAL OFFSET DISTANCE AT END OF HORN.
2400 Eh=Bh*SIN(Angleh)  !HALF OF HORN APERTURE.
2410 Fh=Bh*COS(Angleh)  !HORIZONTAL LENGTN OF HORN FROM Xoh.
2420 !
2430 !
2440 ! THE FOLLOWING LINE PLACES A CONDITION ON THE LENGTN OF Glt. THIS IS
2450 ! DONE TO ALLOW SUFFICENT ROOM BETWEEN THE MICROSTRIP CROSSING POINT,
2460 ! AND THE 45 DEGREE BEND IN THE SLOT TO THE LEFT OF THE MICROSTRIP.
2470 IF Glt<St+Jt+Blt+5*Mm THEN Glt=St+Jt+Blt+5*Mm
2480 !
2490 !
2500 ! STEP FOUR: DEFINE "X" AND "Y" PLANES IN TERMS OF VARIABLES LISTED ABOVE.
2510 !          ALL OF THE POINTS THAT WILL BE USED TO DEFINE THE DRAWING
2520 !          SHOULD BE ON THE INTERSECTION OF TWO OF THESE PLANES. OTHER
2530 !          POINTS CAN BE DRAWN TOO, BUT ONLY IF THEY ARE DEFINED WITNIN
2540 !          THE "DRAW" COMMAND (THIS SHOULD BE AVOIDED, AS IT WILL DESTROY
2550 !          THE "CAD" ASPECT OF THIS PROGRAM).
2560 !
2570 Xot=0            !SETS LOCATION OF DRAWING WITH RESPECT TO THE ORIGIN.
2580 Xat=Xot-Et-Ct    !LEFT EDGE OF DIFFERENCE PORT.
2590 Xbt=Xot-Et       !LEFT EDGE OF THE DIELECTRIC WITHIN THE FIXTURE.
2600 Xct=Xbt+Lt       !TIP OF THE DIFFERENCE NOTCH.
2610 Xdt=Xot-Kt/2-Nt-Bht !CENTER OF THE LOOP HALF CIRCLE.
2620 Xet=Xdt-Mt/2+Bat    !EDGE OF DIFFERENCE MICROSTRIP.
2630 Xft=Xdt+Bht-Bct     !LOWER LEFT LOOP CORNER.
2640 Xgt=Xdt+Bht         !UPPER LEFT LOOP CORNER.
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2650  Xht=Xot-At/2          !LEFT EDGE OF THE TAB OF DIELECTRIC ON THE SUM PORT.
2660  Xit=Xot-Bt/2          !LEFT EDGE OF SUM MICROSTRIP TRANSITION.
2670  Xjt=Xot-Kt/2-Bdt      !LOWER RIGHT LOOP CORNER.
2680  Xkt=Xot-Kt/2          !LEFT EDGE OF SUM MICROSTRIP.
2690  Xlt=Xot+Kt/2          !RIGHT EDGE OF SUM MICROSTRIP.
2700  Xmt=Xot+Bt/2          !RIGHT EDGE OF SUM MICROSTRIP TRANSITION.
2710  Xnt=Xot+At/2          !RIGHT EDGE OF THE TAB OF DIELECTRIC ON THE SUM PORT.
2720  Xpt=Xot-Kt/2+Bft      !UPPER RIGHT EDGE OF COUPLED SLOTS.
2730  Xqt=Xpt+Bet           !LOWER RIGHT EDGE OF COUPLED SLOTS.
2740  Xrt=Xpt+Blt           !UPPER LEFT EDGE OF "INPUT" SLOTS.
2750  Xst=Xrt+Bgt           !LOWER LEFT EDGE OF "INPUT" SLOTS.
2760  Xtt=Xqt+Bmt           !LEFT TIP OF THE ISOLATION SLOT.
2770  Xut=Xtt+Bnt           !START OF ISOLATION SLOT TIP.
2780  Xvt=Xot+Ft            !RIGHT EDGE OF THE FIXTURE.
2790  Xwt=Xvt+Rt            !UPPER RIGHT EDGE OF "INPUT" SLOT.
2800  Xxt=Xwt+Bgt           !LOWER RIGHT EDGE OF "INPUT" SLOT.
2810  Xyt=Xvt+Tt            !TOP OF 45 DEGREE CUTOUT.
2820  Xzt=Xvt+St            !LEFT SIDE OF VERTICAL SLOT.
2830  Xaat=Xzt+Jt           !RIGHT SIDE OF VERTICAL SLOT.
2840  Xabt=Xaat+Blt-Bgt     !LEFT EDGE OF UPPER SLOT CORNER.
2850  Xact=Xaat+Blt         !RIGHT EDGE OF UPPER SLOT CORNER.
2860  Xadt=Xvt+Glt         !LEFT EDGE OF INPUT NOTCH.
2870  Xaet=Xadt+At/2-Bt/2  !LEFT EDGE OF INPUT TRANSITION.
2880  Xaft=Xadt+At/2-Kt/2  !LEFT EDGE OF INPUT MICROSTRIP.
2890  Xagt=Xadt+At/2       !CENTER OF INPUT NOTCH.
2900  Xaht=Xagt+Kt/2       !RIGHT EDGE OF INPUT MICROSTRIP.
2910  Xait=Xagt+Bt/2       !RIGHT EDGE OF INPUT TRANSITION.
2920  Xajt=Xadt+At         !RIGHT EDGE OF INPUT NOTCH.
2930  Xakt=Xaht+Bbt        !RIGHT END OF SLOTS.
2940  Xalt=Xajt+Grt        !RIGHT EDGE OF DIELECTRIC.
2950  !
2960  !
2970  Xoh=Xvt+Ch-Jt/(2*TAN(Angleh)) !APEX OF HORN OPENING ANGLE
2980                                ! REFERENCED TO EDGE OF FIXTURE.
2990  Xah=Xoh+Fh                    !OUTER EDGE OF HORN OPENING.
3000  Xbh=Xah-Ch                    !UPPER OUTER EDGE OF HORN.
3010  Xch=Xoh+Jt/(2*TAN(Angleh))    !HORN MOUTH.
3020  Xdh=Xch-Ch                    !HORN/FIXTURE JOINT.
3030  Xeh=Xkt-Bbt                   !END OF HORN SLOT.
3040  !
3050  !
3060  Xwmh=Xwt-TAN(22.5)*Lambdad/2  !USED TO MOVE X34t LEFT TO X34mh.
3070  Xxmh=Xxt+Lambdad*(SQR(.5)-.125) !MOVES  X25t RIGHT TO X25mh.
3080  Xzmh=Xzt-Lambdad/2            !USED TO MOVE X32t/X33t LEFT TO X32mh/X33mh.
3090  Xaamh=Xaat+Lambdad/2          !USED TO MOVE X26t/X27t RIGHT TO X26mh/X27mh.
3100  Xabmh=Xabt-TAN(22.5)*(Lambdad/2) !USED TO MOVE X31t LEFT TO X31mh.
3110  Xacmh=Xact+TAN(22.5)*(Lambdad/2) !USED TO MOVE X28t RIGHT TO X28mh.
3120  !
3130  !
3140  Yot=0
3150  Yat=Yot+Vt+Jt+Wt      !TOP OF THE DIELECTRIC.
3160  Ybt=Yat-(Ct+Lt)       !TIP OF INPUT NOTCH.
3170  Yct=Yat-Tt            !BOTTOM OF 45 DEGREE CUTOUT.
3180  Ydt=Yot+Vt+Jt         !UPPER EDGE OF THE HORN SLOT.
3190  Yet=Yot+Vt            !LOWER EDGE OF THE HORN SLOT.
3200  Yft=Yet-Blt+Bgt       !UPPER EDGE OF THE UPPER SLOT CORNER.
3210  Ygt=Yet-Blt           !LOWER EDGE OF THE UPPER SLOT CORNER.
3220  Yht=Yot+Dt+Ct         !TOP EDGE OF SUM PORT DIELECTRIC.
3230  Yit=Yet-Bat           !END OF PORT ONE MICROSTRIP.
3240  Yjt=Yot+Dt            !TOP OF DIELECTRIC IN THE FIXTURE.
3250  Ykt=Yot+Bjt+Bkt+Bgt   !UPPER EDGE OF LOWER SLOT CORNER.
3260  Ylt=Ykt-Bgt           !LOWER EDGE OF LOWER SLOT CORNER.
3270  Ymt=Yjt-Lt            !TIP OF SUM NOTCH.
3280  Ynt=Yot+At/2          !TOP EDGE OF THE DIFFERENCE PORT DIELECTRIC TAB.
3290  Ypt=Yot+Ht/2+Ht       !TOP EDGE OF THE SLOT IN THE LOOP.
3300  Yqt=Yjt-Ot            !TOP EDGE OT THE INPUT SLOT.
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3310 Yrt=Yjt-Qt-Jt        !LOWER EDGE OF THE INPUT SLOT.
3320 Yst=Yot+Mt/2         !LOWER EDGE OF THE LOOP SLOT.
3330 Ytt=Yot+Pt/2         !TOP EDGE OF THE ISOLATION SLOT.
3340 Yut=Yot+Ot/2+It      !UPPER EDGE OF THE COUPLED SLOT.
3350 Yvt=Yot+Bt/2         !UPPER EDGE OF THE DIFFERENCE PORT CENTER CONDUCTOR.
3360 Ywt=Yot+Ot/2         !LOWER EDGE OF THE COUPLED SLOT.
3370 Yxt=Yot+Kt/2         !UPPER EDGE OF THE DIFFERENCE MICROSTRIP.
3380 Yyt=Yot-Kt/2         !LOWER EDGE OF THE DIFFERENCE MICROSTRIP.
3390 Yzt=Yot-Bt/2         !LOWER EDGE OF DIFFERENCE PORT CENTER CONDUCTOR.
3400 Yaat=Yot-Ot/2-It-Bat!END OF SUM PORT MICROSTRIP.
3410 Yabt=-Yit            !END OF PORT 2 MICROSTRIP.
3420 Yact=-Ybt            !TIP OF LOWER INPUT NOTCH (USED TO DRAW MICROSTRIP).
3430 Yadt=-Yat            !BOTTOM OF LOWER INPUT PORT.
3440 Yaet=Yadt-Space      !TOP OF THE RULER.
3450 Yaft=Yaet-2*Sixteenth  !LOWER TIP OF A RULER MARK.
3460 Yagt=Yaft-Sixteenth    !LOWER TIP OF A RULER MARK.
3470 Yaht=Yagt-Sixteenth    !LOWER TIP OF A RULER MARK.
3480 Yait=Yaht-Sixteenth    !LOWER TIP OF A RULER MARK.
3490 Yajt=Yait-Sixteenth    !LOWER TIP OF A RULER MARK.
3500 Yakt=Yaet-.57*In     !FIRST LINE OF WORDS UNDER THE RULER.
3510 Yalt=Yaet-.72*In     !SECOND LINE OF WORDS UNDER THE RULER.
3520 !
3530 !
3540 Yoh=Yot              !CENTER OF HORN.
3550 Yah=Yot+Jt/2         !TOP OF HORN SLOT.
3560 Ybh=Yot+Eh           !END OF HORN OPENING.
3570 IF Drawing$="MONO" THEN 3600
3580 Ych=Yjt              !PLACE WHERE HORN JOINS THE FIXTURE.
3590 GOTO 3610
3600 Ych=Yot+Qt+Jt/2      !THIS KEEPS THE COPPER Lambdad/2 ABOVE THE SLOT.
3610 Ydh=Ybh+Dh           !TOP OF HORN.
3620 !
3630 !
3640 Ydmh=Ydt+Lambdad/2               !USED TO MOVE X31t UP TO X31mh.
3650 Yemh=Yet-Lambdad/2               !USED TO MOVE X28t DOWN TO X28mh.
3660 Yfmh=Yft+TAN(22.5)*(Lambdad/2)  !USED TO MOVE X32t UP TO X32mh.
3670 Ygmh=Ygt-TAN(22.5)*(Lambdad/2)  !USED TO MOVE X27t DOWN TO X26mh:
3680 Ykmh=Ykt+TAN(22.5)*(Lambdad/2)  !USED TO MOVE X33T UP TO X33mh.
3690 Ylmh=Ylt-TAN(22.5)*(Lambdad/2)  !USED TO MOVE X26t DOWN TO X26mh.
3700 Yqmh=Yqt+Lambdad/2               !USED TO MOVE X34t UP TO X34mh.
3710 Yrmh=Yrt-Lambdad/2               !USED TO MOVE X25t DOWN TO X25mh.
3720 ! STEP FIVE: CALCULATION OF CORRECTIONS THAT WILL BE USED TO REMOVE
3730 !                ERRORS FROM THE DRAWING THAT ARE CAUSED BY THE PLOTTER.
3740 !
3750 !     THERE IS A SLIGHT BIT OF LOSENESS IN THE PEN CABLE ON THE HP 9872C
3760 !     PLOTTER. THE AMOUNT OF ERROR THAT THIS INDUCES IS WITHIN THE PLOTTERS
3770 !     SPECIFICATIONS AND DOES NOT CAUSE ANY PROBLEM IN MOST PLOTTER
3780 !     APPLICATIONS. HOWEVER, DUE TO THE EXTREMELY SMALL DIMENSIONS IN THE
3790 !     AREA NEAR THE COUPLED SLOTS, THESE ERRORS MUST BE ACCOUNTED FOR IN
3800 !     THIS PROGRAM. THESE CORRECTIONS CAME FROM EMPIRICAL TESTING AND
3810 !     WILL HAVE TO BE ADJUSTED TO MATCH THE PARTICULAR PLOTTER THAT IS
3820 !     BEING USED. THE In/Mm SCALING IS INTENTIONALLY OMITTED TO KEEP THE
3830 !     THE CORRECTIONS TO THE SCALE OF THE ACTUAL DRAWING AND PEN.
3840 Plottercorrect1=.07
3850 Plottercorrect2=0
3860 Plottercorrect3=0
3870 Plottercorrect4=0
3880 Pen=.32              !THIS IS THE PEN THICKNESS, AND IT IS CORRECTED
3890                      ! FOR AUTOMATICALLY IN THE DRAWING.
3900 !
3910 !
3920 ! STEP SIX: ENTER TWO MAJOR LOOPS THAT MAKE THE DESIRED DRAWING:
3930 !
3940 !     THE FIRST LOOP (THE "Fill" LOOP) IS USED TO FILL IN THE BLACK
3950 !     PORTIONS OF THE DRAWING. THIS IS DONE BY MOVING EACH POINT OF THE
3960 !     FIGURE IN 60% OF THE PEN THICKNESS, AND THEN DRAWING IT OVER AGAIN.
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3970  !
3980  !    THE SECOND LOOP (THE "Im" LOOP) IS USED TO DRAW THE FIN-LINE PATTERN.
3990  !    THE BOTTOM HALF IS ESSENTIALLY A MIRROR IMAGE OF THE TOP. THEREFORE,
4000  !    ONLY THE TOP HALF IS DEFINED. THE BOTTOM HALF IS DRAWN BY MULTIPLYING
4010  !    THE "Y" COORDINATES BY MINUS ONE. ANY NON-SYMETRIC AREAS (SUCH AS
4020  !    THE SUM PORT) ARE TAKEN CARE OF WITH "IF" STATEMENTS, THAT CHECK TO
4030  !    SEE IF THE TOP OR BOTTOM HALF IS BEING DRAWN.
4040  !
4050  !
4060  FOR Fill=1 TO 1 STEP 2            !START OF THE "Fill" LOOP.
4070  FOR Image=0 TO 2 STEP 2           !START OF THE "Im" LOOP.
4080  Im=1-Image                        !Im=1 DRAWS THE TOP, AND Im=-1 DRAWS THE
4090                                    ! BOTTOM OF THE SLOTLINE SIDE.
4100  IF Fill=3 THEN Segmentsize=Segmentsize*3
4110  IF Fill>1 THEN GOTO 4180          !SKIPS TO THE "Fill" ROUTINE.
4120  IF Im=1 THEN Penn=Pen*Fill                  !PLOTTER CORRECTION FOR THE
4130                                              ! TOP HALF OF SLOTLINE SIDE.
4140  IF Im=-1 THEN Penn=Pen*Fill+Plottercorrect1 !PLOTTER CORRECTION FOR THE
4150                                              ! BOTTOM HALF OF THE SLOTLINE
4160                                              ! SIDE.
4170  GOTO 4230                         !SKIPS "Fill" ROUTINE ON FIRST PASS.
4180  IF Im=1 THEN Penn=Pen*Fill*.60    !"Fill" ROUTINE. MOVES PEN IN 60% OF
4190                                    ! IT'S WIDTH AND THEN DRAWS THE
4200                                    ! FIGURE AGAIN.
4210  !
4220  !
4230  ! STEP SEVEN: CALCULATION OF CORRECTIONS THAT WILL BE USED TO REMOVE
4240  !             ERRORS FROM THE DRAWING THAT ARE CAUSED BY THE PEN.
4250  !
4260  !    THE FOLLOWING CALCULATIONS ARE USED TO ELIMINATE ANY INACCURACY IN
4270  !    THE DRAWING DUE TO THE WIDTH OF THE PEN THAT IS BEING USED.
4280  !    THESE ADJUSTMENTS WILL AUTOMATICALLY MOVE THE PEN THE APPROPRIATE
4290  !    AMOUNT AND DIRECTION TO ACCOUNT FOR HALF OF THE THICKNESS OF THE PEN.
4300  !
4310  Angle1=(180-ATN((Bt-Kt)/(2*Lt)))/2     !HALF OF THE ANGLE FORMED BY
4320                                         ! POINTS 102,103 AND 104.
4330  Penoffset1=Penn/(2*TAN(Angle1))        !CORRECTS POINTS 102, 103, 106 AND
4340                                         ! 107 IN THE "X" DIRECTION AND
4350                                         ! POINTS 111, 112, 115 AND 116 IN
4360                                         ! "Y" DIRECTION.
4370  !
4380  Angle2=ATN(At/(2*Lt))                  !HALF OF THE ANGLE FORMED BY
4390                                         ! POINTS 2,1 AND THE IMAGE OF 1.
4400  Penoffset2=Penn/(2*SIN(Angle2))        !CORRECTS POINT 1 IN THE "X"
4410                                         ! DIRECTION AND POINT 5 IN THE
4420                                         ! "Y" DIRECTION.
4430  !
4440  Angle3=(180-ATN((Bt-Kt)/(2*(Lt+Ct))))/2!HALF OF THE ANGLE FORMED BY
4450                                         ! POINTS 118,119 AND 120.
4460  Penoffset3=Penn/(2*TAN(Angle3))        !CORRECTS POINTS 119,122,125 AND
4470                                         ! 128 IN THE "Y" DIRECTION.
4480  !
4490  Angle3a=(90-(180-2*Angle3))/2          ! HALF OF THE ANGLE FORMED BY
4500                                         ! POINTS 117,118 AND 119.
4510  Penoffset3a=Penn/(2*TAN(Angle3a))      !CORRECTS POINTS 117,118, 123 AND
4520                                         ! 124 IN THE "X" DIRECTION.
4530  !
4540  Angle4=ATN(At/(2*(Lt+Ct)))             ! HALF OF THE ANGLE FORMED BY
4550                                         ! POINTS 11, 12 AND 13.
4560  Penoffset4=Penn/(2*SIN(Angle4))        !CORRECTS POINT 12 IN THE "Y"
4570                                         ! DIRECTION.
4580  !
4590  Angle5=(180-ATN(2*Lt/At))/2            !HALF OF THE ANGLE FORMED BY
4600                                         ! POINTS 1,2 AND 3.
4610  Penoffset5=Penn/(2*TAN(Angle5))        !CORRECTS POINT 2 IN THE "Y"
4620                                         ! DIRECTION AND POINTS 4 AND 5
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4630                                            ! IN THE "X" DIRECTION.
4640  !
4650  Angle6=(180-ATN(2*(Lt+Ct)/At))/2         !HALF OF THE ANGLE FORMED BY POINTS
4660                                            ! 10,11 AND 12.
4670  Penoffset6=Penn/(2*TAN(Angle6))          !CORRECTS POINTS 11 AND 13 IN THE
4680                                            ! "X" DIRECTION.
4690  !
4700  Penoffset7=Pen/(2*TAN(67.5))             !CORRECTS POINTS 23, 24, 25, 28
4710                                            ! 31, 34, 35 AND 36 IN THE "X"
4720                                            ! DIRECTION, AND POINTS 26, 27, 32
4730                                            ! AND 33 IN THE "Y" DIRECTION.
4740  Penoffset7a=Penn/(2*COS(45))             !CORRECTS POINT 18 IN THE "X"
4750                                            ! DIRECTION.
4760  !
4770  Angle8=(180-ATN((Mt/2+Nt-Ot/2-It)/Nt))/2 !HALF OF THE ANGLE FORMED BY
4780                                            ! POINTS 37, 38 AND 39.
4790  Penoffset8=Penn/(2*TAN(Angle8))          !CORRECTS POINTS 37 AND 38 IN
4800                                            ! THE "X" DIRECTION.
4810  !
4820  Angle9=(180-ATN((Mt/2-Ot/2)/(Nt+Bet-Bdt)))/2 !HALF OF THE ANGLE FORMED
4830                                            ! BY POINTS 21, 22 AND 23.
4840  Penoffset9=Penn/(2*TAN(Angle9))          !CORRECTS POINTS 21 AND 22 IN
4850                                            ! THE "X" DIRECTION.
4860  !
4870  Angleh1=45-Angleh  !USED TO DETERMINE OFFSETS AT END OF HORN.
4880  Angleh2=(180-Angleh)/2  !USED TO DETERMINE OFFSETS AT MOUTH OF HORN.
4890  !
4900  Penoffseth1=SQR(2)*Penn/2*SIN(Angleh1)  !CORRECTS 2h IN "X" DIRECTION AND
4910                                            ! 3h IN "Y" DIRECTION.
4920  Penoffseth2=SQR(2)*Penn/2*COS(Angleh1)  !CORRECTS 3h IN "X" DIRECTION AND
4930                                            ! 2h IN THE "Y" DIRECTION.
4940  Penoffseth3=Penn/2/TAN(Angleh2)         !CORRECTS 1h AND 4h IN THE "X"
4950                                            ! DIRECTION.
4960  !
4970  !
4980  ! STEP EIGHT: DEFINE ALL NUMBERED POINTS ON THE DRAWING IN TERMS OF THE
4990  !             "X" AND "Y" REFERENCE PLANES LISTED ABOVE.
5000  !
5010  !    THE PEN OFFSET CALCULATIONS ARE ENTERED HERE. THIS KEEPS THE
5020  !    REFERENCE PLANES FREE OF PEN CORRECTIONS.
5030  !
5040  ! THE FOLLOWING POINTS DEFINE THE FIN-LINE SIDE.
5050  !
