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MULTIPLE BEAM ANTENNA SYSTEM

FINAL REPORT

MAY, 1972

Lockheed

MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

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FINAL REPORT

MAY, 1972

PREPARED FOR: NATIONAL AERONAUTICS AND SPACE ADMINSTRATION
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1.0 Introduction

1.1 Scope - This is a final report of the work performed by LMSC under NASA Contract NAS 1-10839 under the cognizance of Langley Research Center, Hampton, Virginia 23365.

The general objectives of this study were to extend earlier work by LMSC to develop directive multibeam reflector antennas for synchronous communication satellites.

The specific tasks were:

(1) Analyze patterns for domestic coverage of
   (a) The four continental United States time zones
   (b) A single beam for the continental United States
   (c) Alaska
   (d) Hawaii
   (e) Caribbean Territories.
(2) Develop Conceptual Designs from the Analyses in (1) above.
(3) Design Feeds and Feed Systems to satisfy the requirements.
(4) Fabricate and test the feeds and the feed distribution system
(5) Measure patterns of these feeds in a parabaloidal reflector.

This study was started in June 1971, originally scheduled for completion in May 1972, and as a consequence of a technical re-direction, actually completed in July 1972.

1.2 Summary - Using a computer program which plots beams from antennas located on synchronous satellites onto the earth's surface, several circular and elliptical reflectors were analyzed for pattern coverage. The reflectors considered were:

(1) 9.9 ft. diameter circular paraboloic
(2) 9.9 ft. by 5.8 ft. diameter elliptical reflector
(3) 9.9 ft. by 14 ft. diameter elliptical reflector
(4) 20 ft. diameter circular paraboloid
(5) 30 ft. diameter circular paraboloid
(6) Multiple 20 ft. and 30 ft. diameter circular paraboloids.

An analysis was performed at a frequency of 4 GHz for these candidate systems using the Kepner-Tregoe Associates (KTA) method of decision making. A final ranking showed the 9.9 ft. by 5.8 ft. diameter elliptical reflector to be the most promising candidate for the measurement portion of the study; the 9.9 ft. by 14 ft. diameter elliptical reflector a close second and next, the 30 ft. diameter circular paraboloid. A test program was set up whereby one reflector could be used to evaluate the two most promising candidate systems.

In late November 1971, LMSC was directed to evaluate the 30-foot reflector approach and to synthesize experimentally the U. S. Eastern Time Zone beam. While LMSC's original choice of the smaller reflector had been based on an "operational" compromise among such factors as coverage performance, weight and complexity, the re-direction was based on the belief that the potentially superior coverage performance obtainable with the 30-foot system made it a more appropriate candidate for study in tne program.

Thus, a 12 foot diameter paraboloid with 8 feeds was tested at 10 GHz (a 2/5 scale of a 4 GHz 30 foot reflector). A special dielectrically loaded feed was developed to achieve the proper spatial positioning of the feeds. Secondary patterns were measured of the composite feed system with each feed having equal phase and amplitude. Pattern contours were made from the patterns and were overlaid onto the Eastern Time Zone.

2.0 CONCEPTUAL DESIGN

2.1 Coverage Analysis - An existing LMSC computer program was updated to include the ability to sum individual antenna beams and form a composite beam on the earth's surface from a synchronous satellite. The program uses an analytical expression for the far field pattern which is given by:

$$E = K1 \ \Lambda_1 (\psi) + K2 \ \Lambda_2 (\psi)$$

where K1 and K2 are constants

$\psi = (\pi D/\lambda) \ \mathrm{Sin}\ \theta$

D = aperture diameter

λ = Wavelength

θ = polar angle

and the function (Λ) Lambda is defined as

$$\Lambda_p = \frac{2^p (p!) Jp(\psi)}{\psi^p}$$

where Jp (ψ) is a Bessel function of the first kind and order p

In addition to inputting the pattern parameters, the program also requires the following inputs:

(a) Satellite Location (Longitude)

(b) Reflector aim point (Latitude and Longitude)

(c) Earth area to be plotted
(latitude maximum and minimum)
(longtitude maximum and minimum)

(d) Number of pattern contours to be plotted

(e) db levels of pattern contours

The computer plots the intersections of cones (corresponding to constant dB levels on an antenna pattern) with the spherical earth and then over-plots the geographical boundaries. Where the horizon falls within the portion of the earth displayed on each plot, the horizon is also plotted.

2.2 Satellite Location

The program was first utilized to evaluate several satellite locations to select that position which would provide the optimmm coverage to all the geographical areas required. To do this, the reflector diameter was set to

10 ft. and the operating frequency to 9 GHz. Figure 1 through 5 show the contiguous 48 states as viewed from five satellite positions from west to east.

The north-south line appearing on Fig. 1 and Fig. 5 is the horizon line. Fig. 1 shows that the Caribbean area, the Eastern time zone and part of the Central time zone cannot be covered from a satellite position of 170°W. Thus, the 170°W satellite station cannot be used for the intended application. Fig. 1 does indicate, however, that the desired eastern coverage could be obtained from satellite positions 30 degrees eastward of the 170° position --- that is, at 140°W longtitude.

Fig. 5 indicates that Alaska, Hawaii and the Pacific time zone cannot be covered from the eastern most satellite position. The major Hawaiian Islands lie eastward of 160°W and could be covered by satellite position 40 degrees west of 40°W -- that is, at 80°W. This can be confirmed by Fig. 6 which shows the principal islands just on or beyond the horizon for a satellite position at 75°W. Including all the lesser islands of the Hawaiian group (out to Midway and Kure) would require another 20° westward shift, placing the satellite position at 100°W.

The Alaskan problem is illustrated in Fig. 7 and 8. Fig. 7 indicates that Alaskan coverage could not be obtained by a satellite position of 75°W. At least 30° westward shift of the satellite would be required to cover Alaska. Fig. 8 indicates the effect of a 19° westward shift. Thus, Alaska (except for some of the Aleutian islands) could be covered by a satellite position west of about 105°W.

Thus, at this point the following conclusions were reached:

1. The satellite position of 94°W provides good coverage of the contiguous 48 states, the major and many of the smaller island of the Hawaiian group, the major portion of Alaska, and the Caribbean.

2. A satellite position of about 105° should include all areas of interest (except for the Aleutian chain) and is the easternmost satellite position.

which would.

3. Satellite positions west of about 140° will not provide coverage of the eastern areas of interest.

4. Of the five satellite positions previously considered, only the position at 122°W satisfies requirements, although the one at 94°W is close.

The coverage plots for the 122°W satellite position are presented in Fig. 9 through Fig. 15. In Fig. 9, considerable elongation of the beam will be noted. The contour line marked "1" indicates the half power contour of a 9 GHz 10 ft. reflector. There are several ways that the coverage of Alaska can be optimized. This takes advantage of the elongation to cover the more remote northern regions. A second method would be to reduce the aperture size by not quite 2:1 and reposition the beam for optimum coverage.

Caribbean coverage is shown in Fig. 10. There is a moderate amount of elongation to this beam. Some repositioning of the beam and a reduction of about 2:1 in aperture diameter would improve coverage.

Fig. 11 indicates adequate or nearly optimum coverage of the principal islands of the Hawaiian group. A reduction in aperture by a factor of 2:1 or the addition of a second beam would permit coverage of the smaller islands in the group.

Coverage of the Eastern time zone is shown in Fig. 12. The oblique skewing of the beam is beneficial in that it almost conforms to the general shape of the Atlantic coastline. Moving the satellite somewhat eastward would improve the conformance to the area of interest. Movement to 94°W makes the axis of elongation appropriate but reduces the amount of elongation at the same time. Some satellite position between these two should be the basis for an appropriate design. Reduction in aperture by a factor of 2:1 would improve coverage, but it is hard to determine from this figure if it would be adequate. The beam in the figure is pointed toward Washington D. C., and some repositioning would obviously be required.

Central time zone coverage is shown in Fig. 13. The beam is about half as wide in the east-west direction as is required. Reduction in aperture by a factor of 2:1 or a combination of several beams is indicated here also. The same general remarks can be made about Mountain zone coverage shown in Fig. 14 and the Pacific zone coverage shown in Fig. 15. The Eastern time zone is the only time zone in which there is pronounced elongation of the beam and indications are that this can be used to advantage. At worst, the elongation will spill over into the ocean and cause no interference with foreign countries.

In all of the above cases, two approaches could be used to improve coverage:

1. Reduce the aperture by 2:1 and reposition the beams.
2. Maintain the same aperture and form a composite beam from several feeds.

Fortunately, techniques applicable to one coverage area provide improvement in all other areas as well. The aperture reduction method will cause a portion of the Alaskan beam to radiate past the earth but should not, if properly positioned, cause appreciable radiation into foreign countries.

2.3 Candidate Approaches

At this point there was an obvious need for a first cut at the design concept to determine a general impression regarding feasibility, size,and problem areas. Accordingly, a preliminary analysis using approximate calculations of various geometrical parameters was undertaken.

As can be seen from Fig. 16, the approximate beamwidth required to cover a band of latitudes on the earth's surface can be calculated from

$$\tan \gamma_2 = \frac{r \sin \Gamma_2}{(h + r) - r \cos \Gamma_2} \qquad (1)$$

$$\tan \gamma_1 = \frac{r \sin \Gamma_1}{(h + r) - r \cos \Gamma_1} \qquad (2)$$

$$\gamma_d = \gamma_2 - \gamma_1 \qquad (3)$$

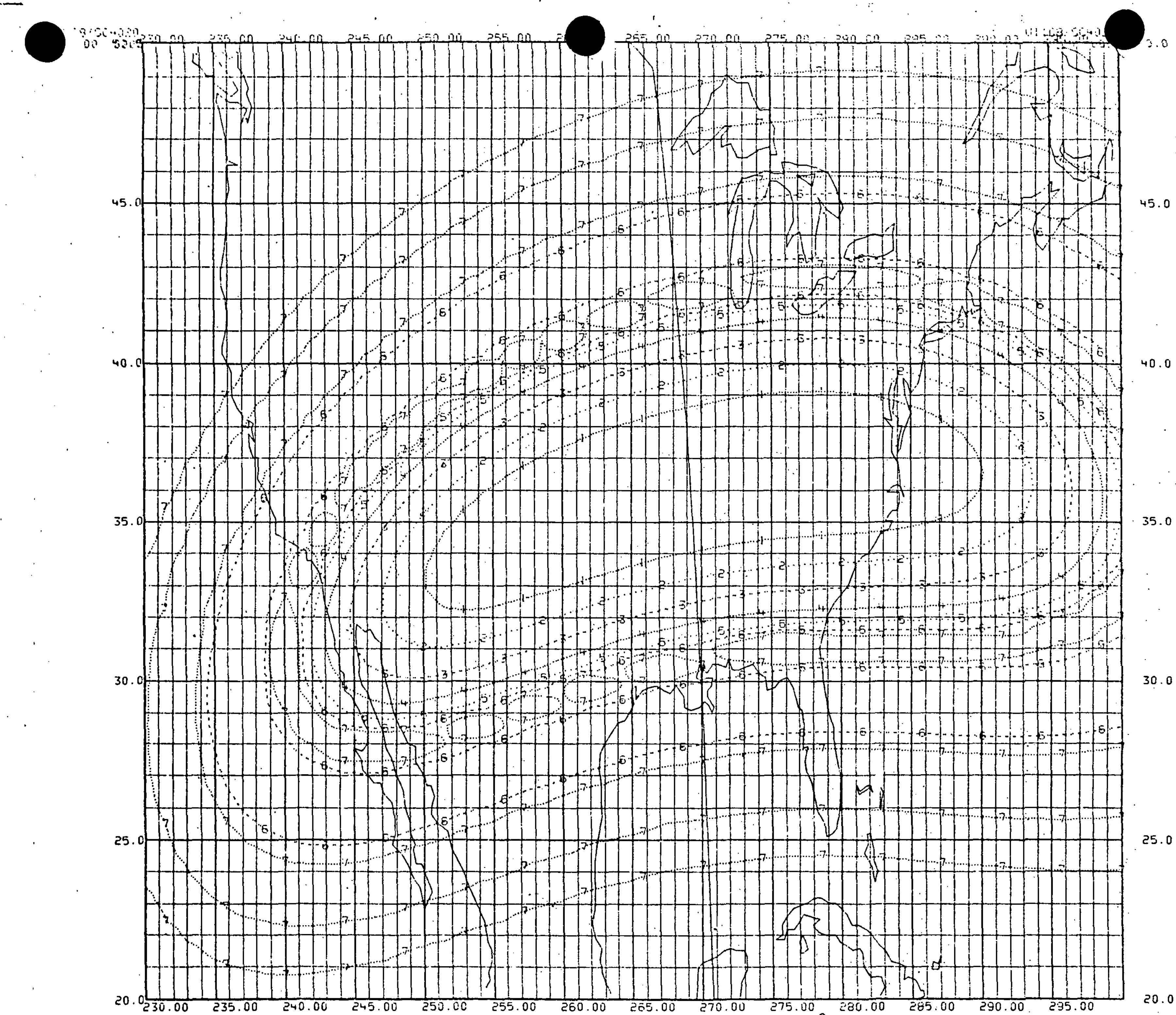

FIGURE 1 - CONTINENTAL U. S. CONTOURS FOR SATELLITE AT 170°W

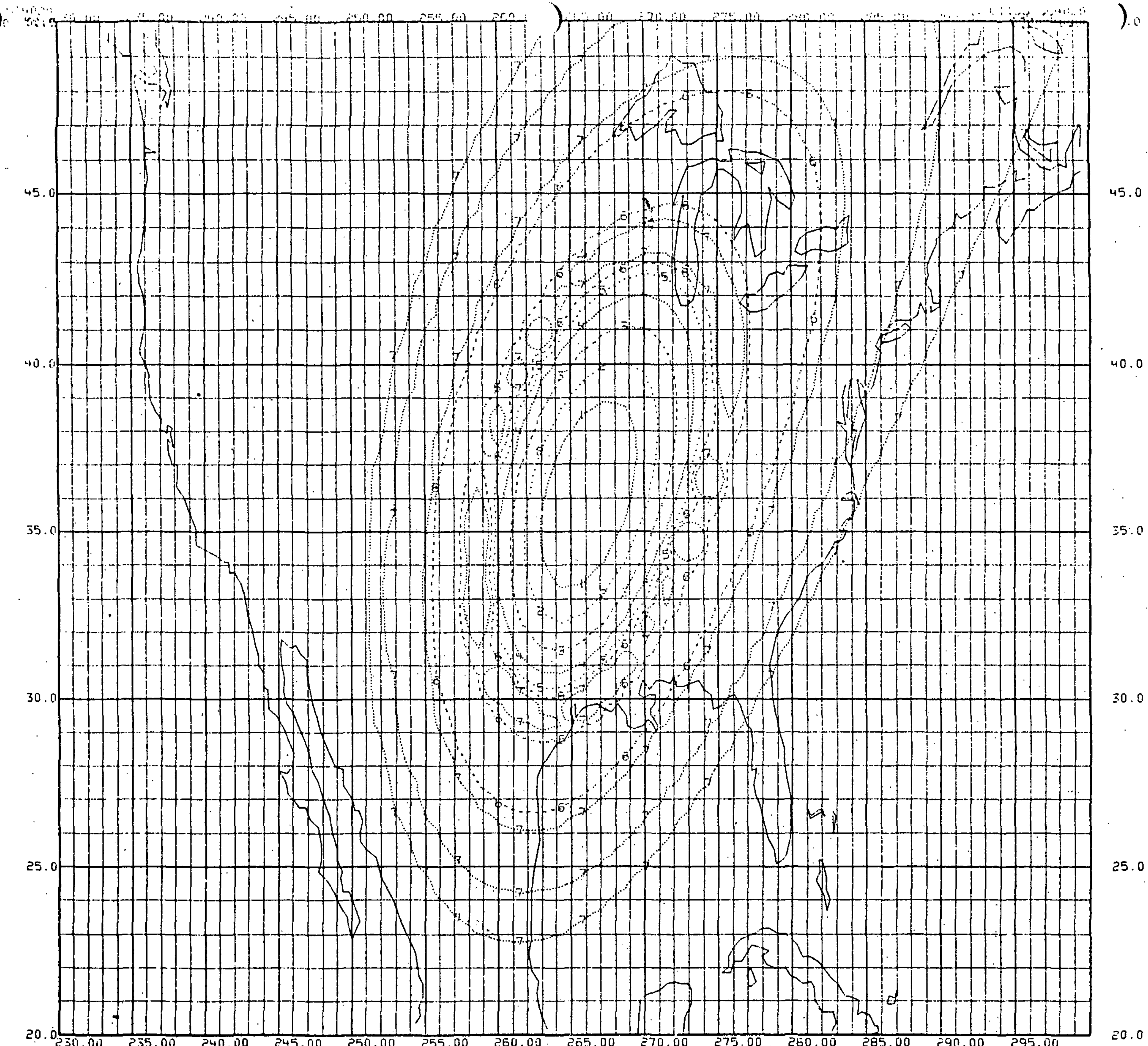

FIGURE 2 - CONTINENTAL U. S. CONTOURS FOR SATELLITE AT 122°W

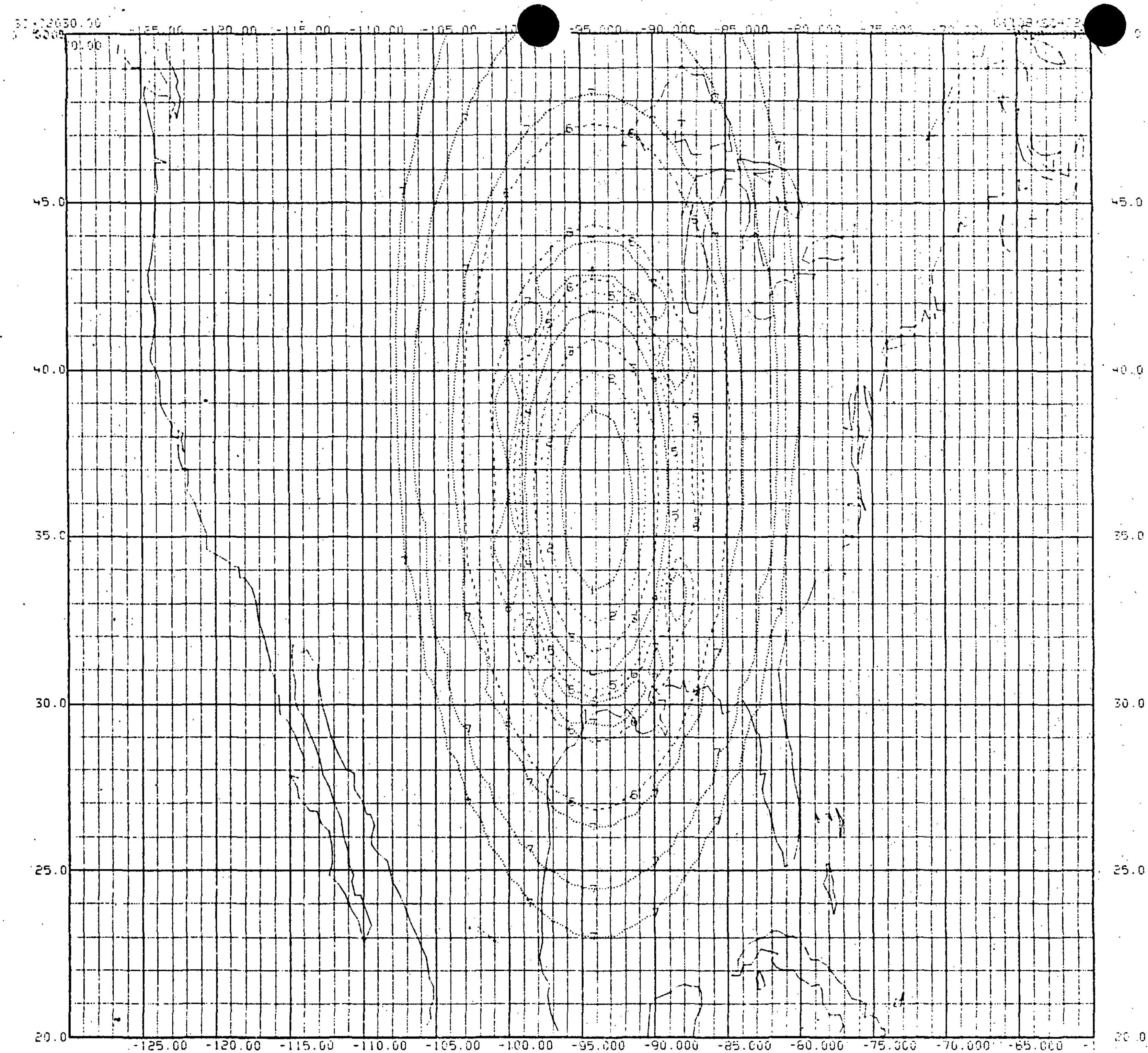

FIGURE 3 - CONTINENTAL U. S. CONTOURS FOR SATELLITE AT 94°W

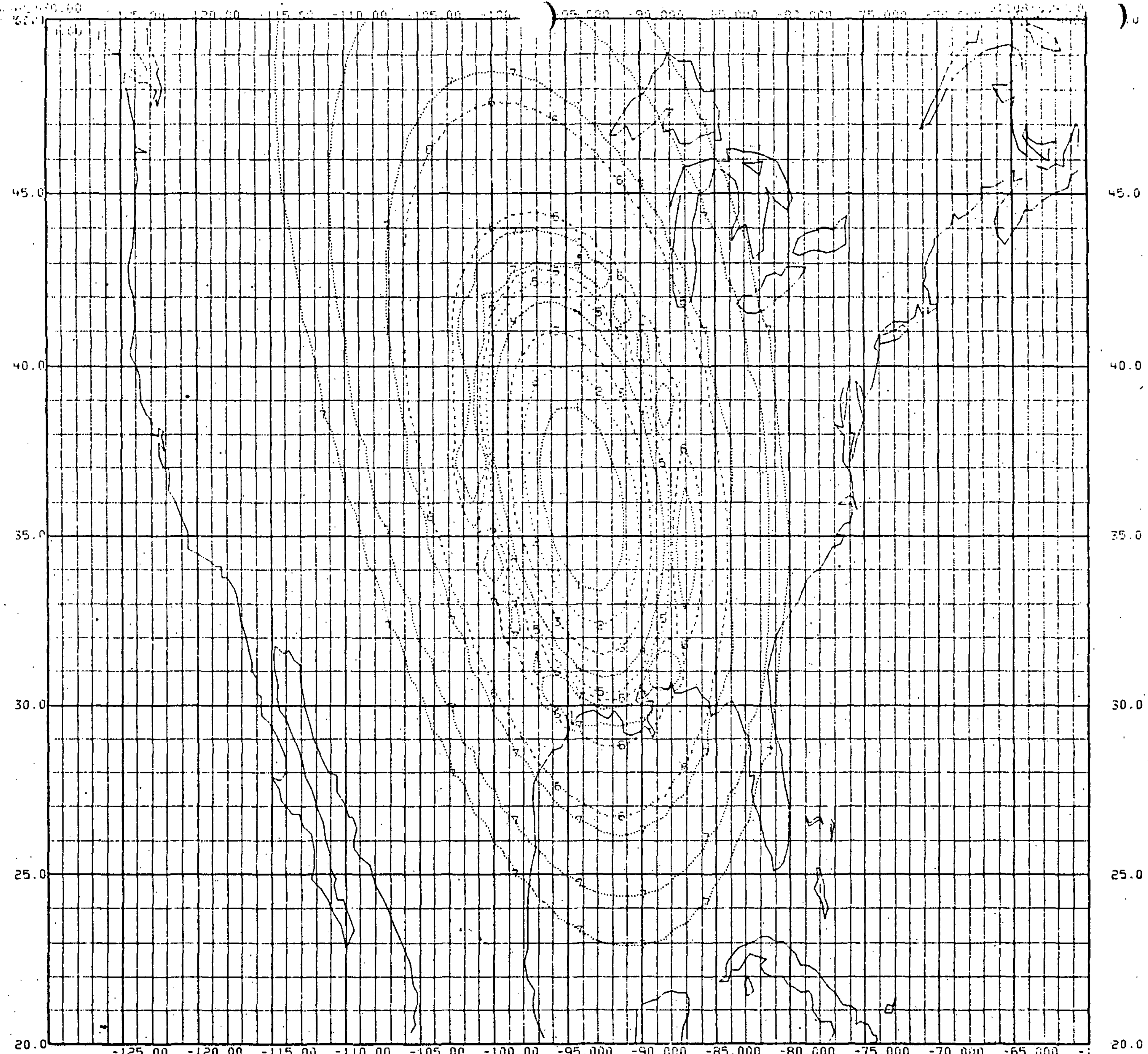

FIGURE 4 - CONTINENTAL U. S. CONTOURS FOR SATELLITE AT 75°W

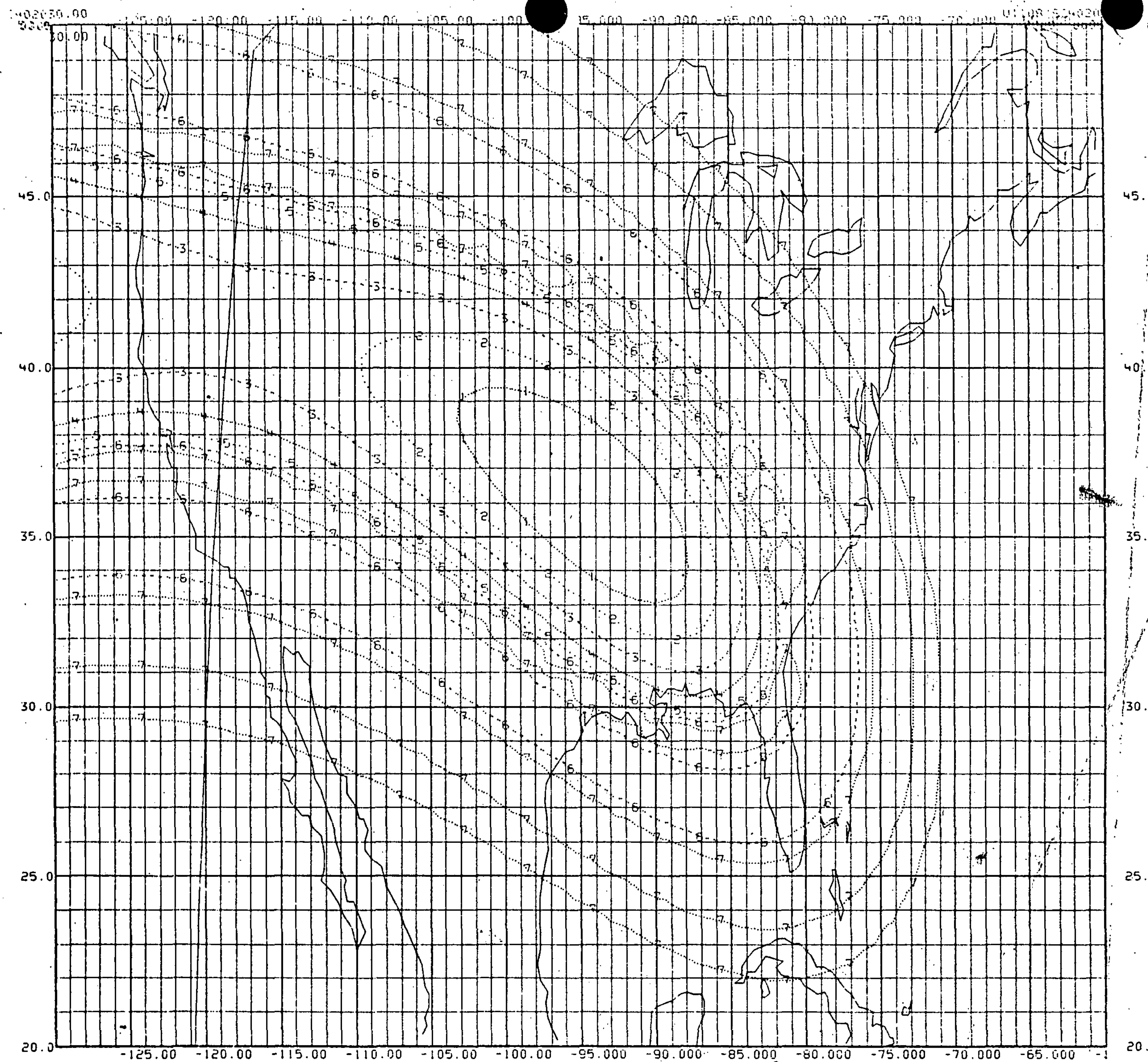

FIGURE 5 - CONTINENTAL U. S. CONTOURS FOR SATELLITE AT 40°W

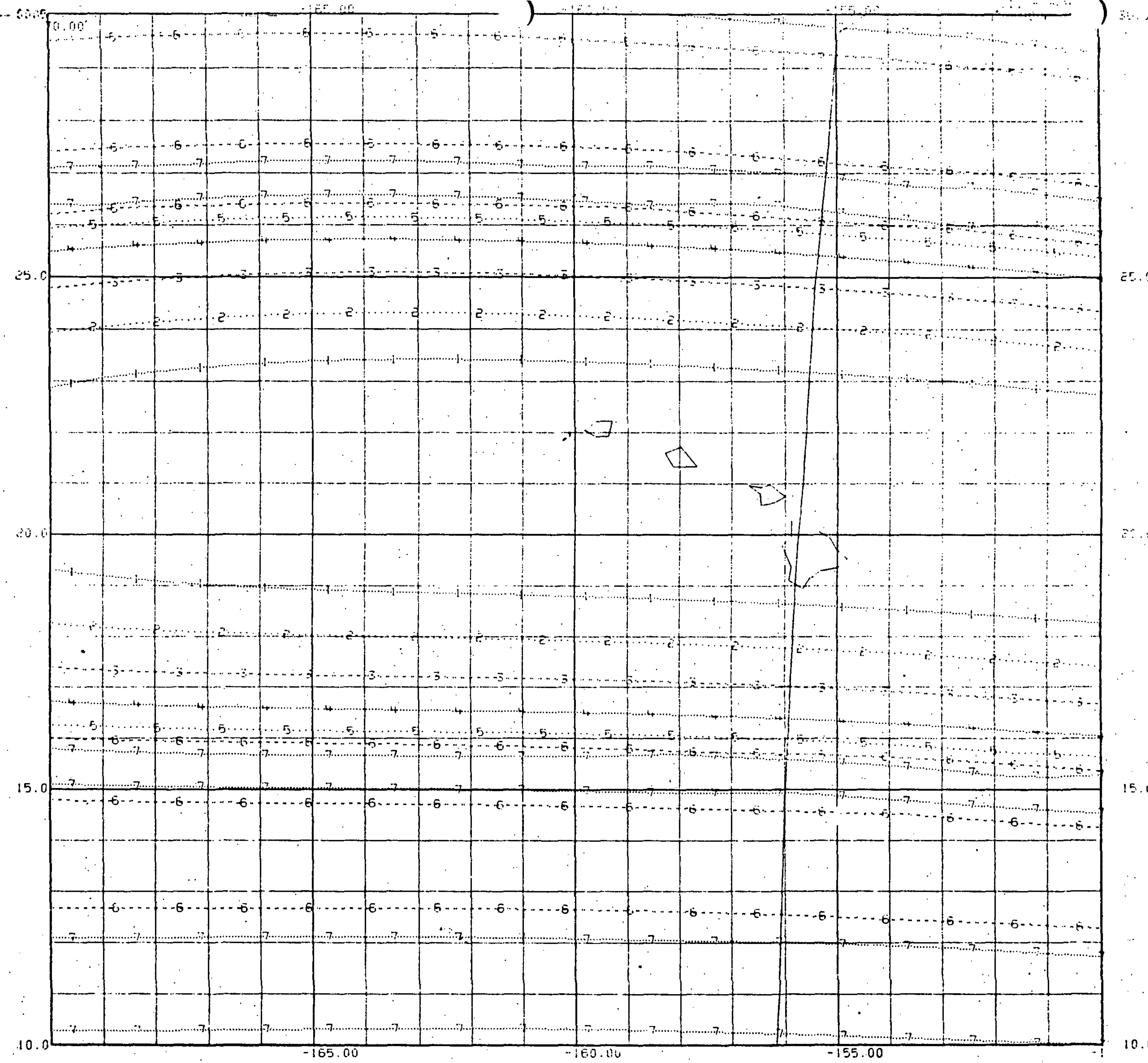

FIGURE 6 - HAWAII CONTOURS FOR SATELLITE AT 75°W

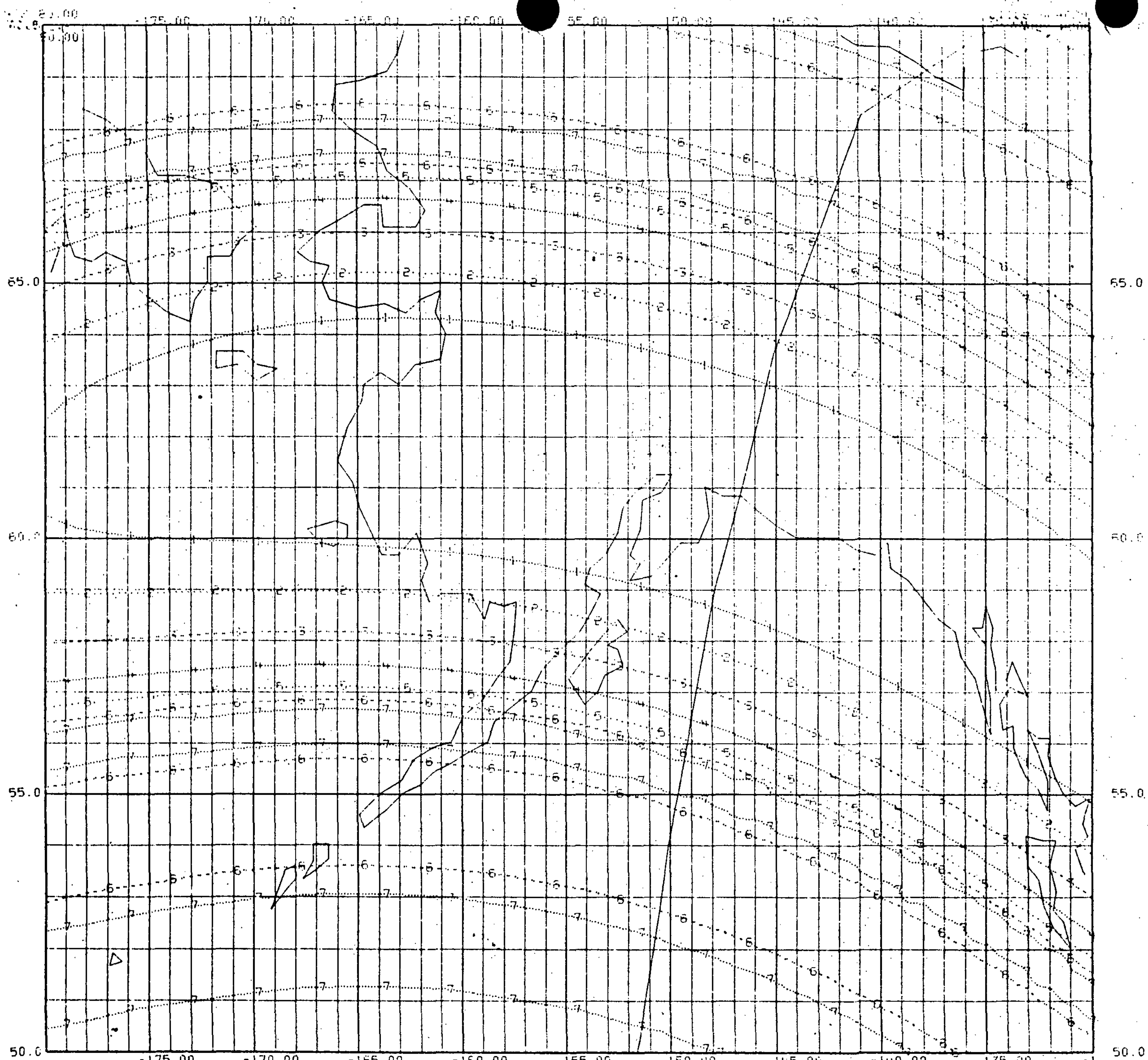

FIGURE 7 - ALASKA CONTOURS FOR SATELLITE AT 75°W

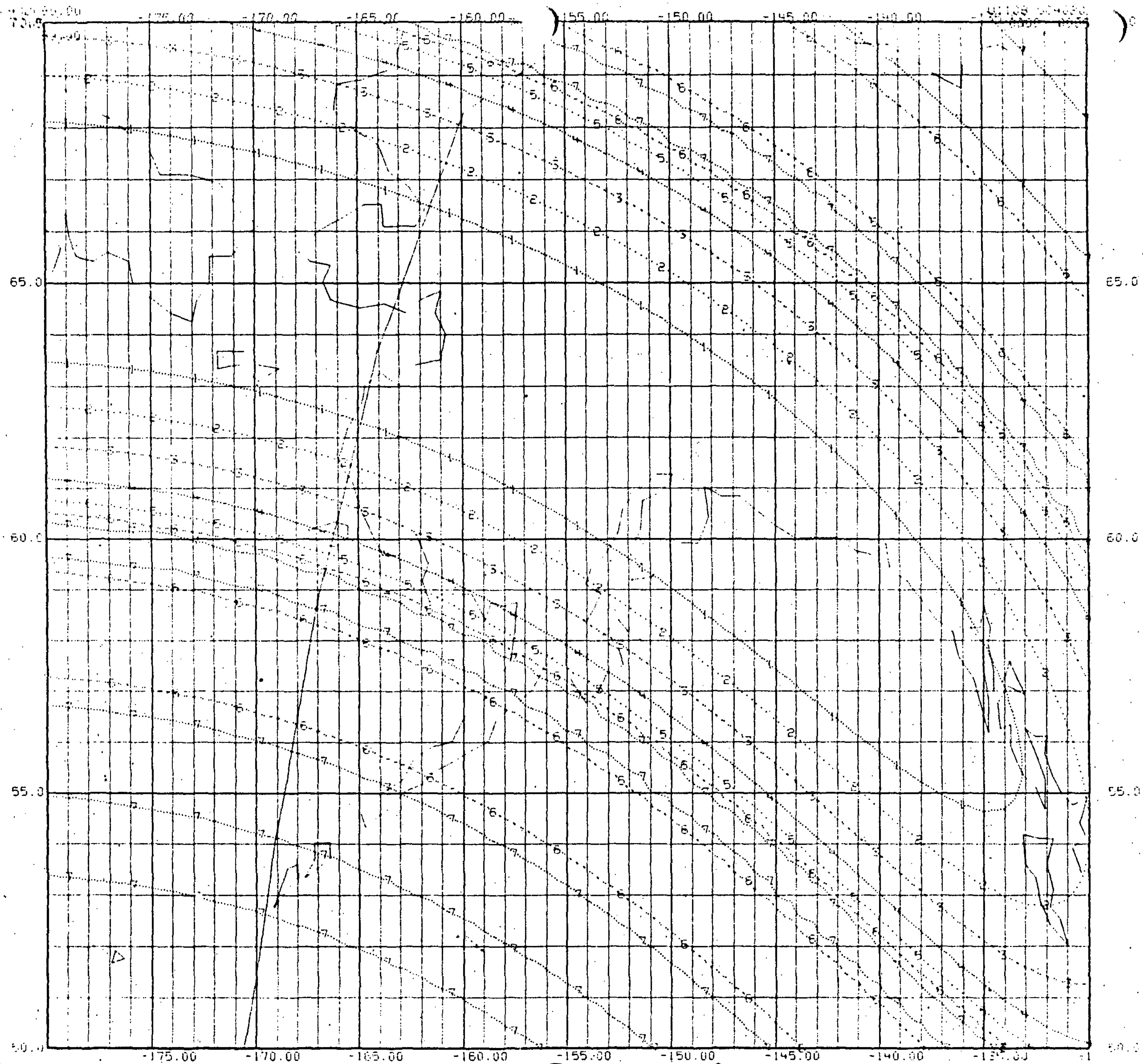

FIGURE 8 - ALASKA CONTOURS [illegible] SATELLITE AT 94°W

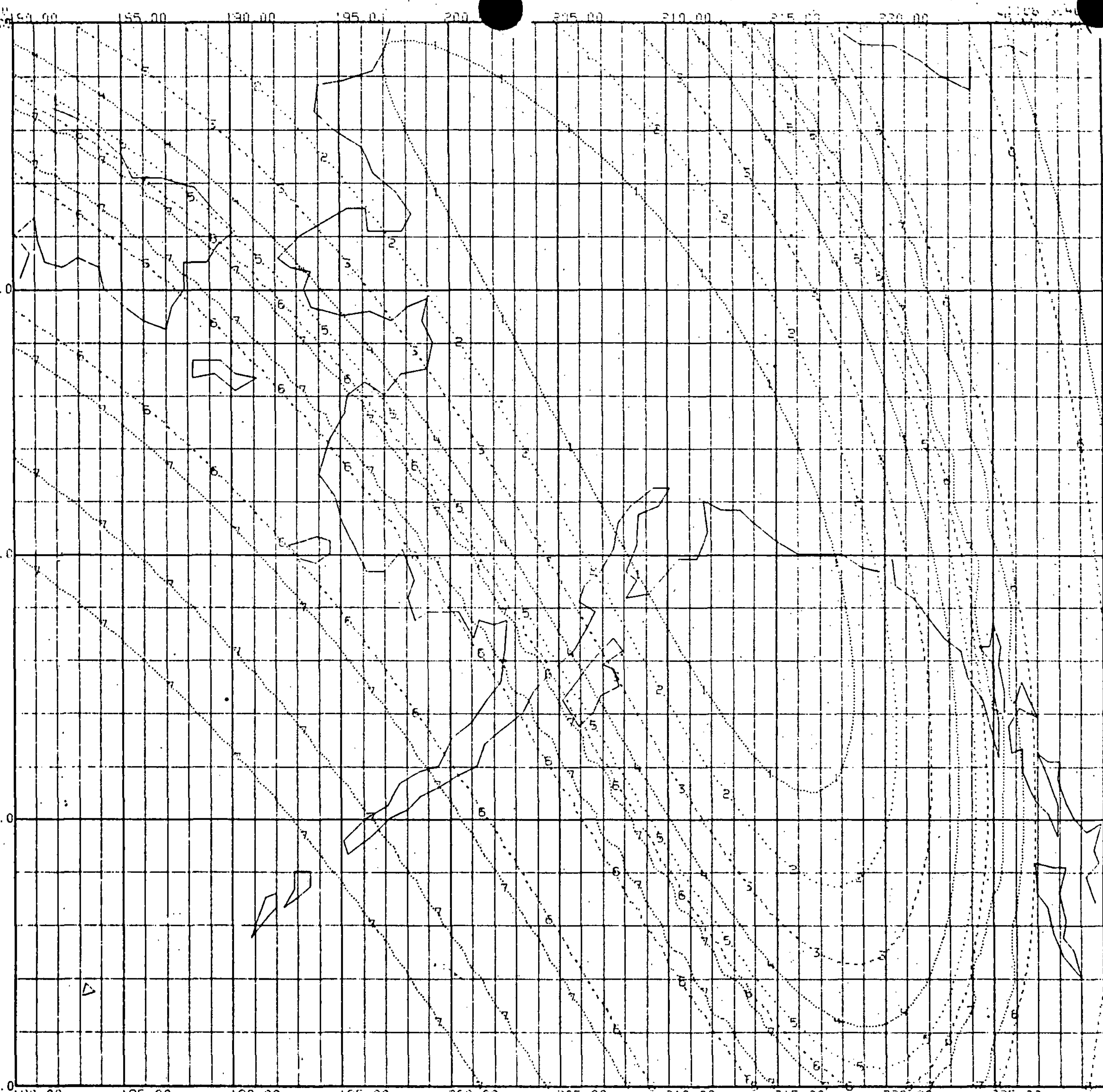

FIGURE 9 - ALASKA CONTOURS FOR SATELLITE AT 122°W

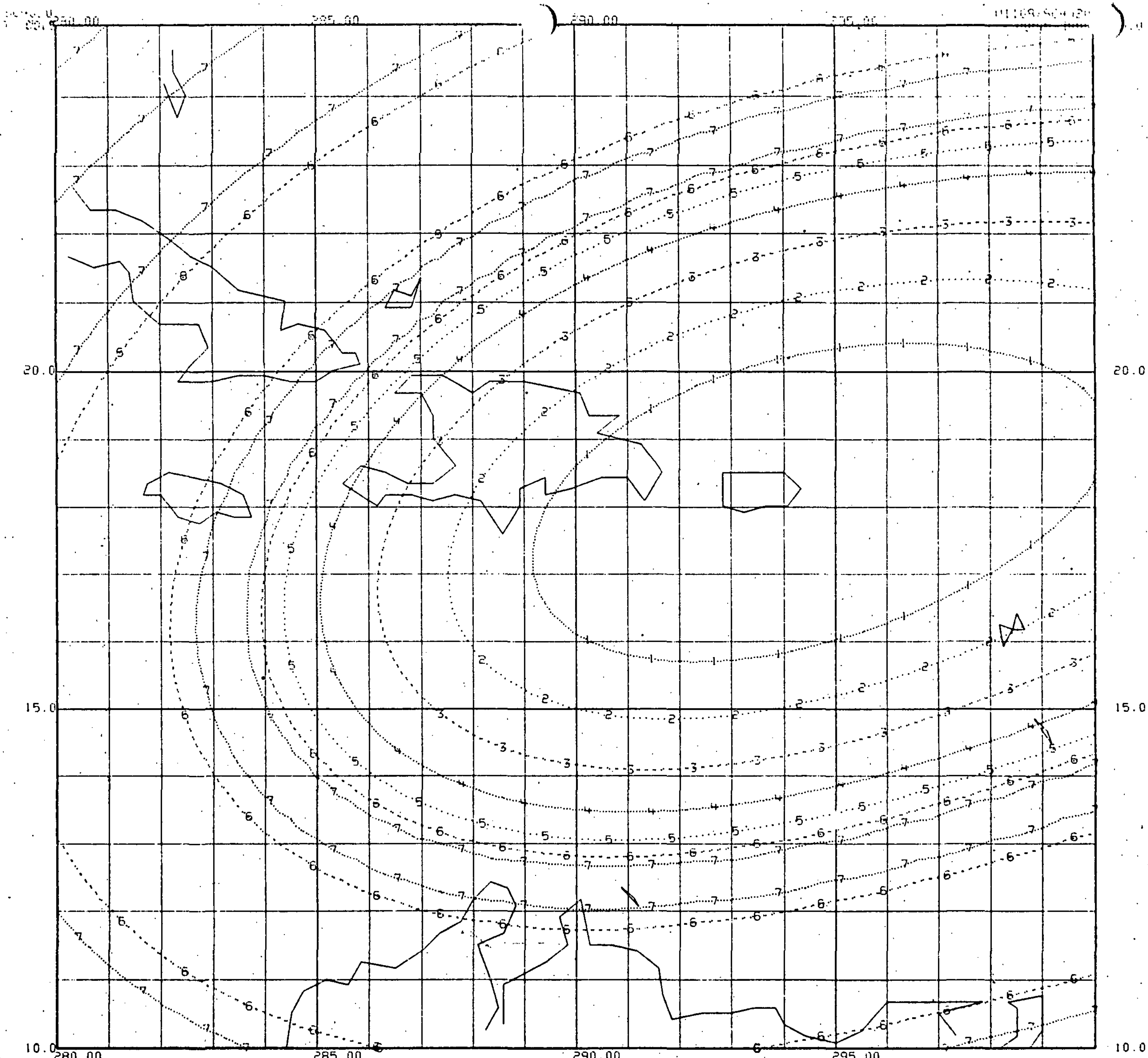

FIGURE 10 - CARIBBEAN CONTO[illegible] FOR SATELLITE AT 122°W

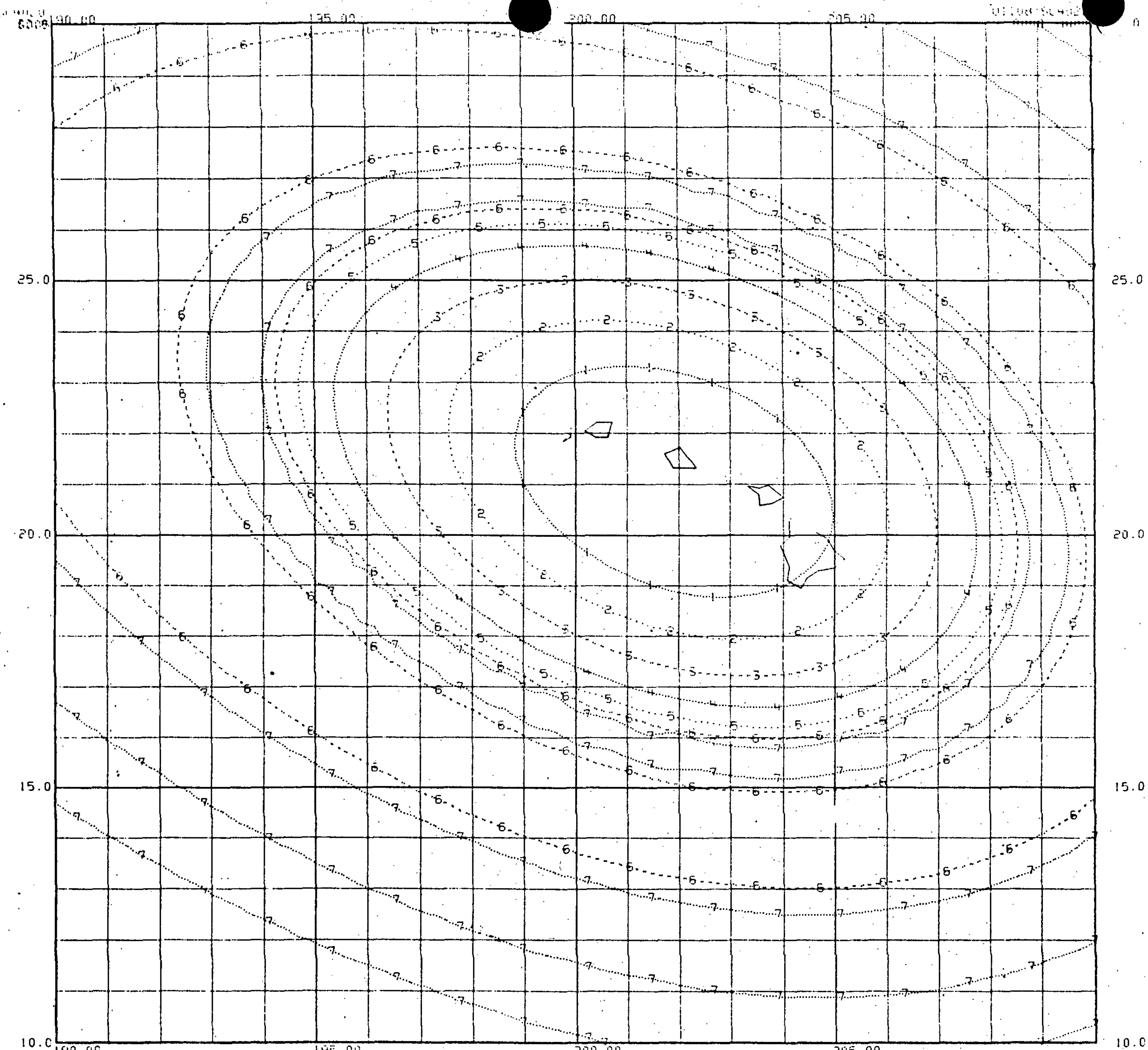

FIGURE 11 - HAWAII CONTOURS FOR SATELLITE AT 122°W

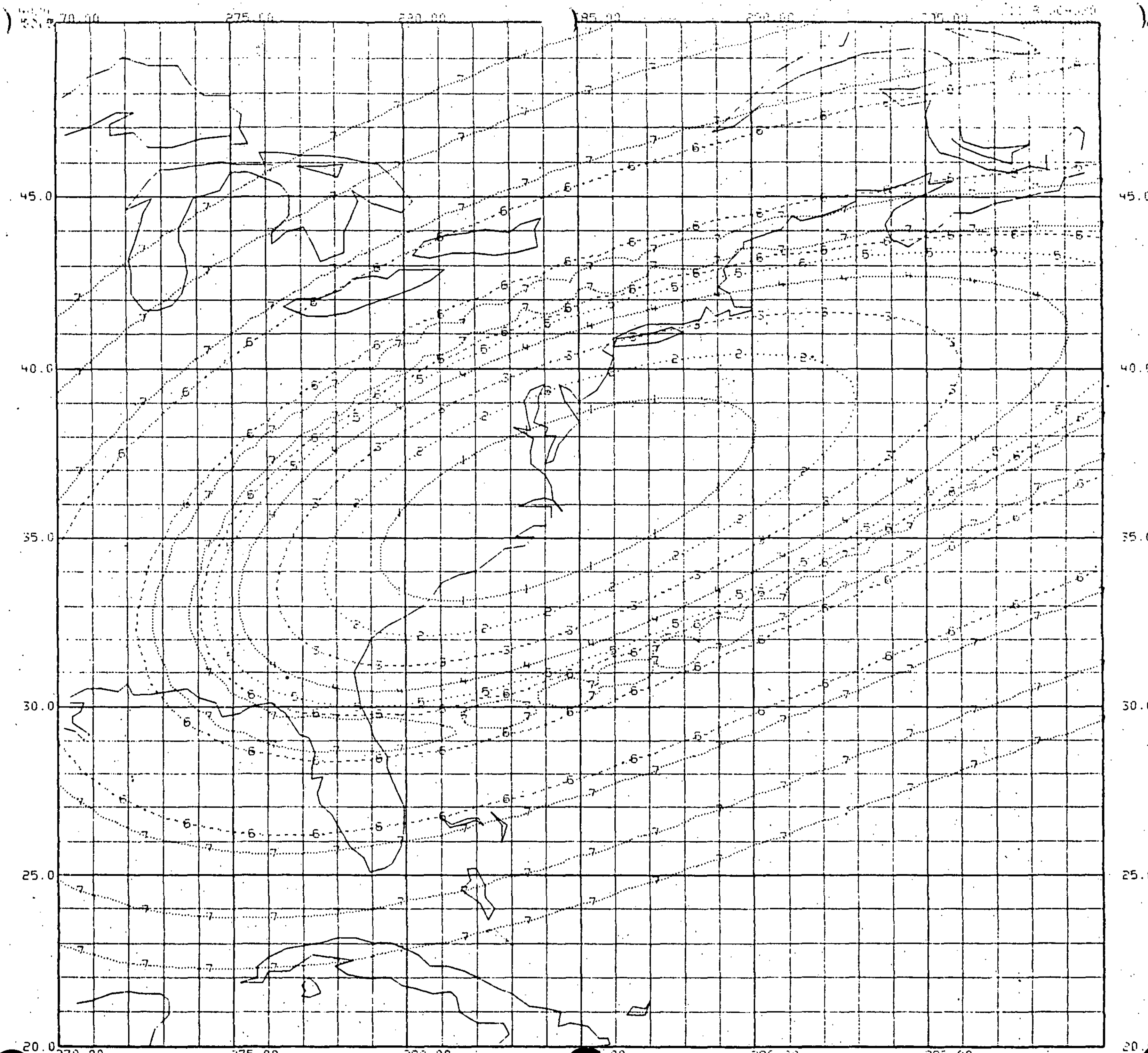

FIGURE 12 - EASTERN TIME ZONE CONT FOR SATELLITE AT 122°W

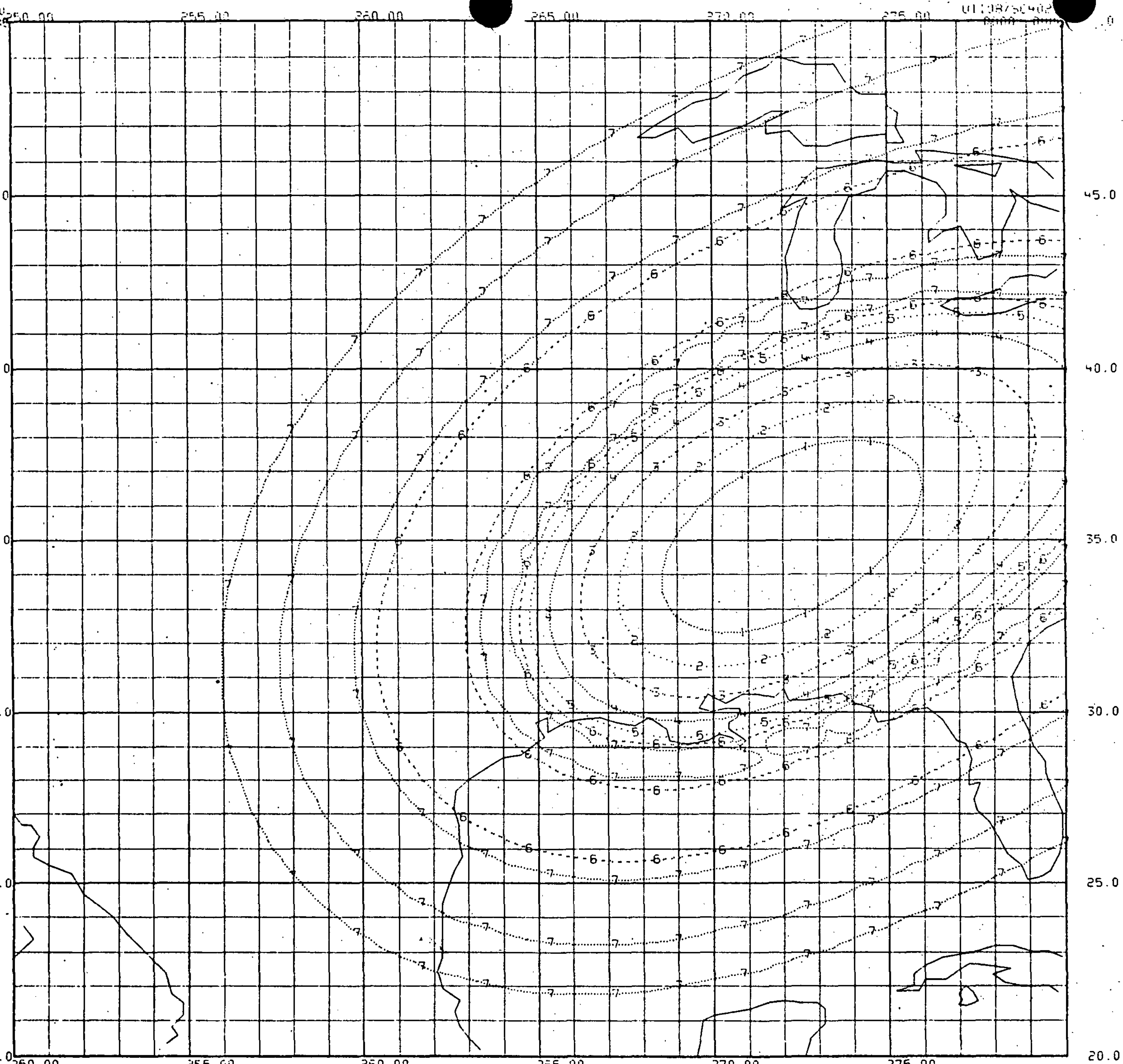

FIGURE 13 - CENTRAL TIME ZONE CONTOURS FOR SATELLITE AT 122°W

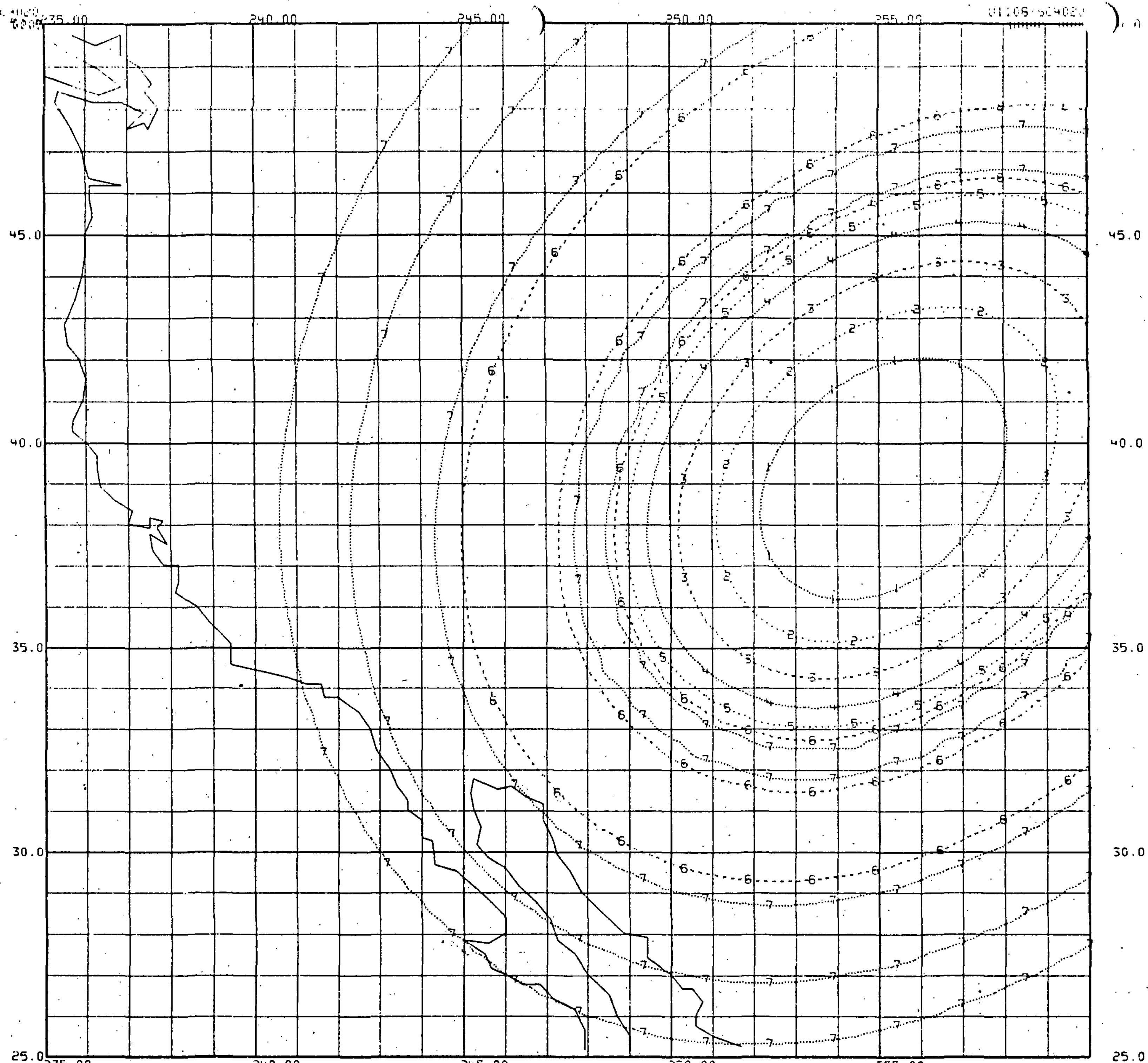

FIGURE 14 - MOUNTAIN TIME ZONE CONTOURS FOR SATELLITE AT 122°W

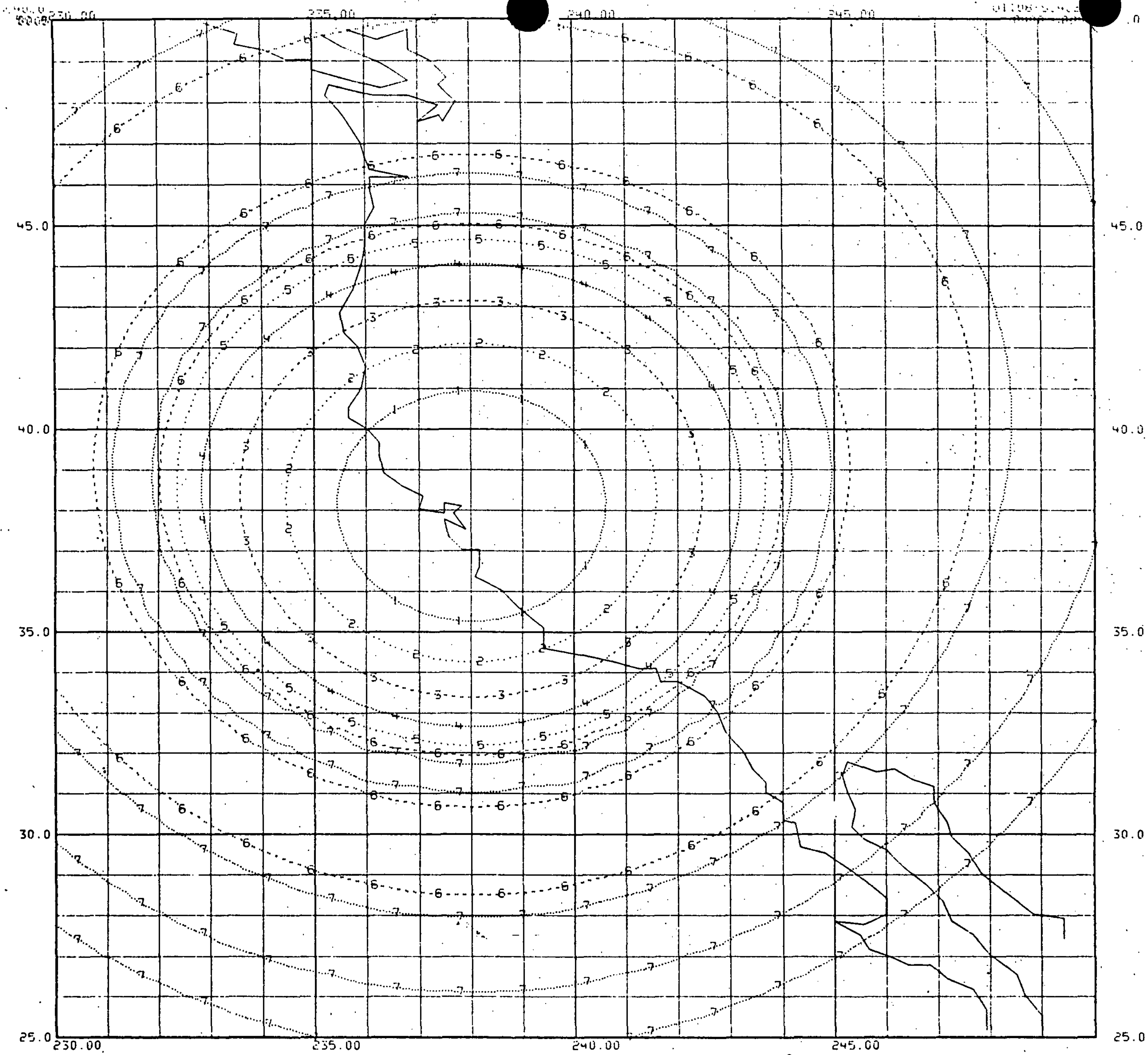

FIGURE 15 - PACIFIC TIME ZONE CONTOURS FOR SATELLITE AT 122°W

where h is 19370 nm and where r is 3440 nm. From these equations the basic beamwidth required for coverage between latitudes 49°N and 25°N is about 3°. This corresponds to a minimum aperture of 2.6 feet at 9 GHz or of 5.8 feet at 4 GHz.

The geographical positions of the approximate centers of the insular Carribbean area and the non-contiguous states of Alaska and Hawaii are approximately as follows:

Place	Latitude	Longitude
Anchorage	150°W	61°N
Honolulu	158°W	21°N
Puerto Rico	67°W	18°N
Salt Lake City	112°W	41°N

The position of Salt Lake City is given since it is approximately centrally located with respect to the three non-contiguous areas and is only about one time zone away from the geographical center of the contiguous 48 states. Wherever the satellite is positioned, the nominal main axis of the reflector should point toward Salt Lake City to make the offset required for coverage of the eastern and western extremes symmetrical, thereby minimizing degradations due to lateral offset of the feeds from the main axis of the paraboloid. If the satellite position is chosen to be at the longitudinal coordinate of Salt Lake City -- that is, at 112°W, the satellite position falls within the limits of 105°W to 140°W determined above on the basis of ability to view all areas of interest and is toward the eastern end of the range to provide preferential treatment of the contiguous 48 states. Thus, 112°W is the tentative choice of satellite position and Salt Lake City is the tentative choice for boresight reference of the complete antenna system.

Approximate great circle distances for various points of interest are

Salt Lake City to Honolulu	2600 nm
Salt Lake City to Anchorage	1850 nm
Salt Lake City to Puerto Rico	2700 nm

Salt Lake City to Maine	2000 nm
San Francisco to Maine	2500 nm

Thus beam offset to Honolulu and to Puerto Rico will be approximately equal if the satellite is located at the longitude of Salt Lake City.

A quick calcuation of the beamwidth required in the east-west direction to cover the contiguous 48 states with four beams can be obtained from

$$\theta_o \simeq \tan^{-1} \left(\frac{2500}{4\bar{R}}\right)$$

where $\bar{R}$ is the arithmetic mean of R_1 and R_2 of Fig. 16. $\bar{R}$ is approximately 20,215 nm which gives an east-west beamwidth of about 1.77^o for each of the four beams. This corresponds to a 4.4 foot reflector at 9 GHz or a 9.9 foot reflector at 4 GHz. The beam aspect ratio is 3/1.77 = 1.7. This aspect ratio should be readily obtainable in an oval segment of a paraboloidal refelctor.

Thus, if we shape the reflector to provide the approximate oval beam contours necessary for the four time zones, the reflector would be 2.6 by 4.4 feet at 9 GHz and 5.8 by 9.9 feet at 4 GHz. This (in particular, the east west dimension) is compatible with the 2:1 reduction in aperture predicted by examining the contour plots in the previous section. The use of any larger aperture will require the application of beam shaping techniques to broaden these beams or the combination of several beams to form a composite beam for each time zone.

The angle between Salt Lake City and a point 112^oW and 61^oN is about 1.72^o (from Eqs. 1 through 3). Anchorage is west of this point by about 1100 miles which corresponds to less than 3^o when viewed from the satellite. The offset of Anchorage from Salt Lake City is at least 1.72^o but not more than about 3.5^o. Thus, Anchorage will be offset by about 2 beamwidths corresponding to the maximum dimension of the reflector. This will not lead to serious pattern degradation. If a larger aperture is used and the beams are formed by adding several beams together, the offset will be proportionately larger in terms of beamwidths and may lead to some degradation for apertures more than twice the minimum size.

Honolulu and Puerto Rico both are about 2600 nm from Salt Lake City. Each will require an offset of about 4 beamwidths (corresponding to the maximum dimension of the reflector). Increasing the aperture of the antenna in the east west direction will increase the number of beamwidths offset to cover these two outlying areas. Doubling the aperture would require 8 beamwidths offset and might lead to pattern degradations. Since these are predominantly ocean areas, the pattern degradations might be tolerable. The degradations can be minimized by using a long focal length reflector, but this causes problems in obtaining the proper illumination of the reflector in the north-south direction.

The first approach then is to use a reflector having the minimum dimensions given above, since for these dimensions the various beam offsets measured in terms of beamwidths will be minimized and the patterns improved. The second approach would be to have a circularly symmetric paraboloid having a diameter equal to the minimum required in the east-west direction (that is, 4.4 feet at 9 GHz or 9.9 feet at 4 GHz). Proper shaping of the pattern for north-south coverage could be obtained in several ways for the latter case. The third candidate system would employ a larger aperture and would rely on beam combinations or beam shaping techniques to provide the area coverage.

It is probable that the second or third candidate system will prove to be the choice. The first candidate, the use of an oval segment of a paraboloid of minimum dimensions, is the simplest. The approach will be to evaluate this system first to determine what deficiencies exist. This, in turn, will lead to more complex systems.

One of the most important problems to deal with is the matter of crossover level for the time zone coverage beams. Ordinarily one attempts to obtain a crossover level of -3 dB between adjacent beams, but there are arguments in favor of a crossover level of about -4 dB. With the minimum east-west aperture dimensions given above (4.4 feet for 9 GHz and 9.9 feet for 4 GHz), the half-power beamwidths in the east west direction are about 1.77 degrees and the beams are offset from each other by this amount resulting in a -3 dB crossover.

For reflectors with F/D ratios of the order of .4 to .5, the physical separation required to produce a given beam separation is given approximately by

$$S = R_m \tan \theta$$

where R_m is the mean radius from the focal point to the reflector and θ is the separation of beam maxima desired. For the 4 GHz case (9.9 foot reflector) this separation is about 1.75 inches or a little over a half-wavelength. The problem with this is that the east-west aperture dimension of the feed is physically restricted to less than this separation, resulting in a limitation on the control available over the primary illumination of the reflector and also that such close spacing leads to high interaction between the feeds. Using a -4 dB crossover would require a slightly larger east-west reflector dimension and would result in a proportionately larger physical separation of the feeds to obtain the same angular beam separation. This would tend to reduce the aforementioned problems to a degree. While a -3 dB crossover level would require a 0.6 wavelength separation, the lower crossover would increase the separation to about 0.7 wavelength. An additional advantage of the lower crossover is that it is approximately the proper value (-3.93 dB) for synthesis of the broad coverage required for the contiguous 48 states employing the Woodward method of synthesis (as for example in a Butler array system). The disadvantage, in addition to the obvious one of lower coverage at the edges of time zones, is that the offsets required will be slightly larger in terms of beamwidths resulting in more degradation with offset. This should not be a serious problem.

A couple of options were considered:

One is to provide a polarization diversity capability in the four time zones. If the Pacific and Central time zones have a common polarization and the Eastern and Mountain zones have the complementary polarization, maximum isolation between the adjacent time zones will be obtained, but there may be problems in combining the four beams to obtain Continental coverage. Thus, it may be necessary to have the polarization for two of the zones selectable. The use of complementary polarizations on adjacent feeds also helps reduce mutual interaction between feeds.

A second option considered is the possibility of providing a tracking capability on the Continental coverage beam. This would permit the satellite user to obtain a periodic update of pointing coordinates by switching into the tracking mode and aligning the antenna system with a known beacon on the ground.

To summarize, three candidate approaches were selected, namely:

1. An oval reflector having minimum east-west and minimum north-south aperture dimensions.
2. A circularly symmetric reflector having a diameter equal to the minimum east-west dimension.
3. A larger reflector.

A preliminary conceptual design for an antenna system which represents something between the first and second classes above (since the north-south dimension is larger than minimum) has evolved.

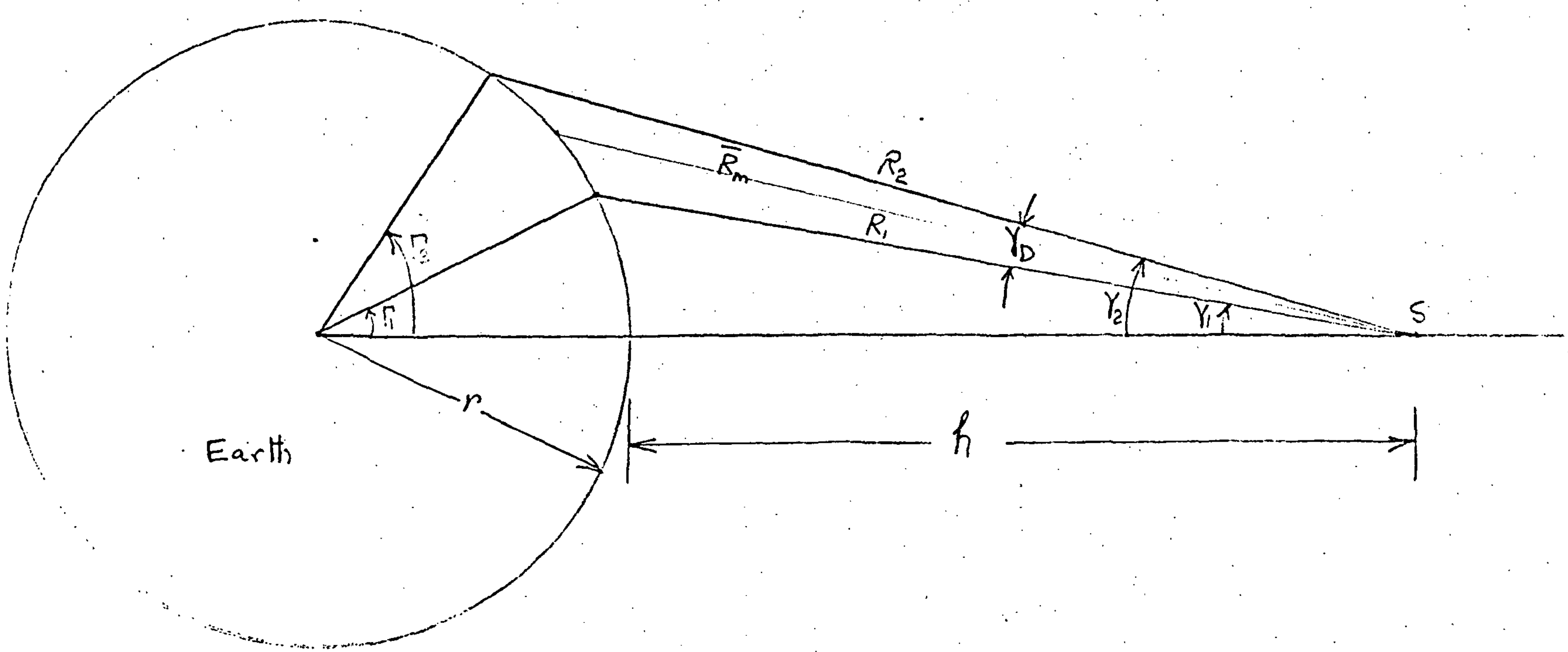

FIGURE 16 EQUATORIAL TWENTY-FOUR HOUR SATELLITE

2.4 Candidate Evaluation

2.4.1 General

Based on the preceding analysis, earth contours for the following cases were evaluated.

E-W Dimension (ft)	N-S Dimension (ft)	Reflector Shape	Frequency (GHz)
9.9	9.9	Circular Paraboloid	4
9.9	5.8	Ellipitical Paraboloid	4
4.4	4.4	Circular Paraboloid	9
4.4	2.6	Ellipitical Paraboloid	9

Naturally, it will be recognized that the latter two cases are scaled versions of the first two. Runs were made at 4 GHz for the first two cases but are applicable for the 9 GHz cases as well. To improve clarity, only the -3 and -4 dB contours were plotted, except for some cases where the -30 dB contour was also included.

It was considered desirable to present all four time zone contours on a single map of the United States. Some difficulty was experienced with the plotter in attempting to do this, and rather than waste time in debugging the program to provide this capability, the plots were superimposed by hand.

The international boundaries of the United States with Canada and Mexico have been added to the figures. For the cases depicting time zone coverage within the contiguous 48 states, the time zone boundaries have been added. The time zone boundaries are rather complex and perhaps are subject to some change by local option. Therefore, a compromise was made by selecting appropriate representative boundaries along the most suitable line of longitude. These are:

Eastern-Central Boundary	86°W
Central-Mountain Boundary	102°W
Mountain-Pacific Boundary	115°W

New reference boresight positions were selected for each of the time zones. These are:

Eastern	36°N, 82°W
Central	36°N, 96°W
Mountain	36°N, 108°W
Pacific	36°N, 120°W

Boresight positions for Alaska, Hawaii, and the Carribbean area will be discussed later on.

2.4.2 Time Zone Coverage

The coverage obtained with a circular paraboloid 9.9 feet in diameter at 4 GHz is shown in Fig. 17. Contours 1 indicate the -3 dB level and contours 2 indicate the -4 dB level. The boresight positions are also marked.

Several observations can be made from Fig. 17. First of all, the 9.9 foot dimension is approximately correctfor east-west coverage of the time zones. The east-west dimension of the beam is too broad for the Pacific and the Eastern time zones, approximately correct for the Mountain zone, and slightly too narrow for the Central zone. Since any change in aperture dimension would affect all beams, the 9.9 foot dimension seems to be a reasonable compromise at this stage of the design.

The boresight positions should be adjusted to improve coverage, but, even so, complete coverage would not be obtained with the circular paraboloid. To optimize coverage with the circular aperture, the Eastern time zone boresight should be moved eastward and northward, and the other three boresight positions should all be moved northward. With this adjustment the coverage should be centralized within each zone but large pockets of degraded signal level would result.

The alternative is to readjust the boresights and use two or more beams to cover each time zone. For example, the boresights for the Central, Mountain and Pacific zones could be readjusted southward to accommodate a second beam to the north in each case. Coverage in each of these zones would then be obtained by summing appropriate pairs of beams. The obvious disadvantage of this approach is that spillover into Canada and Mexico would be increased. This in turn indicates than an increase in the north-south aperture dimension would be required to reduce spillover for the paired beam concept. Thus, we evolve from the circular aperture case to the elliptical aperture case.

The Eastern time zone is a special and very difficult problem. Here it seems that an increase in the "north-south" dimension would be required and possibly three beams would have to be used to obtain even the crudest approximation to the geographical shape without high spillover.

Since the results of the circular aperture case lead to an elliptical aperture concept because of incomplete north-south coverage, the next step is to consider elliptical apertures. But instead of increasing the north-south aperture so as to use two beams to form each time zone beam, the north-south dimension will be decreased (the second case listed above) to spread the radiation of a single beam in the north-south direction. The results are shown in Fig. 18.

The coverage of the four time zones shown in Fig. 18 is quite good, considering the simplicity of the approach used. The Pacific, Mountain and Central time zones would benefit by a slight northward adjustment of the boresight position, but at the same time this would increase the spillover into the southern part of Canada. The boresight of the Eastern time zone beam should be moved slightly eastward to improve isolation between the Central and Eastern coverages, but this tends to degrade radiation into the state of Michigan.

The cross-over levels between adjacent time-zone coverage patterns is at about the -3 to -4 dB level. The first nulls of each beam would occur somewhere in the vicinity of the boresight positions of adjacent beams. As an example, the main beam of the Mountain time zone coverage beam would extend from the boresight of the Pacific time zone to the boresight of the Central time zone approximately. Conversely, the reception in the western half of the Mountain time zone would be affected by main beam skirt radiation of the Pacific zone and first side lobe radiation of the Central zone pattern, and so on. It is clear that adequate isolation can be obtained between adjacent time zones for this case only by frequency or polarization diversity.

Thus, it can be concluded that a reasonable approximation of time zone coverage can be obtained with the elliptical segment of a paraboloid of the dimensions selected. Polarization or frequency diversity must be used to isolate the adjacent areas.

Spillover into Canada and Mexico will be relatively high compared to more sophisticated approaches which might be considered. The basic advantage of the approach just considered is its relative simplicity.

2.4.3 Coverage of the Contiguous 48 States

Coverage maps for combining the four time zone coverage beams into a single beam for servicing the entire contiguous 48 states are shown in Fig. 19 for the circular aperture and Fig. 20 for the elliptical aperture. These diagrams are obtained by summing the four beams, assuming they are in phase, of equal weighing, and have identical polarizations. Thus, a composite uniformly polarized beam is obtained.

As can be seen from Fig. 19, the coverage resulting from the circular aperture is incomplete, particularly in the western part of the United States, and the same comments that apply to improving the north-south coverage for Fig. 17 would apply here also.

The coverage resulting from the elliptical aperture case is shown in Fig. 20. There is significant radiation into Canada and Mexico, as can be seen, and this extends beyond the nominal half-power boundaries of the individual beams. The slight dumbbell shape is due to the fact that the western pair and the eastern pair of beams have higher crossovers than the central pair. The "fill-in" beyond the individual beams results from the fact that radiation at intermediate points between beams is the result of contributions from at least two beams. Note that the east and west boundaries of the composite beams are approximately the same as the boundaries of the appropriate individual beams because along these boundaries the other individual beams contribute only side lobe radiation.