5060  X1t=Xct+Penoffset2
5070  X2t=Xbt+Penn/2          !THIS IS FOR THE FIN-LINE SIDE OF POINT 2.
5080  X2at=Xbt-Penn/2         !THIS IS FOR THE DIELECTRIC TAB SIDE OF POINT 2.
5090  X3t=Xbt+Penn/2
5100  X4t=Xht-Penoffset5      !THIS IS FOR THE FIN-LINE SIDE OF POINT 4.
5110  X4at=Xht-Penn/2         !THIS IS FOR THE DIELECTRIC TAB SIDE OF POINT 4.
5120  X5t=Xet
5130  X6t=Xnt+Penoffset5      !THIS IS FOR THE FIN-LINE SIDE OF POINT 6.
5140  X6at=Xnt+Penn/2         !THIS IS FOR THE DIELECTRIC TAB SIDE OF POINT 6.
5150  X7t=Xut+Penn/2
5160  X8t=Xut+Penn/2
5170  X9t=Xut+Penn/2
5180  X10t=Xyt+Penoffset7
5190  X11t=Xadt-Penoffset6
5200  X12t=Xagt
5210  X13t=Xajt+Penoffset6
5220  X14t=Xalt-Penn/2
5230  X15t=Xalt-Penn/2
5240  X16t=Xalt-Penn/2
5250  X17t=Xut-Penoffset7
5260  X18t=Xtt-Penoffset7a
5270  X19t=Xdt  !THE PEN OFFSET FOR THE ARC IS DONE WHILE MAKING THE DRAWING.
5280  X20t=Xdt
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5290  X21t=Xft-Penoffset9
5300  X22t=Xjt-Penoffset5
5310  X23t=Xqt+Penoffset7
5320  X24t=Xst+Penoffset7
5330  X25t=Xxt+Penoffset7
5340  X26t=Xaat+Penn/2
5350  X27t=Xaat+Penn/2
5360  X28t=Xact+Penoffset7
5370  X29t=Xakt+Penn/2
5380  X30t=Xakt+Penn/2
5390  X31t=Xabt-Penoffset7
5400  X32t=Xzt-Penn/2
5410  X33t=Xzt-Penn/2
5420  X34t=Xut-Penoffset7
5430  X35t=Xrt-Penoffset7
5440  X36t=Xpt-Penoffset7
5450  X37t=Xkt+Penoffset8
5460  X38t=Xgt+Penoffset8
5470  X39t=Xdt
5480  X40t=Xat-Penn/2
5490  X41t=Xat-Penn/2
5500  X42t=Xht-Penn/2
5510  X43t=Xnt+Penn/2
5520  !
5530  !
5540  ! THE FOLLOWING POINTS DEFINE THE MICROSTRIP SIDE.
5550  !
5560  !
5570  X101t=Xat+Penn/2
5580  X102t=Xbt-Penoffset1
5590  X103t=Xct-Penoffset1
5600  X104t=Xet-Penn/2
5610  X105t=Xet-Penn/2
5620  X106t=Xct-Penoffset1
5630  X107t=Xbt-Penoffset1
5640  X108t=Xat+Penn/2
5650  X109t=Xit+Penn/2
5660  X110t=Xmt-Penn/2
5670  X111t=Xmt-Penn/2
5680  X112t=Xlt-Penn/2
5690  X113t=Xlt-Penn/2
5700  X114t=Xkt+Penn/2
5710  X115t=Xkt+Penn/2
5720  X116t=Xit+Penn/2
5730  X117t=Xaet+Penoffset3a
5740  X118t=Xait-Penoffset3a
5750  X119t=Xaht-Penn/2
5760  X120t=Xaht-Penn/2
5770  X121t=Xaft+Penn/2
5780  X122t=Xaft+Penn/2
5790  X123t=Xait-Penoffset3a
5800  X124t=Xaet+Penoffset3a
5810  X125t=Xaft+Penn/2
5820  X126t=Xaft+Penn/2
5830  X127t=Xaht-Penn/2
5840  X128t=Xaht-Penn/2
5850  !
5860  ! THE FOLLOWING POINTS DEFINE THE HORN.
5870  X1h=Xdh+Penoffseth3
5880  X2h=Xbh-Penoffseth1
5890  X3h=Xah-Penoffseth2
5900  X4h=Xch-Penoffseth3
5910  X5h=Xeh-Penn/2
5920  X6h=Xeh-Penn/2
5930  !
5940  ! THE FOLLOWING POINTS ARE USED TO MERGE THE MAGIC-TEE AND HORN INTO THE
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5950 ! MONOPULSE SYSTEM.
5960 X25mh=Xxmh-Penoffset7
5970 X26mh=Xaamh-Penn/2
5980 X27mh=Xaamh-Penn/2
5990 X28mh=Xacmh-Penoffset7
6000 X31mh=Xabmh+Penoffset7
6010 X32mh=Xzmh+Penn/2
6020 X33mh=Xzmh+Penn/2
6030 X34mh=Xumh+Penoffset7
6040 !
6050 ! THE FOLLOWING POINTS ARE USED TO DRAW THE RULER, BULL'S EYES AND
6060 ! COMMENTS.
6070 X150t=Xat                !LEFT SIDE OF THE RULER.
6080 Xbullleft=Xat+.25*In     !CENTER OF LEFT BULL'S EYE.
6090 Xbullright=Xalt-.25*In   !CENTER OF RIGHT BULL'S EYE.
6100 !
6110 !
6120 ! THE FOLLOWING LINES DEFINE THE "Y" COORDINATES OF THE FIN-LINE SIDE.
6130 !
6140 Y1t=Yot
6150 Y2t=Ynt+Penoffset5
6160 Y2at=Ynt+Penn/2
6170 Y3t=Yjt-Penn/2
6180 Y4t=Yjt-Penn/2
6190 Y4at=Yjt+Penn/2
6200 Y5t=Ymt-Penoffset2
6210 Y6t=Yjt-Penn/2
6220 Y6at=Yjt+Penn/2
6230 Y7t=Yjt-Penn/2
6240 Y8t=Yct-Penn/2
6250 Y9t=Yat-Penn/2
6260 Y10t=Yat-Penn/2
6270 Y11t=Yat-Penn/2
6280 Y12t=Ybt-Penoffset4
6290 Y13t=Yat-Penn/2
6300 Y14t=Yat-Penn/2
6310 Y15t=Ytt+Penn/2
6320 Y16t=Yot
6330 Y17t=Ytt+Penn/2
6340 Y18t=Yot
6350 Y19t=Yot
6360 Y20t=Yst-Penn/2
6370 Y21t=Yst-Penn/2
6380 Y22t=Yut-Penn/2
6390 Y23t=Yut-Penn/2
6400 Y24t=Yrt-Penn/2
6410 Y25t=Yrt-Penn/2
6420 Y26t=Ylt-Penoffset7
6430 Y27t=Ygt-Penoffset7
6440 Y28t=Yet-Penn/2
6450 Y29t=Yet-Penn/2
6460 Y30t=Ydt+Penn/2
6470 Y31t=Ydt+Penn/2
6480 Y32t=Yft+Penoffset7
6490 Y33t=Ykt+Penoffset7
6500 Y34t=Yqt+Penn/2
6510 Y35t=Yqt+Penn/2
6520 Y36t=Yut+Penn/2
6530 Y37t=Yut+Penn/2
6540 Y38t=Ypt+Penn/2
6550 Y39t=Ypt+Penn/2
6560 Y40t=Yot
6570 Y41t=Ynt+Penn/2
6580 Y42t=Yht+Penn/2
6590 Y43t=Yht+Penn/2
6600 !
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6610  !
6620  ! THE FOLLOWING POINTS DEFINE THE MICROSTRIP SIDE.
6630  Y101t=Yvt-Penn/2
6640  Y102t=Yvt-Penn/2
6650  Y103t=Yxt-Penn/2
6660  Y104t=Yxt-Penn/2
6670  Y105t=Yyt+Penn/2
6680  Y106t=Yyt+Penn/2
6690  Y107t=Yzt+Penn/2
6700  Y108t=Yzt+Penn/2
6710  Y109t=Yht-Penn/2
6720  Y110t=Yht-Penn/2
6730  Y111t=Yjt+Penoffset1
6740  Y112t=Ymt+Penoffset1
6750  Y113t=Yaat+Penn/2
6760  Y114t=Yaat+Penn/2
6770  Y115t=Ymt+Penoffset1
6780  Y116t=Yjt+Penoffset1
6790  Y117t=Yat-Penn/2
6800  Y118t=Yat-Penn/2
6810  Y119t=Ybt+Penoffset3
6820  Y120t=Ylt+Penn/2
6830  Y121t=Ylt+Penn/2
6840  Y122t=Ybt+Penoffset3
6850  Y123t=Yadt+Penn/2
6860  Y124t=Yadt+Penn/2
6870  Y125t=Yact-Penoffset3
6880  Y126t=Yabt+Penn/2
6890  Y127t=Yabt-Penn/2
6900  Y128t=Yact-Penoffset3
6910  !
6920  Y1h=Ych-Penn/2
6930  Y2h=Ydh-Penoffseth2
6940  Y3h=Ybh+Penoffseth1
6950  Y4h=Yah+Penn/2
6960  Y5h=Yah+Penn/2
6970  Y6h=Yot
6980  !
6990  ! THE FOLLOWING POINTS ARE USED TO MERGE THE MAGIC-TEE AND THE HORN
7000  ! INTO THE MONOPULSE SYSTEM.
7010  Y25mh=Yrmh+Penn/2
7020  Y26mh=Ylmh+Penoffset7
7030  Y27mh=Ygmh+Penoffset7
7040  Y28mh=Yemh+Penn/2
7050  Y31mh=Ydmh-Penn/2
7060  Y32mh=Yfmh-Penoffset7
7070  Y33mh=Ykmh-Penoffset7
7080  Y34mh=Yqmh-Penn/2
7090  !
7100  ! THE FOLLOWING POINTS ARE USED TO DRAW THE BULL'S EYES.
7110  Ybulltopt=Yat+2*Space
7120  Ybullbottom=-Ybulltopt
7130  !
7140  ! STEP NINE: MAKE THE DESIRED DRAWING.
7150  !
7160  ! THE CENTER OF THE DRAWING IS Xo,Yo. THIS IS THE POINT WHERE THE
7170  ! CENTERS OF THE SUM AND DIFFERENCE MICROSTRIP LINES WOULD CROSS IF
7180  ! EXTENDED. ALL OF THE DRAWINGS ARE REFERENCED FROM Xo,Yo.
7190  !
7200  IF Drawing$="TEE" THEN 7600 !SKIP TO MAGIC-TEE SECTION.
7210  IF Drawing$="MONO" THEN 8700 !SKIP TO THE MONOPULSE SYSTEM SECTION.
7220  !
7230  ! THIS SECTION DRAWS THE FIN-LINE SIDE OF A SINGLE FIN-LINE HORN.
7240  !
7250  IF Side$="M" THEN 7450  !SKIP TO MICROSTRIP SIDE.
7260  MOVE X1t,Y1t
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7270  DRAW X2t,Y2t*Im
7280  DRAW X3t,Y3t*Im
7290  IF Im=-1*Flip THEN 7330
7300  DRAW X4t,Y4t*Im
7310  DRAW X5t,Y5t*Im
7320  DRAW X6t,Y6t*Im
7330  GOSUB 10250  !DRAWS HORN.
7340  ! THE NEXT FEW LINES OUTLINE THE DIELECTRIC TABS TO MATCH THE FIXTURE.
7350  MOVE X40t,Y40t
7360  DRAW X41t,Y41t*Im
7370  DRAW X2at,Y2at*Im
7380  IF Im=-1*Flip THEN 7430
7390  MOVE X4at,Y4at*Im
7400  DRAW X42t,Y42t*Im
7410  DRAW X43t,Y43t*Im
7420  DRAW X6at,Y6at*Im
7430  NEXT Image
7440  GOTO 7570!SKIP MICROSTRIP SIDE.
7450  ! THIS SECTION DRAWS THE MICROSTRIP SIDE OF THE THE FIN-LINE HORN.
7460  MOVE XI09t,YI09t
7470  DRAW XI18t,YI18t
7480  DRAW XI11t,YI11t
7490  DRAW XI12t,YI12t
7500  Ybottomhms=Yot-Jt/2-Qumicrostrip+Penn/2 !ONLY POINT UNIQUE TO HORN.
7510  DRAW XI13t,Ybottomhms
7520  DRAW XI14t,Ybottomhms
7530  DRAW XI15t,YI15t
7540  DRAW XI16t,YI16t
7550  DRAW XI89t,YI89t
7560  !
7570  NEXT Fill
7580  GOTO 9300 ! SKIP TO THE RULER SECTION.
7590  !
7600  ! THIS SECTION DRAWS THE MAGIC-TEE.
7610  !
7620  IF Side$="M" THEN 8230    !THIS SKIPS TO MICRO-STRIP SIDE.
7630  !
7640  ! THIS SECTION DRAWS THE FIN-LINE SIDE OF THE FIN-LINE TEE.
7650  MOVE X1t,Y1t*Im
7660  DRAW X2t,Y2t*Im
7670  DRAW X3t,Y3t*Im
7680  IF Im=-1*Flip THEN GOTO 7720
7690  DRAW X4t,Y4t*Im
7700  DRAW X5t,Y5t*Im
7710  DRAW X6t,Y6t*Im
7720  DRAW X7t,Y7t*Im
7730  DRAW X8t,Y8t*Im
7740  DRAW X10t,Y10t*Im
7750  DRAW X11t,Y11t*Im
7760  DRAW X12t,Y12t*Im
7770  DRAW X13t,Y13t*Im
7780  DRAW X14t,Y14t*Im
7790  DRAW X16t,Y16t*Im
7800  MOVE X19t-Mt/2+Penn/2,Y19t
7810  FOR Angle=89 TO 180 STEP 2
7820  X=X19t-(Mt/2-Penn/2)*SIN(Angle)
7830  Y=(Y19t-(Mt/2-Penn/2)*COS(Angle))*Im
7840  DRAW X,Y
7850  NEXT Angle
7860  DRAW X21t,Y21t*Im
7870  IF Y22t>Yot THEN GOTO 7900 !KEEPS PEN BETWEEN COUPLED SLOTS.
7880  Y22t=Yot
7890  Y23t=Yot
7900  DRAW X22t,Y22t*Im
7910  DRAW X23t,Y23t*Im
7920  DRAW X24t,Y24t*Im
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7930  DRAW X25t,Y25t*Im
7940  DRAW X28t,Y28t*Im
7950  DRAW X29t,Y29t*Im
7960  DRAW X30t,Y30t*Im
7970  DRAW X31t,Y31t*Im
7980  DRAW X34t,Y34t*Im
7990  DRAW X35t,Y35t*Im
8000  DRAW X36t,Y36t*Im
8010  DRAW X37t,Y37t*Im
8020  DRAW X38t,Y38t*Im
8030  DRAW X39t,Y39t*Im
8040  FOR Angle=0 TO 91 STEP 1
8050  X=X19t-(Mt/2+Ht+Penn/2)*SIN(Angle)
8060  Y=(Y19t+(Mt/2+Ht+Penn/2)*COS(Angle))*Im
8070  DRAW X,Y
8080  NEXT Angle
8090  MOVE X40t,Y40t
8100  DRAW X41t,Y41t*Im
8110  DRAW X2at,Y2at*Im
8120  IF Im=-1*Flip THEN GOTO 8170
8130  MOVE X4at,Y4at*Im
8140  DRAW X42t,Y42t*Im
8150  DRAW X43t,Y43t*Im
8160  DRAW X6at,Y6at*Im
8170  MOVE X1,Y1
8180  NEXT Image
8190  GOTO 8560    !FIN-LINE SIDE IS COMPLETE. THIS COMMAND SKIPS THE
8200               ! MICROSTRIP SIDE, AND CONTINUES ON WITH THE PROGRAM.
8210  !
8220  ! THE FOLLOWING SECTION DRAWS THE MICROSTRIP SIDE OF THE MAGIC-TEE.
8230  MOVE X101t,Y101t
8240  DRAW X102t,Y102t
8250  DRAW X103t,Y103t
8260  DRAW X104t,Y104t
8270  DRAW X105t,Y105t
8280  DRAW X106t,Y106t
8290  DRAW X107t,Y107t
8300  DRAW X108t,Y108t
8310  DRAW X101t,Y101t
8320  MOVE X109t,Y109t*Flip
8330  DRAW X110t,Y110t*Flip
8340  DRAW X111t,Y111t*Flip
8350  DRAW X112t,Y112t*Flip
8360  DRAW X113t,Y113t*Flip
8370  DRAW X114t,Y114t*Flip
8380  DRAW X115t,Y115t*Flip
8390  DRAW X116t,Y116t*Flip
8400  DRAW X109t,Y109t*Flip
8410  MOVE X117t,Y117t
8420  DRAW X118t,Y118t
8430  DRAW X119t,Y119t
8440  DRAW X120t,Y120t
8450  DRAW X121t,Y121t
8460  DRAW X122t,Y122t
8470  DRAW X117t,Y117t
8480  MOVE X123t,Y123t
8490  DRAW X124t,Y124t
8500  DRAW X125t,Y125t
8510  DRAW X126t,Y126t
8520  DRAW X127t,Y127t
8530  DRAW X128t,Y128t
8540  DRAW X123t,Y123t
8550  ! THIS SECTION IS COMMON TO BOTH THE FIN-LINE AND THE MICROSTRIP SIDES.
8560  ! THE NEXT FEW LINES PLACE THE NUMBER OF THE MAGIC TEE NEAR THE DEVICE.
8570  CSIZE .06*In,.5
8580  MOVE Xvt+Penn,Yct+.68*Tt+Penn
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8590  LABEL Title$  !DRAWS THE NAME OF THE TEE ON THE DEVICE.
8600  NEXT Fill
8610  GOTO 9380 !MAGIC-TEE IS DONE, SKIP TO THE RULER SECTION.
8620  !
8630  ! THIS SECTION DRAWS THE FIN-LINE SIDE OF THE MONOPULSE SYSTEM.
8640  !
8650  IF Side$="M" THEN 9170      !SKIP TO MICROSTRIP SIDE.
8660  MOVE X1t,Y1t*Im
8670  DRAW X2t,Y2t*Im
8680  DRAW X3t,Y3t*Im
8690  IF Im=-1*Flip THEN 8730     !Flip CONTROLS THE LOCATION OF PORT-3.
8700  DRAW X4t,Y4t*Im
8710  DRAW X5t,Y5t*Im
8720  DRAW X6t,Y6t*Im
8730  DRAW X7t,Y7t*Im       !THIS IS THE UPPER LEFT EDGE OF THE FIXTURE.
8740  DRAW X34mh,Y34mh*Im !THIS IS THE FIRST POINT IN THE MONOPULSE SYSTEM
8750                      ! PORTION.
8760  DRAW X31mh,Y31mh*Im
8770  Imm=Im          !USED TO DRAW HORN CORRECTLY.
8780  GOSUB 10250    !DRAW HALF OF THE HORN.
8790  DRAW X31t,Y31t*Im
8800  DRAW X34t,Y34t*Im
8810  DRAW X35t,Y35t*Im
8820  DRAW X36t,Y36t*Im
8830  DRAW X37t,Y37t*Im
8840  DRAW X38t,Y38t*Im
8850  DRAW X39t,Y39t*Im
8860  FOR Angle=0 TO 91 STEP 1    !NEXT FIVE LINES DRAW THE LEFT QUARTER ARC.
8870  X=X19t-(Mt/2+Nt+Penn/2)*SIN(Angle)
8880  Y=(Y19t+(Mt/2+Nt+Penn/2)*COS(Angle))*Im
8890  DRAW X,Y
8900  NEXT Angle
8910  MOVE X25mh,Yct      !MOVE BACK TO CENTER OF THE MONOPULSE SYSTEM PORTION.
8920  DRAW X28mh,Y28mh*Im
8930  Imm=-1*Im  !FLIPS Im IN THE HORN SUBROUTINE TO DRAW BOTTOM HALF OF HORN.
8940  GOSUB 10250         !DRAW BOTTOM HALF OF THE HORN
8950  DRAW X28t,Y28t*Im  !THIS IS THE MAGIC-TEE PORTION AGAIN.
8960  DRAW X25t,Y25t*Im
8970  DRAW X24t,Y24t*Im
8980  DRAW X23t,Y23t*Im
8990  DRAW X22t,Y22t*Im
9000  DRAW X21t,Y21t*Im
9010  DRAW X20t,Y20t*Im
9020  FOR Angle=0 TO 91 STEP 1
9030  X=X19t-(Mt/2-Penn/2)*SIN(Angle)
9040  Y=(Y19t+(Mt/2-Penn/2)*COS(Angle))*Im
9050  DRAW X,Y
9060  NEXT Angle
9070  MOVE X40t,Y40t
9080  DRAW X41t,Y41t*Im
9090  DRAW X2at,Y2at*Im
9100  IF Im=-1*Flip THEN 9150
9110  MOVE X4at,Y4at*Im
9120  DRAW X42t,Y42t*Im
9130  DRAW X43t,Y43t*Im
9140  DRAW X6at,Y6at*Im
9150  NEXT Image
9160  GOTO 9360!SKIP THE MICROSTRIP SIDE.
9170  ! THIS SECTION DRAWS THE MICROSTRIP SIDE OF THE MONOPULSE SYSTEM.
9180  MOVE X101t,Y101t
9190  DRAW X102t,Y102t
9200  DRAW X103t,Y103t
9210  DRAW X104t,Y104t
9220  DRAW X105t,Y105t
9230  DRAW X106t,Y106t
9240  DRAW X107t,Y107t
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9250 DRAW X100t,Y100t
9260 DRAW X101t,Y101t
9270 MOVE X109t,Y109t
9280 DRAW X110t,Y110t
9290 DRAW X111t,Y111t
9300 DRAW X112t,Y112t
9310 DRAW X113t,Y113t
9320 DRAW X114t,Y114t
9330 DRAW X115t,Y115t
9340 DRAW X116t,Y116t
9350 DRAW X109t,Y109t
9360 NEXT Fill
9370 !
9380 ! THIS SECTION DRAWS THE RULER AND COMMENTS.
9390 !
9400 IF Ruler$="N" THEN 10200
9410 ! THE NEXT PORTION OF THE PROGRAM DRAWS THE NUMBERS AND COMMENTS BELOW
9420 ! THE RULER.
9430 LINE TYPE 1          !THIS RETURNS THE PLOTTER TO A NORMAL HIGH SPEED LINE.
9440 Penn=Pen
9450 FOR I=1 TO 3*Scale STEP 1
9460 Penn=.8*Pen+Penn
9470 CSIZE .135*In,.35   !(HEIGHT OF LETTERS),(WIDTH/HEIGHT RATIO)
9480 MOVE X150t+.05*In+Penn,Yajt-Penn
9490 LABEL "1"
9500 MOVE X150t+1.05*In+Penn,Yajt-Penn
9510 LABEL "2"
9520 MOVE X150t+2.05*In+Penn,Yajt-Penn
9530 LABEL "3"
9540 IF I>Scale THEN GOTO 9800
9550 MOVE X150t+Penn,Yakt+Penn
9560 CSIZE .08*In,.48    !(HEIGHT OF LETTERS),(WIDTH/HEIGHT RATIO)
9570 LABEL "WHEN REDUCED TO 1:1 SCALE, THIS"
9580 MOVE X150t+Penn,Yalt+Penn
9590 LABEL "RULER WILL BE EXACTLY IN INCHES."
9600 !
9610 ! THE FOLLOWING LINES DRAW THE COMMENTS BETWEEN THE BULL'S EYES.
9620 MOVE Xbullleft+.2*In+Penn,Ybulltop+Penn
9630 LABEL "MAGIC TEE ";Title$;" by LCDR ROWLEY"
9640 !
9650 ! THE FOLLOWING LINES DRAW THE BULL'S EYES.
9660 MOVE Xbullleft+Penn,Ybulltop+.15*In+Penn
9670 DRAW Xbullleft+Penn,Ybulltop-.05*In+Penn
9680 MOVE Xbullleft-.1*In+Penn,Ybulltop+Penn+.05*In
9690 DRAW Xbullleft+.1*In+Penn,Ybulltop+Penn+.05*In
9700 FOR Angle=0 TO 360 STEP 5
9710 DRAW .1*In*COS(Angle)+Xbullleft+Penn,.1*In*SIN(Angle)+Ybulltop+.05*In+Penn
9720 NEXT Angle
9730 MOVE Xbullright+Penn,Ybulltop+.15*In+Penn
9740 DRAW Xbullright+Penn,Ybulltop-.05*In+Penn
9750 MOVE Xbullright-.1*In+Penn,Ybulltop+Penn+.05*In
9760 DRAW Xbullright+.1*In+Penn,Ybulltop+Penn+.05*In
9770 FOR Ang=0 TO 360 STEP 5
9780 DRAW .1*In*COS(Ang)+Xbullright+Penn,.1*In*SIN(Ang)+Ybulltop+.05*In+Penn
9790 NEXT Ang
9800 NEXT I
9810 ! THE NEXT SEGMENT OF THE PROGRAM DRAWS THE RULER.