The question of polarization for the U.S. coverage beam requires some careful consideration. Heretofore, we have considered it essential to have a uniformly polarized U.S. coverage beam. To providethis when polarization diversity is used to assure isolation between the coverages of individual time zones, it has been necessary to consider feeds which have a dual polarization capability. Further consideration indicates this is not the approach that should be used if we chose to form the composite beam from the time zone coverage beams (rather than providing the U.S. beam on a separate antenna).

First, consider the operational use of the composite beam. This beam would be used when it is necessary to transmit simultaneously to all parts of the contiguous 48 states. If the polarization of the composite beam were, for example, north-south linear, the users in the two time zones which utilized east-west linear for time zone coverage would have to switch to the alternate polarization or re-orient their antennas to receive the composite beam. This requires that the user either know whether the program information is being transmitted on the composite or the time zone beam or that he monitor both polarizations continuously. We are assuming matched polarizations at the ground stations for maximum signal reception. The same arguments would also apply to the use of complementary circular polarizations for the four time zone beams.

It seems highly desirable to be able to transmit either on the time zone beams or the composite beam to a ground user without his having to know which is being used or having to make any adjustments. If we make the four time zone beams and the composite beam all co-polarized, then frequency diversity <u>must</u> be used to separate the signals in adjacent time zones.

Consider the alternative. If alternate time zone beams are co-polarized and adjacent beams are cross-polarized, the adjacent beams are isolated and the composite coverage can be obtained simply by feeding a single transmitter through a four-way power splitting network to the four time-zone coverage ports on the antenna. The user on the ground will receive the same signal level as he would if the same transmitter were connected to the time-zone beam appropriate to his area, except for the -6 dB that results from the power splitting network (to first order). Near the boundaries of each time zone the contributions of the two adjacent beams will add in space quadrature and tend to make the polarization oblique with respect to the north-south or east-west directions. Users near the boundaries could maximize the signal by adjusting polarization, but if they did not, they would be only 6 dB lower in received signal for the same transmitted power. Thus, the formation of the composite beam from four time zone coverage beams with two orthogonal polarizations provides isolation for adjacent time zone coverages to maximize frequency reuse and makes the user more independent of the satellite.

There is one further advantage. Because the fields from two adjacent beams will add in space quadrature on the ground instead of directly, the fill-in beyond the bounds of the individual beams should be less than in the case where the beams are co-polarized. The coverage diagrams for the composite beams have not as yet been calculated on this basis.

2.4.4 Hawaiian Coverage

For the simplest and most direct approach to approximating the required time zone coverage, the elliptical aperture paraboloid seems appropriate. It is important to investigate the effect of going to the elliptical aperture on other beams.

The boresight position for the Hawaiian beam previously used was considered satisfactory and remains at 21°N and 158°W. The coverage obtained with a circular aperture of 9.9 feet at 4 GHz is illustrated in Fig. 21. That obtained with the selected elliptical aperture is shown in Fig. 22.

The change produced in coverage by going from the circular to the elliptical aperture proved beneficial in the Hawaiian case. While there will be a reduction in signal near the principal islands of the Hawaiian group due to the reduction in gain of the antenna itself, the elongation of the beam produced by the reduction in the north-south aperture dimension will provide better coverage of the outlying lesser islands of the group. A slight westward readjustment of the boresight would also help raise the signal at the extreme northwest end of the chain. There are, of course, no problems in fitting tne geographical shape as there were in the time zone cases.

2.4.5 Caribbean Area

The boresight position of the Caribbean beam remained at 18°N and 66°W. The coverage using the circular aperture is shown in Fig. 23 and that obtained from the elliptical aperture is shown in Fig. 24. The coverage of the Caribbean area was not improved by changing to the elliptical aperture, due mainly to the fact that the wider north-south beam increased the signal level in northern Venezuela and Columbia. From Fig. 24 it can be seen that an adjustment in the boresight position, principally in a northward direction, will improve the spillover radiation problem.

2.4.6 Alaskan Coverage

Alaskan coverage for a boresight position of 61°N and 150°W is shown in Fig. 25 and 26 for circular and elliptical aperture cases, respectively. The coverage of the main body of the Alaskan peninsula is unaffected by the change from the circular to the elliptical aperture shape, except of course for the lower gain of the elliptical antenna. The horizon line is shown on the Alaskan contours. The main body of Siberia is beyond the horizon and would not receive interference caused by radiation from the satellite. The exception is the thinly-populated Chukotskiy peninsula. Moving the satellite position approximately 9 degrees eastward would place the Chukotskiy peninsula beyond the horizon, but much more than that would tend to cut off portions of the main body of Alaska.

An attempt was made to close the -3 dB and -4 dB contours on the earth by shifting the Alaskan boresight to 53°N and 143°W. As can be seen from Fig. 27 and 28 for the circular and elliptical aperture cases, this was not successful.

Thus, the radiation into the Chukotskiy peninsula is the only problem area for the Alaskan coverage and this can be eliminated by moving the satellite position 8 to 10 degrees eastward. This would cause some changes in the time zone coverages and is not considered warranted at this time.

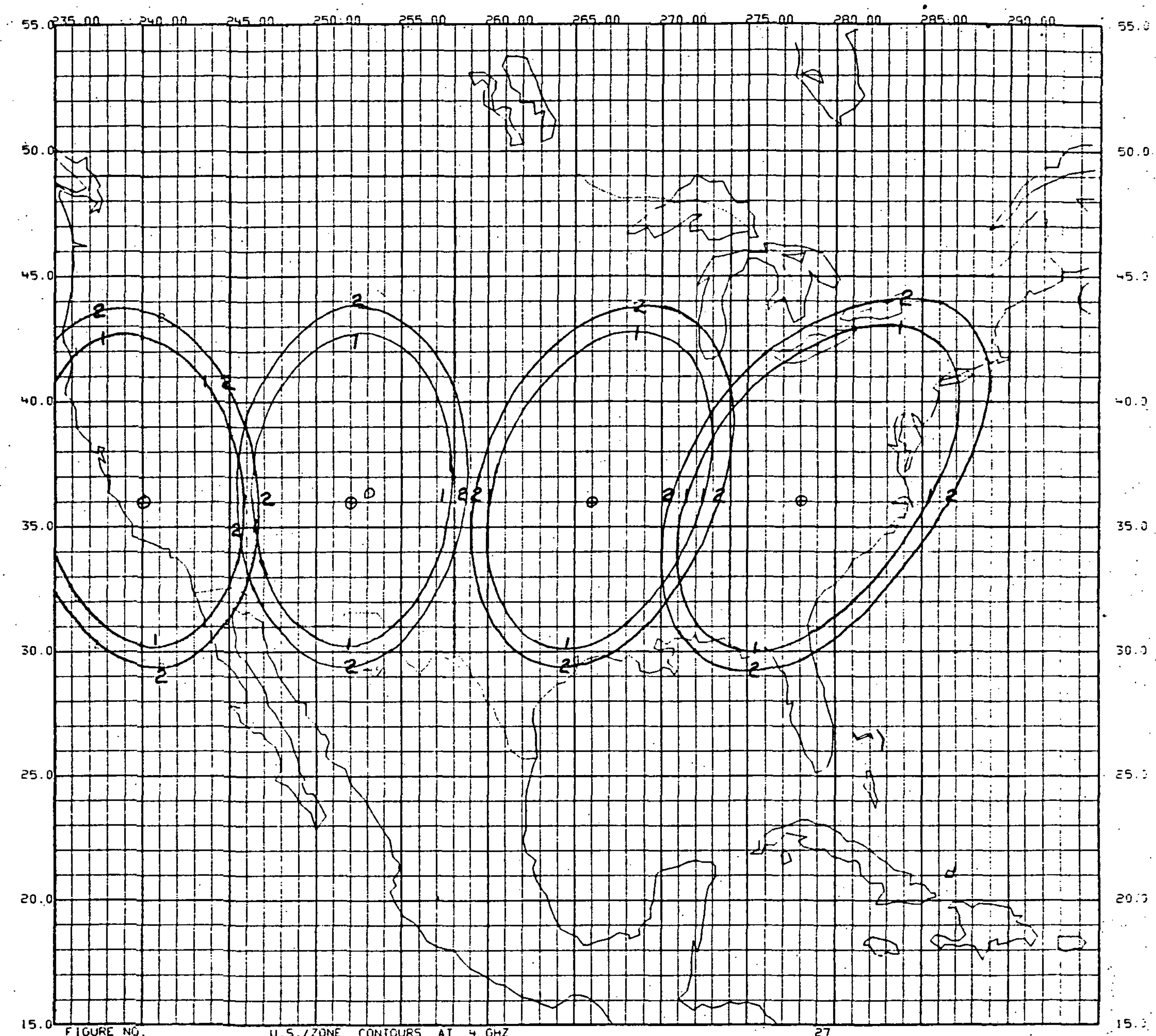

FIGURE NO. 17 U.S./ZONE CONTOURS AT 4 GHZ

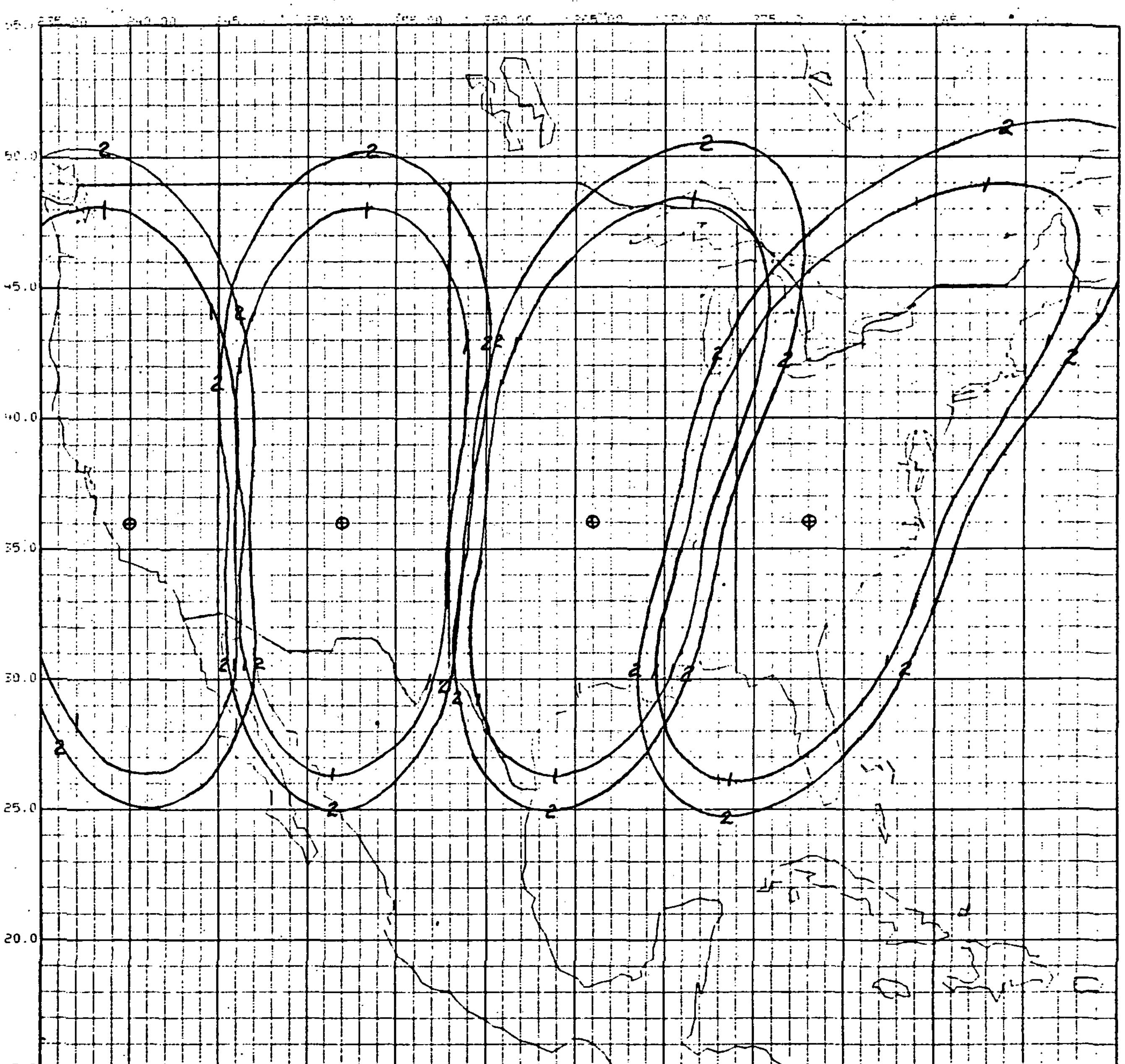

FIGURE NO. 18 U.S. ZONE CONTOURS AT 4 GHZ (ELLIPTIC PARABOLOID) 21

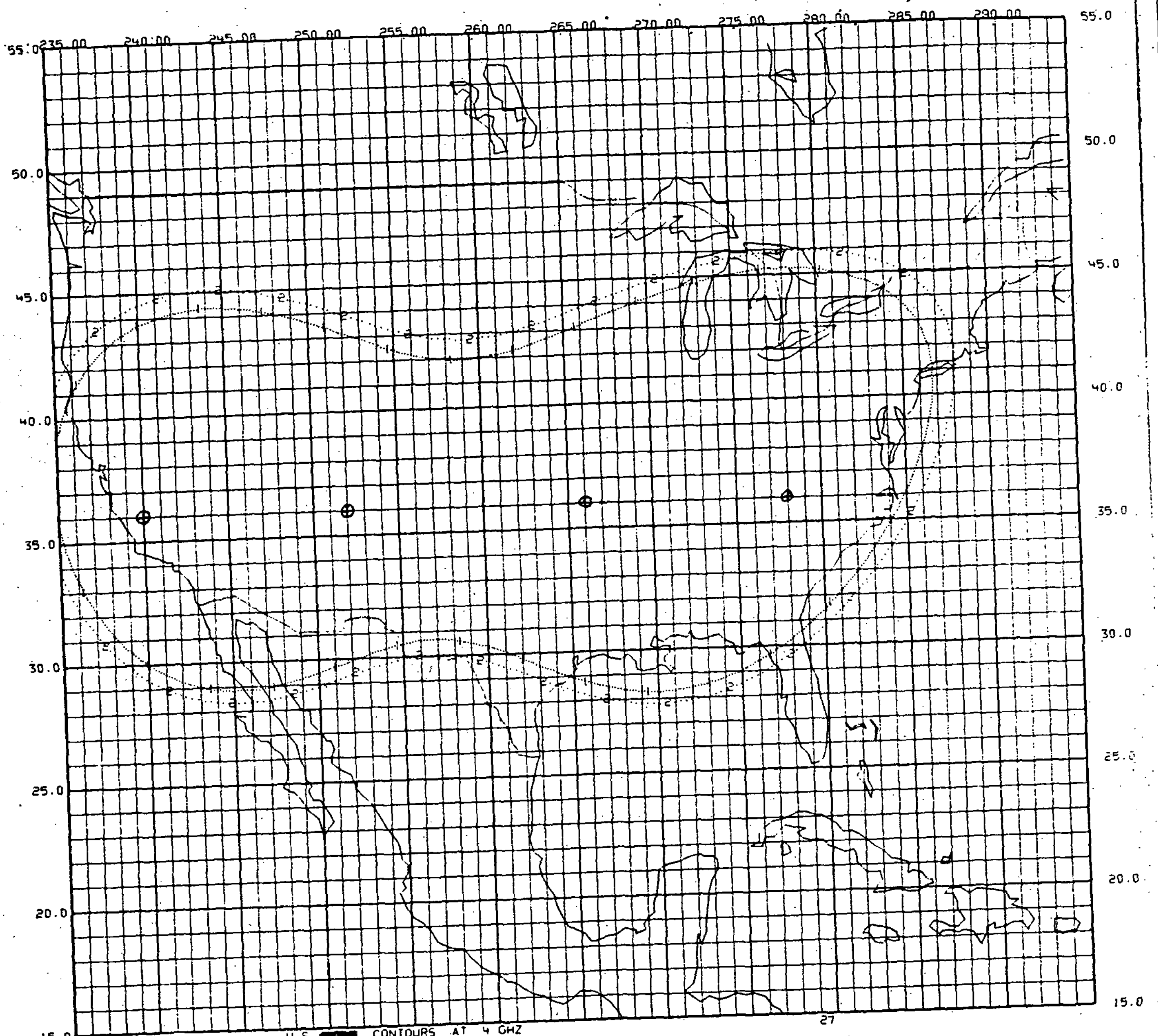

FIGURE NO. 19 U.S. [redacted] CONTOURS AT 4 GHZ

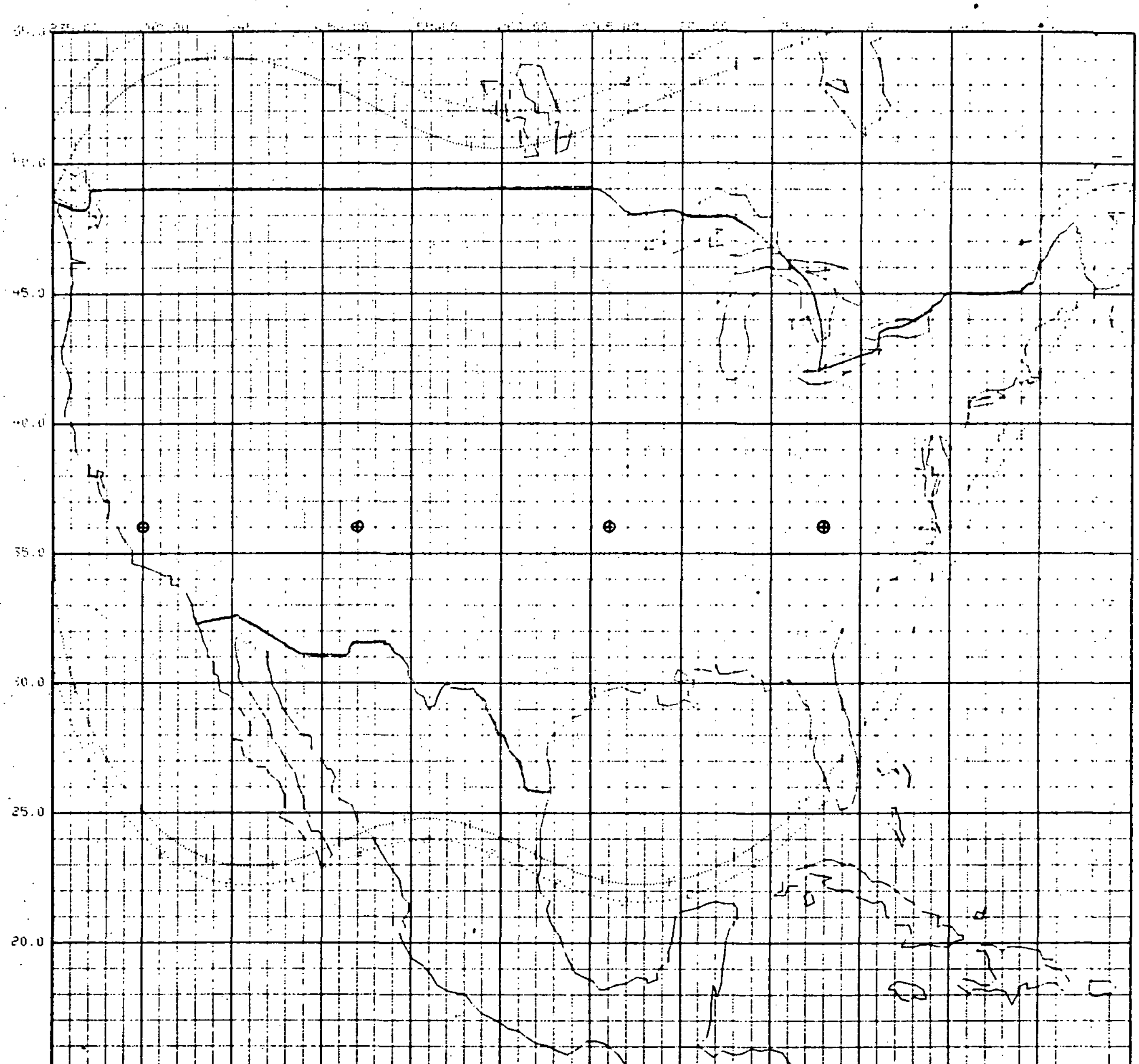

FIGURE NO. 20 U.S. [redacted] CONTOURS AT 4 GHZ (ELLIPTIC PARABOLOID) 21

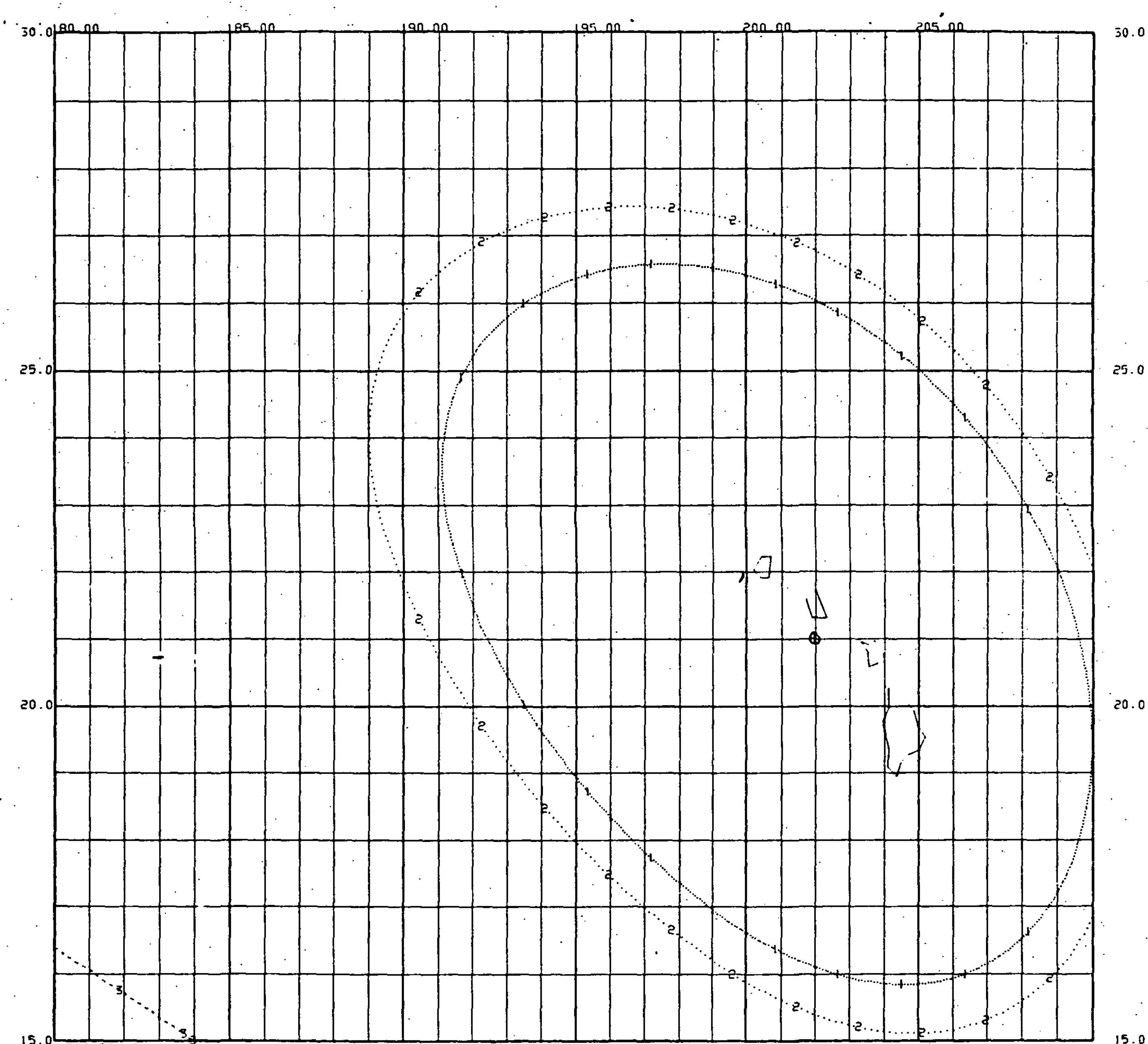

FIGURE NO. 21 HAWAII CONTOURS AT 4 GHZ

14

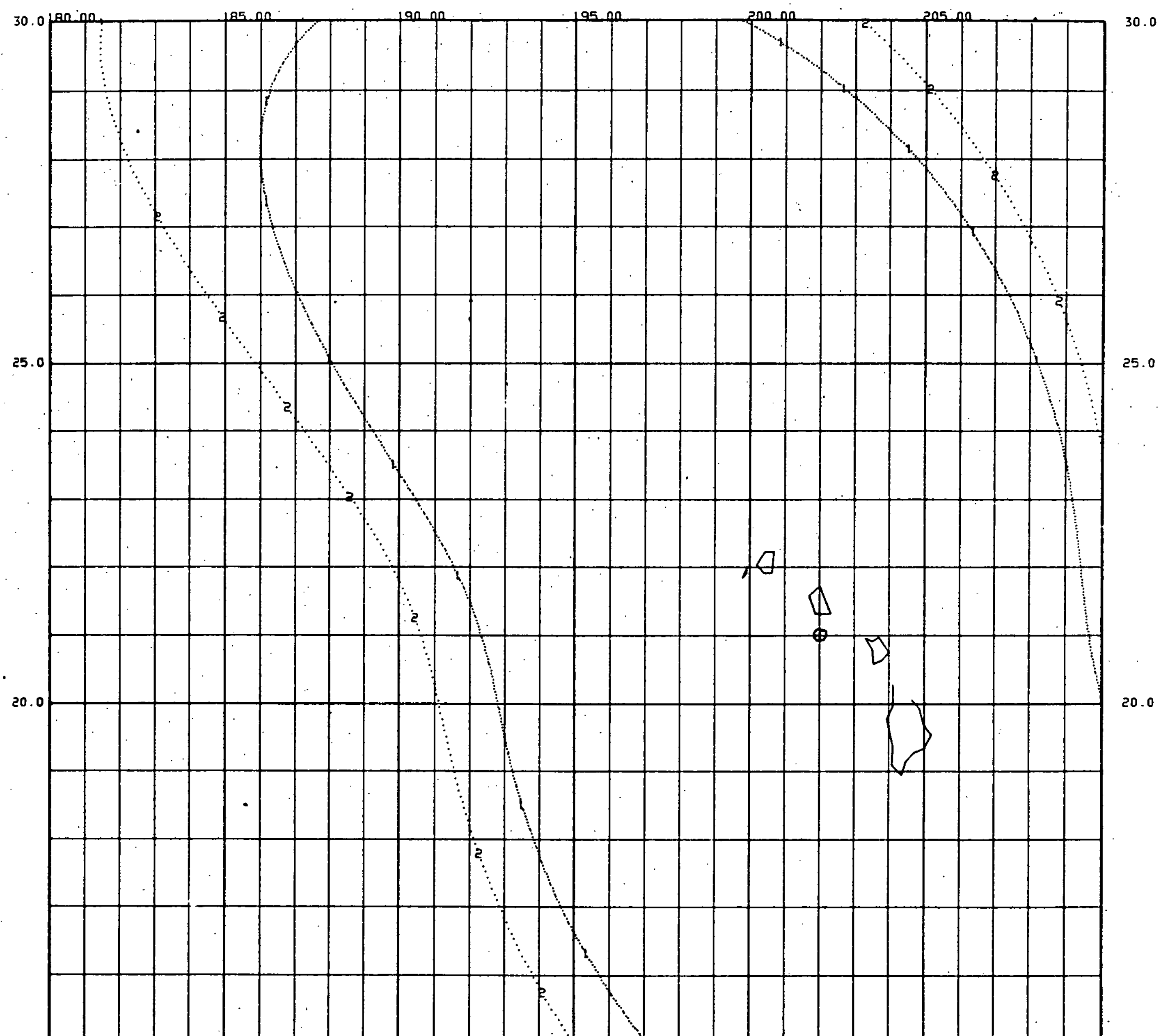

FIGURE NO. HAWAII CONTOURS AT 4 GHZ (ELLIPTIC PARABOLOID) 17

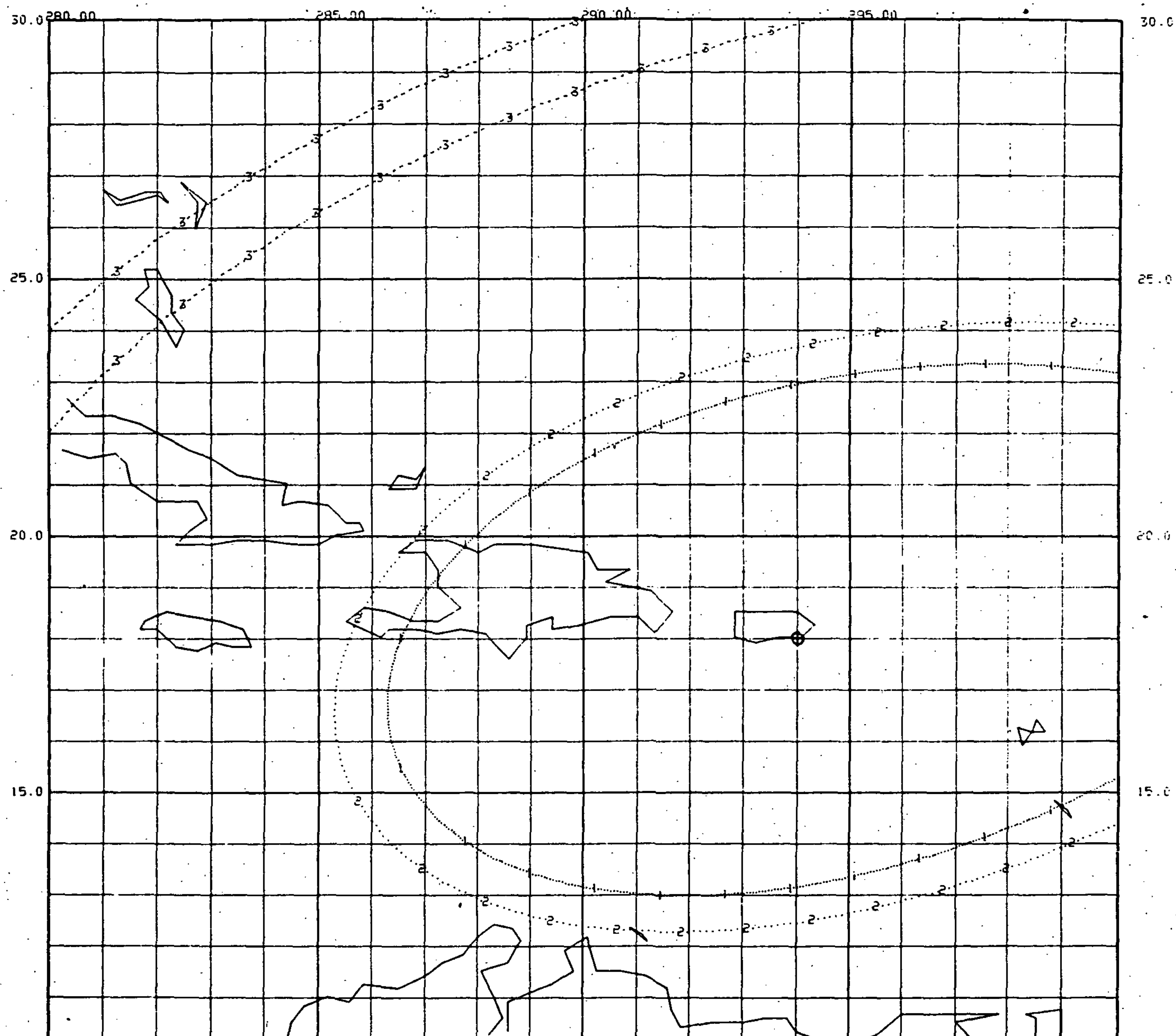

FIGURE NO. 23 CARIBBEAN CONTOURS AT 4 GHZ

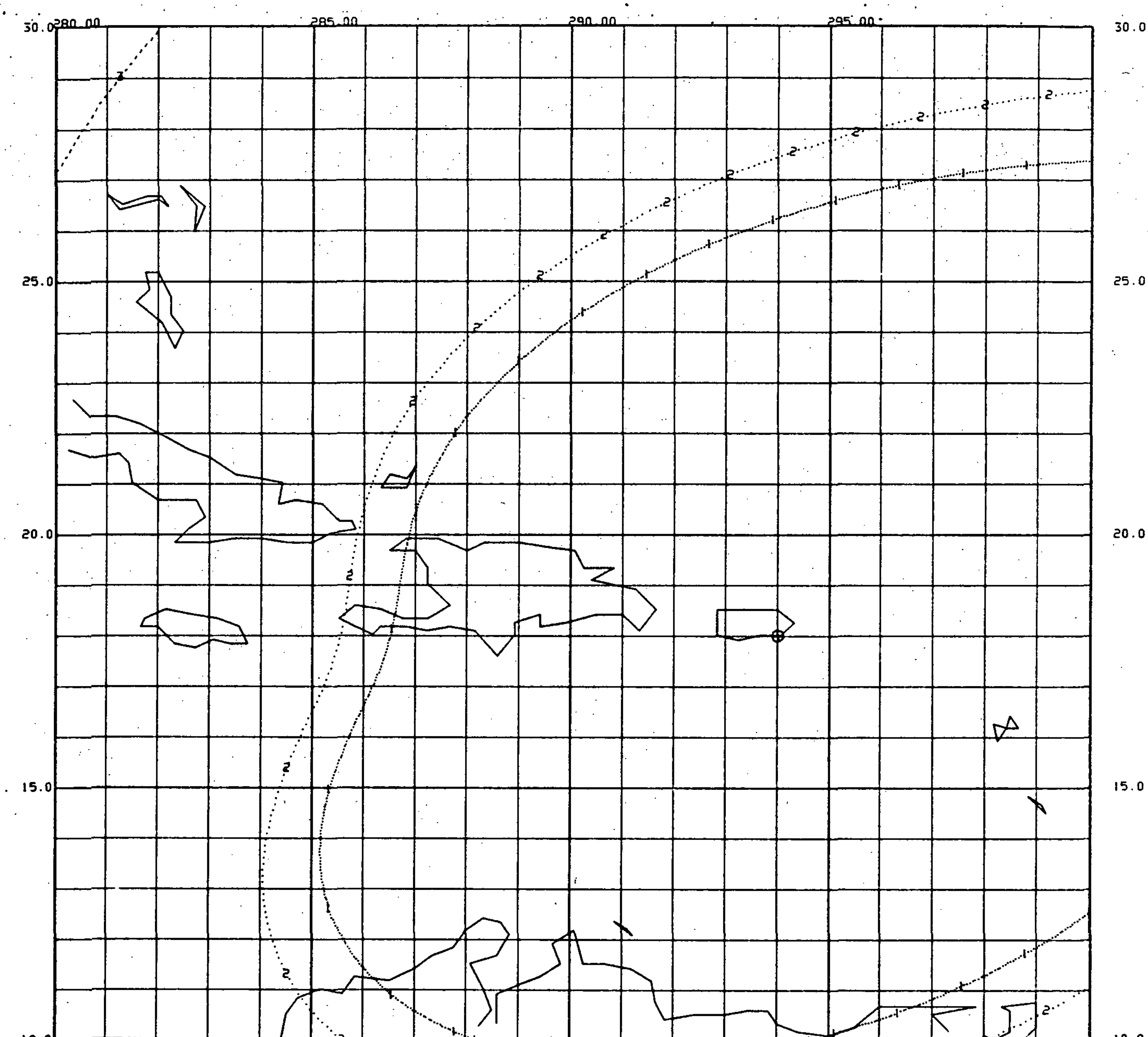

FIGURE NO. 24 CARIBBEAN CONTOURS AT 4 GHZ (ELLIPTIC PARABOLOID)

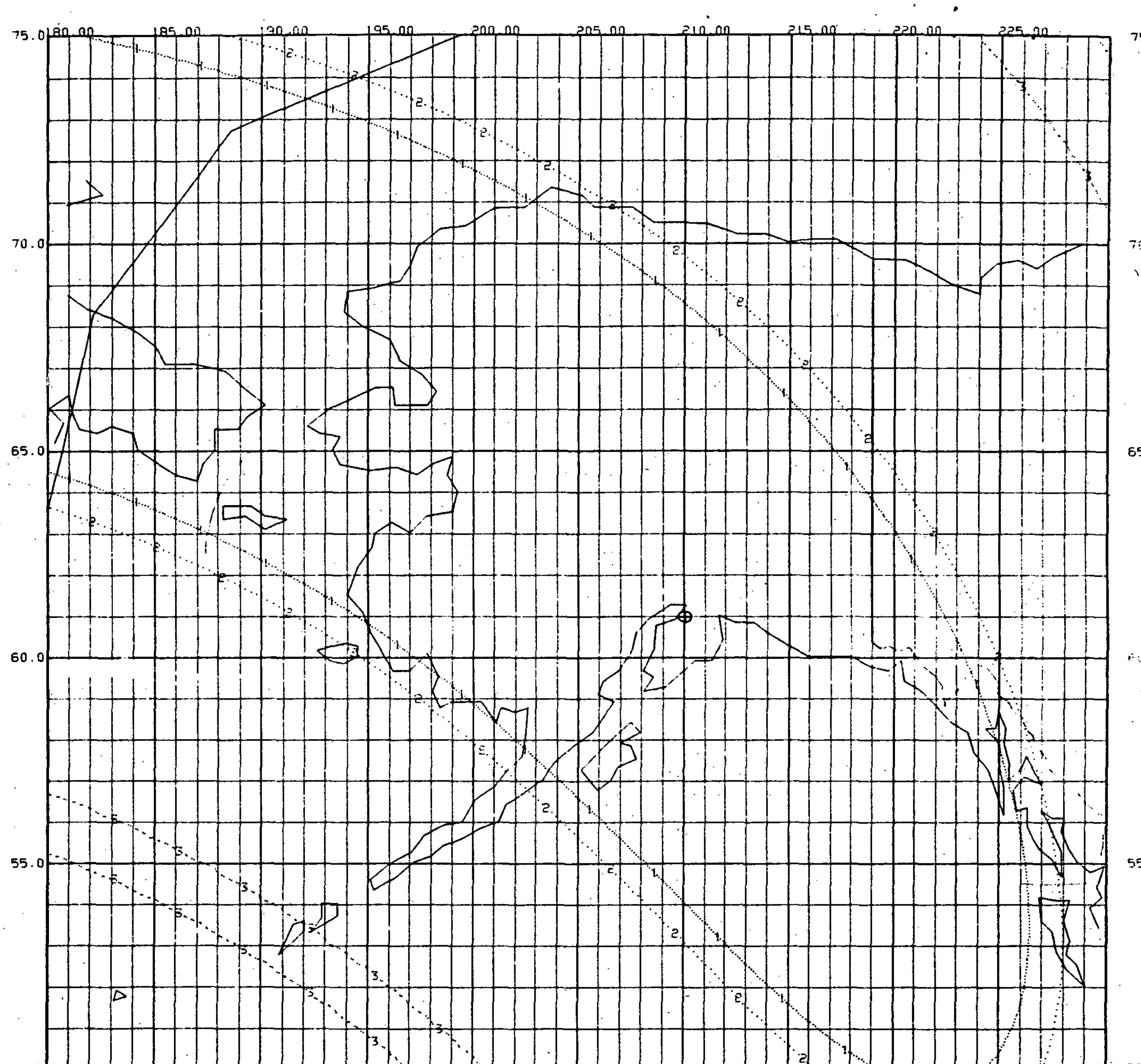

FIGURE NO 25 ALASKA CONTOURS AT 4 GHZ

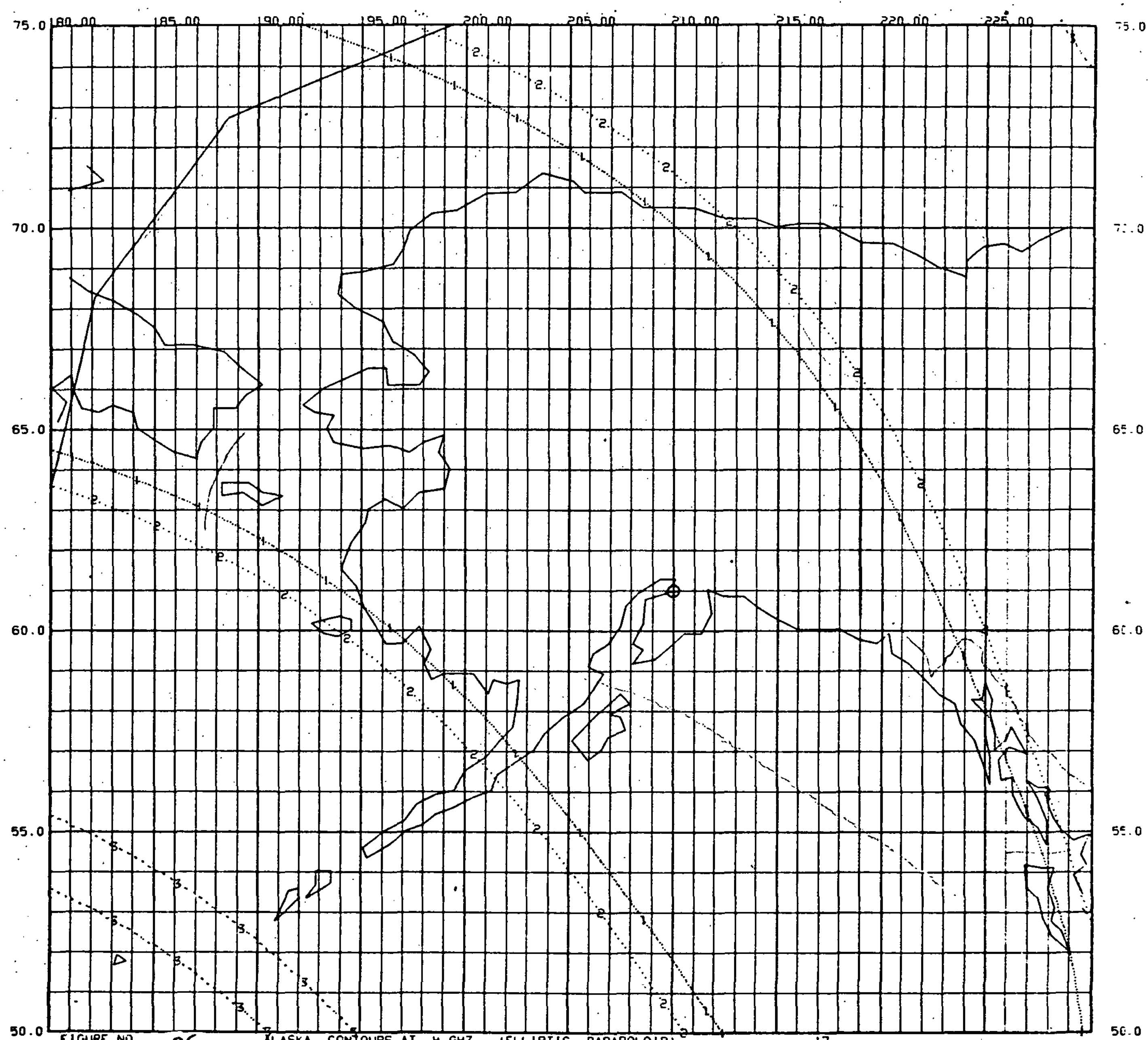

FIGURE NO. 26 ALASKA CONTOURS AT 4 GHZ (ELLIPTIC PARABOLOID) 17

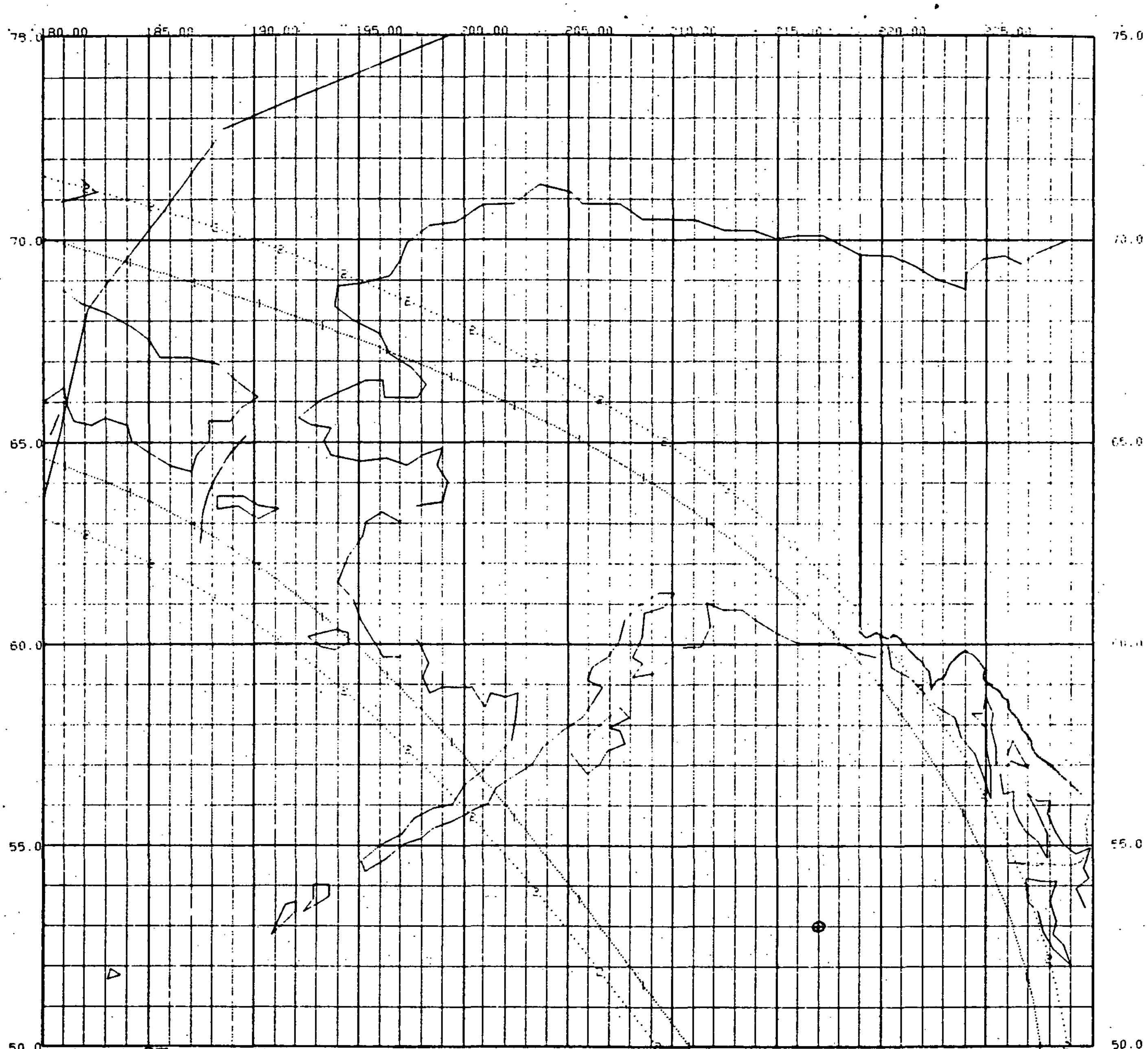

FIGURE NO. 27 ALASKA CONTOURS AT 4GHZ

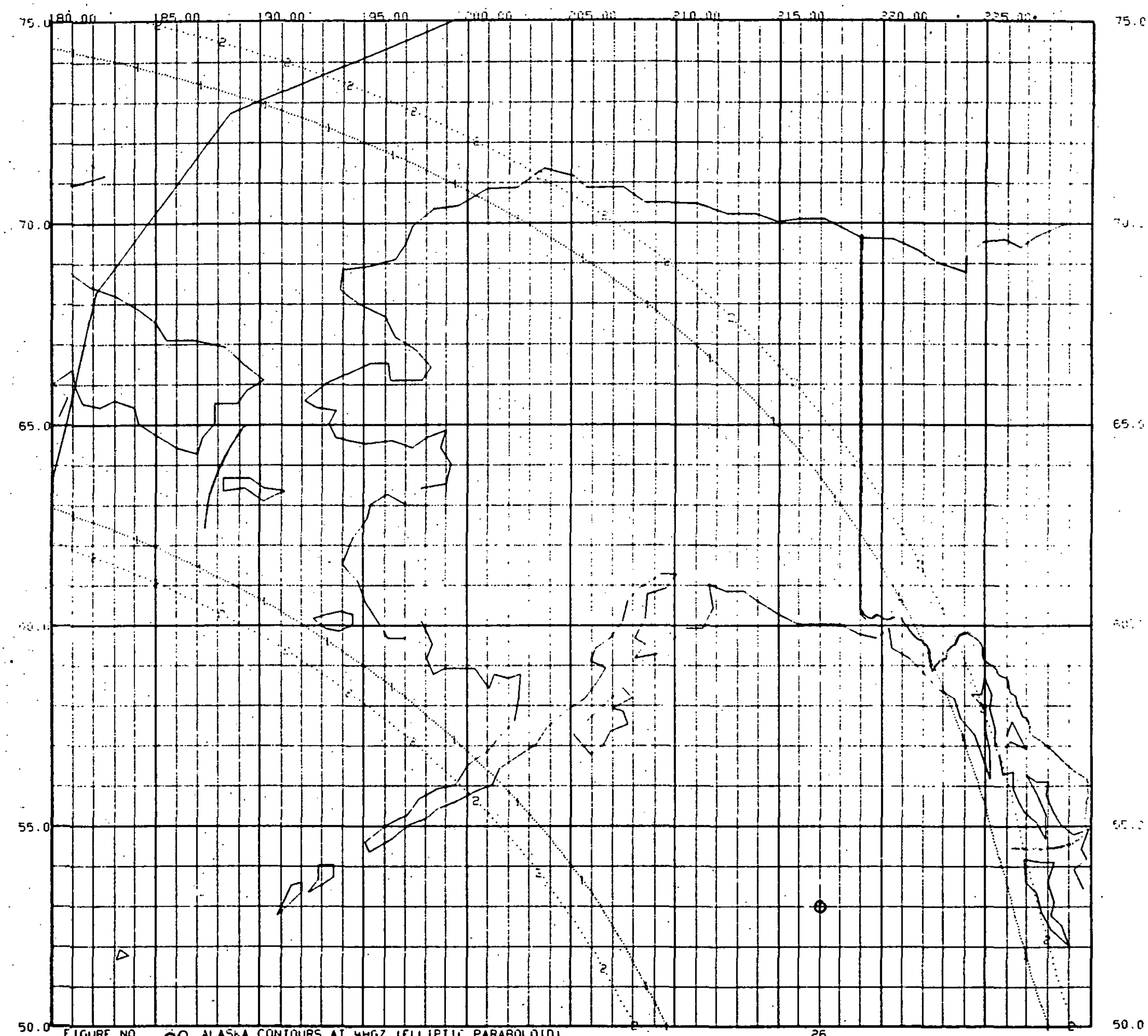

FIGURE NO. 28 ALASKA CONTOURS AT 4HGZ (ELLIPTIC PARABOLOID)

26

2.4.7 Eastern Time Zone Coverage by Beam Synthesis

Although not immediately apparent from the footprints presented herein, tne spillover into Canada and Mexico is significant for any of the simple approaches which provide the required time zone coverage. From the beams shown in Fig. 18 for the elliptical aperture, we can expect the main lobes of the time zone beams to extend from as far north as Hudson's Bay to as far south as below the Yucatan peninsula. Of course, the signal level will be falling off rapidly in the areas outside of the United States since the angular slope of the patterns increases rapidly outside of the -3 dB contours. But still quite a lot of radiation will be present in our neighboring countries.

One approach to solving this problem is to use a highly directive antenna and to synthesize the geographical coverage by combining several beams. As a trial case, we selected the Eastern time zone for study, since this represents the most difficult of the time zones to cover.

We selected the NASA ATS F and G 30-foot reflector as a candidate antenna size because it represents a technology that will be available in time for any flight experiments which would eventually result from follow-on work to this program and because making use of this reflector would capitalize on present NASA expenditures by lowering development costs and by providing a reflector with growth potential.

In regard to the growth potential aspect, it should be noted that the reflector is designed for operation at frequencies up to 8.25 GHz (although the ATS F and G experiments will not go that high) and is probably usable to at least 10 GHz. This could provide for beam synthesis techniques using a large number of beams and resulting in very good control over tne shaping of geographical areas.

Since this technique tends to drift out of the scope of what was originally intended for this program and may not really solve the Canadian problem to be discussed later, we selected a frequency of only 4 GHz for our trial analysis. Figure 29 shows the coverage that can be obtained with 10 beams from the 30-foot antenna with the actual time zone boundary shown on the map.

To form the time zone coverage beam all ten beams would be co-polarized and would be summed. The resultant time zone beam is shown in Fig. 30. The fill-in effect tends to smooth the rather scalloped appearance of the edge of the cluster of beams.

The improvement in the coverage of the Eastern time zone compared with the comparable pattern of Fig. 18 is outstanding. The coverage generally conforms to the geographical outlines of the Eastern time zone. Coverage in ocean areas is limited to the coastal waters, which is probably desirable anyway. The only significant "hole" in the coverage in this first trial is located on the upper Michigan peninsular and the upper edge of the lower Michigan peninsula. The southernmost tip of Florida and the northermost tip of Maine also are slightly outside of the -3 dB contours.

There are only two areas where there is serious encroachment on foreign territory. One is the New Brunswick province of Canada and part of Nova Scotia. It is possible that some rearrangement of the beams could improve this situation. The other area of encroachment is the triangular land mass that lies among Lakes Huron, Erie and Ontario. Illumination of this area is a consequence of attempting to provide service to the state of Michigan. If beam J could be eliminated (perhaps included in the Central time zone coverage), then the boundary of the beam would follow the contour of the international boundary down to Toledo at the western end of Lake Erie. Some movement of beam J northward may tend to produce a notch effect between Lake Huron and Lake Erie, but this would not seem to be a strong effect since fill-in occurs in this area from three beams, H, I, and J.

The general encroachment of the composite Eastern time zone beam would probably not extend northward of the 48th parallel. Beyond that line only side lobe radiation should occur. This is a signficant improvement when compared on an area basis with the case associated with Fig. 18.

If this principle is applied to the other three time zones we could expect similar improvement in the coverage and in the suppression of the radiation into Canada and Mexico. Approximately 10 beams would be required for each of the other zones. The other zones are about as wide (10 to 15 degrees in longitude) as the Eastern time zone and extend five degrees further north in latitude. Thus, if we discard beams A, B, and E, place two beams north of J and H, and place another beam in the southeastern corner next to C and D, we have the approximate coverage required for the other zones. This does not take into account the reduced beam elongation present in the other zones.

If we attempted to cover all four time zones with this beam synthesis principle in one antenna, we would need at least forty beams. The maximum offset is of the order of 5 to 6 beamwidths for the Main beam (A) with the reflector axis pointed at Salt Lake City. Coverage of the Hawaiian and Alaskan sectors would require larger offsets in terms of beamwidths and would experience some degradation.

The improvement in coverage and in suppression of radiation outside the United States is excellent, but it is achieved at the cost of added weight and complexity. Forty-odd feeds in the NASA ATS F and G reflector would not be out of the question, but this does represent a significant increase in the degree of difficulty in designing the radiating system and the associated feed matrix. The added complexity would also open up new possibilities of greater utility and flexibility at the same time. For example, while all the ten beams of the Eastern time zone are combined at one frequency for time zone coverage, they could be used individually at other frequencies for spot beam coverage of local areas within the Eastern time zone.

An alternate to a single antenna might be to use four 30-foot reflectors on a single vehicle to cover each of the time zones (or two for the eastern and western pairs of time zones) with perhaps a smaller reflector for coverage of the outlying areas. This option would not be within the scope of the present project, but it may offer a method of reducing the complexity per antenna and of reducing the beam offset required to improve performance.

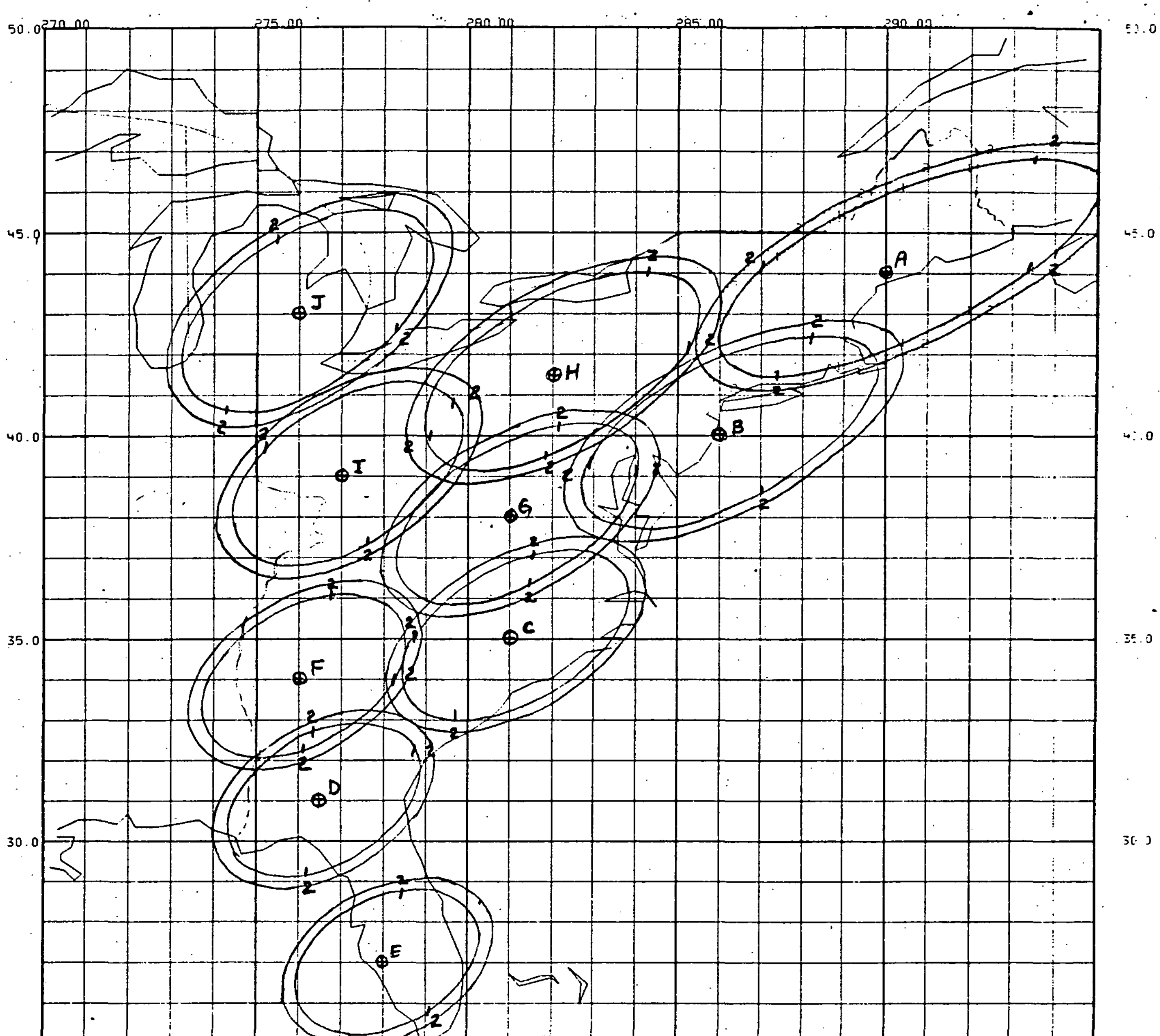

FIGURE NO. 29 U.S. EASTERN TIME ZONE (30 FT REFLECTOR) - MULTIPLE BEAMS 08

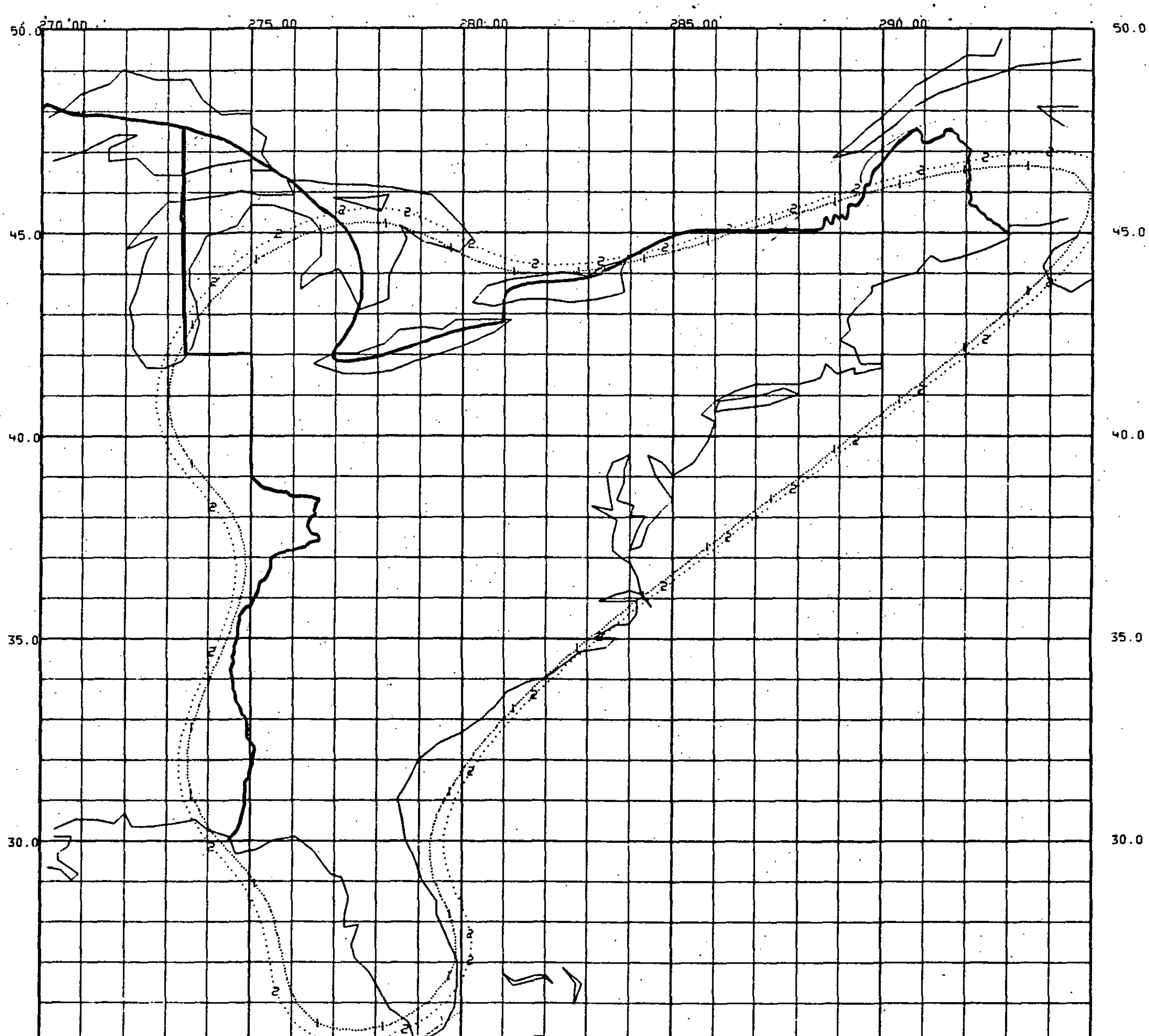

FIGURE NO 30 U.S. EASTERN TIME ZONE (30 FT REFLECTOR) - BEAMS SUMMED

2.5 The Coma Problem

The generation of coma lobes when the feed of a paraboloidal reflector antenna is moved off axis is a well-known problem and one which will have a significant effect on design and performance of the multiple beam antenna system. Although quite a serious problem, it is not considered critical in that it does not have the same bearing on selection of the basic concept as does the problem of suppressing radiation into Canada.

As the feed is moved off axis in a paraboloidal antenna system, the beam emanating from the reflector degrades. The gain decreases, the beamwidth increases, and on the axis side of the main lobe coma lobes appear. In general, the beamwidth and gain is not a problem for coverage of the 48 states. The increase in amplitude of side lobes will affect isolation between the various time zone beams and the formation of the composite beam for the U. S. coverage.

For time zone coverage using the approach of Fig. 18 with the small elliptical reflector, the beam offsets required are -.6, +.4, +1.4, and +2.4 from west to east. With alternate beams co-polarized and separated by about 2 beamwidtns, there is likelihood of interference between co-polarized beams through these coma effects.

For the Eastern time zone beam of Fig. 18 at about a +2.4 beamwidth off-axis displacement, the side lobe is about -14.4 dB and occurs at +1 beamwidth from the axis. The side lobe will then be at the very edge of the Mountain zone coverage (which is co-polarized with the Eastern zone coverage), and may cause interference as high as 14.4-3 = 11.4 dB. There may be some variation in position and/or level of these side lobes as a function of feed type of F/D ratio, but the possibility of interference is certainly present. For the Hawaiian beam which would probably be offset about -4.6 beamwidths, the side lobe is quite high (-10 dB) but falls upon the ocean without causing trouble. Displacements for Alaskan and Caribbean coverages are not in the same plane of displacement required for time zone coverages and may not cause trouble to the patterns, but further analysis is needed to verify this.

If all time zone beams are co-polarized, it is certain that the lobe resulting from the displacement needed for Eastern zone coverage would interfere with either the Mountain or Central time zone patterns, depending on its exact location. This confirms the need for two polarizations. If two polarizations are used and the interference between co-polarized beams is acceptable, then at most two frequencies would be needed for the system.

If the reflector is viewed in the receiving sense, then if a plane wave is incident on the reflector at some small angle with respect to the reflector axis, there exists an area in the focal region where essentially all of the power is available. In an optic sense this area degenerates into a point when the wave is incident along the axis. Thus, for reasonable offset, it should be possible to place a feed large enough to intercept nearly all of the power resulting from an off axis wave. If the energy collected is then corrected in phase, then nearly full gain should be realized and consequently less of the energy should go into the side lobe.

The trouble with this approach is that it may require a large (as well as complex) feed. For the time zone coverage patterns where beams are closely spaced, there would be physical interference of the correcting feeds, according to preliminary estimates. Unfortunately, this is where the correction is most needed. For the coverages of outlying areas (Hawaii, etc.) it might be possible to provide the feed aperture necessary, but even though the coma effect is more severe in this case, its effect on performance is lessened, as mentioned above.

2.6 Spillover

The potential spill-over into the contiguous nations of Canada and Mexico presents a critical problem area. This problem arises because of the significant population density on both sides of the U.S.-Mexico and U.S.-Canada borders, particularly the latter. The U.S. cities and towns in the border regions would expect service from a domestic multi-purpose communications satellite. At the same time Mexican and Canadian cities in the border regions may object to the use of these frequencies inside their borders.

The population of Mexico is 48,313,438 (1970 census) of whom about one million live in border towns (Tijuana, Nogales, Juarez, Laredo, etc.). Within about 100 miles of the border there are a number of cities, notably Monterrey (pop. about 400,000). However, the border area contains less than 10% of the population. There are, however, a number of U.S. cities near the Mexican border (San Antonio, El Paso, Tucson, Phoenix, and San Diego alone total nearly three million) which cannot be neglected.

While the population of Canada (21,324,000 by 1970 estimate) is much less than that of Mexico the problem is more acute. It is estimated that 70% of Canada's population resides within 100 miles of the U.S. border. The seven most populous metropolitan areas (Montreal, Toronto, Vancouver, Winnepeg, Ottawa, Hamilton, Quebec) are close to the U.S. border and contain 7,353,000 people. The twenty-One largest metropolitan areas contain 10 million people of whom 86% reside within 100 miles of the U.S. border. This location of the people along the border is illustrated in Fig. 31 which shows the density distribution of population. The high density of population along the Great Lakes and St. Lawrence River, almost all close to the border, is significant in the context of spill-over.

Now the length of a meridian of the Earth (360° great circle through the geographic poles) is 24,860 statute miles. Thus, 100 statue miles in a North-South direction is about 1.5° of latitude. The beamwidth (angle) between latitudes Γ_1 and Γ_2 for a synchronous satellite is given by

$$\gamma_d = \gamma_2 - \gamma_1$$

$$\gamma_2 = \frac{r \sin \Gamma_2}{(h+r) - r \cos \Gamma_2}$$

$$\gamma_1 = \frac{r \sin \Gamma_1}{(h+r) - \cos \Gamma_1}$$

where r is the Earth radius (3440 nautical miles)

h is the height of the satellite above the Earth's surface (19370 nautical miles)

The Canadian border from longitude 95°W to Vancouver lies along the 49th parallel. The Vermont-Quebec border lies along the 45th parallel.

For $\Gamma_1 = 45^\circ$ $\Gamma_2 = 46.5^\circ$ $\gamma_2 - \gamma_1 \approx 10' = 0.167^\circ$

$\Gamma_1 = 49^\circ$ $\Gamma_2 = 50.5^\circ$ $\gamma_2 - \gamma_1 \approx 8' = 0.133^\circ$

These two lines of latitude will suffice to examine the practicality of providing a beam with a sufficient rate of fall off in gain ("skirt").

If we wish the signal level to fall from -3 dB at the border to the first null 1.5 degrees north of the border (i.e. 100 miles inside Canada) we need a reflector which provides such a signal fall off within about 0.14 degrees (see Fig. 32). That is, the beamwidth between the first nulls shall be 0.28 degrees wider than the beamwidth between the -3 dB points. At 4 GHz this implies a reflector of about 60 ft. diameter. However, this means that the signal falls off in about 100 miles and is therefore significant within approximately the first 50 miles of the border which encompasses Montreal, Toronto and Vancouver, and some other cities.

While a reflector of 60 ft. in diameter is not outside the limits of present technology, it is worth noting that this fall off rate (0.14 degrees of beam in 1.5 degrees of latitude) is provided by a 27 ft. reflector at 9 GHz - that is scaling the 60 ft. reflector from 4 GHz to 9 GHz. Thus, the NASA ATS F&G 30 ft. reflector at 9 GHz would provide slightly better fall off so that the null would fall a little less than 100 miles from the U.S.-Canadian border. It should be noted that a 30 ft. reflector operating at 9 GHz would need more beams to cover the Eastern time zone than the ten beams, for 4 GHz operation, shown in Fig. 29.

Now considering the elliptical paraboloidal reflector with a north-south diameter of 5.8 ft., the beamwidth from the -3 dB level to the first null is approximately 1.5 degrees. At a rate of about 0.14 degrees of beam for 1.5 degrees of latitude this means that 1.5 degrees of beamwidth is equivalent to approximately 16° of latitude. Thus, if the -3 dB contour of the 5.8 by 9.9 ft. elliptical reflector falls on the 49th parallel, the null lies at about the 65th parallel. Therefore, a large portion of Canada is illuminated by signals of a significant level.

For a circular paraboloid of 9.9 ft. diameter the beamwidth from the -3 dB level to the first null is approximately 0.9 degrees which corresponds to about 10.5 degrees of latitude. Thus, in this case if the -3 dB contour fell at 49°N the null would be at 59.5°N, which still implies considerable illumination of the populated areas of Canada.

Returning to a reflector which yields a fall off from the -3 dB contour to the first null in 100 miles (1.5 degrees of latitude), to achieve the potential promised by the reflector's pattern characteristics, a stabilization rate much better than the gain fall off rate will be needed. This would not be needed of all the beams covering a single time zone nor of those which spill over into lightly populated Canadian border areas. However, it would be required of those beams illuminating heavily populated Canadian border areas, otherwise there is little value in developing such an antenna system. Therefore, monopulse self-steering of at least those beams illuminating populated border areas is imperative.

Even if an antenna (and corresponding pointing accuracy) which provides good isolation of Montreal, Toronto and Vancouver, can be developed there remains the fact that isolation between, say Detroit and Windsor, is not a practical possibility at this time.

The illumination of Canada therefore becomes a matter of considering the percentages. By this one means the percentage of population and not of land area. Spill over into agricultural land in the prairies is of no great importance compared with the repercussions of spill over into the large metropolitan and industrial areas of Southern Ontario and Southern Quebec. Reduction of spill over in these highly populated areas may be essential to international harmony. In other words, technical design considerations- and indeed cost-may be subservient to political considerations. If the cost of trying to isolate Canada is deemed to be too high by the government it may be considered advisable to employ the single 5.8 x 9.9 ft. elliptic paraboloidal reflector.

Canadian satellites have already been placed in orbit and undoubtedly Canada is planning to develop communications satellites along the same lines as the United States. It is quite probable that they will eventually wish to use the same frequencies as those employed by the U.S. Isolation by frequency diversity does not, therefore, appear to be a suitable alternative.

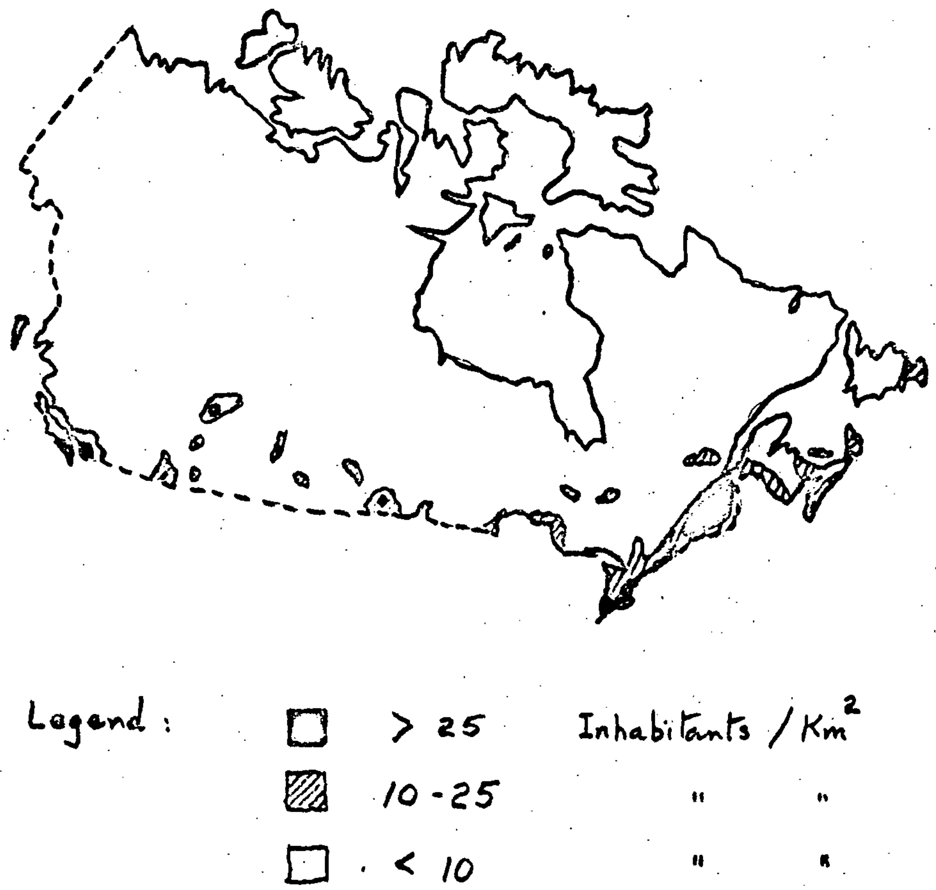

FIGURE NO. 31 POPULATION DISTRIBUTION OF CANADA

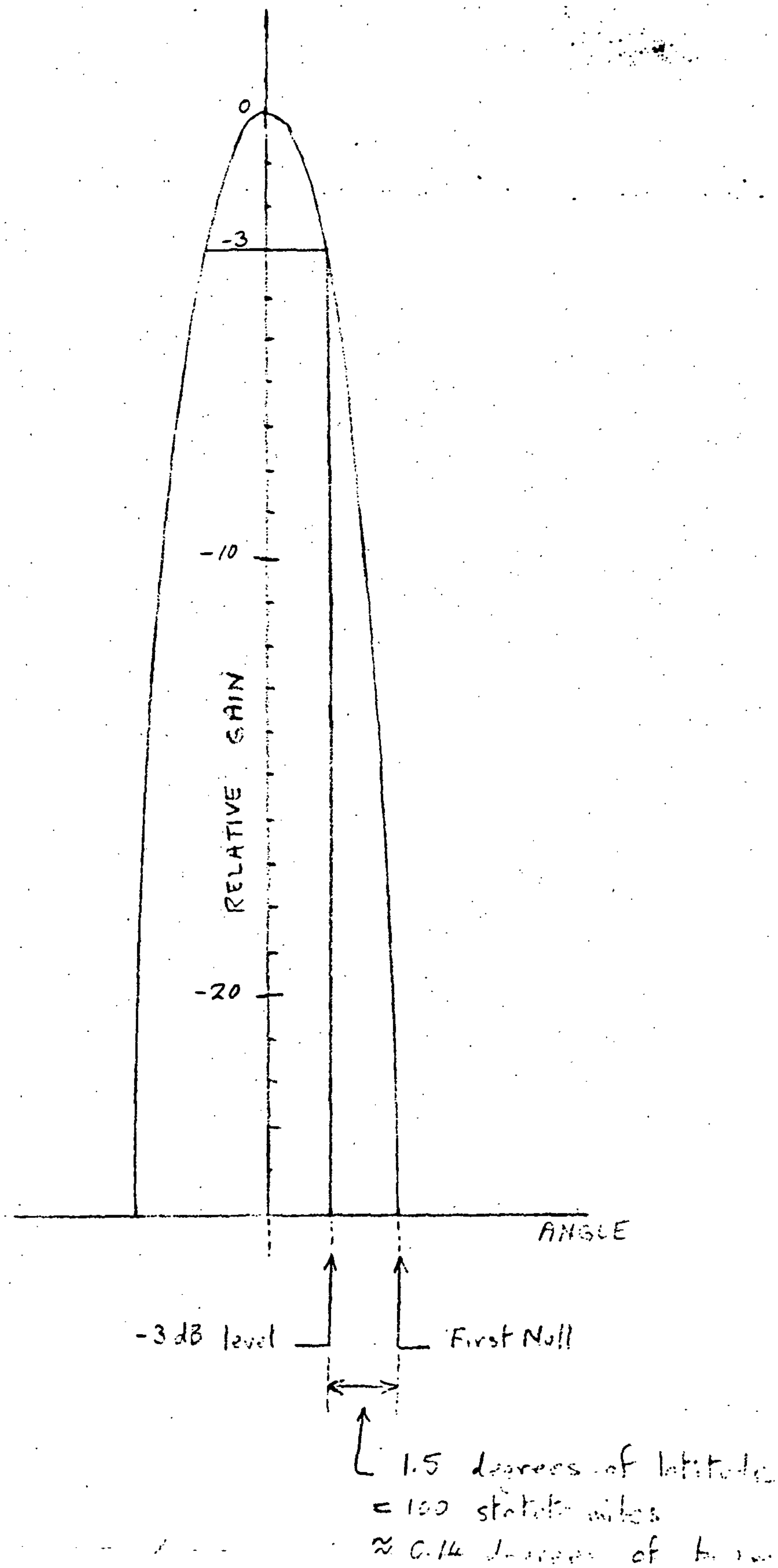

FIG. 32. DESIRABLE FALL-OFF IN CANADIAN BORDER

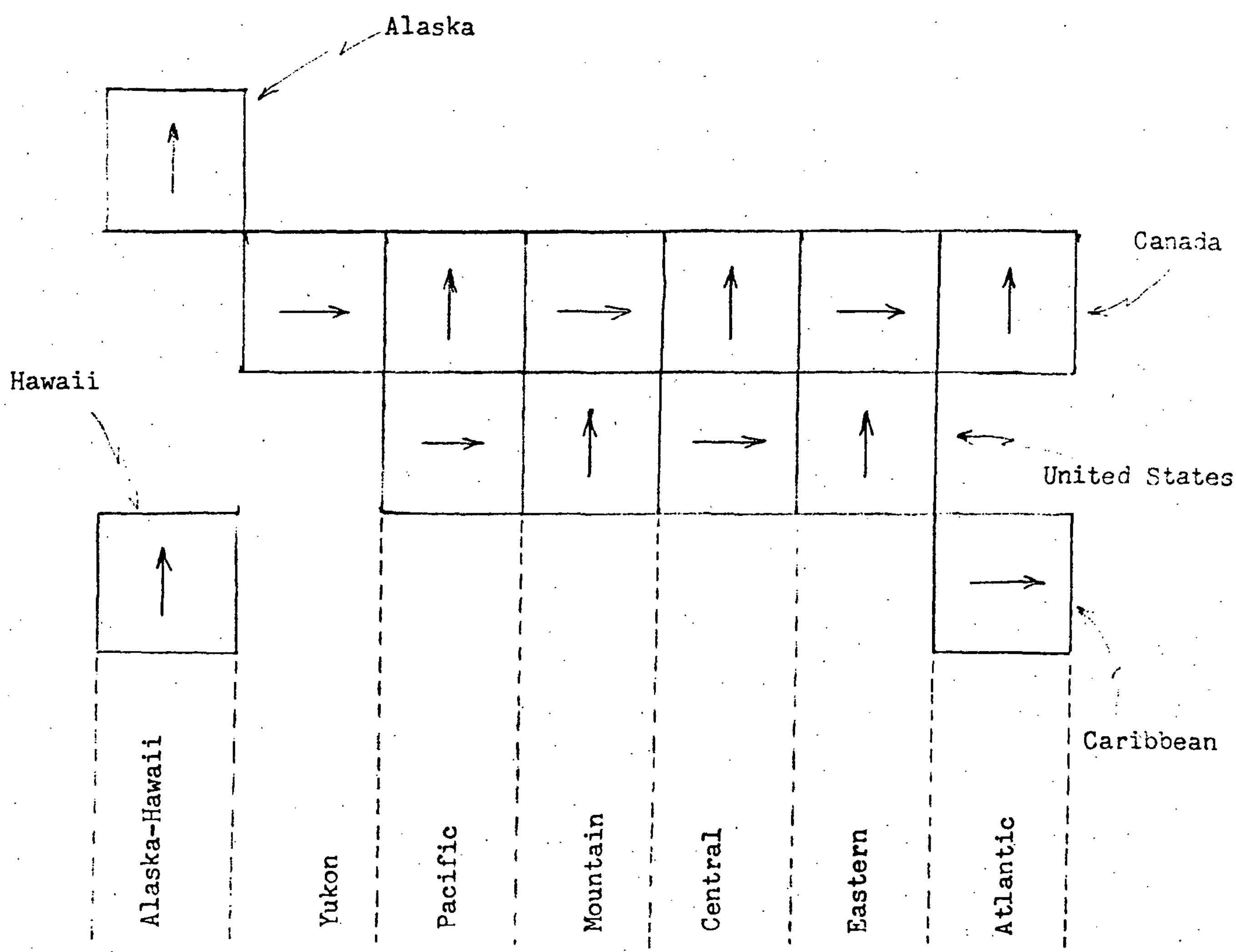

FIG 33 Polarization Diversity for Canadian and U.S. Time Zones

If a satellite uses a low gain antenna and the ground station employs a high gain antenna with a narrow beam it is then possible for a ground station to discriminate between two satellites transmitting the same frequencies from different locations. Thus, 4 GHz could be transmitted by both U. S. and Canadian satellites, somewhat separated, and ground stations in Detroit and Windsor could receive from the U. S. and Canadian satellites, respectively, without interference from the other. This implies highly directive and more expensive ground station antennas. This is a most unlikely alternative in view of the number of ground stations which may eventually be located within Canada and the Unites States; the cost would become prohibitive.