9820 J=1
9830 Penn=Pen
9840 FOR I=0 TO 6 STEP 1
9850 J=J+1
9860 X150t=Xat+I*(.5*In)
9870 MOVE X150t+Penn,Yaet      !TOP OF THE RULER.
9880 ! THE RULER IS DRAWN IN SIX HALF INCH SEGMENTS. THE ODD SEGMENTS START
9890 ! WITH A LONG INCH MARK, WHILE THE EVEN SEGMENTS START WITH A SHORTER
9900 ! HALF INCH MARK. THE NEXT SEVEN LINES CONSTRUCT THE FIRST MARK IN EACH
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```
9910  ! HALF INCH SEGMENT.
9920  IF I=1 THEN GOTO 9980      !SKIPS TO THE HALF INCH MARK LENGTH.
9930  IF I=3 THEN GOTO 9980      !SKIPS TO THE HALF INCH MARK LENGTH.
9940  IF I=5 THEN GOTO 9980      !SKIPS TO THE HALF INCH MARK LENGTH.
9950  DRAW X150t+Penn,Yajt       !THIS IS THE INCH MARK (LONGEST LINE).
9960  IF I=6 THEN GOTO 10150     !THIS TERMINATES THE RULER AFTER THREE INCHES.
9970  GOTO 10000                 !THIS SKIPS THE HALF INCH MARK LENGTH.
9980  DRAW X150t+Penn,Yait       !THIS IS THE HALF INCH MARK LENGTH.
9990  ! THE NEXT 14 LINES DRAWS EACH HALF INCH SEGMENT OF THE RULER.
10000 MOVE X150t+Penn+Sixteenth,Yaet
10010 DRAW X150t+Penn+Sixteenth,Yaft
10020 MOVE X150t+Penn+2*Sixteenth,Yaet
10030 DRAW X150t+Penn+2*Sixteenth,Yagt
10040 MOVE X150t+Penn+3*Sixteenth,Yaet
10050 DRAW X150t+Penn+3*Sixteenth,Yaft
10060 MOVE X150t+Penn+4*Sixteenth,Yaet
10070 DRAW X150t+Penn+4*Sixteenth,Yaht
10080 MOVE X150t+Penn+5*Sixteenth,Yaet
10090 DRAW X150t+Penn+5*Sixteenth,Yaft
10100 MOVE X150t+Penn+6*Sixteenth,Yaet
10110 DRAW X150t+Penn+6*Sixteenth,Yagt
10120 MOVE X150t+Penn+7*Sixteenth,Yaet
10130 DRAW X150t+Penn+7*Sixteenth,Yaft
10140 NEXT I
10150 IF J>8*Scale THEN GOTO 10200 !THIS TERMINATES THE PROGRAM WHEN LINES ARE
10160                              ! ARE THICK ENOUGH.
10170 Penn=Penn+Pen                ! THIS SHIFTS THE RULER SLIGHTLY AND REDRAWS
10180                              ! IT. THIS MAKES THE LINES THICK ENOUGH.
10190 GOTO 9840                    ! THIS CONTINUES THE LOOP.
10200 PEN 0                        ! THE PEN IS PUT BACK IN THE HOLDER.
10210 MOVE 5000,500                ! THE PEN DRIVE ARM IS MOVED ASIDE.
10220 STOP
10230 !
10240 ! STEP TEN: HORN SUBROUTINE.
10250 ! THE FOLLOWING SUBROUTINE DRAWS HALF OF THE HORN AT A TIME.
10260 IF Drawing$="HORN" THEN 10320!SKIP OFFSET FOR SINGLE HORN.
10270 Xoff=Xact-Xvt+Lambdad    !MOVES HORN OPENING ONE WAVELENGTH LEFT OF THE
10280                          ! LAST SLOT BEND (MONOHORN ONLY).
10290 Yoff=(Vt+Jt/2)*Im        ! MOVES HORN OPENING UP/DOWN TO MATCH SLOTS IN
10300                          ! THE MONOPULSE SYSTEM.
10310 GOTO 10350               !SKIP TO DRAWING ROUTINE.
10320 Imm=Im    !NEEDED FOR SINGLE HORN ONLY.
10330 Xoff=0    !INSURES OFFSETS ARE ZERO FOR SINGLE HORN.
10340 Yoff=0
10350 DRAW X1h+Xoff,Y1h*Imm+Yoff
10360 DRAW X2h+Xoff,Y2h*Imm+Yoff
10370 DRAW X3h+Xoff,Y3h*Imm+Yoff
10380 DRAW X4h+Xoff,Y4h*Imm+Yoff
10390 IF Drawing$="MONO" THEN 10420 !POINTS 5&6 ARE FOR THE SINGLE HORN ONLY.
10400 DRAW X5h+Xoff,Y5h*Im+Yoff
10410 DRAW X6h+Xoff,Y6h*Im+Yoff
10420 ! THE NEXT PORTION DRAWS THE DOTTED LINE OF THE LENS ARC.
10430 IF F(11)>1 THEN 7430
10440 LINE TYPE 4,.5*Scale              !DOTTED LINE.
10450 FOR Beta=0 TO Anglen STEP 1       !Beta(MAX)=Anglen.
10460 ! THE FOLLOWING LINES ARE THE EQUATION THAT DEFINES A PARALLEL
10470 ! PHASE FRONT LENS.
10480 Aarc=1-COS(Beta)
10490 Barc=1-COS(Anglen)
10500 Carc=1/SQR(Er)-COS(Beta)
10510 Darc=COS(Anglen)-1/SQR(Er)
10520 Earc=COS(Beta)*(1-SQR(Er))
10530 Brh=Bh*(Aarc+Barc*Carc/Darc)/Earc     !THICKNESS OF LENS.
10540 Radh=Bh+Brh+Pen                       !RADIUS FROM Xoh,Yoh TO LENS EDGE.
10550                                       ! Bh IS RADIUS OF ARC WITHOUT LENS.
10560 Xarc=Xoh+Radh*COS(Beta)               !X POSITION OF ARC.
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10570 Yarc=Yoh+Radh*SIN(Beta)              !Y POSITION OF ARC.
10580 IF Beta=0 THEN MOVE Xarc+Xoff,Yarc+Yoff  !POSITIONS PEN FOR ARC.
10590 DRAW Xarc+Xoff,Yarc*Imm+Yoff
10600 NEXT Beta
10610 IF Drawing$="H" THEN 10650 ! FOLLOWING LINES ARE FOR MONOHORN ONLY.
10620 MOVE X4h+Xoff,Y4h*Imm+Yoff !RETURNS DRAWING TO PROPER POINT AFTER L2HS IS
10630                            ! IS DRAWN.
10640 LINE TYPE Linenumber,Segmentsize  !RETURNS LINE TYPE TO PREVIOUS SETTING.
10650 RETURN
10660 END
```

APPENDIX B

FIGURES

FIN-LINE MAGIC-TEE NUMBER THREE

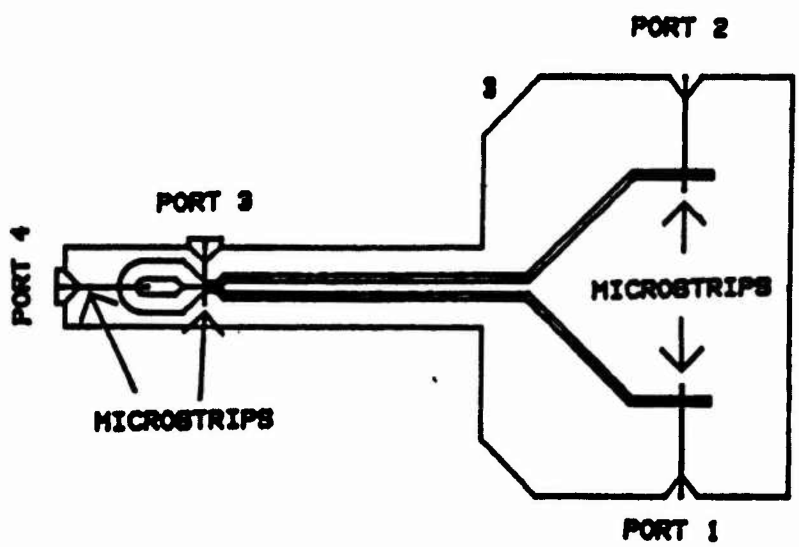


Figure 1 Fin-Line Magic-Tee.

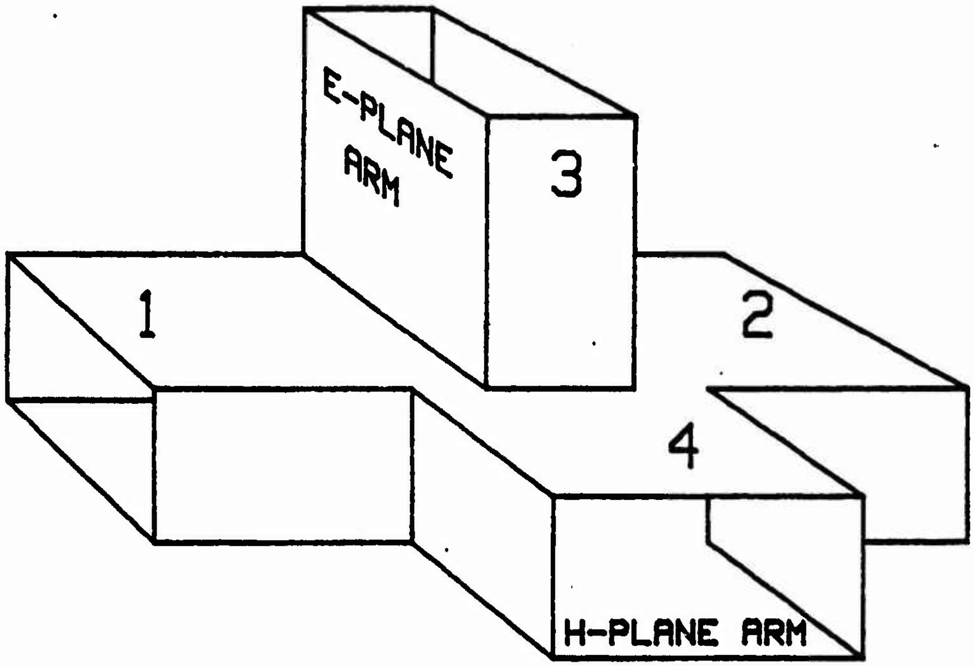


Figure 2 Waveguide Magic-Tee.

$$S = \begin{bmatrix} 0 & 0 & .707e^{j000} & .707e^{j000} \\ 0 & 0 & .707e^{-j180} & .707e^{j000} \\ .707e^{j000} & .707e^{-j180} & 0 & 0 \\ .707e^{j000} & .707e^{j000} & 0 & 0 \end{bmatrix}$$

Figure 3 Theoretical Magic-Tee Scattering Matrix.

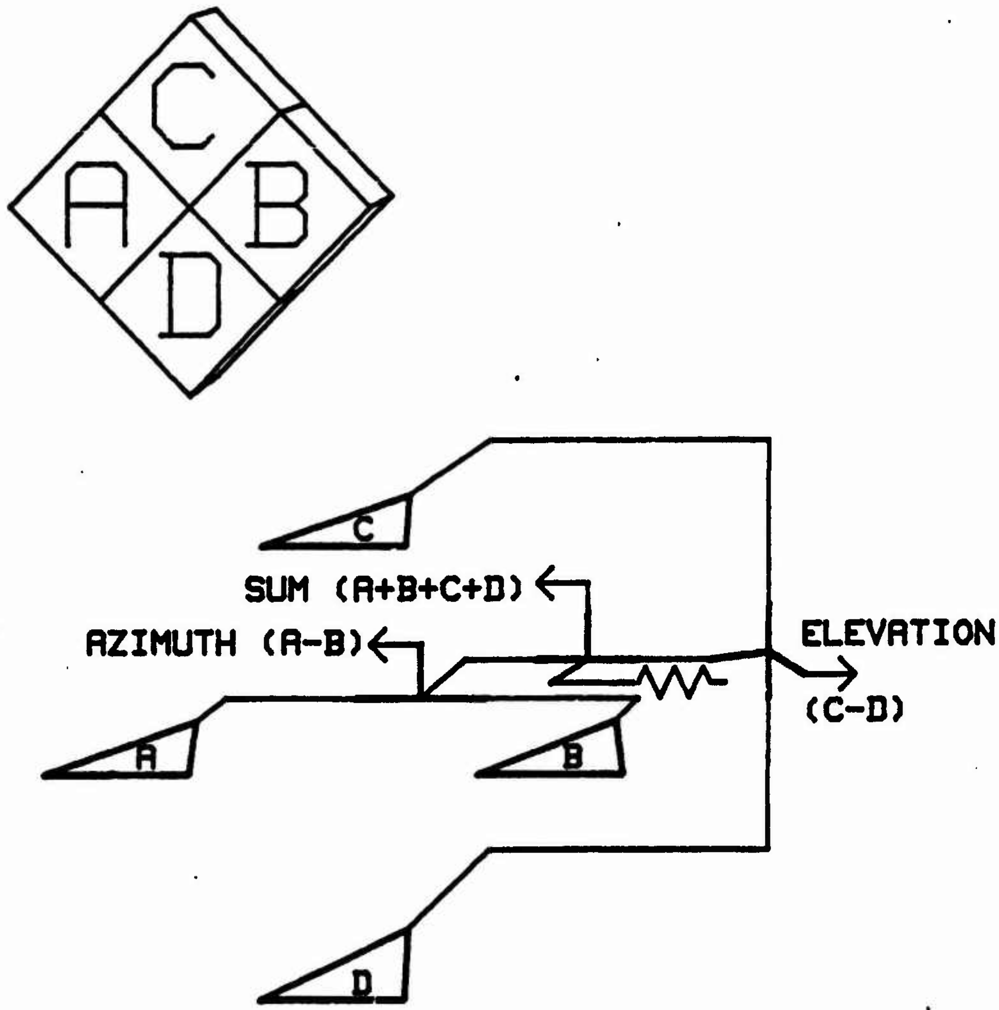


Figure 4 Diamond Monopulse Feed.

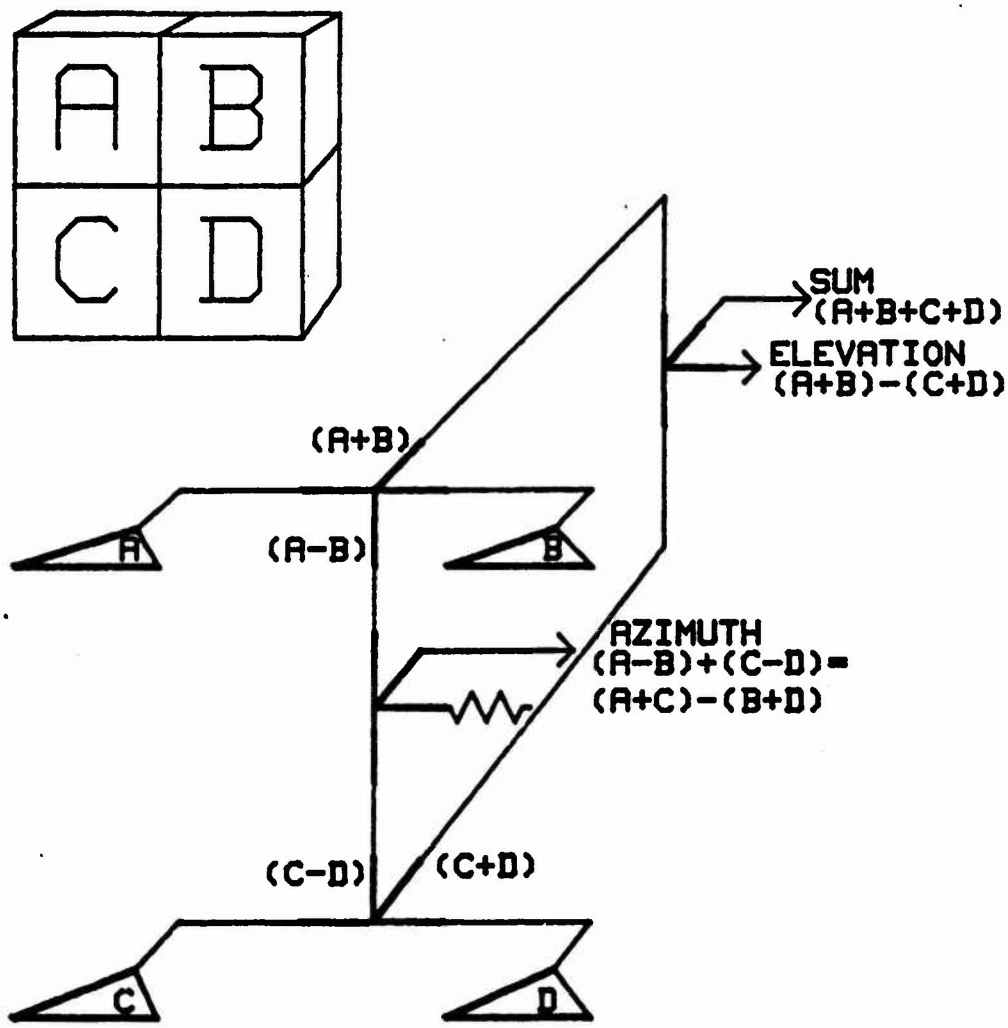
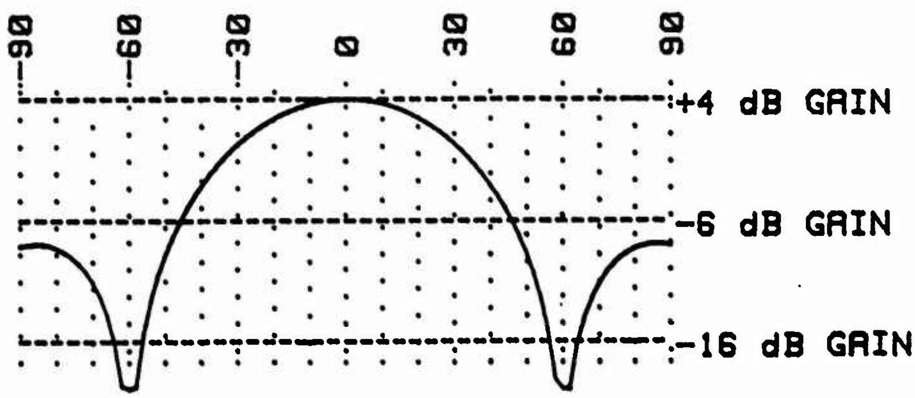
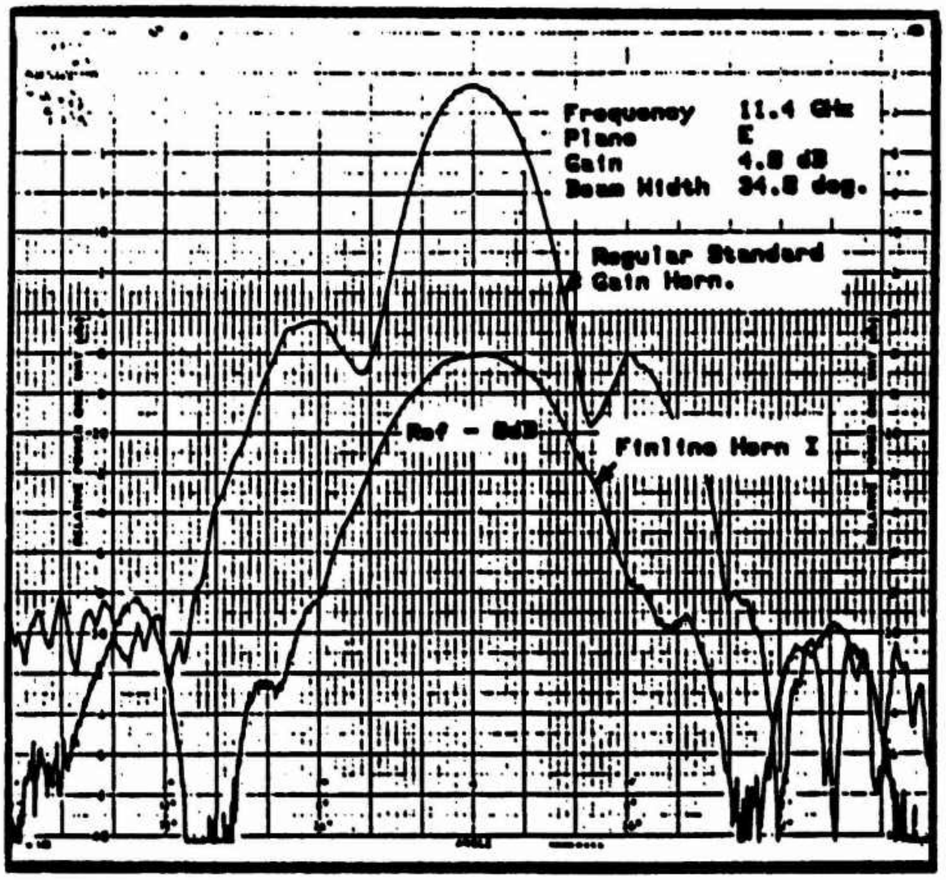


Figure 5 Square Monopulse Feed.

Degrees Left(-) and Right(+) of Boresight .

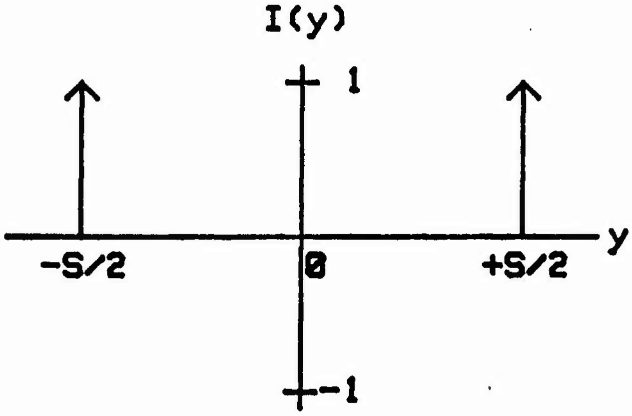


Computer Simulation of Actual
Element Pattern.

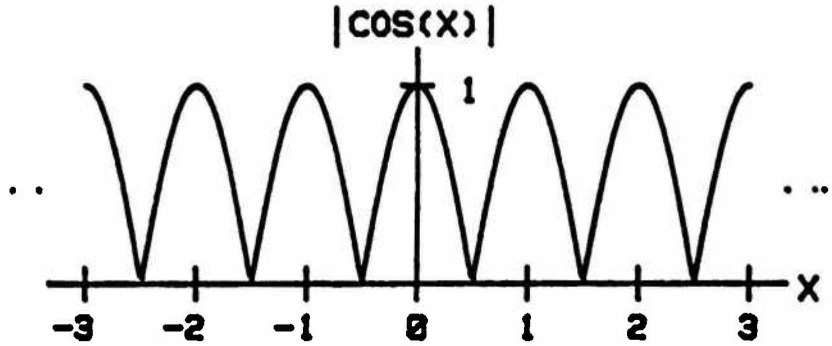


Actual Element Pattern at 11.4 GHZ.

Figure 6 Simulated and Actual Element Pattern.



Spacing between elements of a Monopulse Feed, showing the elements in phase with each other. Each element is represented by a delta function. The element pattern is accounted for later.



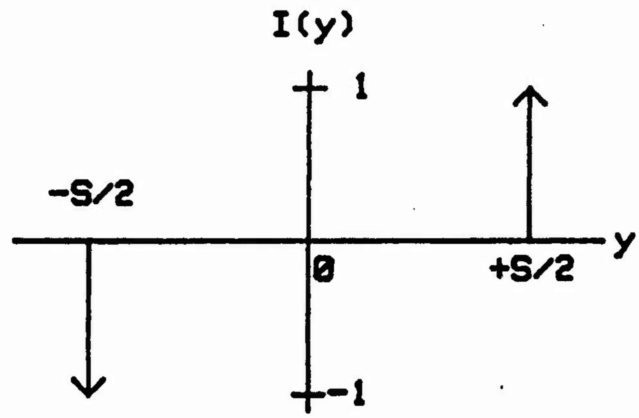
Fourier Transformed Sum Group pattern.

NOTES:

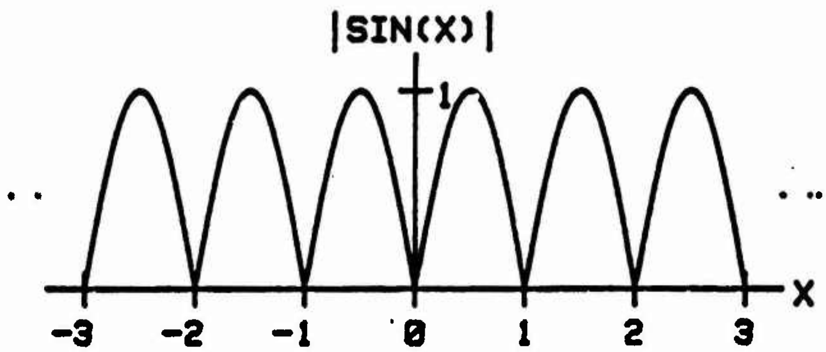
1. X=SIN(Theta)*(S/Lambda); Theta is the angle left(-), or right(+), of the antenna's boresight. 'S' is the spacing between the antenna elements.

2. At +/- 90 degrees, SIN(Theta) reaches it's maximum value of one. These two pionts are called the pattern's visible limits. They occur where X=+/-(1)*(S/Lambda) on the transformed pattern.

Figure 7 Theoretical Sum Group Pattern.



Spacing between elements of a Monopulse Feed, showing the elements out of phase with each other. Each element is represented by a delta function. The element pattern is accounted for later.



Fourier Transformed Difference Group Pattern.

NOTES:

1. X=SIN(Theta)*(S/Lambda); Theta is the angle left(-), or right(+), of the antenna's bore sight. 'S' is the spacing between the antenna elements.

2. At +/- 90 degrees, SIN(Theta) reaches it's maximum value of one. These two pionts are called the pattern's visible limits. They occur where X=+/-(1)*(S/Lambda) on the transformed pattern.

Figure 8 Theoretical Difference Group Pattern.

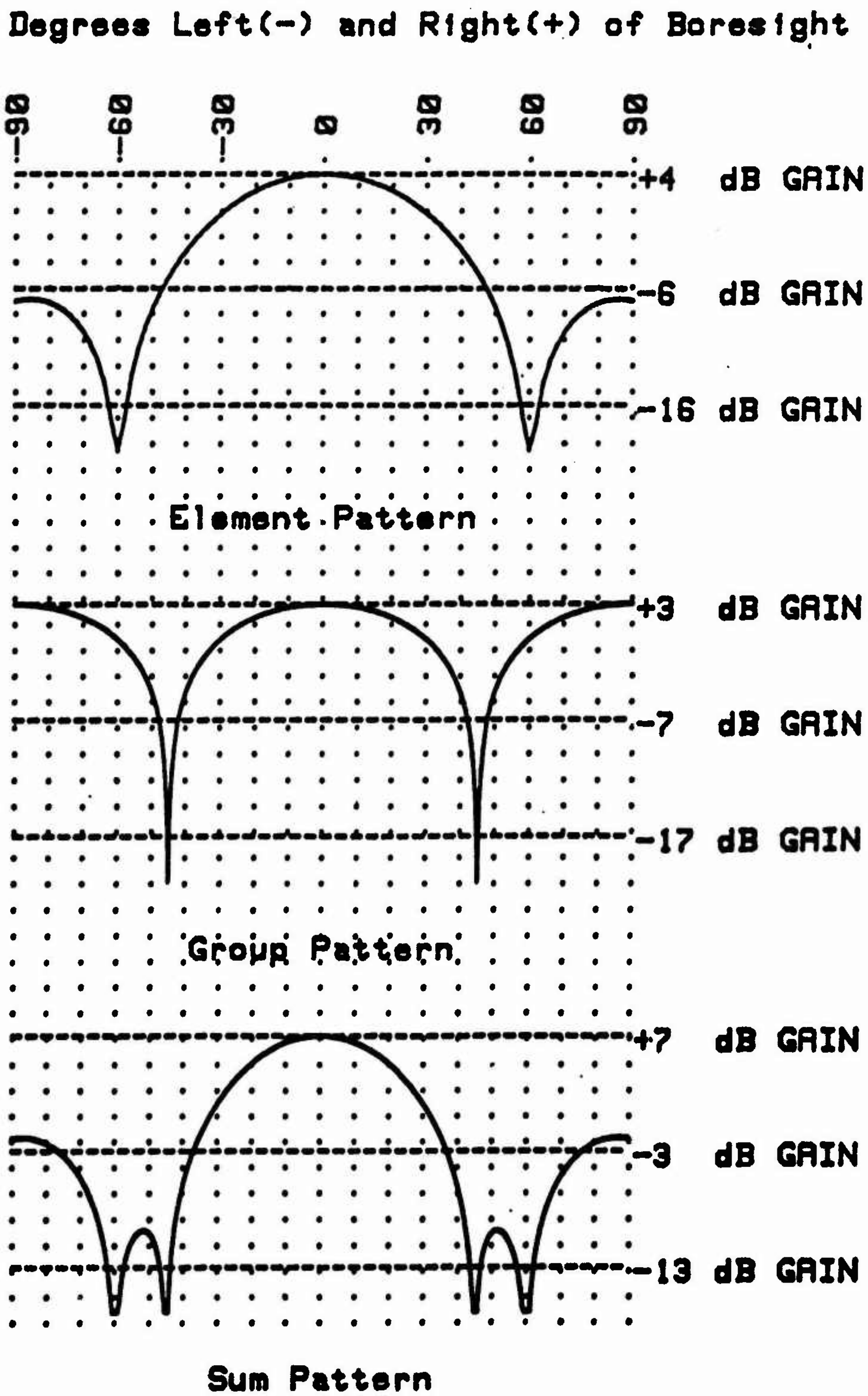


Figure 9 Theoretical Sum Pattern.

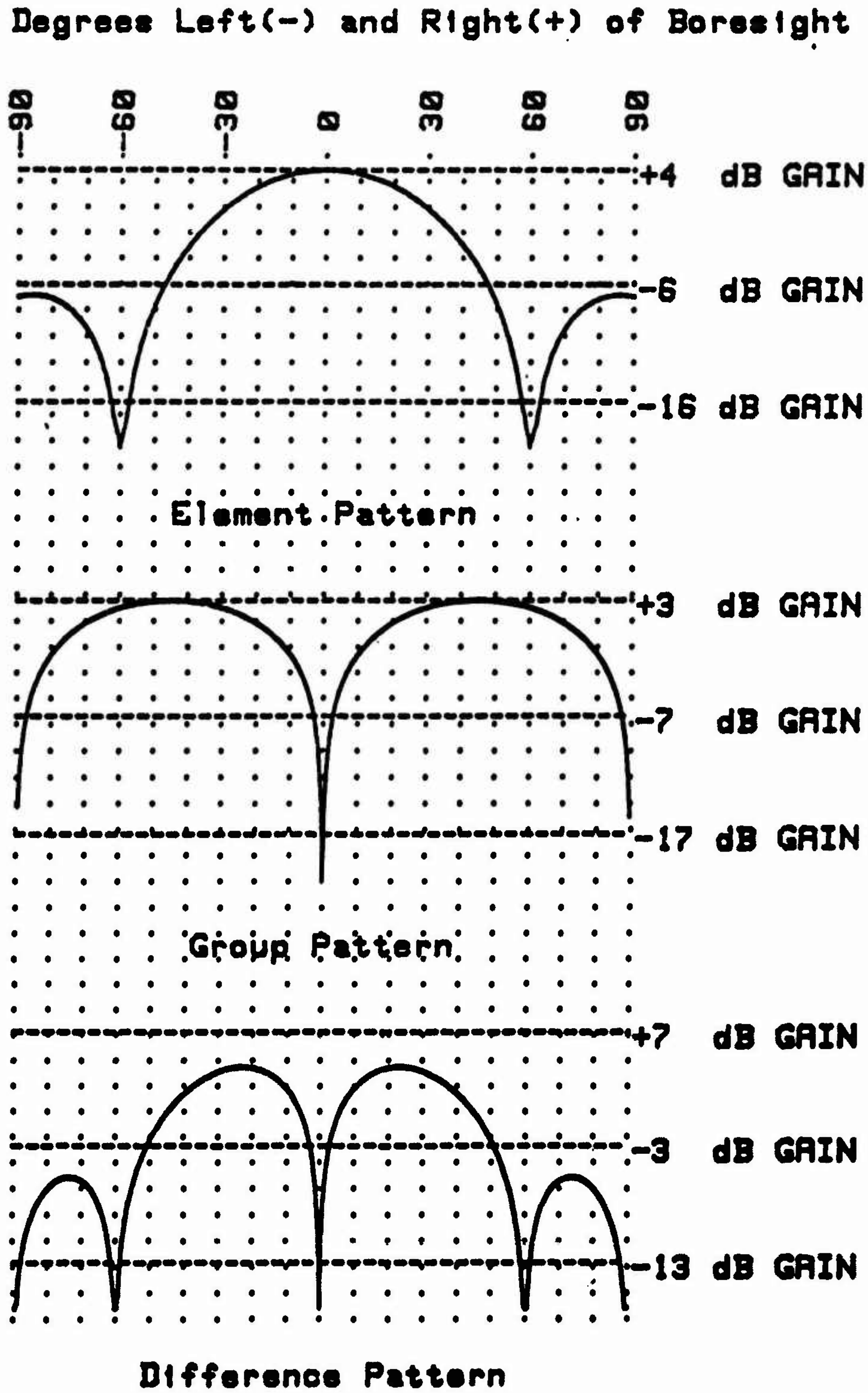


Figure 10 Theoretical Difference Pattern.

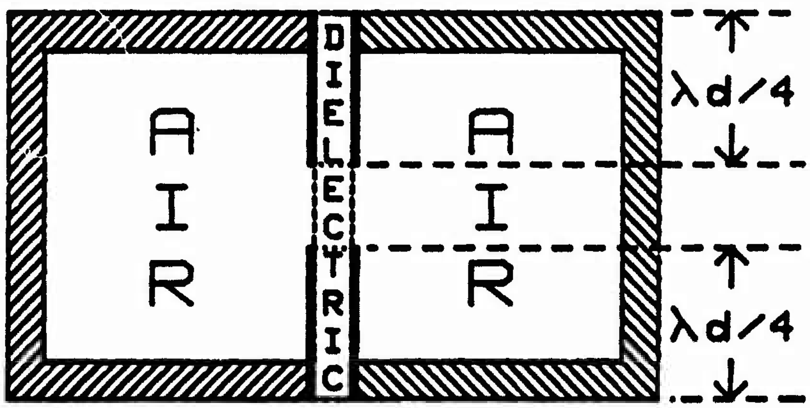


Figure 11 Bilateral Fin-Line.

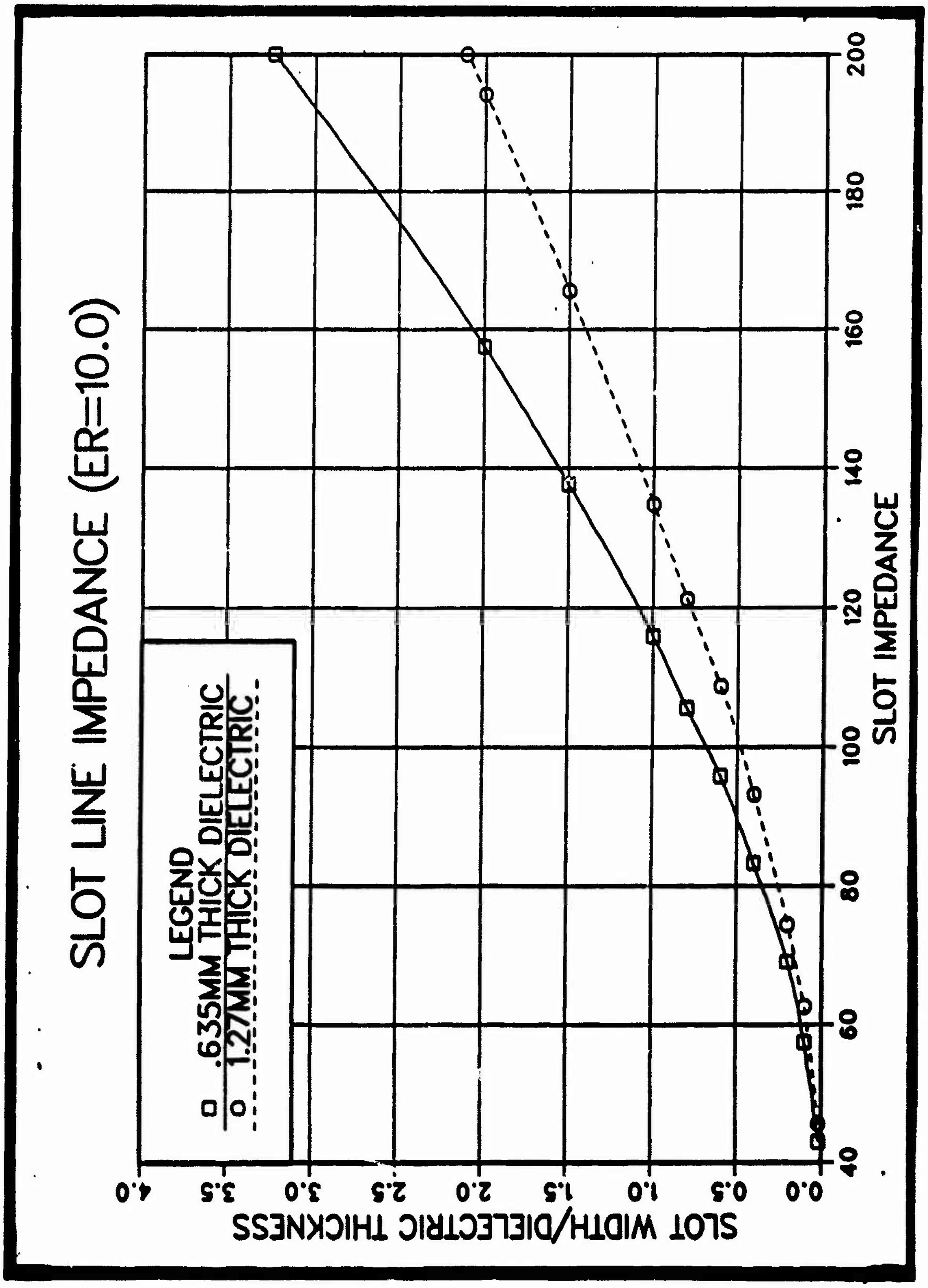


Figure 12 Slotline Impedance.

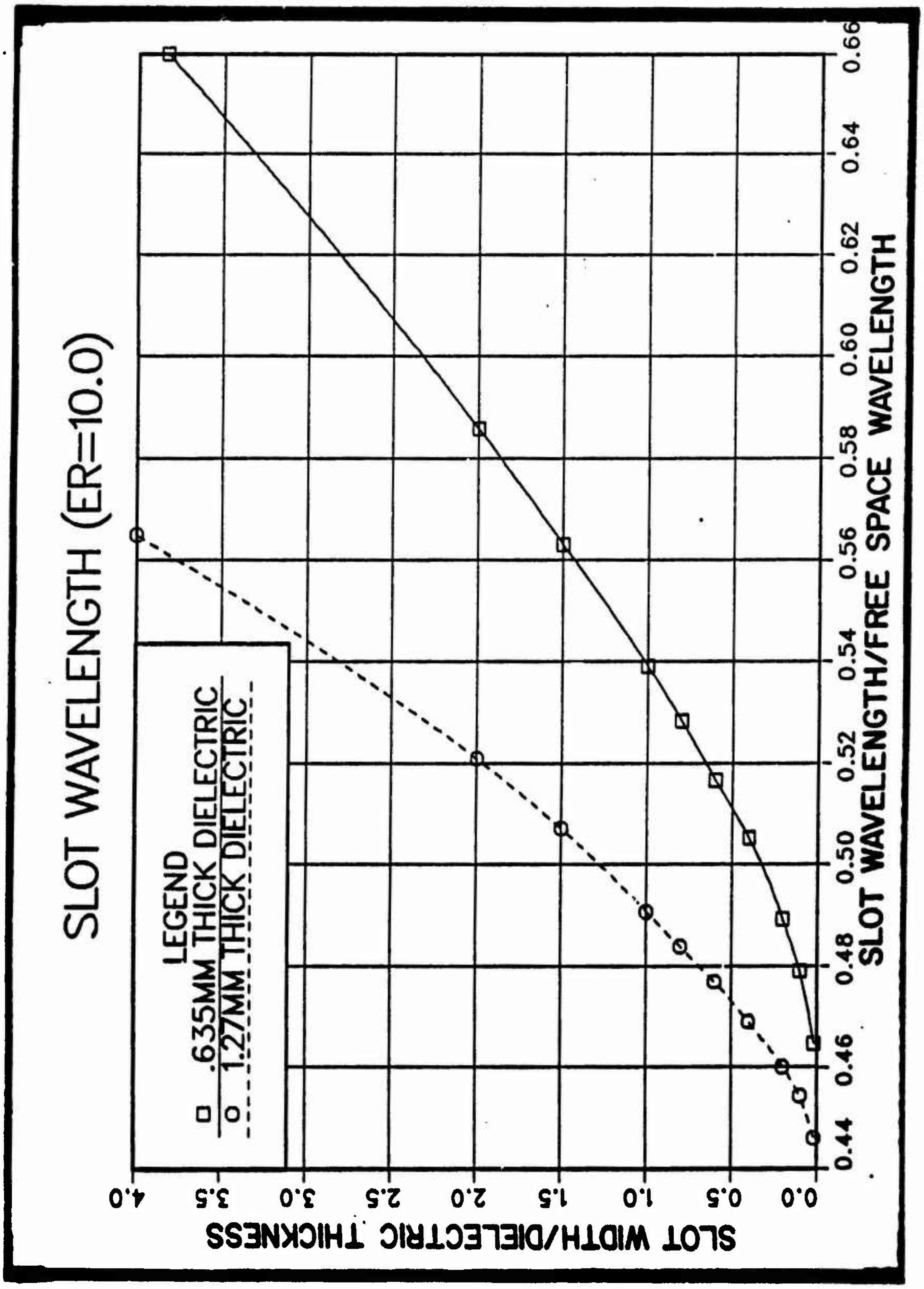


Figure 13 Slotline Wavelength.

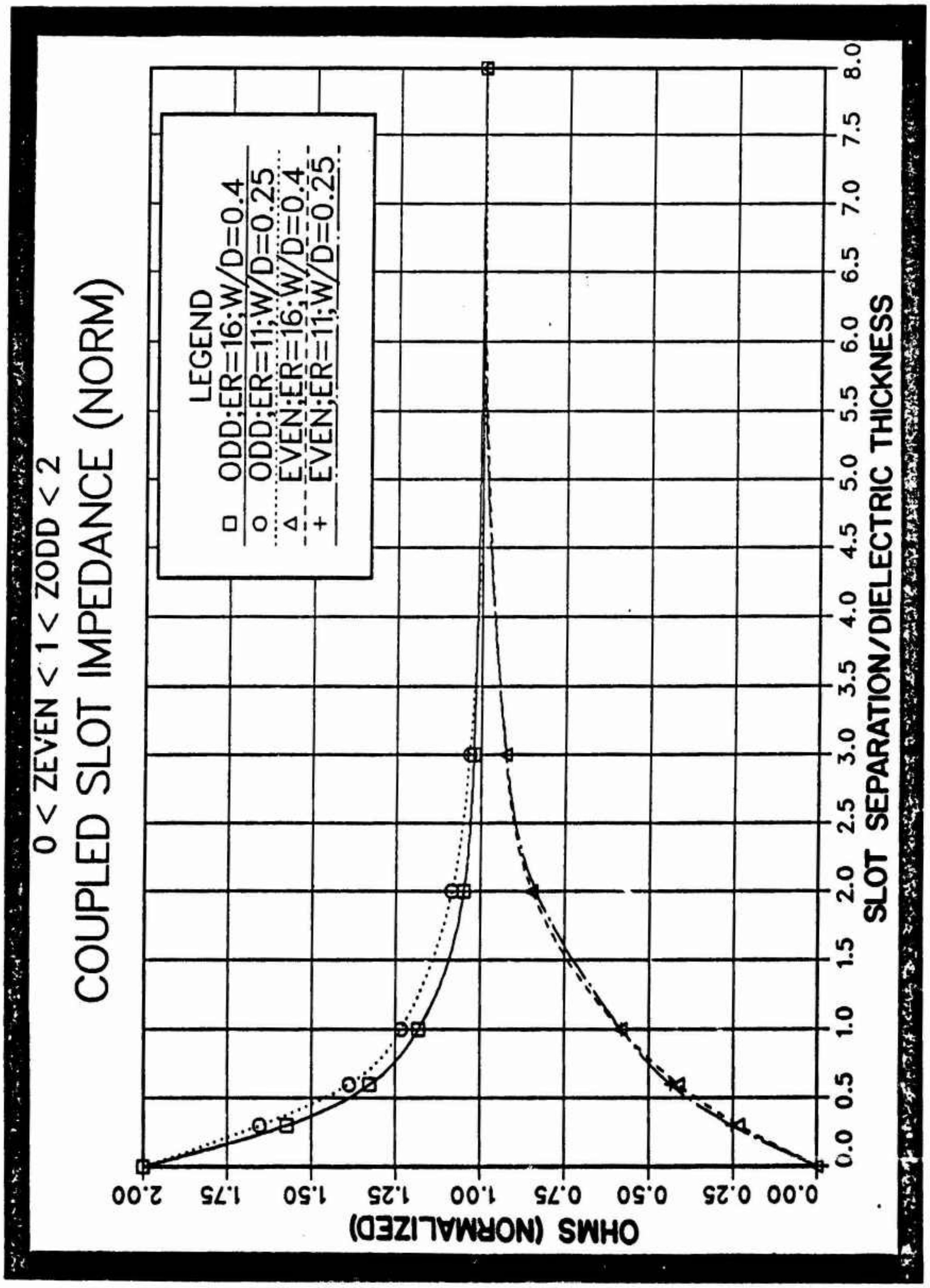


Figure 14 Normalized Coupled Slotline Impedance.