The most promising scheme for isolation between Canadian and U. S. satellites is the use of polarization diversity. The Canadian time zone boundaries are at approximately the same lines of longitude as the U. S. time zones. It may be possible to arrange that the U. S. and Canada use orthogonal polarization for each time zone as shown schematically in Fig. 33. 32

This scheme appears to have some potential particularly in solving the problem of spillover into the Southern points of Ontario and Quebec (both in the Eastern time zone). There appears, from the schematic diagram, some possibility of spillover from a U. S. time zone into the next time zones of Canada. For example, there might be spillover from the U. S. mountain time zone into the Canadian Pacific and Central time zones. The elliptical shape of the contours, however, causes in some cases a "clipping" of the corners of the time zones, thus reducing the possibility of this type of spillover. One place where this could be a problem is on the eastern border of Maine. The Canadian provinces of New Brunswick, Nova Scotia and Prince Edward Island, together with the Gaspé Peninsula of Quebec, are in the Atlantic time zone. Spillover from the U. S. Eastern time zone would interfere with a Canadian satellite transmitting to Canada's Atlantic time zone, as indicated in Figs. 13 and 30, whether an elliptic or a large circular parabolic reflector is used.

2.7 Elliptical Reflector Evaluation

It was now decided to evaluate a 9.9' x 14' elliptical aperture paraboloid. The 14' aperture dimension was selected because its larger beamwidth would cover the desired coverage areas with fewer feeds.

Without going to a much large diameter (such as 20 or 30 ft) the East-West reflector diameter of 9.9 ft has been found to be a good compromise for the time zone coverage. It is too small for the Eastern and Pacific Time Zones, but the spillover can be directed into tne Atlantic and Pacific Oceans, respectively, which may, indeed, be an advantage in that it would provide some maritime coverage. The 9.9 ft diameter is a little too small for the Mountain Time Zone (but spillover into the adjacent time zones can be separated by polarization diversity) and about right for the Central Time Zone.

Figs. 34 and 35 show the component beams for the Pacific Time Zone with respective boresights at:

43.5°N	120.0°W	(Central Oregon)
34.5°N	120.0°W	(Near Santa Barbara, California)

Fig. 36 depicts the composite contours of these two beams. There is virtually no spillover of the -4 dB contour into British Columbia and very little of the -3 and -4 dB contours into Baja California Norte. In both cases the spillover can be reduced by moving the appropriate component beam's boresight away from the international boundary. There is a slight "clipping" of the North-East corner of tnis time zone, in the sparsely populated area where Idaho borders on Canada. However, in regions such as this there is much less interference than in a metropolitan area and a somewhat lower signal level is often quite acceptable. There is a considerable spillover into the Mountain Time Zone (as wll as the Pacific Ocean) but this can be separated by polarization diversity.

The component beams for the Mountain Time Zone are shown in Figs. 37 and 38 with respective boresights located at:

43.5°N	108.0°W	(Central Wyoming)
34.5°N	108.0°W	(Southwest of Albuquerque, New Mexico)

The composite contours of these two beams are illustrated in Fig. 39. There is very slight spillover of the -4 dB contour into Saskatchewan and of the -3 and -4 dB contours into Mexico between Nogales and Juarez. This is considerable less than the spillover of the 9.9 x 5.8 ft. elliptical reflector. It can be reduced by moving the boresights slightly awary from the international boundaries, but this would increase the "clipping" of the corners of the time zone.

Component beam contours for the Central Time Zone are depicted in Figs. 40 and 41 with respective boresights situated at:

42.0°N	94.0°W	(Central Iowa)
33.0°N	94.0°W	(South of Texarkana, Arkansas)

The composite contours are shown in Fig. 42. There is no spillover of the -3 and -4 dB contours into Canada and Mexico but this is at the expense of more extensive corner clipping than was experienced in the Pacific and Mountain Time Zones. The areas suffering this "clipping" are:

North Dakota, Western South Dakota and Northern Minnesota, Southwest Texas including San Antonio and Brownsville, Southern Alabama

These three regions represent a fair amount of degraded coverage on an area basis and some coverage on a population basis. This loss of coverage can be decreased somewhat by changing the boresights to the two component beams, but probably at the expense of some more spillover into the two contiguous foreign countries. Spillover into adjacent time zones is not extensive and can be separated by use of orthogonal polarizations in these areas.

The component beam contours for the Eastern Time Zone are shown in Figs. 43 and 44, the respective boresights being

41.0°N	79.0°W	(West Central Pennsylvania)
31.0°N	80.0°W	(Off the Coast of Georgia)

Composite contours are depicted in Fig. 45. There is considerable spillover into the sourthern parts of the Canadian provinces of Ontario and Quebec, which are densely populated. This is a continuing problem in all candidate configurations which have been considered. The penalty incurred in reducing the spillover is a reduction in the coverage of Michigan. Since even this reflector (9.9 x 14.0 ft) and boresight (41°N, 79°W) places northern Michigan and its upper Peninsula outside the -4 dB contour, any further reduction in the Michigan coverage may not be acceptable. One solutions may be to place the Michigan coverage in the Central Time Zone and Fig. 42 shows that this is a feasible alternative.

In addition to the problem of Michigan, part of Maine bordering on New Brunswich, and Southern Florida fall outside the -4 dB contour. The border area of Maine is sparsely populated and may still receive a satisfactory signal, but the uncovered Florida area includes Miami and is large enough to demand some attention. Moving the boresight of the second beam from 31°N to about 29°N will probably resolve this problem, but it will cause some spillover into the Bahamas. Some spillover into the Central Time Zone exists but, once again, the effect of this is avoided by use of orthogonal polarizations.

Coverage of the contiguous forty-eight states will be provided by dividing power to the four time zone beams. This coverage is represented by Figs. 36, 39, 42 and 45.

Coverage of Alaska is illustrated in Fig. 46. The boresight of 61°N, 150°W (near Anchorage) was used again as no advantage could be found in changing this location. As with the previous configurations considered there is some spillover into the Chukotskiy Peninsula of Siberia and into the south western part of the Yukon and orthwestern part of British Columbia. None of this is serious from the density of population viewpoint and does not warrant changing of the beam's boresight.

Coverage of the Hawiian Islands is shown in Fig. 47. The boresight position for the Hawiian beam previously used was considered satisfactory and remains at 21°N, 158°W (near Pearl Harbor). As with previous candidate configurations the coverage of the principal islands is complete with no spillover problem.

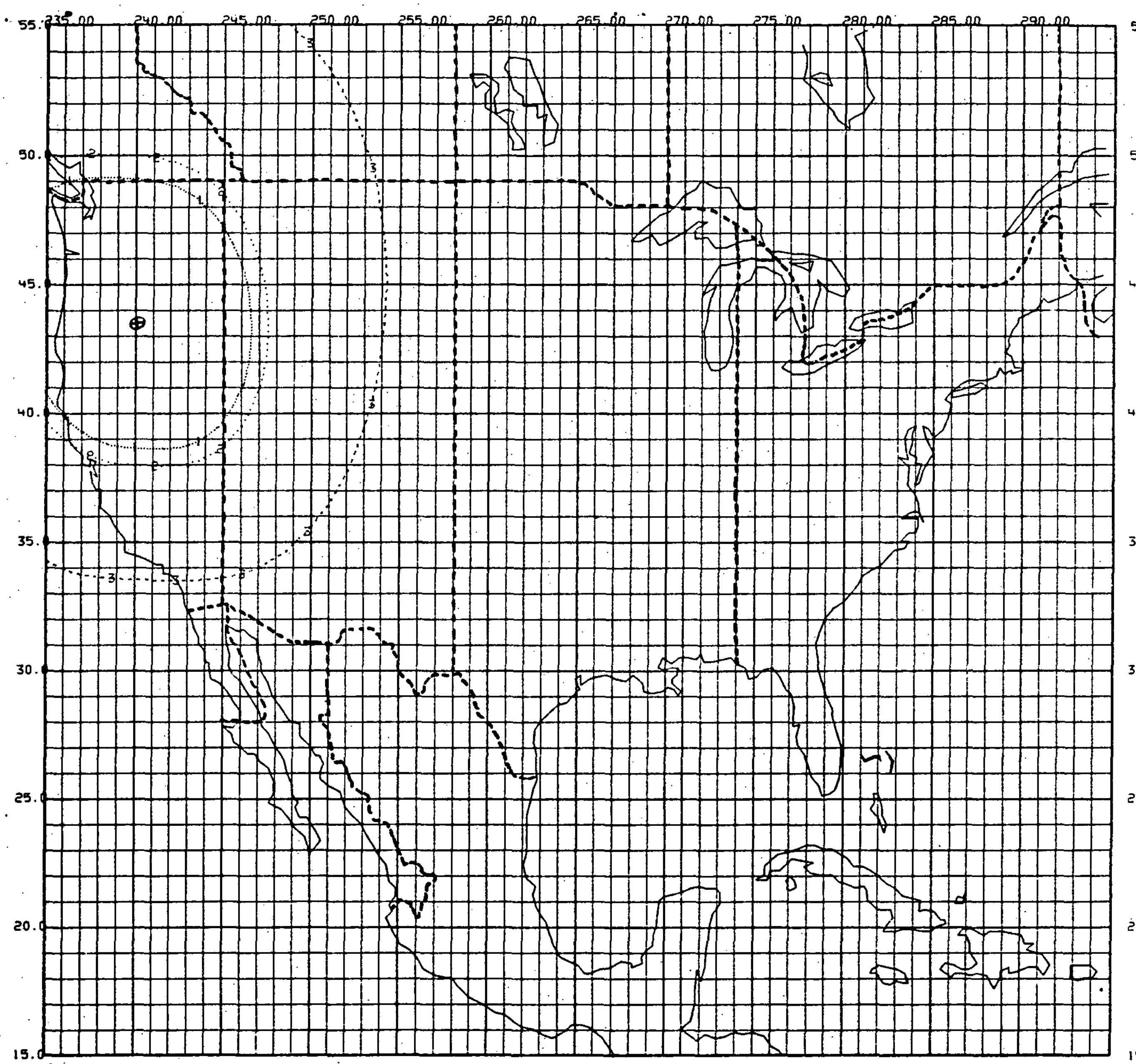

FIG. 34 PACIFIC TIME ZONE (9.9 X 14 FT. REFLECTOR) - BEAM 1

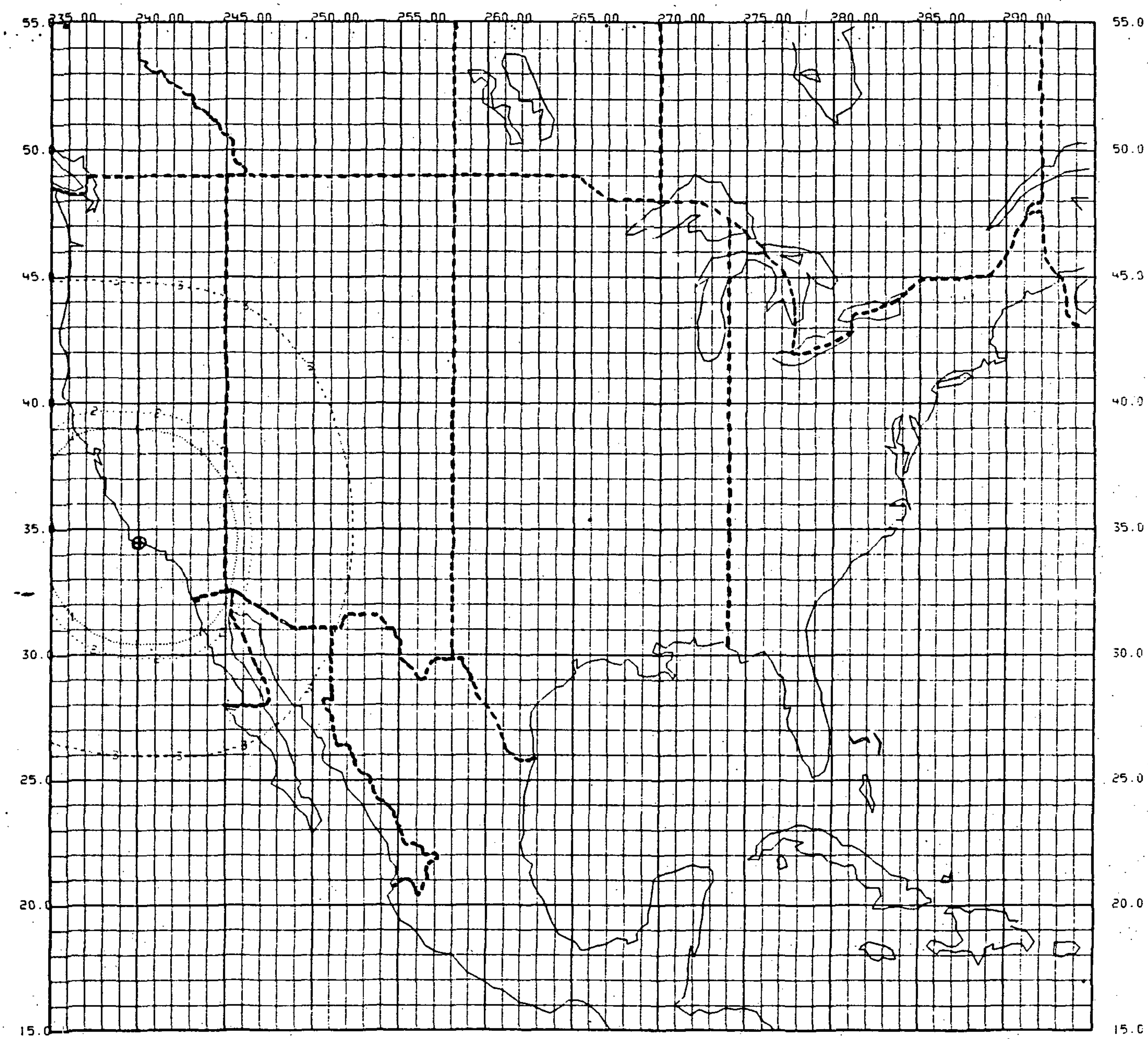

FIG. 35 PACIFIC TIME ZONE (9.9 X 14 FT. REFLECTOR) - BEAM 2

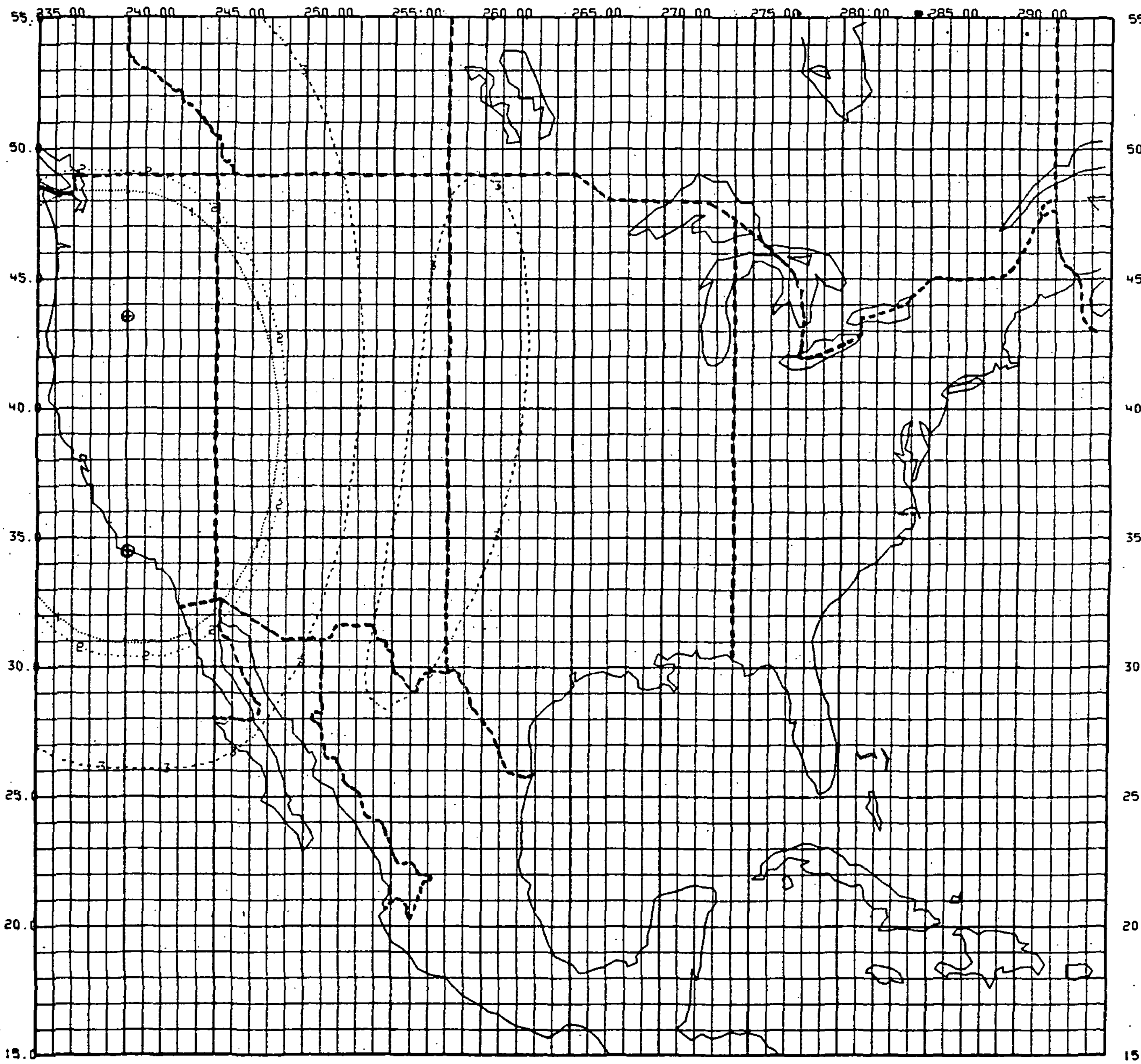

FIG. 36 PACIFIC TIME ZONE (9.9 X 14 FT. REFLECTOR) - COMPOSITE BEAM

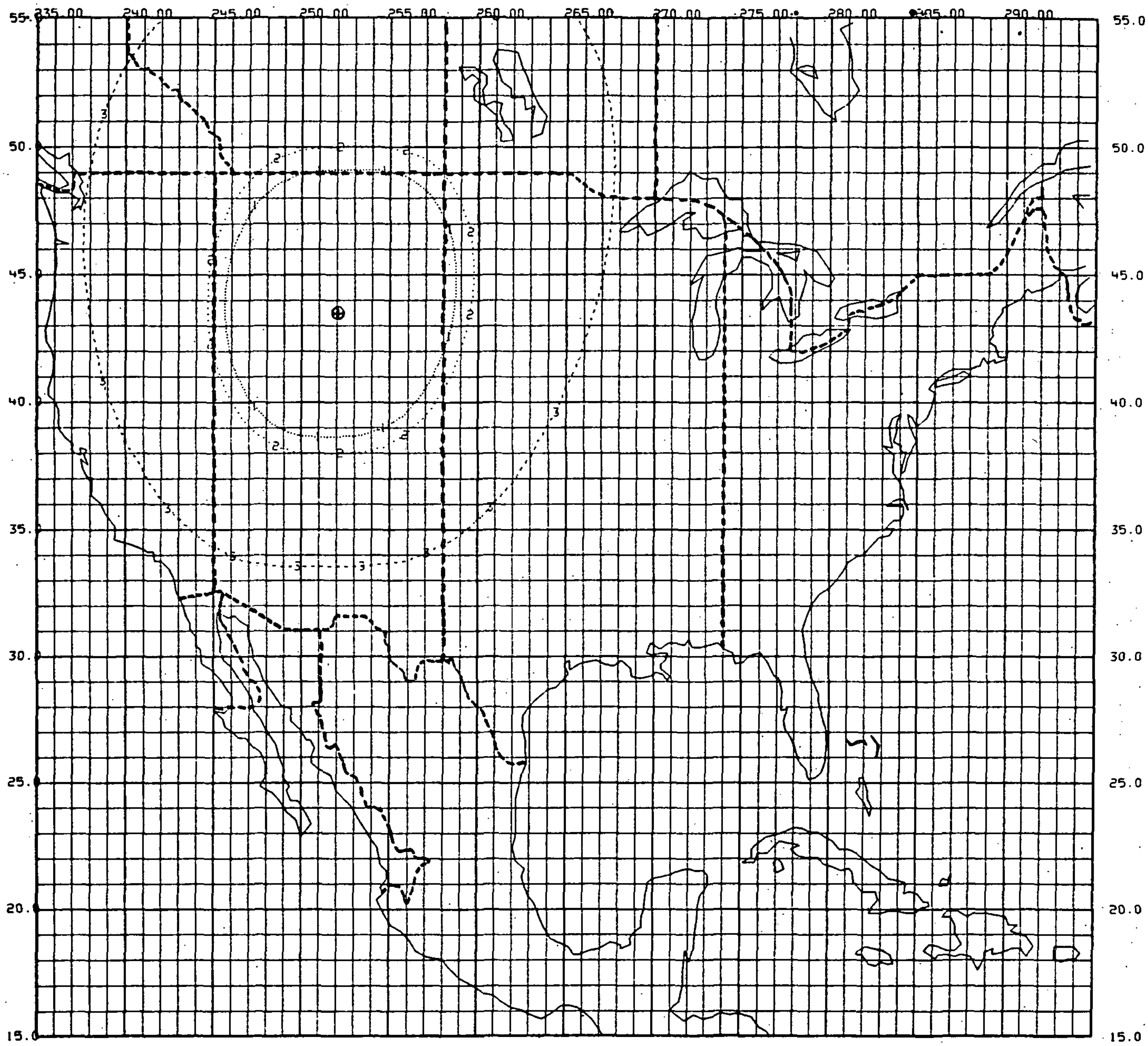

FIG. 37- MOUNTAIN TIME ZONE (9.9 X 14 FT REFLECTOR) - BEAM 1

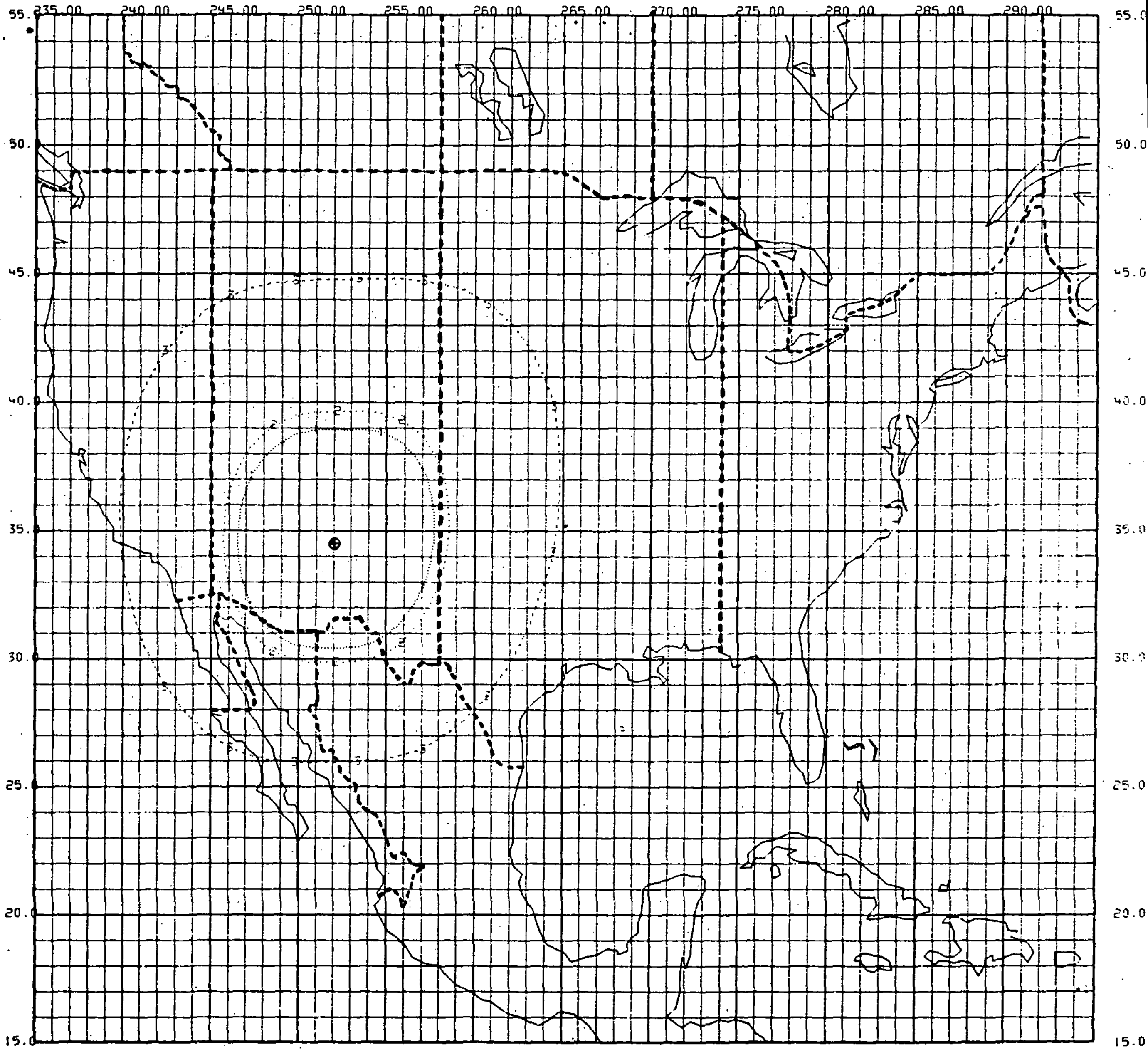

FIG. 38 MOUNTAIN TIME ZONE (9.9 X 14 FT REFLECTOR) - BEAM 2

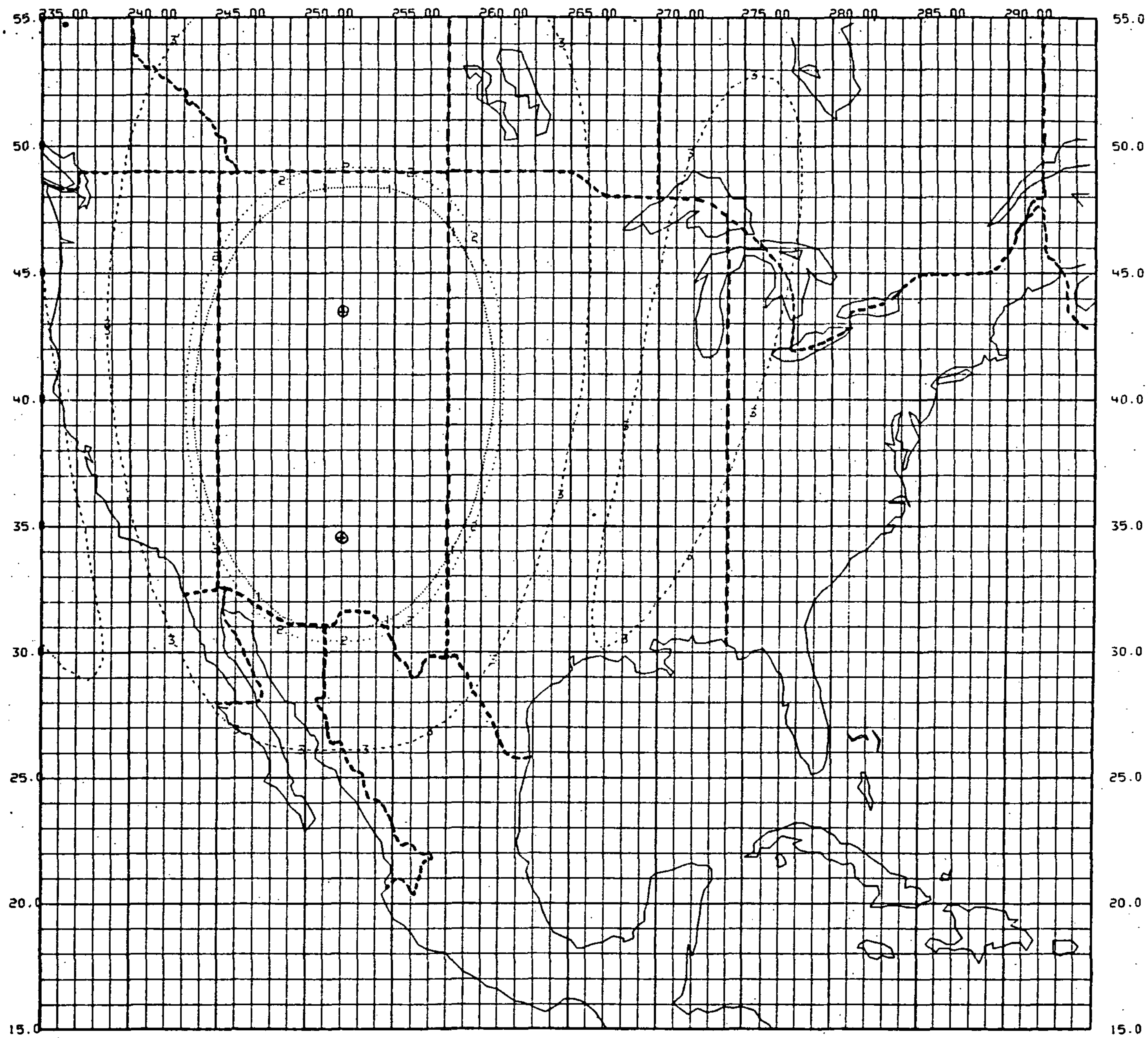

FIG. 39 MOUNTAIN TIME ZONE (9.9 X 14 FT. REFLECTOR) - COMPOSITE BEAM

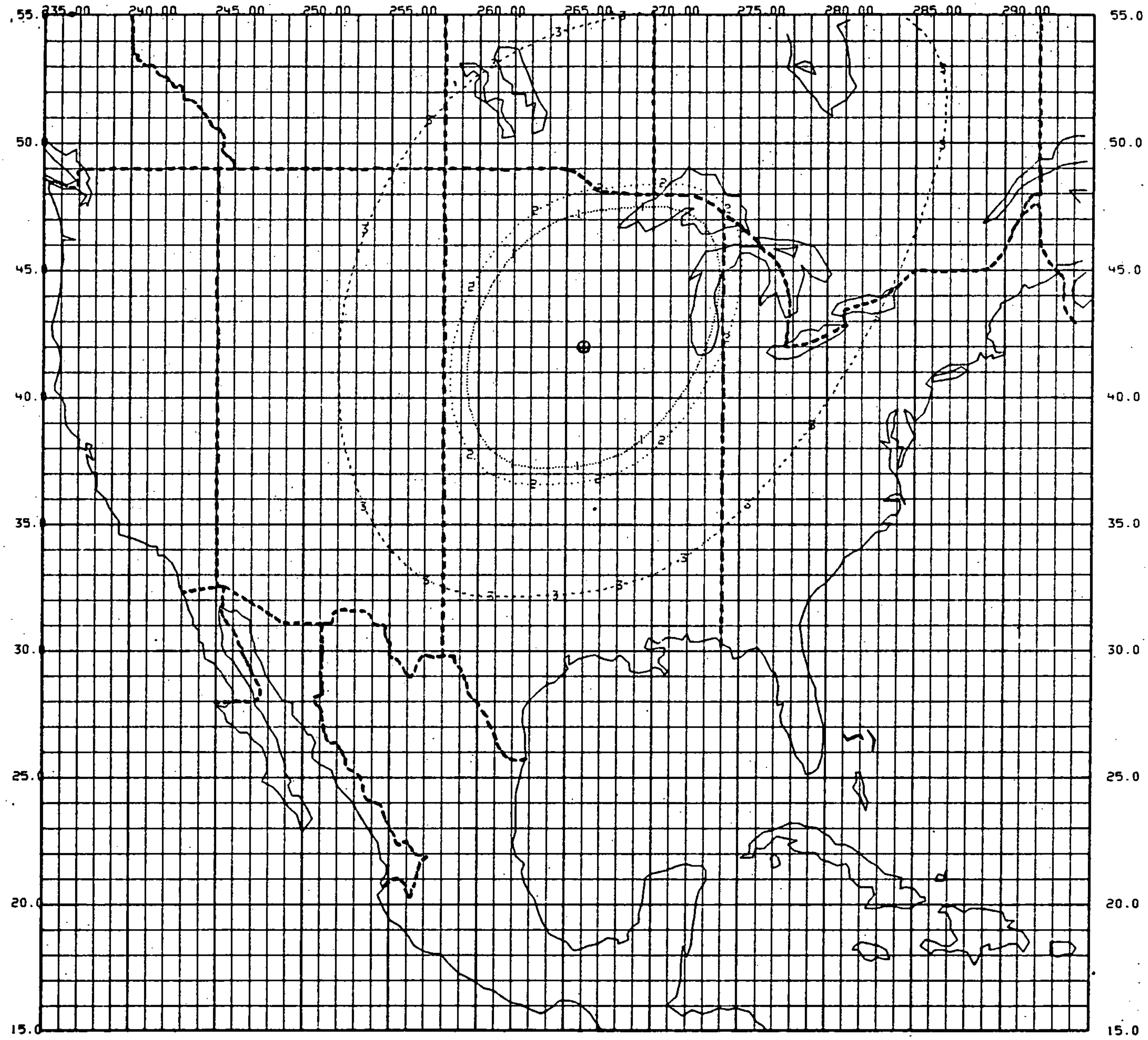

FIG. 45 - CENTRAL TIME ZONE (9.9 X 14 FT REFLECTOR) - BEAM 1

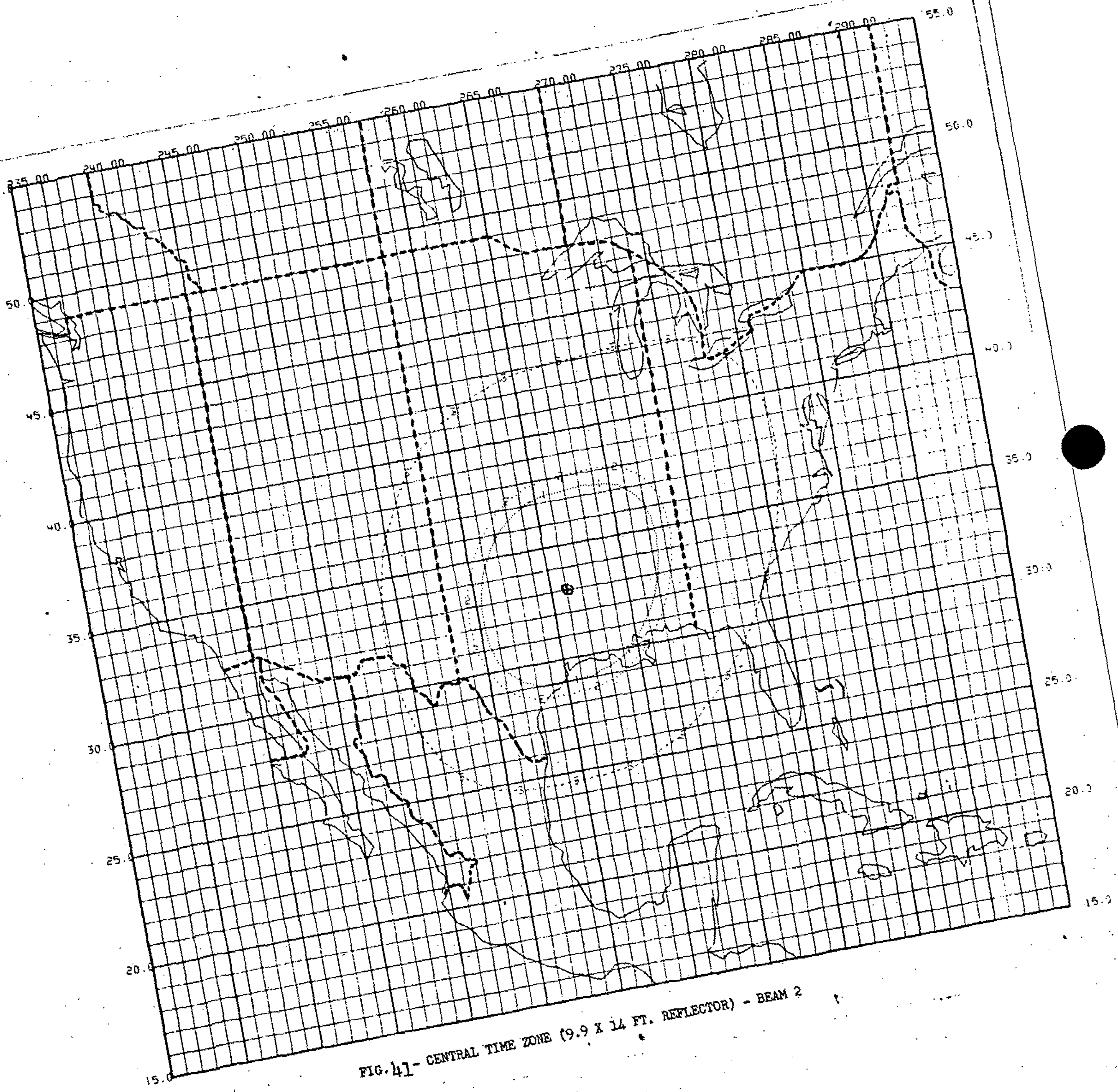

FIG. 41- CENTRAL TIME ZONE (9.9 X 14 FT. REFLECTOR) - BEAM 2

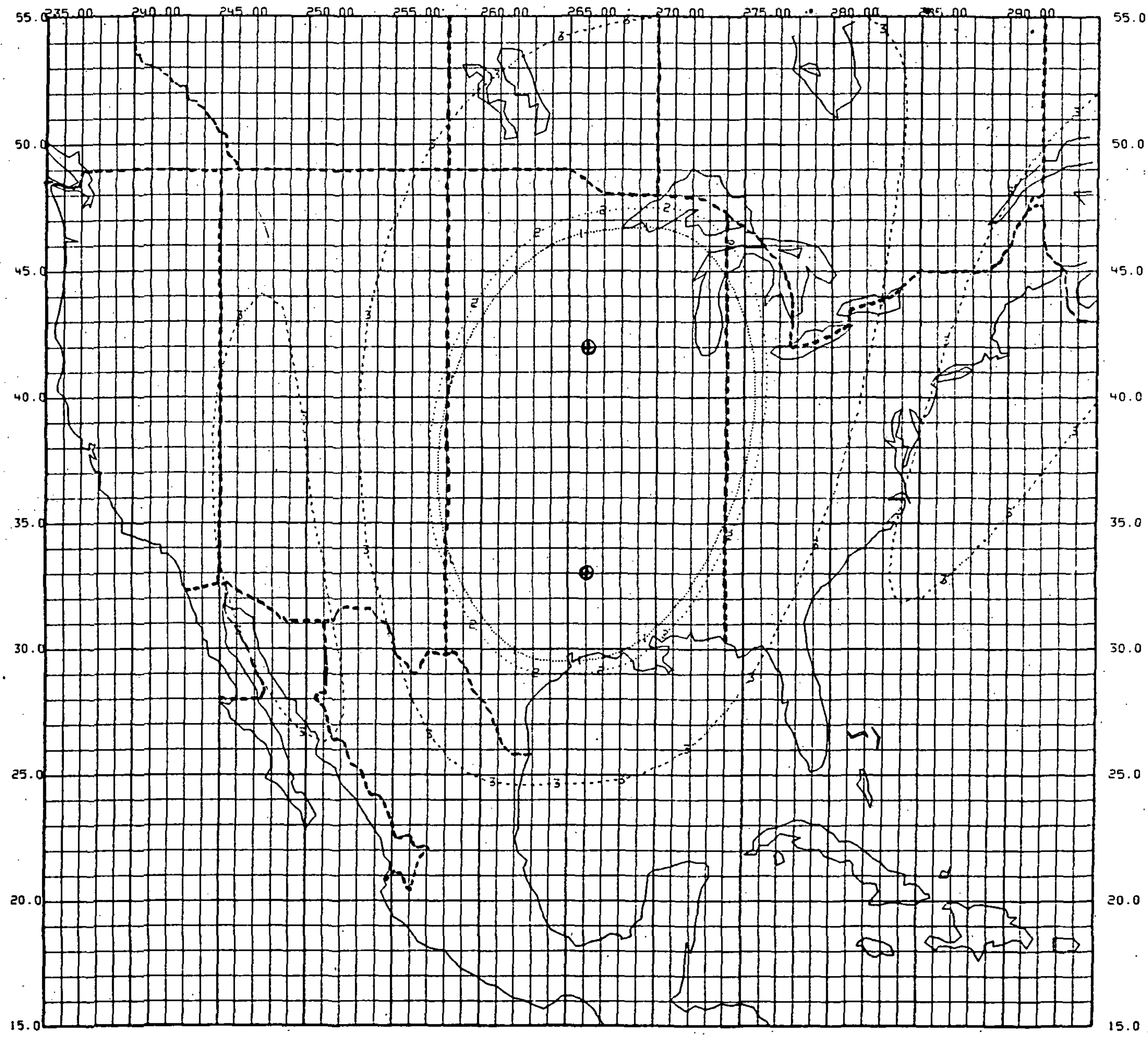

FIG. 42- CENTRAL TIME ZONE (9.9 X 14 FT. REFLECTOR) - COMPOSITE BEAM

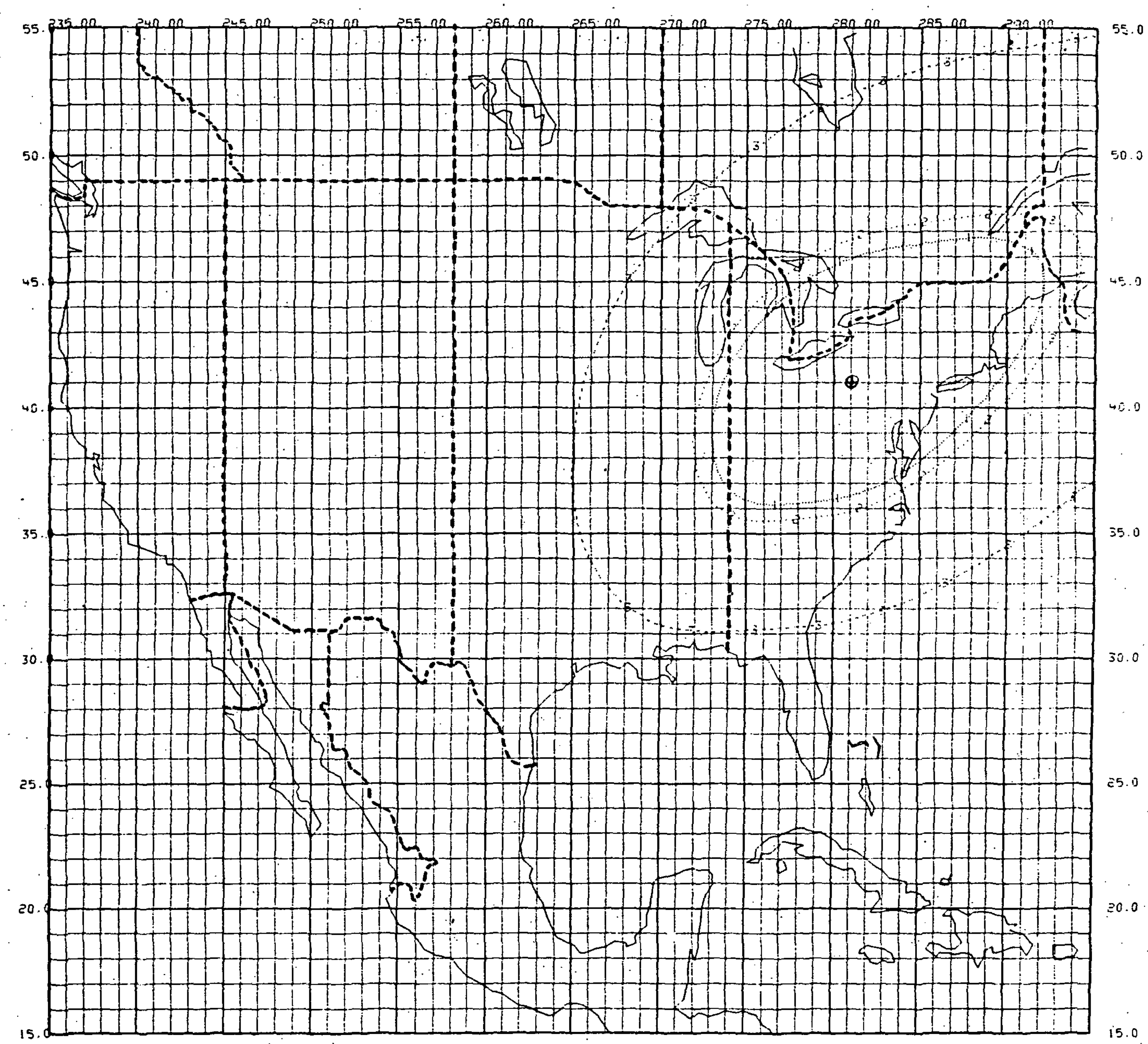

FIG. 43 - EASTERN TIME ZONE. (9.9 X 14 FT. REFLECTOR) - BEAM 1

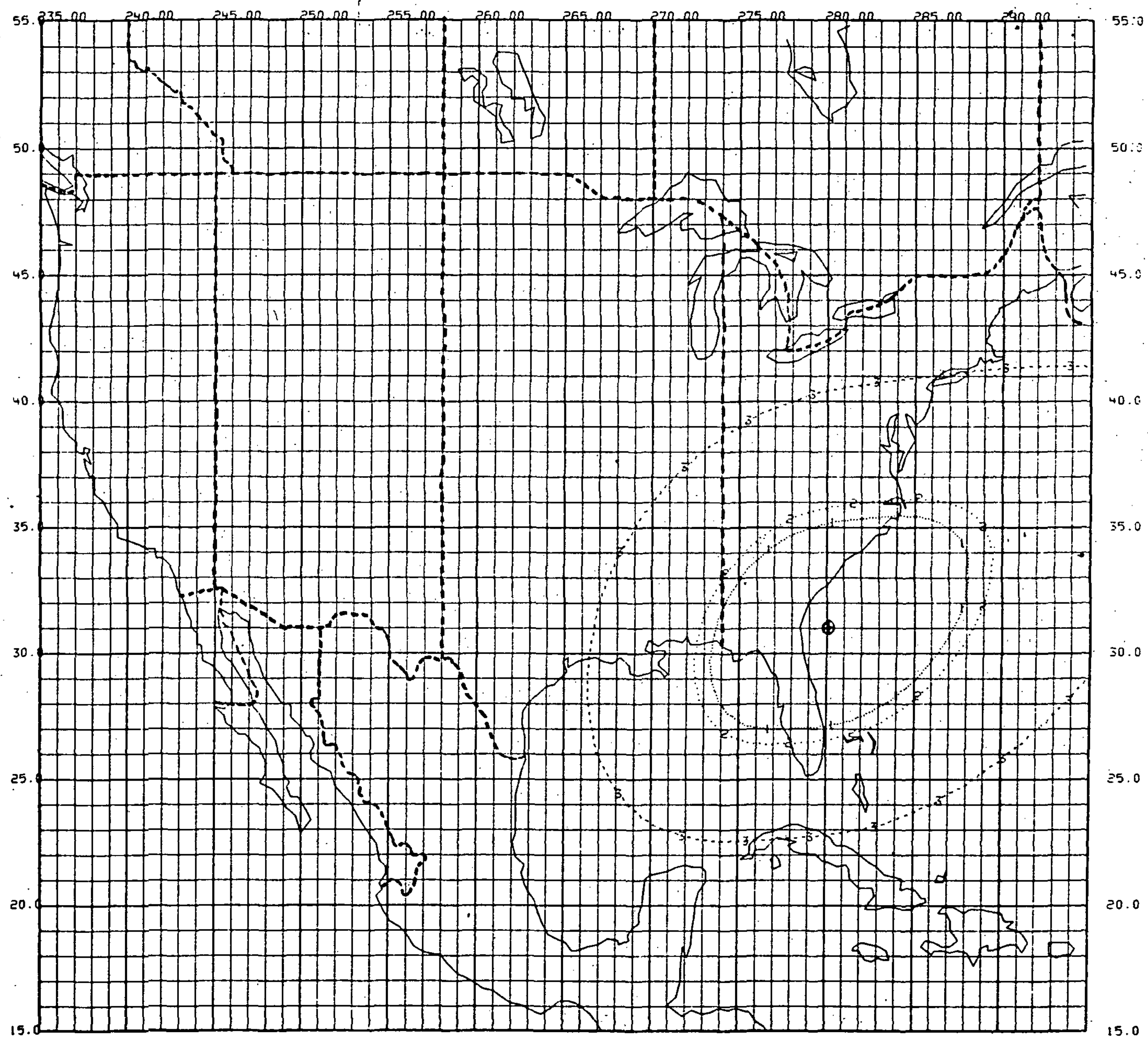

FIG. 44 - EASTERN TIME ZONE (9.9 X 14 FT. REFLECTOR) - BEAM 2

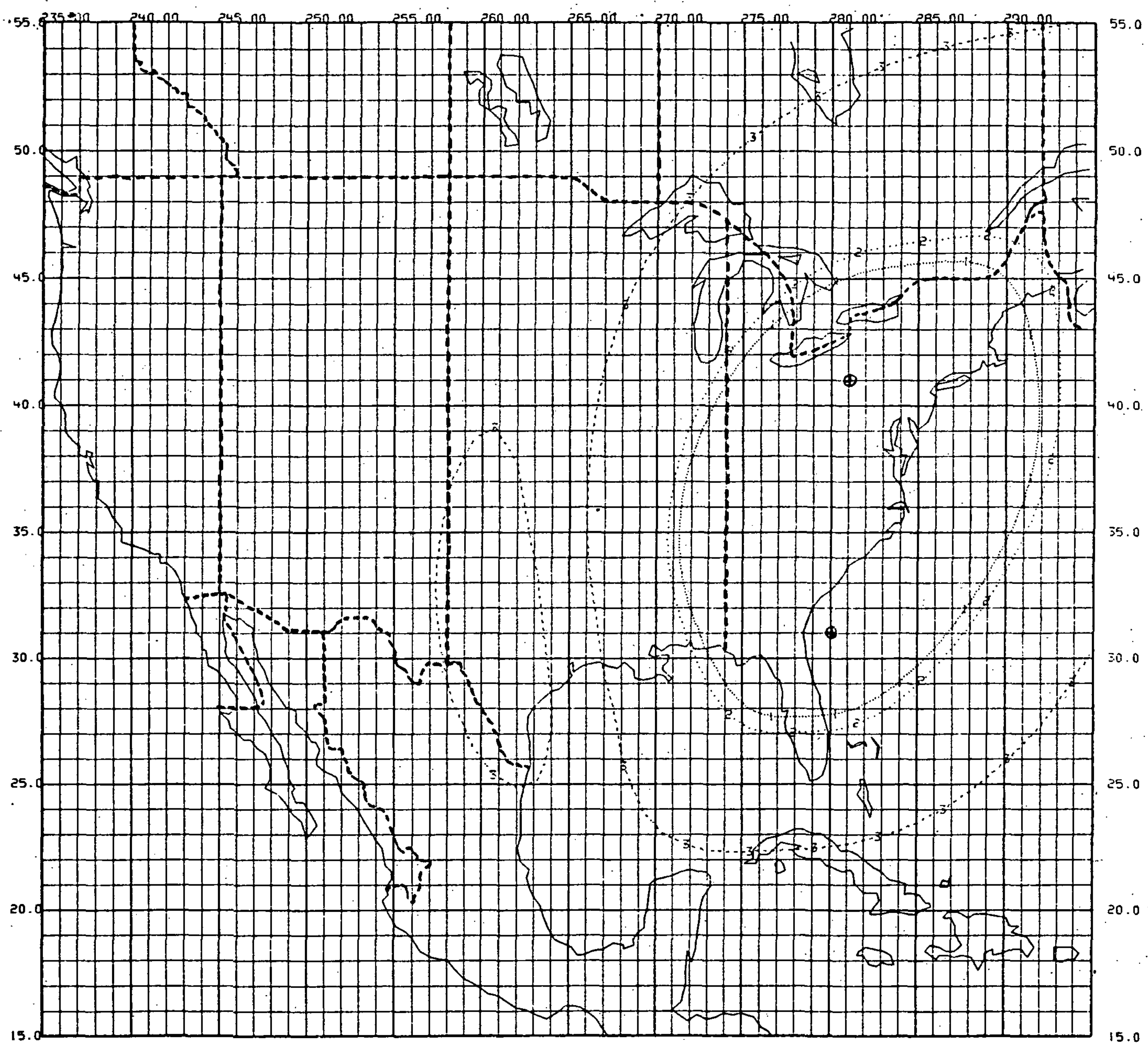

FIG. 45 EASTERN TIME ZONE (9.9 X 14 FT. REFLECTOR) - COMPOSITE BEAM

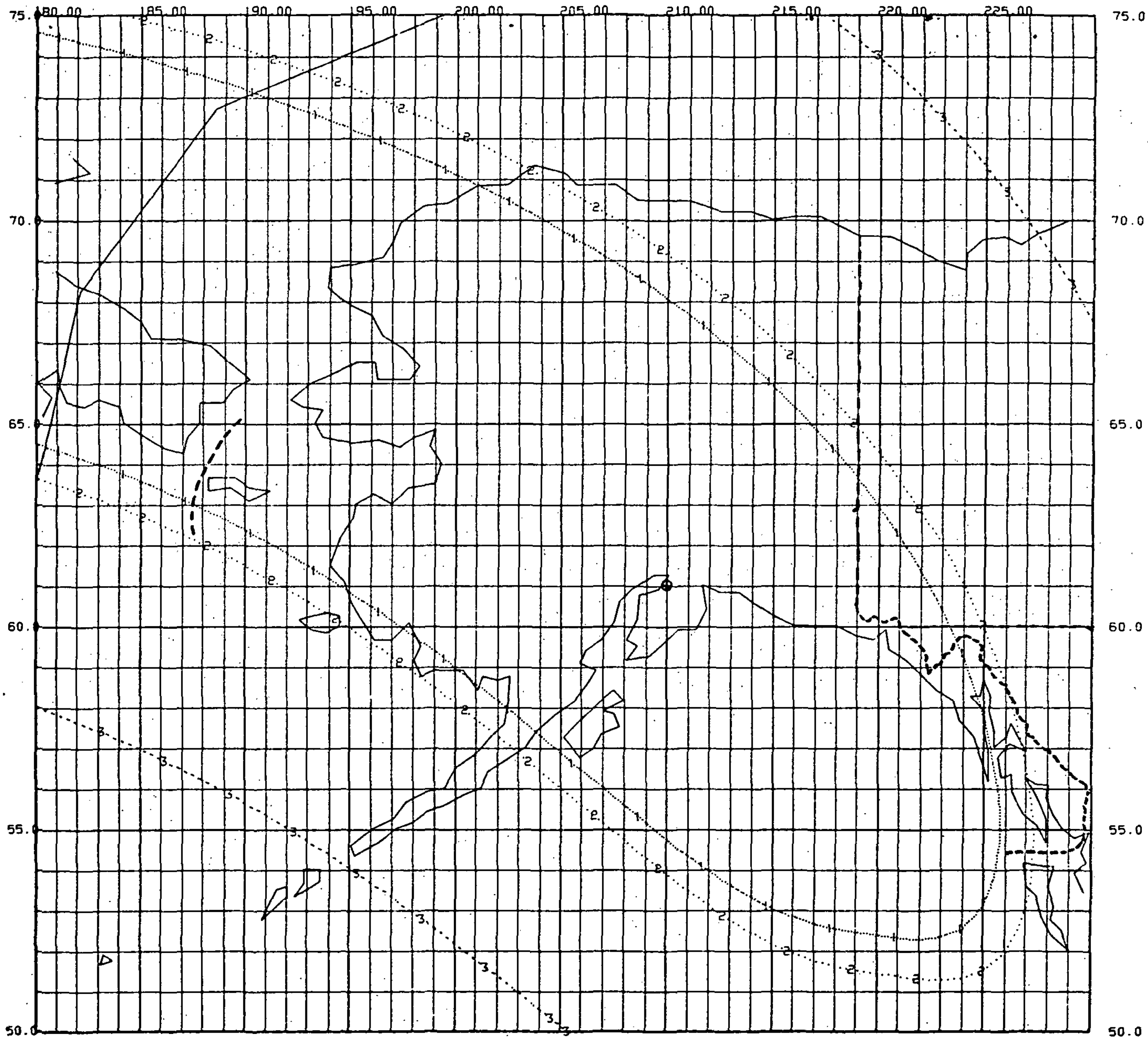

FIG. 46 ALASKA (9.9 X 14 FT. REFLECTOR)

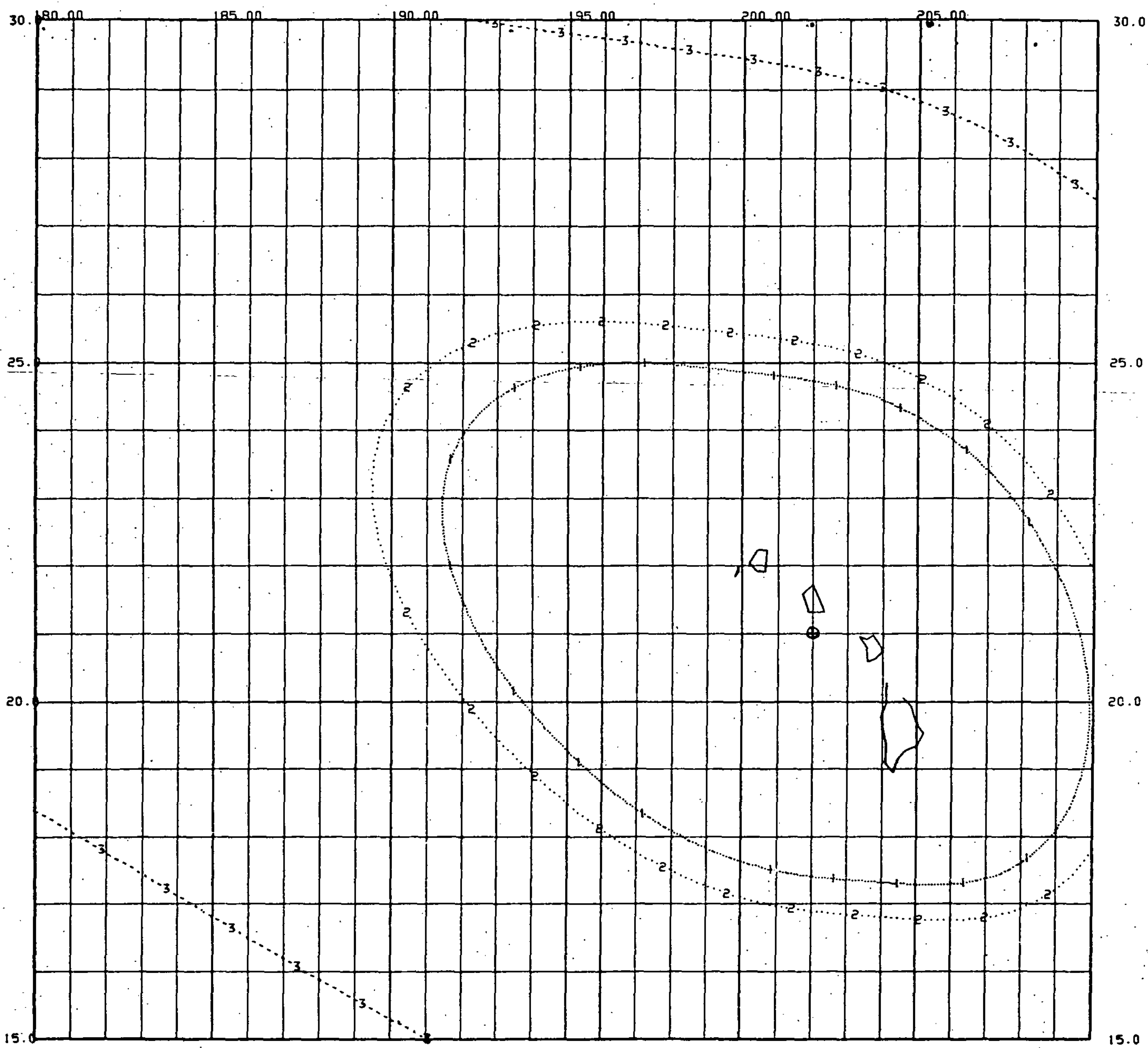

FIG. 47 - HAWAII (9.9 X 14 FT. REFLECTOR)

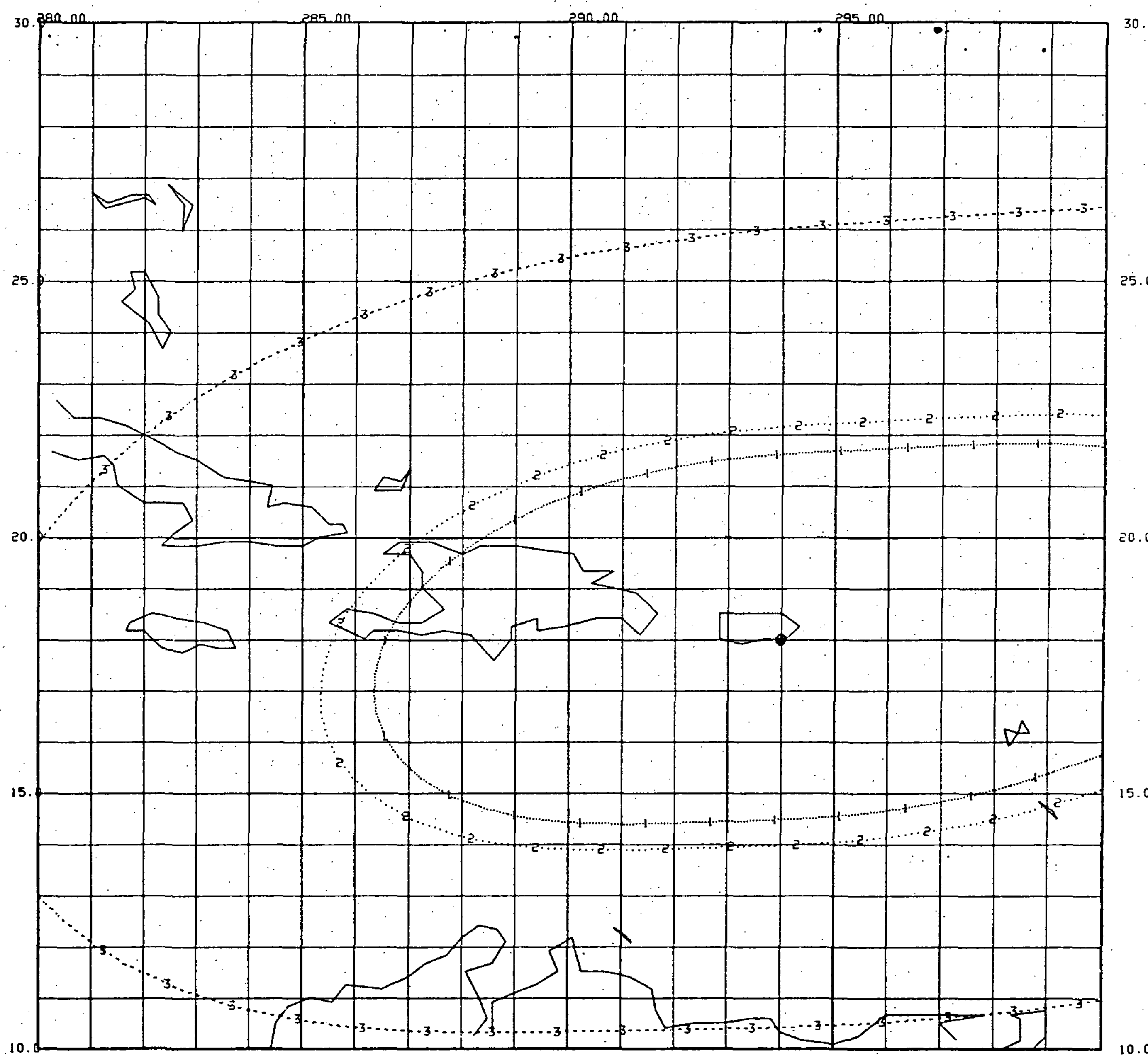

FIG. 48 CARIBBEAN (9.9 X 14 FT. REFLECTOR)

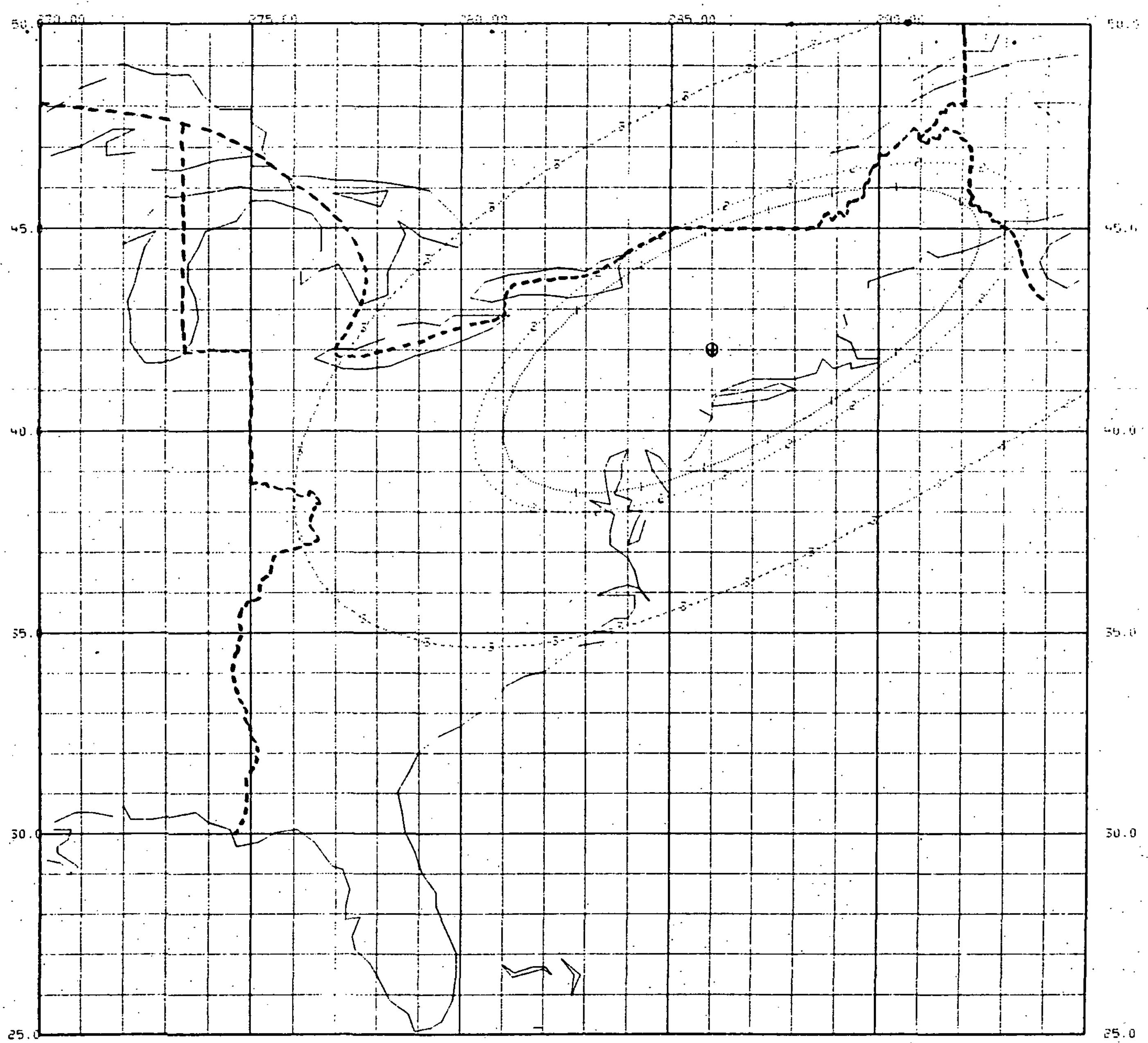

FIG.49 - EASTERN TIME ZONE (20 FT. REFLECTOR) - BEAM 1

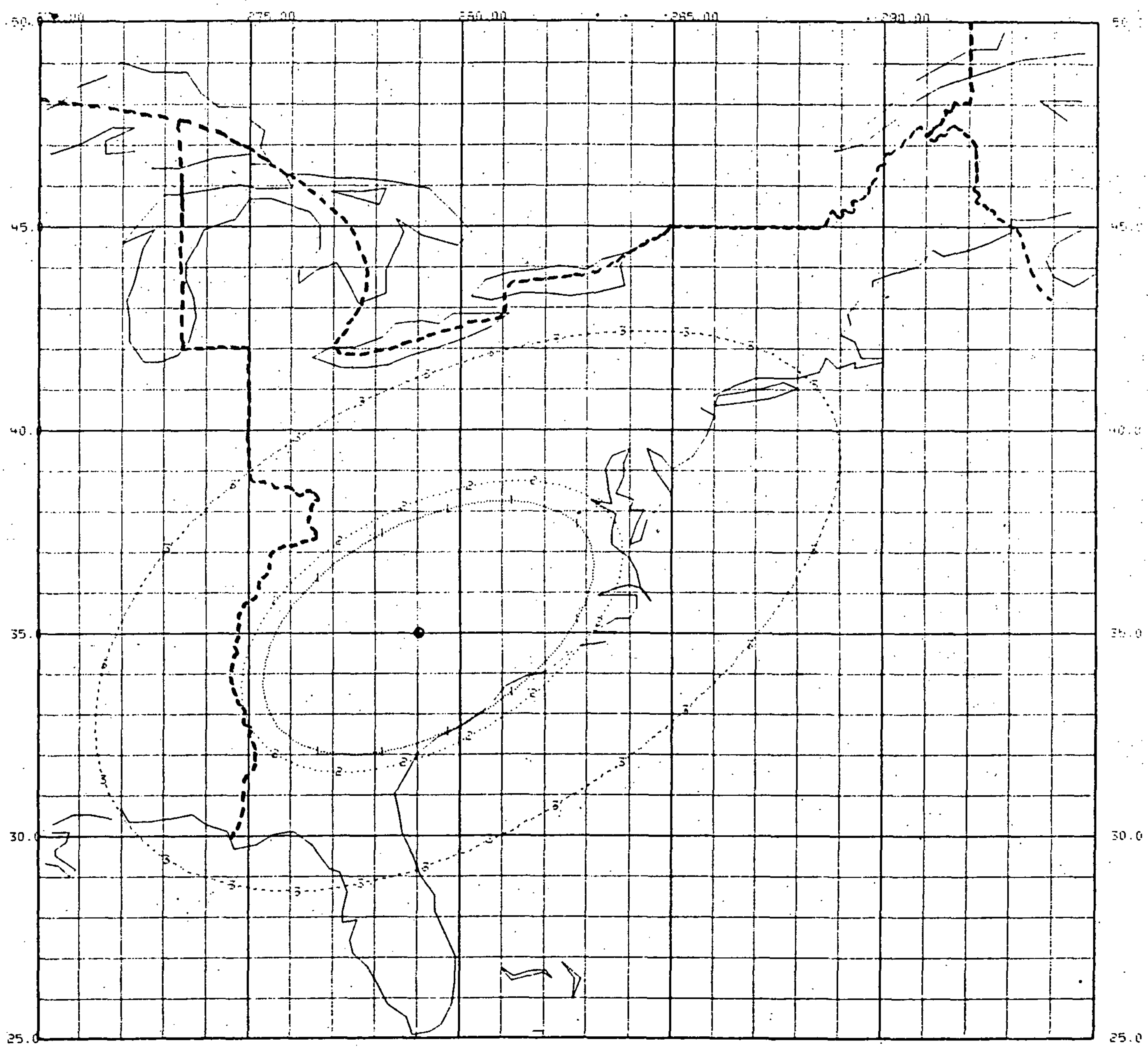

FIG. 50 - EASTERN TIME ZONE (20 FT. REFLECTOR) - BEAM 2

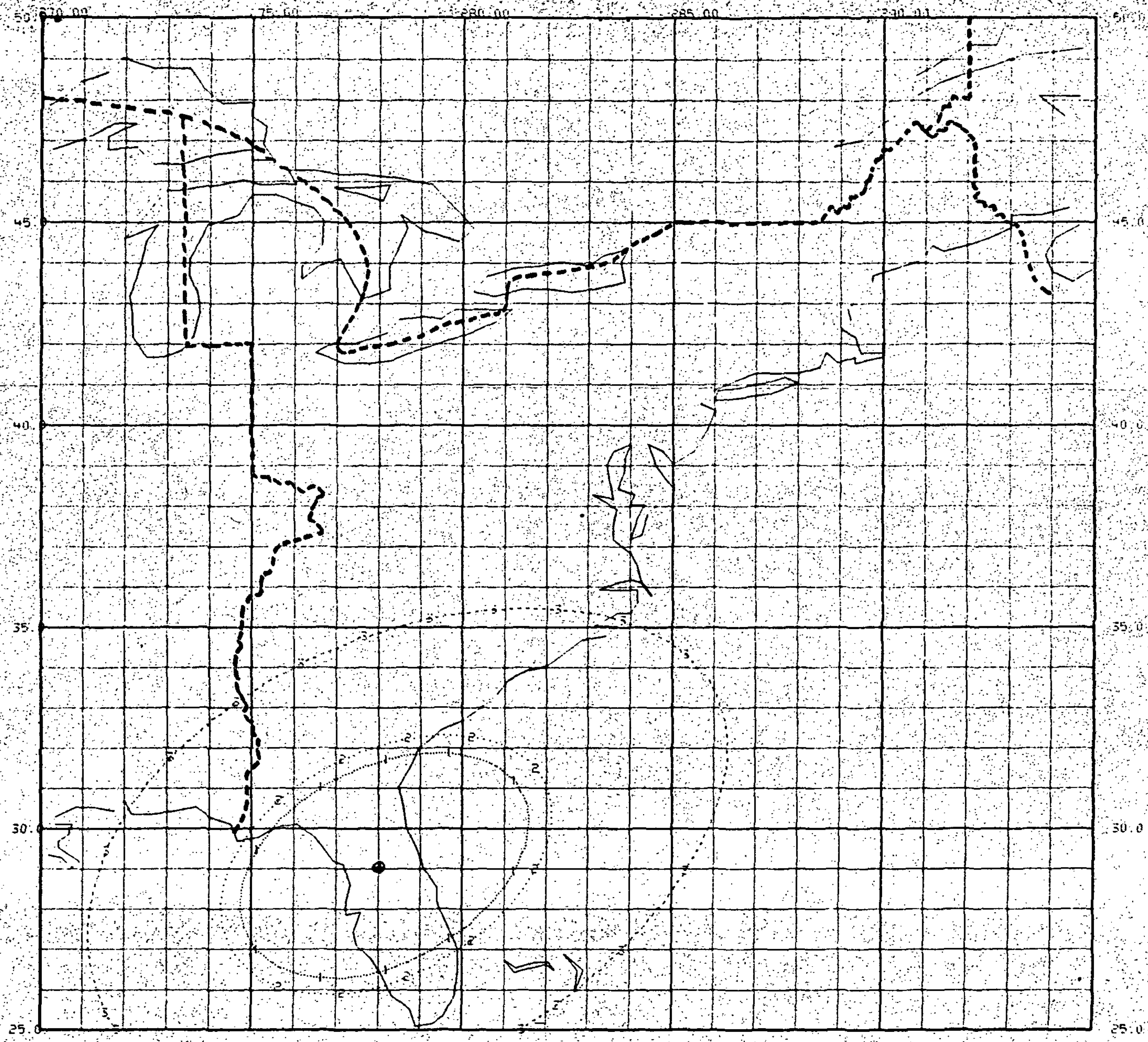

FIG. 54 EASTERN TIME ZONE (20 FT. REFLECTOR) - BEAM 3

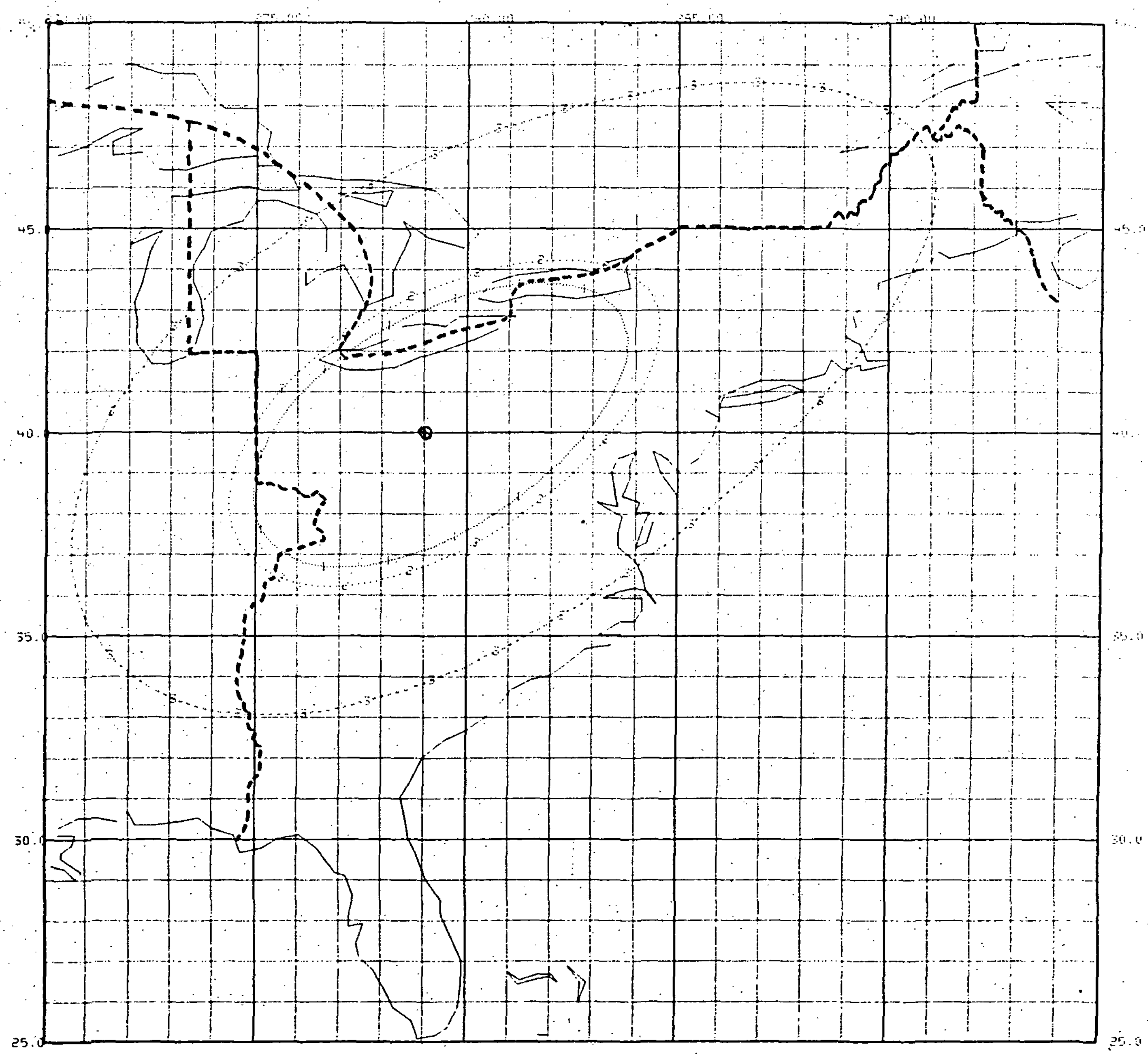

FIG.52 - EASTERN TIME ZONE (20 FT. REFLECTOR) - BEAM 4

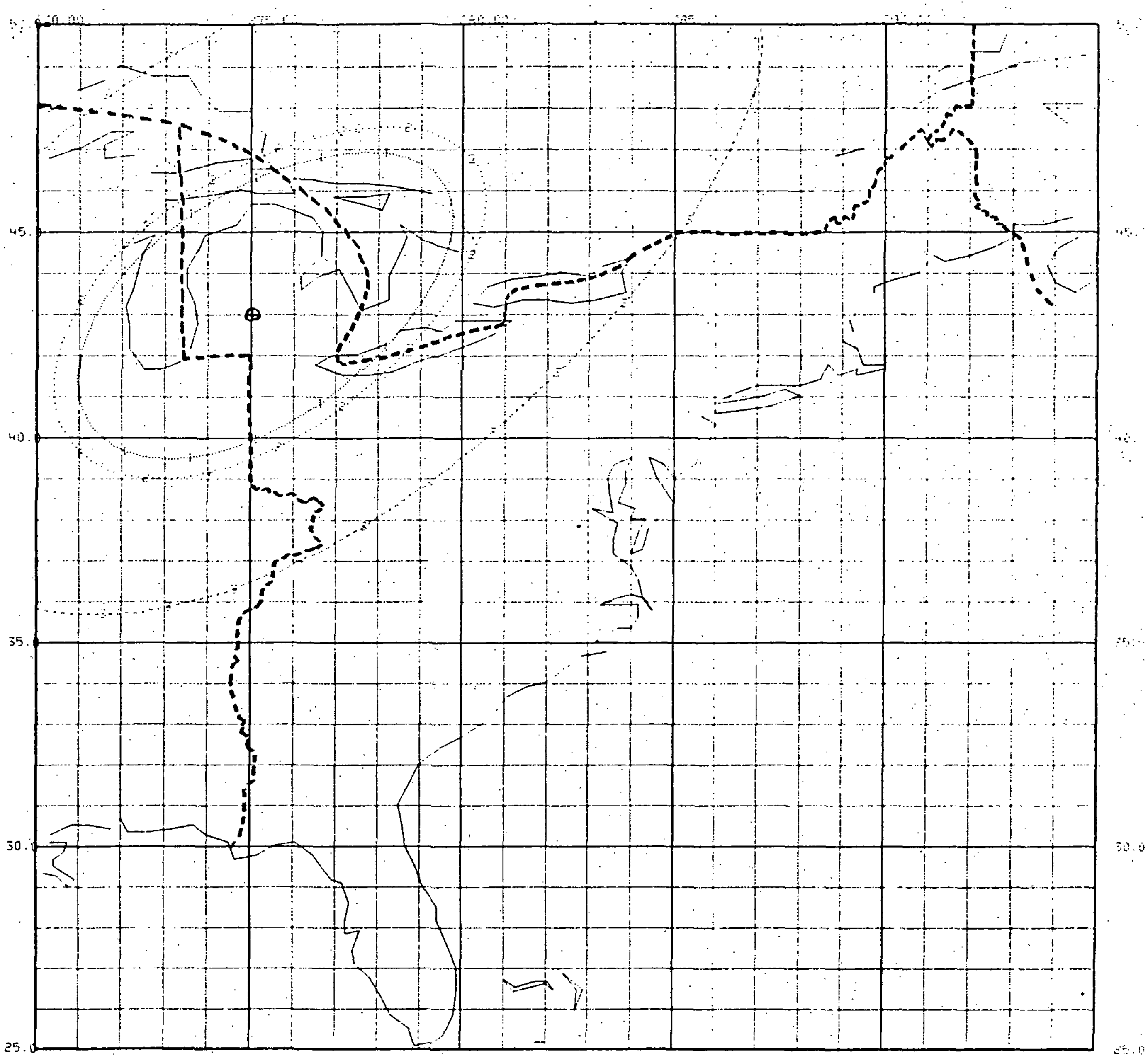

FIG. 53 EASTERN TIME ZONE (20 FT. REFLECTOR) - BEAM 5

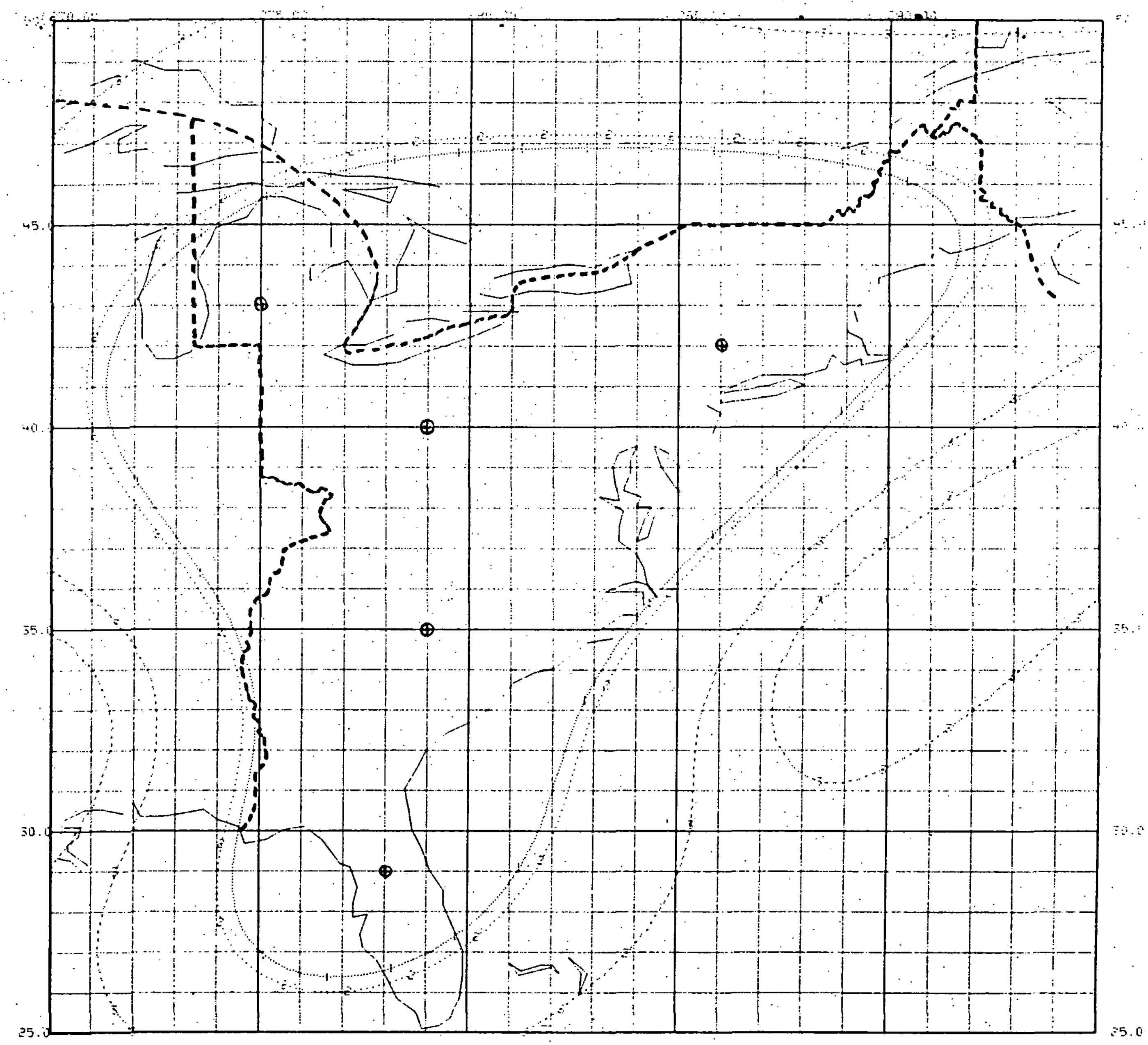

FIG. 54 EASTERN TIME ZONE (20 FT. REFLECTOR) - COMPOSITE OF BEAMS 1-5

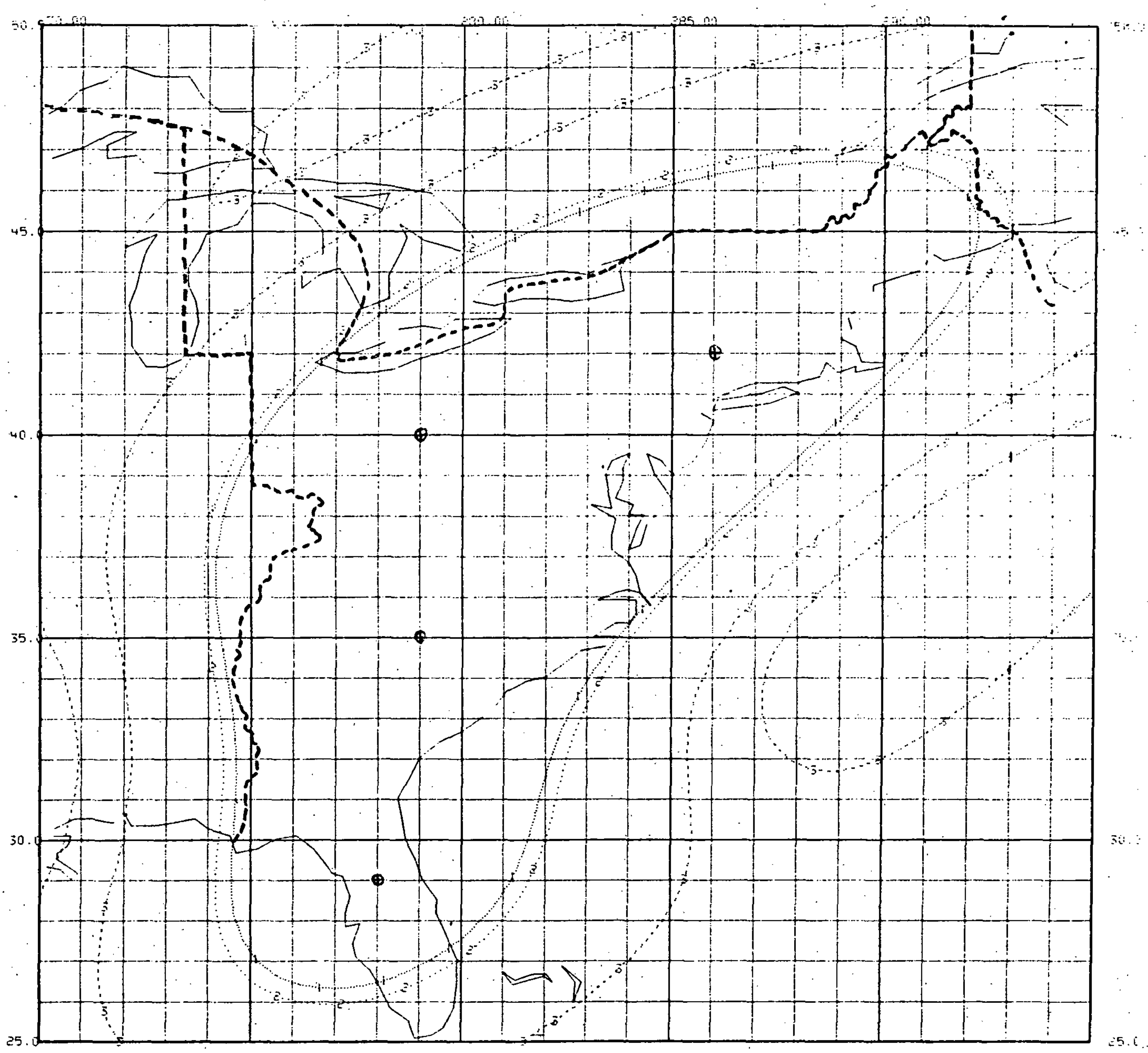

FIG. 55 - EASTERN TIME ZONE (20 FT. REFLECTOR) - COMPOSITE OF BEAMS 1-4

The footprint for the Caribbean is shown in Fig. 48. The boresight is located at 18°N, 66°W (near San Juan). Coverage of Puerto Rico and the U.S. Virgin Islands is complete. In the case of this reflector spillover into neighboring Caribbean Islands is diminished vis-a-vis the 9 ft diameter circular reflector and there is no spillover into South America as was found with the 9.9 x 5.8 ft elliptical paraboloidal reflector. Thus, this reflector is a decided improvement in Caribbean coverage as compared to the other two reflectors with the same East-West diameter.