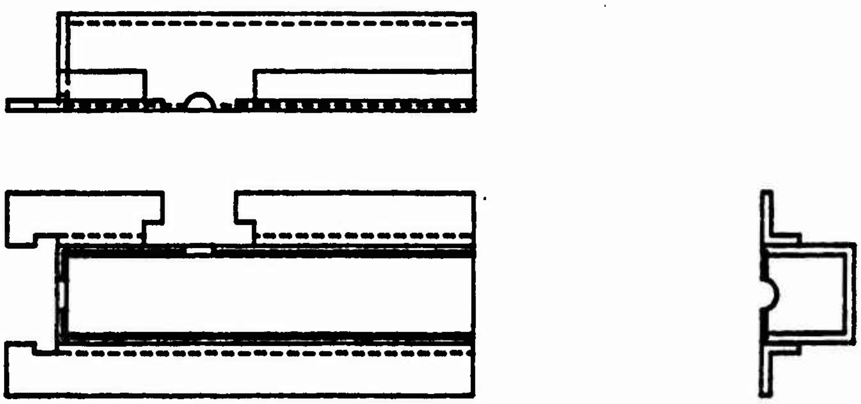


Figure 15 Original Fixture Design.

$$
S = \begin{bmatrix}
.202e^{-j169} & .023e^{-j023} & .462e^{+j004} & .310e^{+j006} \\
.030e^{-j030} & .269e^{-j148} & .314e^{-j178} & .192e^{-j020} \\
.487e^{-j008} & .313e^{-j179} & .132e^{-j001} & .077e^{-j069} \\
.316e^{-j002} & .277e^{+j017} & .052e^{-j042} & .154e^{+j162}
\end{bmatrix}
$$

This data was taken on an HP 8409B Vector Network Analyzer at 10 GHZ.

This matrix is corrected for uneven transmission line lengths caused by launcher placement and fixture design. 10 degrees is added to port-1, 84 degrees is subtracted from port-3 and 22 degrees is added to port-4. The corrections are uniform throughout the matrix.

Figure 16 S-Matrix for Magic-Tee Number Two.

$$S=\begin{bmatrix} .452e^{-j157} & .042e^{+j046} & .473e^{+j005} & .327e^{+j004} \\ .100e^{+j042} & .483e^{-j168} & .282e^{-j173} & .410e^{-j009} \\ .442e^{-j008} & .280e^{-j182} & .435e^{+j024} & .046e^{+j012} \\ .305e^{-j007} & .376e^{+j003} & .040e^{+j011} & .170e^{+j000} \end{bmatrix}$$

This data was taken on an HP 8409B Vector Network Analyzer at 11.4 GHZ.

This matrix is corrected for uneven transmission line lengths caused by launcher placement and fixture design. 106 degrees is added to port-1, 122 degrees is added to port-2 and 180 degrees is added to port-3. The corrections are uniform throughout the matrix.

Figure 17 S-Matrix for Magic-Tee Number Three.

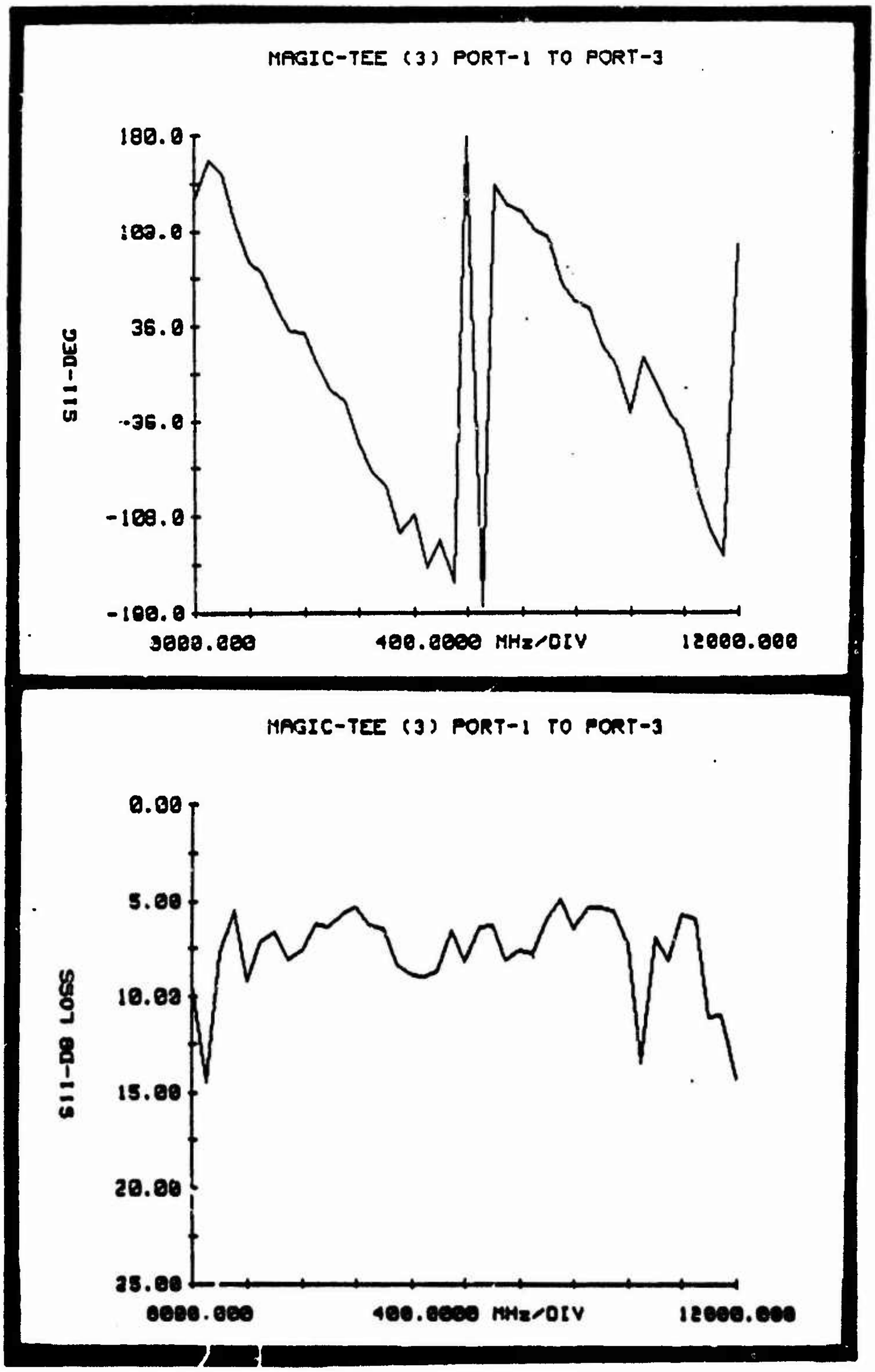


Figure 18 S11 Phase and Magnitude for Magic-Tee Three.

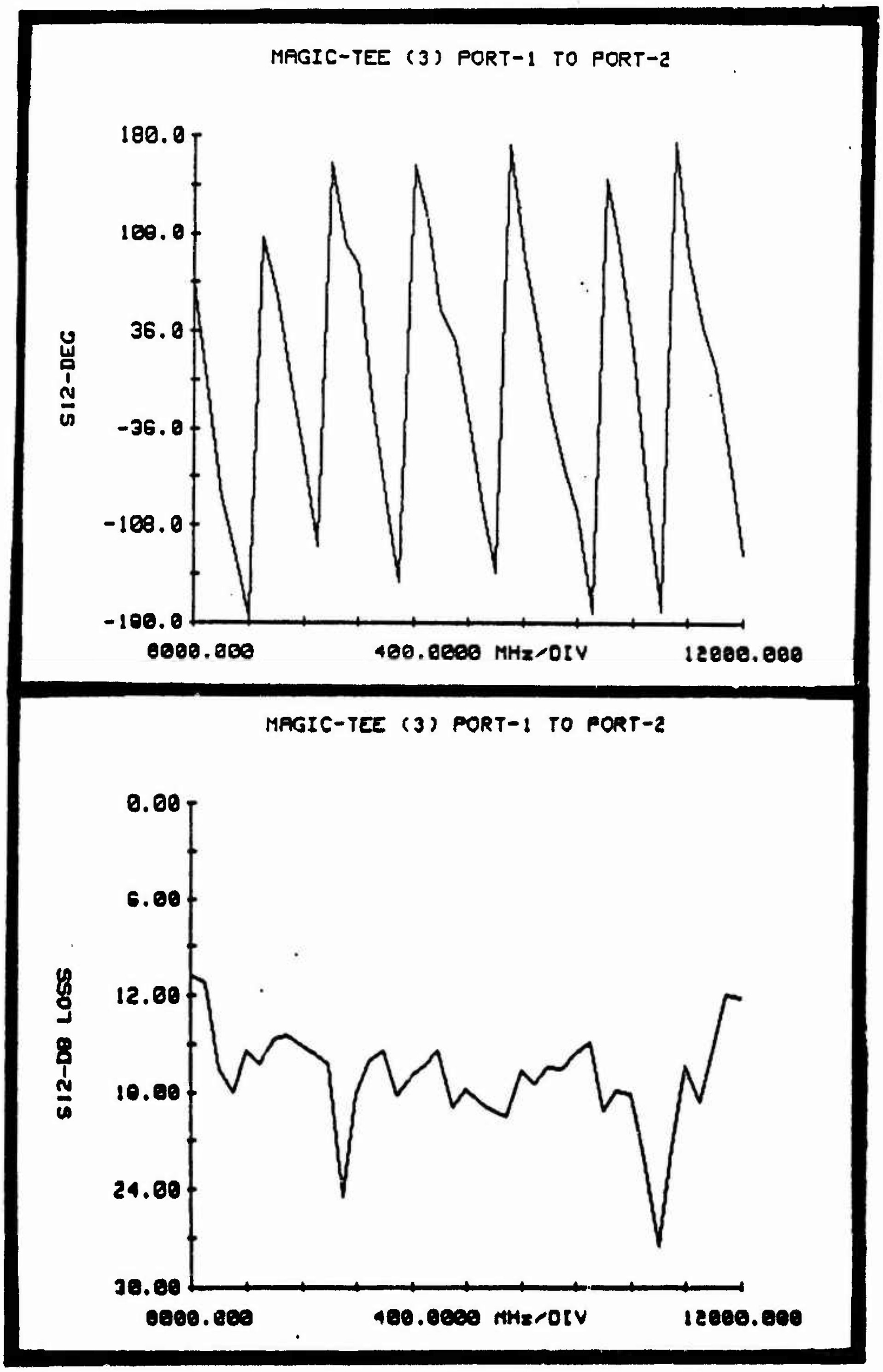


Figure 19 S12 Phase and Magnitude for Magic-Tee Three.

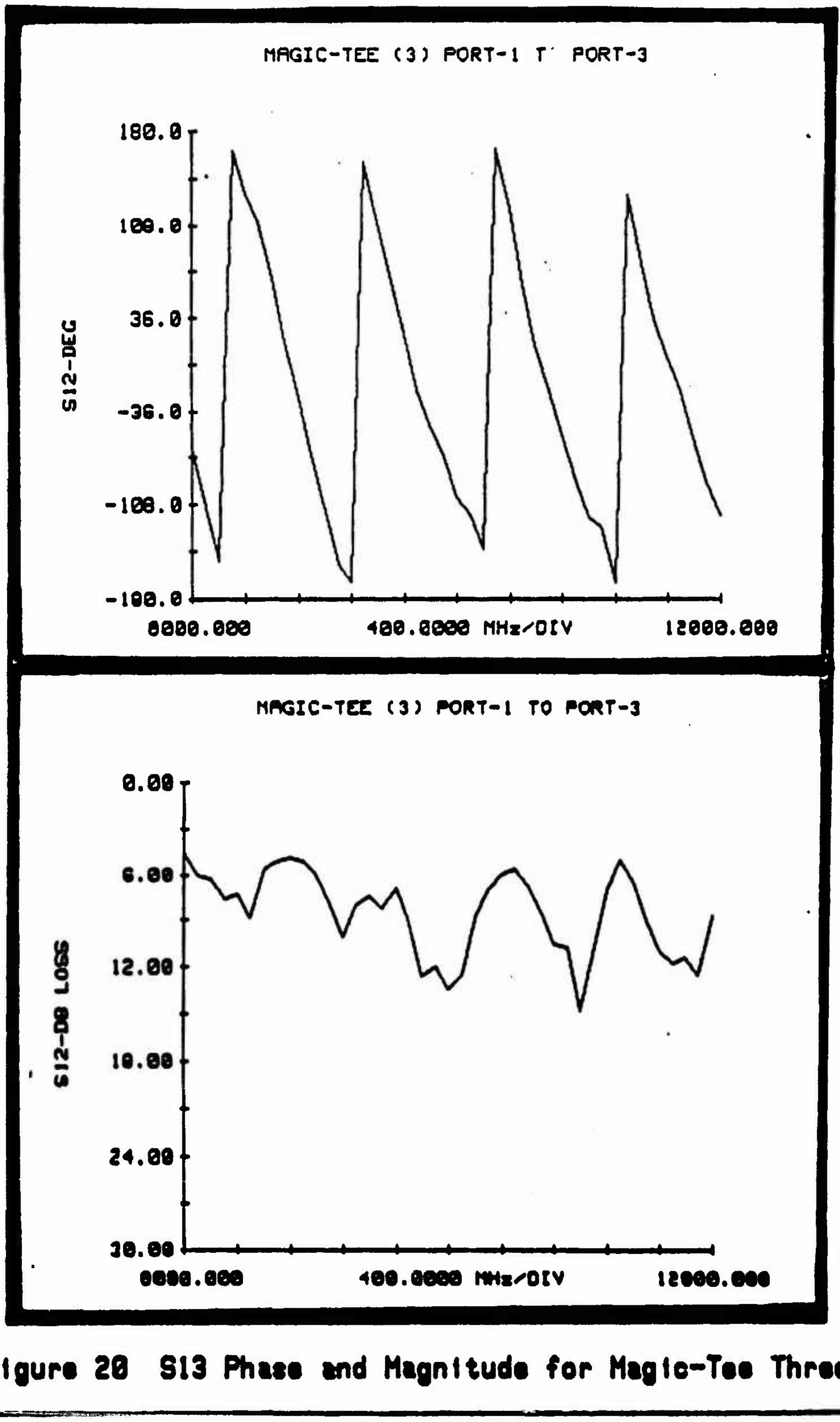


Figure 20 S13 Phase and Magnitude for Magic-Tee Three.

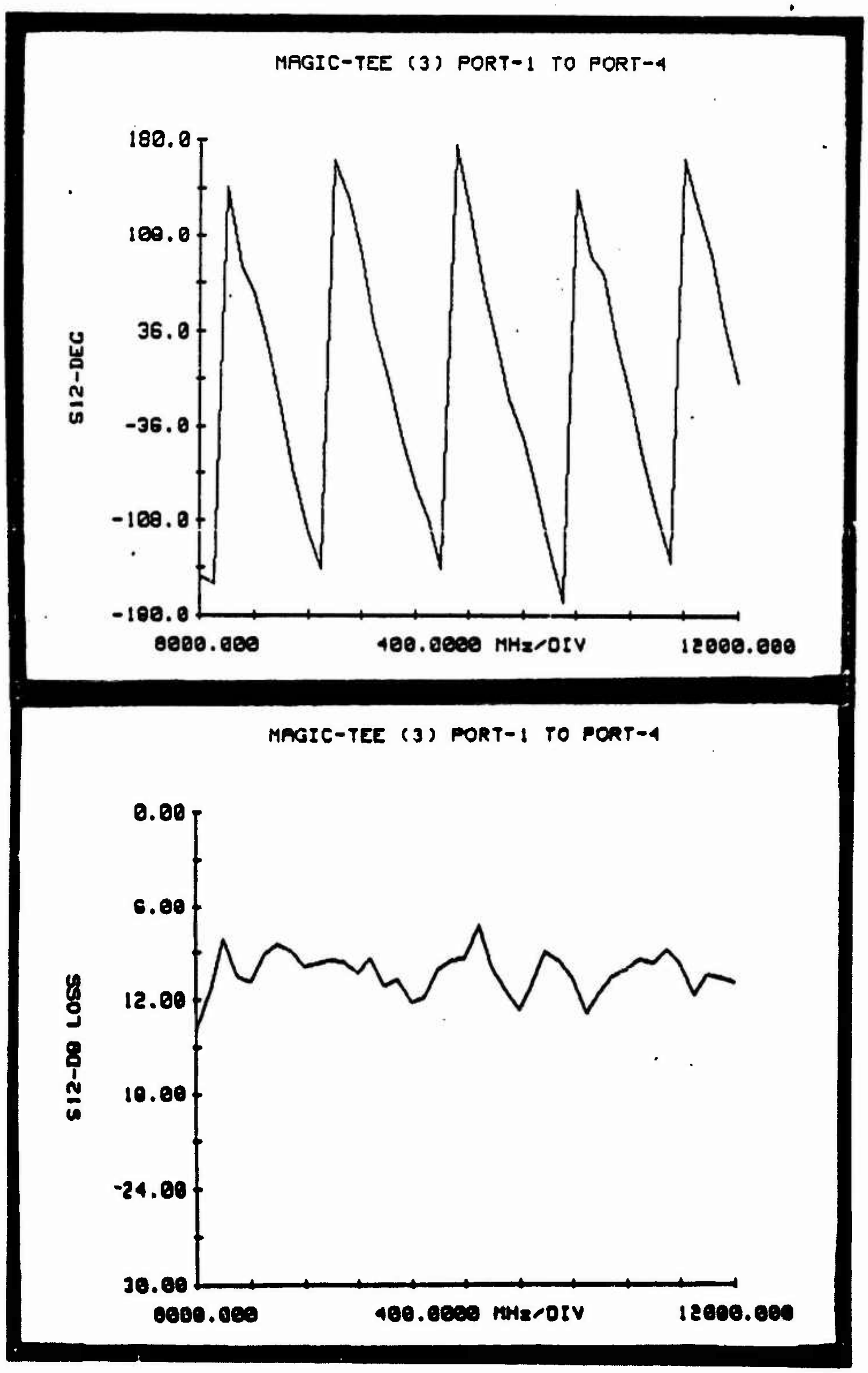


Figure 21 S14 Phase and Magnitude for Magic-Tee Three.

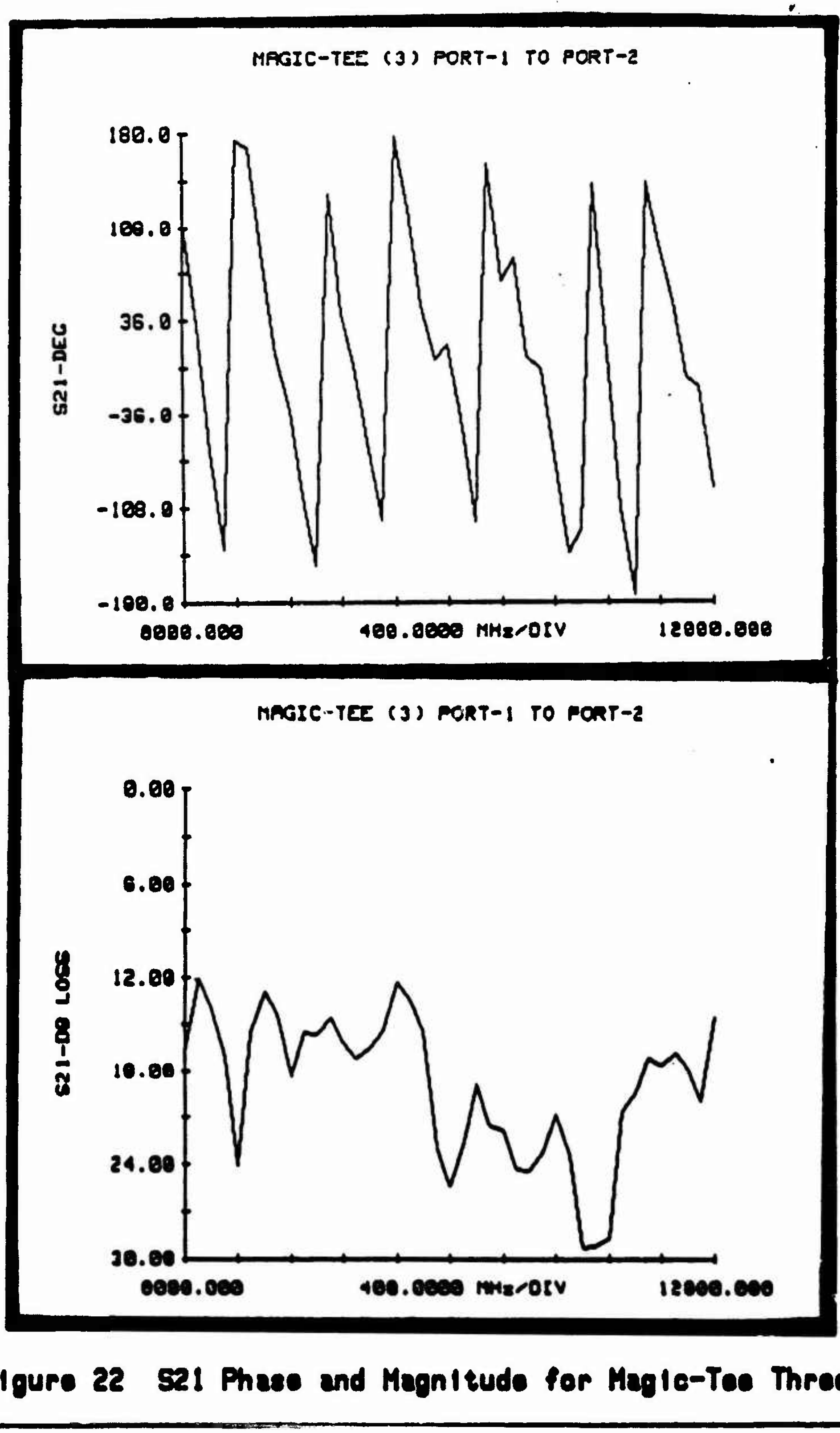


Figure 22 S21 Phase and Magnitude for Magic-Tee Three.

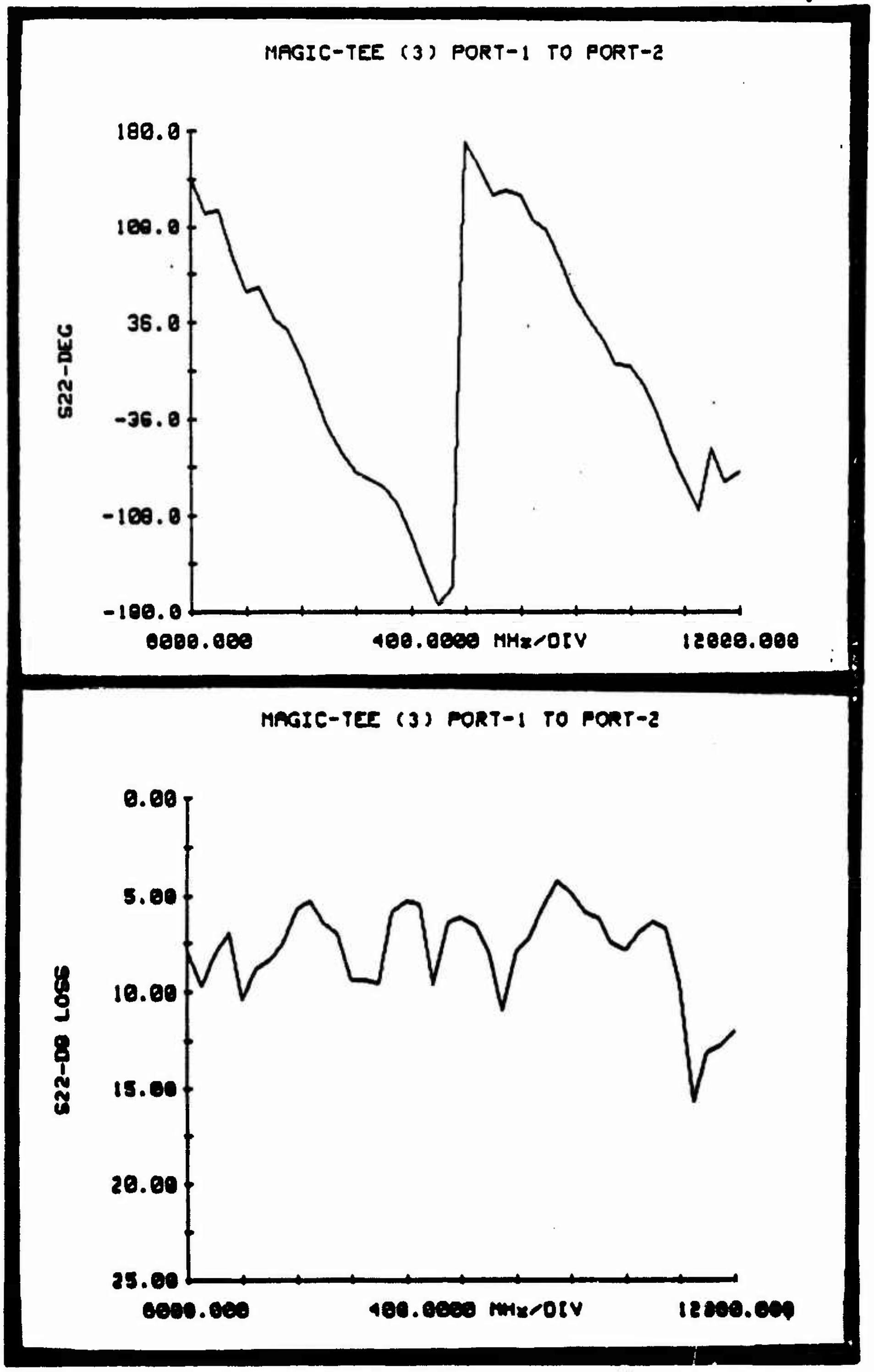


Figure 23 S22 Phase and Magnitude for Magic-Tee Three.

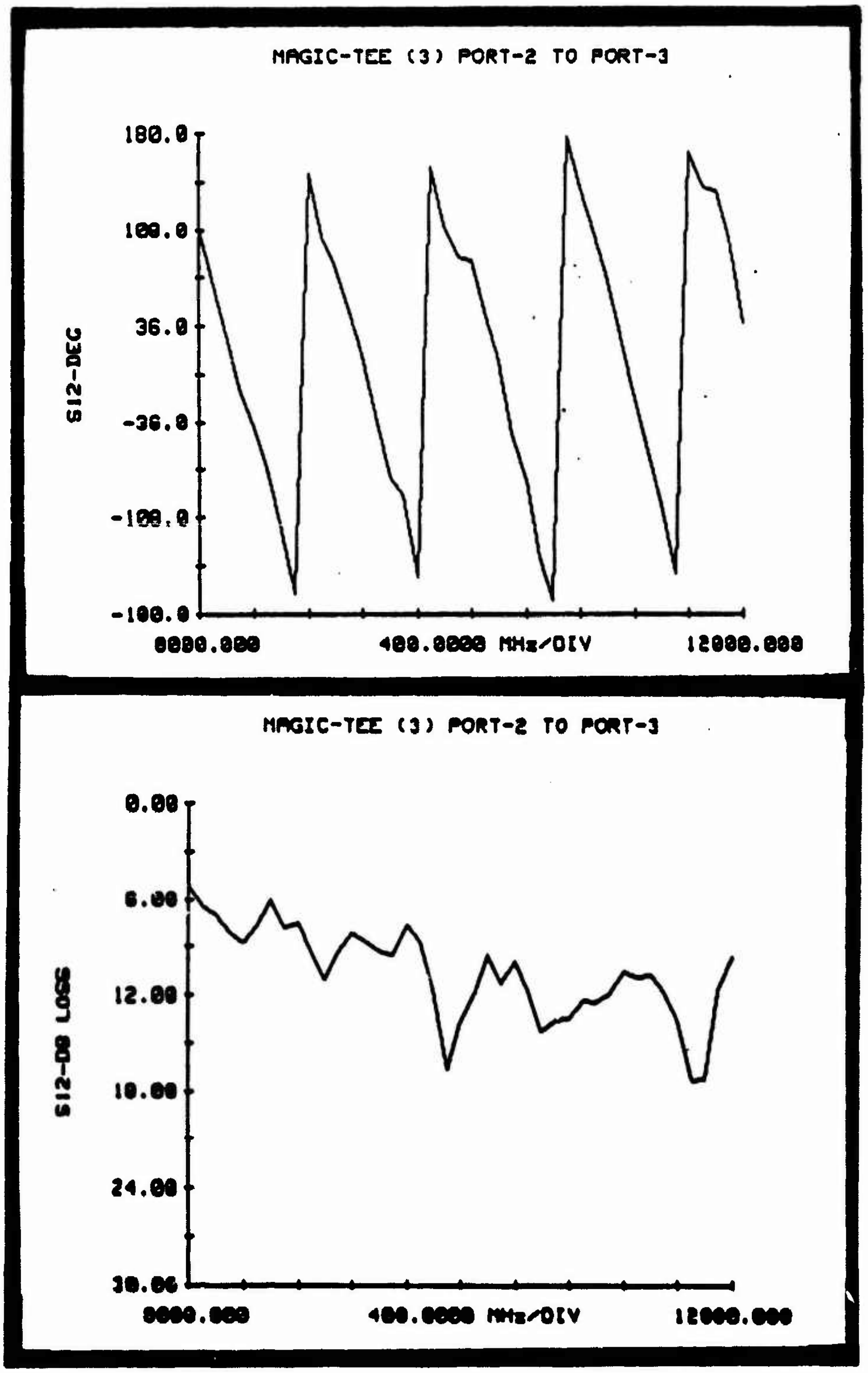


Figure 24 S23 Phase and Magnitude for Magic-Tee Three.

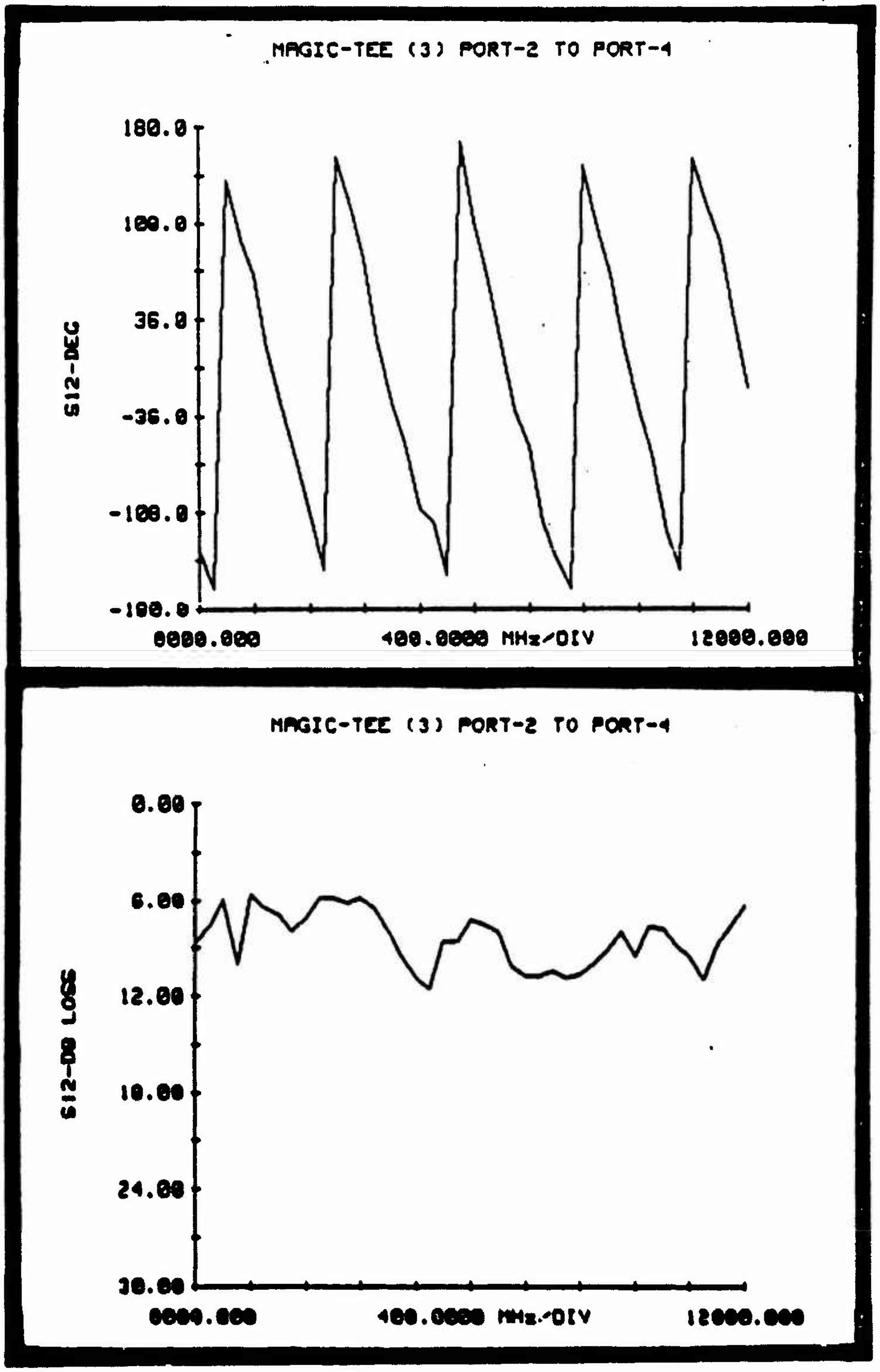


Figure 25 S24 Phase and Magnitude for Magic-Tee Three.

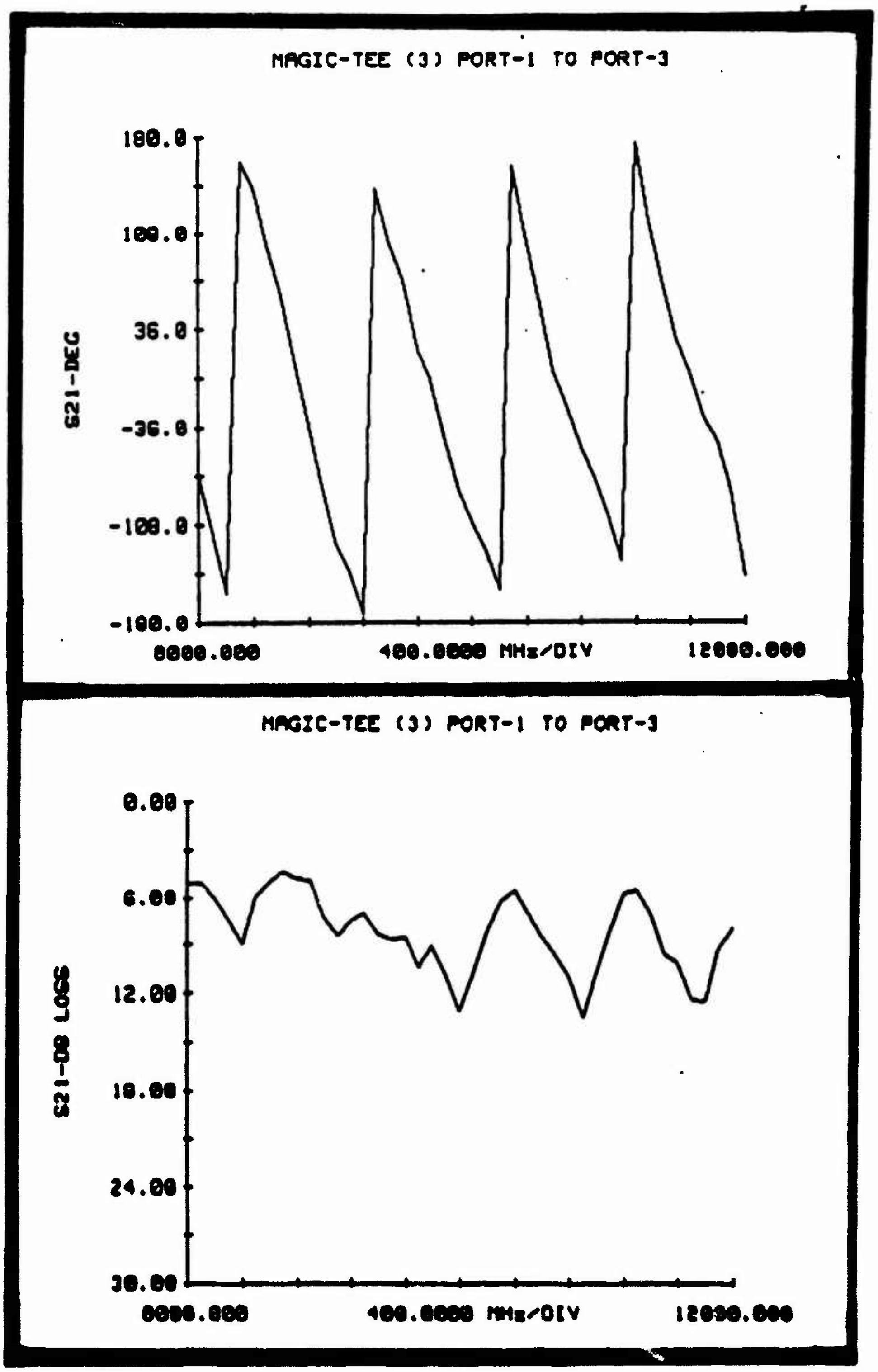


Figure 26 S31 Phase and Magnitude for Magic-Tee Three.

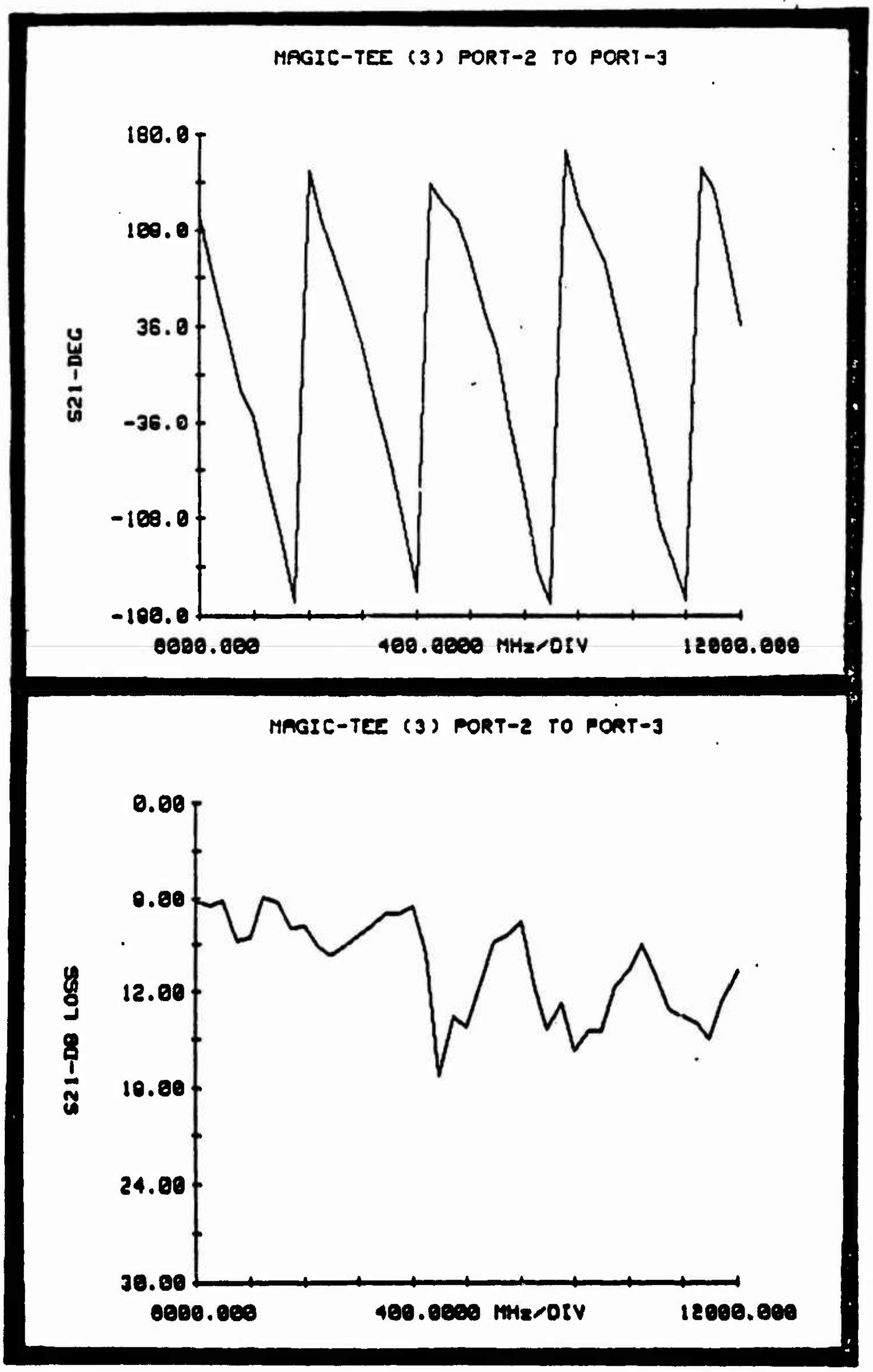


Figure 27 S32 Phase and Magnitude for Magic-Tee Three.

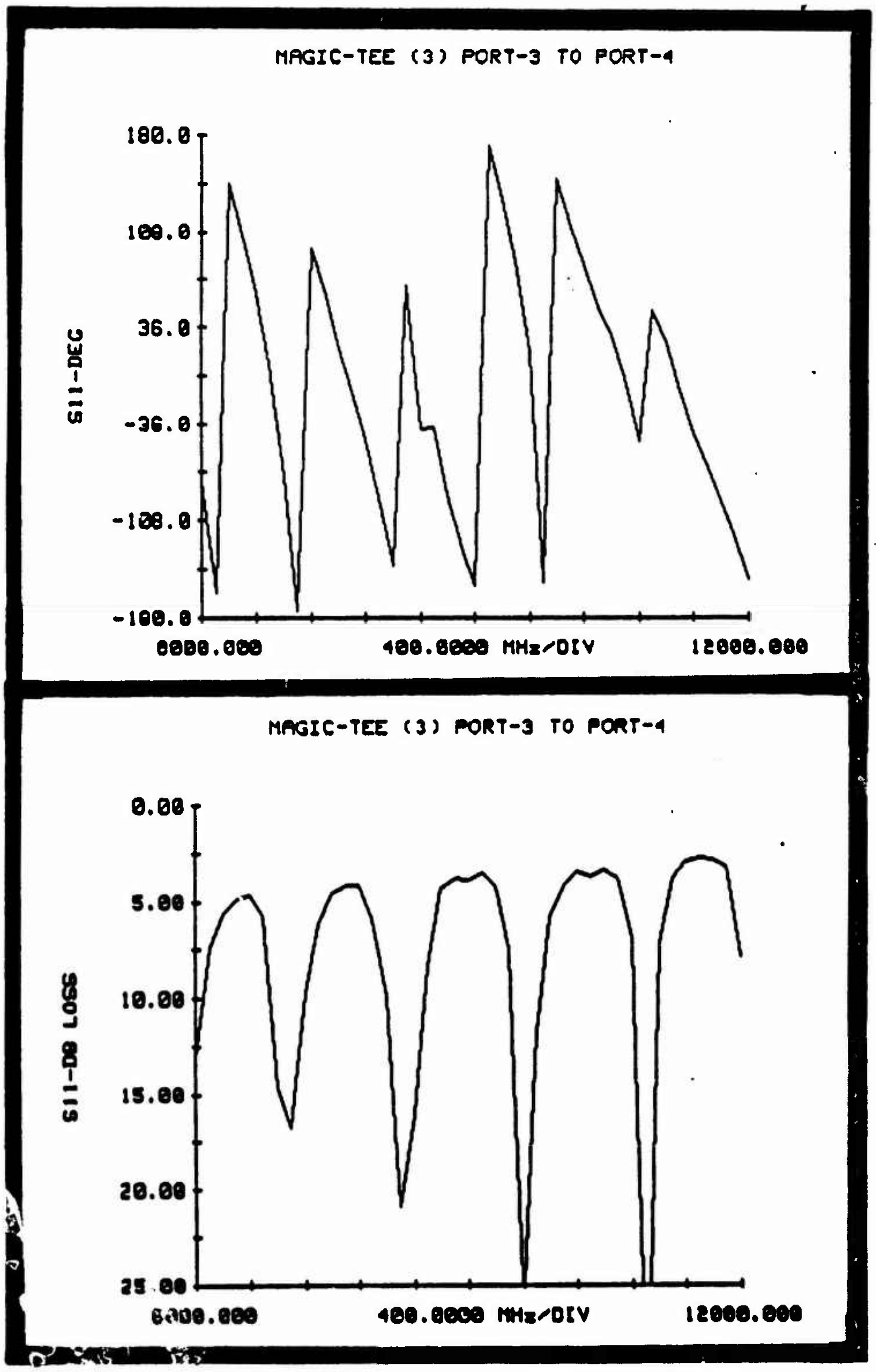


Figure 28 S33 Phase and Magnitude for Magic-Tee Three.

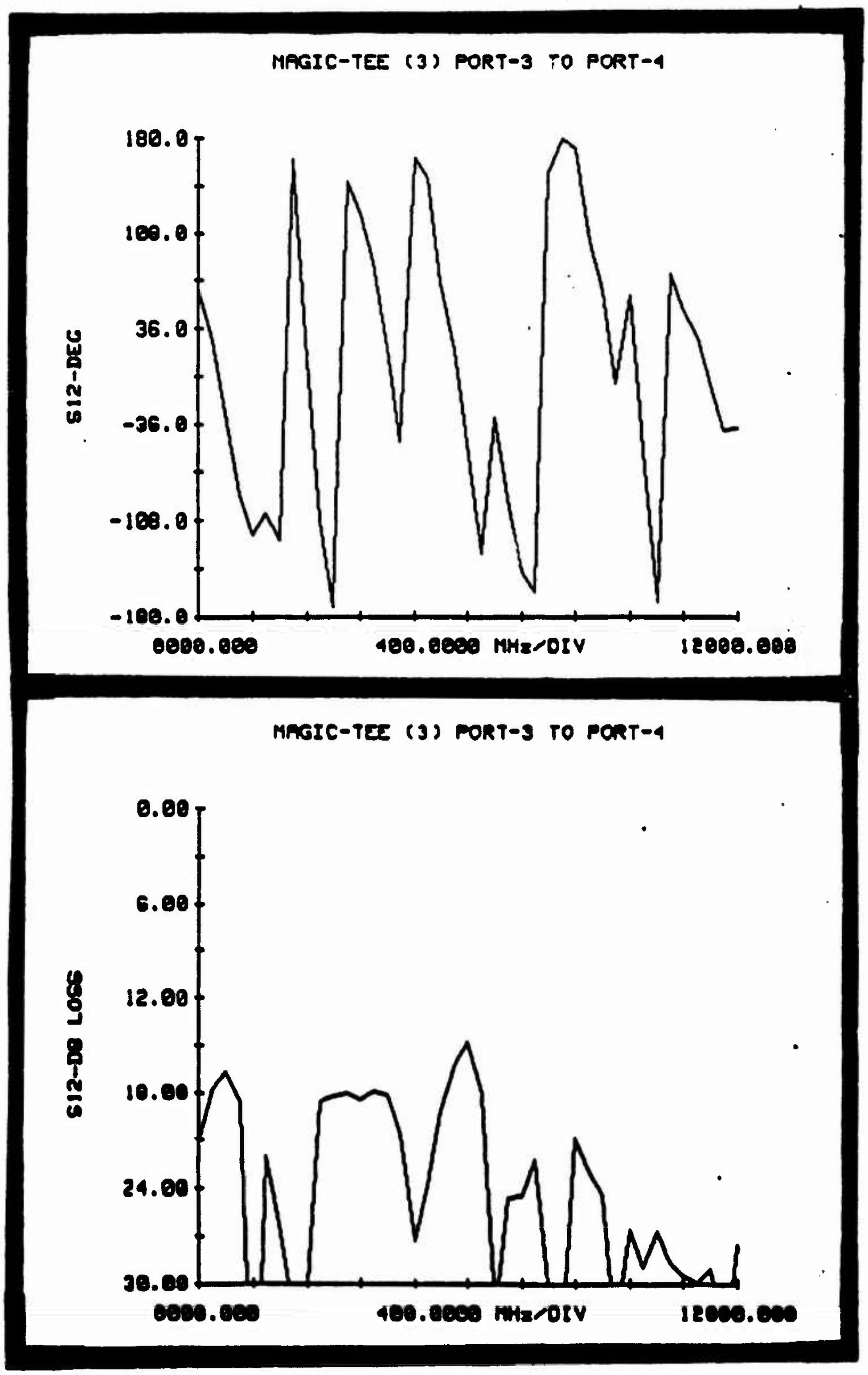


Figure 29 S34 Phase and Magnitude for Magic-Tee Three.