2.8 Eastern Time Zone Coverage by Beam Synthesis

The problem of spillover into Canada and Mexico when a single beam is used to illuminate a time zone led to the concept of using a much larger reflector and multiple beams to synthesize the coverage of a single time zone. Spillover is then reduced by carefully controlling the boresight of the component beams which illuminate border regions and by the fact that the contour fall off of the individual beams from the -3 dB points is much greater for much larger reflectors.

The Eastern Time Zone is the most difficult of the four time zones to cover because of its shape and because the densely populated regions of Quebec and Ontario lie within its potential spillover area. A very good fit of the -3dB contour to the zone's boundaries was realized in using a 30 ft reflector. It appeared that the fit could be improved by adjusting the boresights of the component beams and/or feeding the beams with unequal power levels.

With these facts in mind it was considered that beam synthesis coverage of at least the Eastern Time Zone, using a 20 ft diameter circular paraboloidal reflector, warranted some attention.

Figs. 49 through 53 depict the component beams of a 20 ft reflector which can be used to synthesize coverage of the Eastern Time Zone. The boresights selected were:

Fig.	Beam	Latitude	Longitude	Location
49	1	42°W	74°W	Kingston, New York
50	2	35°N	80°W	Near Charlotte, No.Carolina
51	3	29°N	82°W	Near Orlando, Florida
52	4	40°N	81°W	Eastern Ohio
53	5	43°N	85°W	East of Grand Rapids, Mich.

The footprints of the composite beam formed by these five beams is shown in Fig. 54. The boundary of the Eastern and Central Time Zones is drawn accurately here rather than arbitrarily drawing it along the 86°W meridian.

The attempt to include Michigan in the Eastern Time Zone, to which it properly belongs, resulted in considerable spillover into the southern regions of Quebec and Ontario, a problem which the synthesis technique is designed to overcome. In addition, the Upper Peninsula of Michigan lies entirely beyond the -3 dB controur. Undoubtedly, changing the boresights of some beams and/or using unequal power distribution can reduce the problem. The boresight of beam 5 could be moved towards the northwest and reduced in signal level relatvie to the other beams. Beams 1 and 4 could be moved about 1° or 2° south. All this would decrease the spillover into Eastern Canada and increase the coverage of Michigan.

The possibility of placing Michigan in the Central Time Zone, alluded to earlier in this report, offers a possible solution. With this in mind it was decided to determine the contours of the composite beam formed by beams 1 through 4. The result is illustrated in Fig. 55.

Exclusion of Michigan from the Eastern Time Zone does help, in this case, to reduce spillover into the adjacent and densely populated regions of Canada. Further reduction of this spillover can be realized by altering the boresights of beams 1 and 4 and/or reducing the relative power of these beams.

In either case, including or excluding Michigan coverage, it will be noted that the region of Maine bordering on New Brunswick, and Southern Florida lie without the -3 dB contour. The "clipping"in Maine is not very serious and the slight loss of signal here may still be tolerable. However, if the boresight of beam 1 is moved southward for the purpose of reducing spillover into Canada, this will degrade the coverage of Maine. Coverage of Southern Florida can be enhanced by moving the boresight of beam 3 northwards by 1° or 2° of latitude. It does seem, though, that moving beam 3 to the south will cause some scalloping along the western Georgia state line. This can probably be prevented by moving beam 3 slightly westward when it is moved southward.

From the patterns of the Eastern Time Zone coverage for the various candidate reflectors it appears that, from the point of view of accuracy of coverage and minimum spillover, the 20 ft reflector is an improvement of the elliptical reflectors and the 9.9 ft reflector, but not as good as the 30 ft reflector.

The relative merits of the candidate configurations in coverage and spillover in the Eastern Time Zone can be extended to the other three time zones. When it comes to coverage of Alaska it is expected that two beams would be required of the 20 ft and 30 ft reflectors in order that they match the coverage of the smaller reflectors. Coverage of the principal Hawaiian Islands would be excellent with one beam, but in the case of both these larger reflectors a second beam would be necessary to cover Midway and Kure if this is a desirable feature. In regard to Caribbean coverage the 20 ft and 30 ft reflectors would be better than the smaller reflectors since complete coverage of Puerto Rico and the U. S. Virgin Islands can be realized with a single beam and less spillover into the Bahamas and other Caribbean Islands would occur.

It is, of course, abundantly clear that the 20 ft and 30 ft reflector candidates will be more complex, larger, and heavier than the reflectors using a 9.9 ft East-West diameter. It is estimated, for example, that a 20 ft diameter reflector will need 21 feeds and 30 ft reflector will need 45 feeds.

2.9 Decision Analysis

In the development of conceptual designs for the candidate antenna systems studied during the analysis stage, consideration was given to several parameters which act as secondary requirements to the prime requirement of providing antenna coverage to the four U. S. Time Zones, Alaska, Hawaii, Caribbean, and the 48 contiguous U.S. states from a synchronous satellite.

Consideration was given to the following items as additional requirements:

1) Minimum spillover into contiguous countries for each of the coverage areas.
2) Low side lobe levels (25-30 dB)
3) Minimum reflector size, weight, and complexity of design
4) Maximum beam isolation
5) Tracking capability

In studying the computer predicted footprints for each of the candidate antenna systems in each of the required coverage areas, it obviously becomes a serious problem to compare the available choices taking into consideration all of the secondary requirements. For example, is the one system that provides the *minimum spillover of the time zone patterns into Canada and/or* Mexico better than the one system which provide maximum isolation between adjacent time zone beams yet has high spillover into Canada and/or Mexico? Is that system which provides the best time zone coverage better than one which has less coverage capability but weighs only one-half as much as the best system? The analyst soon gets mired down in making firm decisions about one candidate system which then change when evaluating the performance of the next candidate system. To avoid this problem and to increase the probability of making a correct decision based on facts, a systemized approach must be employed.

During the course of the analysis, several different candidate approaches have evolved, each offering different capabilities and different good and bad features. One is relatively simple, but does not provide good performance; another has excellent performance but may be somewhat complex; and there are several other candidates offering different levels of performance coupled with varying degrees of complexity. If the choice among candidates were to be based on a single factor alone, making this choice would be a simple matter. It would, indeed, be easy to select an automobile on the basis of horsepower alone.

More often the choice depends on several factors which tend to conflict and which are not measureable in common units. In selecting an automobile we must decide how much extra we are willing to pay initially for such options as air-conditioning, stereo, prestige or appearance. We must decide whether economy of operation is more important to us than the big, powerful engine. We must find a way to bring the various diverse factors into perspective for the comparison process. Our final choice may range from a 10-year-old VW "bug" to a brand new Eldorado, depending on what factors are considered and the relative importance attached to each.

At LMSC we often use the KTA (Kepner-Tregoe Associates) Decision Analysis Procedure for making choices among several candidates. Although originally a formalized procedure for making successful management decisions, we have applied it very effectively to technical problems. It requires that you determine what you want out of the selected candidate <u>before</u> you begin considerinch which candidate is best -- not an illogical procedure, when you think about it. It documents and makes the entire selection process visible so that everyone knows what factors were considered and how much importance was attached to each. If someone disagrees with the choice or with the relative importance attached to each factor, he can supply his own weightings and re-compare the candidates using the same information originally used. The whole process, being formal and visible, leads to selections which are more soundly based on facts and logic and less influenced by subjective factors.

We have applied KTA Decision Analysis Procedure to the selection of an appropriate antenna candidate for further study. In this section we shall explain how we went about the process and in the next we shall discuss the results.

The first step is to make a decision statement. This statement specifies exactly what we expect the selection process to do. Its usual form is: to select an (option) for (a purpose). It is important to make this statement as specific as possible to narrow down the number of candidates to be considered. The statement selected was: "to select a multiple beam reflector antenna concept to satisfy requirements of the NASA-Langley domestic satellite study". The phrase "reflector antenna:" precludes consideration of lenses and arrays which we take to be out of scope of the present study. The term "concept" is included because we want the freedom to consider more than one antenna, that is, a multiple antenna concept. The purpose, "to satisfy the requirements of the NASA-Langley domestic satellite study", tells us where to look for the requirements the selected candidate must satisfy.

The next step was to draw up a list of musts and wants. "Musts" are absolute requirements. If a particular candidate does not satisfy everyone of the musts, it must be discarded immediately without any further consideration -- no matter what other attractive features it offers. Measurement of a candidate against a must is a go/no-go propostion. "Wants" on the other hand are desirable features which can be satisfied to a relative degree. As examples of each, "capable of operation on a synchronous satellite" was considered a must; thus no candidate system would be considered that could not be designed for this situation. "Side lobes at least 30 dB down" - considered a want, because a system, with say, 22 dB side lobes might be acceptable if it has other features (such as better coverage) which might make it attractive. At least we would want to consider what other features a candidate approach had before discarding it and would not automatically rule out the particular candidate system on the basis of its higher side lobes.

The fit to musts is simply a yes or no proposition, as mentioned before; therefore there is no need to weight the musts. The wants are different. Since only relative fit is required to wants, we must attach a weighting to each want in proportion to its relative importance. The most important want is given a weighting of 10 and less important wants are given lower weightings. Having too many wants with high weightings tends to de-emphasize the weighting of the most important want, so the weighting process must be handled with care. The purpose of assigning weightings is to provide a common basis of comparison of different features in accordance with importance -- that is, in perspective. If one candidate system provides both good side lobes and good coverage, there would be no problem. But if one has low side lobes, we have to be able to decide between the two.

After the weightings have been assigned, the candidates to be considered are defined in detail. Then each candidate is measured against the must list for fit. Any candidate that does not satisfy all of the must is automatically discarded. Then for each want the candidates are measured and scored for relative fit. This is done by finding among the candidates the one which best satisfies the particular want in question and assigning to that candidate a score of 10 for that want. The other candidates are compared with the candidate best fitting the want and are assigned scores from 10 to 0 depending on how well they satisfy the want compared to the candidate system receiving the score of 10. For example, if candidates A, B and C have side lobe levels of 16, 22 and 25 dB, respectively, no candidate exactly satisfies the want. But candidate C satisfies it best and receives a score of ten. Candidate B is next best and if we decide that the three dB difference in side lobe level is unimportant, candidate B might receive a score of 10 or 9. If the 3 dB difference is significant, a lower score might be assigned. Clearly, candidate A does not come close and would receive a low score. It is important not to make the scores reflect the numerical differences between the candidates but instead to make them reflect the importance of the numerical differences. The complete range from 10 to 0 does not have to be covered. For example, if the three systems had 25, 26, and 24 dB side lobes and the differences were relatively unimportant, all candidates might receive scores of 10 or 9.

When all candidates have been scored for all wants, the scores and weightings are multiplied together and the weighted scores for each candidate are added together to find the total weighted score for each system. The candidates are then ranked, the one receiving the highest score being the one which best fits the want list. Small differences in scores can and should be neglected, since the method is not considered to be ultra precise. For example, a difference in weighted scores of 10 points should be neglected because changing the weightings of a single factor by one or two points could conceivably change the rankings.

A further step included in the KTA Decision Analysis Process is to determine the risk factor incurred from selecting each of the candidates which rank high in fitting the want list. This is done by listing all the bad things that can happen if a particular candidate is selected, assigning a probability of occurrence on a scale from 0 to 10 to each adverse consequence, and a seriousness rating from 0 to 10, should the adverse consequence happen. For each candidate the risk factor is the sum of the products of the probability factor times the seriousness factor for adverse consequence. Thus, a candidate system with a high ranking in satisfying the want list could be derated or discarded if its risk factor was high in comparison to other candidates which offer almost as good a fit to the want list.

To summarize, the steps in the decision analysis process are as follows:

1. Make a specific decision statement.
2. Draw up a list of must and wants.
3. Assign weightings to the wants.
4. Define in specific detail what candidate systems are to be considered.
5. Measure candidates against a must list on a go/no-go basis.
6. Measure remaining candidates against a want list and assign scores based on relative fit to wants.
7. Multiply weightings by scores to find weighted scores; sum weighted scores for each candidate system.
8. Assess possible adverse consequences for high ranking candidates.
9. Interpret scores and make final selection.

In the next Section we shall discuss the application of this technique to the present study.

2.10 Selection of the Preferred Antenna Concept

This KTA Decision Analysis procedure was used to select a preferred antenna concept. The analysis was completed using the best information available at the time and leads to a preliminary conclusion as to the antenna concept ultimately best-suited for fitting the technical requirements outlined in the work statement.

The decision statement selected as as follows: "To select a multiple beam reflector antenna concept to satisfy requirements of the NASA-Langley domestic satellite study". By this statement we limit our consideration to multiple beam reflector antennas and may consider two or more such antennas in a system. We are concerned with satisfying the technical requirements and achieving the functional objectives of the intended application, whether or not the selected concept is compatible with the original intent and scope of the study.

To establish the list of musts and wants, the first step was to make a list of all the nouns and adjectives in relevant portions of the work statement. The next step was to see if we could generate musts and wants from this list. We then added other wants and musts which we felt were either implied by the the work statement or were pertinent to the projected functional use of the antenna system.

Three musts were defined. One is that the candidate system must be a multiple beam reflector antenna system. Any other candidate approach was discarded primarily as being out of the scope or intent of the study. A second must was that the antenna system be capable of operation on a synchronous satellite. A third must was that the antenna system provide some access to all the geographical areas mentioned in the work statement.

How effectively each area is covered will be dealt with in the list of wants, but inclusion of the access requirement in this form in the must list prevents consideration of any concept which does not have the potential of covering the maximum east-west and maximum north-south fields of view.

Sixteen wants were established. These are:

1. Side lobes should be 30 db down.
2. Stowed volume should be a minimum.
3. Deployed size should be a minimum.
4. Weight should be a minimum.
5. Coverage of the U. S. Time Zone should be a maximum on a population basis.
6. Coverage of the U. S. time zones should be a maximum on an area basis.
7. The U.S. time zone patterns should have minimum spillover into Mexico and Canada on an area basis.
8. Coverage of Hawaii and Caribbean area should be maximum on an area basis.
9. Spillover of the Caribbean beam into foreign Caribbean areas and South America should be minimized.
10. Coverage of Alaska should be maximized on an area basis.
11. Spillover of the Alaskan beam into Siberia and Canada should be minimized.
12. Single beam coverage of the contiuous 48 states should be maximized on an area basis.
13. Spillover of the 48 state beam into Canada and Mexico should be minimized.
14. The isolation between beams should be maximized.
15. A reference capability for tracking should be provided for updating the system.
16. The complexity of the system should be kept at a minimum. Coverage refers to the geographical area within the -4 dB contours of the beam.

The wants and musts are listed in Table 1 together with the weightings for the wants. To arrive at the weightings shown, we first had a general discussion of all wants to make certain the basic idea of each was clear. Then three engineers set down independently their own weightings. Differences were discussed until agreement was reached (as contrasted to averaging the independent weightings). The results are tabulated in Tables I and II.

The most important want was considered to be coverage of the four U. S. time zones on an area basis. "Coverage" is the primary intent of this type of antenna system, and since covering the entire area of the four U. S. time zones provides service to a very large number of people, this seemed to be the most important want. Coverage of the time zones on a population basis was also included and given a lower weighting; the purpose here was to give a little plus to a candidate which failed to provide full area coverage but did cover nearly all the population and to give a little minus to one which left out a heavily populated portion of the desired service area. Of course, any candidate providing full area coverage also scores well in the population coverage.

Hawaiian, Alaskan and Caribbean coverages were the next most important wants. These were considered on an area basis only. There could be some justification for giving these wants relatively low weightings since relatively few people are involved compared to those residing within the contiguous 48 states. But we chose to assign weightings of 9 and 8 to cover these remote areas because while few people are involved, few alternatives exist to the services which would be provided by the satellite.

Single beam coverage of the contiguous 48 states was assigned a relatively low weighting since this coverage could be provided by separate channels on the four U. S. time zone beams.

Spillover was everywhere considered on an area basis. There does not seem to be any hope, even with very directive antennas, of reducing spillover to the bulk of the Canadian population, so that country might just as well be considered on an area basis. Mexico is more evenly distributed and could be treated on an area or population basis equally as well.

Spillover, in general, was assigned moderate to low weightings. To place strong weightings on spillover would tend to have spillover considerations influence the design or choice, and we do not believe it should. Interference can be overcome by cooperative efforts between neighboring countries. Minimizing spillover may be more important for political reasons than for technical ones, and therefore, the effort to minimize spillover may be the important thing. Spillover into Canada and Mexico, our closest neighbors, received a higher weighting than spillover into South Smerican and foreign Caribbean territories where our ties are not as strong and into Siberia which is sparsely populated.

The impact of the antenna system configuration on the vehicle system is depicted by wants, 2, 3 and 4. A compact launch configuration is desirable but not a dominant factor and thus receives a low weighting. Minimum deployed size is highly desirable to minimize the length of solar array booms and other vehicle structures which must clear the edge of the aperture. This also receives a low weighting in that a large size only complicates vehicle design problems. Minimum weight has a direct bearing on how much electronics subsystem hardware can be carried and in some cases on the choice of boost system. Therefore, weight was assigned the highest weighting of the vehicle interaction factors.

Low side lobes is a direct requirement appearing in the work statement, but it receives a relatively low weighting because it is believed that want 14, maximum isolation between beams, more clearly defines the functional problem. The effects of side lobes on spillover is already taken care of in several wants related to spillover into specific countries. The remaining effect of side lobes to be considered is the effect on beam-to-beam isolation. We know, for example, that certain of the antenna concepts will result in high side lobes which fortunately fall into ocean areas with little detriment to over-all performance. It does not seem prudent to penalize a particular concept for that; but if high side lobes cause interference between co-polarized beams, that is a serious matter in that it restricts the frequency reuse capability of the system. Thus, a want related to beam-to-beam isolation receives a relatively high weighting.

Tracking capability forupdating tne system is desirable but is not nearly as important as other features.

The final want to be discussed is complexity. High degrees of complexity will affect development costs, product cost and lead time to operational use. A very complex system may or may not affect reliability. A simple system seems inherently more reliable, but a failure may be catastrophic. A more complex system conceivably can have very useful failure modes in that failures tend to affect limited portions of the system. Complexity in general is a development inconvenience and therefore minimum complexity seems to be desirable.

Eight candidate approaches were defined. They are:

A. A 9.9 foot circular paraboloid with 7 feeds
B. A 9.9 x 5.8 foot elliptical paraboloid with 7 feeds
C. A 9.9 x 14 foot elliptical paraboloid with 11 feeds
D. A 20 foot circular paraboloid with 21 feeds
A'. The 30-foot ATS Reflector with 45 feeds
B' Two 30-foot reflectors with a total of 45 feeds
C' Four 30-foot reflectors with a total of 45 feeds
D' Two 20-foot reflectors with a total of 21 feeds

We did not have quantitative data on side lobe performance, so we made judgements based on factors which would tend to cause side lobe problems. Blockage due to a large number of feeds, elliptical shaping of the aperture (leading to difficulty in obtaining proper reflector illumination in both planes) and the amount of feed offset were factors considered.

Stowed volume scoring was based on furled diameters of previously built antennas of appropriate sizes and on the number of antennas required in each case. Weight estimates were obtained using past data for the appropriate reflectors and using a figure of 1 pound for each feed. The totals are not absolutely accurate, but do tend to separte the various candidates.

Isolation between beams was estimated by considering the probable side lobe and coma lobe performance of the candidate system and taking into consideration where such lobes would fail.

Complexity was scored primarily on the number of feeds and the number of reflectors required for each candidate.

The rankings of the candidates are as follows:

Rank	Candidate	Score
1.	D	577
2.	D'	563
3.	A'	559
4.	B' & C'	549
6.	B	536
7.	C	529
8.	A	444

The total possible score was 690.

The difference in scores for all but candidate A are not as wide as one would like to have to say that a decision is clear cut. A review of this analysis was made by NASA-Langley with specific emphasis on the relative weightings which have been assigned to the desired objectives.

The technical monitor suggested that in the area of spillover, our weightings were too high, and in the area of system complexity, our weighting was too low.

TABLE I

Decision Statement: To Select a Multiple Beam Reflector Antenna Concept to Satisfy Requirements of the Langley Domestic Satellite Study

- What are we trying to decide?
- What is the decision to be made?
- What decisions must have already been made?

Decision Analysis Worksheet (1 of 2)

OBJECTIVES — ALTERNATIVES

MUST (– Is it absolutely essential? – Is it measurable?)

MUST	A 9.9 ft Circular Paraboloid INFO	GO/NO	B 9.9 x 5.8 ft Elliptical Paraboloid INFO	GO/NO	C 9.9 x 14 ft Elliptical Paraboloid INFO	GO/NO	D 20 ft Circular Paraboloid INFO	GO/NO
1. Multiple Beam Reflector Antenna System	Yes	✓	Yes	✓	Yes	✓	Yes	✓
2. Capable of Operation on a Synchronous Satellite	Flex-Rib Reflector	✓	Flex-Rib Reflector	✓	Flex-Rib Reflector	✓	Flex-Rib Reflector	✓
3. Provide Access to Four U.S. Time Zones, Alaska, Hawaii, Caribbean and 48 Contiguous U.S. States	Need Offset Feeds	✓	Need Offset Feeds	✓	Needs Offset Feeds	✓	Need Offset Feeds	✓

WANT (– All objectives that are not "musts" – "Musts" we wish to minimize or maximize)

WANT	WT	A INFO	SC	WT SC	B INFO	SC	WT SC	C INFO	SC	WT SC	D INFO	SC	WT SC
1. Side Lobes at Least 30 dB down	4	Less offset; Fewer Feeds	10	40	As A	10	40	Worse than A & B	7	28	Worse than C	5	20
2. Minimum Stowed Volume	2	≈ 17" dia	10	20	≈ 17" dia	10	20	≈ 24" dia	9	18	≈ 42" dia	6	12
3. Minimum Deployed Size	2	Worse than B	10	20	Best	10	20	Worse than A	9	18	Worse than C	6	12
4. Minimum Weight	4	‡ F = 7 R = 16	10	40	F = 7 R = 15.5	10	40	F = 11 R = 25	9	36	F = 21 R = 35	8	32
5. * Maximum Coverage of Time Zones – Population Basis	3	Poor	0	0	Good	10	30	Clips part of Mich.	8	24	Good	10	30
6. * " " " " " – Area Basis	10	No Fla., S. Tex., Me. Poor above 44°N	0	0	All except two corners.	7	70	About same as B	7	70	Better than B, C (E.T.Z)	9	70
7. † Minimum Spill-Over " " " Into Canada/Mexico	4	Very good	10	40	25°N to 50°N	2	8	A little more than D	6	24	200-250 miles into Canada	7	28
8. * Maximum Coverage of Hawaii/Caribbean – Area Basis	9	Good (No Midway)	9	81	Good	10	90	Good (No Midway)	9	81	Good (No Midway)	9	81
9. † Minimum Spill-Over into Caribbean/S. America	3	Good	5	15	Could be improved	2	6	Better than A	7	21	Better than C	8	24
10. * Maximum Coverage of Alaska – Area Basis	8	Clips Aleutian, NE corner	10	80	Better than A	10	80	Slightly Worse than A	10	80	1 beam worse than C, 2 " better " "	10	80
11. † Minimum Spill-Over " " Into Siberia/Canada	2	Chukotskiy Peninsula/Yukon	10	20	About same	10	20	About same	10	20	About same	10	20
12. * Maximum Coverage of 48 States – Area Basis	4	Poor	0	0	Almost all	10	40	Slightly worse than B	8	32	Better than C	10	40
13. † Minimum Spill-Over " " " Into Canada/Mexico	2	Very good (as #7)	10	20	As #7	2	4	As #7	6	12	As #7	7	14
14. Maximum Isolation between Beams	7	Possible coma & first s.l.	4	28	As A	4	28	As A	4	28	No coma; poorer s.l.	8	56
15. Reference Tracking Capability for System Update	1	Difficult	0	0	Difficult	0	0	Maybe	1	1	Yes	10	10
16. Minimum Complexity	4	Best	10	40	Slightly worse than A	10	40	11 feeds, elliptic	9	36	21 feeds	7	28
* Within –3/–4 dB Contour † Area Basis		‡ 1 lb per Feed (F) Flex-Rib Reflector (R) Est.											
TOTAL WT SC		↳ Max Score = 690		444			536			529			577

WEIGHTING
- Which of our "Want" objectives is the most important? (10)
- What is the relative importance of all other "Want" objectives?
- Does the weight assigned to each objective accurately indicate the contribution that the objective should make in the ultimate decision?

SCORING
- How well do all alternatives under consideration satisfy each specific objective?
- Which alternative provides the greatest satisfaction? (10)
- What is the relative satisfaction provided by all other alternatives?

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TABLE II

Decision Analysis Worksheet (2 of 2)

Decision Statement: To Select a Multiple Beam Reflector Antenna Concept to Satisfy Requirements of the Langley Domestic Satellite Study

- What are we trying to decide?
- What is the decision to be made?
- What decisions must have already been made?

OBJECTIVES — ALTERNATIVES

MUST (– Is it absolutely essential? – Is it measurable?)

MUST	A′ 30 Ft Circular Paraboloid INFO	GO/NO	B′ Two - 30 Ft Circ. Par's INFO	GO/NO	C′ Four - 30 Ft Circ. Par's INFO	GO/NO	D′ Two - 20 Ft Circ. Para's. INFO	GO/NO
1. Multiple Beam Reflector Antenna System	Yes	✓	As A′	✓	As A′	✓	As D	✓
2. Capable of Operation on a Synchronous Satellite	Flex-Rib Reflector	✓	As A′	✓	As A′	✓	As D	✓
3. Provide Access to Four U.S. Time Zones, Alaska, Hawaii, Caribbean and 48 Contiguous U.S. States	Needs Offset Feeds	✓	Better than A′	✓	Better than B′	✓	Better than D	✓

WANT (– All objectives that are not "musts" – "Musts" we wish to minimize or maximize)

WANT	WT	A′ INFO	SC	WT SC	B′ INFO	SC	WT SC	C′ INFO	SC	WT SC	D′ INFO	SC	WT SC
1. Side Lobes at Least 30 dB down	4	Many feeds; Large offset	4	16	Better than A′	5	20	Better than B′	8	32	Better than D	8	32
2. Minimum Stowed Volume	2	≈78" dia	3	6	Two-78" dia.	1	2	Four ≈78" dia	0	0	Two ≈42" dia	2	4
3. Minimum Deployed Size	2	Worse than D	4	8	Twice A′	1	2	Twice B′	0	0	Twice D	1	2
4. Minimum Weight	4	‡ F=45 R=150	3	12	F=45 R=300	2	8	F=45 R=600	0	0	F=21 R=70	6	24
5.* Maximum Coverage of the Time Zones - Population Basis	3	Good	10	30	Good	10	30	Good	10	30	Good	10	30
6.* " " " " " - Area Basis	10	Very good (ETZ)	10	100	As A′	10	100	As A′	10	100	As D	9	90
7.† Minimum Spill-Over " " Into Canada/Mexico	4	Very good (<100 miles)	8	32	As A′	8	32	As A′	8	32	As D	7	28
8.* Maximum Coverage of Hawaii/Caribbean - Area Basis	9	Good (No Midway)	9	81	As A′	9	81	As A′	9	81	As D	9	81
9.† Minimum Spill-Over Into Caribbean/S. America	3	Best	10	30	As A′	10	30	As A′	10	30	As D	8	24
10.* Maximum Coverage of Alaska - Area Basis	8	Requires 2 beams	10	80	As A′	10	80	As A′	10	80	As D	10	80
11.† Minimum Spill-Over " Into Siberia/Canada	2	About same	10	20	As A′	10	20	As A′	10	20	As D	10	20
12.* Maximum Coverage of 48 States - Area Basis	4	Very good	10	40	As A′	10	40	As A′	10	40	As D	10	40
13.† Minimum Spill-Over " " " Into Canada/Mexico	2	As #7	8	16	As #7	8	16	As #7	8	16	As #7	7	14
14. Maximum Isolation between Beams	7	No time zone coma or s.l. effects on copol. beam	10	70	As A′	10	70	As A′	10	70	As D	8	56
15. Reference Tracking Capability for System Update	1	Yes	10	10	As A′	10	10	As A′	10	10	As D	10	10
16. Minimum Complexity	4	Worst	2	8	About same as A′	2	8	About same as B′	2	8	About same as D	7	28
* Within -3/-4 dB Contour † Area Basis		‡ 1 lb per Feed (F) Flex-Rib Reflector (R) Est.											
		Max Score = 690	TOTAL WT SC	559	TOTAL WT SC		549	TOTAL WT SC		549	TOTAL WT SC		563

WEIGHTING
– Which of our "Want" objectives is the most important? (10)
– What is the relative importance of all other "Want" objectives?
– Does the weight assigned to each objective accurately indicate the contribution that the objective should make in the ultimate decision?

SCORING
– How well do all alternatives under consideration satisfy each specific objective?
– Which alternative provides the greatest satisfaction? (10)
– What is the relative satisfaction provided by all other alternatives?

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Therefore, LMSC reviewed the weighting of the spillover and system complexity. As a result the weighting of the spillover has been reduced to unity for each of the spillover wants, namely,

Want #	Want
7	Minimum spillover of Time Zones into Canada/Mexico
9	Minimum spillover of Caribbean into Caribbean/S.America
11	Minimum spillover of Alaska into Siberia/Canada
13	Minimum spillover of 48 States into Canada/Mexico

The requirement that the multiple beam antenna system have minimum complexity (want #16) had been weighted four. This was raised to seven, a weighting only slightly less than that for the coverage of the three outer regions (Alaska, Hawaii and the Caribbean.

In addition, the scores of the candidates for all the "wants" were reviewed very carefully. In particular the scores for coverage, complexity and electrical performance were re-examined and in some cases revisions were made.

For those candidates and wants whose weightings and/or scores were modified new weighted scores were entered into the Decision Analysis Tables and new weighted scores of the eight candidate antenna systems were calculated. The new total weighted scores, in order of ranking are:

Ranking	Alternative	Paraboloid	Total Weighted Score
1	B	9.9 x 5.8 ft. Elliptical	544
2	C	9.9 x 14 ft. Elliptical	533
3	A'	30 ft. Circular	499
4	B'	Two-30 ft. Circulars	493
	C'	Four-30 ft. Circulars	
6	D	20 ft. Circular	492
7	D'	Two-20 ft. Circulars	478
8	A	9.9 ft. Circular	414

The maximum possible score was 650. The KTA trade-off analysis is presented in detail in Tables III and IV.

The KTA analysis shows the 9.9' x 5.8' elliptical paraboloidal reflector to be the most promising candidate for the study with the 9.9 x 14 ft. elliptical paraboloidal reflector a close seond. It was decided that the smaller elliptical reflector represented the conceptual design while the second offered a suitable alternative.

2.11 Reflector Test Philosophy

The analysis presented up to now in this report represents the completion of the development of conceptual designs based on the performance analysis of candidate reflector antenna systems.

In October 1972, a document furnishing all operational antenna requirements was prepared and transmitted to NASA-Langley. It contained a description and list of tne specifications for the two candidate reflector antenna systems.

1. 9.9 x 5.8 ft. Elliptical Paraboloidal Reflector Antenna
2. 9.9 x 14.0 ft. Elliptical Paraboloidal Reflector Antenna

The major diameter/minor diameter ratios of the two elliptical paraboloidal reflector antennas are:

Concept	Reflector Size E-W	Reflector Size N-S	Diameter Ratio
1.	9.9 x	5.8 ft.	1.707
2.	9.9 x	14.0 ft.	1.414

If these diameter ratios were identical the same elliptical reflector could be used to test both concepts by appropriate scaling of frequency.

In order to make the diameter ratios equal the best compromise is to decrease the ratio for the first concept and increase it for the second. For both concepts this implies decreasing the E-W diameter and/or increasing the N-S diameter.

TABLE III

Decision Statement: To Select a Multiple Beam Reflector Antenna Concept to Satisfy Requirements of the Langley Domestic Satellite Study.

- What are we trying to decide?
- What is the decision to be made?
- What decisions must have already been made?

Decision Analysis Worksheet
(1 of 2)

OBJECTIVES / ALTERNATIVES

MUST (– Is it absolutely essential? – Is it measurable?)	A 9.9 ft Circular Paraboloid INFO	GO/NO	B 9.9 x 5.8 ft Elliptical Paraboloid INFO	GO/NO	C 9.9 x 14 ft Elliptical Paraboloid INFO	GO/NO	D 20 ft Circular Paraboloid INFO	GO/NO
1. Multiple Beam Reflector Antenna System	Yes	✓	Yes	✓	Yes	✓	Yes	✓
2. Capable of Operation on a Synchronous Satellite	Flex-Rib Reflector	✓	Flex-Rib Reflector	✓	Flex-Rib Reflector	✓	Flex-Rib Reflector	✓
3. Provide Access to Four U.S. Time Zones, Alaska, Hawaii, Caribbean and 48 Contiguous U.S. States.	Need Offset Feeds	✓	Need Offset Feeds	✓	Need Offset Feeds	✓	Need Offset Feeds	✓

WANT (– All objectives that are not "musts" – "Musts" we wish to minimize or maximize)	WT	A INFO	SC	WT SC	B INFO	SC	WT SC	C INFO	SC	WT SC	D INFO	SC	WT SC
1. Side Lobes at Least 30 dB down	4	Less offset, Fewer Feeds	10	40	As A	10	40	Worse than A & B	9	36	Worse than C	5	20
2. Minimum Stowed Volume	2	≈ 17" dia	10	20	≈ 17" dia	10	20	≈ 24" dia	9	18	~~≈ 42" dia~~	6	12
3. Minimum Deployed Size	2	Worse than B	10	20	Best	10	20	Worse than A	9	18	Worse than C	6	12
4. Minimum Weight	4	‡ F = 7 R = 16	10	40	F = 7 R = 15.5	10	40	F = 11 R = 25	9	36	F = 21 R = 35	8	32
5.* Maximum Coverage of Time Zones – Population Basis	3	Poor	0	0	Good	10	30	Clips part of Mich.	9	27	Good	10	30
6.* " " " " " – Area Basis	10	No Fla, S. Tex, Me. Poor above 44°N	0	0	All except two corners	7	70	About same as B	8	80	Better than B, C (ETZ)	8	80
7.† Minimum Spill-Over " " Into Canada/Mexico	1	Very Good	10	10	22°N to 50°N	2	2	A little more than D	6	6	200-250 miles into Canada	7	7
8.* Maximum Coverage of Hawaii/Caribbean – Area Basis	9	Good (No Midway)	9	81	Good	10	90	Good (No Midway)	9	81	Good (No Midway)	9	81
9.† Minimum Spill-Over Into Caribbean/South America	1	Good	5	5	Could be improved	2	2	Better than A	7	7	Better than C	8	8
10.* Maximum Coverage of Alaska – Area Basis	8	Clips Aleutian, N.E. corner	10	80	Better than A	10	80	Slightly worse than A	10	80	1 beam, worse than C; 2 beams, better than C	10	80
11.† Minimum Spill-Over Into Siberia/Canada	1	Chukotskiy Pen/Yukon	10	10	About same	10	10	About same	10	10	About same	10	10
12.* Maximum Coverage of 48 States – Area Basis	4	Poor	0	0	Almost all	10	40	Slightly worse than B	9	36	Better than C	10	40
13.† Minimum Spill-Over " " Into Canada/Mexico	1	Very Good (As #7)	10	10	As #7	2	2	As #7	6	6	As #7	7	7
14. Maximum Isolation Between Beams.	7	Possible correct first s.l.	4	28	As A	4	28	As A	4	28	No coma; poorer s.l.	5	35
15. Reference Tracking Capability for System Update	1	Difficult	0	0	Difficult	0	0	Maybe	1	1	Yes	10	10
16. Minimum Complexity	7	Best	10	70	Slightly worse than A.	10	70	11 feeds, elliptic	9	63	21 Feeds	4	28
* Within -3/-4 dB Contour † Area Basis		‡ 1 lb per feed (F) Flex-Rib Reflector (R) Est.											
		Max. Score = 650	TOTAL WT SC	414		TOTAL WT SC	544		TOTAL WT SC	533		TOTAL WT SC	492

WEIGHTING
- Which of our "Want" objectives is the most important? (10)
- What is the relative importance of all other "Want" objectives?
- Does the weight assigned to each objective accurately indicate the contribution that the objective should make in the ultimate decision?

SCORING
- How well do all alternatives under consideration satisfy each specific objective?
- Which alternative provides the greatest satisfaction? (10)
- What is the relative satisfaction provided by all other alternatives?

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TABLE IV

Decision Statement: To Select a Multiple Beam Reflector Antenna Concept to Satisfy Requirements of the Langley Domestic Satellite Study.

- What are we trying to decide?
- What is the decision to be made?
- What decisions must have already been made?

Decision Analysis Worksheet

OBJECTIVES — ALTERNATIVES

MUST (– Is it absolutely essential? – Is it measurable?)

MUST	A' 30 ft Circular Paraboloid INFO	GO/NO	B' Two – 30 ft Circular Parab's INFO	GO/NO	C' Four – 30 ft Circular Parab's INFO	GO/NO	D' Two – 20 ft Circular Parab's INFO	GO/NO
1. Multiple Beam Reflector Antenna System	Yes	✓	As A'	✓	As A'	✓	As D	✓
2. Capable of Operation on a Synchronous Satellite	Flex-Rib Reflector	✓	As A'	✓	As A'	✓	As D	✓
3. Provide Access to Four U.S. Time Zones, Alaska, Hawaii, Caribbean and 48 Contiguous U.S. States.	Needs Offset Feeds	✓	Better than A'	✓	Better than B'	✓	Better than D	✓

WANT (– All objectives that are not "musts" – "Musts" we wish to minimize or maximize)

WANT	WT	A' INFO	SC	WT SC	B' INFO	SC	WT SC	C' INFO	SC	WT SC	D' INFO	SC	WT SC
1. Side Lobes at Least 30 dB down	4	Many feeds; Large offset	3	12	Better than A'	5	20	Better than B'	8	32	Better than D	8	32
2. Minimum Stowed Volume	2	≈ 78" dia	3	6	Two ≈78" dia ea	1	2	Four ≈ 78" dia. ea	0	0	Two ≈ 42" dia. ea.	2	4
3. Minimum Deployed Size	2	Worse than D	4	8	Twice A'	1	2	Twice B'	0	0	Twice D	1	2
4. Minimum Weight	4	‡F = 45 R = 150	3	12	F = 45 R = 300	2	8	F = 45 R = 600	0	0	F = 21 R = 70	6	24
5.* Maximum Coverage of Time Zones – Population Basis	3	Good	10	30	Good	10	30	Good	10	30	Good	10	30
6.* " " " " " – Area Basis	10	Very good (ETZ)	10	100	As A'	10	100	As A'	10	100	As D	8	80
7.† Minimum Spill-Over " " " Into Canada/Mexico	1	Very good (<100 miles)	8	8	As A'	8	8	As A'	8	8	As D	7	7
8.* Maximum Coverage of Hawaii/Caribbean – Area Basis	9	Good (No Midway)	9	81	As A'	9	81	As A'	9	81	As D	9	81
9.† Minimum Spill-Over Into Caribbean/South America	1	Best	10	10	As A'	10	10	As A'	10	10	As D	8	8
10.* Maximum Coverage of Alaska – Area Basis	8	Requires 2 beams	10	80	As A'	10	80	As A'	10	80	As D	10	80
11.† Minimum Spill-Over Into Siberia/Canada	1	About same	10	10	As A'	10	10	As A'	10	10	As D	10	10
12.* Maximum Coverage of 48 States – Area Basis	4	Very Good	10	40	As A'	10	40	As A'	10	40	As D	10	40
13.† Minimum Spill-Over " " Into Canada/Mexico	1	As #7	8	8	As #7	8	8	As #7	8	8	As #7	7	7
14. Maximum Isolation Between Beams	7	No Time Zone coma or s.l. effects on copol. beam	10	70	As A'	10	70	As A'	10	70	As D	5	35
15. Reference Tracking Capability for System Update	1	Yes	10	10	As A'	10	10	As A'	10	10	As D	10	10
16. Minimum Complexity	7	Worst	2	14	About same as A'	2	14	About same as B'	2	14	About same as D	4	28
* Within -3/-4 dB Contour † Area Basis		‡ 1 lb. per feed F; Flex-Rib Reflector (R) Est.											
		Max. Score = 650	TOTAL WT SC	499	TOTAL WT SC		493	TOTAL WT SC		493	TOTAL WT SC		478

WEIGHTING
- Which of our "Want" objectives is the most important? (10)
- What is the relative importance of all other "Want" objectives?
- Does the weight assigned to each objective accurately indicate the contribution that the objective should make in the ultimate decision?

SCORING
- How well do all alternatives under consideration satisfy each specific objective?
- Which alternative provides the greatest satisfaction? (10)
- What is the relative satisfaction provided by all other alternatives?

FORM LMSC 2699 B(FRONT)

LOCKHEED MISSILES & SPACE COMPANY

The increase in the N-S diameter of the second concept causes a decrease in the N-S beamwidth for this reflector but this can be corrected, if necessary, by a change in the boresight of the feeds illuminating a particular time zone.

If a 9.33 x 5.8 ft. reflector is used for testing the first concept at 4 GHz then a 5.8 x 9.33 ft. reflector can be used for testing the second concept at 6.43 GHz. That is, the reflector used for the first series of tests is then rotated through 90° and fitted with a second set of feeds operating at a frequency scaled by a factor of 1.6.

In order to examine this approach in more detail, footprint contours for reflectors of these sizes, with appropriate boresights for the feeds, were generated.

These contours showed that the coverage of the four time zones by the smaller (9.33 x 5.8 ft) reflector is almost identical to that provided by a 9.9 x 5.8 ft. reflector. That is, the change in the E-W diameter from the conceptual size (9.9 ft.) to the proposed experimental size (9.33 ft.) has an insignificant effect on the footprints.

These contours also show that the coverage of the four time zones by the larger (9.33 x 15 ft.) reflector is almost identical to that provided by a 9.9 x 14.0 ft. reflector. Boresights were changed slightly to compensate for the change in size. Corner "clipping" of the time zones was kept the same.

Since the changes in reflector size had little effect on the coverage of the time zones, detailed discussion of the footprints, already provided in previous Monthly Technical Progress Reports, is not now warranted. The approach of using a single reflector to test, experimentally, two concepts has been validated.

3.0 RE-DIRECTION

On November 18, 1971, LMSC was notified by NASA-Langley, that the study would be redirected. Instead of using one and two feeds with an elliptical paraboloidal reflector to illuminate each individual U. S. time zone it was decided to use a large circular paraboloidal reflector with multiple feeds to illuminate a single time zone. In particular, a 30 ft. diameter paraboloid with about ten feeds covering just the Eastern time zone would be the concept to be tested experimentally. In addition to the technical redirection, LMSC was advised that additional time of two months would be allowed for completion of the program, though no additional funding would be available.

Upon receipt of the message that the study would be redirected all work directed towards the testing of an elliptical paraboloidal reflector was stopped.

All work was then directed towards the 30 ft. diameter circular paraboloidal reflector antenna concept.

3.1 Antenna System

At the time the 30 ft. diameter circular paraboloid was first investigated, it was determined that about ten feeds would be required to synthesize a beam which would provide coverage of the Eastern Time Zone. This particular time zone was selected because its geographical shape is such that it is the most difficult to cover completely without, at the same time, creating serious spillover into densely populated regions of Canada's Ontario and Quebec provinces.

This beam synthesis technique appeared to be very promising in that it yielded good coverage of the Eastern Time Zone with less spill-over into Canada than resulted from the use of a smaller elliptical paraboloidal reflector. It also had the potential for a considerable amount of beam shaping by adjustment of the boresights of the individual beams.

The characteristics which argued against a large reflector antenna system were its size, weight, stowed volume and complexity, particularly the complexity. With four time zones and three outlying territories to cover such a reflector requires about forty feeds each of which must be carefully positioned and oriented.

However, since the elliptical paraboloidal reflector concept employing only one or two feeds for each time zone presents fewer difficulties, it appears that the more complex large reflector system is more worthy of investigating by an experimental test program. If the beam synthesis technique can be realized experimentally this antenna concept will provide much better coverage with less spill-over, and a higher gain.

The large reflector will be tested for coverage of the Eastern Time Zone only. Successful coverage of this Time Zone implies that there should be no difficulty in providing coverage of the other three Time Zones and the three outlying territories. In other words, the experimental program is much more of the nature of a feasibility study than would be a program to test a small elliptical paraboloidal reflector.

As a first step in implementing this change, a detailed evaluation of the results of previous analysis of the Eastern Time Zone was undertaken. The objective of this reevaluation was to optimize the number and locations of the component beams to achieve better coverage with, if possible, fewer beams.

The computer program which has been used and modified during this study was originally written in 1968 for another multiple beam study. As originally written, the program, when summing several component beams, did not renormalize with respect to the peak value of the composite beam thus formed. This was done to retain the original reference and this fact was not realized at first. Although the coverage contours shown in previous reports for composite beams (made from two or more beams) are correct, the decibel values for the contour lines shown refer to the peak of a single component beam.

When the detailed structure of the coverage contours for the thirty-foot reflector (as previously configured) was examined, it was found that near the center of the Eastern Time Zone a "pile-up" situation occurred where several component beams were contributing to the coverage. As a result the peak value of the composite beam was +2 dB, making the -3 dB contour actually the -5 dB contour when referred to the peak of the composite beam. It was clear that either the beams should be reboresighted in a more widely-spread configuration or the number of beams should be reduced. The latter choice was more desirable for two reasons: (1) spreading the beams out would tend to increase the area covered, and (2) reducing the number of beams would tend to reduce the complexity. In either case, the beam to beam separation would be reduced, thereby alleviating one of the more critical problems.

Accordingly, effort began to see how well the Eastern Time Zone could be covered by using exactly eight beams. While it is desirable to have as few beams as possible, there is strong argument for having the number of beams equal a power of 2 if the power distribution among beams is to be even; this results in a simple power dividing network fashioned after a family tree or corporate structure. Covering the Eastern Time Zone with only four beams, the next lower power of 2, did not turn out to be feasible (using a 30 foot reflector).

Fig. 56 represents a "first look" at using eight feeds to cover the U.S. Eastern Time Zone. As in previous contours presented, the satellite is in synchronous orbit at $0^{o}N$, $112^{o}W$ and the operating frequency is 4 GHz. The boresight of the eight feeds illuminating a 30 ft. diameter paraboloidal reflector are:

Beam	Latitude (^{o}N)	Longitude (^{o}W)
A	45.0	70.0
B	37.0	76.0
C	31.5	82.5
D	27.0	82.0
E	36.0	83.5
F	41.5	78.0
G	41.5	84.5
H	46.0	86.5

It can be seen from Fig. 56 that there is some spill-over into Canada. For example, within the -3 dB contour lie parts of South-West Ontario, including Windsor, the Canadian city of Sault Ste Marie, the Eastern Townships region of Quebec Province and part of New Brunswick, including Frederickton. Likewise, there are some regions of the Eastern Time Zone which lie without the -3 dB contour, notably Southern Florida including Miami, Eastern Mississippi, the Flint-Port Huron area of Michigan and part of Maine east of Bangor. Also There is some spill-over of the -3 dB contour into the U.S. Central Time Zone, but this can be isolated by polarization diversity.

3.2 Contour Analysis

Figure 57 shows the Eastern Time Zone covered by a composite beam summed from eight individual beams with different boresights. The boresights of the eight beams are:

45° N	70° W
41.5° N	78.5° W
45.5° N	85.5° W
40° N	85° W
36° N	83° W
31.5° N	82.5° W
27° N	82° W
37.5° N	76.5° W

It can be seen from Figure 57 that the -3 dB contour with a few exceptions follows the outline of the time zone. The spillover into Canada can be viewed in three separate areas. The large amounts spilling over into north-east Canada and the Maritime Provinces is unavoidable if the northeastern part of the United States is to be covered as the Earth is falling away rapidly at this angle from the satellite and the beam elongates. The beam falloff between southwest Ontario and the Eastern Townships region of Quebec province is rapid and represents a significant improvement from the elliptical reflector contours reported earlier. In the ideal case of a square-sided beam there would be no spillover into Canada in this area. However, this energy drop-off represents the best possible from a realistic beam produced from this size reflector while still maintaining good U. S. coverage.

The spillover north and northeast from Michigan is also undesirable, but can be reduced to similar levels as those from southwest Ontario eastward, by allotting the coverage of northern Michigan to the Central Time Zone beam.

Figure 58 shows a summed 8 beam Eastern Time Zone contour which bypasses coverage of northern Michigan. The coverage elsewhere is similar to that in Figure 57. The spillover from Sault Ste. Marie thru Quebec province is substantially the same and, again, although not ideal, is significantly improved over beams from smaller diameter reflectors. The boresights of these eight beams are

45°	N	70°	W
41.5°	N	79°	W
42°	N	85°	W
36°	N	83.5°	W
31°	N	85°	W
28°	N	81°	W
33.5°	N	79.5°	W
38.5°	N	75°	W

A brief investigation was undertaken to evaluate coverage of each of the other U.S. Time Zones as well as Hawaii, Alaska and the Caribbean. Examples of coverage to these other areas are shown in Figures 59 through 62. As before, the satellite is a 112° W. Longitude and the reflector boresight is at 37° N. Latitude and 112° W. Longitude. The reflector diameter is 30 feet operating at a frequency of 4 GHz.

Figure 59 shows the -3 db and -20 db contours for single beam coverage of Hawaii. The boresight of the beam is at 20.5° N. Latitude and 157.5° W. Longitude. All the main islands of the Hawaiian chain are within the beam's 3 dB contour.

Figure 60 shows the -3 db and -20 db contours for single beam coverage of the U. S. Caribbean territories. The boresight of the beam is at 18° N. Latitude and 66° W. Longitude. Within the 3 db contour is Puerto Rico and the U.S. Virgin Islands. There is no spillover into Northern South America but there is some into the Dominican Republic. This spillover could be improved by positioning the beam aim point further eastward so that the Western edge of the 3 db contour lies on western Puerto Rico.

Figure 61 shows the -3 db and -20 db contour of a first attempt at a composite beam from four individual beams to cover Alaska. The boresights of the four beams are:

59° N. Lat.	157° W. Long.
60 "	140 "
62.5 "	151 "
67 "	141 "

Because of the large size of Alaska and the relatively small beamwidth of the 30 ft. diameter antenna beam, one beam is not sufficient to cover Alaska. Additionally, it is obvious that two beams are not sufficient, and also that the composite four beam coverage does not include all of Alaska within its 3 db contour. The particular areas not covered will depend on the location of the individual beam boresights. If full coverage within the 3 db contour of the geographical outline of Alaska is an absolute requirement, then more than four beams will be required.

Figure 62 shows the -3, -6, -9 and -12 db contours of an eight beam composite to cover the U. S. Pacific Time Zone. Although not perfect, it does show that the time zone can be fitted to an eight beam composite with a rapid beam fall-off into Canada and Mexico. No contour analyses were done on either the Central or Mountain Time Zone. The boresights of the eight beams are:

34.5° N. Lat.	115° W. Long.
34.5 "	120° "
40 "	115° "
40 "	120° "
40 "	125° "
46.5 "	115° "
46.5 "	120° "
46.5 "	125° "

At this time, the analysis had essentially reached the point where additional refinements of contour shape and individual beam location using analytical functions for the antenna patterns would not aid in the design of the test configuration. The analysis is valuable in that from the required beam locations, it provides a baseline location of the 8 feeds in the focal plane of the reflector. It is anticipated during the test phase that relative feed locations will have to be changed from their baseline locations to compensate for those things such as mutual coupling and feed support reflections, which cannot be incorporated into the theoretical analysis.

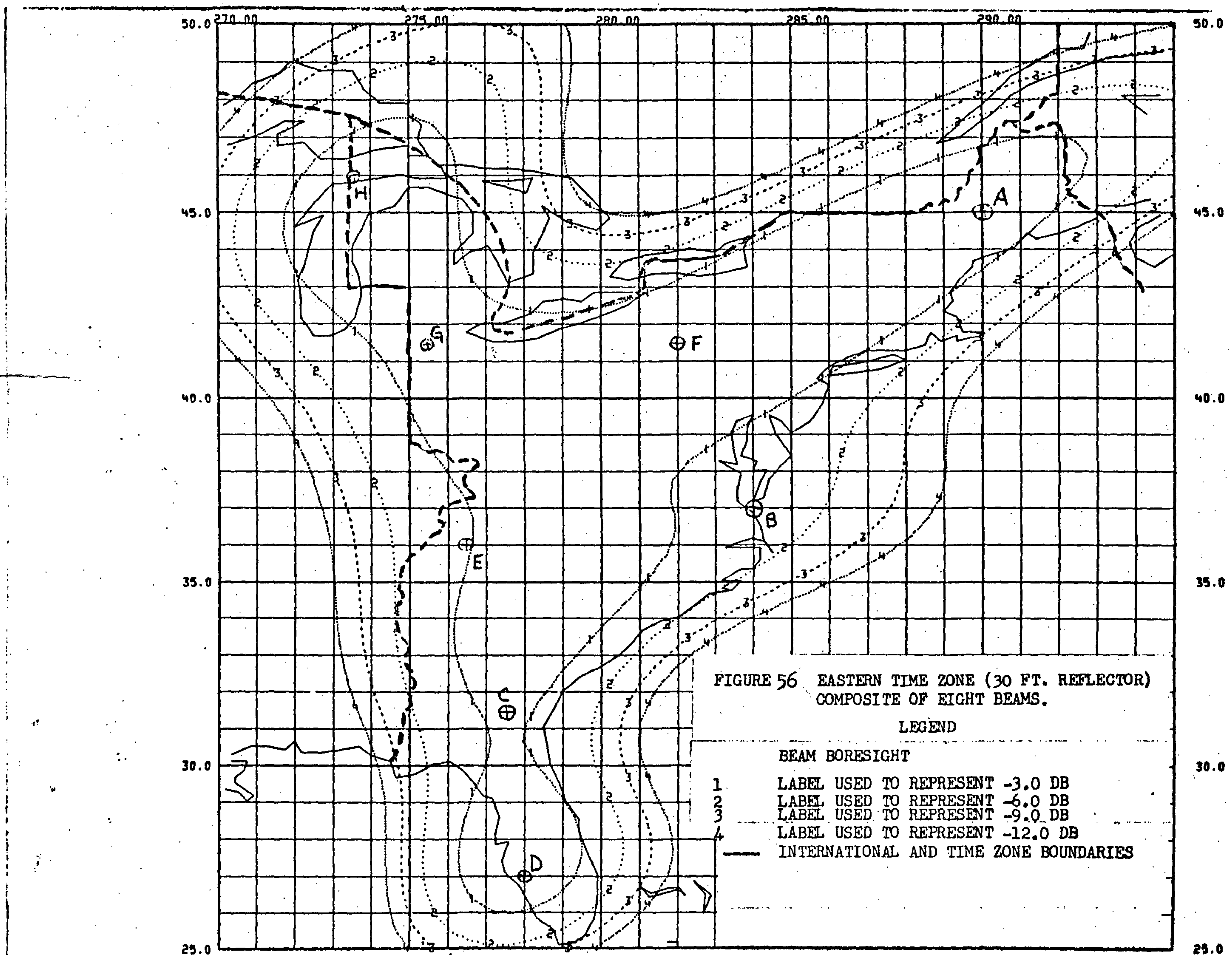


FIGURE 56 EASTERN TIME ZONE (30 FT. REFLECTOR) COMPOSITE OF EIGHT BEAMS.

LEGEND

⊕ BEAM BORESIGHT

1 LABEL USED TO REPRESENT -3.0 DB

2 LABEL USED TO REPRESENT -6.0 DB

3 LABEL USED TO REPRESENT -9.0 DB

4 LABEL USED TO REPRESENT -12.0 DB

—— INTERNATIONAL AND TIME ZONE BOUNDARIES

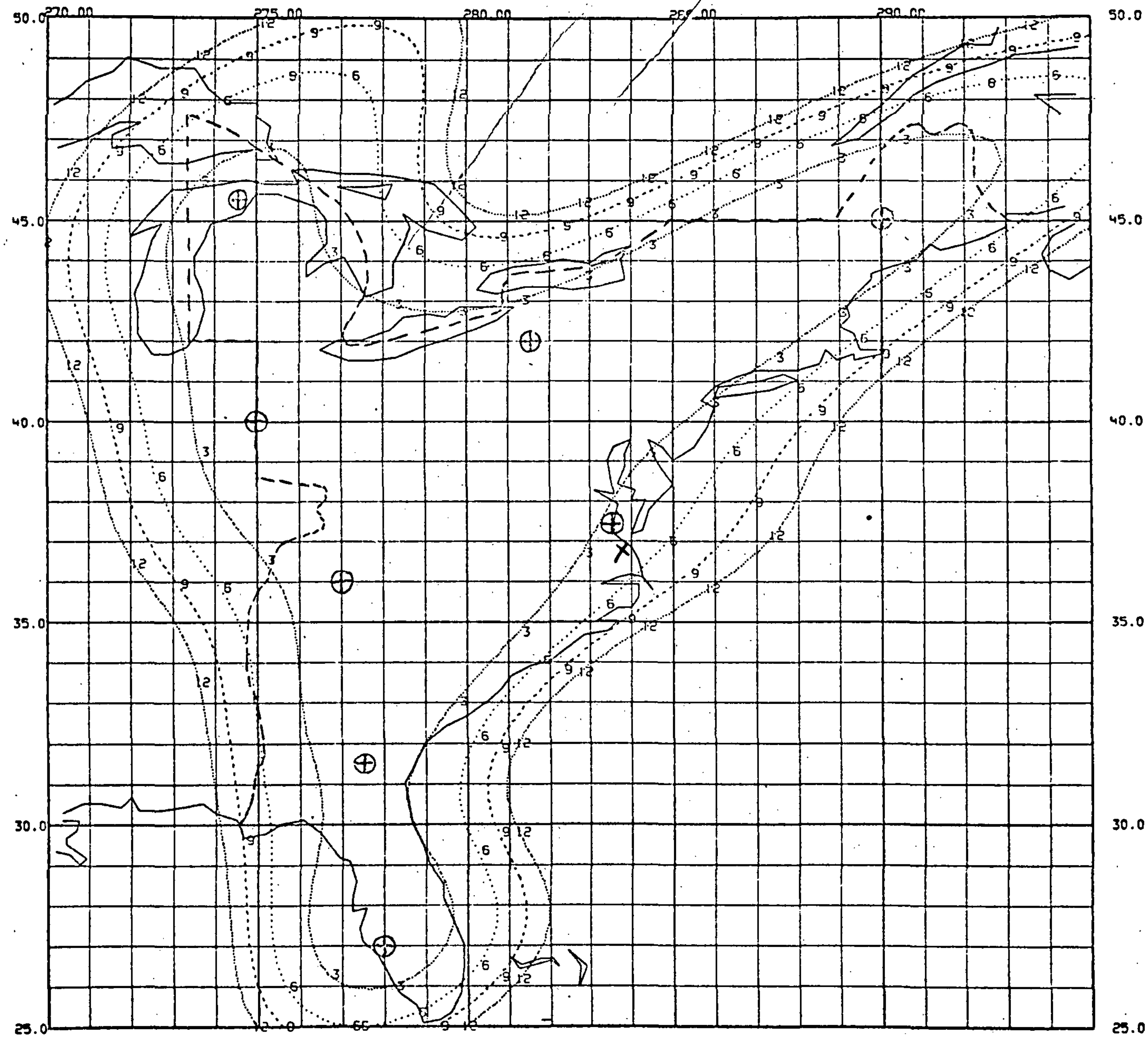


FIGURE 57 30 FT. DIAMETER _--- 8 BEAMS U. S. EASTERN TIME ZONE

WITH NORTHERN MICHIGAN'

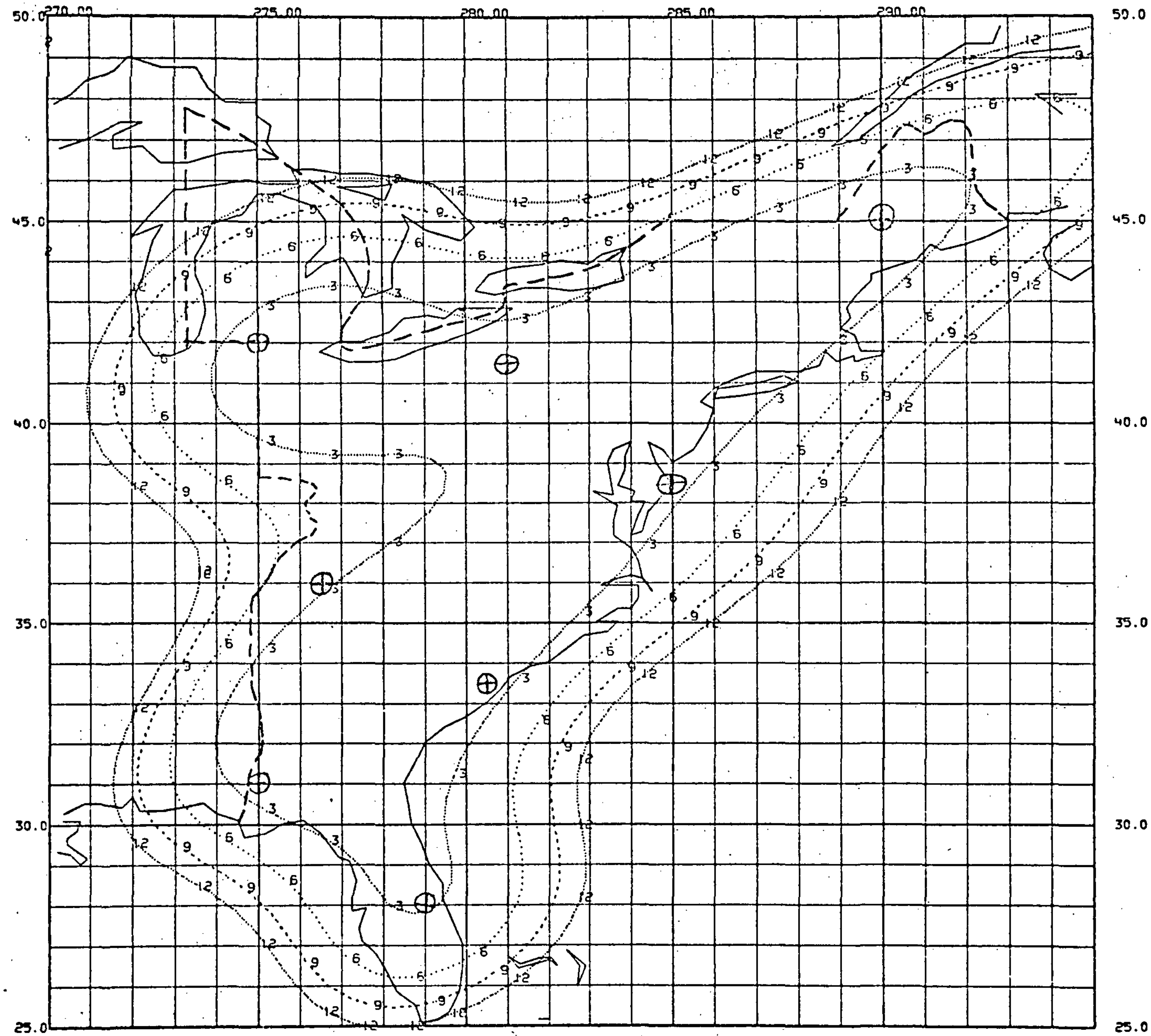


FIGURE 58 30 FT. DIAMETER ---8 BEAMS-- U. S. EASTERN TIME ZONE

W/O NORTHERN MICHIGAN

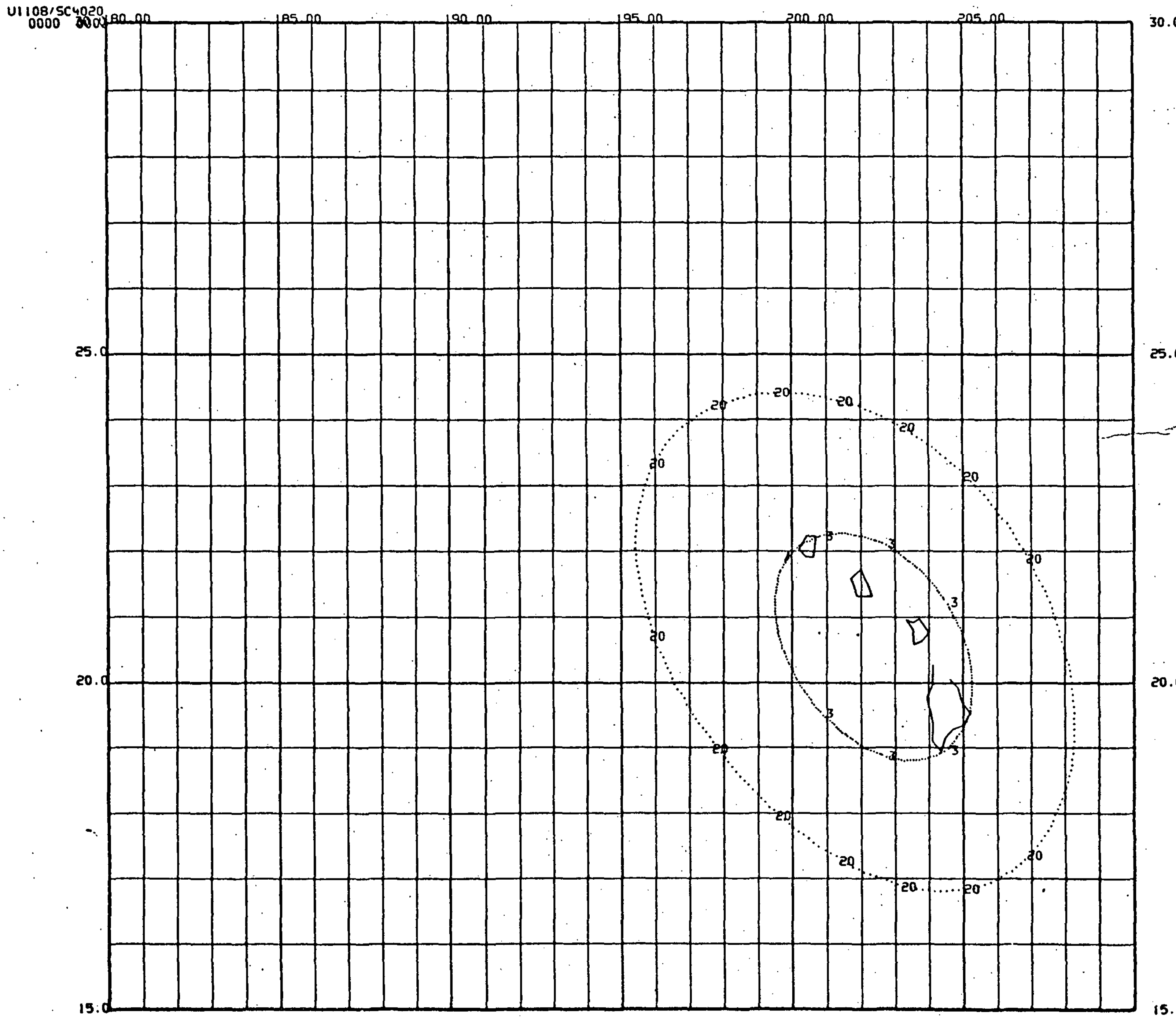


FIG. 59---- 30 FT. DIAMETER---- 4 GHZ.-------- HAWAII

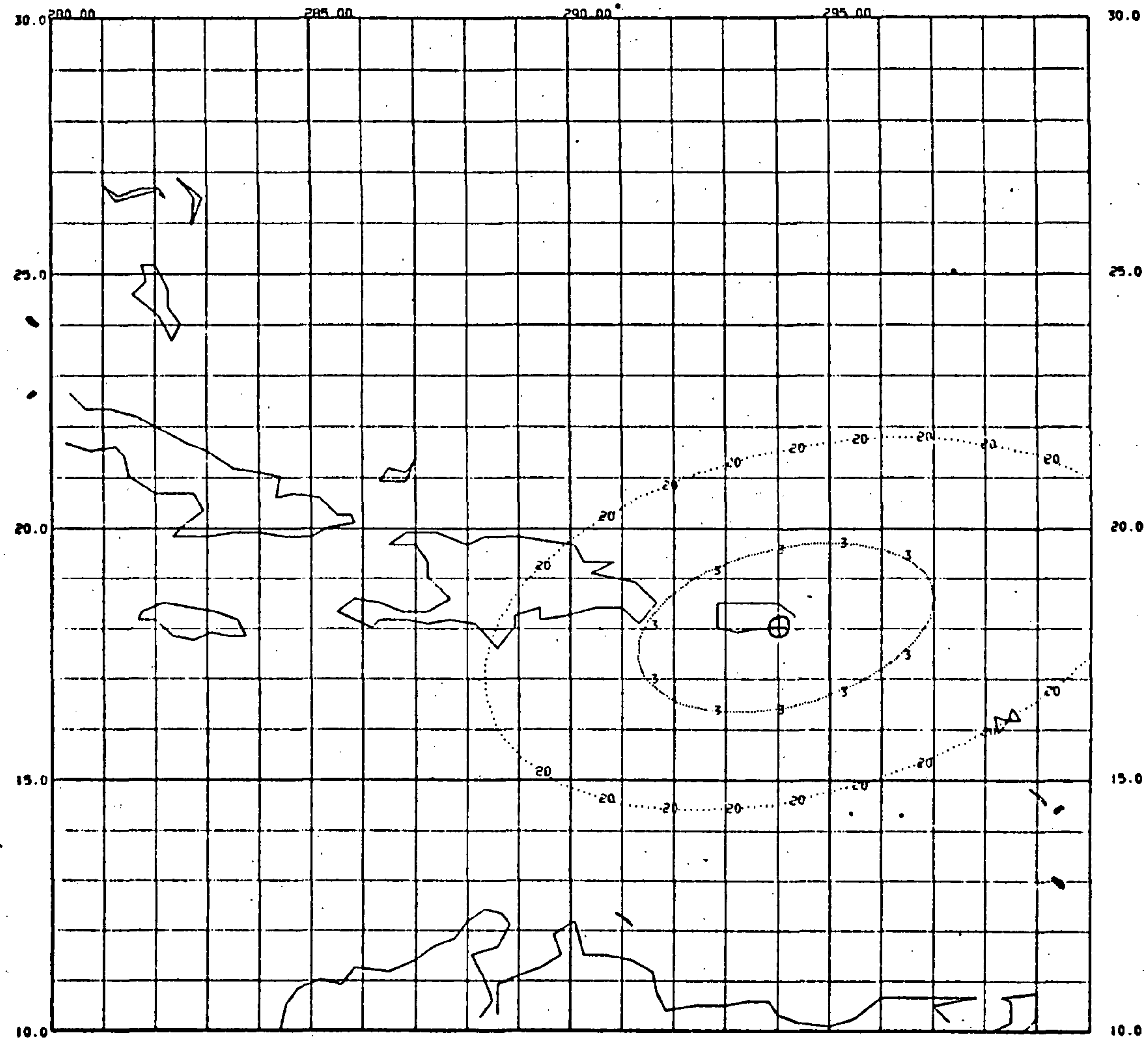


FIGURE 60 _30 FT. DIAMETER---- 4 GHZ.
CARIBBEAN TERRITORIES

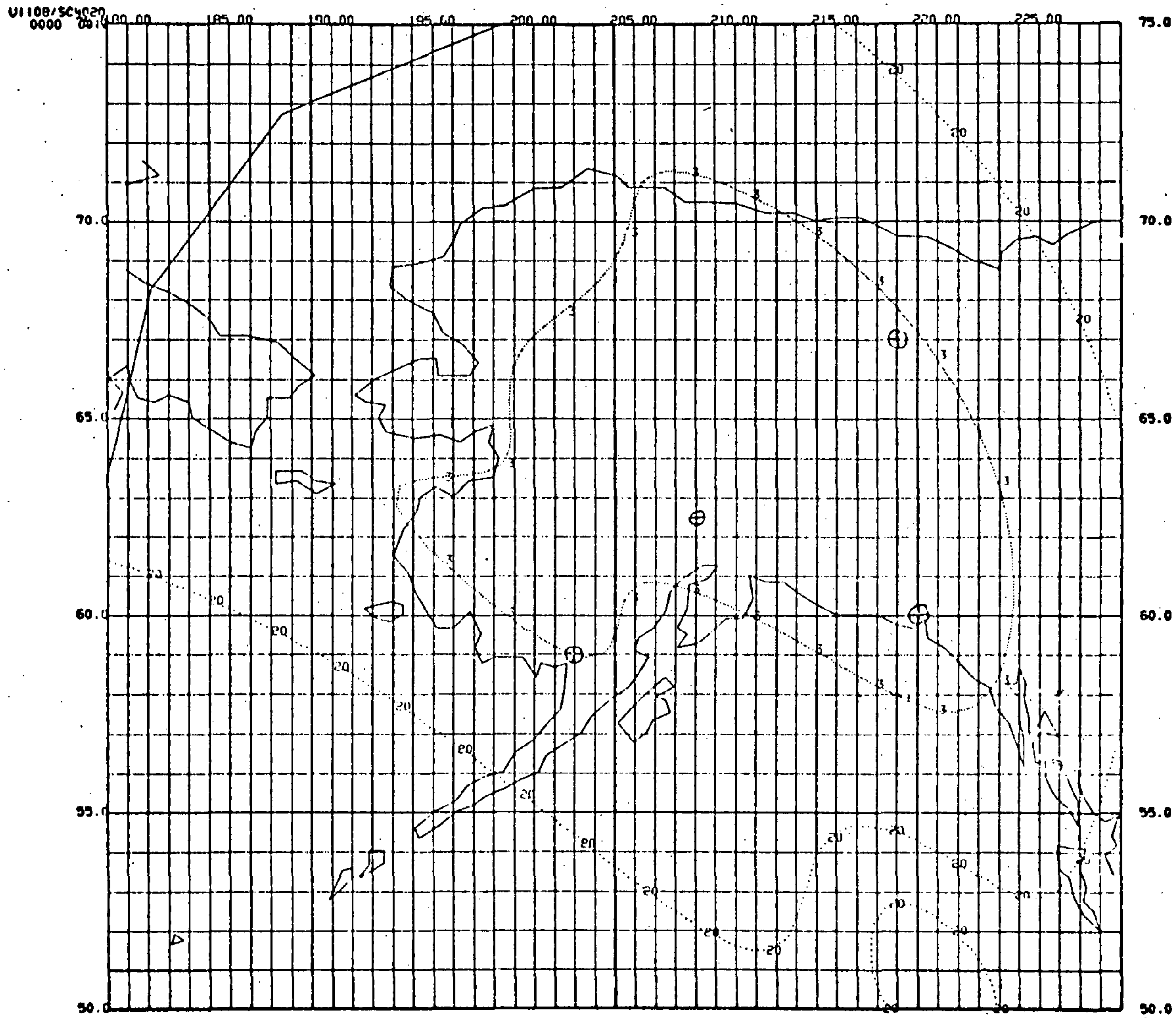


FIG. 62---- 30 FT. DIAMETER---- 4 GHZ.---- 4 BEAMS

ALASKA

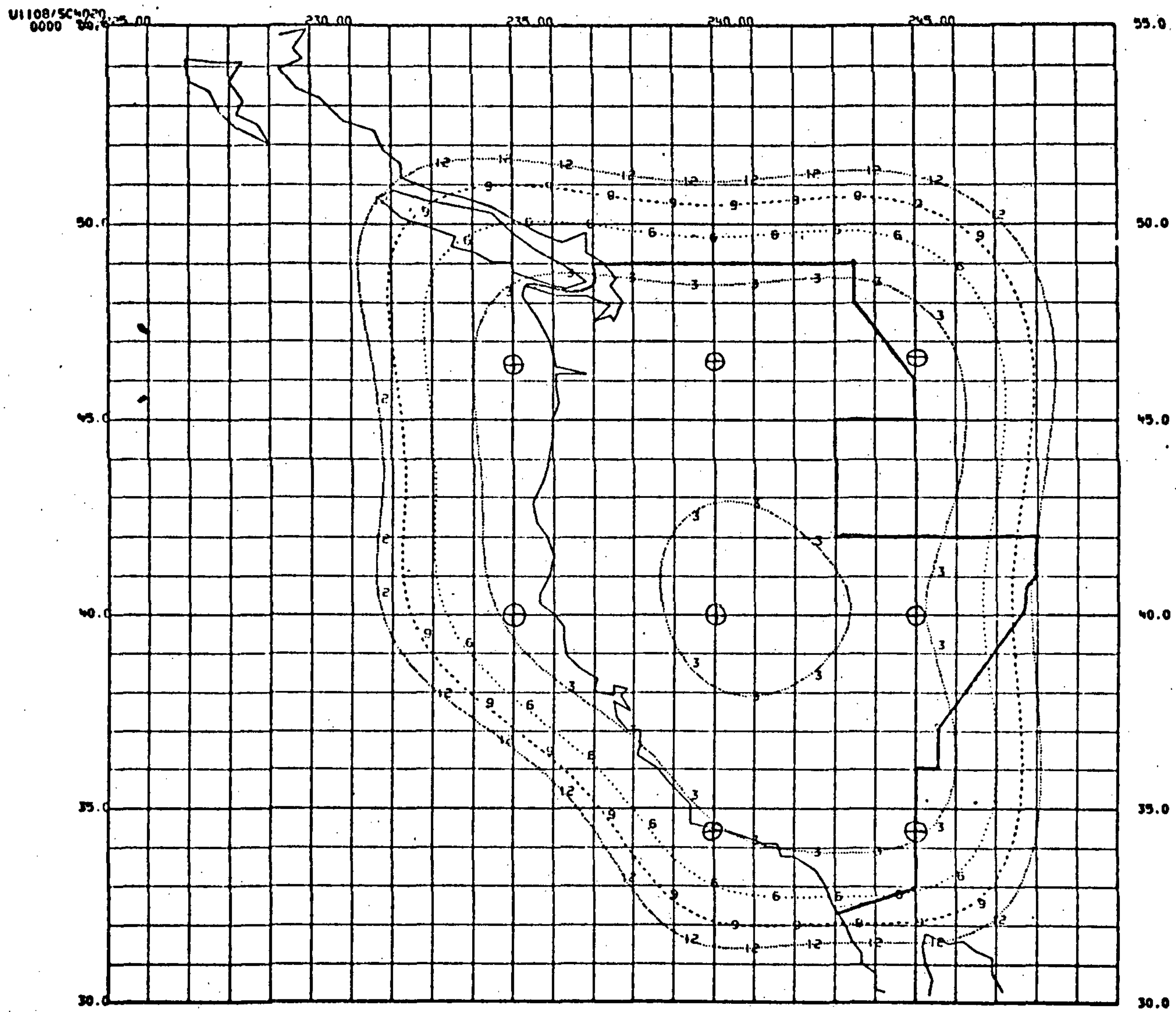


FIG. 62 --- 30 FT. DIAMETER----- 4 GHZ.---- 8 BEAMS

U. S. PACIFIC TIME ZONE

4.0 FEED SYSTEM DESIGN AND FABRICATION

4.1 Feed Design

Although the number of beams required for the coverage of the U. S. Eastern Time Zone has been set at 8, the location of the feed phase centers in the focal plane of a paraboloidal reflector still produces considerable overlap between adjacent aperture if "normal" 10 db edge taper waveguide horn apertures are used. To achieve the same electrical performance from a physically smaller aperture, a dielectric loaded feed has been designed and tested. This feed is a combination of a broadside radiating waveguide horn antenna and an end-fire radiating poly-rod type antenna. By comparison with measured data on sectoral (air) waveguide horns, such a horn would have to be 1.3 times as wide in the E-Plane, and 2.3 times as wide in the H-Plane, to give the same electrical performance.

The details of the feed horn design are shown in Figs. 63 thru 71. There are several prime sources of reflections affecting the impedance match of the antennas. Four of these or about half of the sources are quite critical dimensionally. These are the details of the coax to teflon-filled waveguide transformer, only the external appearance of which is shown in Fig. 63, along with the pre-assembly waveguide details of Figs. 66 thru 69. The length of the extended center conductor extending from the coaxial flange of Fig. 63 down into the .340/.350 inch depth #63 drill hole in the teflon of Fig. 66, the position of this hole from the shorting back section, and the filling of this section with teflon (air gap between teflon face and shorting back plate) are all critical to within 0.003 inch. The degree of flushness of the soldered outer conductor of the coax to the coaxial flange face and in turn to the top thick wall section (.094 nominal stock + 0.040 nominal RG-91 W.G. wall + braze alloy) shown in Fig. 66 constitutes a critical part fabrication and assembly set of problem details.

The functional but not so critical reflection sources are at 1, 2, and 3 (of Fig. 6B). Although not dimensionally critical, per se', the presence of these individual discontinuities along with the comglomerate of region 4 (discussed above) and the variation from perfection in the basic connector 5 as well as its assembly to the coaxial section, spread as they are over several wavelengths, result in an interference pattern in the input VSWR (measured at 5) which goes through several cycles over the 8 to 11 GHz antenna bandwidth. Any slight differences in electrical length of the coaxial section itself, waveguide sections from 4 to 3, and 3 to 2 and teflon radiating section from 2 to 1 although not affecting the input impedance appreciably, will have first order effect on the degree of phase matching of one antenna relative to the others. Any air gap layers between the walls of the teflon and the conducting walls of the waveguide in sections 2-3 and 3-4 (Fig. 63) in addition to any basic inner wall to wall width differences can cause quite large phase errors in the antenna to antenna phase matching from the input at 5 to the phase center of the radiating structure somewhere between 1 and 2.

It was the necessity of minimizing these phase differences from and including the discontinuity at 3 to the termination of the flared waveguide section at 2, that required the electro-forming of this part of the antenna.

In order to obtain electroform to basic waveguide continuity at the waveguide to flare junction the waveguide wall had to be chamfered to knife edge (practically zero thickness) as specified in the drawing of Fig. 67. A first try of 0.005 to 0.010 inch maximum flat was not sufficiently thin to provide enough electric field at the teflon waveguide interface to deposite copper resulting in continuity across the junction.

Although in the finished product only a few mils of copper is required to meet application mechanical and electrical requirements, it was found that extra thickness was required for fabrication.

In the process a very hard copper oxide crust formed on the outside although less than one mil per hour deposition rate was used in order to obtain a fine grained inner surface. Since the only place to accurately hold the resulting part in order that the flared section could be machined back to the required tolerance (see Fig. 64) was the accurate angle smooth wall waveguide section, the electroformed wall thickness was increased to .035-.040 inch to provide a strong enough joint at the waveguide - flare interface to prevent it from breaking as a result of the high initial torque thereon while the mil cutter cut through the hard surface at 2.

4.2 Feeding Network Design

As discussed in the analyses, the composite beam is formed by the far-field summing of eight individual beams with equal amplitude and equal phase. To implement this equi-phase, equi-amplitude distribution in the measurement portion of this study, a commercial 8-way coaxial power divider was purchased from Anaren Microwave Inc, Syracuse, N.Y. (Model 40590, Serial No. 02). To connect the power divider to the feeds, 8 interconnecting semi-rigid aluminum jacketed coaxial cables were fabricated. The electrical performance of these components is discussed in the next section.

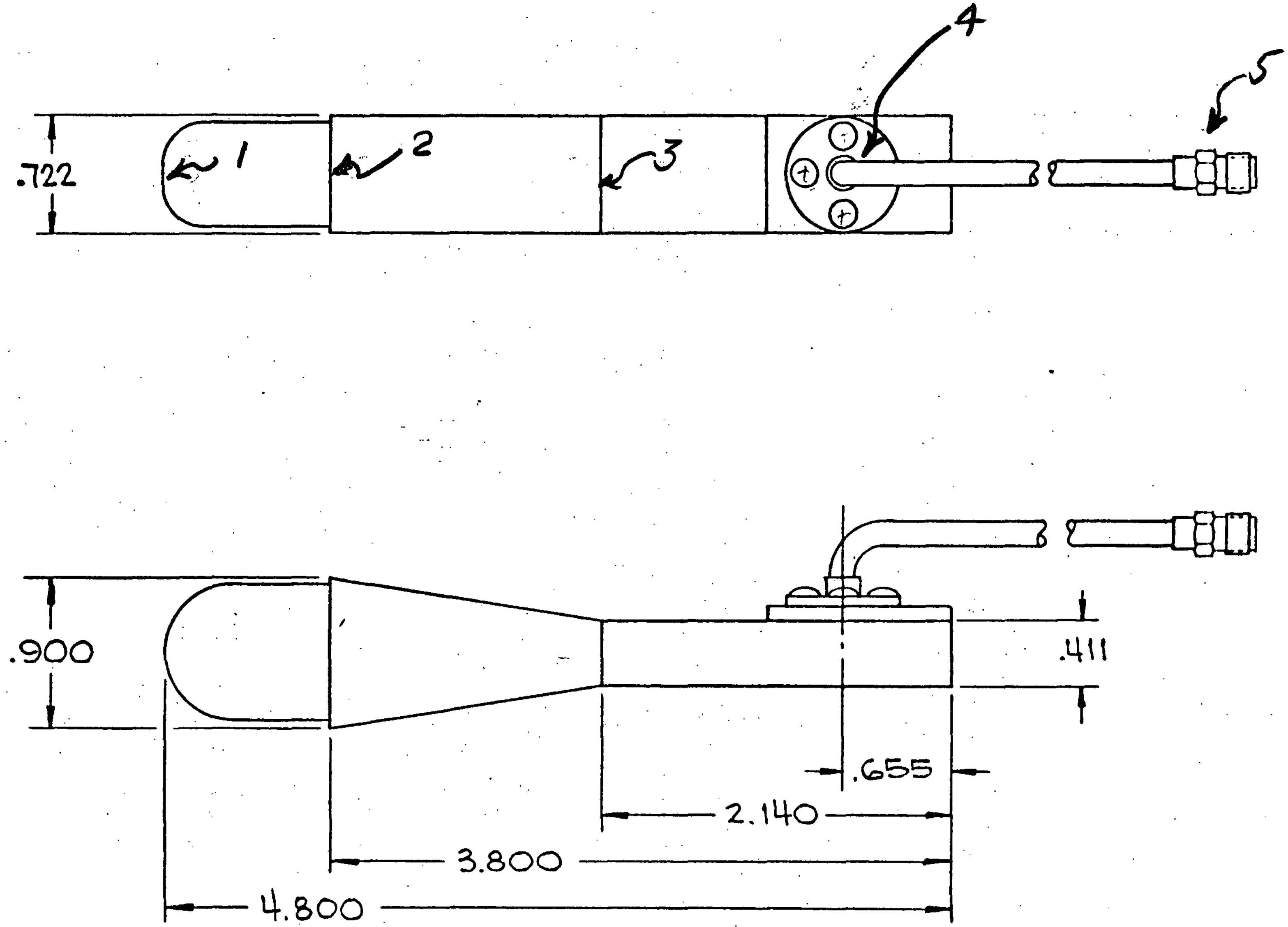


FIGURE 63

ANTENNA CONFIG.
HT 30872

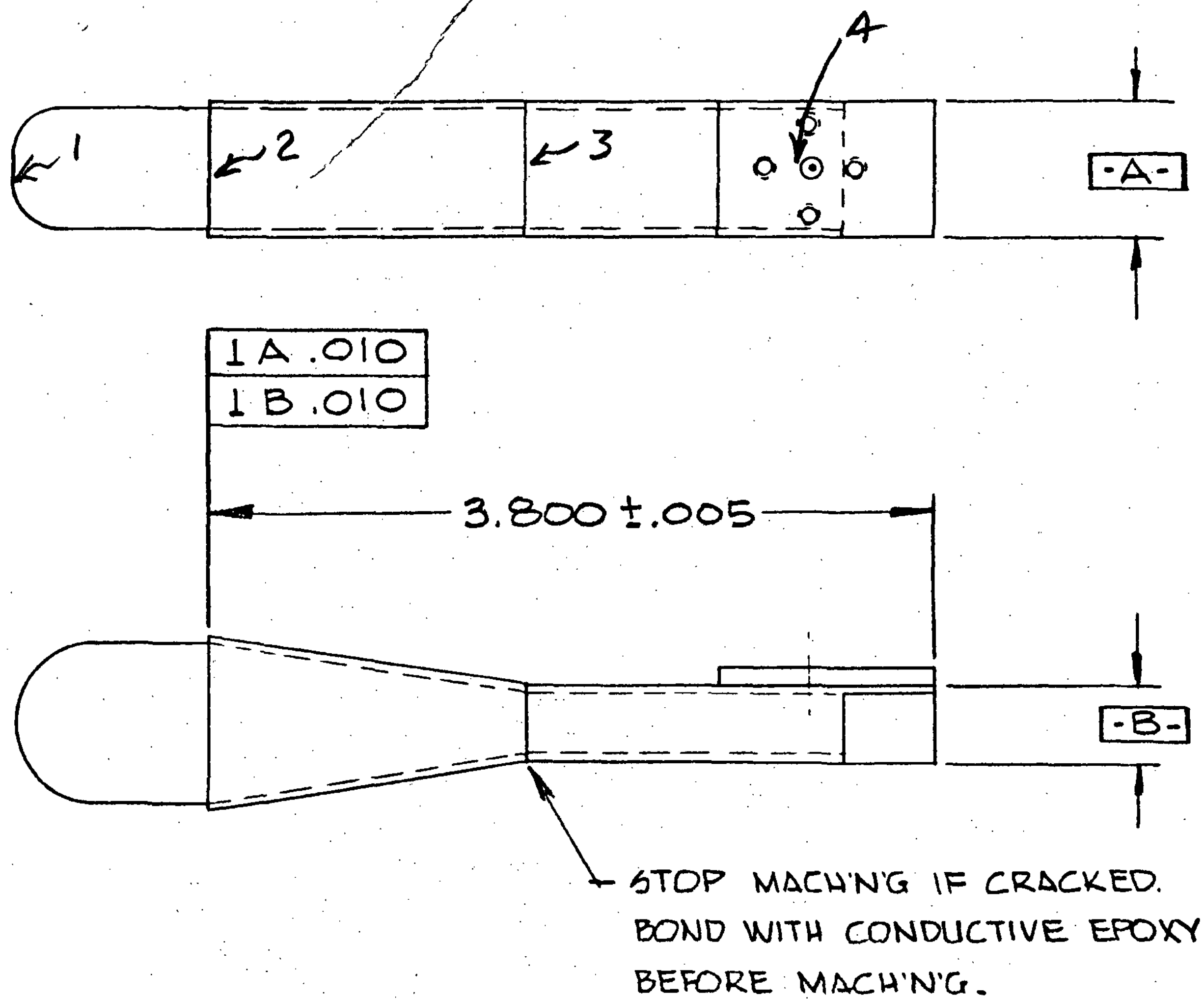


FIGURE 64

NOTE: INSPECT HOLES. CLEAN AS REQ'D TO REMOVE ALL CONTAMINENTS.

HORN - MACHINING
HT 720212

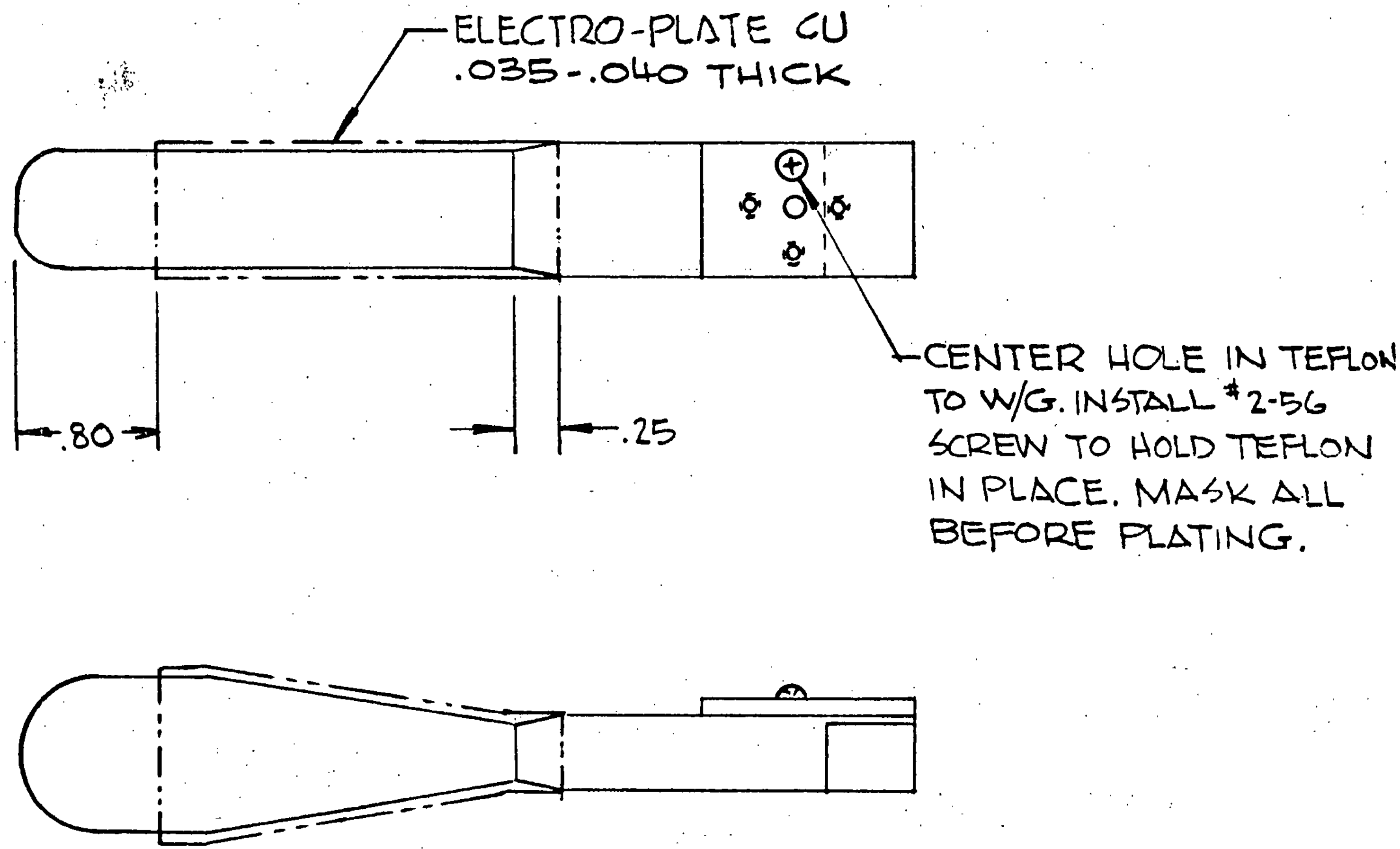


FIGURE 65

HORN, PLATING
HT 760211

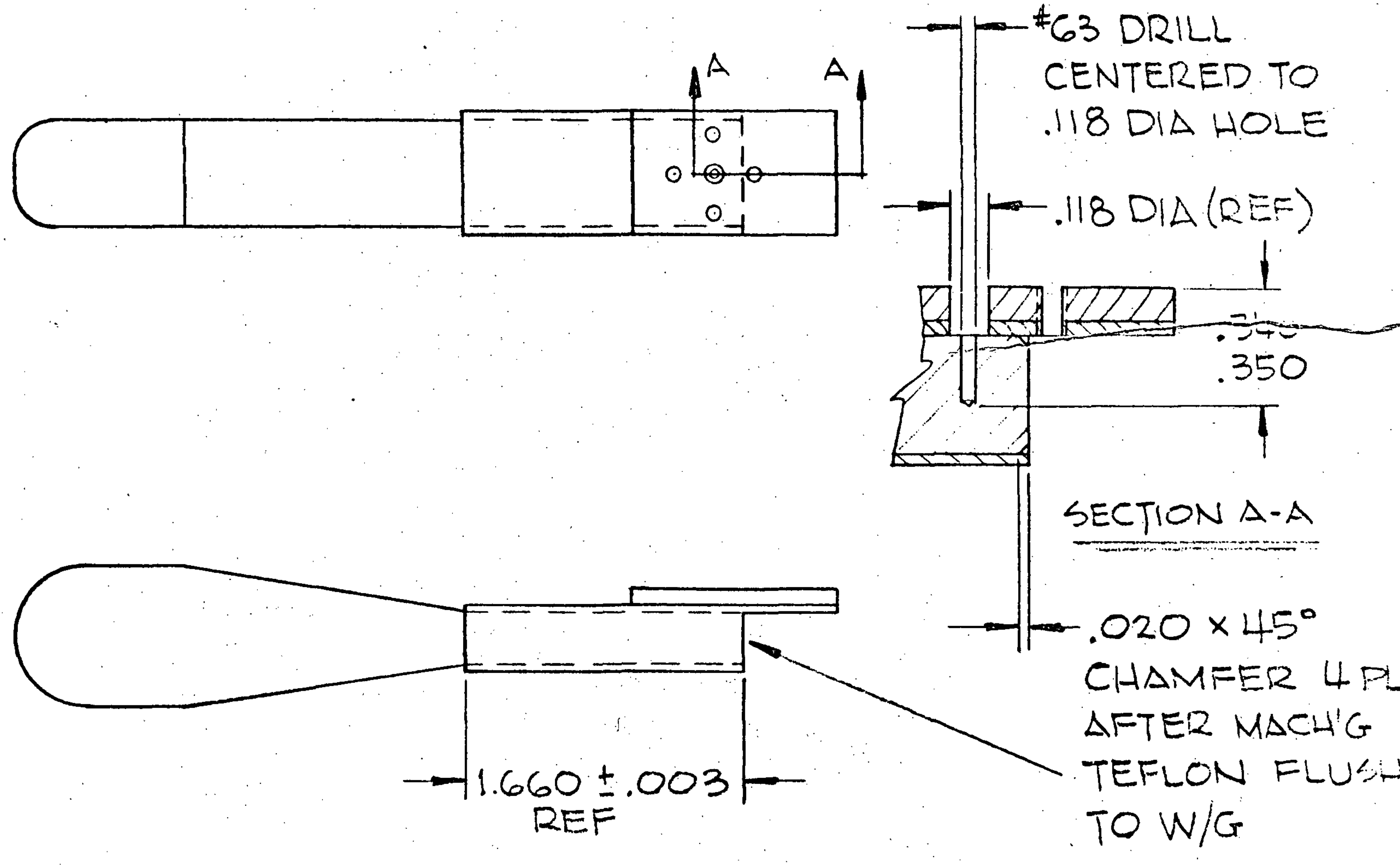


FIGURE 66

WAVEGUIDE ASSY
STEP #3

SK720229 PG 3

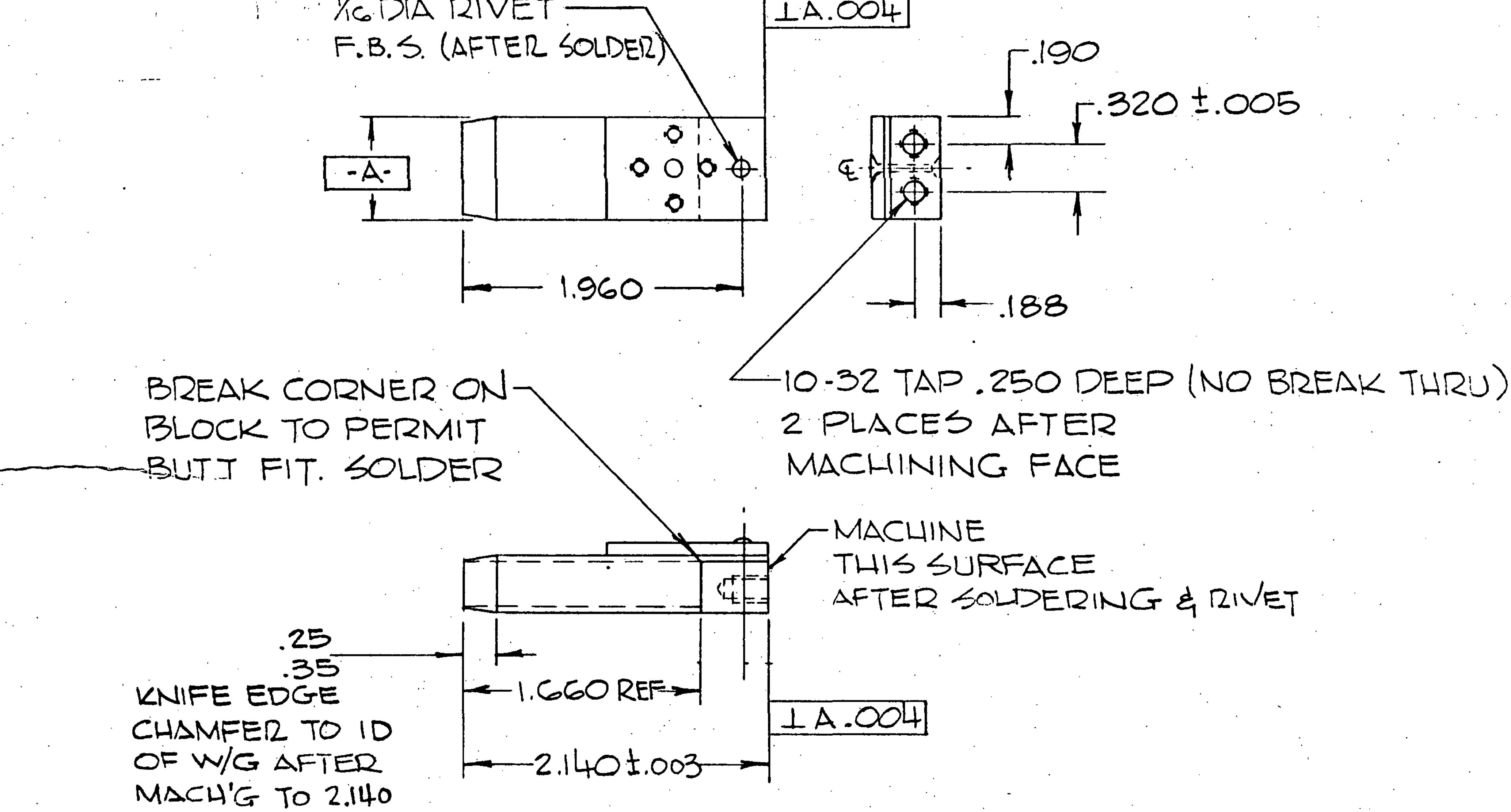


FIGURE 67

WAVEGUIDE ASSY
STEP # 4

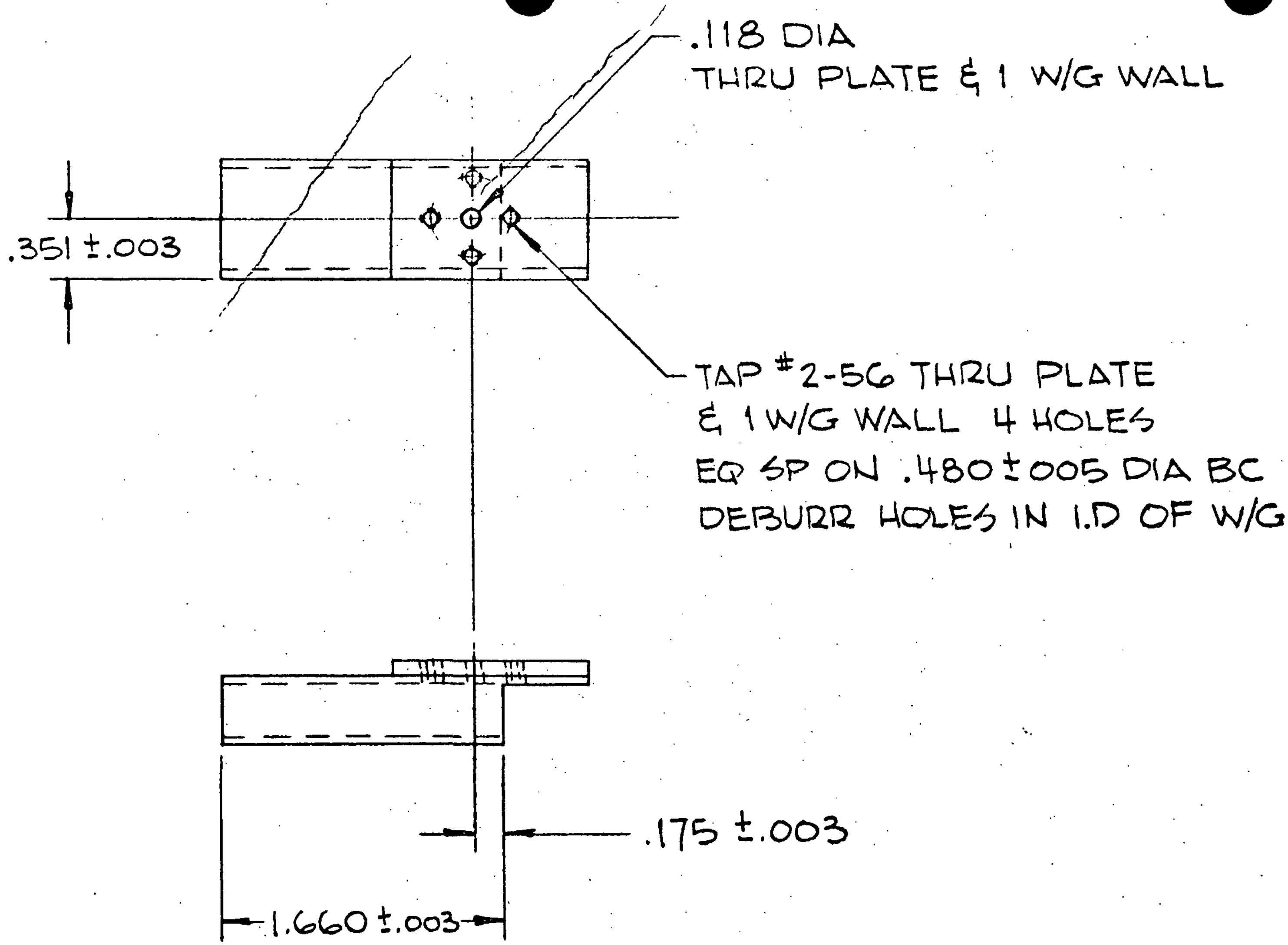


FIGURE 68

WAVEGUIDE ASSY
STEP # 2
SK720229 PG 2

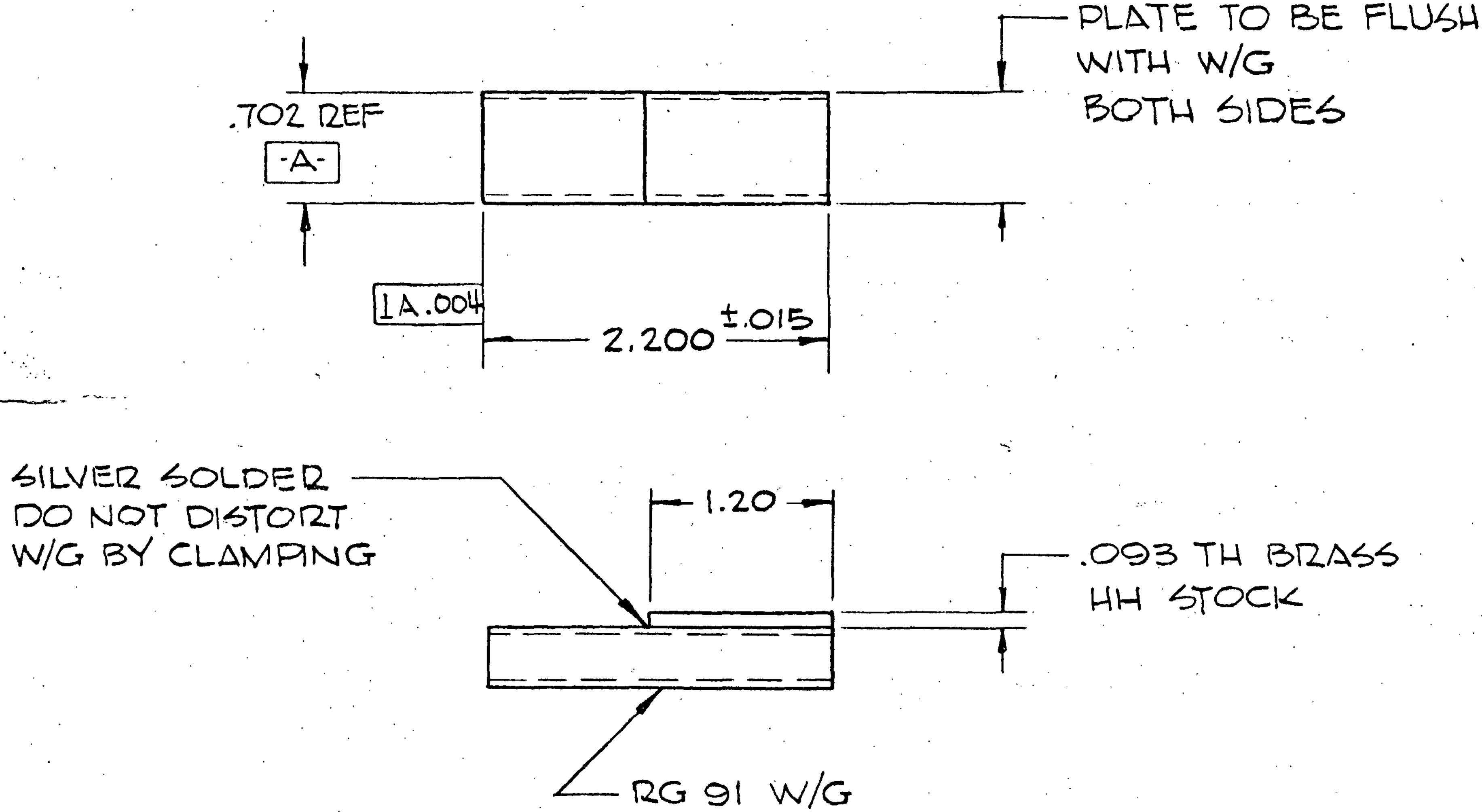


FIGURE 69

NOTE: BRIGHT DIP AFTER SOLDERING

WAVEGUIDE ASSY
STEP #1
SK 720229 PG 1

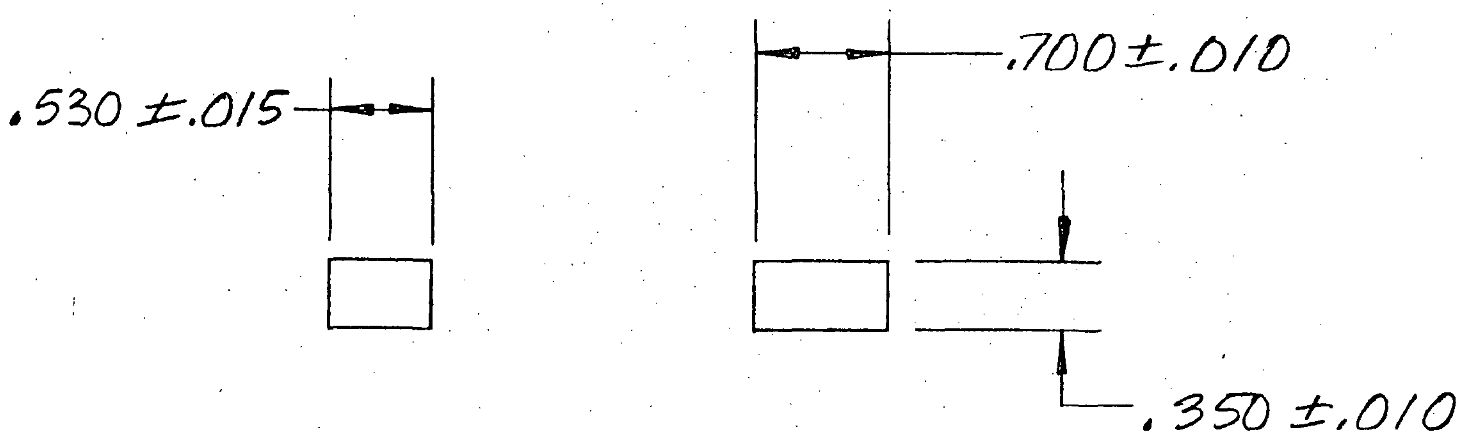


FIGURE 70

MOUNTING BLOCK

MAT'L: BRASS

H6720120

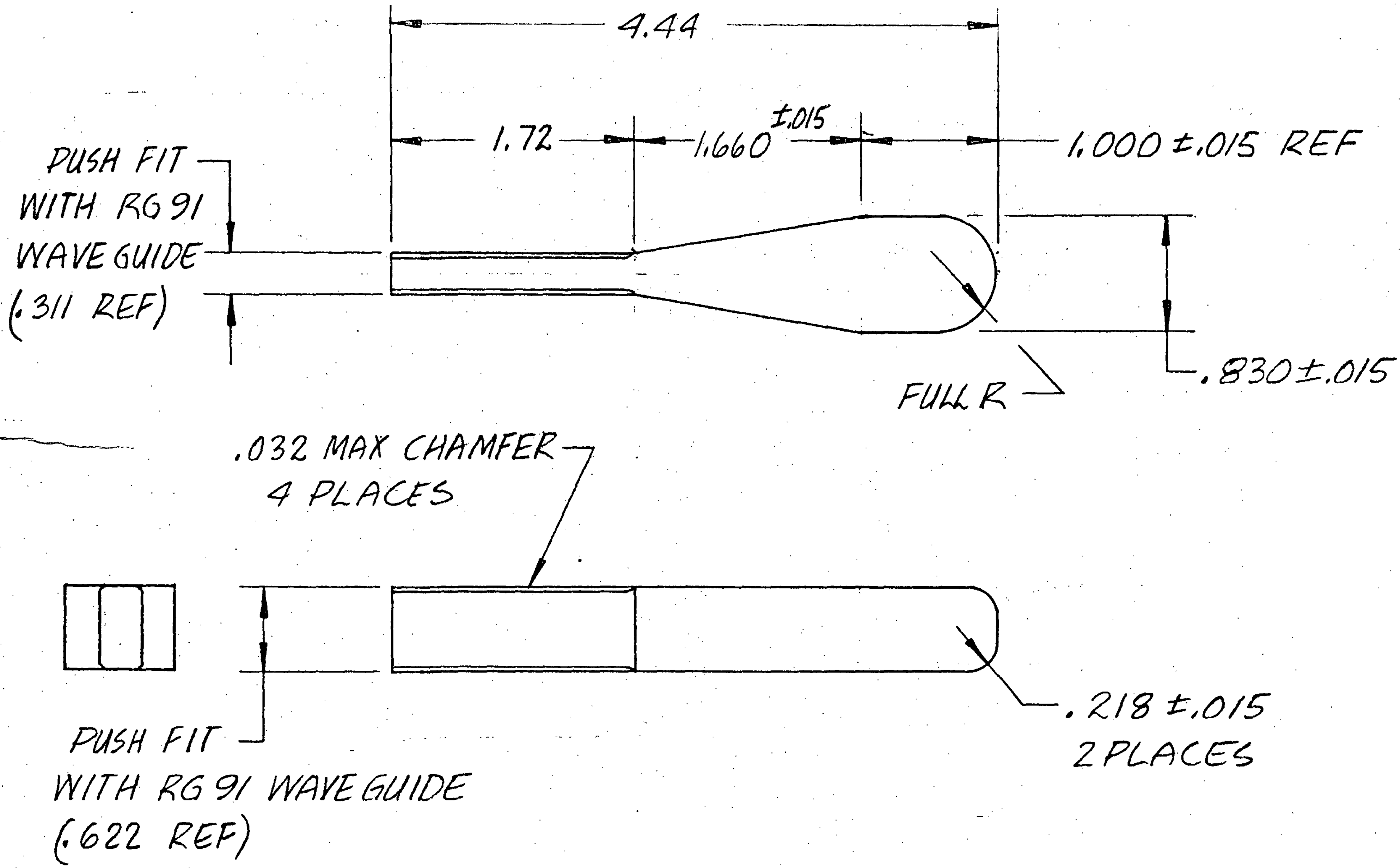


FIGURE 71

TEFLON FILLER

MAT'L: TEFLON

MAKE 2

HG 720126

5.0 FEED SYSTEM TESTS

The following tests were performed on the components which make up the complete Feed System. With the exception of the feed horn patterns, all the measurements were performed using a Hewlett-Packard Network Analyzer using swept frequency techniques.

5.1 Feed Horn

5.1.1 VSWR

The VSWR of each feed was measured over the frequency range of 8 to 12 GHz. The VSWR was first measured of the individual feeds isolated from each other. Then the feeds were mounted in a cluster representing the relative spatial relationship needed to achieve the required composite beam when these feeds are used to illuminate a parabolic reflector (see Fig. 72). The VSWR of each feed, isolated, and in the cluster, are shown in Fig's. 73 thru 80. At 10 GHz, the VSWR ranges from a minimum of 1.2 to a maximum of 1.65 to 1 for all feeds. The difference in VSWR for any given feed from the isolated condition to the clustered condition is very small. The only appreciable difference is for feeds "B" and "E".

5.1.2 Feed Patterns

Measured principal plane pattern of one feed horn, every 500 MHz from 9 to 11 GHz (with 45^{o} plane patterns at 9, 10, and 11 GHz), are shown in Fig's 81 thru 85. At 10 GHz, the measured on-axis gain is 10.6 dBi. Since the VSWR measurements had shown a sameness in all the feeds,and to conserve time and money (both of which were scarce at this time in the study), no patterns were taken of the other feeds.

5.1.3 Port-to-Port Coupling

The eight primary antennas were mounted on the feed support structure with the relative positions in a direct one to one scale view as shown in Fig. 72. This arrangement was deemed a practicable approximation to the optimum or near optimum location of phase centers which was theoretically determined without considering the effects of mutual coupling, mutual scattering, or lateral defocusing. Port to port coupling measurements were made for the five closest combinations as defined and plotted in Fig. 86.

At a frequency of 10 GHz, the worst coupling is -29 db between feeds B and E. The other combinations were less than -30 db over the band from 8 to 12 GHz. This higher coupling between B and E correlates with the H plane proximity between these two antennas as depicted in Fig. 72 .

5.2 8-Way Power Divider

5.2.1 VSWR

A plot of VSWR looking into the input port of the 8-way power divider from 8 to 12 GHz is shown in Fig. 87. Each of the output ports was terminated in 50 ohms. The maximum VSWR over this frequency range is 2.3 to 1 at 8.4 GHz. At 10 GHz, the VSWR is 1.5 to 1. Plots of VSWR looking into the output ports are shown in Figs. 88 thru 90. Each of the other output ports and the input port were terminated in 50 ohms. At 10 GHz, the VSWR varies from 1.15 to 1.37 to 1 for the 8 ports.

5.2.2 Power Divider Port to Port Coupling

Curves of coupling, between four combinations of output ports over the range 8 to 12 GHz are shown in Fig. 91. At 10 GHz, the typical coupling is -27 dB. All other combinations of ports had lower coupling values.

5.2.3 Power Divider Amplitude Distribution

The amplitude distribution for the 8 output ports relative to the input port is shown in Fig. 92. These measurements were made over the range of 8 to 10 GHz. At 10 GHz, the amplitude level for all 8 output ports varies from -9.9 dB to -10.3 dB relative to the power at the input port. Since an 8-way equal power division with zero loss is -9 dB, the loss through the coupler is 1.1 dB ± 0.2 dB.

5.2.4 Power Divider Phase Distribution

The relative phase distribution across the 8 output ports as a function of frequency is shown in Fig. 93. At 10 GHz, the variation in phase between the 8 output ports is ± 0.37 degrees from a nominal value.

5.3 Interconnecting Cables

As the 8 semirigid coaxial cables were fabricated, each one in turn was phase matched to each other. At 10 GHz, the phase variation through the 8 cables relative to each other was ± 2 degrees. The maximum VSWR was 1.15 to 1.

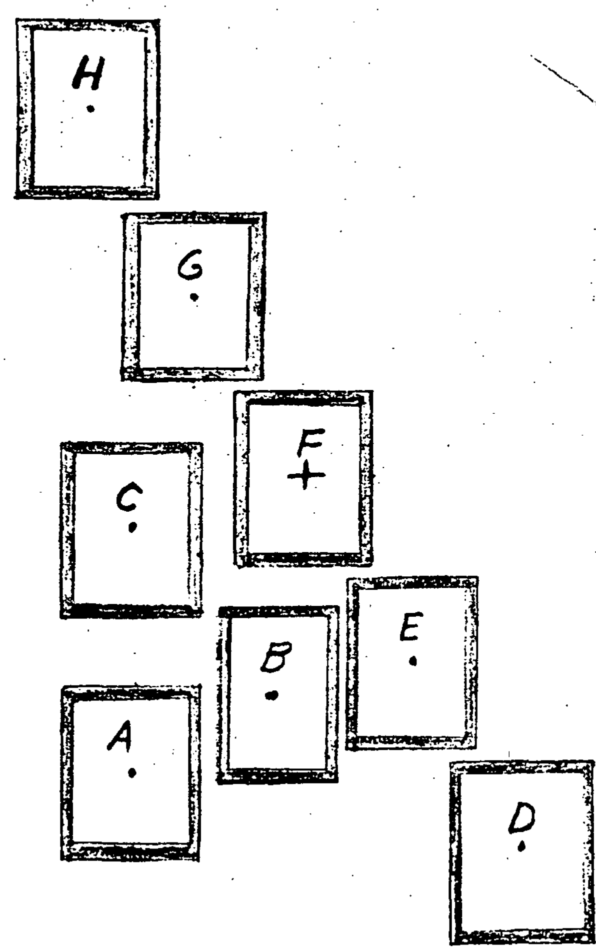


FIG. 72 RELATIVE LOCATION OF FEEDS AS VIEWED FROM REFLECTOR

Component VSWR

COMPONENT: ANT "A"

ENGINEER:

DATE: 10 MAY 72

REMARKS:
——————— ISOLATED
- —— - IN ARRAY

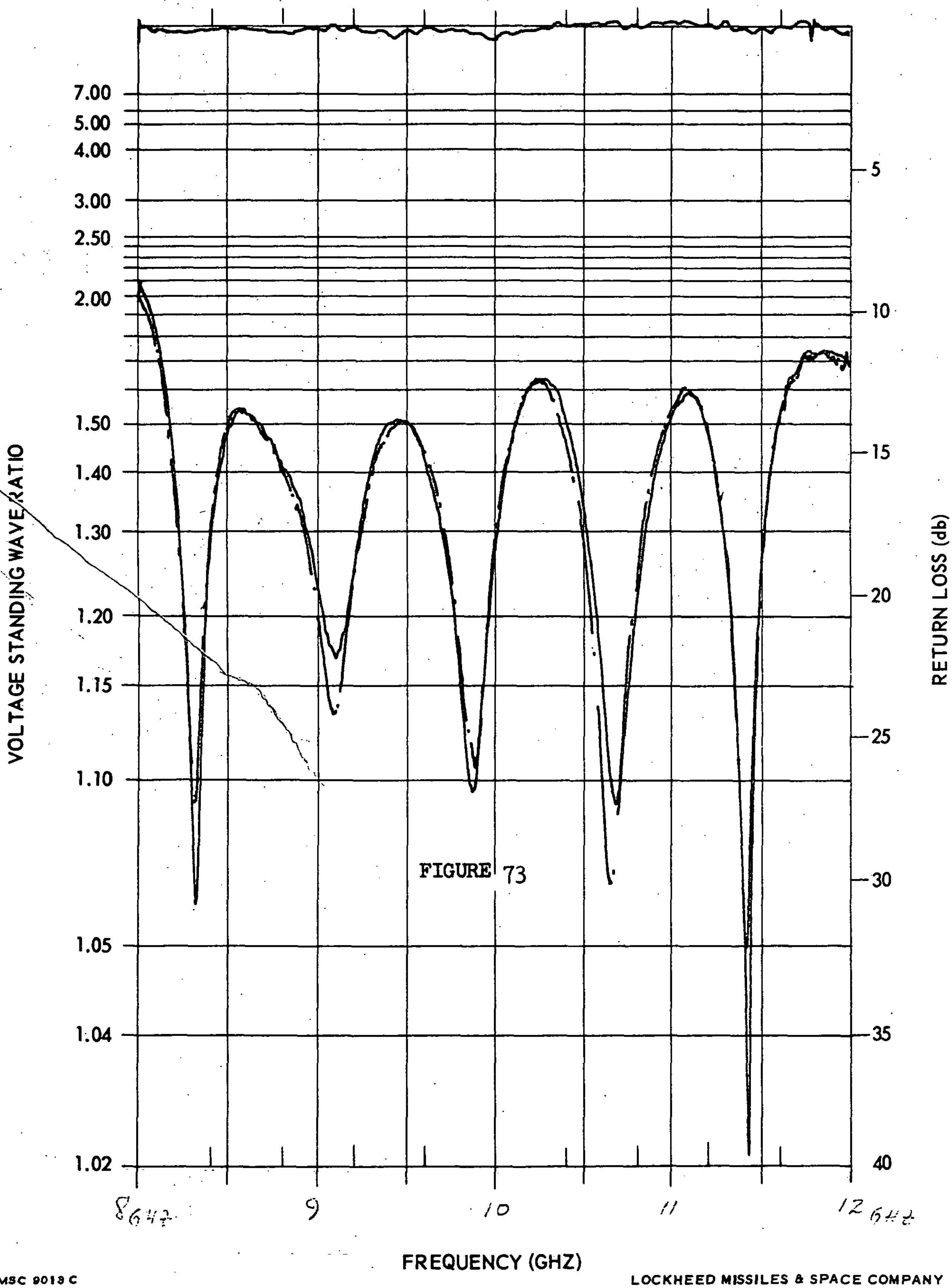


FIGURE 73

73

FORM LMSC 9013 C

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

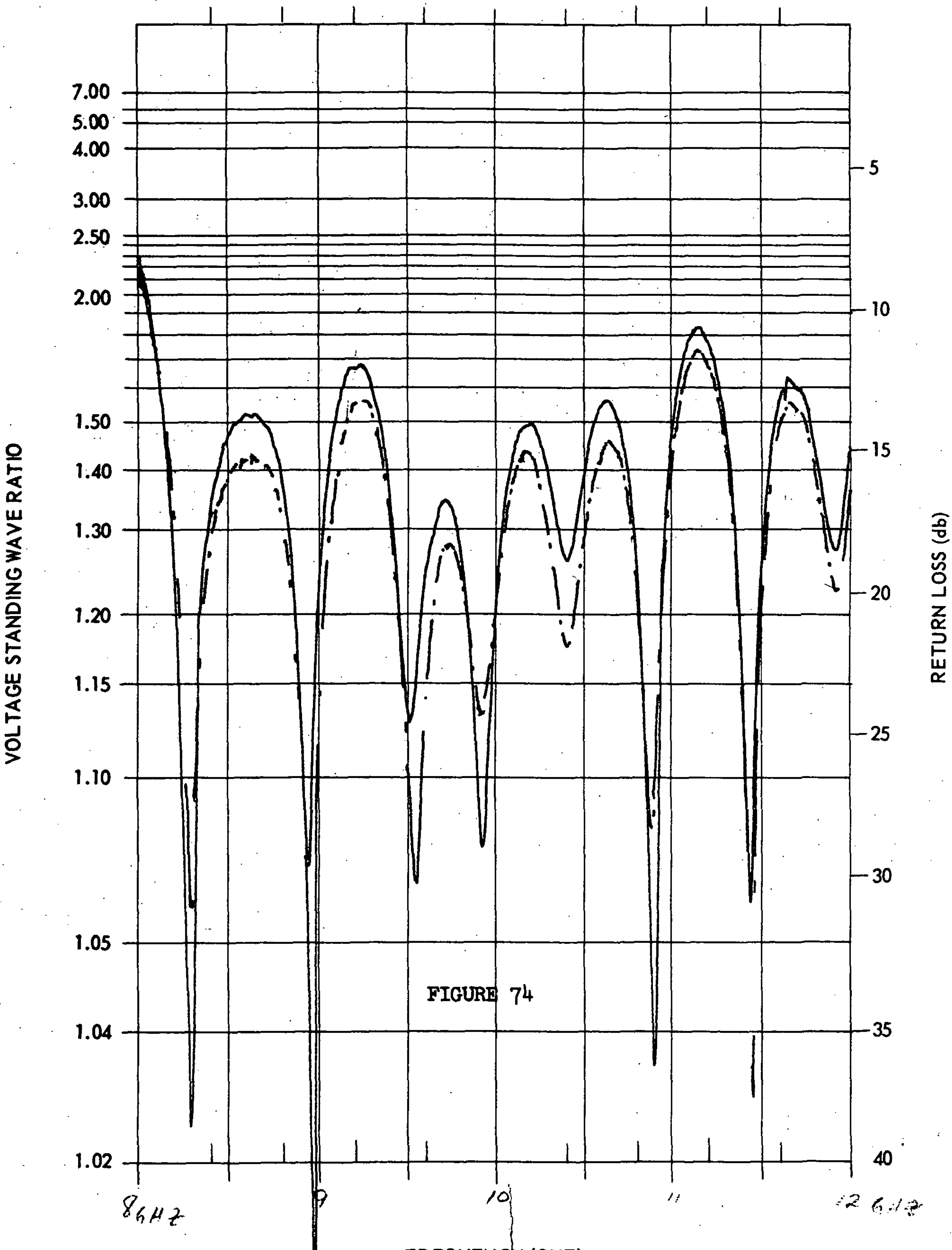
COMPONENT
ANT "B"

ENGINEER

REMARKS
——— ISOLATED

DATE
10 MAY 72

- — - — IN ARRAY



74

FIGURE 74

FORM LMSC 9013 C

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

COMPONENT: ANT "C"

ENGINEER:

REMARKS: ———— ISOLATED; - - - - IN ARRAY

DATE: 10 MAY 72

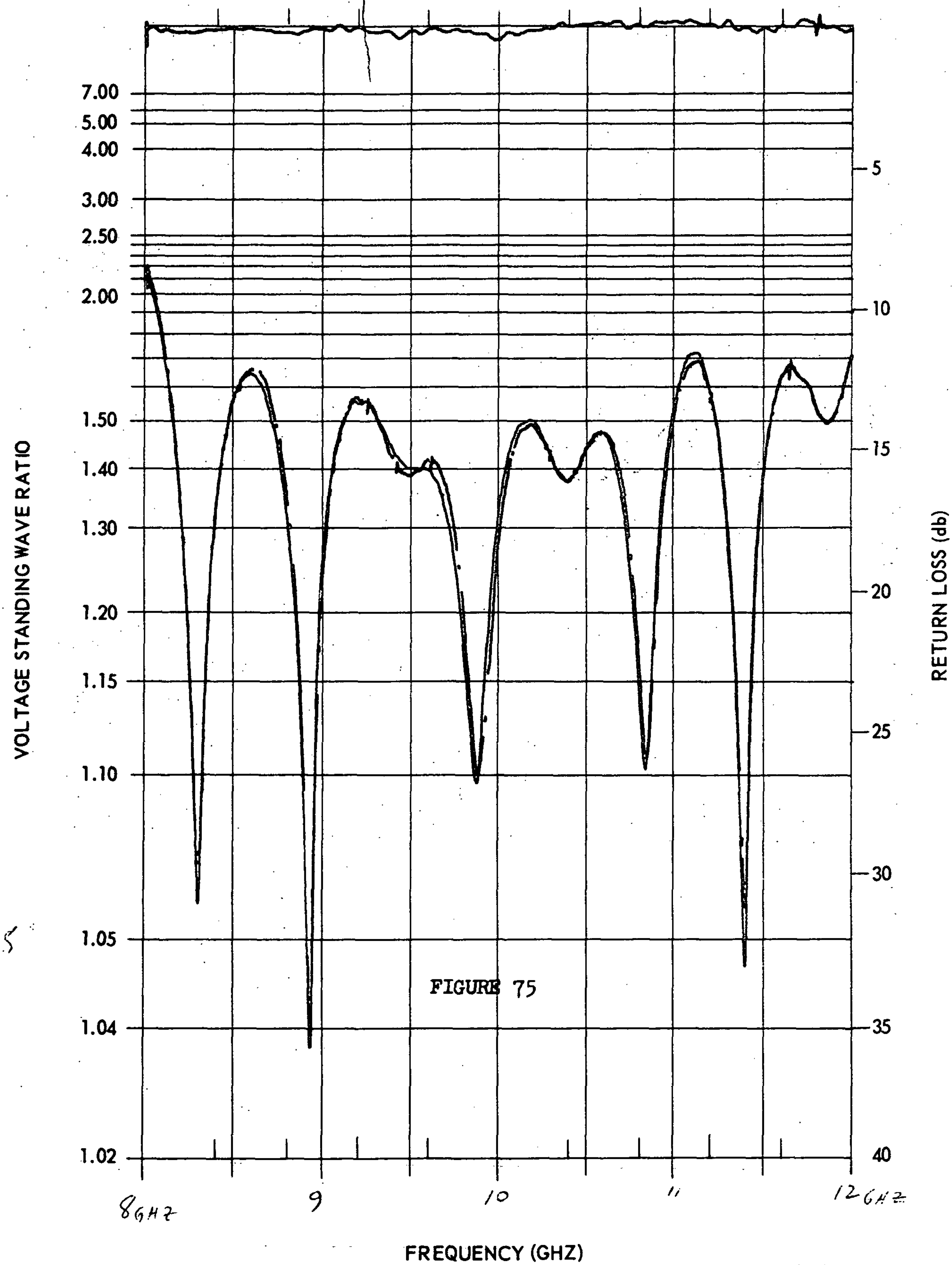


FIGURE 75

75

FORM LMSC 9013 C

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

COMPONENT	
	ANT "D"
ENGINEER	REMARKS
	———— ISOLATED
DATE	
10 MAY	– —— – IN ARRAY

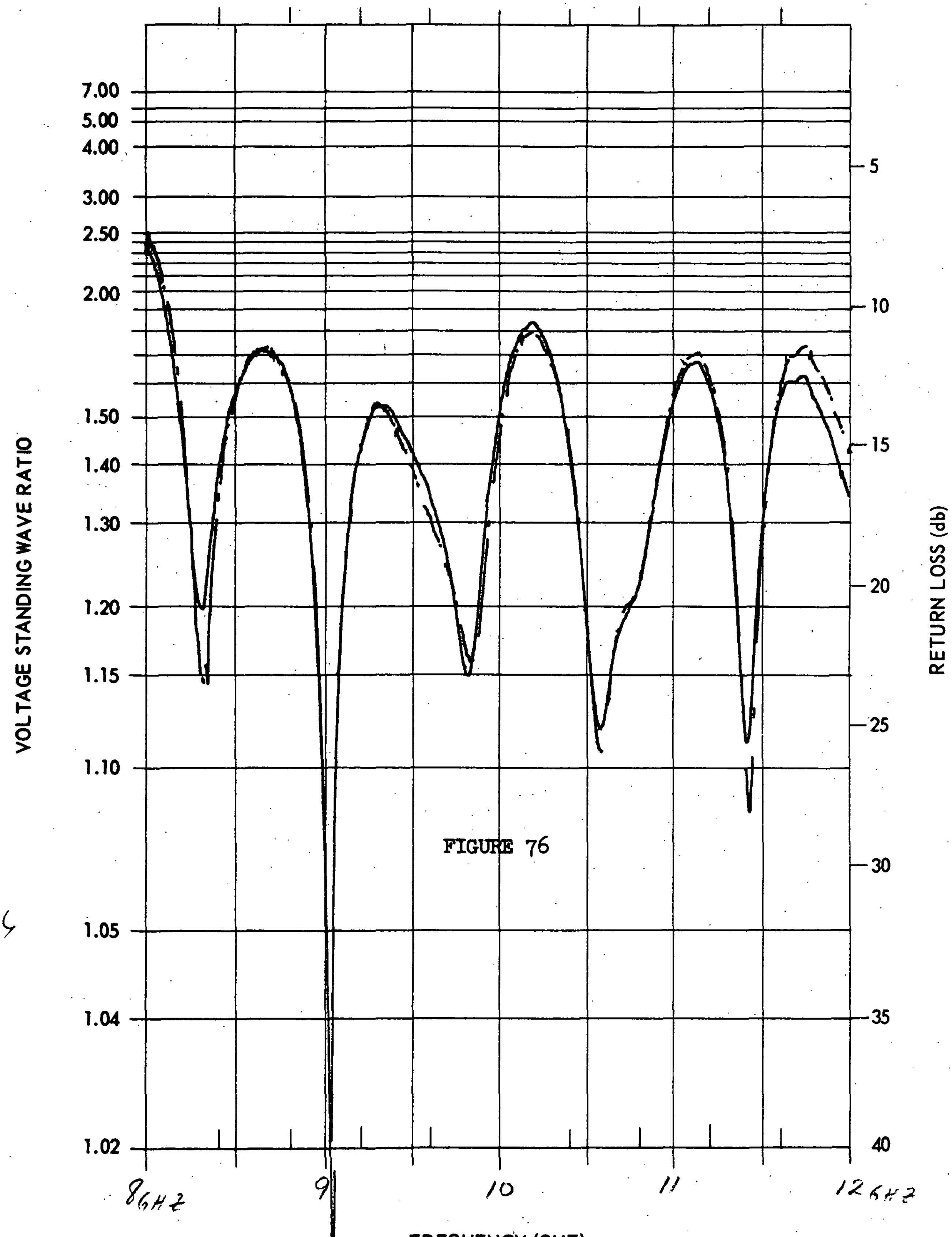


FIGURE 76

Component VSWR

COMPONENT: ANT E

ENGINEER:

DATE: 10 MAY 72

REMARKS:
——— ISOLATED
- — — — IN ARRAY

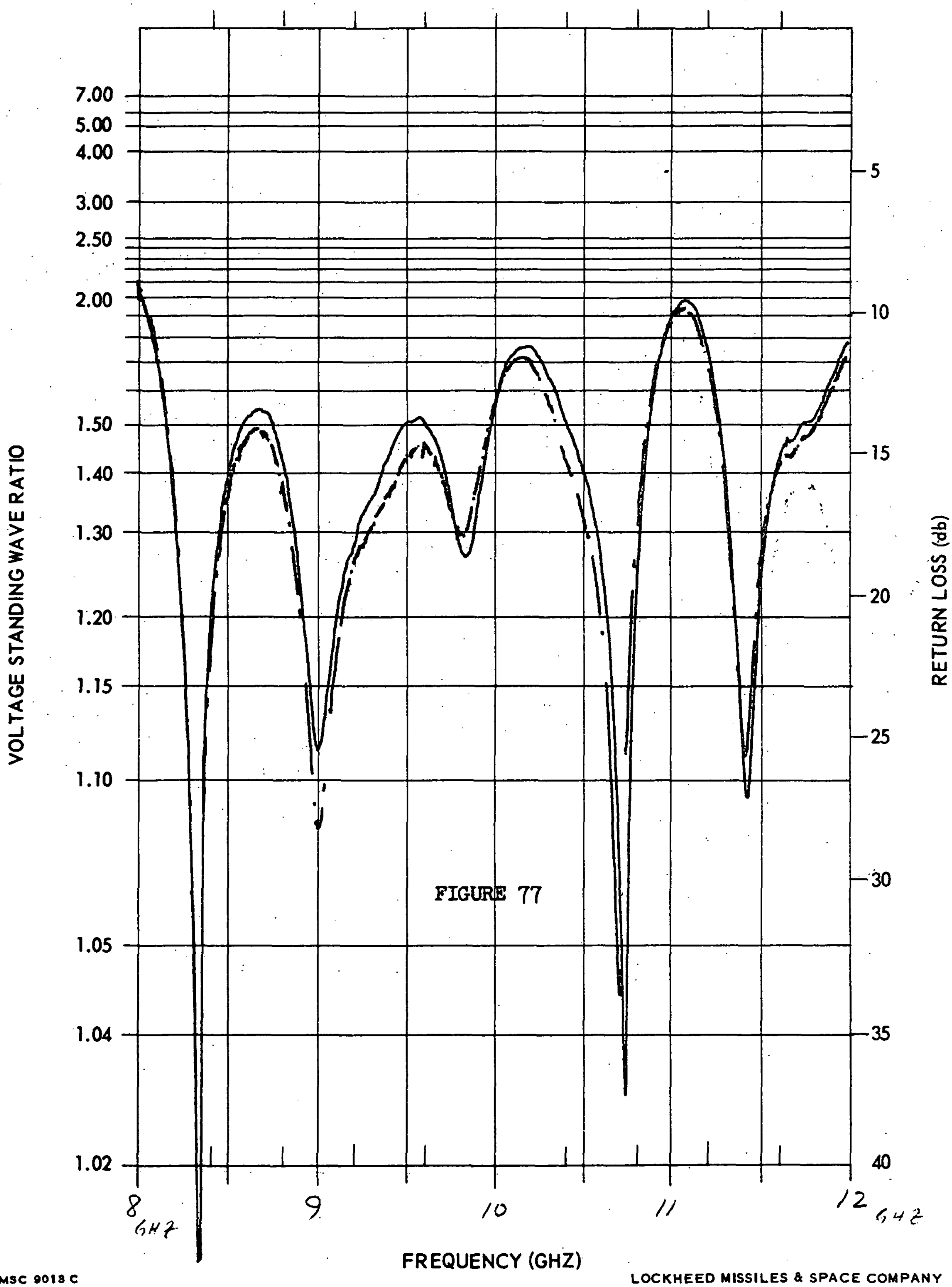


FIGURE 77

77

FORM LMSC 9013 C

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

COMPONENT: ANT "F"

ENGINEER:

REMARKS:
——— ISOLATED
-·—·- IN ARRAY

DATE: 10 MAY 72

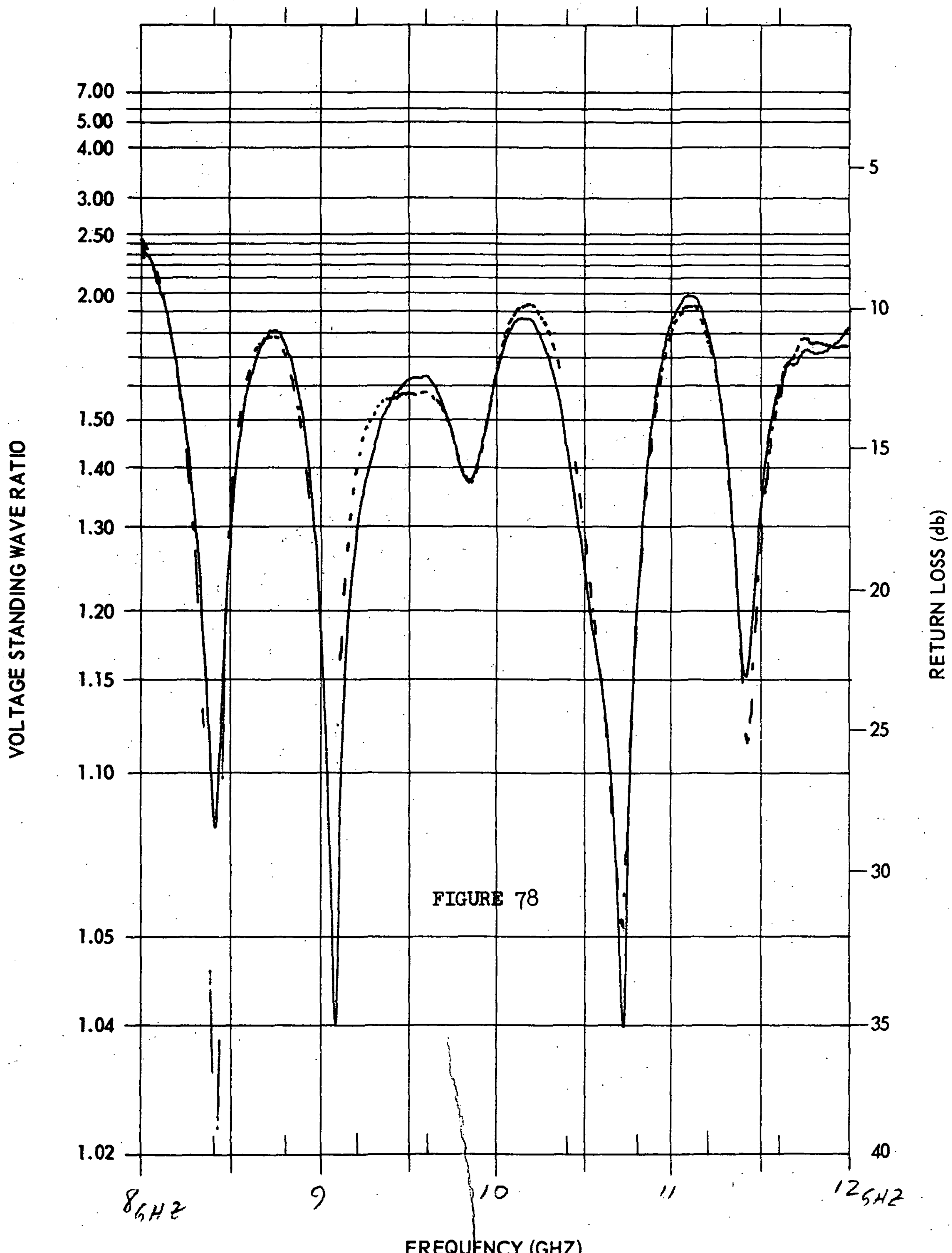


FIGURE 78

78

FORM LMSC 9018 C

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

COMPONENT: ANT "G"

ENGINEER:

REMARKS: ———— ISOLATED

— — — — IN ARRAY

DATE: 10 MAY 72

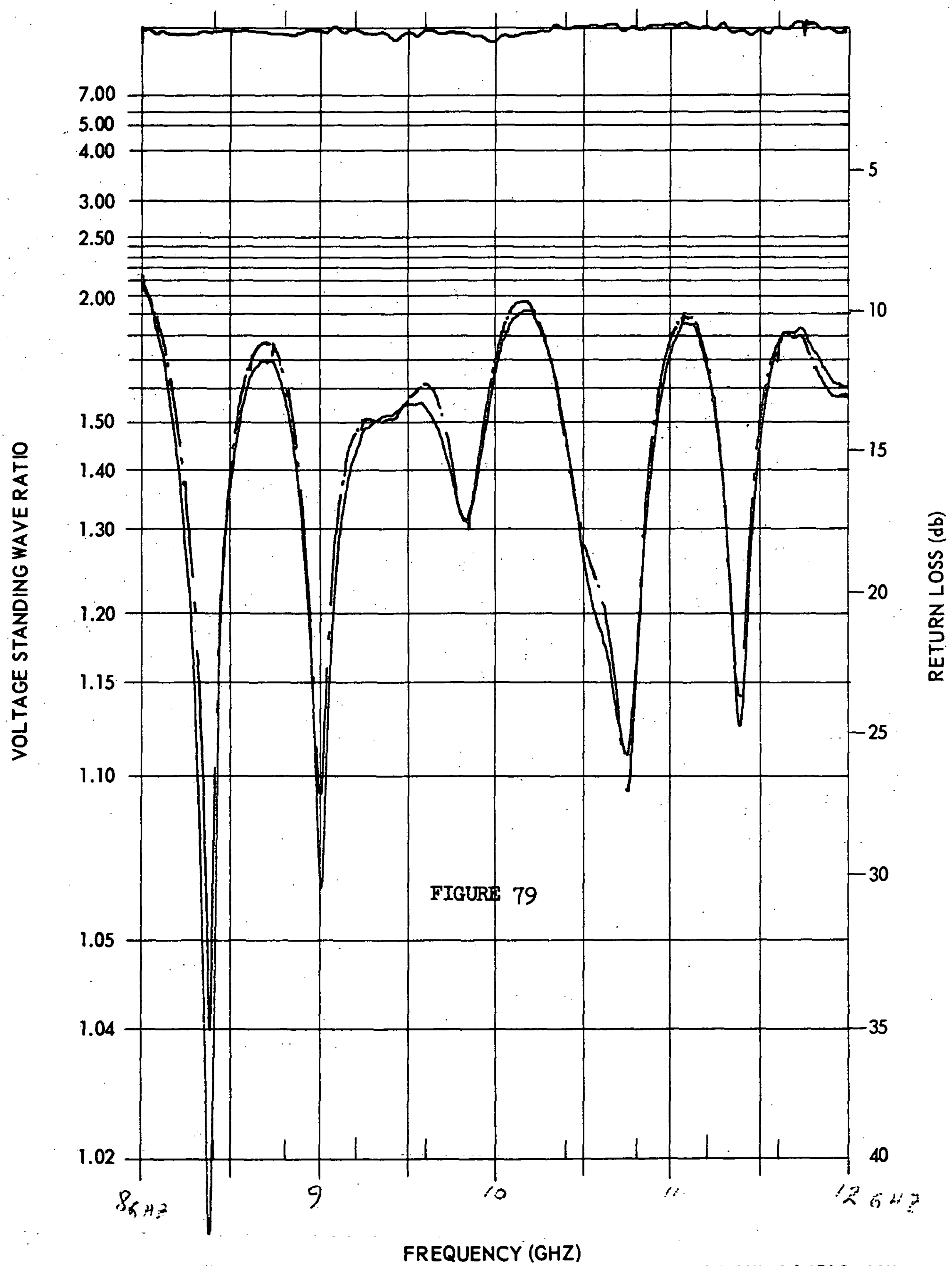


FIGURE 79

79

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

COMPONENT: ANT "H"

ENGINEER:

REMARKS:
——— ISOLATED
- —— - - in array

DATE: 10 MAY 72

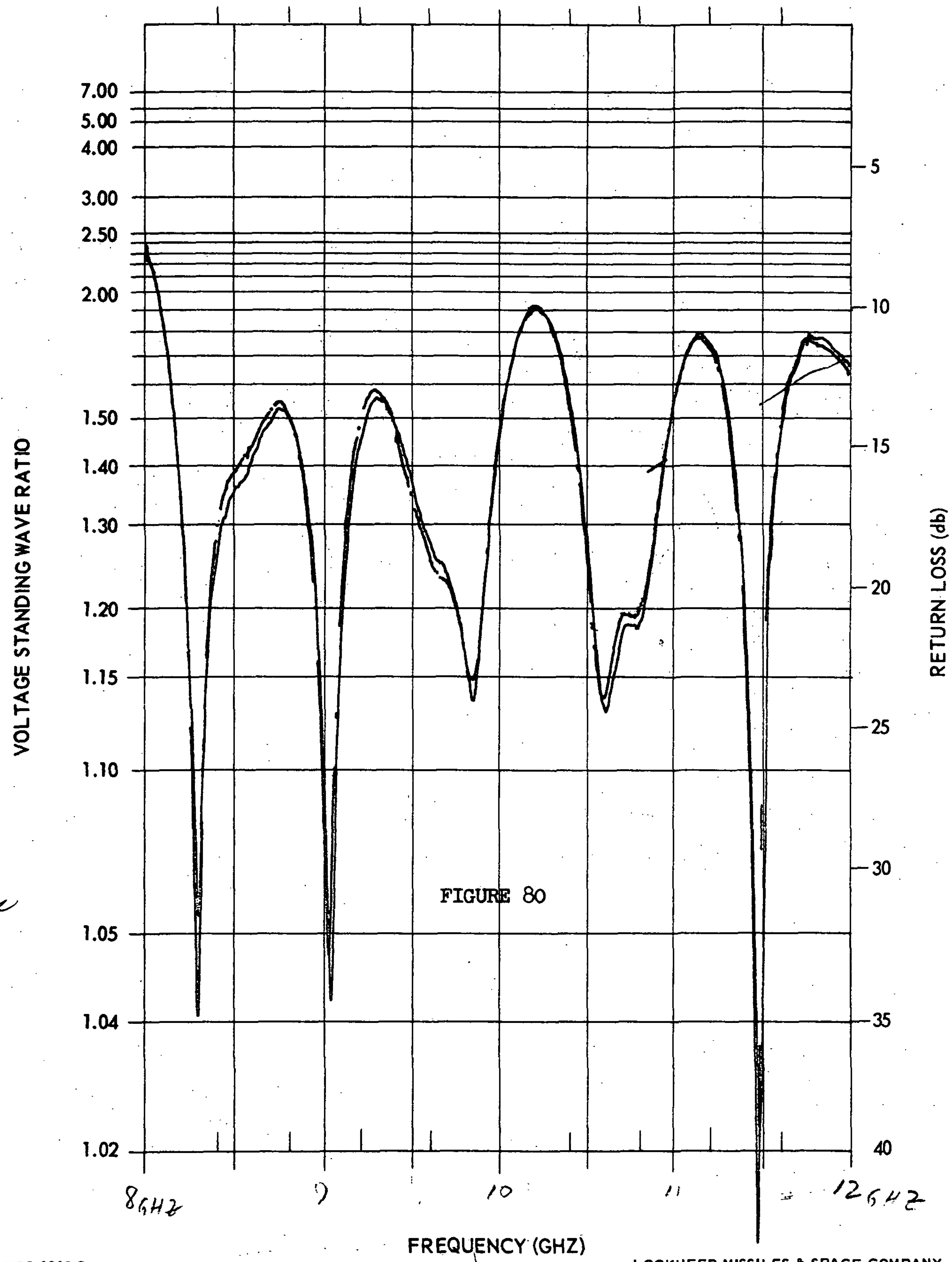


FIGURE 80

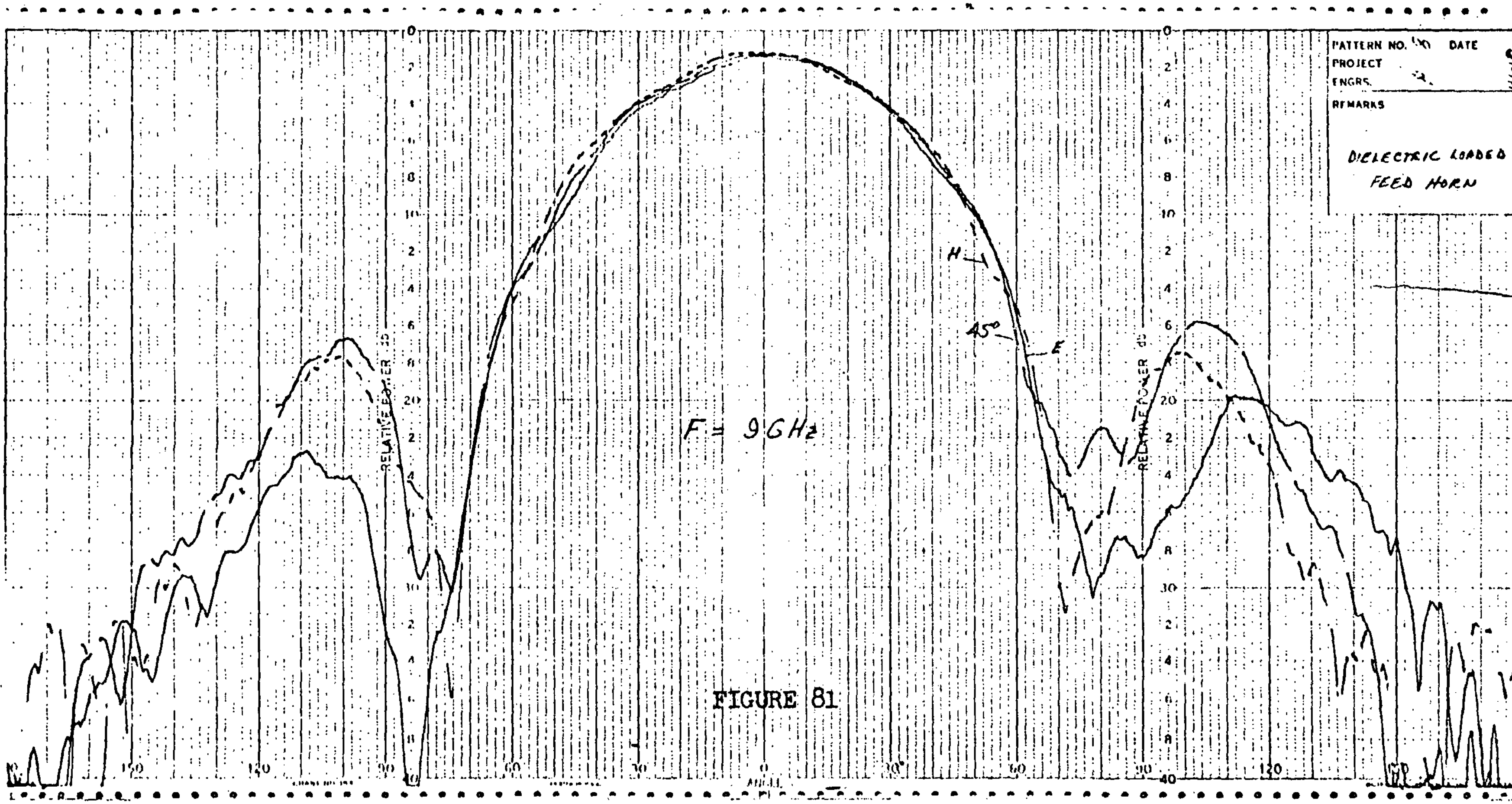
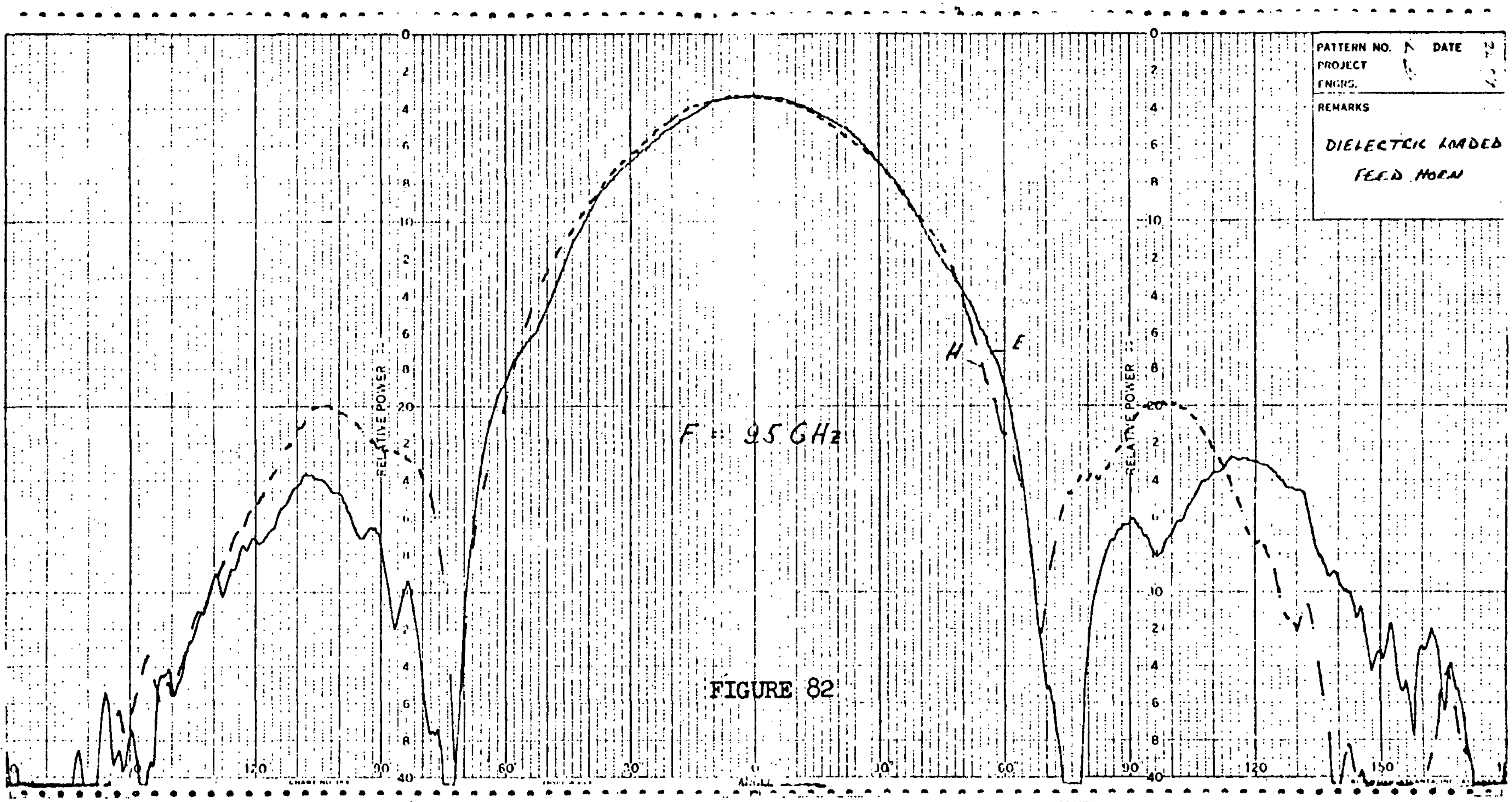
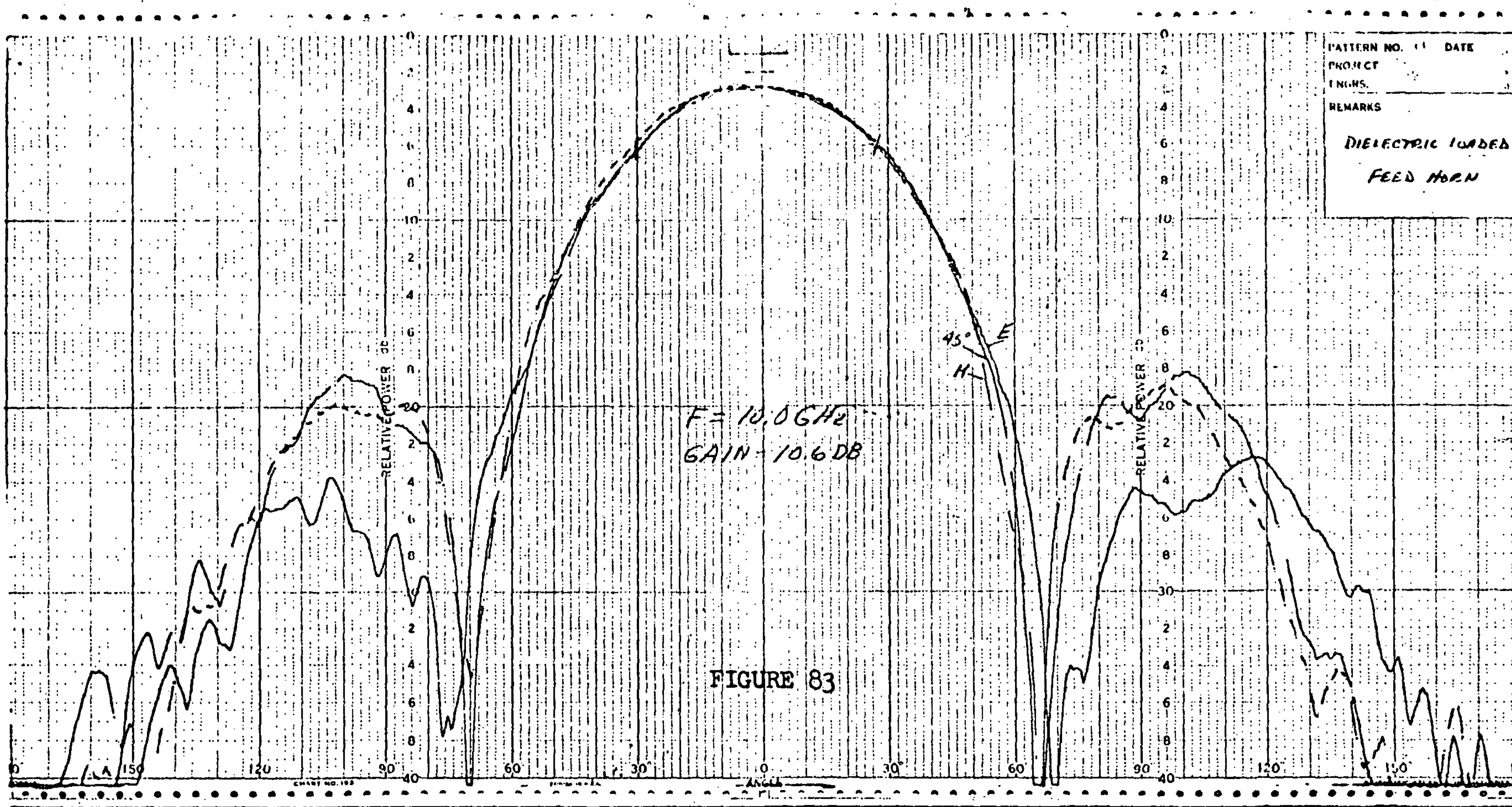