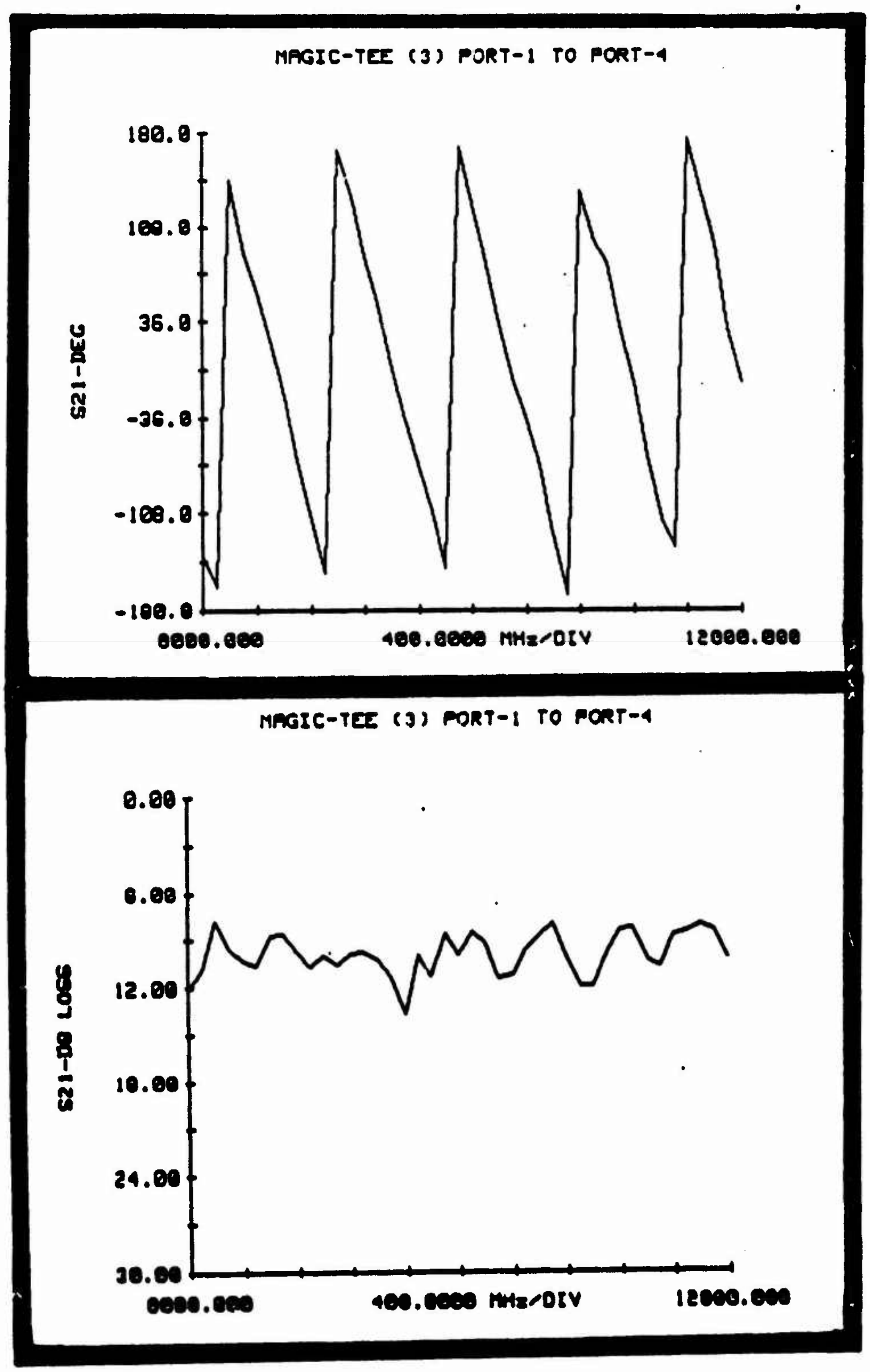


Figure 38 S41 Phase and Magnitude for Magic-Tee Three.

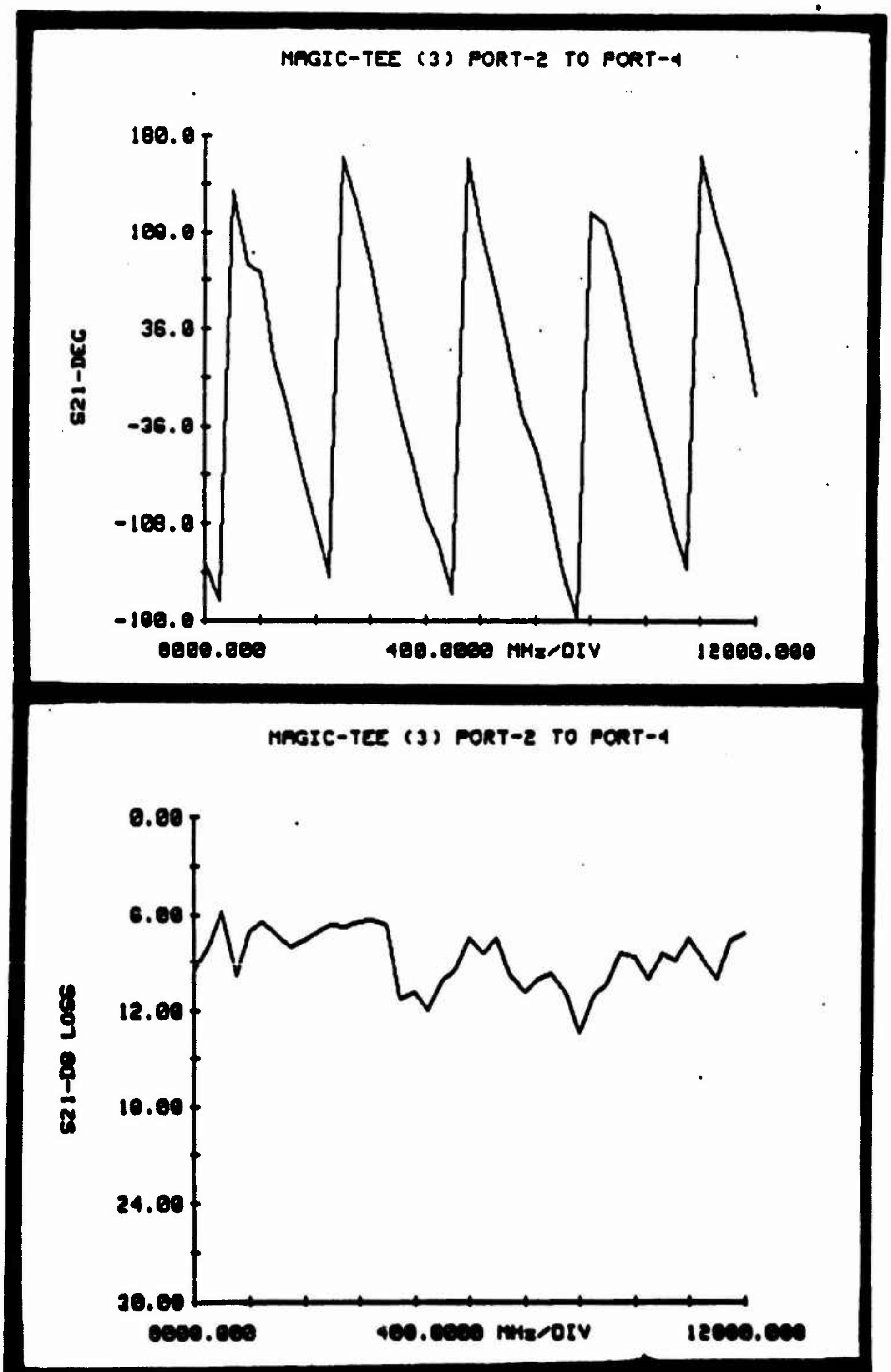


Figure 31 S42 Phase and Magnitude for Magic-Tee Three.

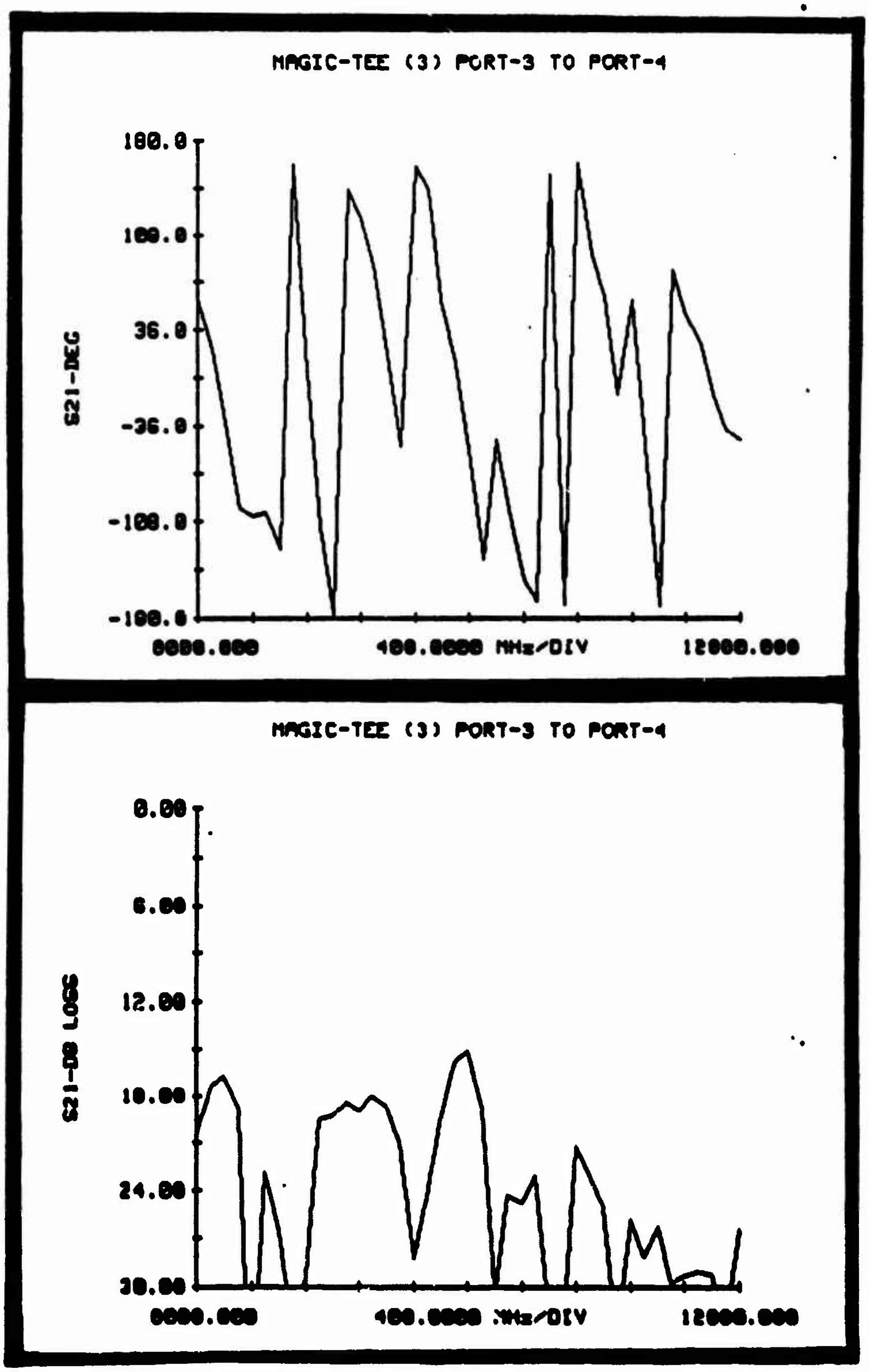


Figure 32 S43 Phase and Magnitude for Magic-Tee Three.

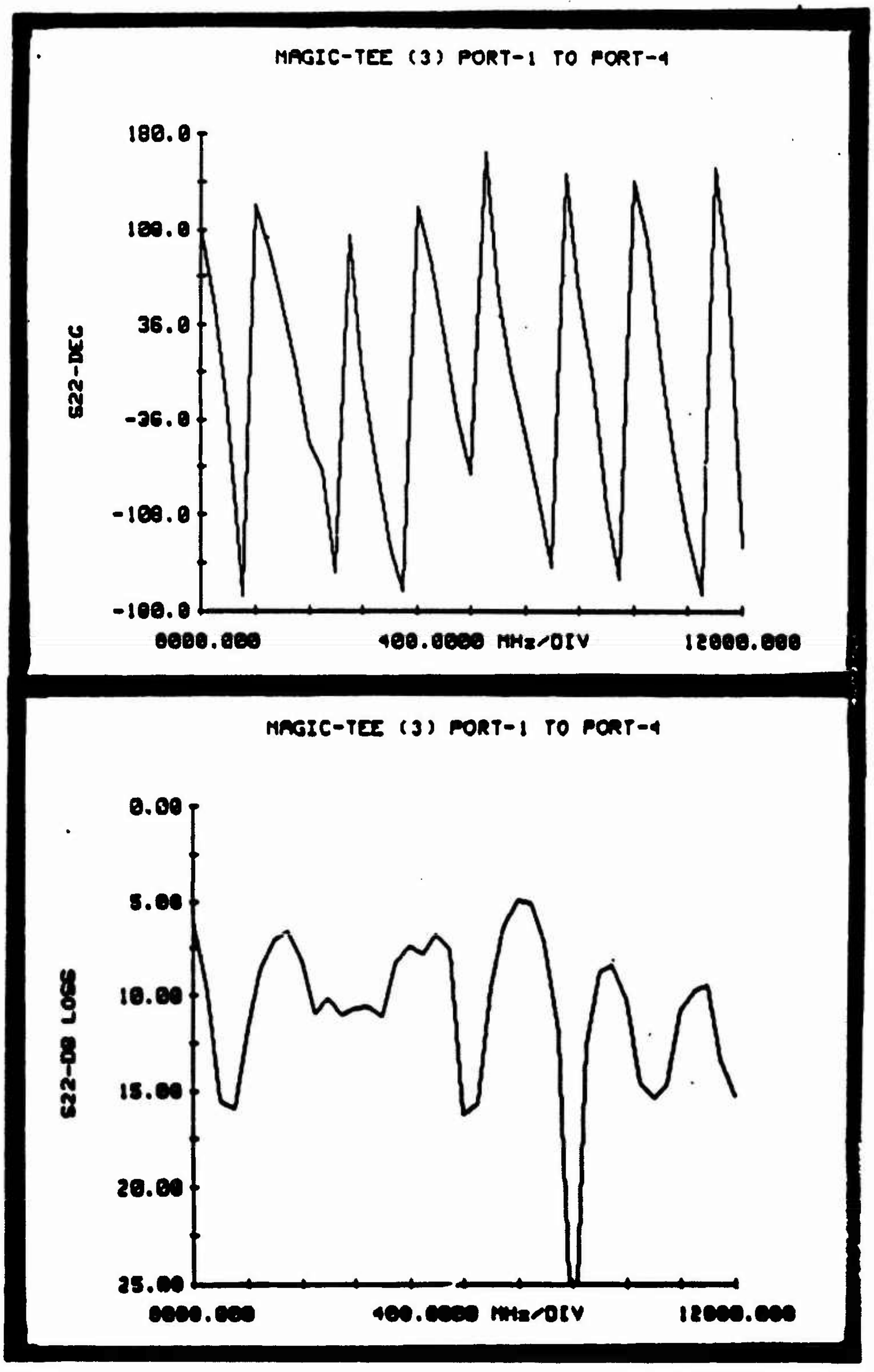


Figure 33 S44 Phase and Magnitude for Magic-Tee Three.

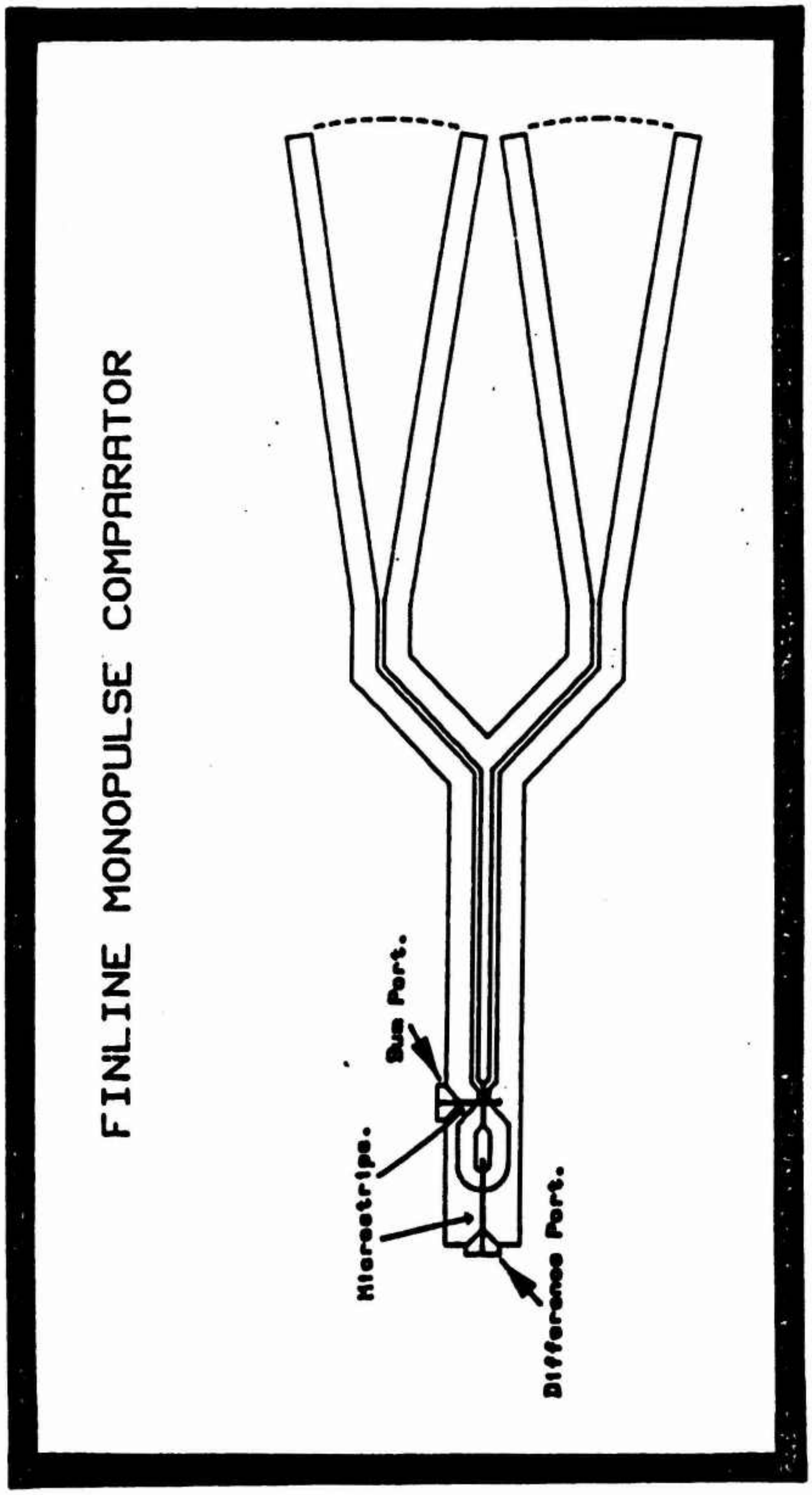


Figure 34 Fin-Line Monopulse System.

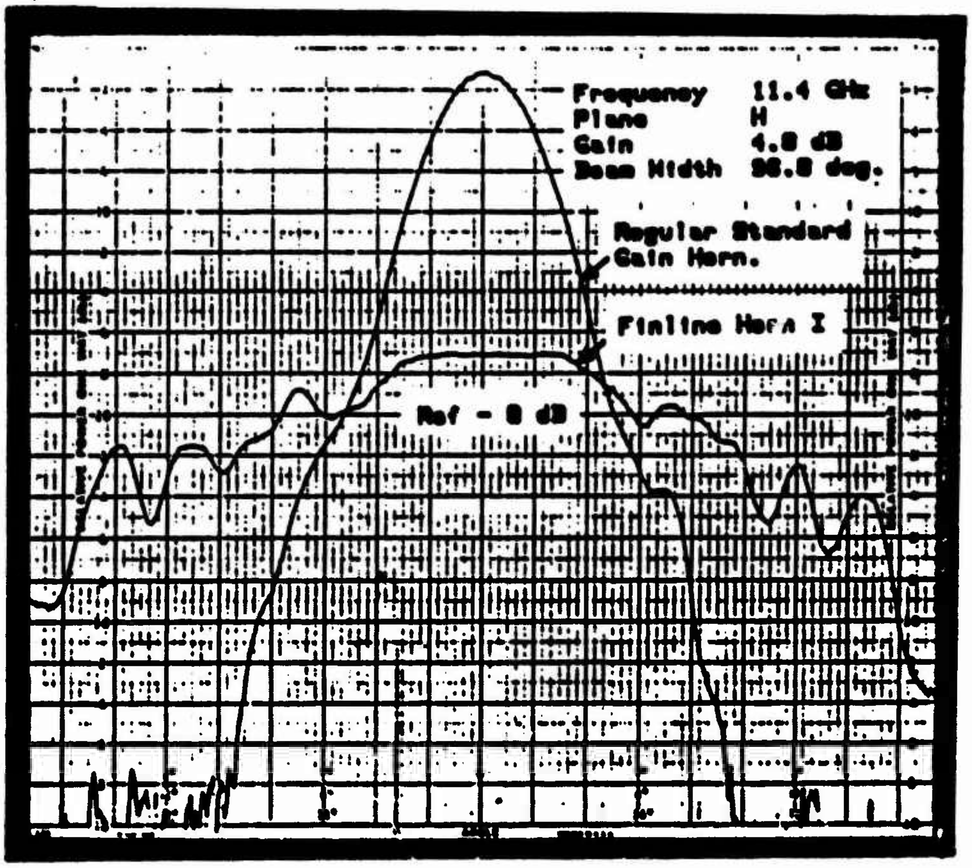


Figure 35 H-Plane Element Pattern.