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
DIELECTRIC LOADED FEED HORN
F = 9 GHz
H
45°
E
RELATIVE POWER dB
ANGLE

FIGURE 81



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
DIELECTRIC LOADED
FEED HORN
F = 95 GHz
H
E
RELATIVE POWER

FIGURE 82



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
DIELECTRIC LOADED
FEED HORN
F = 10.0 GHz
GAIN = 10.6 DB
45° E
H
RELATIVE POWER
ANGLE

FIGURE 83

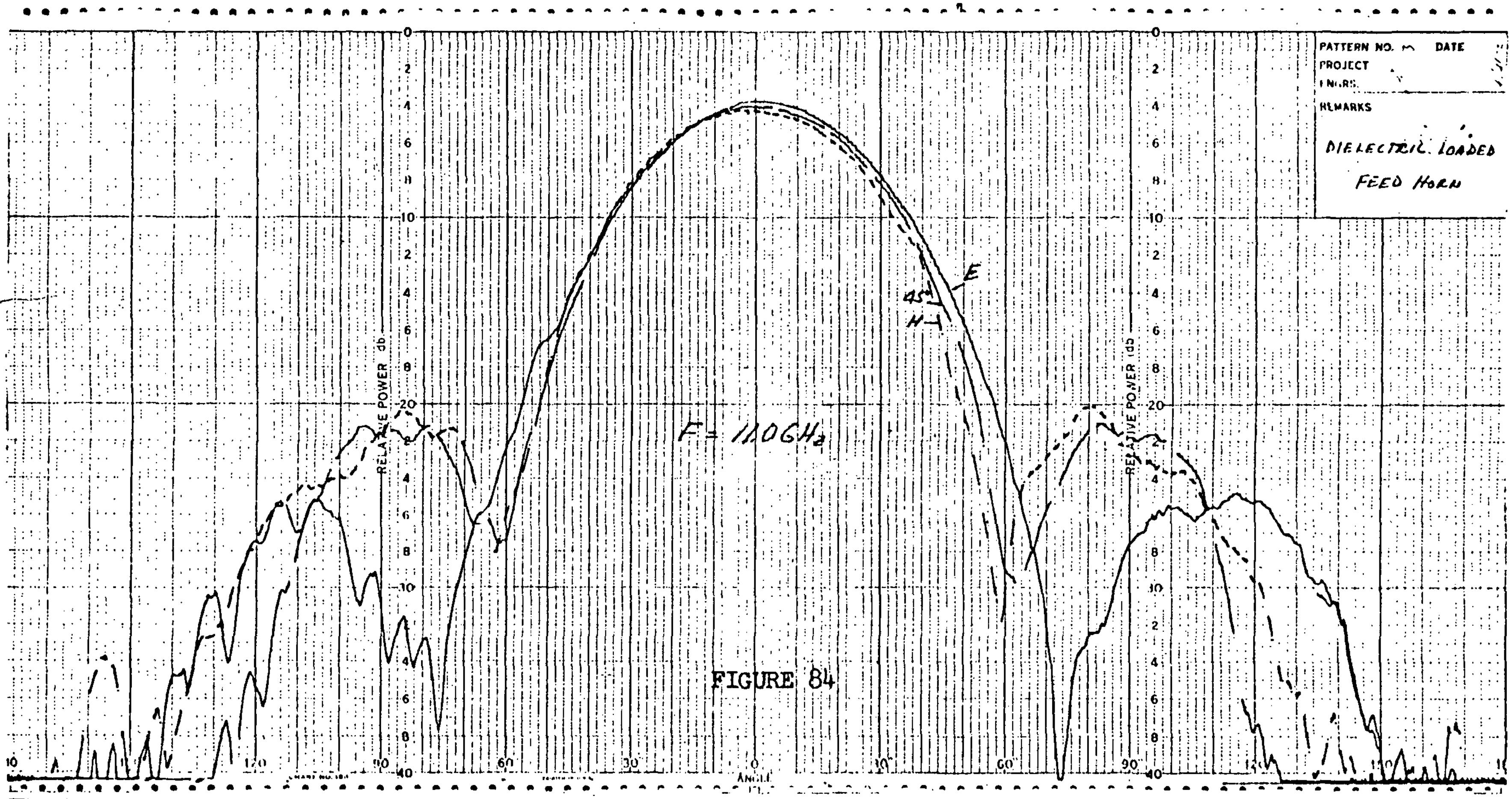
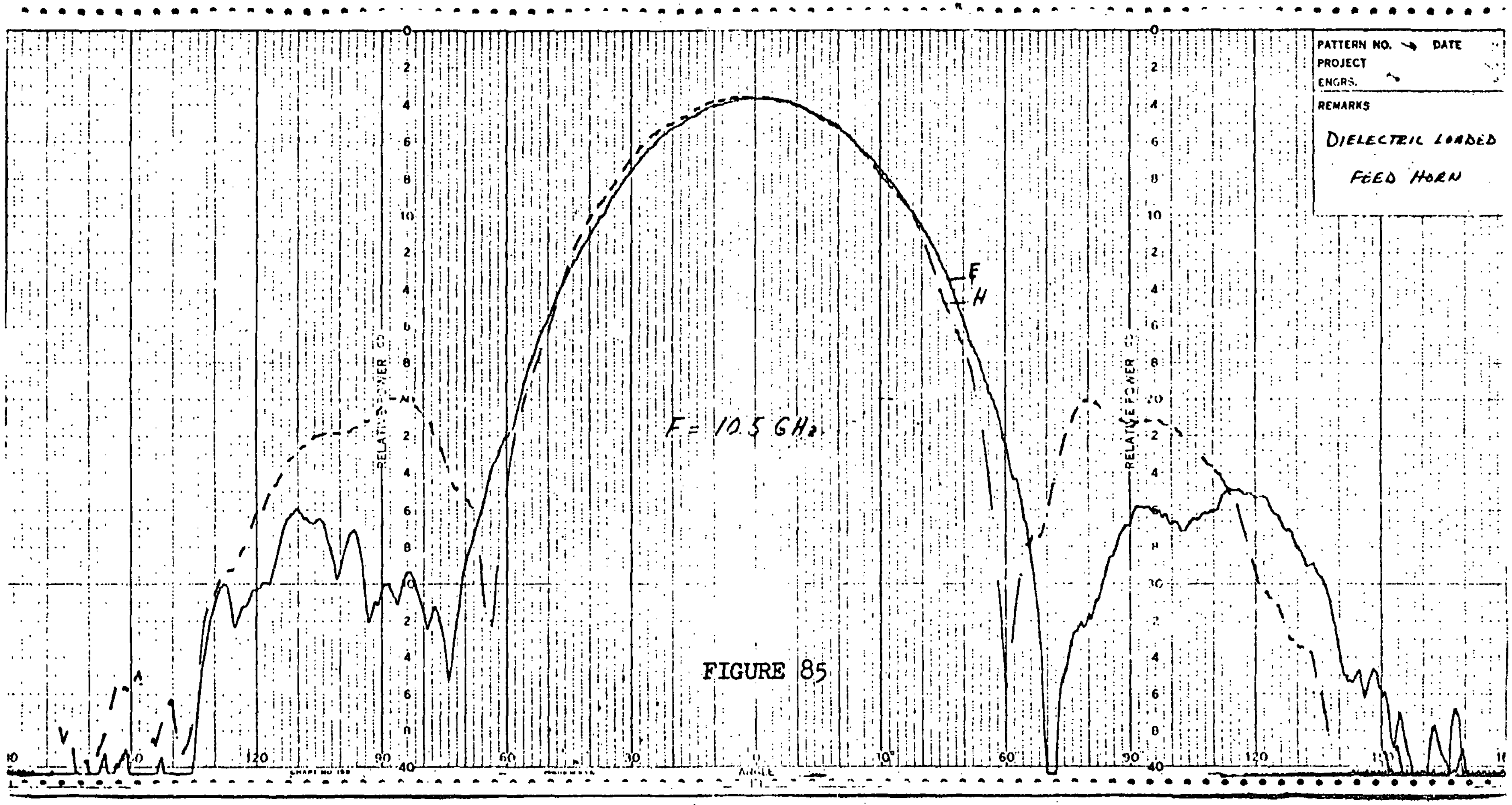

PATTERN NO.
DATE
PROJECT
REMARKS
DIELECTRIC LOADED
FEED HORN
F= 11.0GHz
E
45°
H
RELATIVE POWER db
ANGLE

FIGURE 84



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
DIELECTRIC LOADED FEED HORN
F = 10.5 GHz
F
H
RELATIVE POWER
ANGLE

FIGURE 85

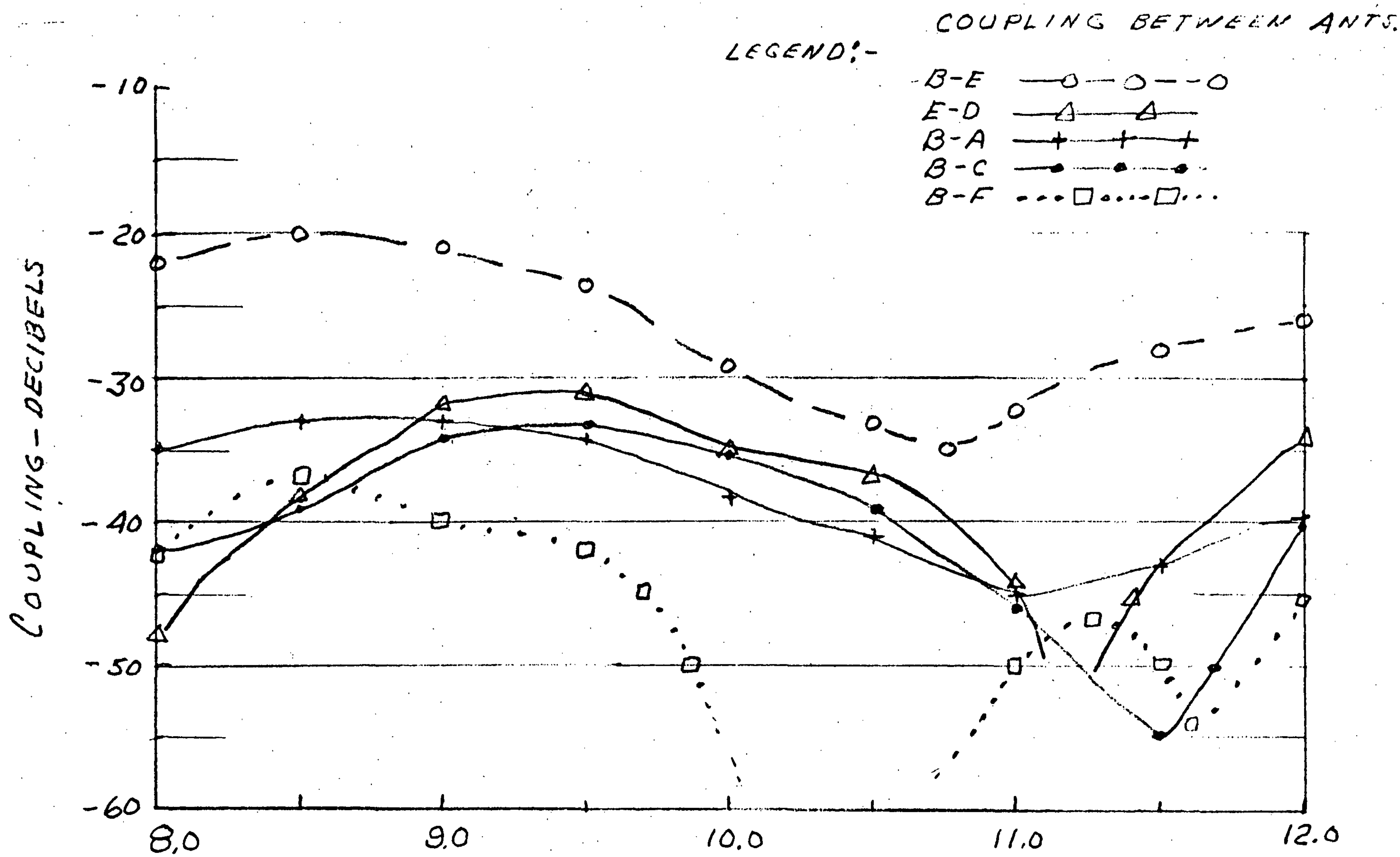


FIG. 86 REPRESENTATIVE COUPLING BETWEEN ANTENNAS IN THE ARRAY

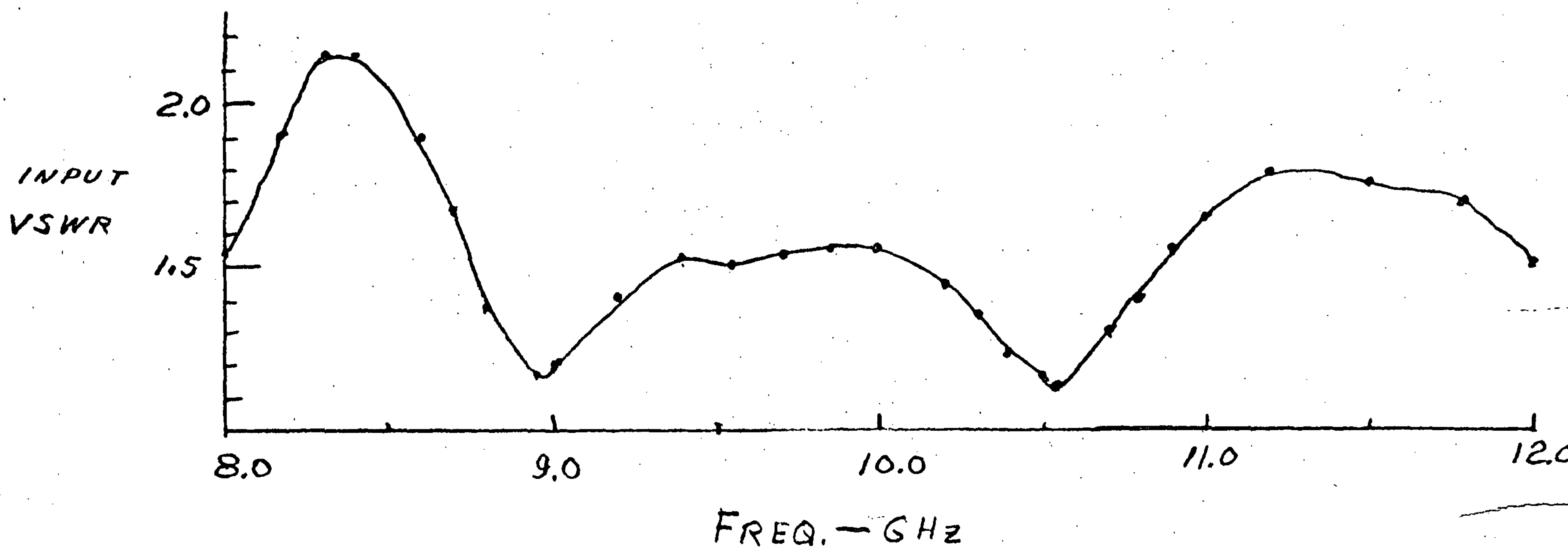


FIG. 87 INPUT VSWR OF ANAREN MODEL 40590
SER. NO. 02 POWER DIVIDER

Component VSWR

COMPONENT

ENGINEER

REMARKS
VSWR at Port 1,2,3

DATE
10 MAY 72

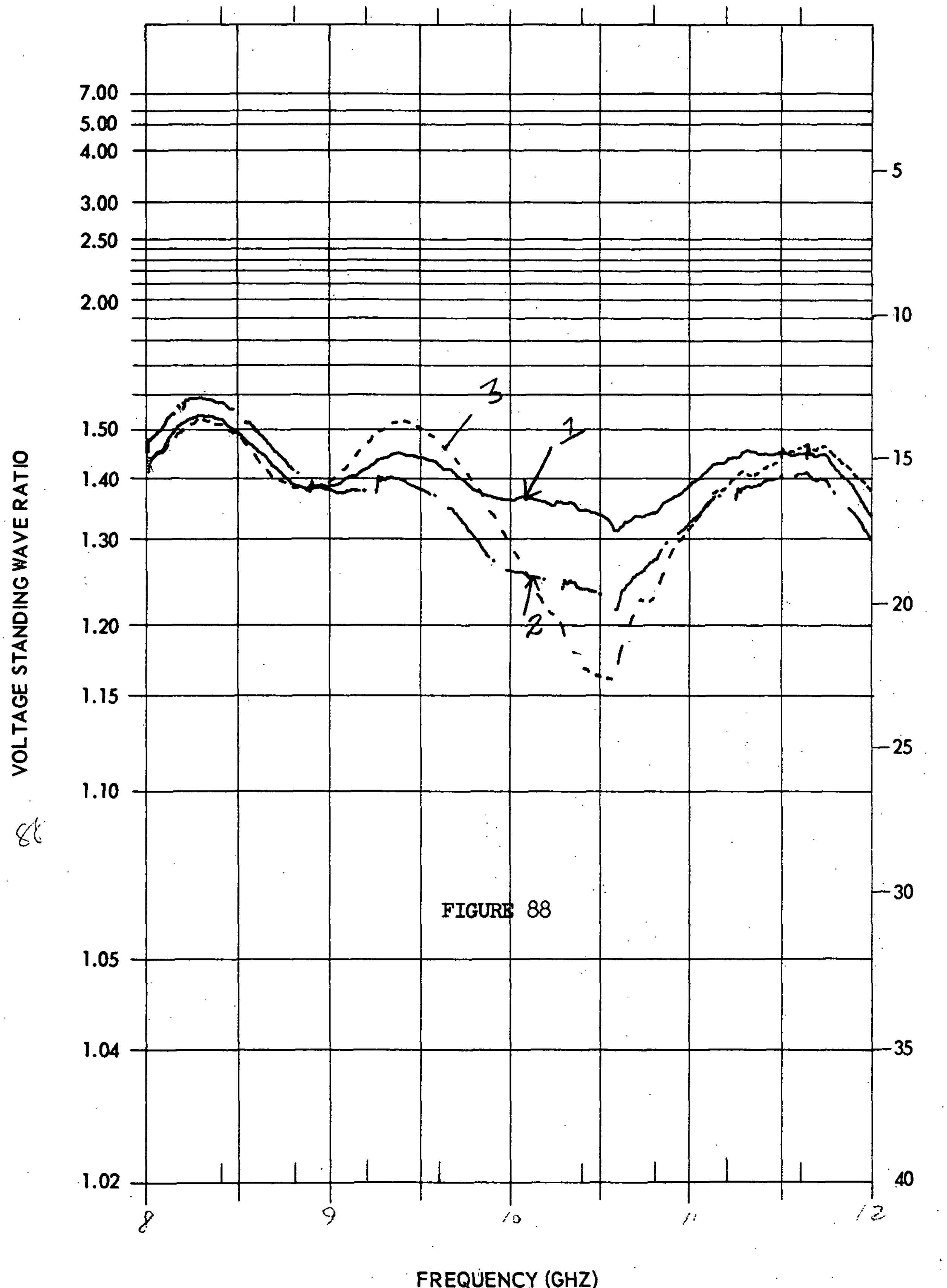


FIGURE 88

FORM LMSC 9013 C

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

COMPONENT: Power DIVIDER

ENGINEER:

REMARKS: VSWR AT PORTS 4,5,6

DATE: 10 MAY 72

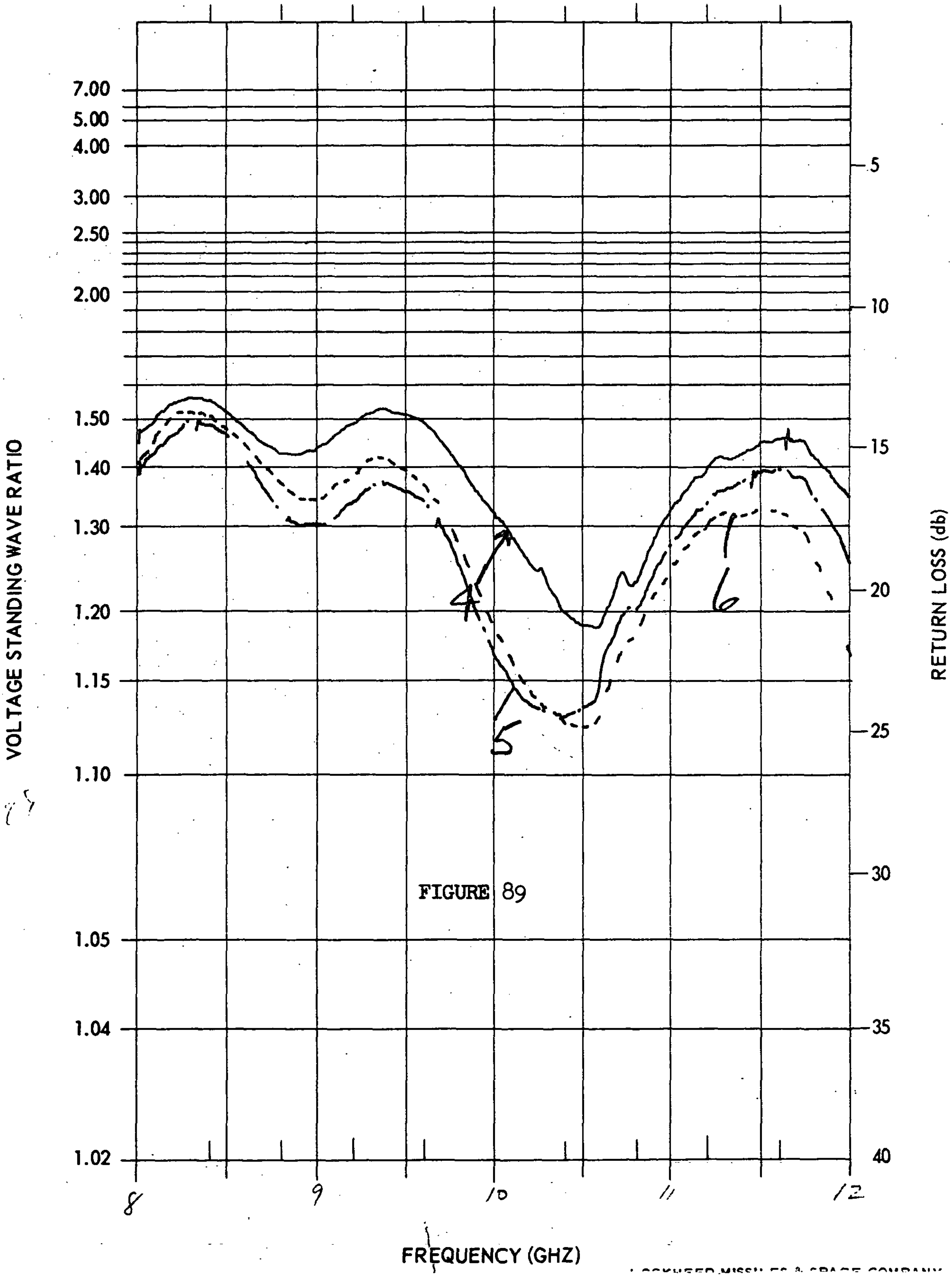


FIGURE 89

LOCKHEED MISSILES & SPACE COMPANY

Component VSWR

COMPONENT
Power DIVIDER

ENGINEER

REMARKS
VSWR AT PORTS 8, 7

DATE
10 MAY - 72

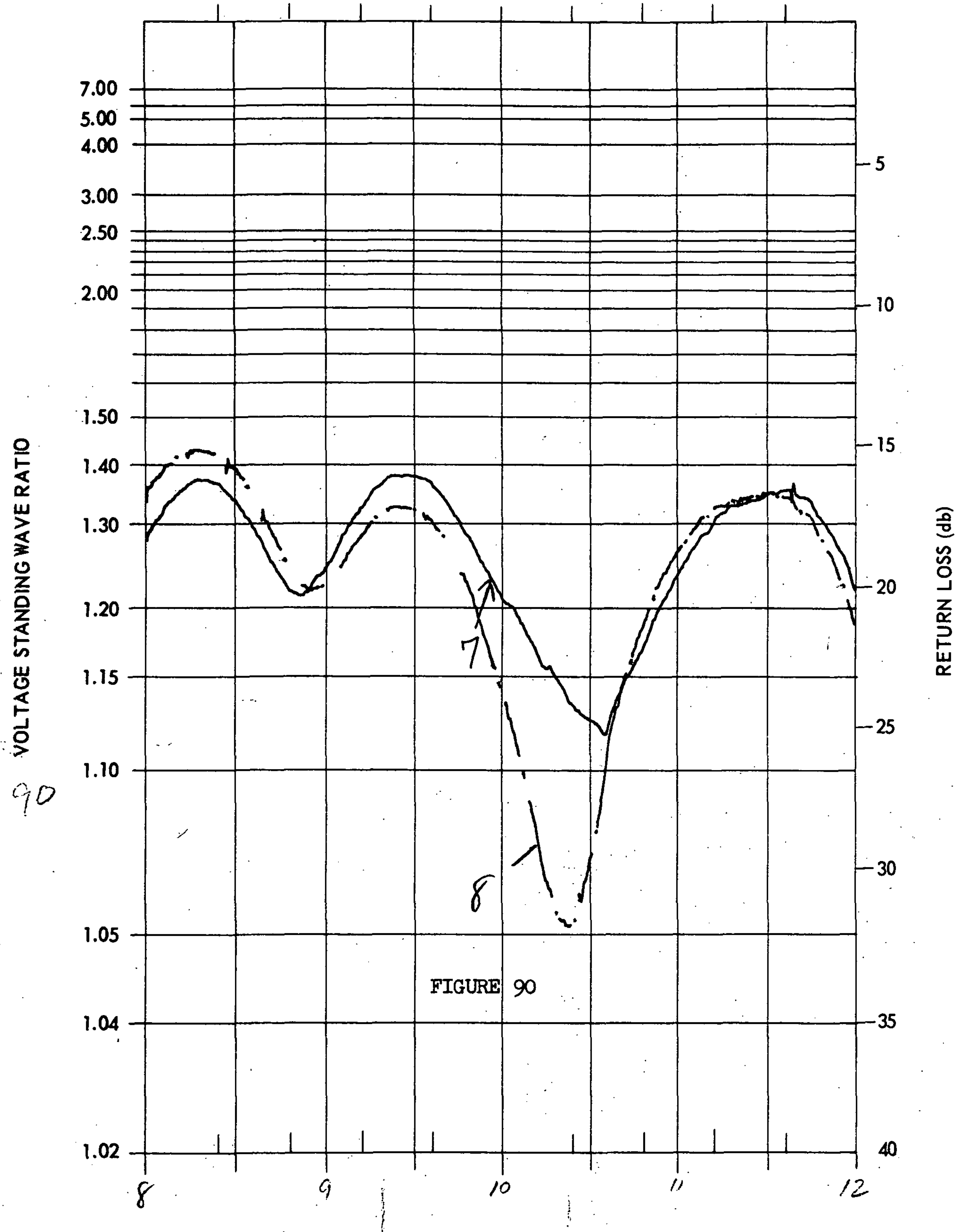


FIGURE 90

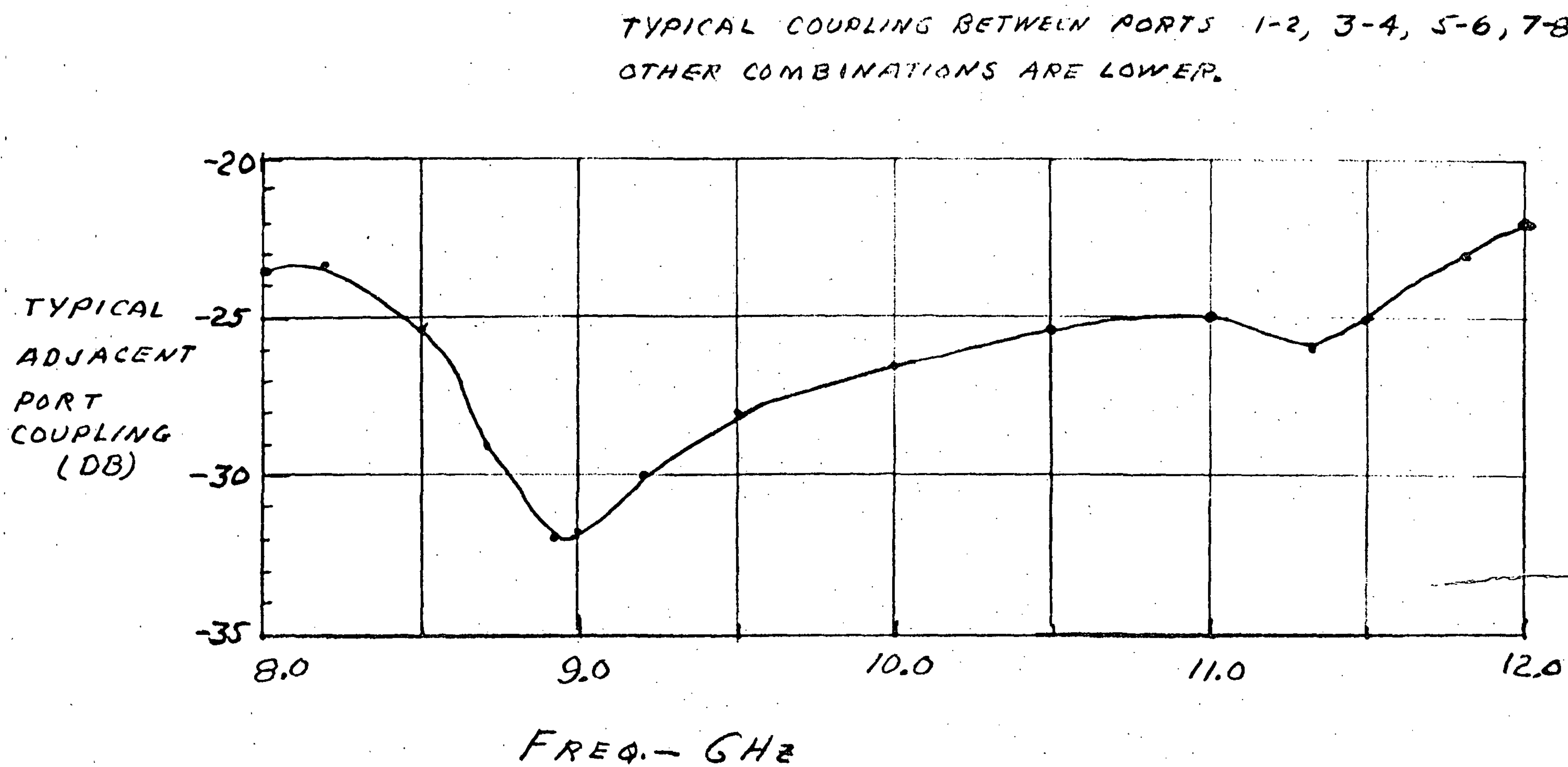


FIG. 91 TYPICAL COUPLING BETWEEN ADJACENT PORTS OF ANAREN MODEL 40590 SER. NO. 02 POWER DIVIDER

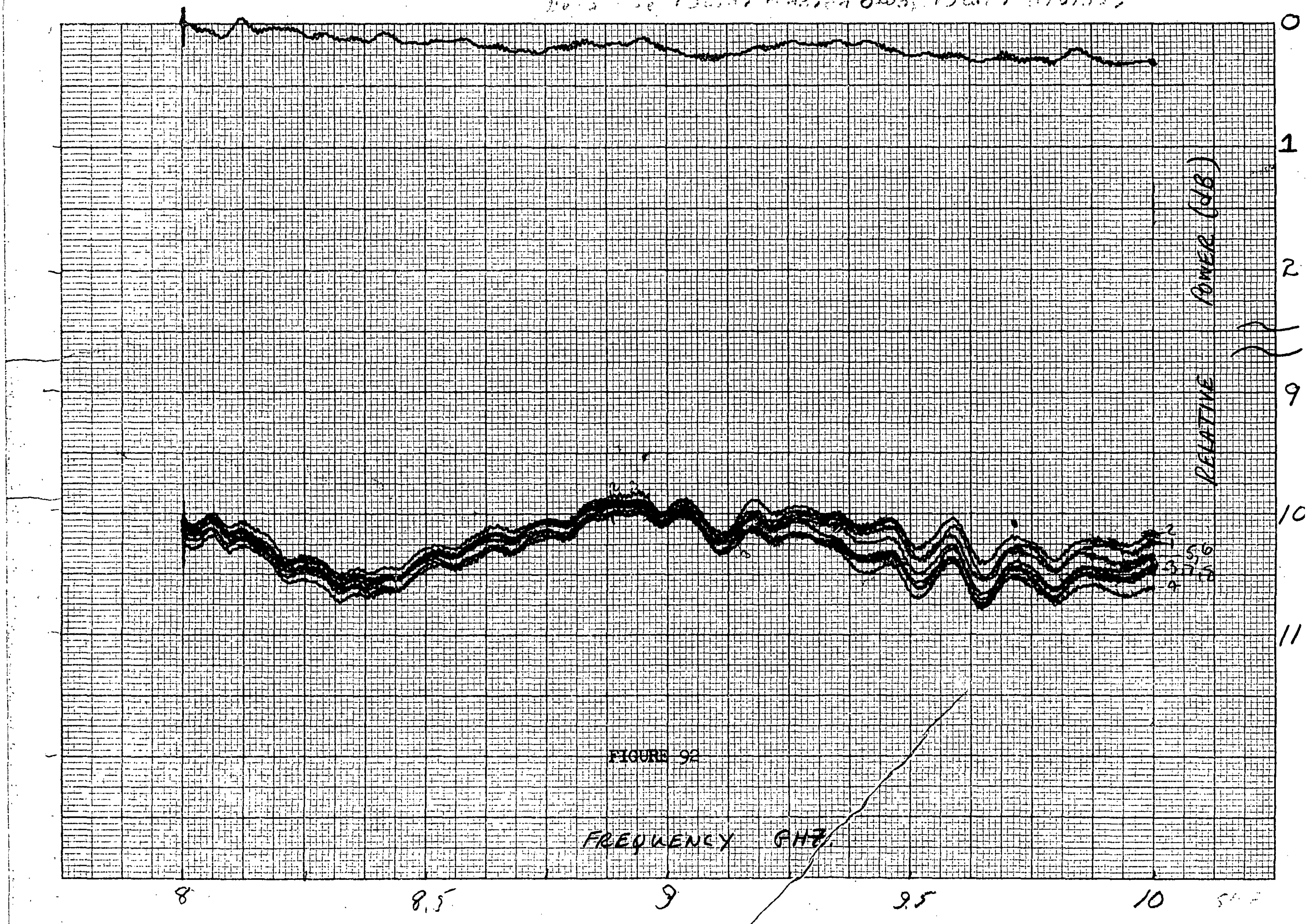


FIGURE 92

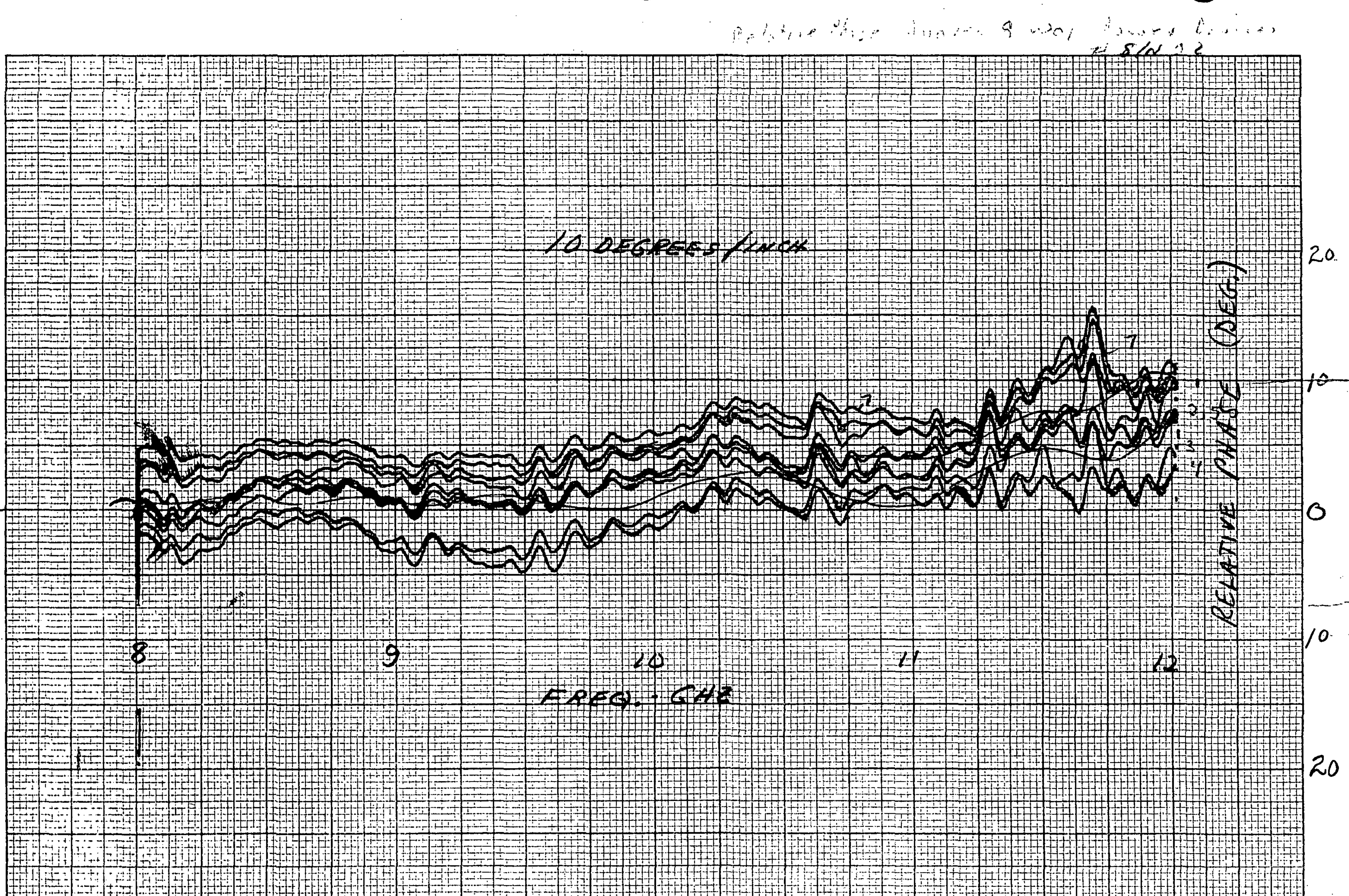

10 DEGREES/INCH
RELATIVE PHASE (DEG)
FREQ. - GHZ
8
9
10
11
12
20
10
0
10
20

FIGURE 93

6.0 REFLECTOR DESIGN AND FABRICATION

The test reflector is a 12 foot diameter circular paraboloid with an F/D ratio of 0.525 and a surface accuracy of 0.040 inches R.M.S. A top assembly drawing is shown in Fig. 94 and detail component drawings are shown in Figs. 95 thru 113.

The reflector was purchased from Structural Technology Inc. (Santa Clara, California). It is made of solid fiberglass laminate 0.40 inches thick coated with a thin layer of conducting material on the front parabolic surface. Its approximate weight is 360 pounds.

The feed support spars form a quadri-pod. The spars were fabricated of 1.5 inch diameter by .065 wall Aluminim alloy tubing (6061-T5).

The positioning and adjusting fixtures were incorporated to allow axial and rotational movement of the feeds. These fixtures would not be incorporated into an end product design.

The spars were secured to a 13-inch square plate lying about 1 foot behind the focal plane away from the reflector vertex.

The feeds were mounted to an aluminum plate with two sets of 8 holes located in one case to position one feed on the reflector axis and in the second case to position this same feed 0.500 inches up and 5.400 inches over from its on-axis position.

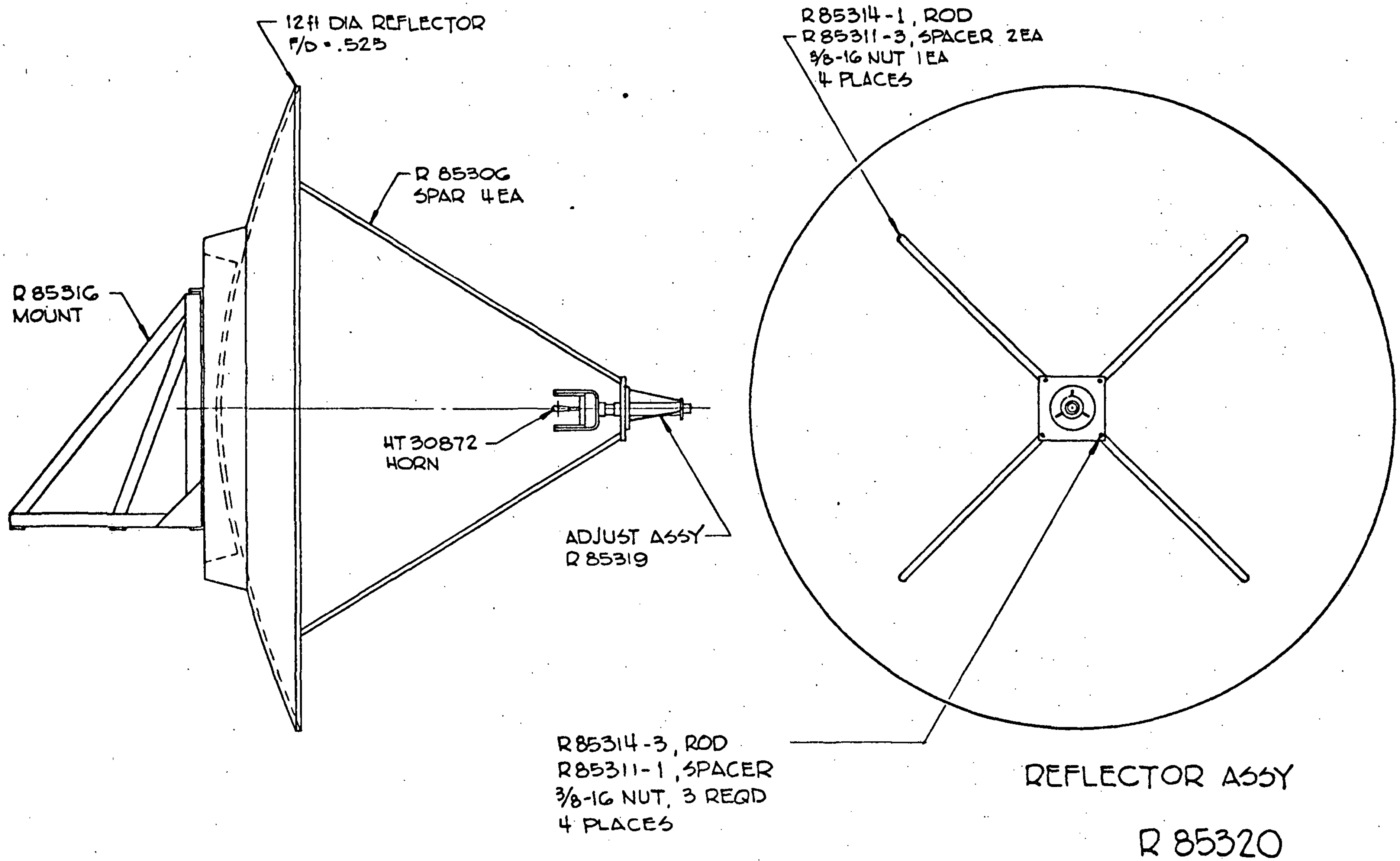
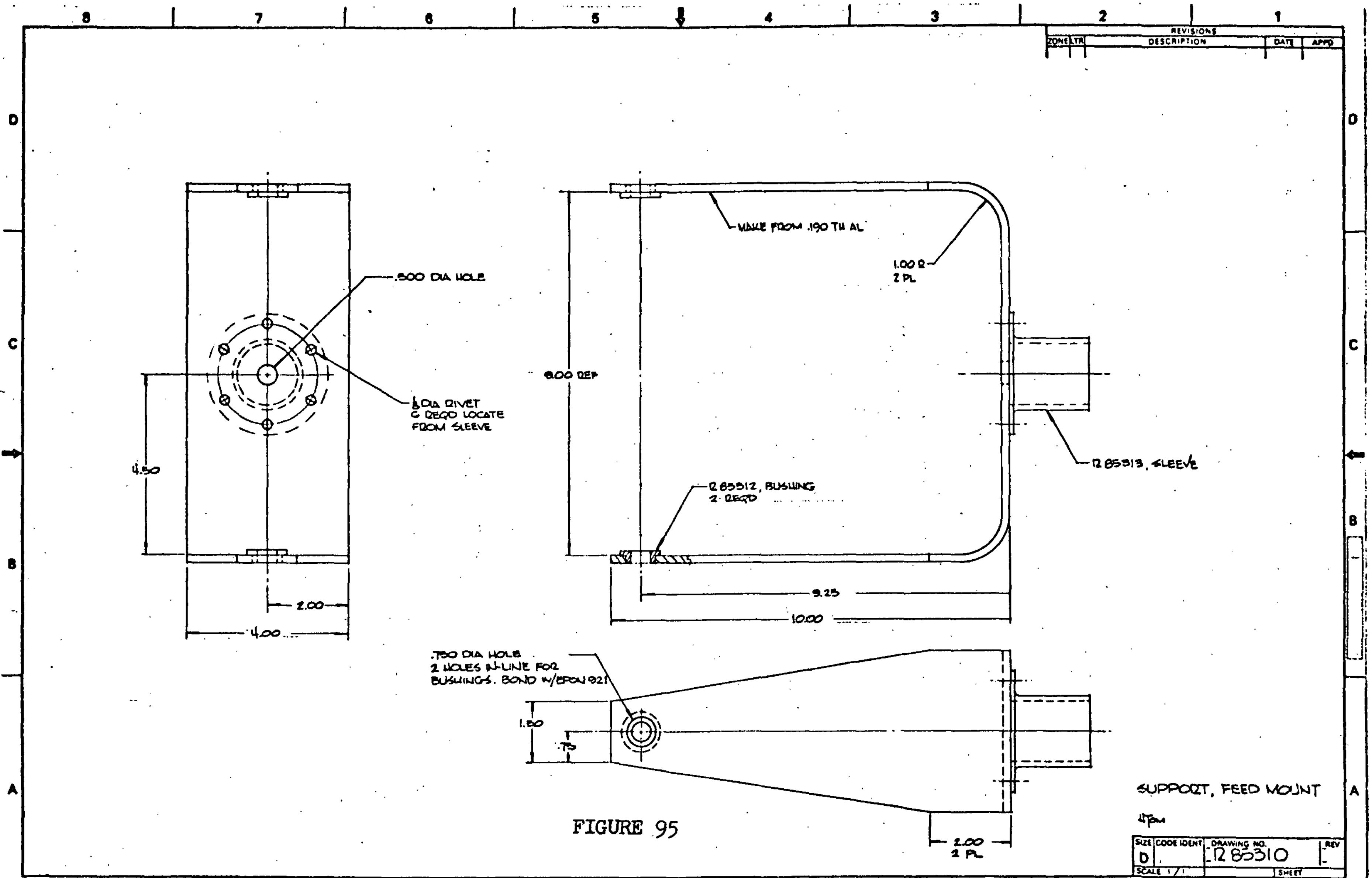

12 ft DIA REFLECTOR
F/D = .525
R 85306
SPAR 4 EA
R 85316
MOUNT
HT 30872
HORN
ADJUST ASSY
R 85319
R 85314-1, ROD
R 85311-3, SPACER 2 EA
3/8-16 NUT 1 EA
4 PLACES
R 85314-3, ROD
R 85311-1, SPACER
3/8-16 NUT, 3 REQD
4 PLACES
REFLECTOR ASSY
R 85320

FIGURE 94



REVISIONS
ZONE LTR DESCRIPTION DATE APPD
.500 DIA HOLE
1/8 DIA RIVET
6 REQD LOCATE
FROM SLEEVE
4.50
2.00
4.00
MAKE FROM .190 TH AL
1.00 R
2 PL
8.00 REF
R 85313, SLEEVE
R 85312, BUSHING
2 REQD
9.25
10.00
.750 DIA HOLE
2 HOLES IN-LINE FOR
BUSHINGS. BOND W/EPON 921
1.50
.75
2.00
2 PL
SUPPORT, FEED MOUNT
SIZE CODE IDENT DRAWING NO. REV
D R 85310
SCALE 1/1 SHEET

FIGURE 95

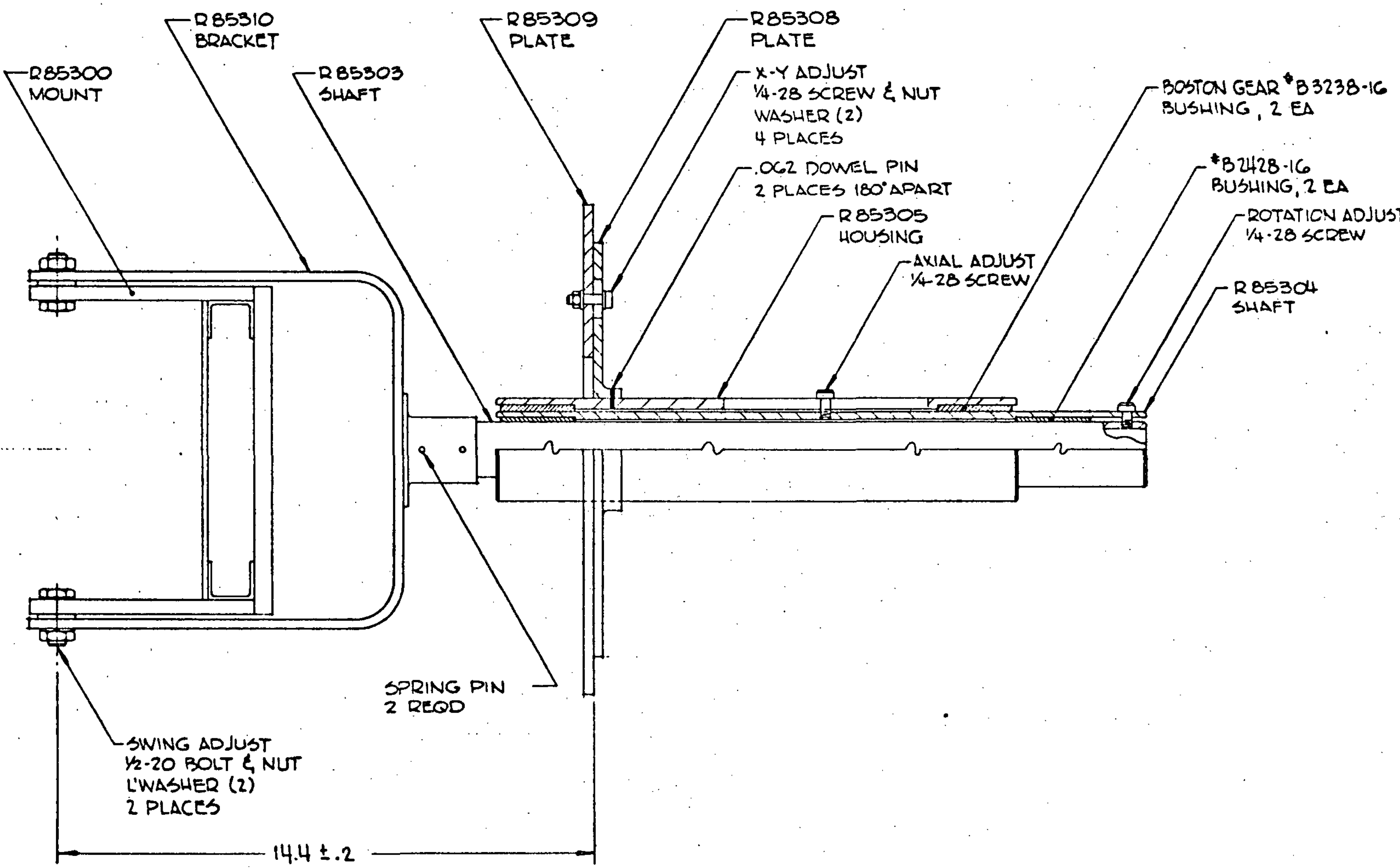


FIGURE 96

ADJUST ASSY

SIZE	CODE IDENT	DRAWING NO.	REV
C		R 85319	
SCALE		SHEET	

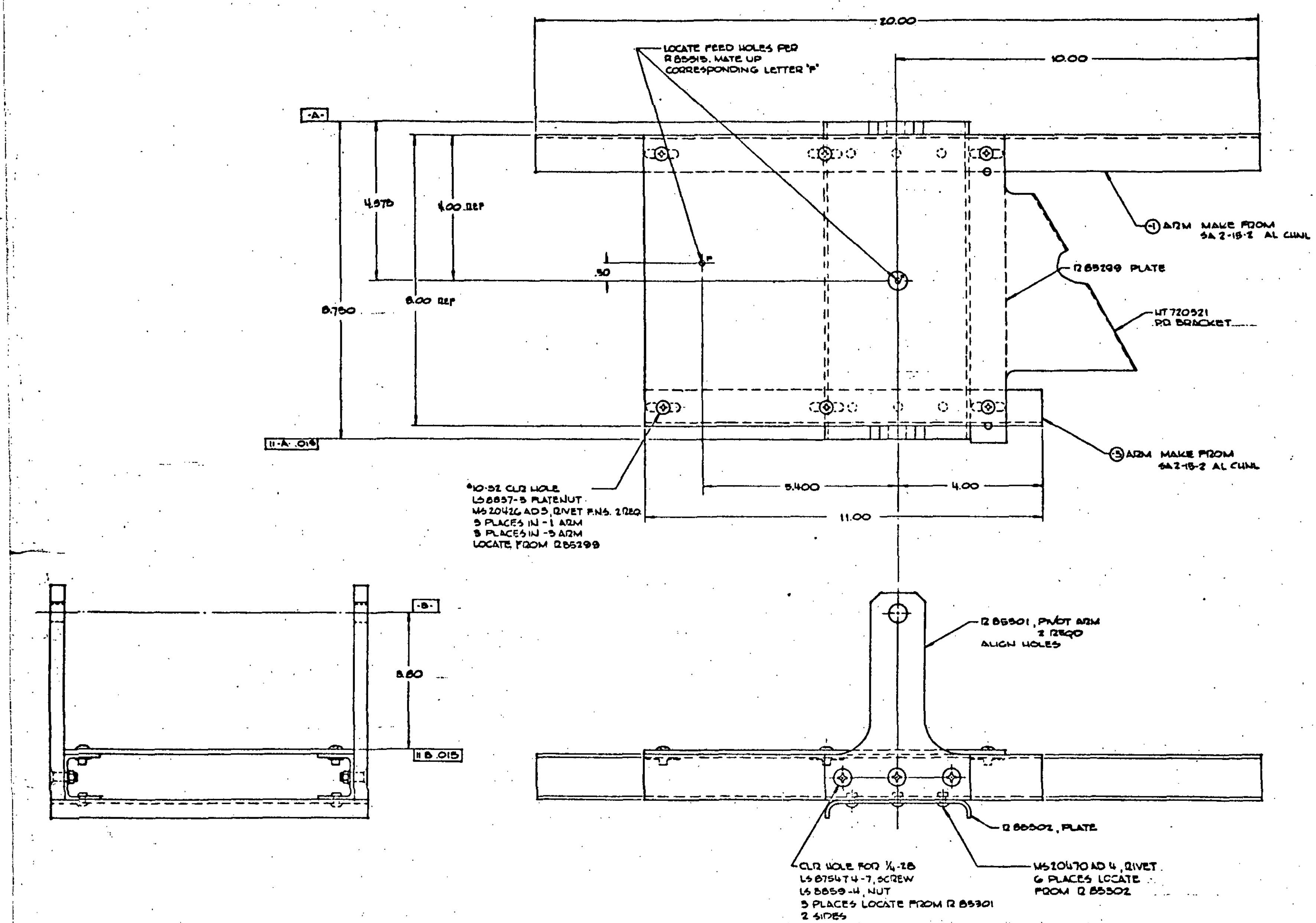
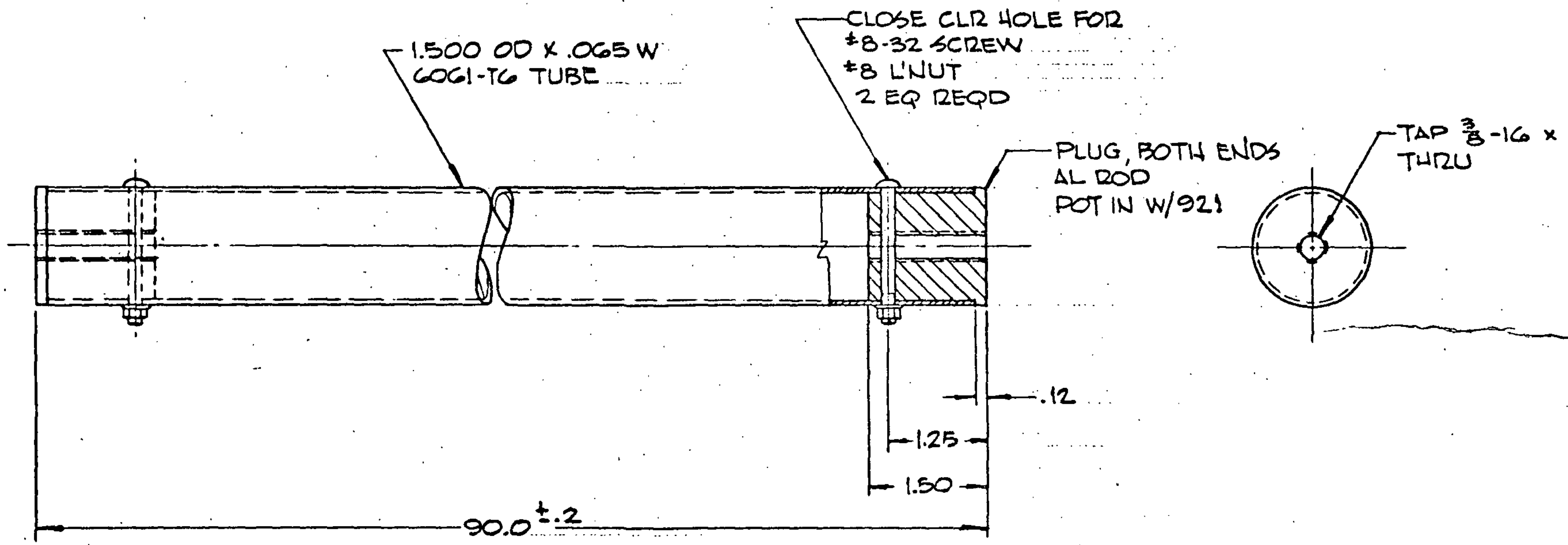


FIGURE 97

FEED MOUNT - 12FT DISH

R 85300



SPAR 4 EQ REQD

FIGURE 98

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPD

SIZE	CODE IDENT	DRAWING NO.	REV
C		1285306	

SCALE 1/1 SHEET

FORM LMSC 1513C-6

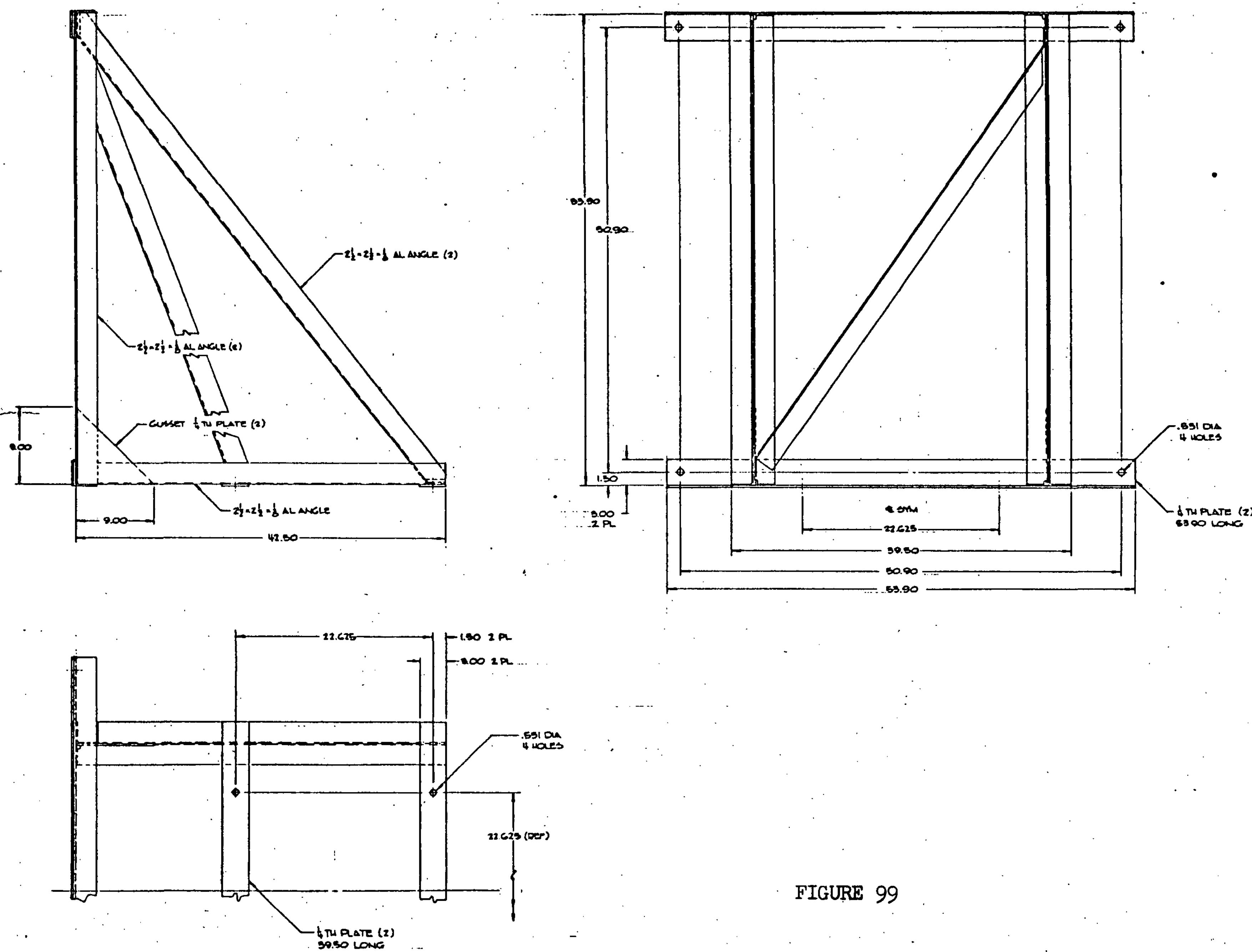


FIGURE 99

NOTE: 1/4 NUTS & BOLTS FOR FASTENERS THRU-OUT

REFLECTOR MOUNT

R 85316

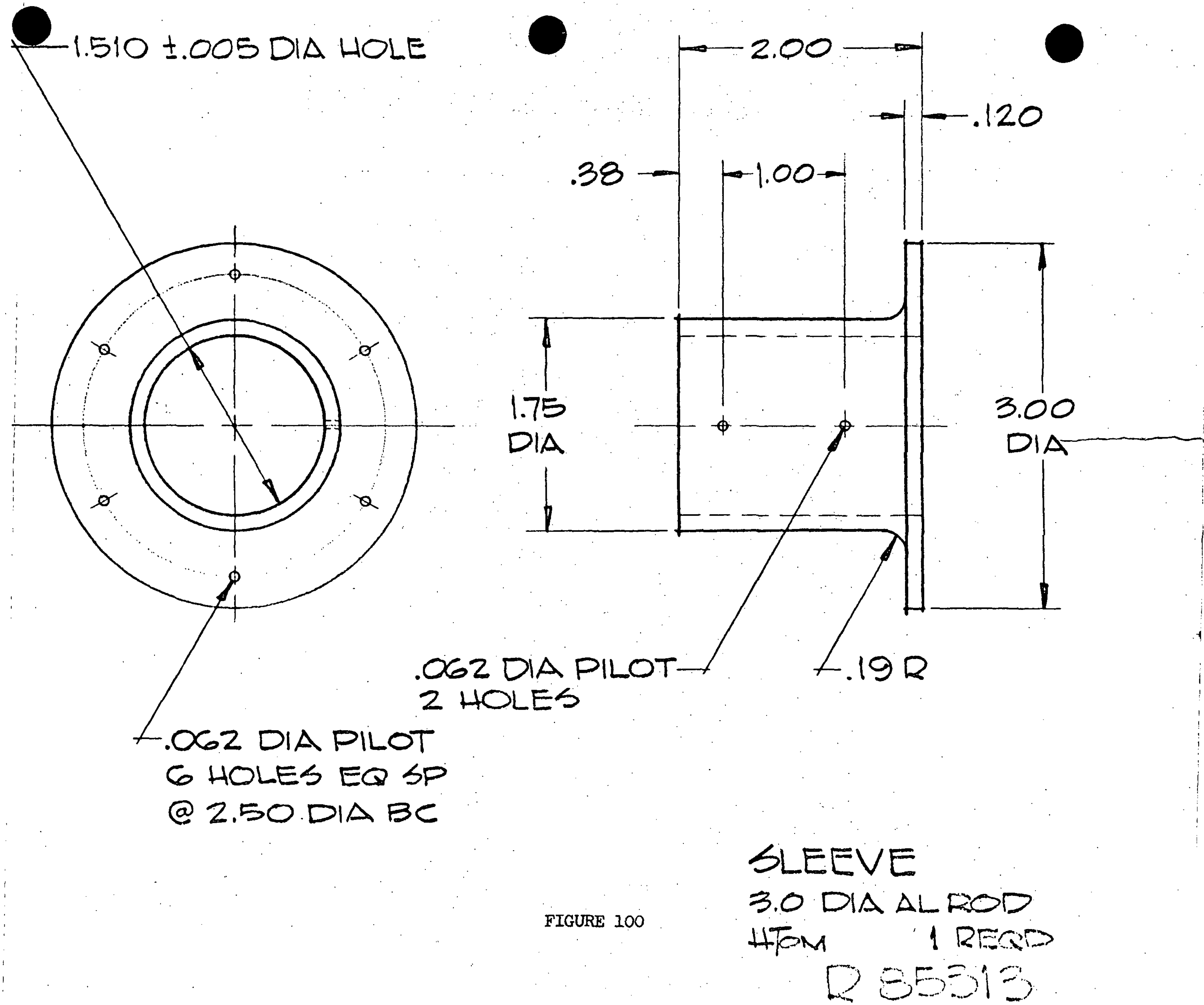

1.510 ±.005 DIA HOLE
2.00
.120
.38
1.00
1.75 DIA
3.00 DIA
.062 DIA PILOT 2 HOLES
.19 R
.062 DIA PILOT 6 HOLES EQ SP @ 2.50 DIA BC
SLEEVE
3.0 DIA AL ROD
HTOM 1 REQD
R 85313

FIGURE 100

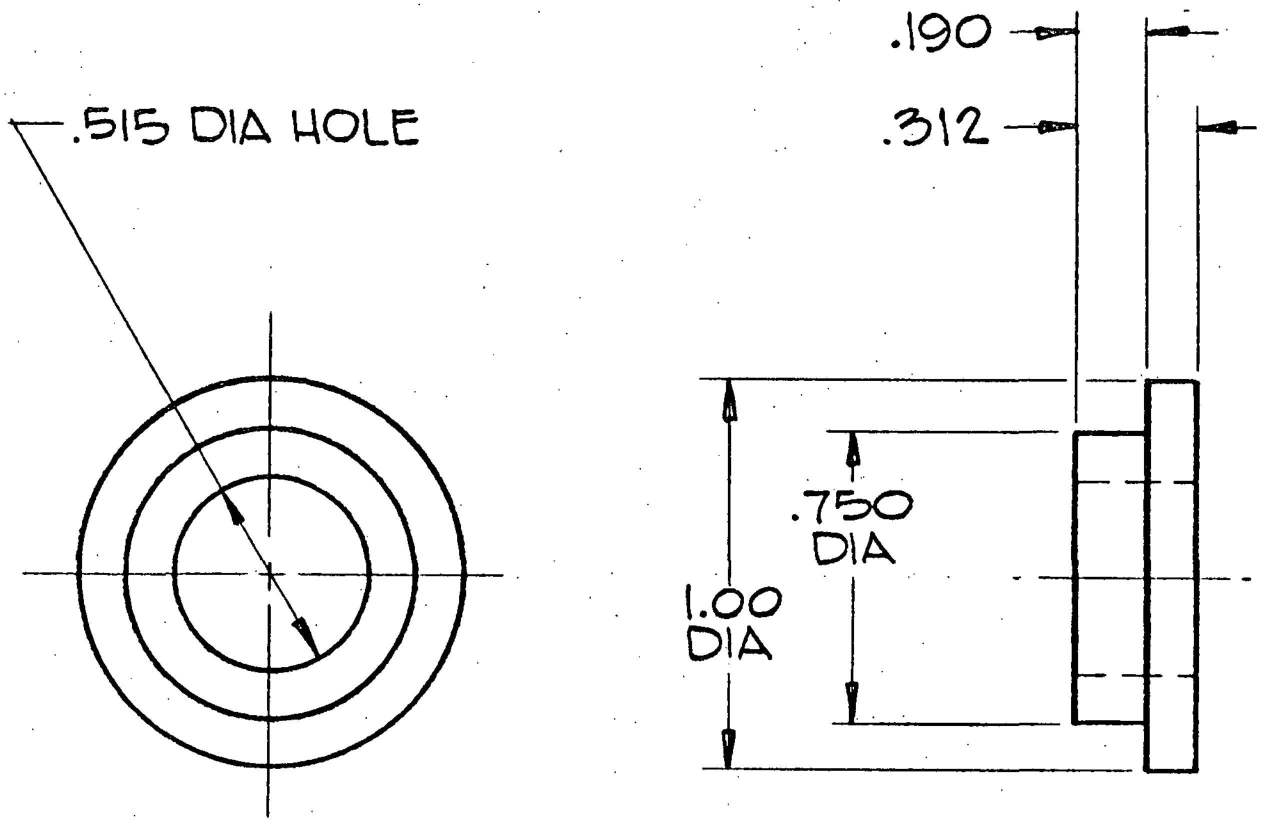
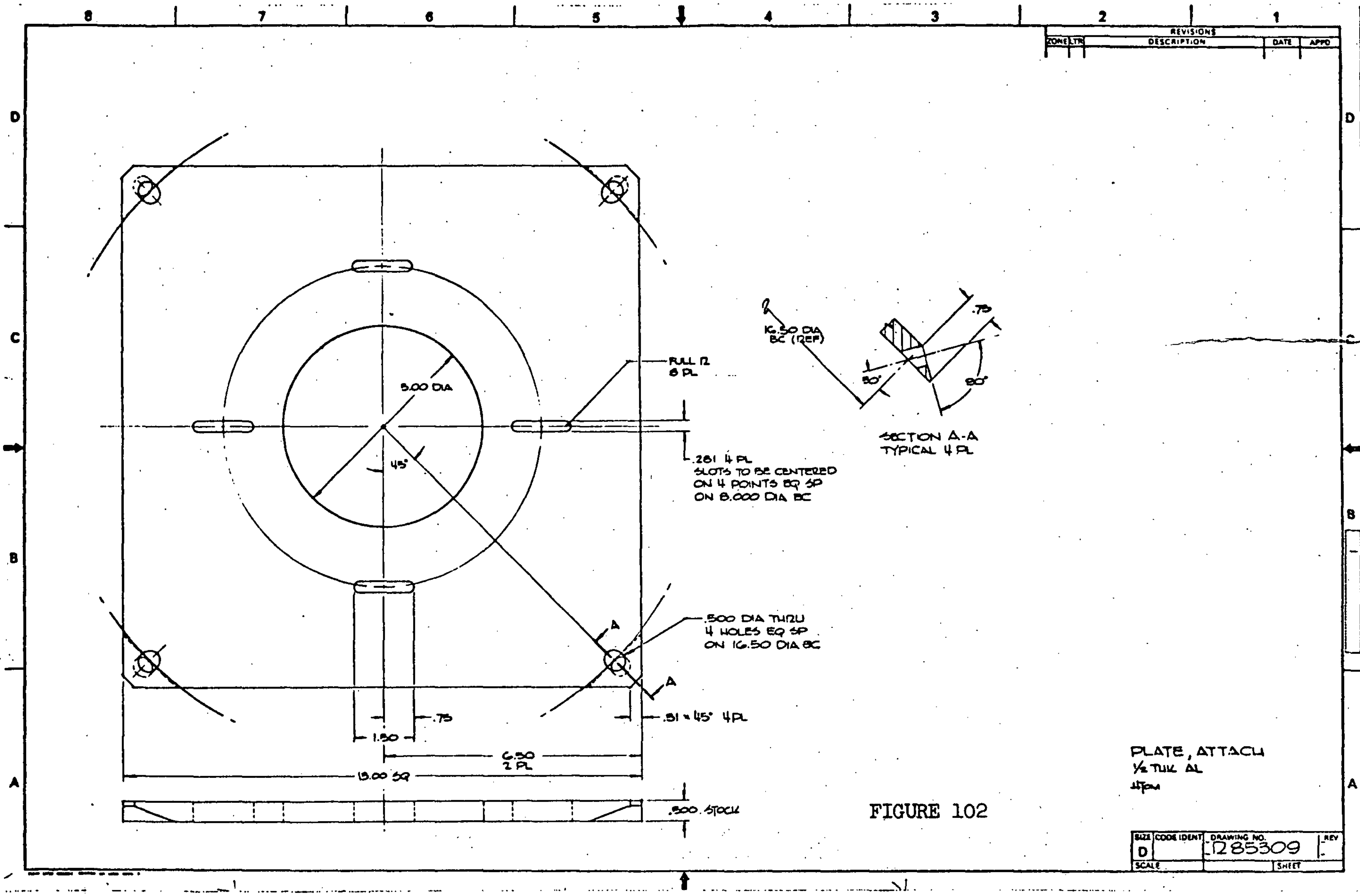


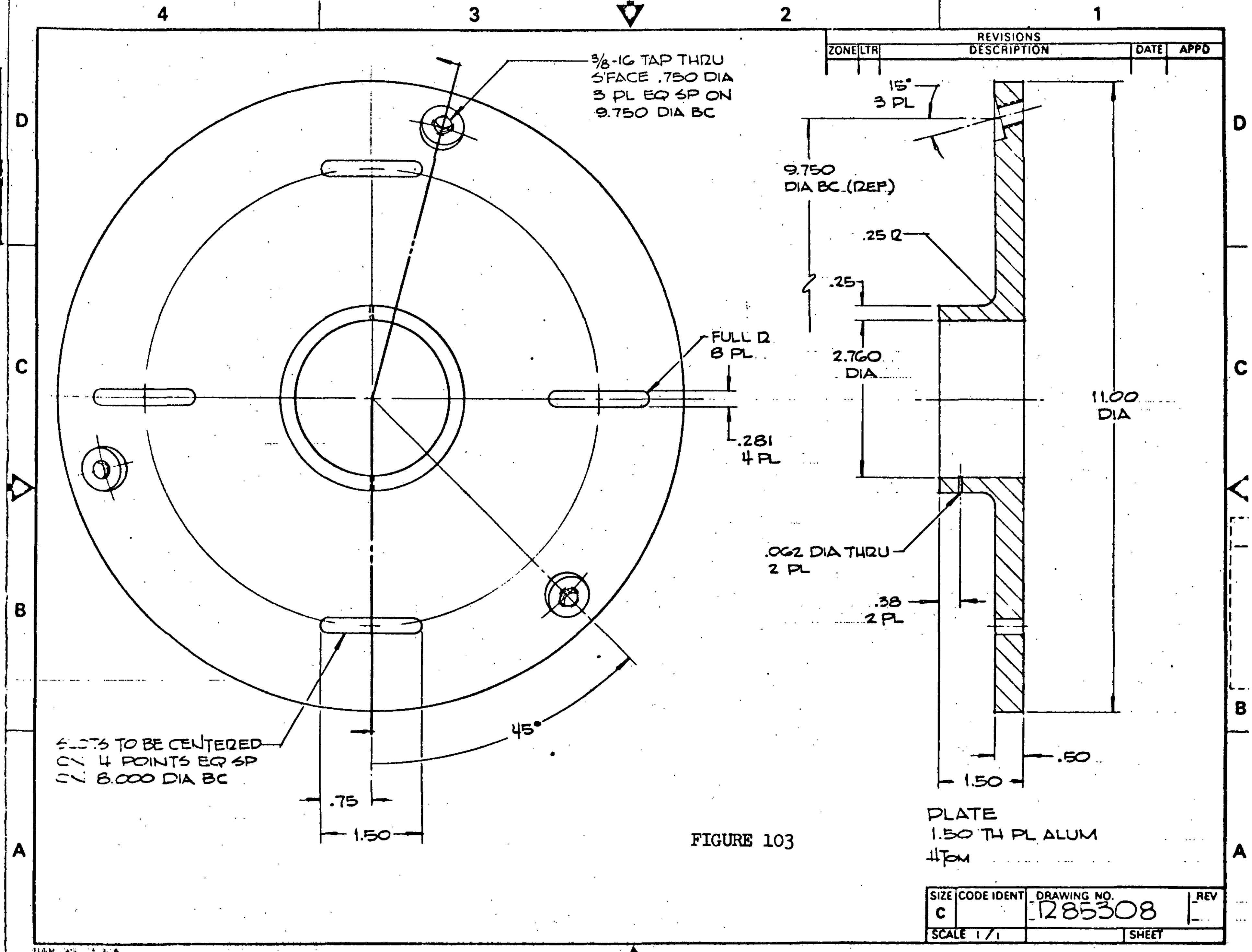
FIGURE 101

BUSHING
1.0 DIA ST STL ROD
H.TOM 2 REQD
R 85312



REVISIONS
ZONE LTR DESCRIPTION DATE APPD
5.00 DIA
45°
FULL R 8 PL
.281 4 PL
SLOTS TO BE CENTERED ON 4 POINTS EQ SP ON 8.000 DIA BC
16.50 DIA BC (REF)
.75
30°
90°
SECTION A-A TYPICAL 4 PL
.500 DIA THRU 4 HOLES EQ SP ON 16.50 DIA BC
A
A
.75
1.50
.51 x 45° 4 PL
6.50 2 PL
13.00 SQ
.500 STOCK
PLATE, ATTACH
½ THK AL
SIZE D
CODE IDENT
DRAWING NO. 1285309
REV
SCALE
SHEET

FIGURE 102



4
3
2
1
D
C
B
A
REVISIONS
ZONE LTR DESCRIPTION DATE APPD
3/8-16 TAP THRU
S'FACE .750 DIA
3 PL EQ SP ON
9.750 DIA BC
15°
3 PL
9.750
DIA BC (REF)
.25 R
.25
FULL R
8 PL
2.760
DIA
11.00
DIA
.281
4 PL
.062 DIA THRU
2 PL
.38
2 PL
SLOTS TO BE CENTERED
ON 4 POINTS EQ SP
ON 8.000 DIA BC
45°
.50
1.50
.75
1.50
PLATE
1.50 TH PL ALUM
SIZE C
CODE IDENT
DRAWING NO. 1285308
REV
SCALE 1/1
SHEET

FIGURE 103

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

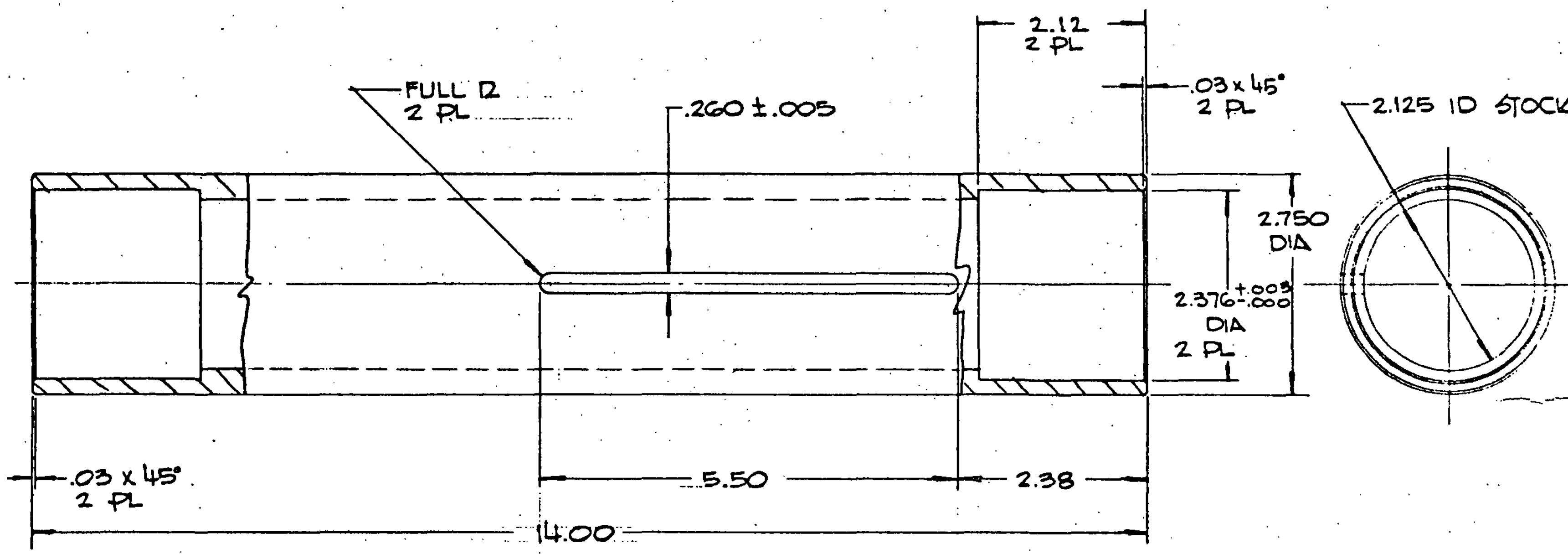
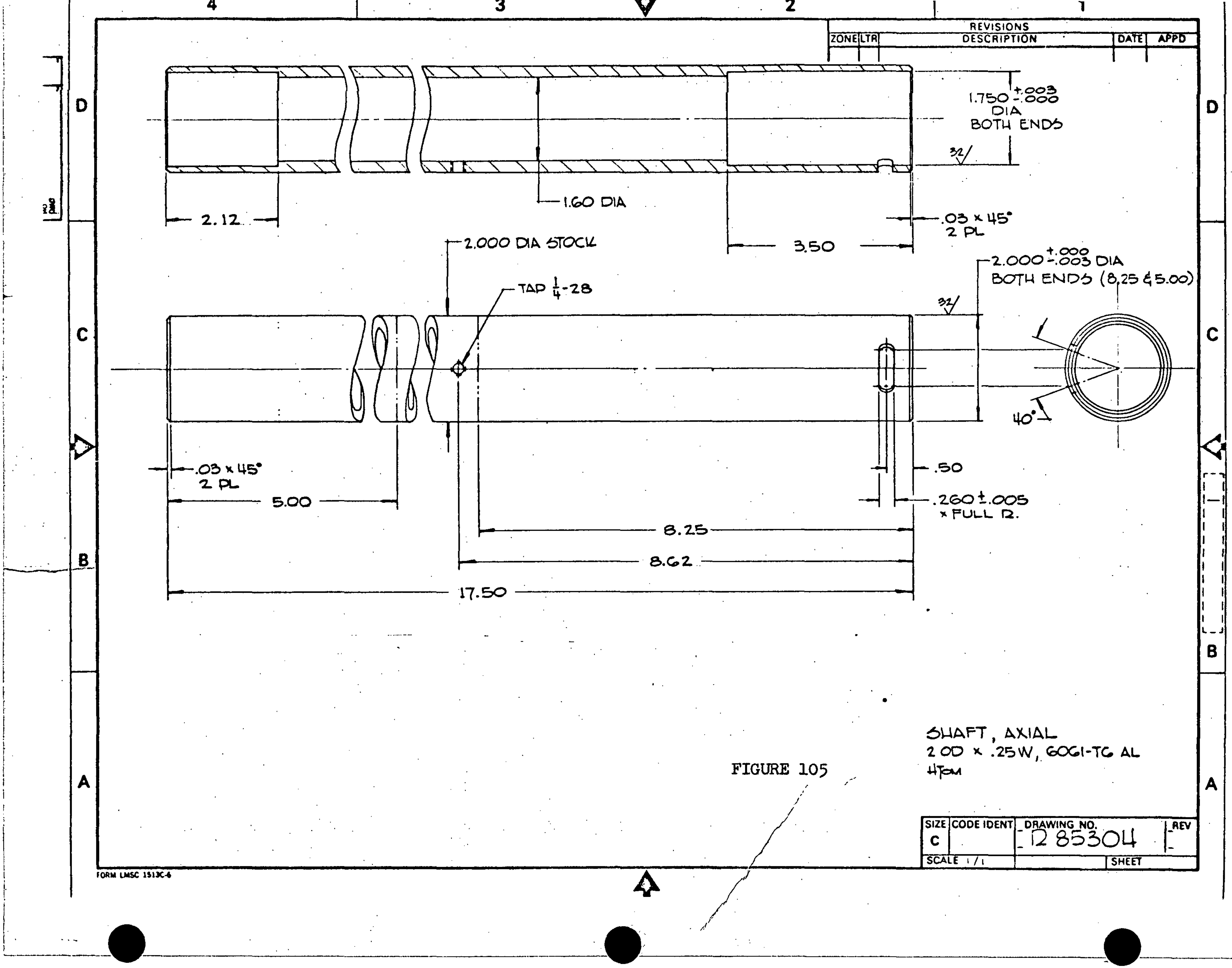


FIGURE 104

HOUSING
3 OD x .438 W, 7075-T651
4 [illegible]

SIZE	CODE IDENT	DRAWING NO.	REV
C		12 85305	
SCALE 1/1		SHEET	

FORM LMSC 1513C-6



REVISIONS
ZONE LTR DESCRIPTION DATE APPD
1.750 +.003 -.000 DIA BOTH ENDS
1.60 DIA
2.12
.03 x 45° 2 PL
3.50
2.000 DIA STOCK
2.000 +.000 -.003 DIA BOTH ENDS (8.25 & 5.00)
TAP 1/4-28
40°
.03 x 45° 2 PL
5.00
.50
.260 ±.005 x FULL R.
8.25
8.62
17.50
SHAFT, AXIAL
2 OD x .25W, 6061-T6 AL
SIZE C
CODE IDENT
DRAWING NO. 1285304
REV
SCALE 1/1
SHEET
FORM LMSC 1513C-6

FIGURE 105

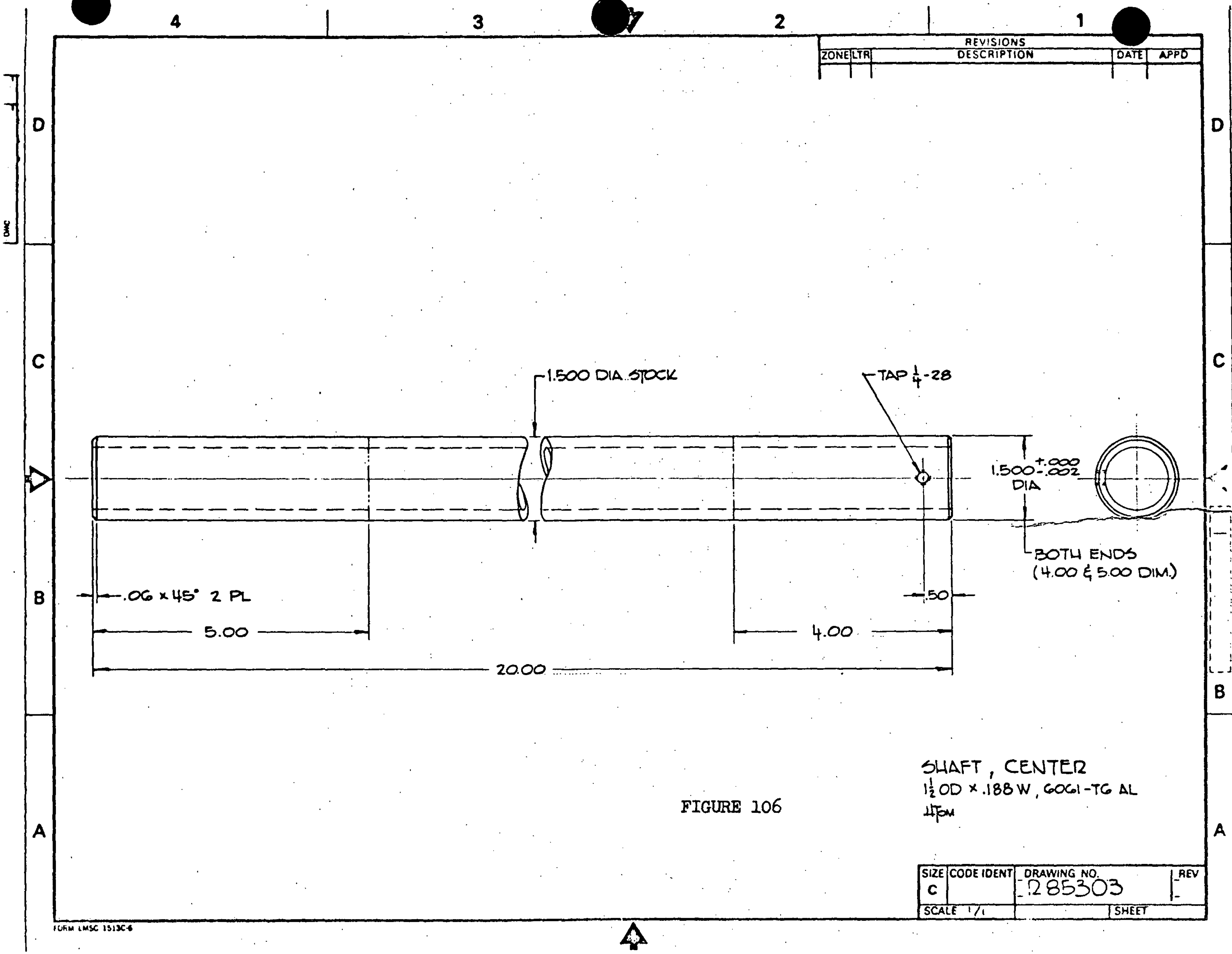
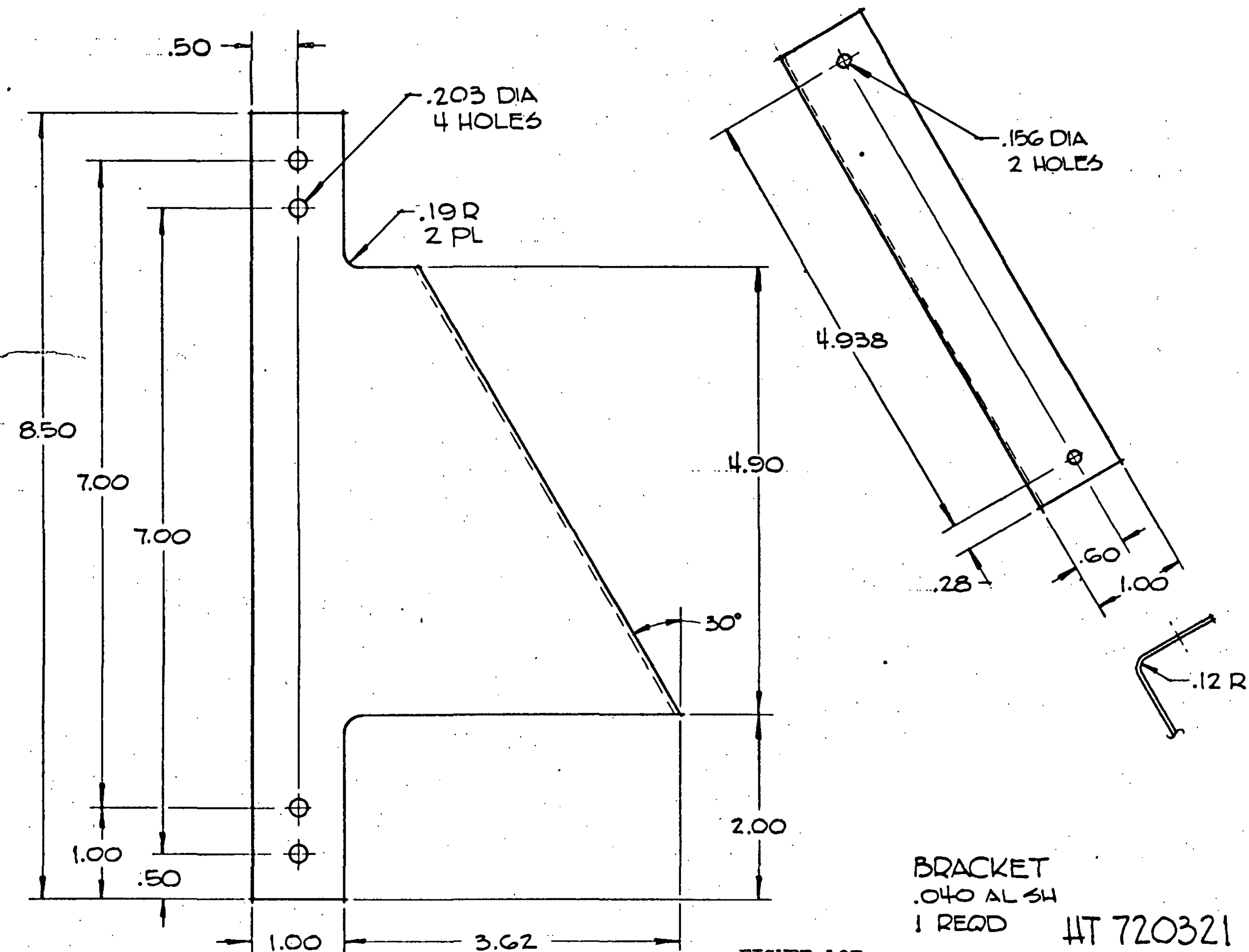

REVISIONS
ZONE LTR DESCRIPTION DATE APPD
1.500 DIA. STOCK
TAP 1/4-28
1.500 +.000 -.002 DIA
BOTH ENDS (4.00 & 5.00 DIM.)
.06 x 45° 2 PL
.50
5.00
4.00
20.00
SHAFT, CENTER
1½ OD × .188 W, 6061-T6 AL
SIZE C
CODE IDENT
DRAWING NO. 1285303
REV
SCALE 1/1
SHEET
FORM LMSC 1513C-6

FIGURE 106



.50
.203 DIA
4 HOLES
.19 R
2 PL
8.50
7.00
7.00
4.90
30°
2.00
1.00
.50
1.00
3.62
.156 DIA
2 HOLES
4.938
.60
1.00
.28
.12 R
BRACKET
.040 AL SH
1 REQD
HT 720321

FIGURE 107

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD

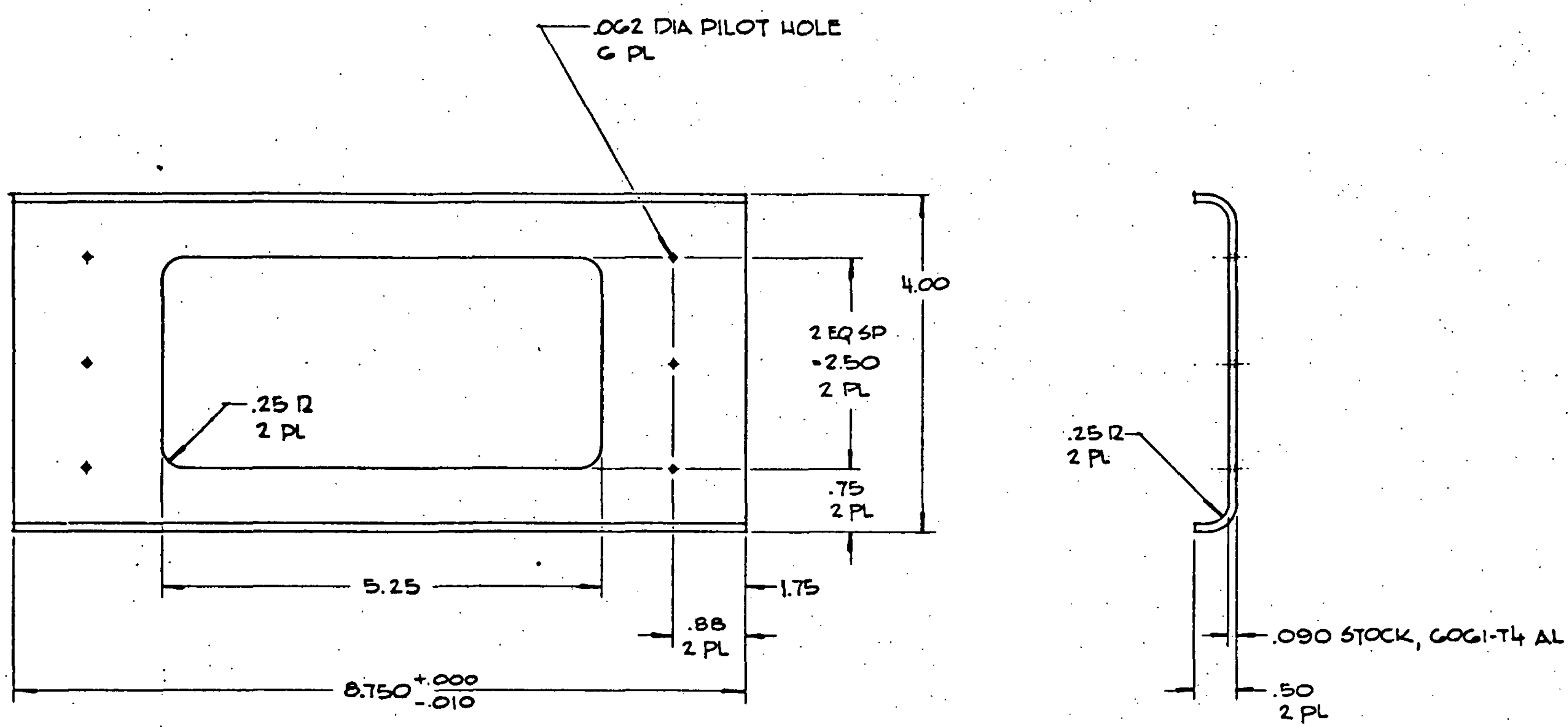


FIGURE 108

PLATE 1 REQD
HTom

SIZE	CODE IDENT	DRAWING NO.	REV
C		D 85302	
SCALE 1/1			SHEET

FORM LMSC 1513C-6

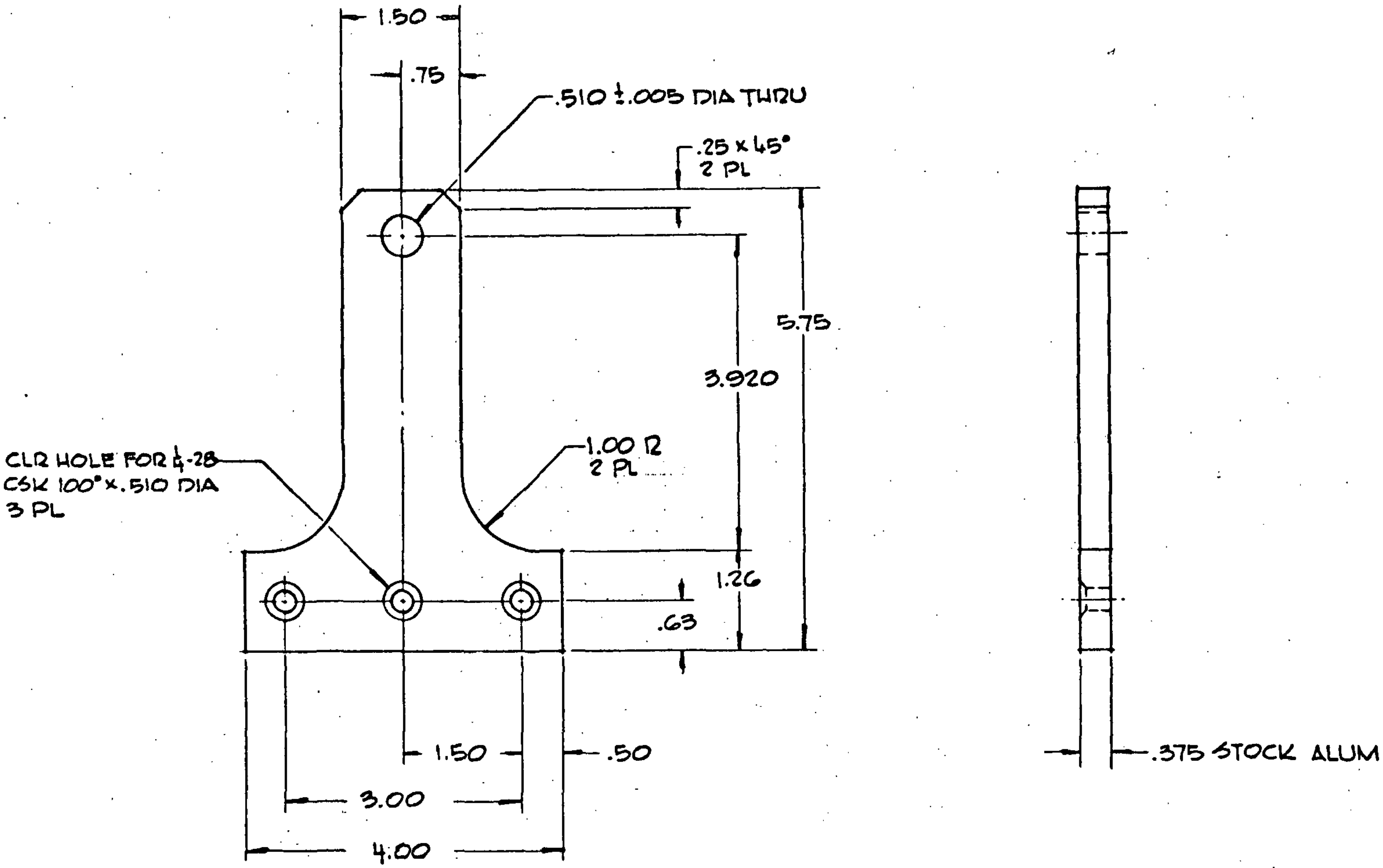


FIGURE 109

PIVOT ARM
2 REQD

SIZE	CODE IDENT	DRAWING NO.	REV
C		D 85301	
SCALE 1/1		SHEET	

FORM LMSC 1513C-6

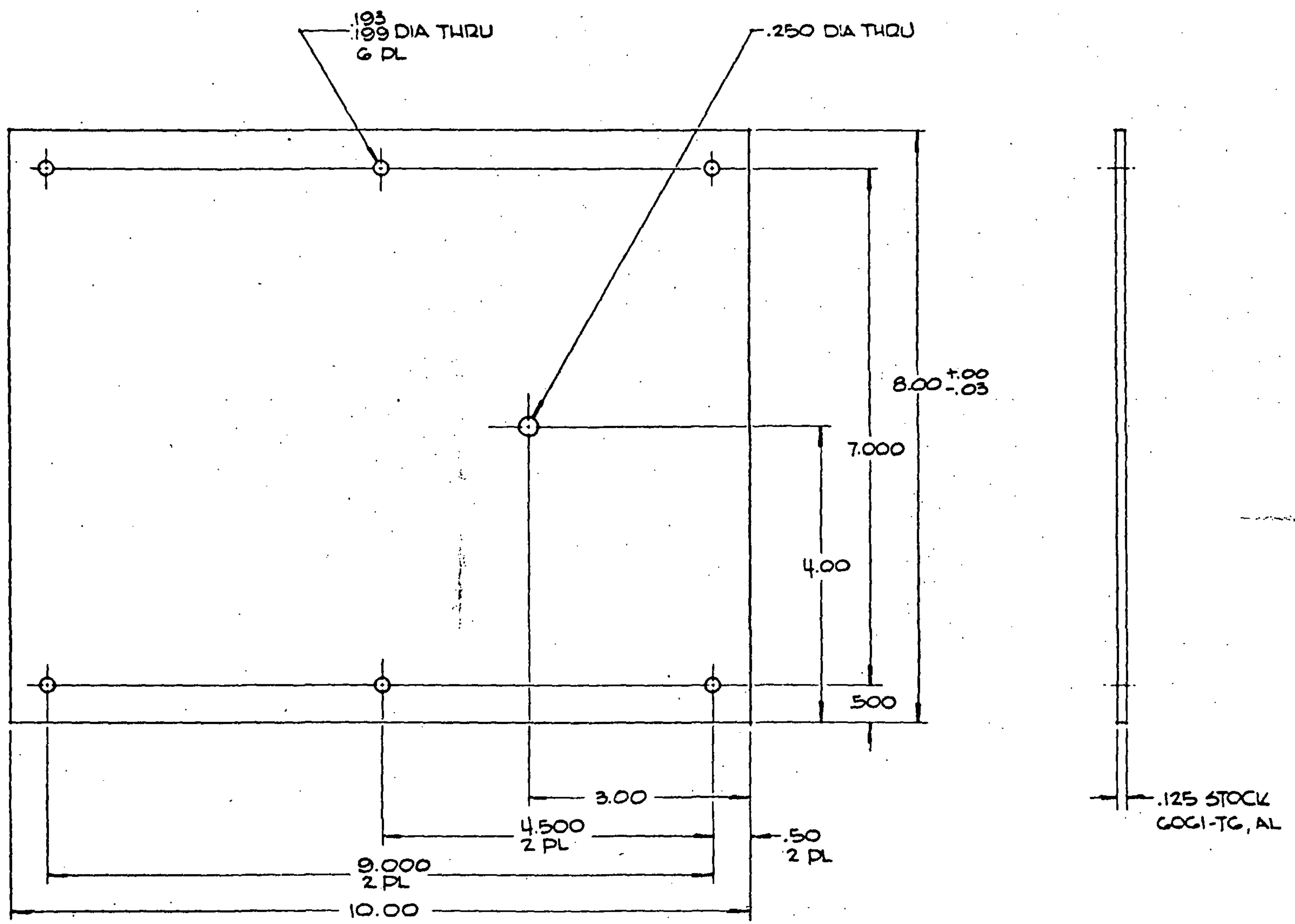


FIGURE 110

PLATE, ANT MOUNT 1 REQD

SIZE	CODE IDENT	DRAWING NO.	REV
C		1285299	
SCALE 1/1			SHEET

FORM LMSC 1513C-6

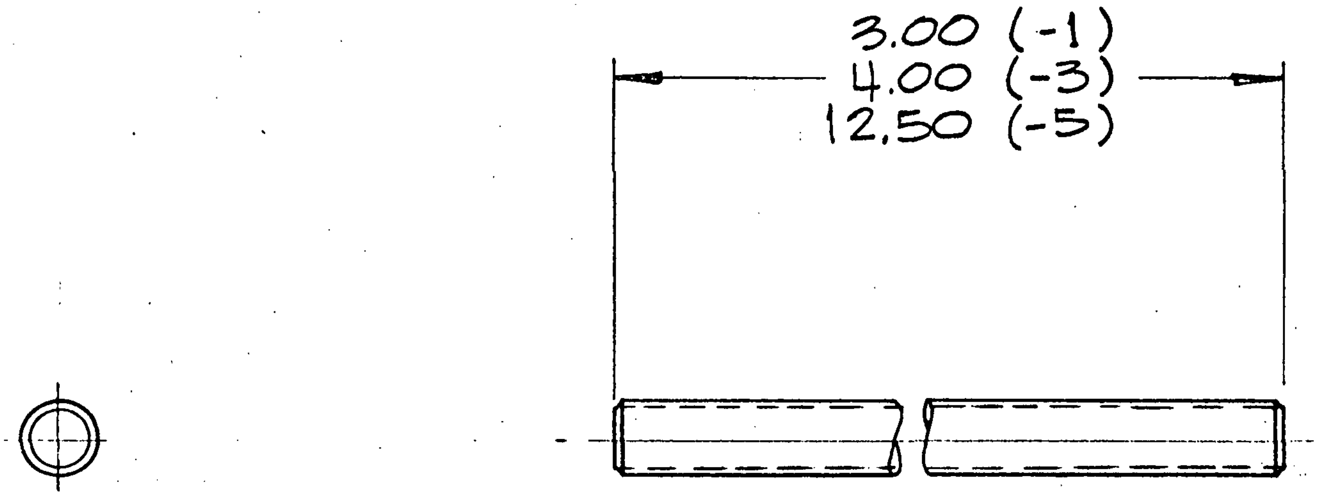
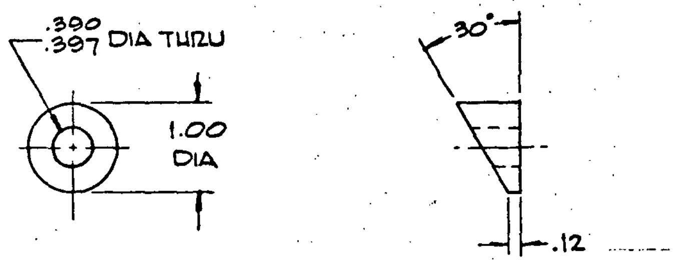


FIGURE 111

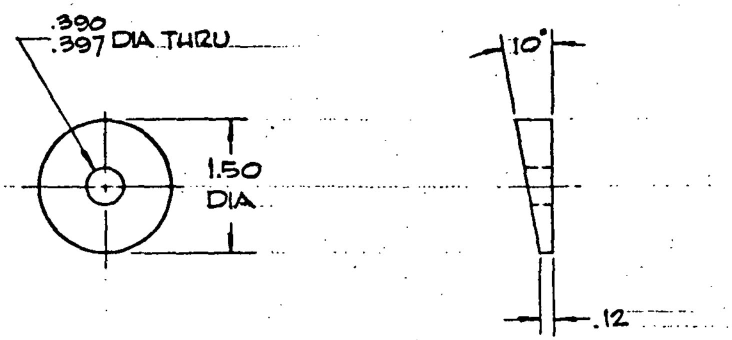
ROD, THREADED
3/8-16 STL ROD
REQD: 4(-1), 4(-3), 3(-5)

R 85314

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPD



-1 SPACER



-3 SPACER

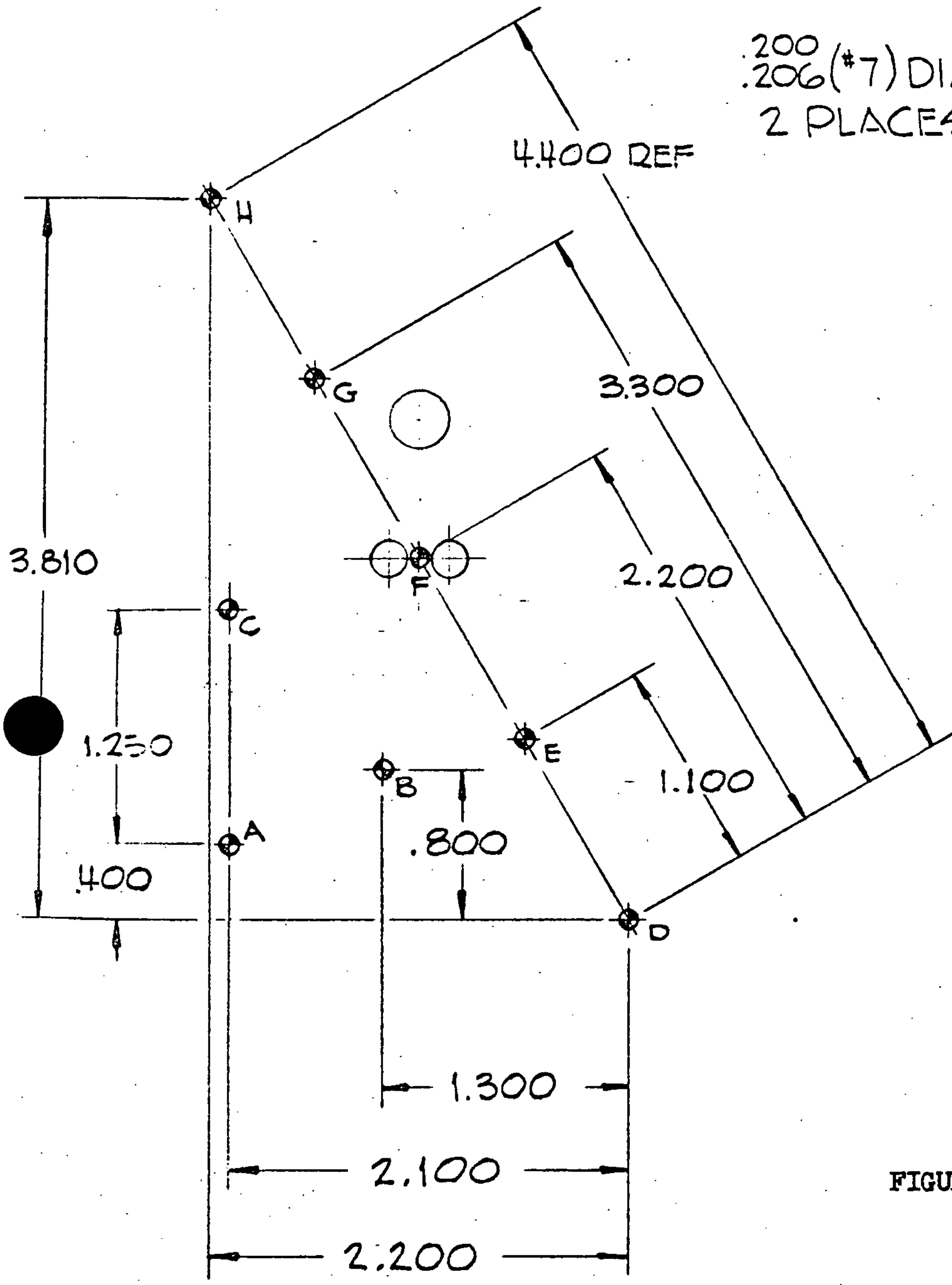
FIGURE 112

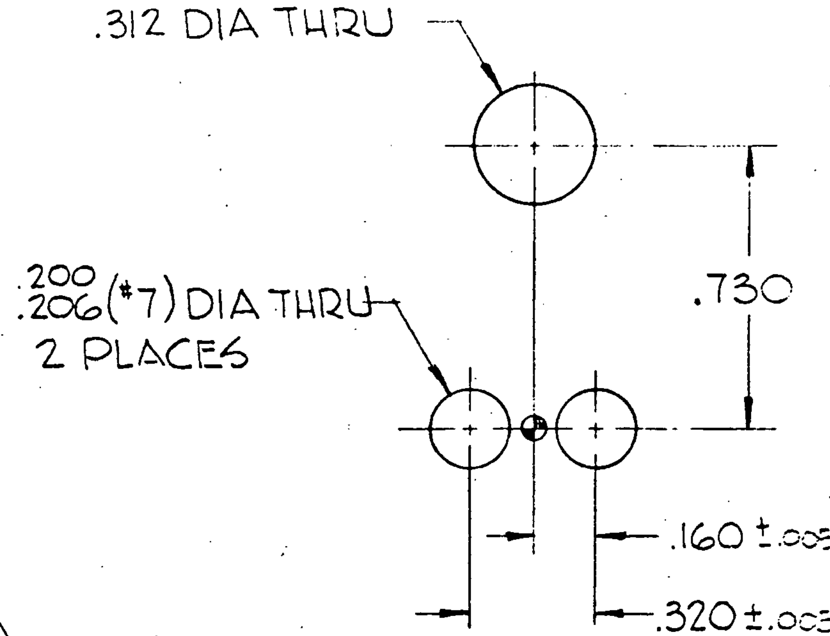
SPACER
ALUM ROD 4(-1), 8(-3) REQD

#PM

SIZE	CODE IDENT	DRAWING NO.	REV
C		1285311	
SCALE 1/1			SHEET

FORM LMSC 1513C-6





HOLE LAYOUT
8 PLACES
SCALE: 2X

FIGURE 113

FEED HORN LAYOUT

HTOM

R 85315

7.0 REFLECTOR TEST

7.1 General

The reflector tests with eight feeds fed through a corporate feed network were performed at the LMSC Large Antenna Test Facility located at Santa Cruz, California. The test reflector is a 12 ft. diameter, circular paraboloid with an F/D ratio of 0.525, and a surface accuracy of 0.040 inches. The tests were run at a center frequency of 10 GH_z (2/5 scale from a 30 ft. diameter at 4 GH_z).

Even with this feed design described earlier some manipulation of the feed positions was still necessary to fit all eight feeds in a desired spatial relationship. The centerline location in the focal plane of the reflector relative to the reflector axis for the eight feeds of both the on-and off-axis cluster is shown in Fig. 113. For the on-axis case, Feed "F" is on the reflector axis; for the off-axis case, Feed "F" is located 5.400 inches over and 0.500 inches up from the reflector axis. The resulting composite theoretical contour from either of these two feed clusters is shown in Fig. 114. Although the -3 dB contour is not the same as those described earlier in the analysis section, it was decided to use these feed positions in the measurement program as they represented a best compromise between the theoretical and practical.

The reflector as shown in Fig. 94 was mounted to the upper azimuth table of a Scientific/Atlanta Azimuth over Elevation over Azimuth 3-axis pedestal, inside a 75 foot diameter air-supported radome. The transmitting site is located across a 1500 foot deep canyon 5700 foot away from the receiving site. A four foot diameter reflector with an X-Band waveguide horn feed was used as the transmitting antenna. A standard Scientific Atlanta heterodyne measurement system was used to record the pattern. A block diagram of the measurement system is shown in Fig. 115. The reflector mounted on-site is shown in 2 different views in Figs. 116 and 117.

7.2 Single Horn Tests

Using the feed location diagram of Fig. 113, a single feed was placed in position "F" of the on-axis cluster. Feed "F" was aligned to lie on the reflector axis. The alignment was performed in the following manner. The manufacturer had left a 5 inch diameter hole in the center of the reflector. A circular wedge with a 3/8" diameter hole drilled through its center was press fit into this 5 inch hole. A 3/8" diameter aluminum tube 24 inches long was inserted thru this hole. This tube was blocked at both ends with plugs having a 1/16" diameter hole with cross hairs in the holes. When viewed thru this tube from behind the reflector, the field of view at the focal plane was approximately one-half the area of the feed horn dielectric tip for all motion of the tube. While one person looked thru the tube from behind the reflector, a second laterally adjusted the feed until it was aligned.

Secondary E - and H-plane patterns (Elevation and Azimuth planes respectively) were measured with this single feed mounted on-axis as its axial position was varied in steps. The theoretical focal plane for a 12 foot diameter paraboloid with an F/D ratio of 0.525 is 75.6 inches from the vertex. The single feed was axially moved so that the distance from the reflector vertex to the tip of the dielectric in the feed horn varied from 73.6 to 77.6 inches. The on-axis feed position that gave maximum gain and deepest first nulls was 75 $\pm \frac{1}{4}$ inch. This would place the equivalent phase center of this feed horn about one-half inch in from the tip of the dielectric.

All of the remaining pattern tests were taken with a vertex to tip distance of 75 inches.

Next, all of the 8 feed horns were mounted to the feed support plate in their proper relative orientation as determined from the analysis. The 8 feeds mounted in the focal plane of the 12 ft diameter reflector is shown in Fig. 118.

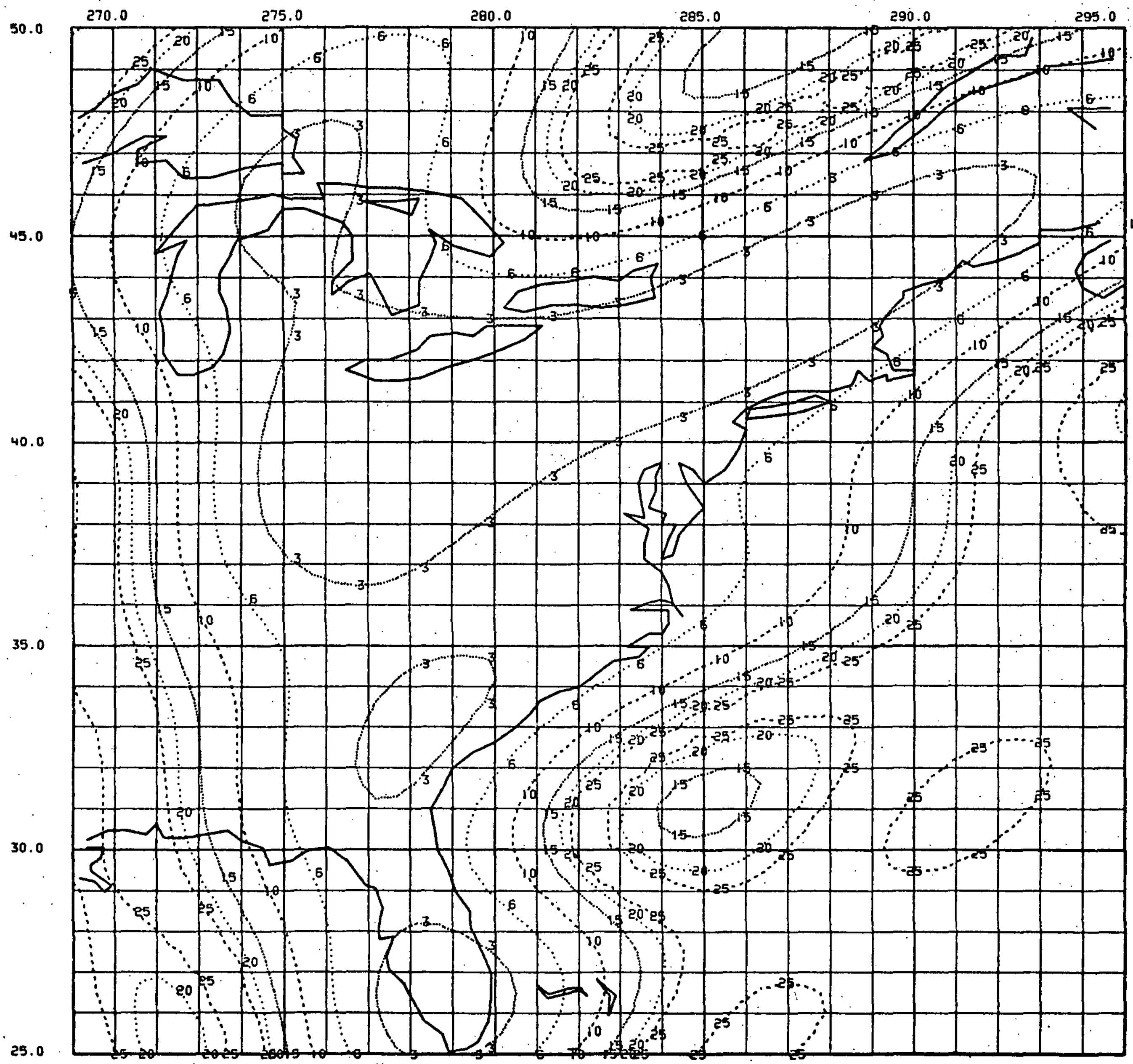
The 8-way power divider and interconnection cables were then mounted and connected to the feed horns. The complete system mounted in the reflector is shown in Fig. 119. The alignment was checked to ensure that feed "F" was still on-axis.

Secondary patterns were measured of each feed in turn with the complete system in place. The pattern for each horn was measured by disconnecting the interconnecting cable from that horn and connecting the mixer directly to the horn. The input to the 8-way power divider was terminated in 50 ohms and all of the other interconnecting cables were left attached to the antennas and to the power divider. Patterns were taken of each of the eight beams for both the on-axis and off-axis clusters. The on-axis patterns are shown in Figs. 120 thru 127 and the off-axis patterns in Figs. 128 thru 135. As the patterns were being taken, the angular bore sights of the beams were measured relative to the bore sight of feed "F". These results will be discussed in the next section.

7.3 Composite Patterns

The ultimate goal of the measurement program was to measure amplitude contours of the composite beam for the two clusters of 8 beams and to transform these contours onto the applicable earth areas. As discussed in previous sections, the eight feeds were connected through an eight way power divider and interconnecting cables. The mixer was connected to the input port of the power divider and azimuth plane patterns were recorded for various elevation positions. Only two of the three axes of the 3-axis pedestal were used so the patterns were measured on an azimuth over elevation system. The measured azimuth patterns for constant elevation angles are shown in Figs. 136 thru 154 for the on-axis cluster and in Figs. 155 thru 178 for the off-axis cluster.

The antenna system was considered to be located on a synchronous satellite with its mechanical axis pointed to some point on the visible earth, then, through a geometrical transformation, lines of constant azimuth and elevation



XMIN	XMAX	YMIN	YMAX
270.0000	295.0000	25.0000	50.0000
XBIGD	SLAMB	SDEL	SIGMA
360.0000	2.9507	.0000	.0000
XPHI	AMU	BONS	BOEW
-1.9548	.0000	.0000	.0000
ALTS	A3		
19323.0000	.0000		

CONTOUR VALUES

-3.0000
-6.0000
-10.0000
-15.0000
-20.0000
-25.0000

BLONG	BLAT
-69.5000	44.9000
-78.6000	41.6000
-76.2000	36.8000
-84.6000	46.5000
-84.3000	40.4000
-83.5000	35.0000
-82.4000	30.1000
-81.0000	25.6000

FIGURE 114

THEORETICAL CONTOURS

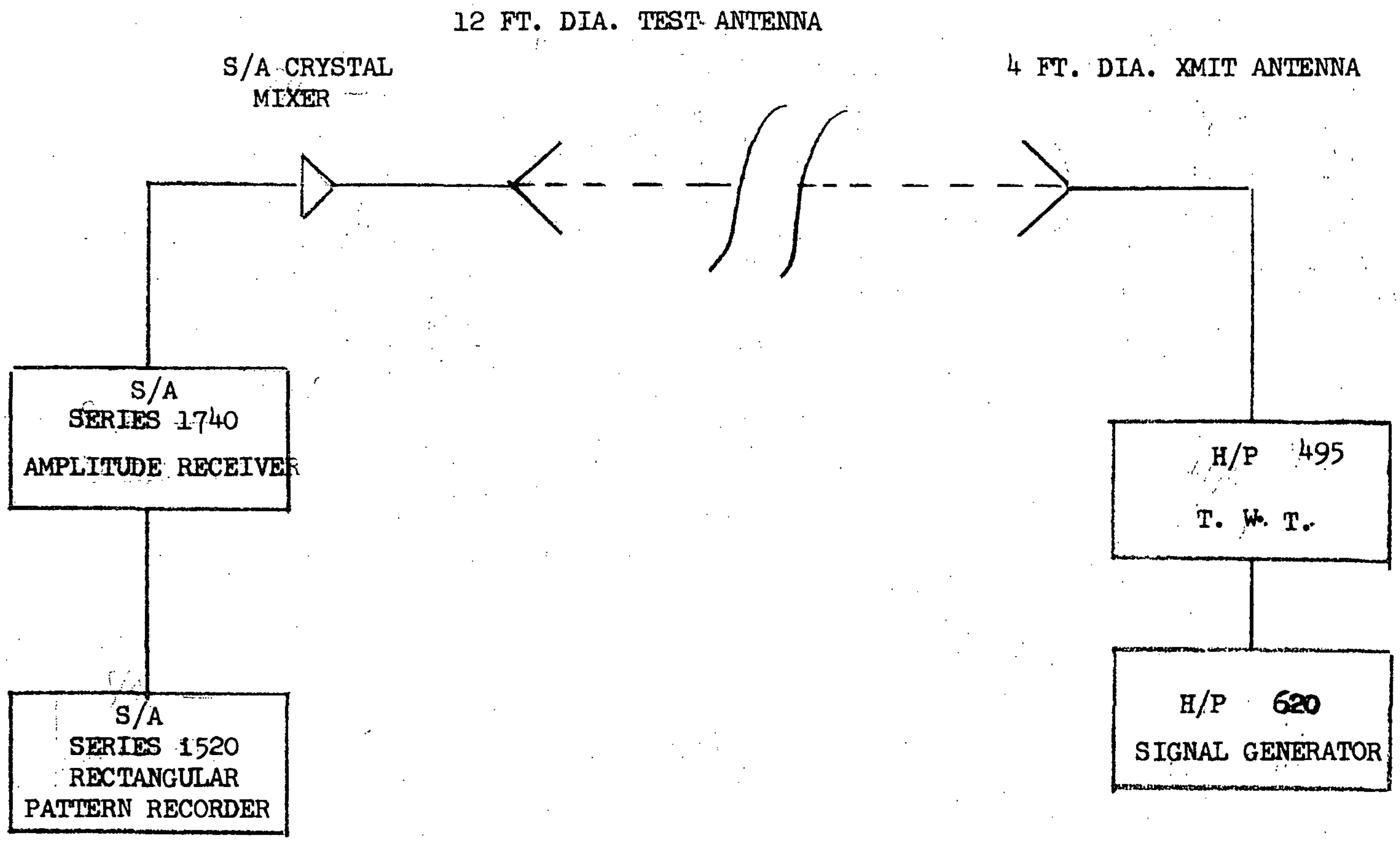


FIG. 115 MEASUREMENT SYSTEM BLOCK DIAGRAM

Fig. 116 Reflector with feeds on site at Santa Cruz Test Facility (View I)

Fig. 117 Reflector with feeds on site at Santa Cruz Test Facility (View II)

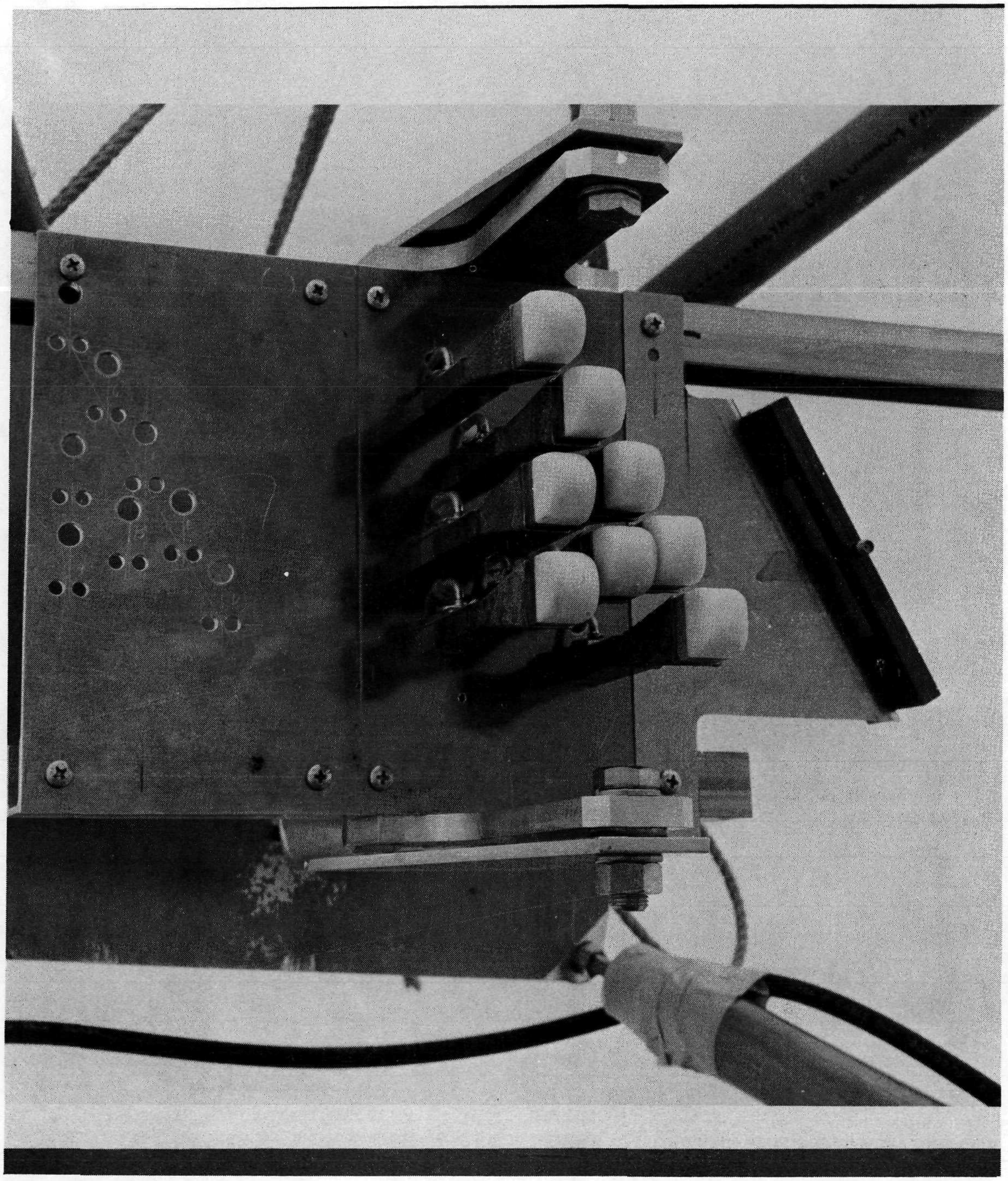


Fig. 118 Eight feeds mounted in the focal plane of a parabolic reflector-on-axis cluster

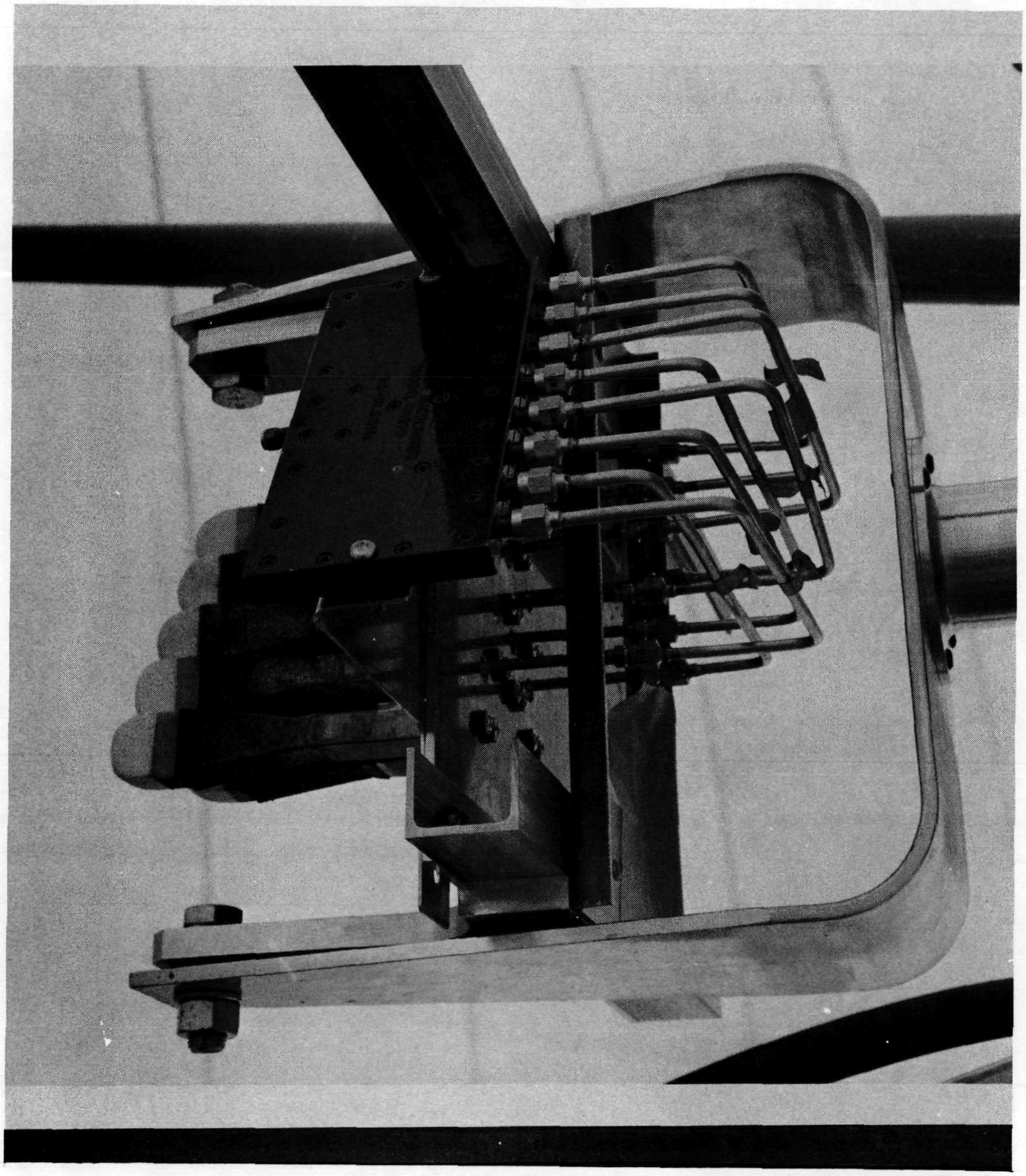
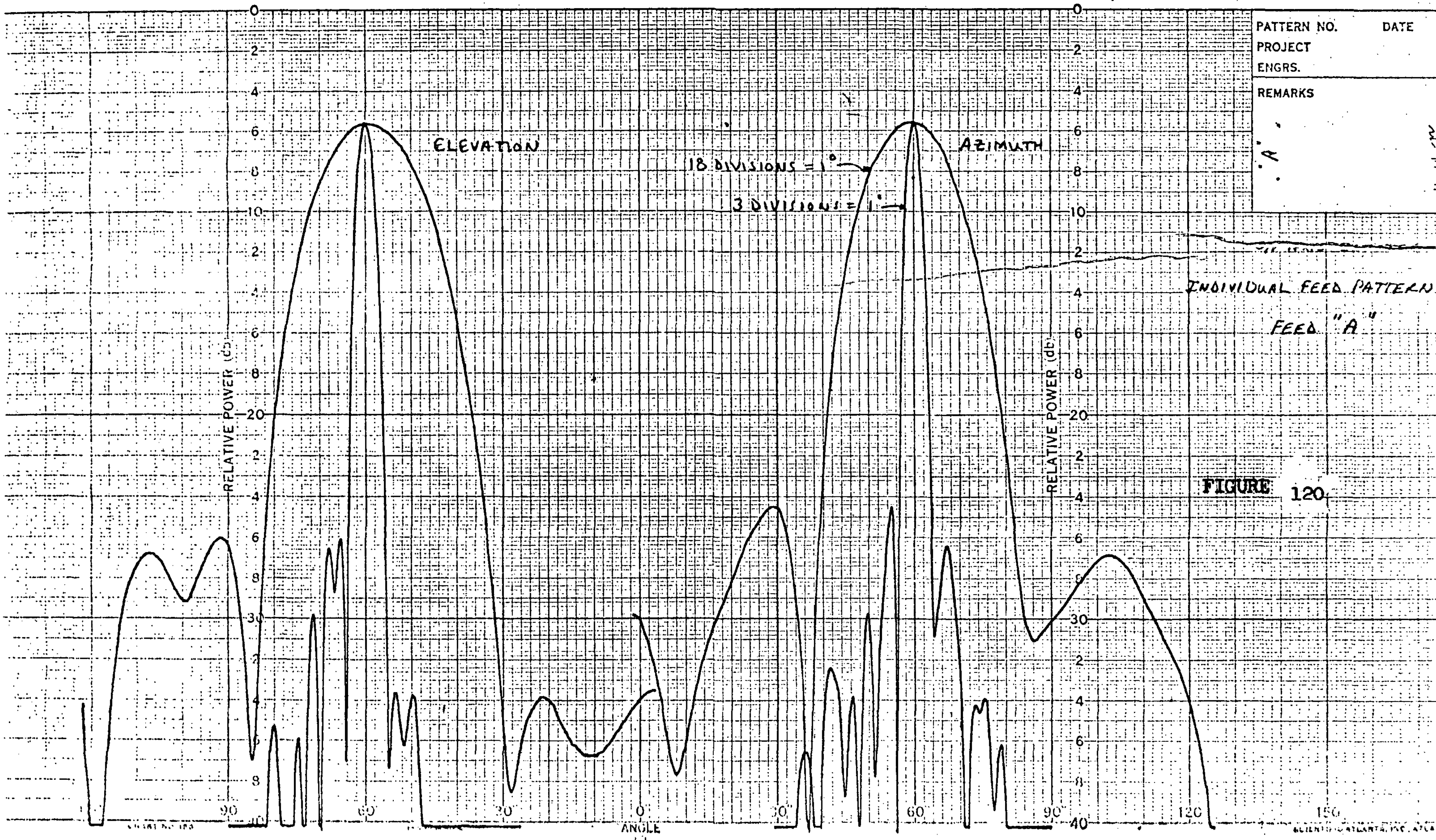


Fig. 119 Eight feeds with combining network for on-axis cluster



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
INDIVIDUAL FEED PATTERN
FEED "A"
RELATIVE POWER (db)
ANGLE

FIGURE 120

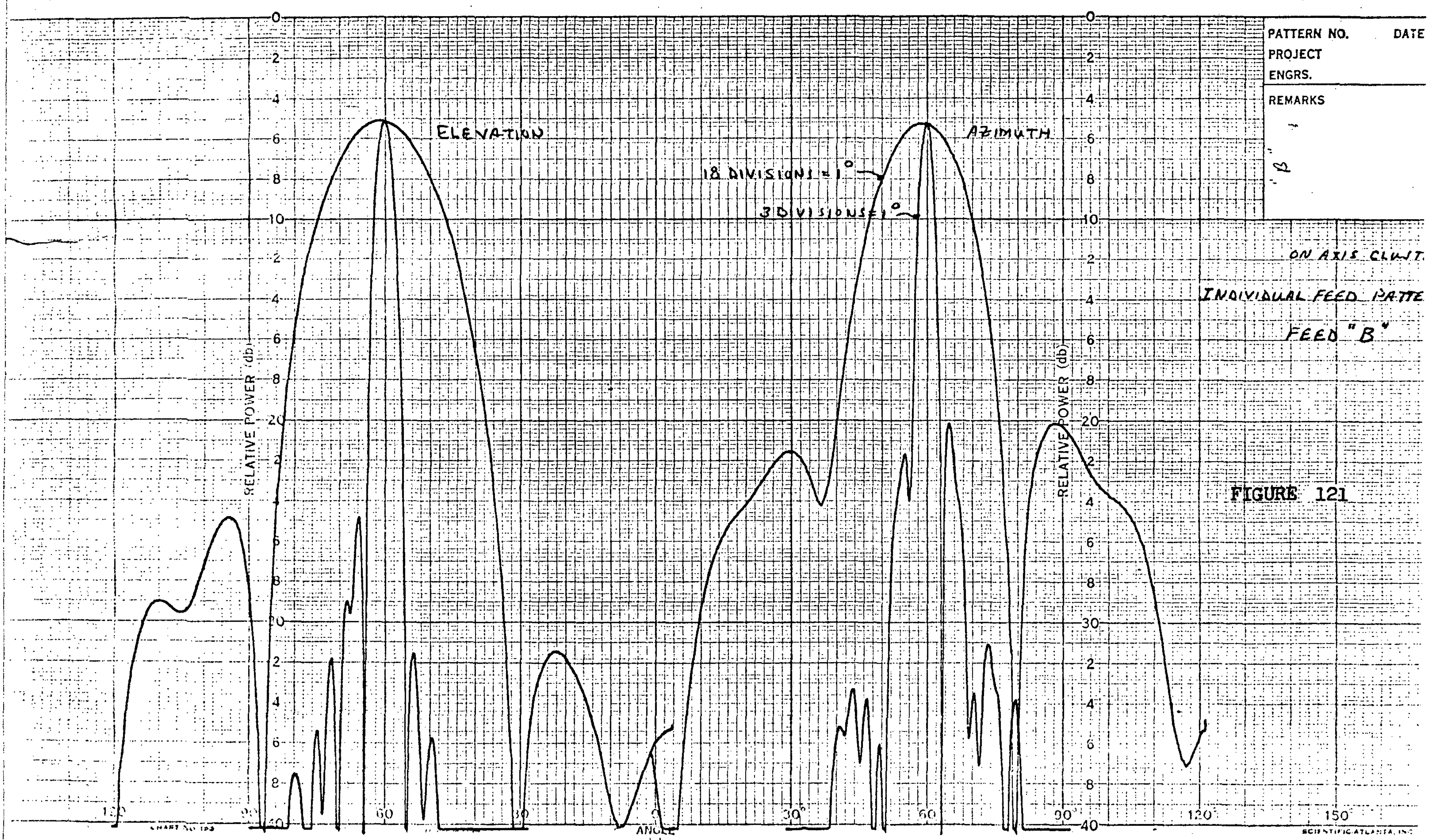
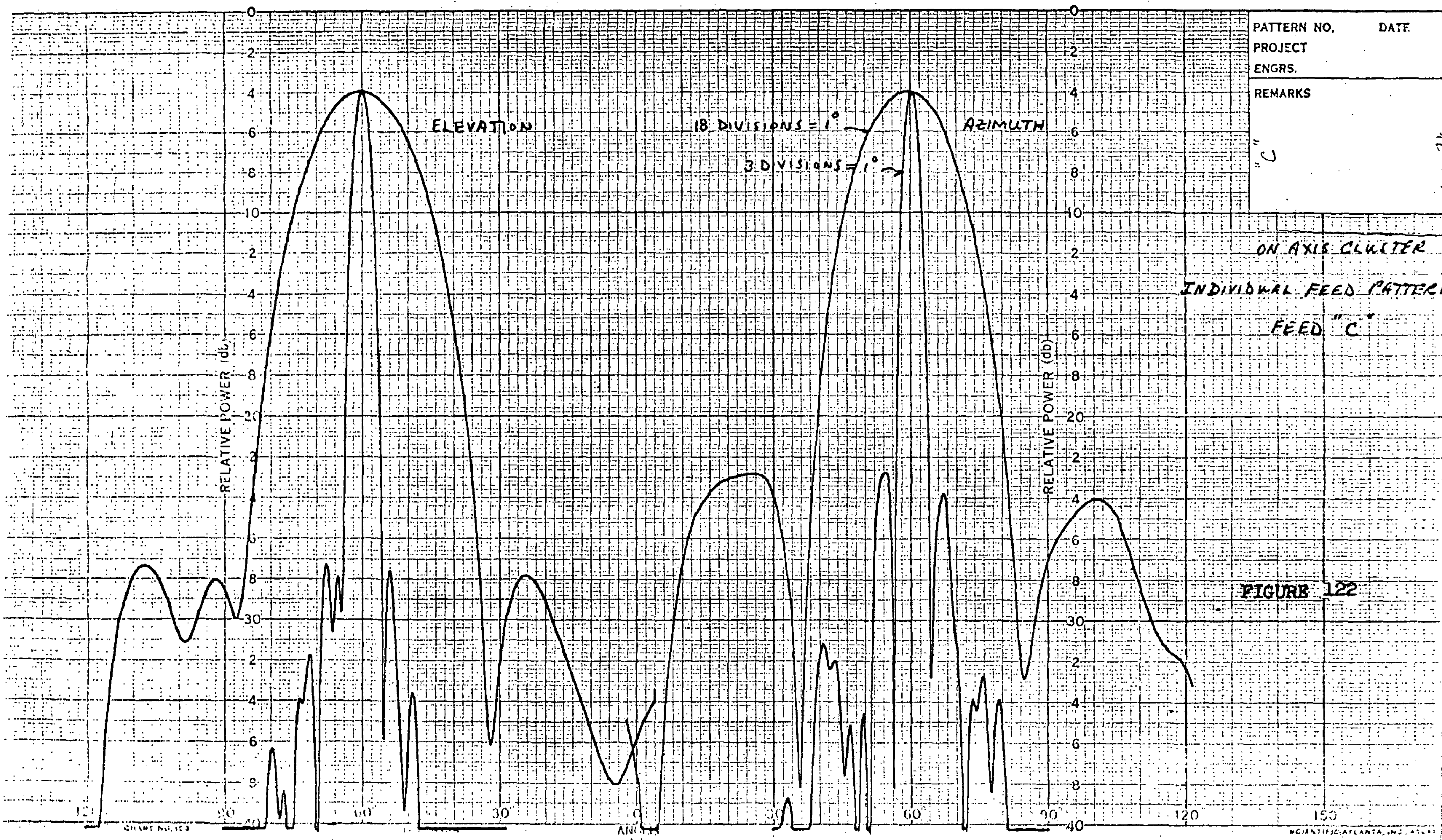

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
"B"
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
30 DIVISIONS = 1°
ON AXIS CLUST.
INDIVIDUAL FEED PATTE
FEED "B"
RELATIVE POWER (db)
ANGLE
SCIENTIFIC-ATLANTA, INC.

FIGURE 121



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
"C"
ELEVATION
18 DIVISIONS = 1°
3 DIVISIONS = 1°
AZIMUTH
RELATIVE POWER (db)
ON AXIS CLUSTER
INDIVIDUAL FEED PATTERN
FEED "C"

FIGURE 122

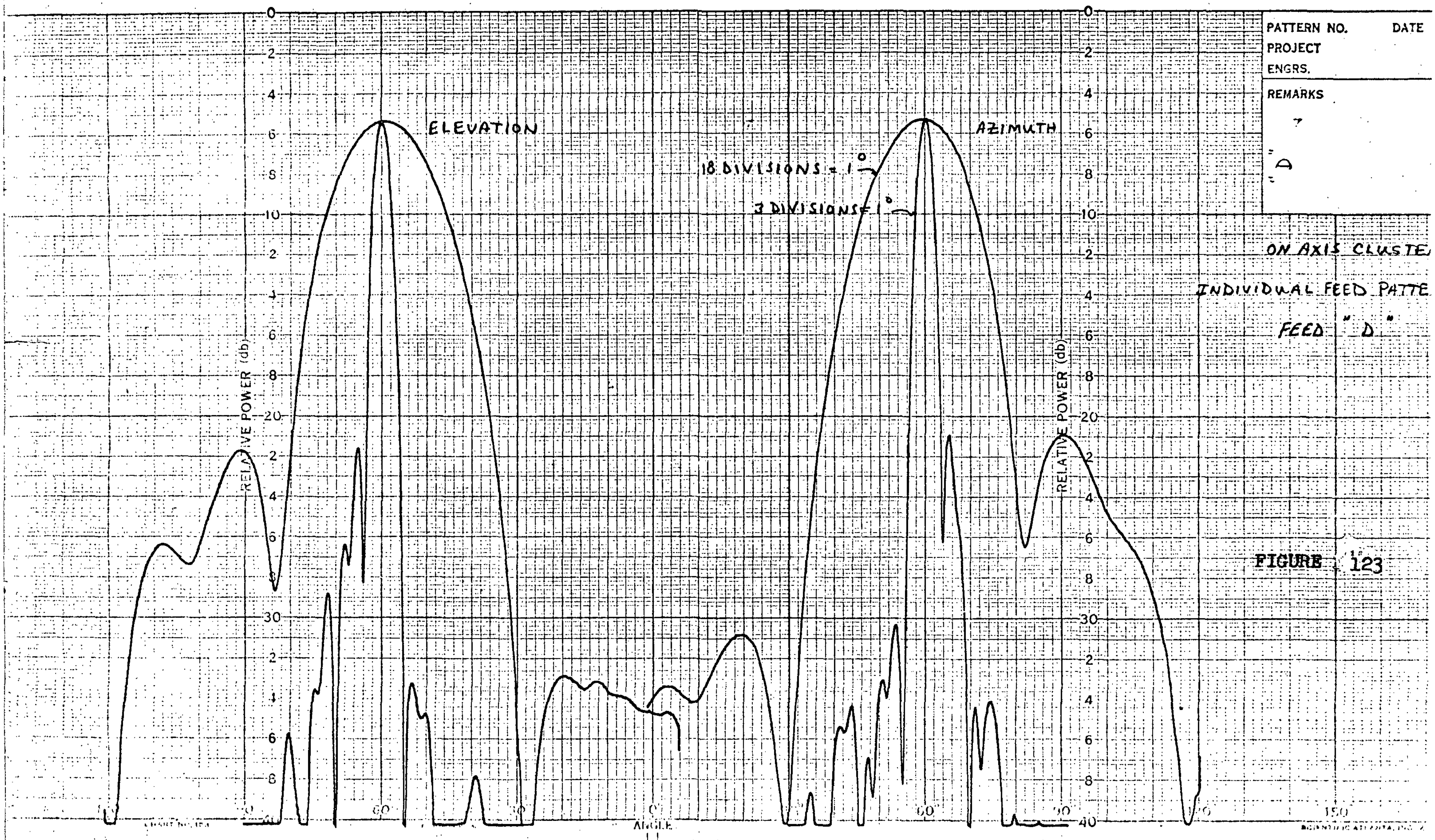
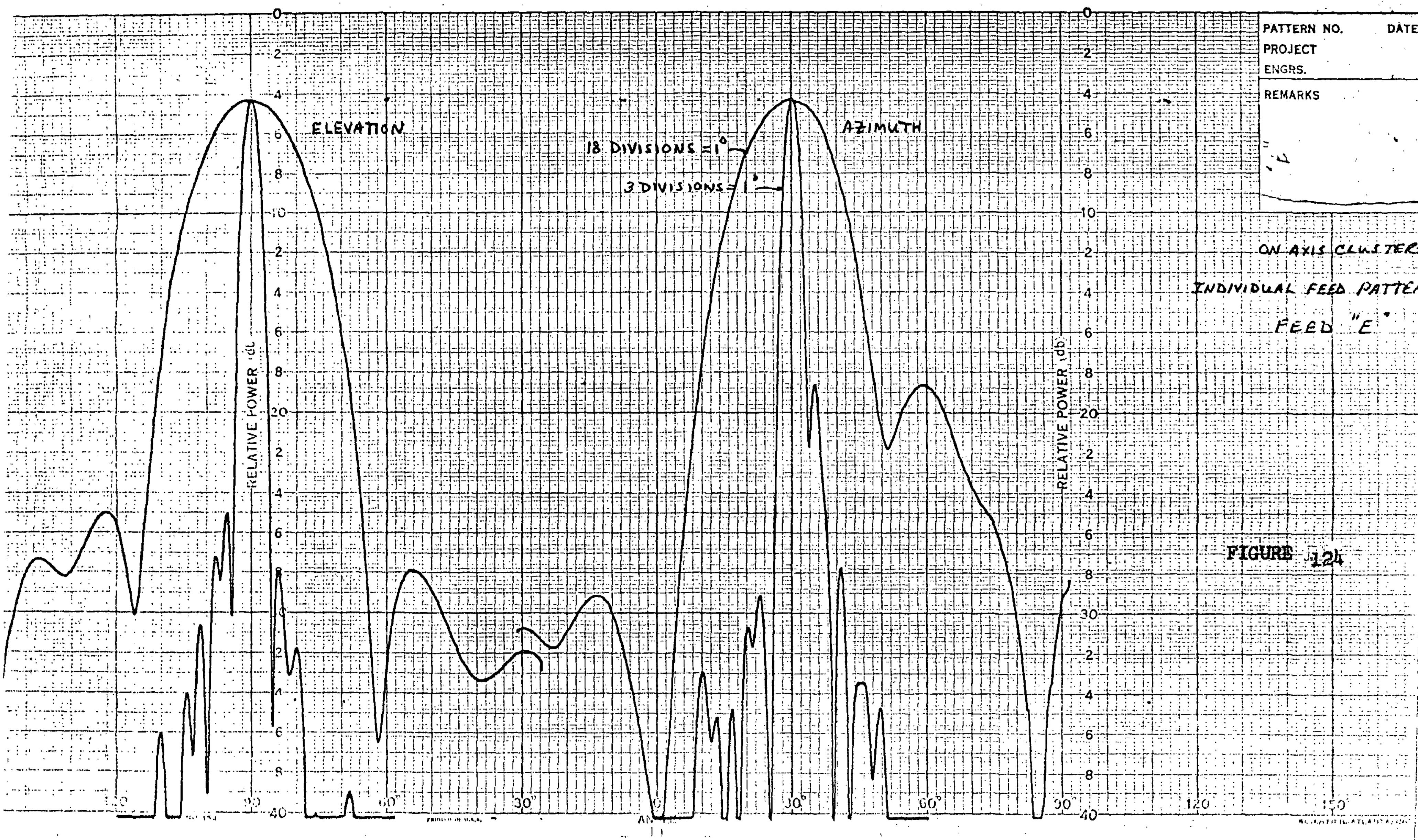
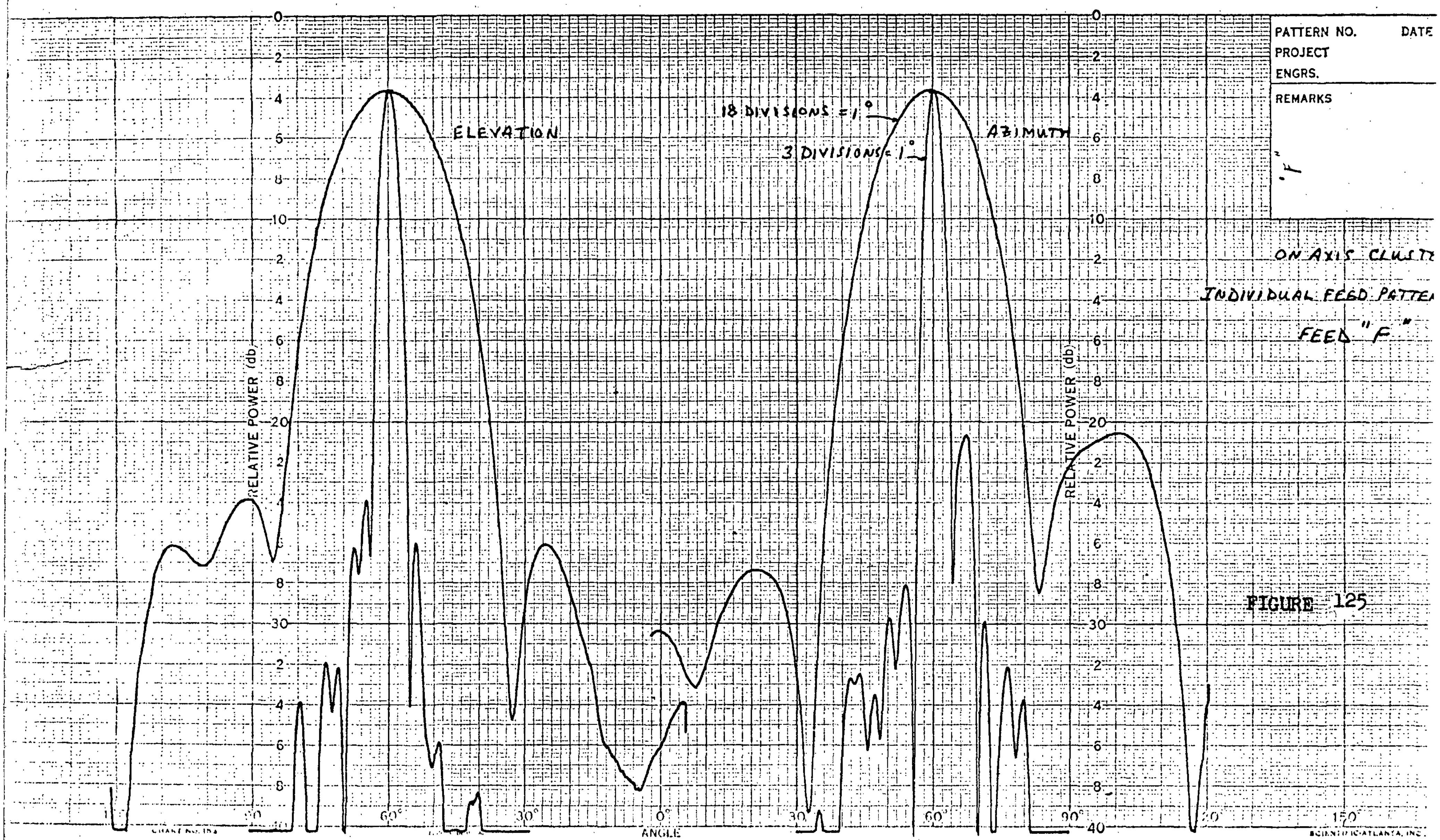

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
RELATIVE POWER (db)
RELATIVE POWER (db)
ANGLE
ON AXIS CLUSTE
INDIVIDUAL FEED PATTE
FEED "D"

FIGURE 123



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
RELATIVE POWER (db)
RELATIVE POWER (db)
ON AXIS CLUSTER
INDIVIDUAL FEED PATTER
FEED "E"

FIGURE 124



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
ON AXIS CLUST
INDIVIDUAL FEED PATTE
FEED "F"