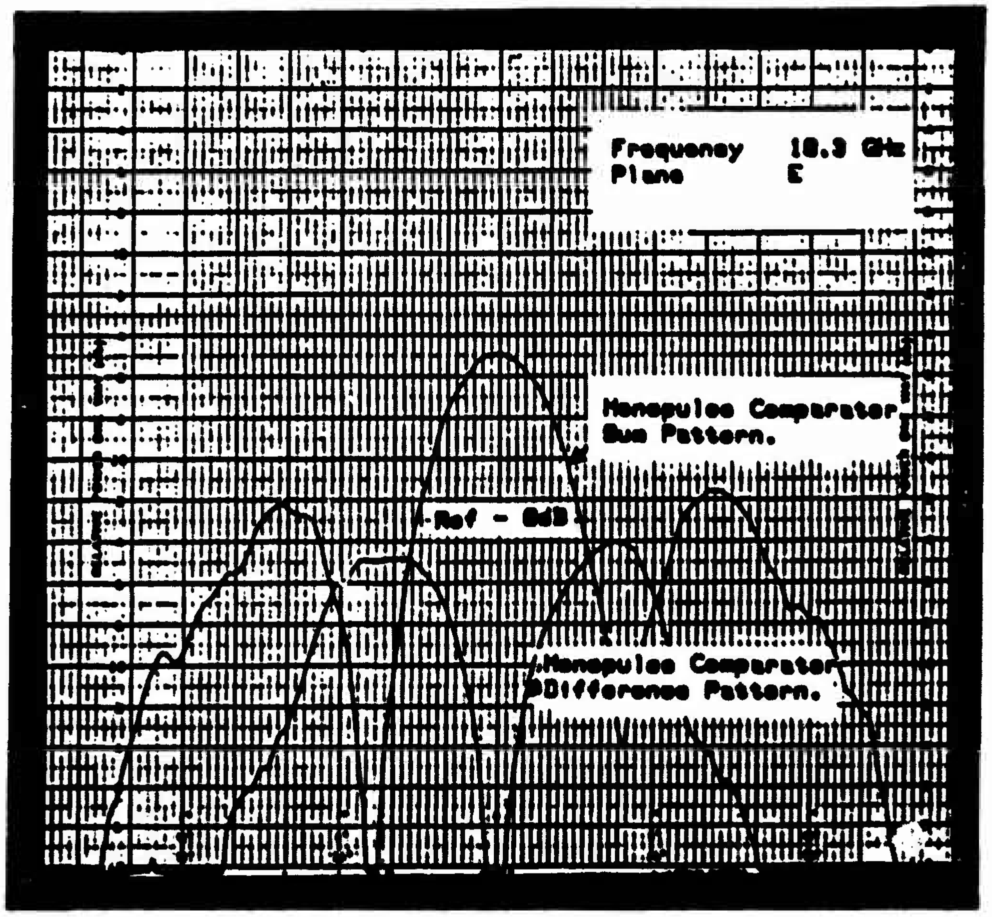


Figure 36 E-Plane System Pattern.

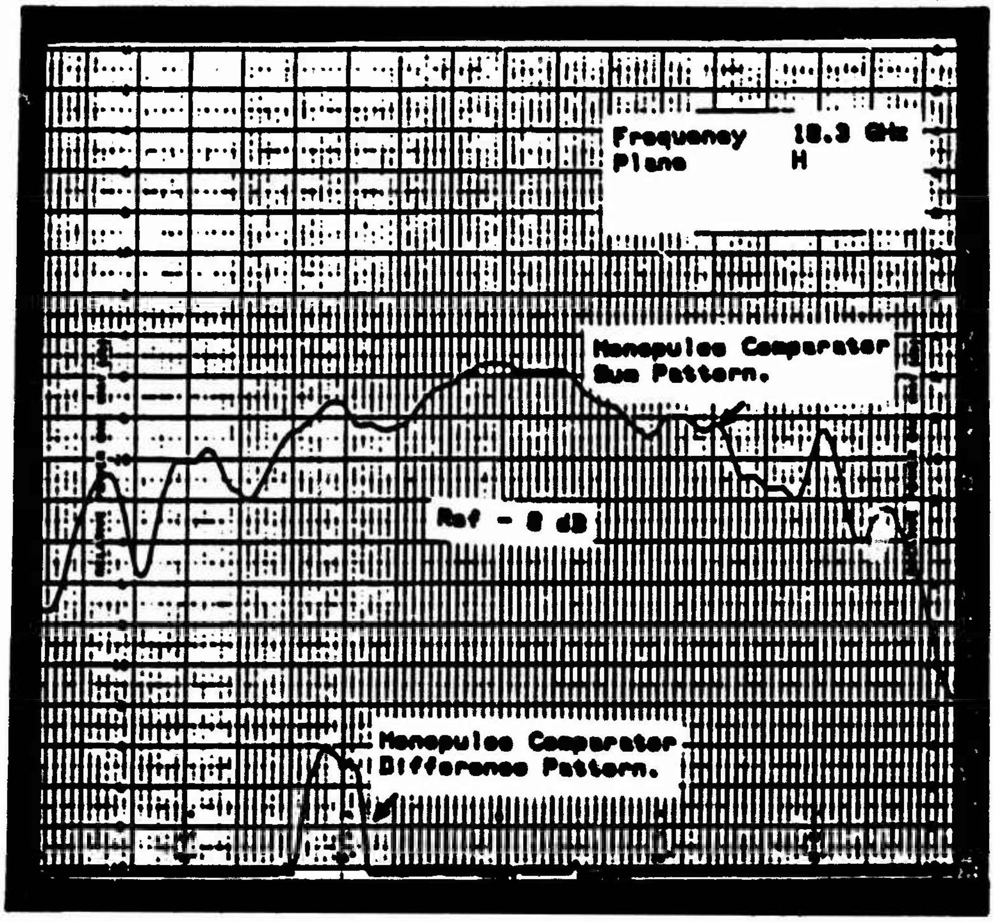


Figure 37 H-Plane System Pattern.

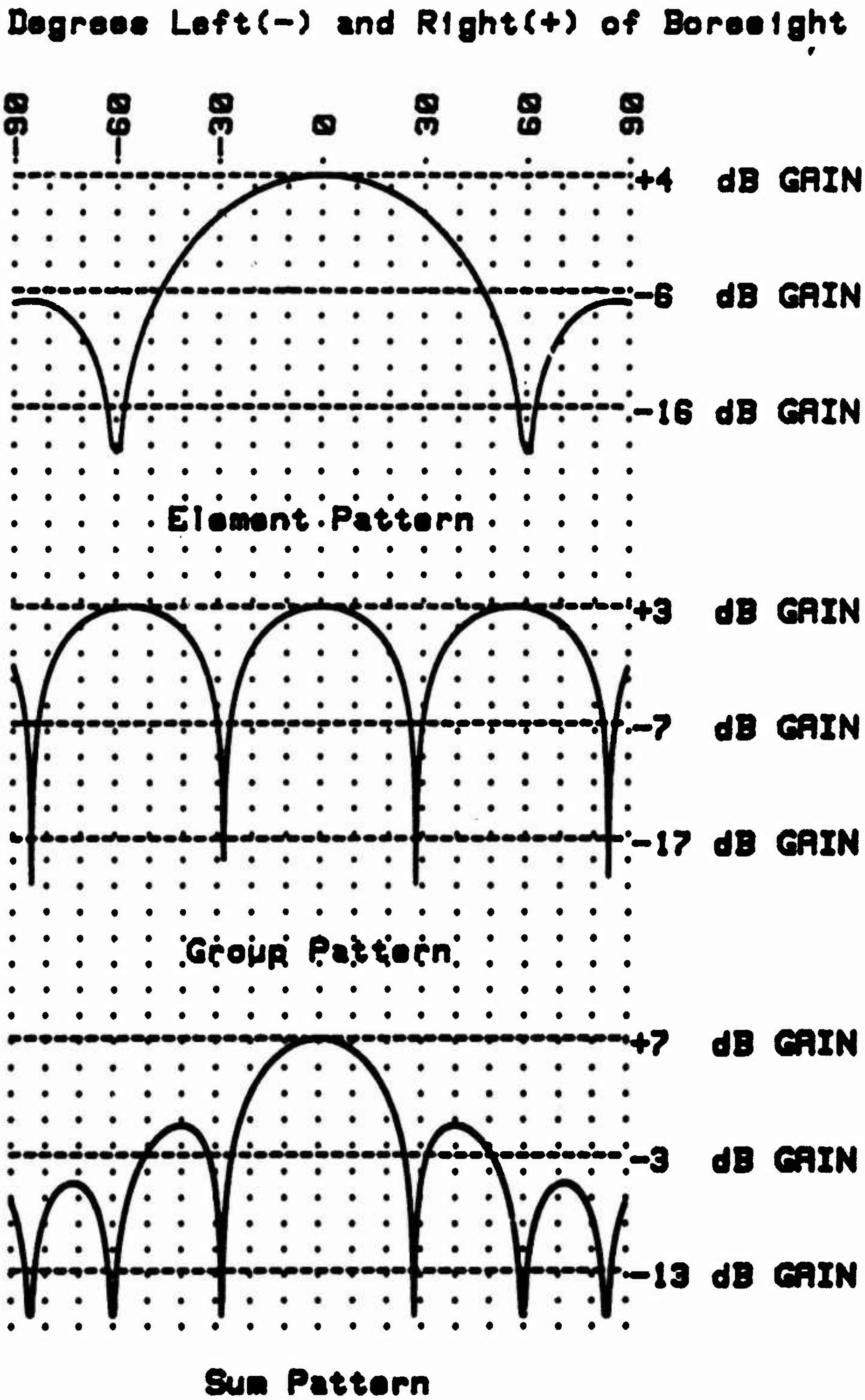


Figure 38 Simulated Sum Pattern.

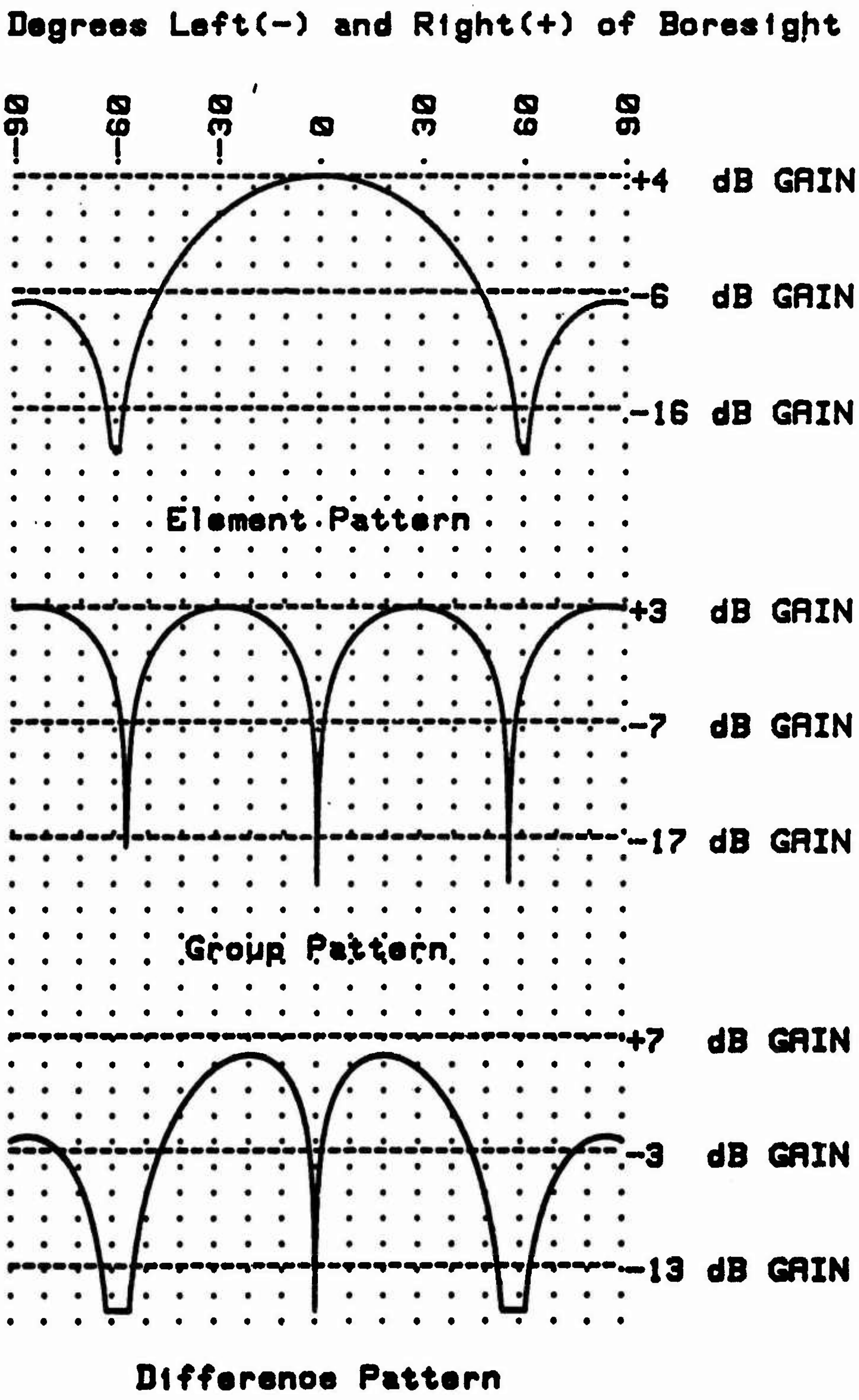


Figure 39 Simulated Difference Pattern.

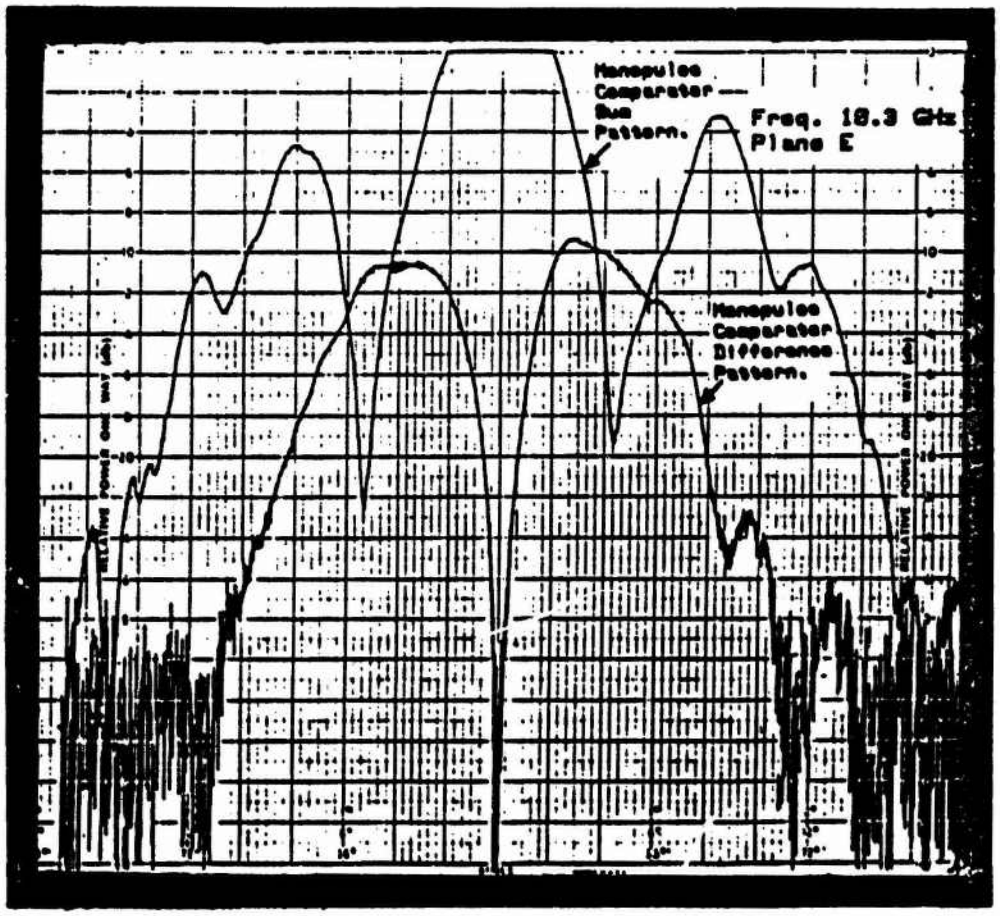


Figure 40 Depth of the Difference Null.

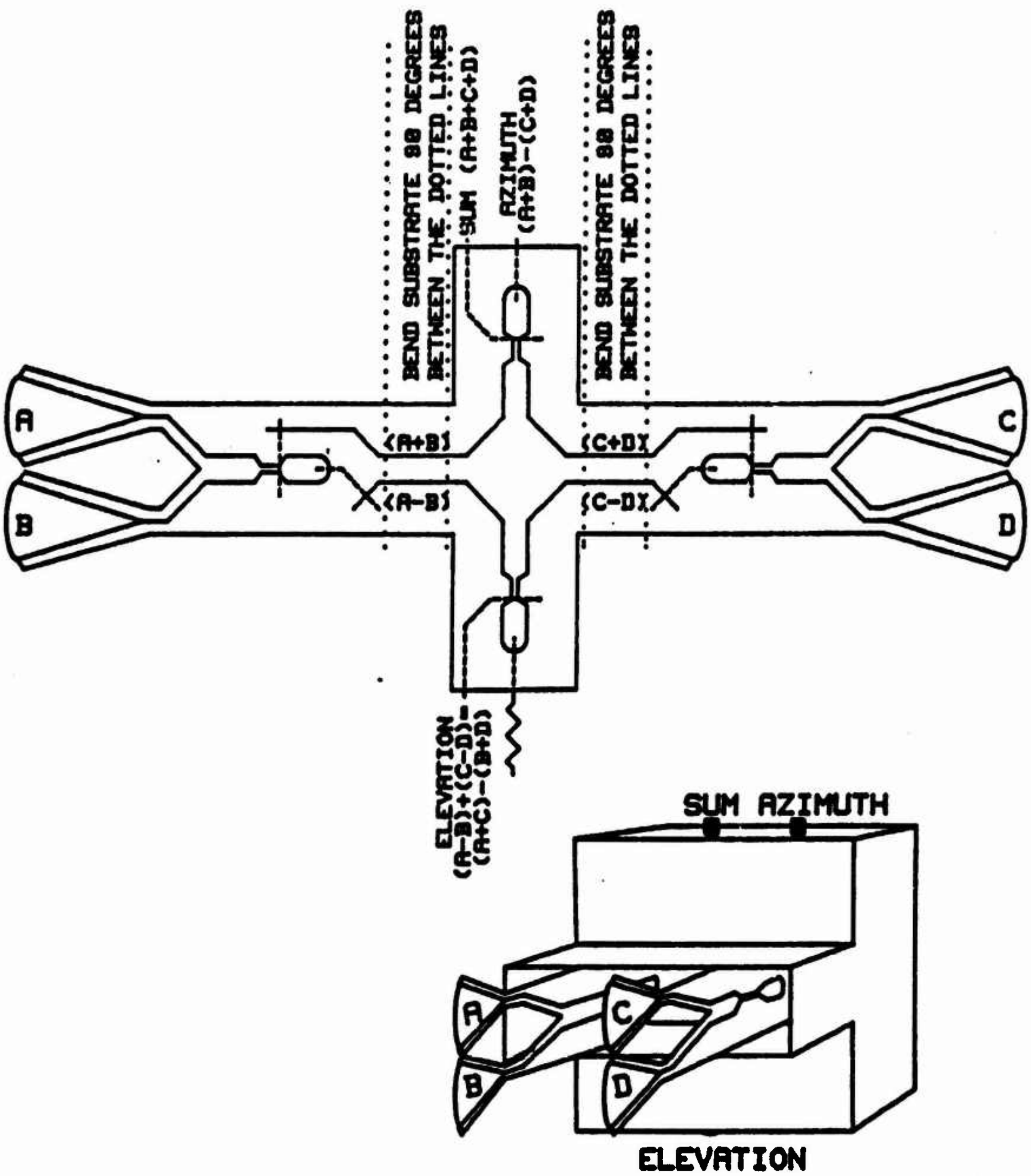


Figure 41 Dual Plane Fin-Line Monopulse System.

LIST OF REFERENCES

1. Avionics Laboratory, Air Force Wright Aeronautical Laboratories Report PB84-108711, Microwave Receivers and Related Components, by J.B. Tsui, 1983.

2. Kefalas, G. P., and Wiltse, J. C., Chap. 8, "Transmission Lines, Components, and Devices," Skolnik, M. I. (Editor-in-Chief), Radar Handbook, McGraw-Hill Book Co., 1970.

3. Syrigos, H., Crossland, D., and Van Wyck, B., "Planar Waveguide Yields MM-Wave Monopulse Comparators," Reprinted from Microwaves & RF, March 1984.

4. Aikawa, M., and Ogawa, H., "A New MIC Magic-T Using Coupled Slot Lines," IEEE Transactions On Microwave Theory And Techniques, Vol. MTT-28, No. 6, June 1980.

5. Haq, M., Finline Horn, M. S. Thesis, Naval Postgraduate School, Monterey, 1985.

6. Gandhi, O. P., Microwave Engineering And Applications, Pergamon Press, 1984.

7. Dunn, J. H., Howard, D. D., and Pendleton, K. B., Chap. 21, "Tracking Radar," Skolnik, M. I. (Editor-in-Chief), Radar Handbook, McGraw-Hill Book Co., 1970.

8. Jordan, E. C., and Balmain, K. G., Electromagnetic Waves and Radiating Systems, Prentice-Hall, Inc., 1968.

9. Shen, L. C., and Kong, J., Applied Electromagnetism, Brooks/Cole Engineering Division, 1983.

10. Gupta, K. C., Garg, R., and Bahl, I. J., Microstrip Lines and S[illegible]tlines, Artech House, Inc., 1979.

11. Sharma, A. [illegible] and Hoefer, W. J. R., "Empirical Expressions for Fin-Line Design," IEEE Transactions On Microwave Theory And Techniques, Vol. MTT-31, No. 4, April 1983.

12. Meier, P. J., "Integrated Fin-Line Millimeter Components," IEEE Transactions On Microwave Theory and Techniques, Vol. MTT-22, No. 12, December 1974.

13. Knorr, J. B., and Kuchler, K., "Analysis of Coupled Slots and Coplanar Strips on Dielectric Substrate," IEEE Transactions On Microwave Theory and Techniques, Vol. MTT-23, No. 7, July 1975.

14. Knorr, J. B., "Slot-Line Transitions," IEEE Transactions On Microwave Theory And Techniques, Vol. MTT-22, No. 5, May 1974.

15. Kuchler, K., Hybrid Mode Analysis of Coplanar Transmission Lines, Ph.D. Thesis, Naval Postgraduate School, Monterey, 1975.

16. Cohn, M., and others, "Slot-Line Characteristics", IEEE Transactions On Microwave Theory And Techniques, Vol. MTT-17, No. 12, December 1969.

17. Saad, T. S., Microwave Engineer's Handbook, Vol. 1, Artech House, Inc., 1971.

18. Bahl, I. J., and Garg, R., "A Designer's Guide To Stripline Circuits," Microwaves, January 1978.

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