FIGURE 125

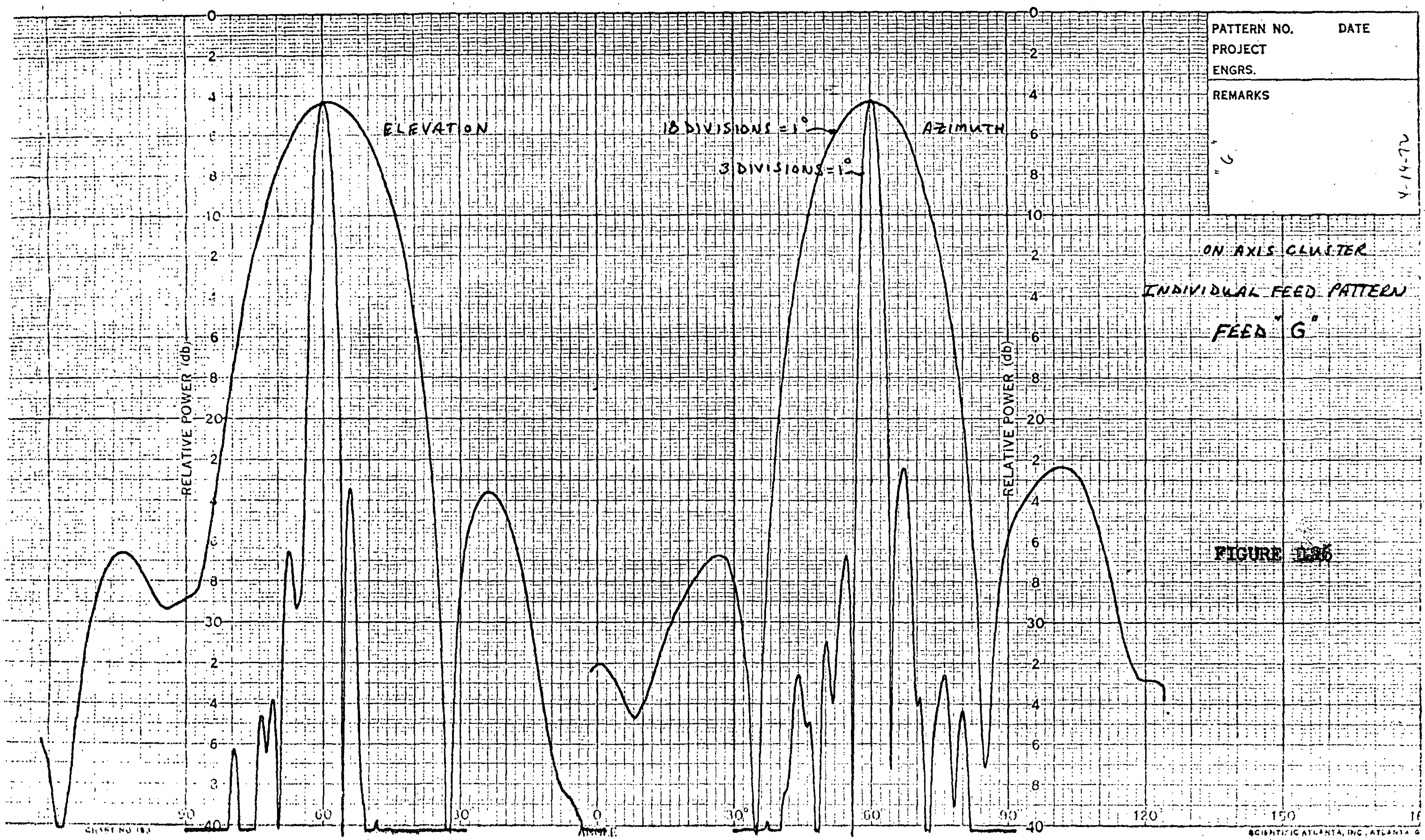

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
"G"
4-14-72
ELEVATION
18 DIVISIONS = 1°
3 DIVISIONS = 1°
AZIMUTH
ON AXIS CLUSTER
INDIVIDUAL FEED PATTERN
FEED "G"
RELATIVE POWER (db)
0
2
4
6
8
10
20
30
40
90
60
30°
0
30°
60°
90°
120°
150
ANGLE

FIGURE D.36

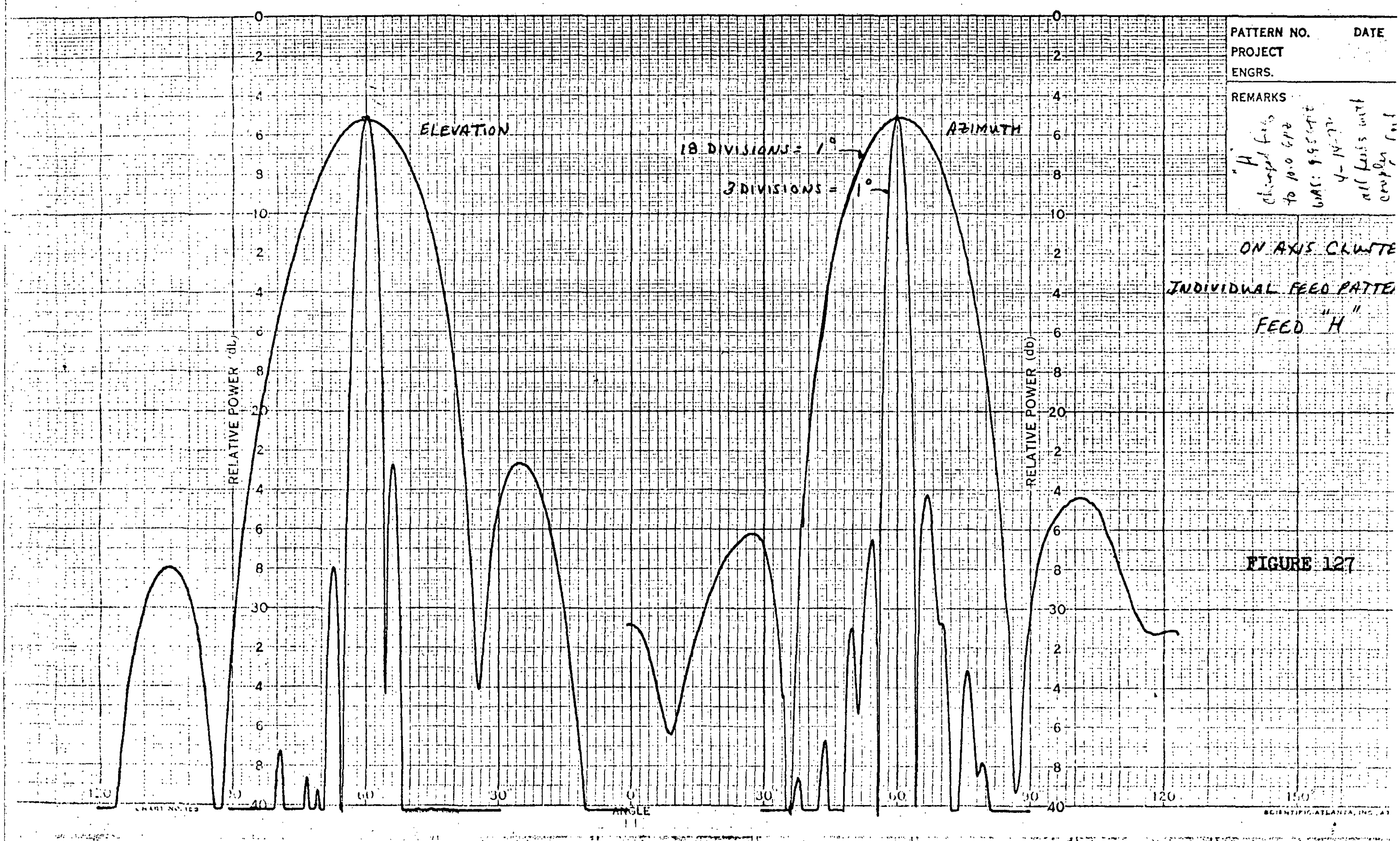
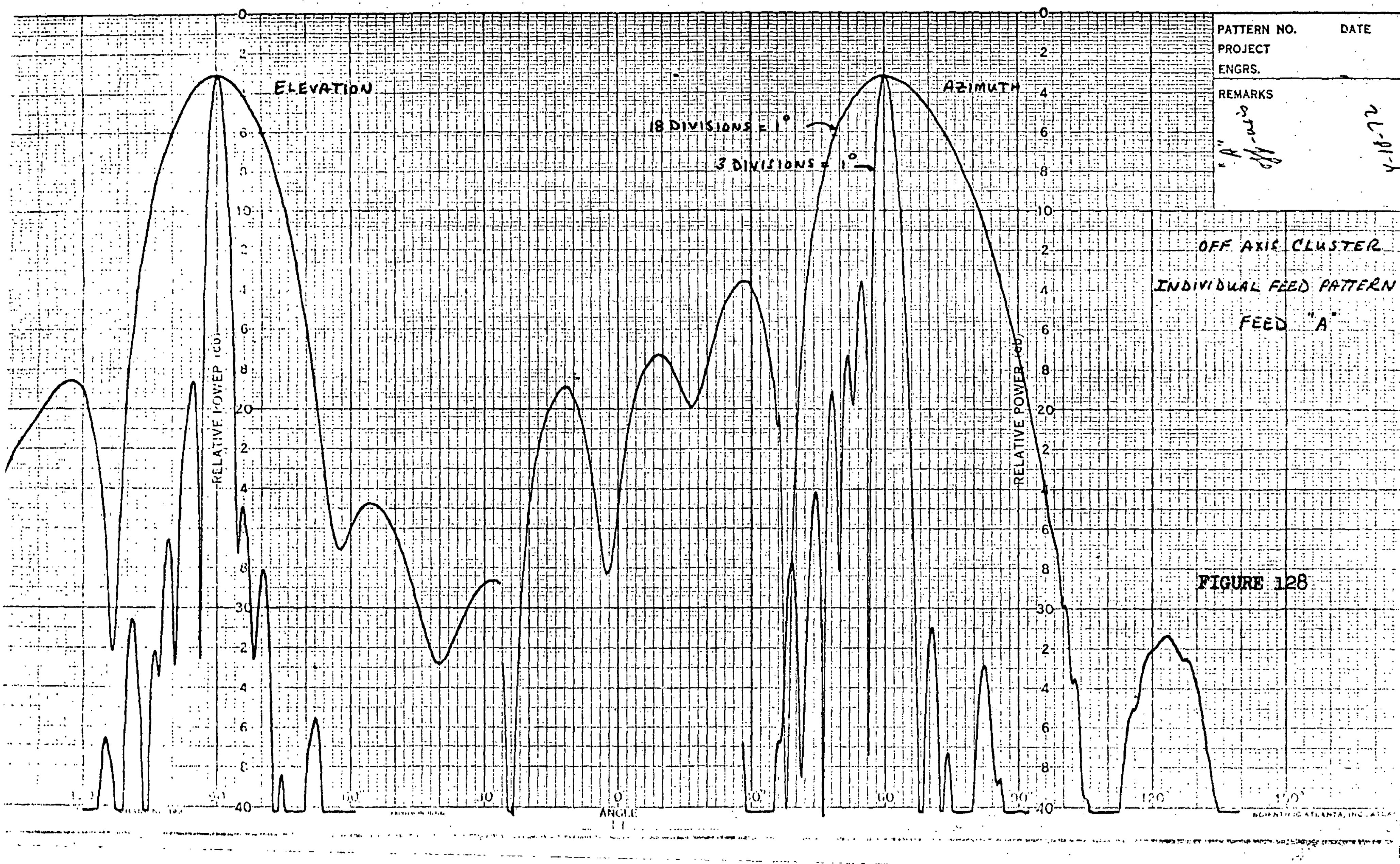
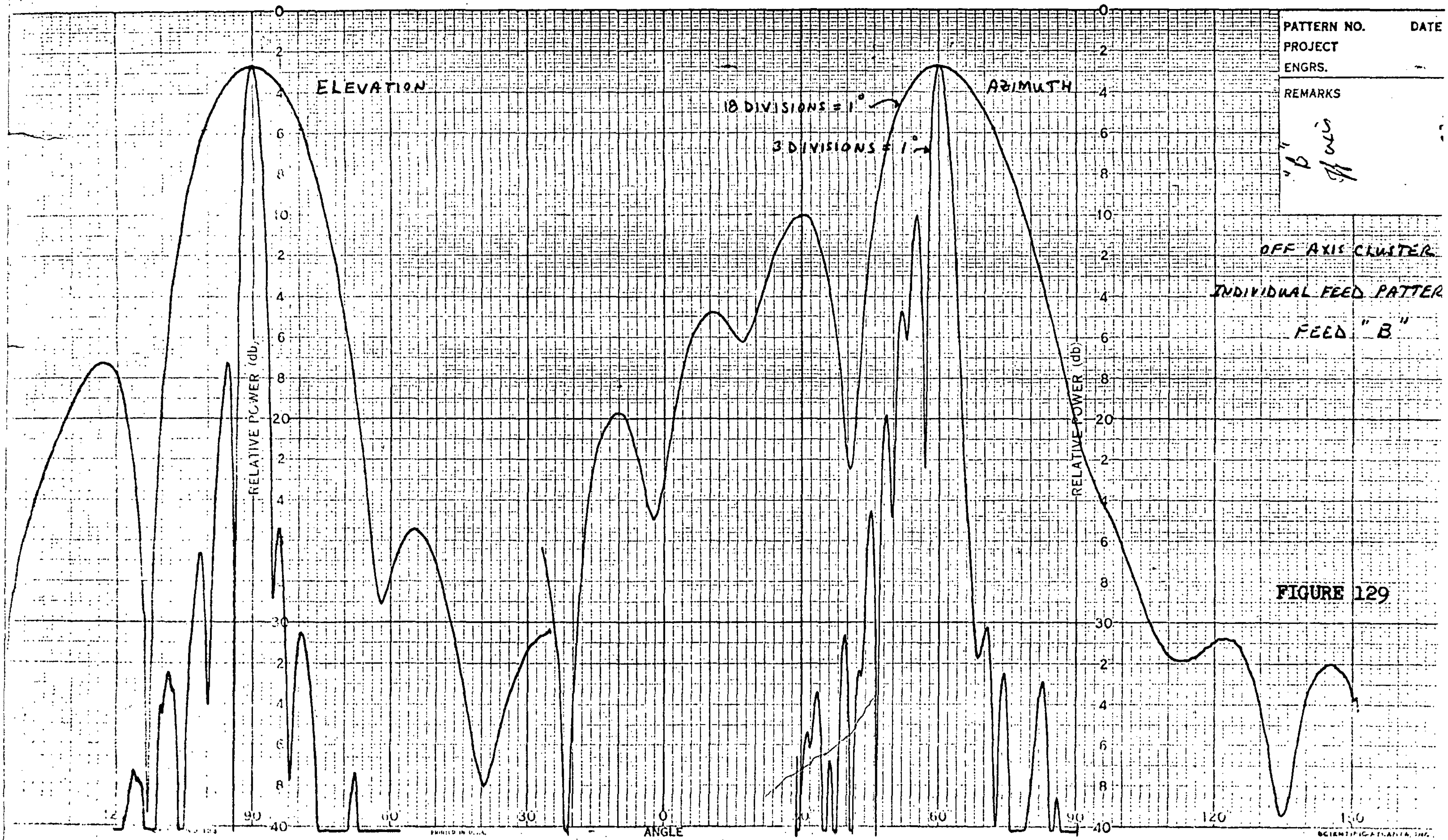

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
ON AXIS CLUSTE
INDIVIDUAL FEED PATTE
FEED "H"

FIGURE 127



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
"A" off-axis
7-18-72
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
OFF AXIS CLUSTER
INDIVIDUAL FEED PATTERN
FEED "A"
RELATIVE POWER (dB)
ANGLE

FIGURE 128



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
OFF AXIS CLUSTER
INDIVIDUAL FEED PATTER
FEED "B"
RELATIVE POWER (db)
ANGLE

FIGURE 129

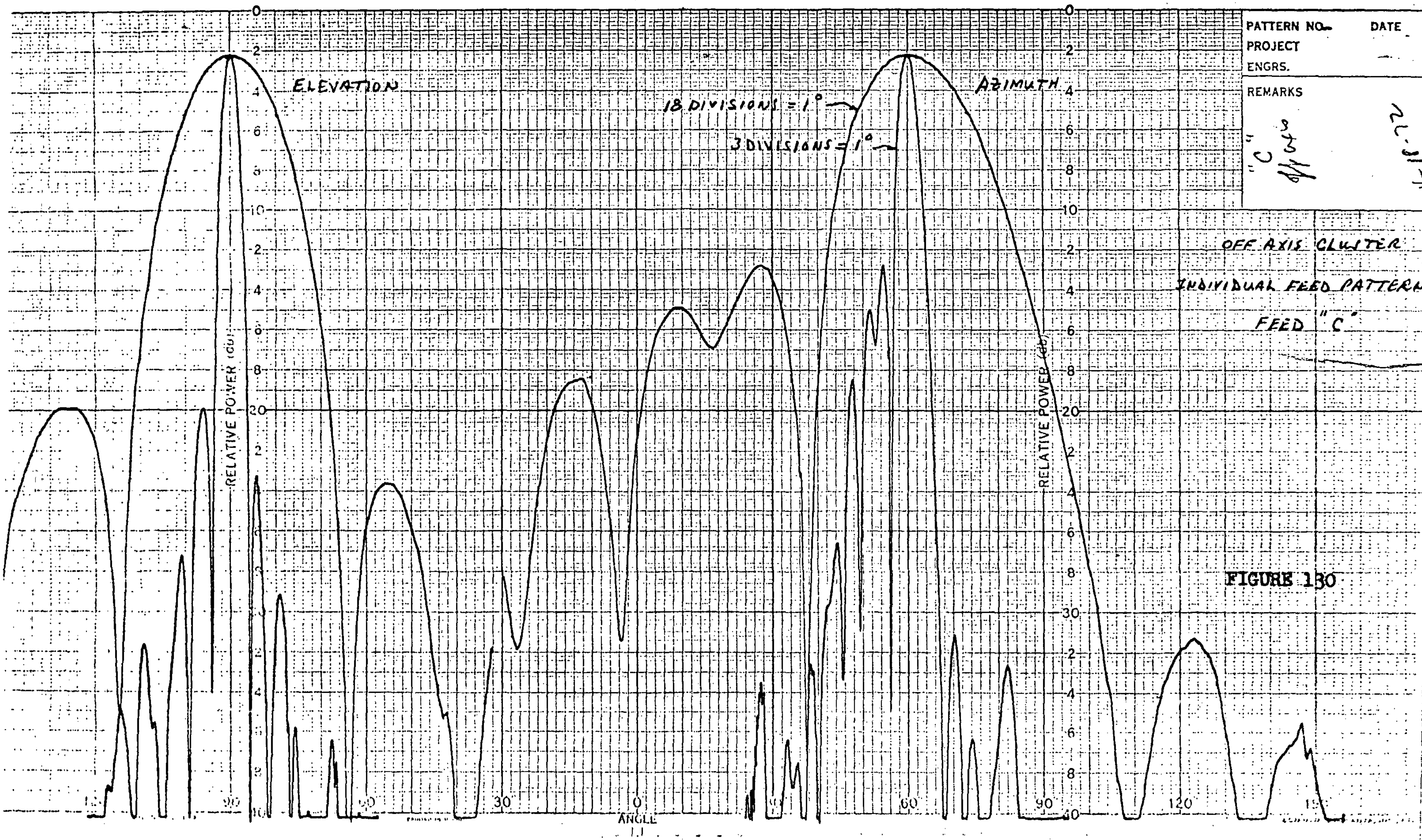

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
OFF AXIS CLUSTER
INDIVIDUAL FEED PATTERN
FEED "C"
RELATIVE POWER (db)
RELATIVE POWER (db)
ANGLE
0
2
4
6
8
10
20
30
40
60
90
120

FIGURE 130

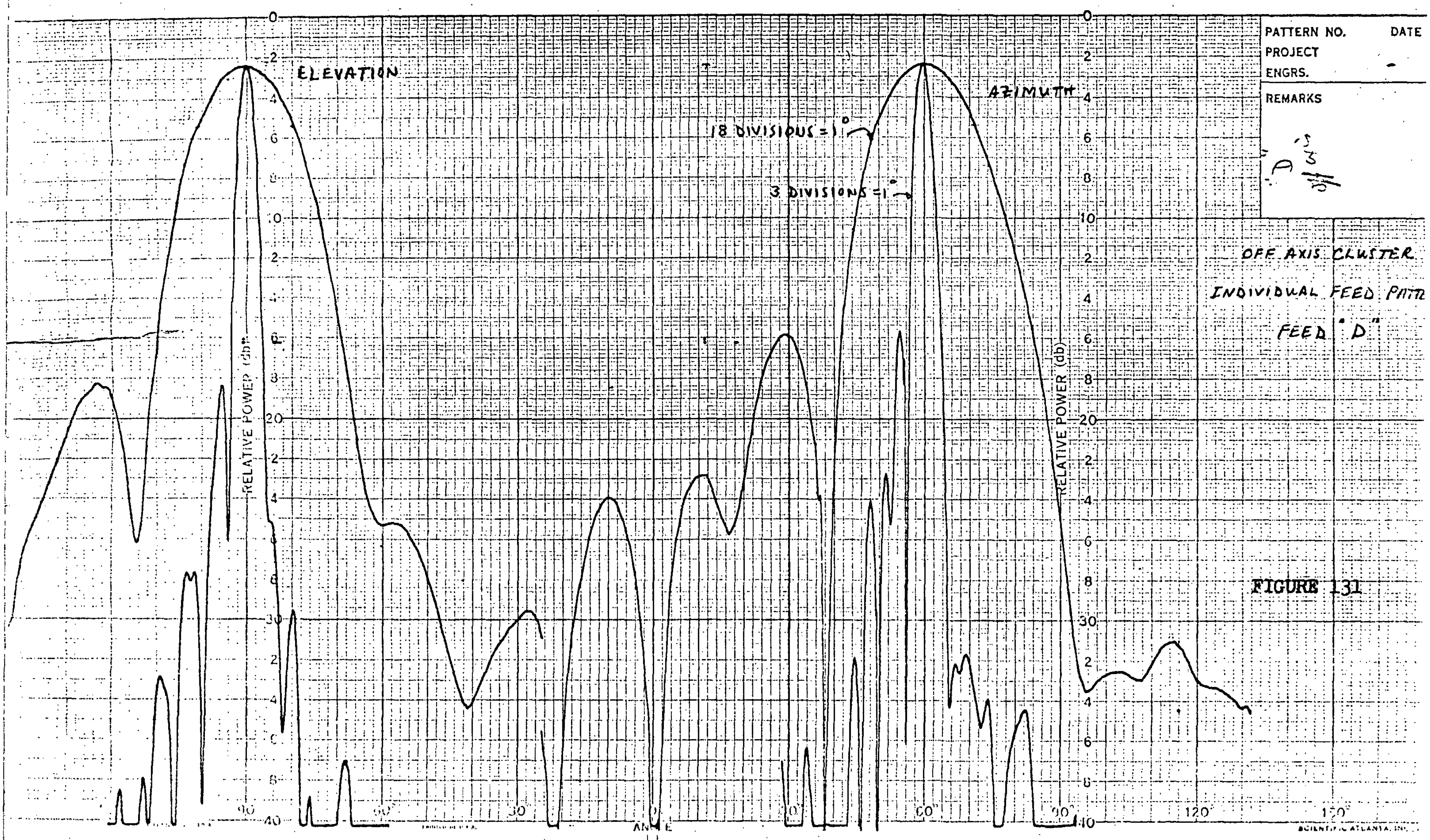

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
RELATIVE POWER (db)
RELATIVE POWER (db)
OFF AXIS CLUSTER
INDIVIDUAL FEED PATTR
FEED "D"
SCIENTIFIC ATLANTA, INC.

FIGURE 131

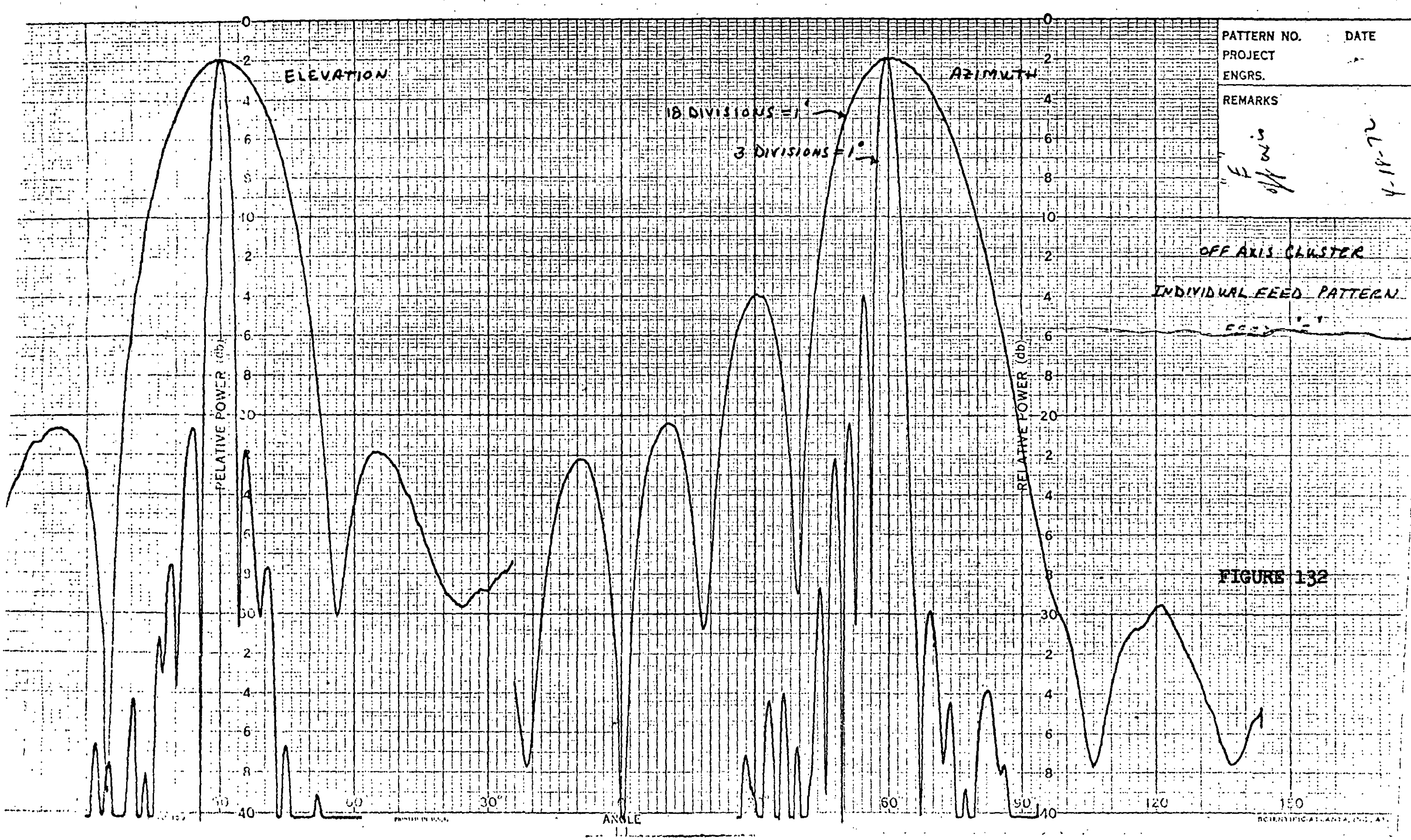
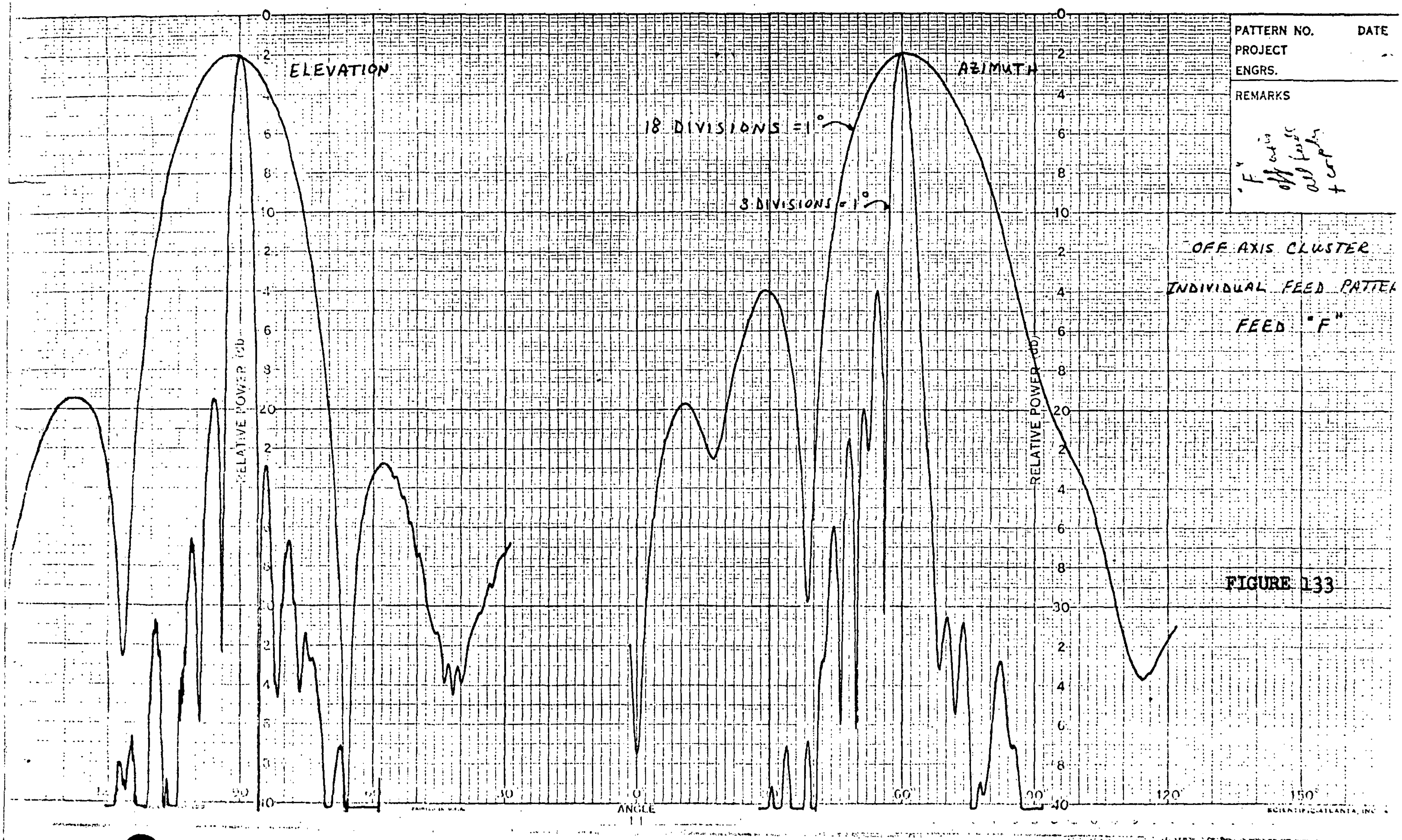

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
OFF AXIS CLUSTER
INDIVIDUAL FEED PATTERN
RELATIVE POWER (db)
ANGLE

FIGURE 132



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
RELATIVE POWER (DB)
ANGLE
OFF AXIS CLUSTER
INDIVIDUAL FEED PATTE
FEED "F"

FIGURE 133

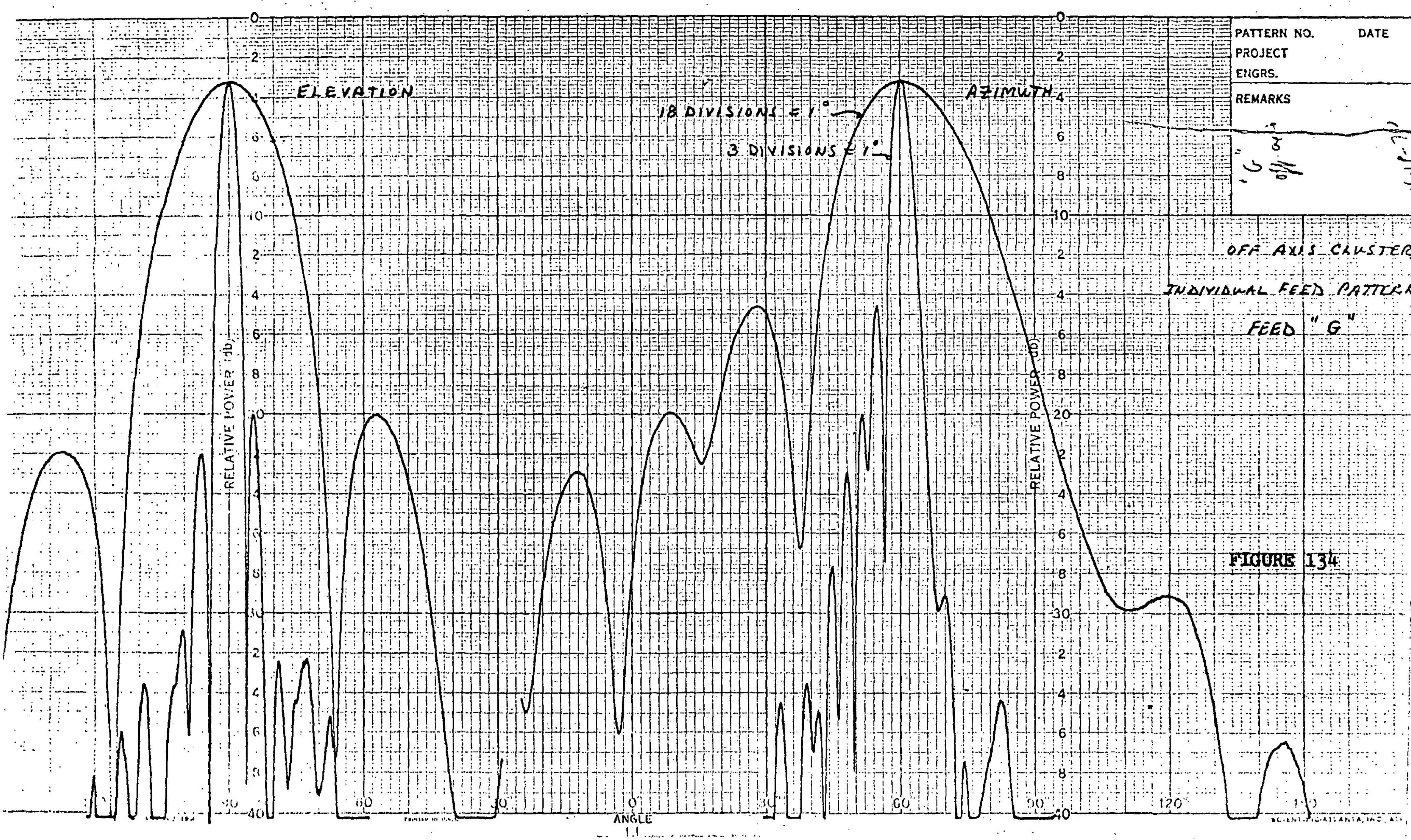
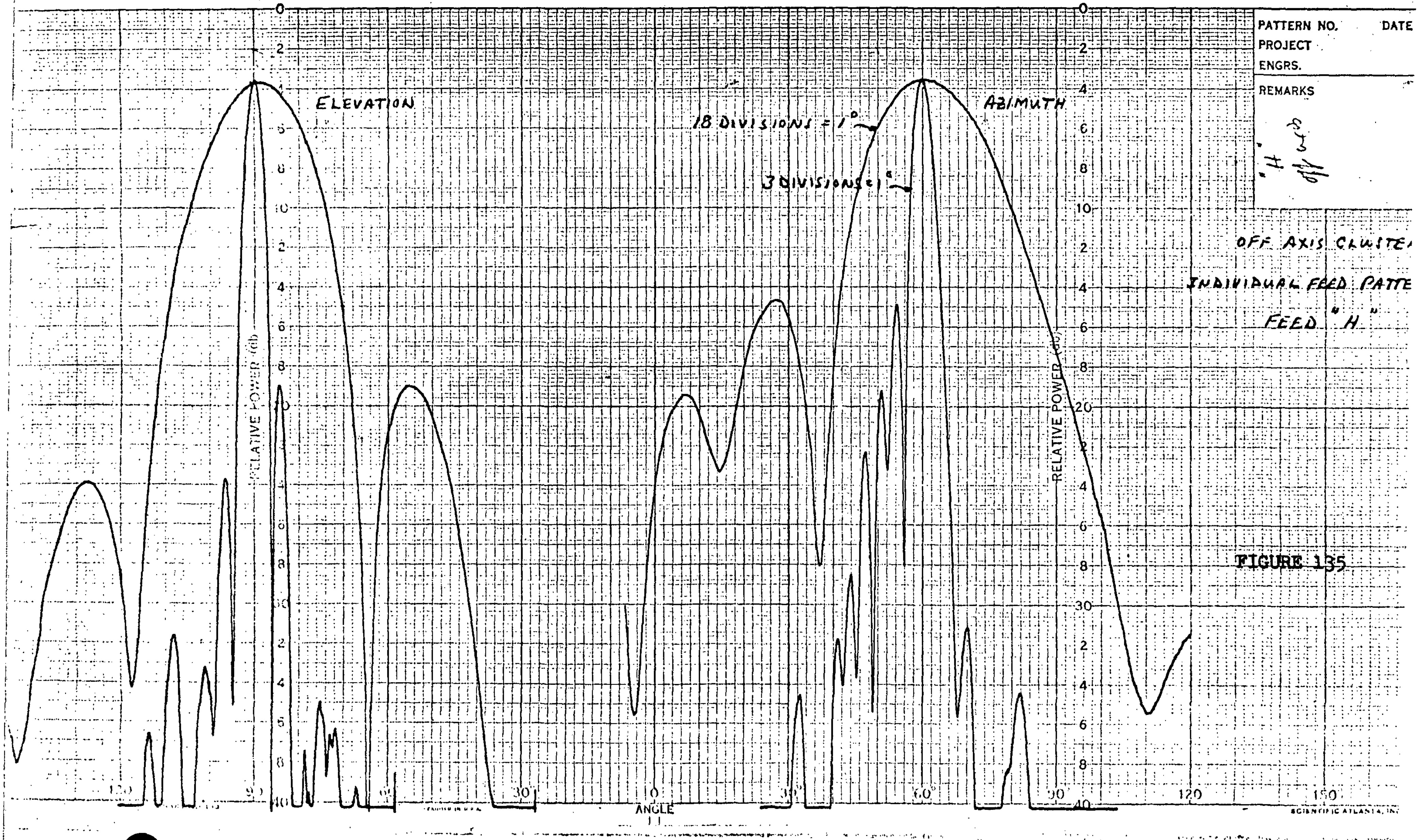

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
OFF AXIS CLUSTER
INDIVIDUAL FEED PATTERN
FEED "G"
RELATIVE POWER (db)
ANGLE

FIGURE 134



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ELEVATION
AZIMUTH
18 DIVISIONS = 1°
3 DIVISIONS = 1°
OFF AXIS CLUSTE
INDIVIDUAL FEED PATTE
FEED "H"
RELATIVE POWER (db)
ANGLE
SCIENTIFIC ATLANTA, INC.

FIGURE 135

can be overlayed onto the earth as a function of latitude and longitude. These overlays are functions of the satellite longitude, the reflector aim point (latitude and longitude), and the antenna azimuth and elevation angle limits.

In our measurements, for the on-axis cluster of feeds, the reflector axis was bore sighted to 35° N. Latitude, and 83.5° W. Longitude; for the off-axis cluster, the reflector was bore sighted to 37° N. Latitude and 112° W. Longitude. Overlays of lines of constant azimuth and elevation onto the applicable earth areas are shown for the on-axis case in Figs. 179 and 180 and for the off-axis case in Figs. 181 and 182. The satellite location for both cases is 112° W. Longitude.

To form the antenna contour, the sequence of steps is as follows:

(a) View all the patterns for the cluster of feeds measured. Find that pattern which has the maximum pattern response. Establish this level as the 0 dB reference for the rest of the patterns.

(b) Choose any one of the constant azimuth patterns (for example, the 0° elevation pattern).

(c) Find the angular azimuth position(s) on both sides of bore sight, where the relative signal level is down 3 dB from the peak level established in step (a).

(d) Mark this angular position on the azimuth and elevation overlay grid.

(e) Find the angular azimuth position(s), on both sides of bore sight where the relative signal level is down 6 dB from the reference level. Mark these positions on the grid overlay (usually, different colored pencils are used to distinguish between the different contour levels, e.g., red for 3 dB, blue for 6 dB, green for 10 dB, etc.).

(f) Find the angular position(s) for all other desired dB levels and plot them on the grid.

(g) Repeat sequence (a) thru (f) for each of the other elevation patterns.

(h) Connect up the marks of the same color. In areas of rapid change of pattern level, both up and down, over small angular increments, it is necessary to code the marks on the grid so that the proper ones are connected. The usual procedure is to add small horizontal lines to the vertical marks. If the horizontal line is toward bore sight, this indicates the pattern is decreasing in amplitude at that point; if the line is away from bore sight the pattern level is increasing at that point.

The contour plot is now complete.

The amplitude contours for the on-axis cluster are shown for the Eastern U.S. Time Zone in Fig. 183, and in overview form for the continental United States in Fig. 184. Looking first at the expanded time zone plot, the -3 dB contour follows the time zone outline with the exception that it "necks in" between 30° and 35° N. Latitude. The -6 dB contour follows the time zone outline with the exception of some broadening in the West-Central, and North-West portions.

As was pointed out in the analysis, there is no chance of reducing the spill-over in the North East Section, due to the falling off of the earth away from the satellite, nor in the North West Section due to the beam positions necessary to cover Northern Micigan. The spill-over above the North Central area is not as rapid as predicted but still is 25 dB down from the peak signal at 49° N. Latitude.

Looking at the overview, the signal levels in the Mountain Time Zone is most important. If a complete system with multiple reflectors were used to cover all U.S. Time Zones, alternate zones would be crossed polarized. Thus, the signals in the Eastern and Mountain Zones would be co-polarized. The pattern levels in the Mountain Time Zone from the Eastern Time Zone beam are between -20 dB and -30 dB from the pattern maximum.

These levels are strongly influenced by the feed support structure. It has been pointed out earlier that a superfluous amount of metal structure was used in these tests for axial and angular positioning of the feeds. In an end item system, these levels would be reduced from the levels shown here, and most likely, would be on the order of -30 dB from the co-polarized beam peak.

The amplitude contours for the off-axis cluster are shown for the Eastern U.S. Time Zone in Fig. 185, and in overview form for the Continental United States in Fig. 186. The Eastern Time Zone contours are very similar to those from the on-axis case. The -3 dB contour follows portions of the time zone outline, but where in the on-axis case, the pattern "necked in" between 30° and 35° N. Latitude, it now is disconnected in this area. The -6 dB contour again follows the time zone outline very closely. It comes in slightly in the South West portion but does not elongate as much north of Michigan. The spill-over is rapid in the North Central Section and again, unavoidably, elongates in the North East.

An additional consequence of the off-axis feeds, is the presence of a composite coma lobe. In the lower left-hand corner of Fig. 185, a lobe exists which is less than 6 dB down from the beam maximum. The structure of these lobes is more apparent when looking at the overview in Fig. 186. These relatively high coma lobes all fall in the Central Time Zone.

It should be remembered that, this off-axis feed position is where these feeds would be if additional clusters of feeds were present for coverage of the other 3 time zones from a single reflector. To re-use frequency, the beams for the eastern and central zones would be cross polarized. Thus, these high coma lobe levels become unimportant, as orthogonal polarization is used for isolation between these zones.

The co-polarized pattern levels in the Mountain Time Zone are better than those from the on-axis case but still are in the range of -20 dB to -30 dB from the beam maximum. The same rationale for expecting lower levels in an end item system as was used for the on-axis cluster apply here also.

To investigate other factors which may have contributed to the small differences between the contours predicted from the analysis and those measured, the individual beam bore sights were measured. In each case, the beam resulting from feed "F" was positioned at 35° N. Latitude and 83.5° W. Longitude. All other bore sights were measured relative to this "F" position. The calculated and measured beam bore sights are shown for the on- and off-axis clusters in Figs. 187 and 188 respectively. The small differences between computed and measured bore sights are considered to be within experimental error, when one considers that, for example, at beam position "A", a change of .05 degrees in azimuth results in a change of 0.5 degrees in longitude, and a change of 0.05 degrees in elevation results in a 0.7 degree change in latitude.

7.4 Cross Polarization

Since frequency re-use is a consideration in a complete domestic communications system, the relative level and angular location of cross-polarized energy from the composite beam is of major importance. The cross-polarization component was measured in the following manner:

For both the on- and off-axis feed clusters, the reflector was set to that azimuth and elevation position at which the reflector axis would be bore sighted to 35° N. Latitude and 83.5° W. Longitude. Thus, in the measurement set up, the reflector axis was pointed directly at the transmitting antenna. A co-polarized signal level was established near the top of the recorder chart paper (the total dynamic range was 40 dB). The feed in the transmitting antenna was rotated about its own axis until a minimum signal was obtained on the recorder. In both the on- and off-axis cases, the recorder pen dropped to the bottom of the chart, indicating a cross-polarized level, relative to the co-polarized level, of -40 dB.

It should be noted that the rotation of the transmitting feed was to a position where the cross-polarized signal was a minimum. This position is not necessarily 90° from the co-polarized position, nor is it important that it be 90°. In actual operation, a user on the ground would line up his system by "nulling out" on the cross-polarized signal, and then rotating his antenna 90° from this position.

No attempt was made to measure the transmitting feed position where the composite beam cross-polarized beam was a minimum. As a generality, however, it can be said that the feed positions were not 90° from the co-polarized position, the two positions were different for the two cases, and the maximum deviation from the 90° position was about 5°.

Cross-polarized patterns were recorded for each azimuth and elevation position that the co-polarized patterns were recorded. (The rotational position of the transmitting feed was extremely sensitive so that when the feed was tied down to record these patterns, the level on the recorder paper actually was established about 31 dB down from the co-polarized level). The level at this angular position was the highest level recorded over the complete contour.

No cross-polarized patterns are included in this report, as most of the patterns consist of a straight line along the bottom of the pattern paper.

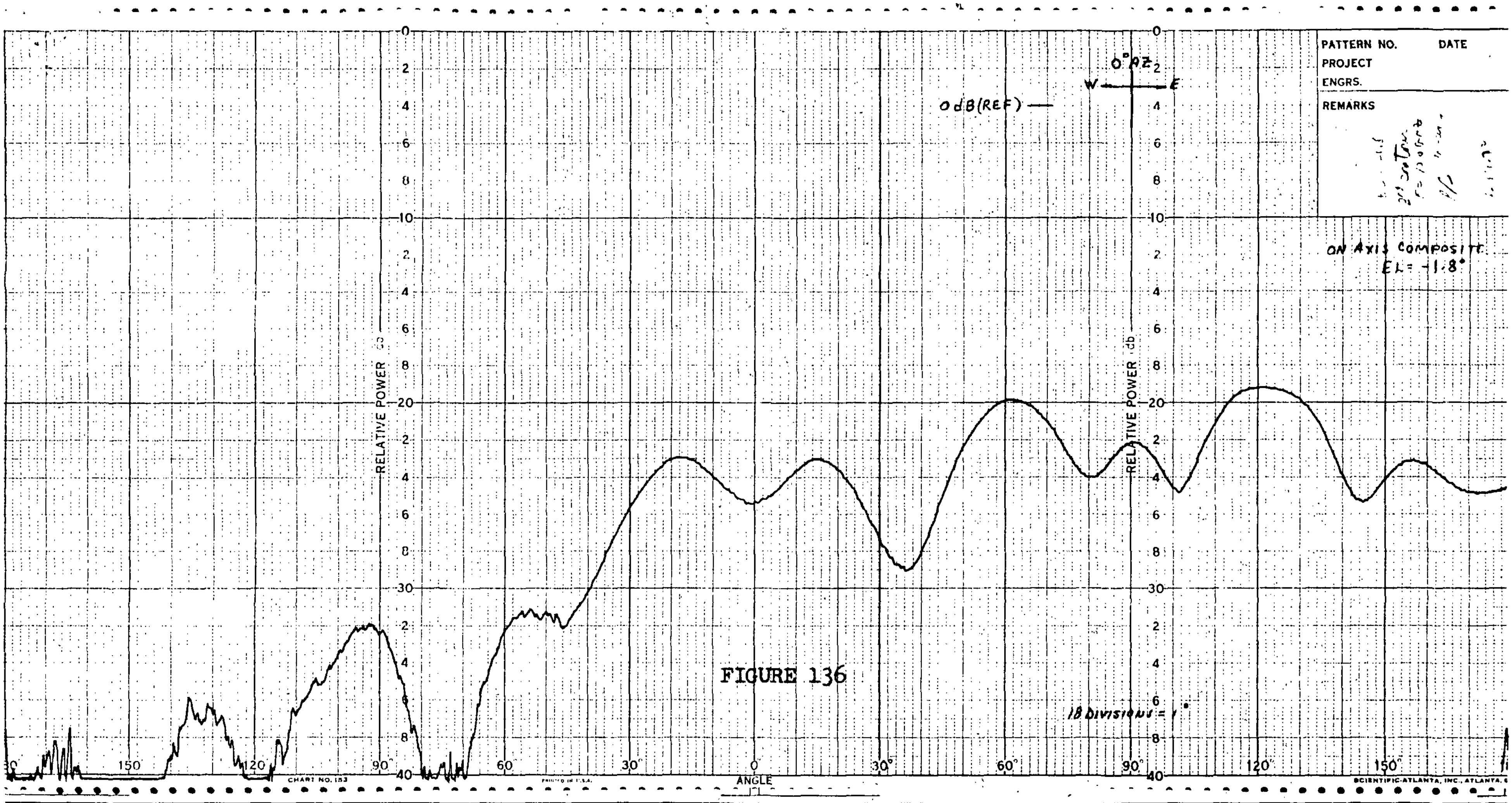

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0°AZ
W
E
0dB(REF)
ON AXIS COMPOSITE
EL= -1.8°
18 DIVISIONS = 1°
RELATIVE POWER db
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 136

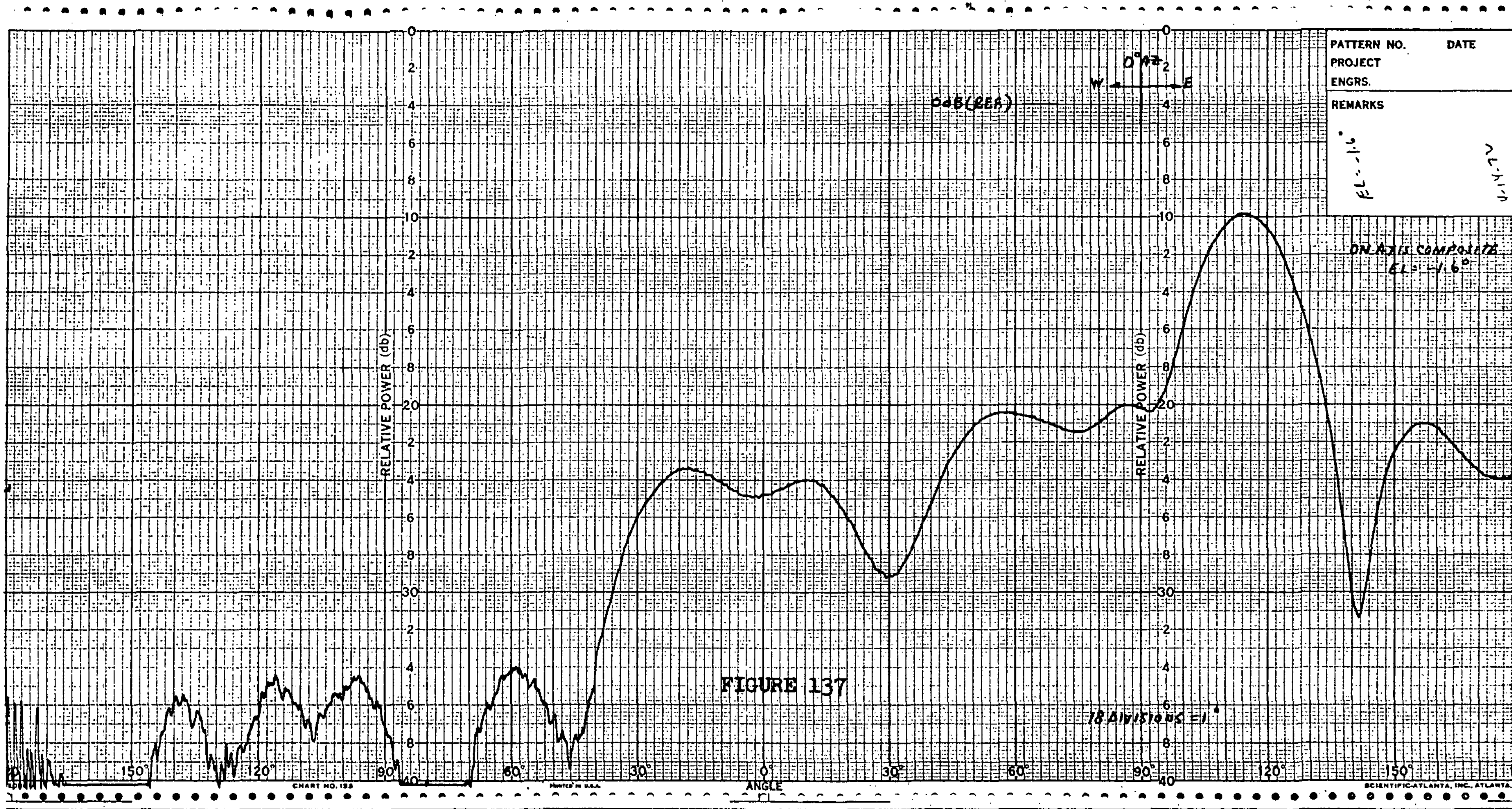
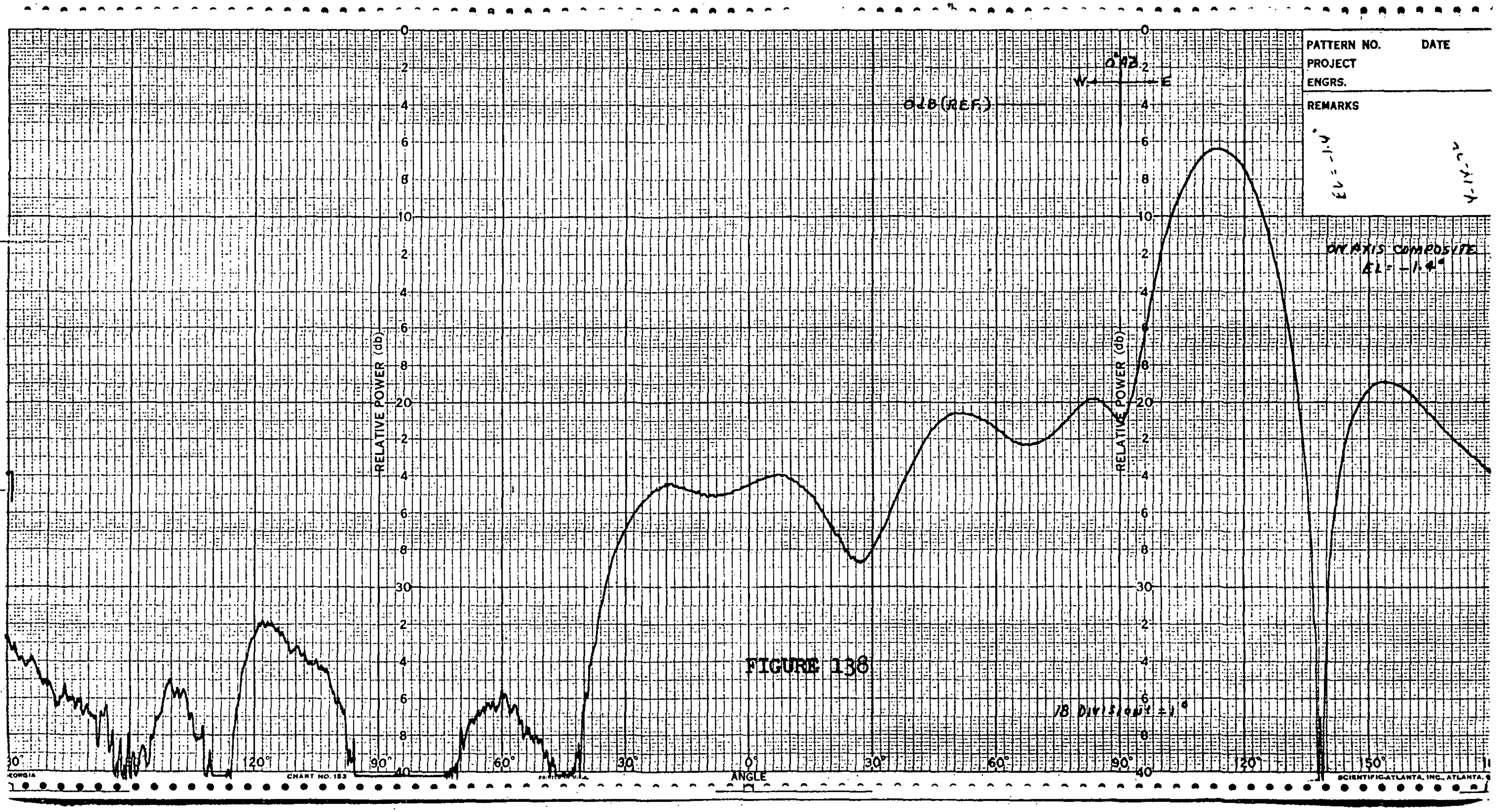
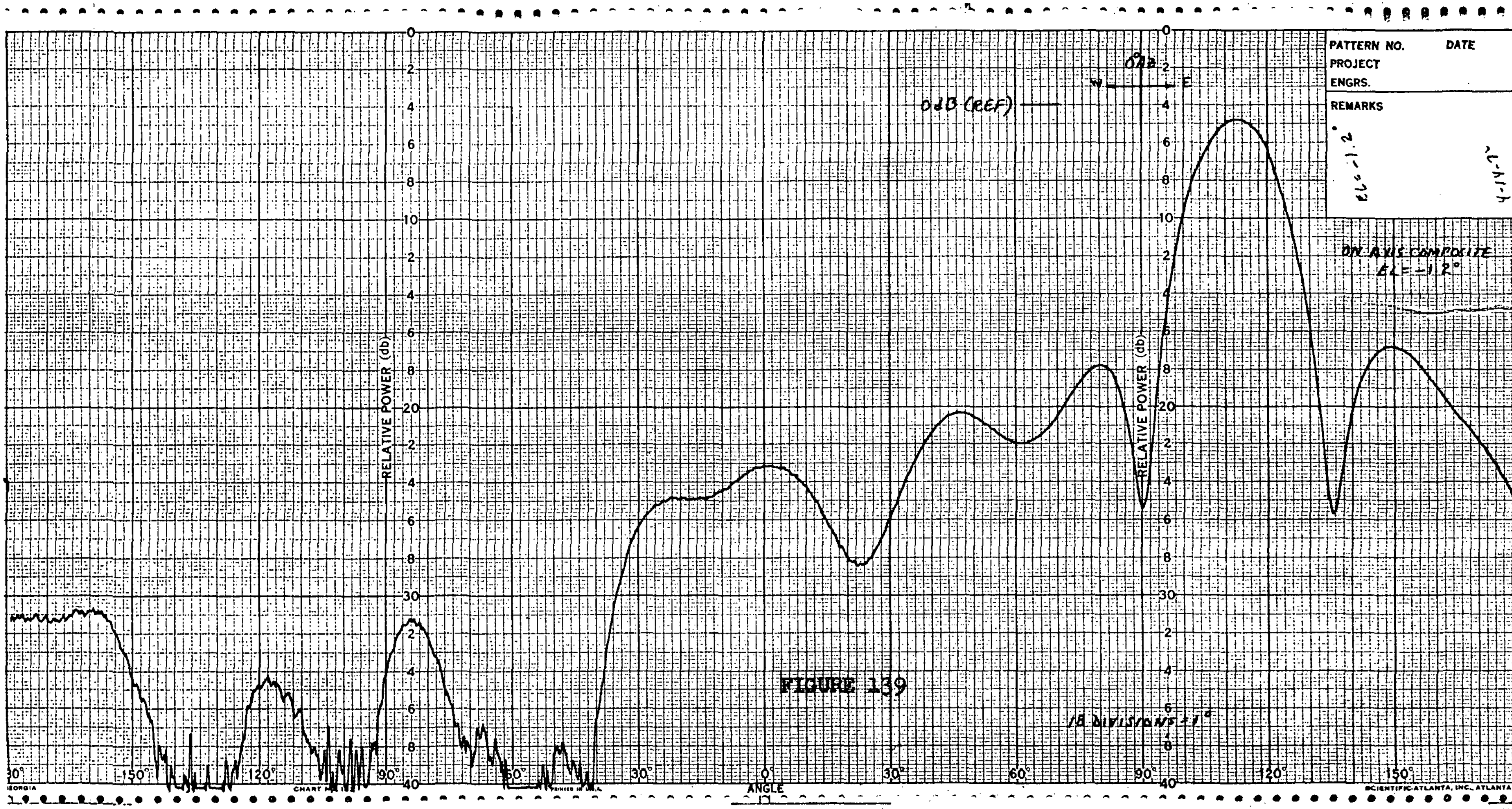

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0° AZ
W
E
0dB (REF)
ON AXIS COMPOSITE
EL = -1.6°
18 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 137



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (REF.)
0° AZ
W
E
ON AXIS COMPOSITE
EL = -1.4°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA,

FIGURE 138



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (REF)
W
E
ON AXIS COMPOSITE
EL = -1.2°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°
SCIENTIFIC-ATLANTA, INC., ATLANTA,

FIGURE 139

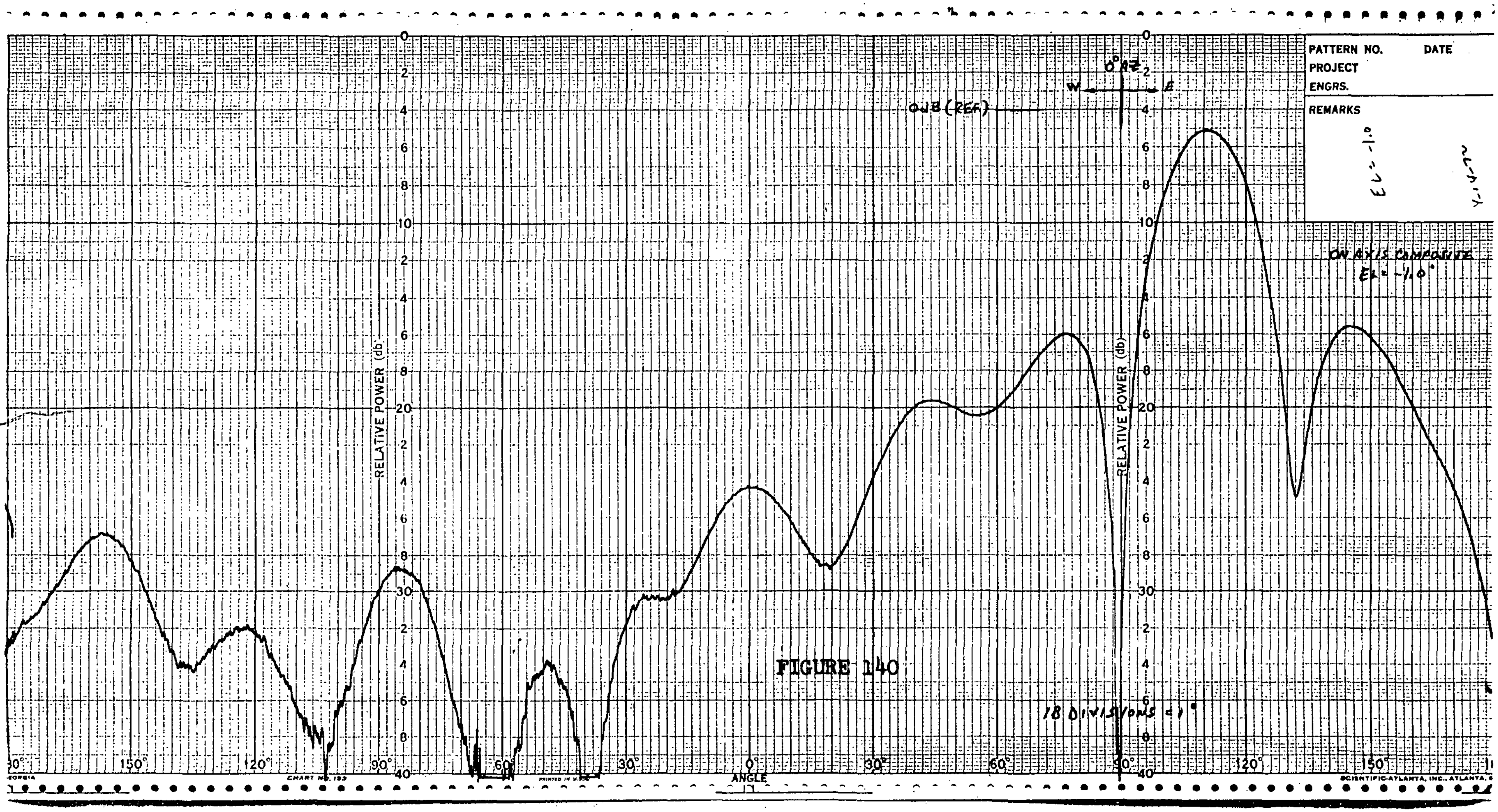

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0° AZ
W
E
0dB (REF)
ON AXIS COMPOSITE
EL = -1.0°
18 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
150°
120°
90°
60°
30°
0°
SCIENTIFIC-ATLANTA, INC., ATLANTA,

FIGURE 140

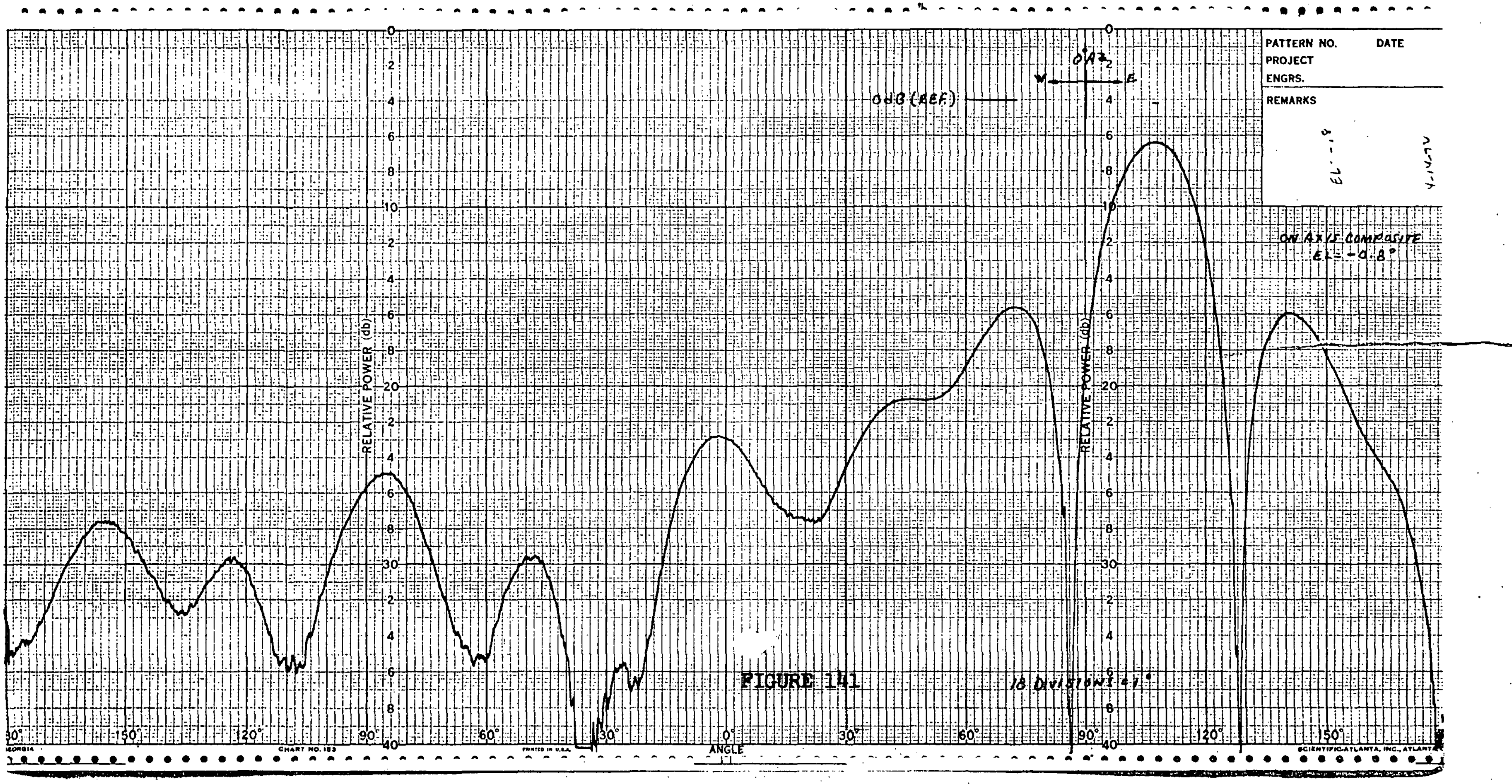
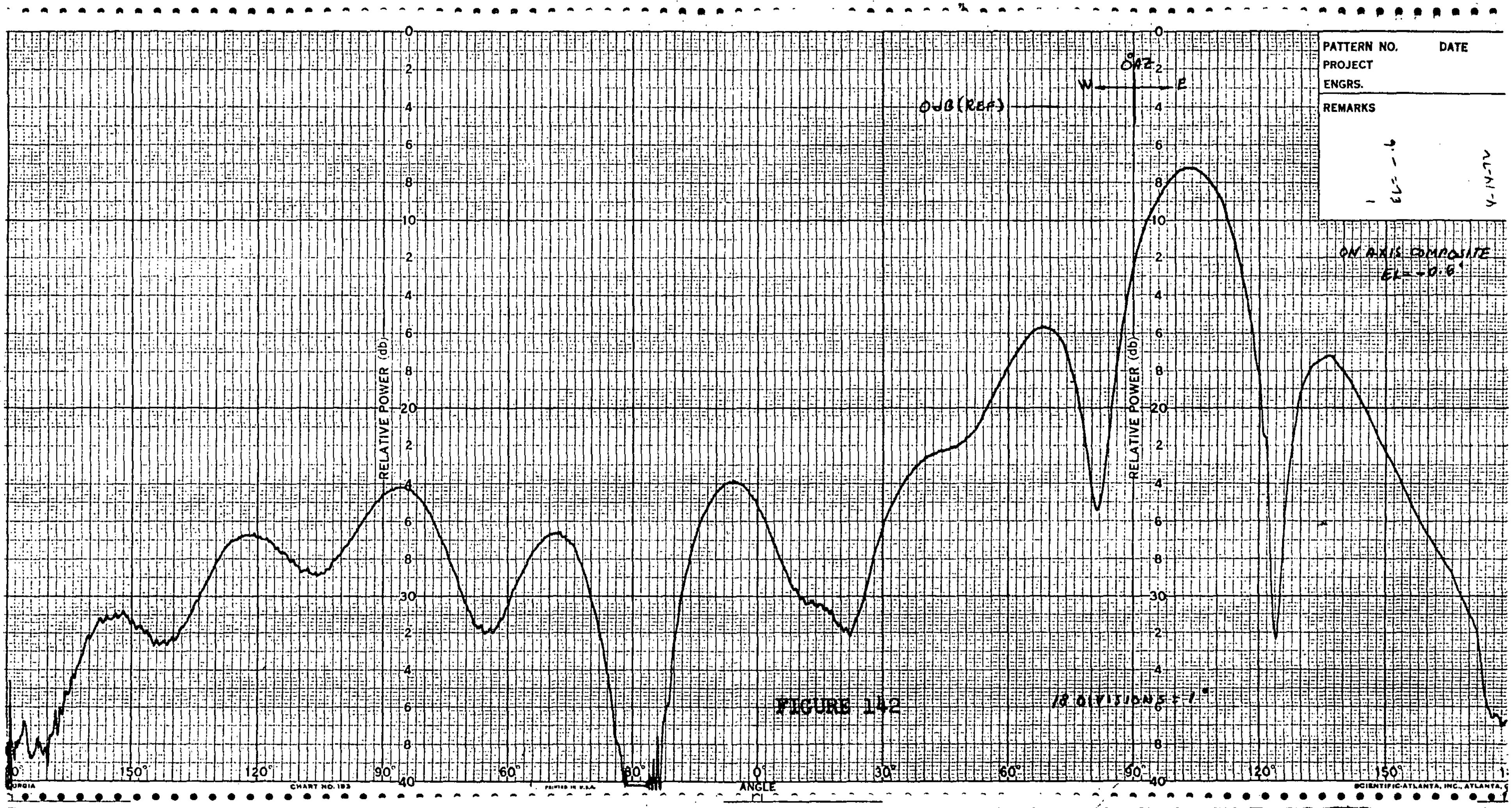

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0dB (REF)
W
E
ON AXIS COMPOSITE
EL = -0.8°
RELATIVE POWER (db)
RELATIVE POWER (db)
ANGLE
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 141



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (REF)
W
E
0° AZ
ON AXIS COMPOSITE
EL = -0.6°
RELATIVE POWER (db)
RELATIVE POWER (db)
18 DIVISIONS = 1°
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°
ANGLE
CHART NO. 193
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 142

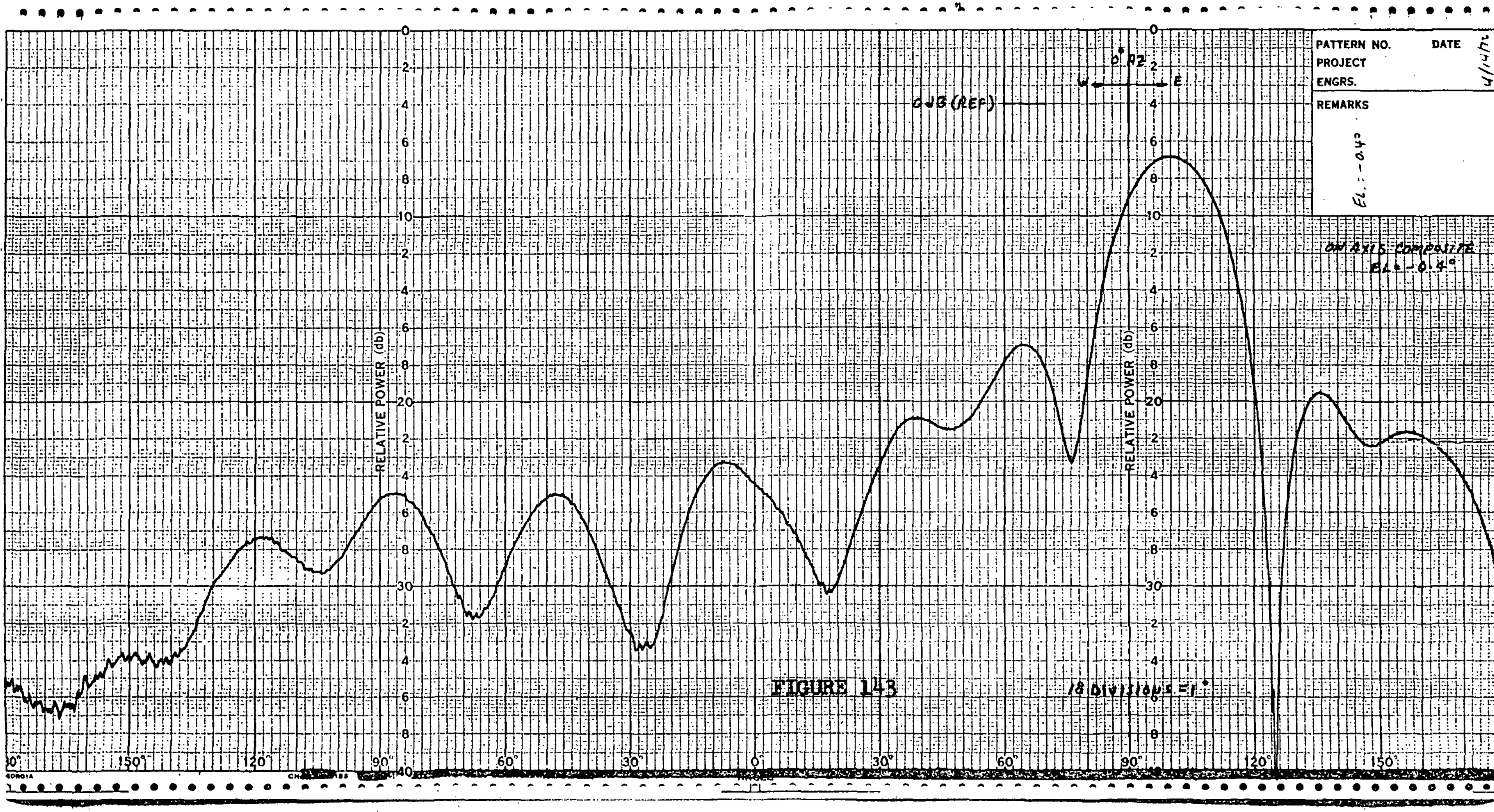

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
0dB (REF)
0° AZ
W
E
ON AXIS COMPOSITE
EL = -0.4°
18 DIVISIONS = 1°
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°

FIGURE 143

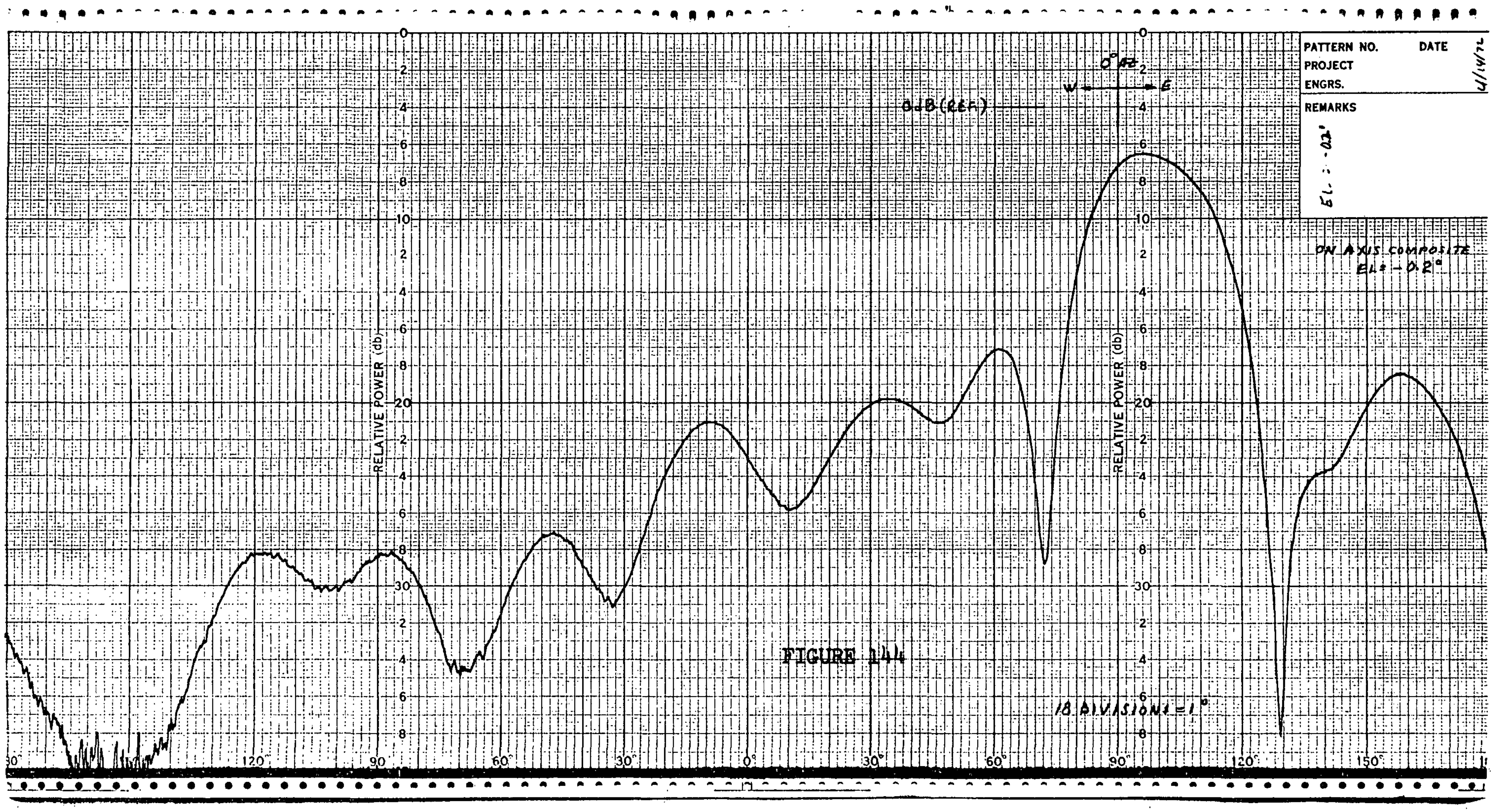

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
0dB (REF)
W
E
ON AXIS COMPOSITE
EL = -0.2°
18 DIVISIONS = 1°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°

FIGURE 144

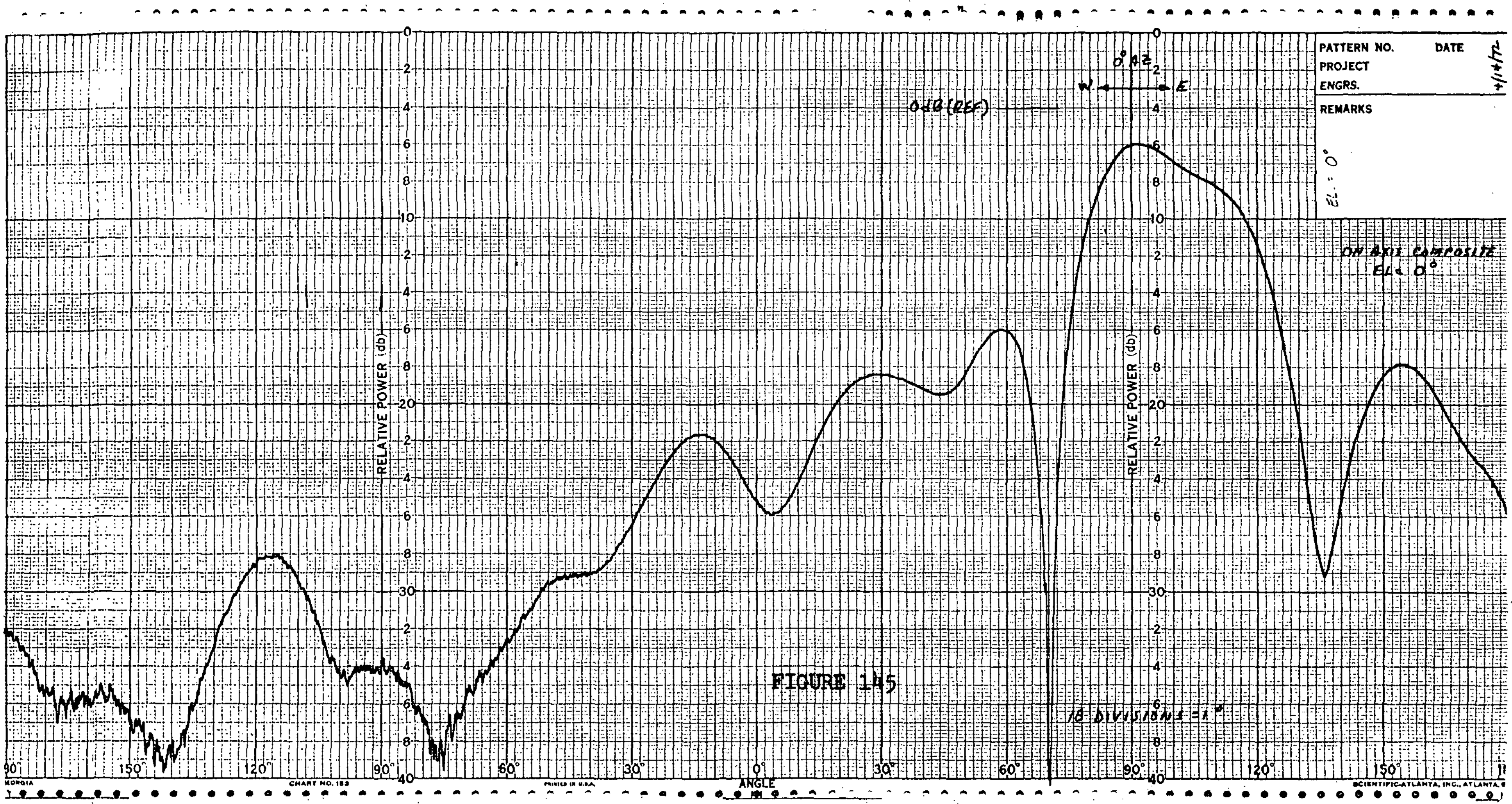

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
EL: 0°
0° AZ
W
E
0dB (REF)
ON AXIS COMPOSITE
EL: 0°
RELATIVE POWER (db)
10 DIVISIONS = 1°
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 145

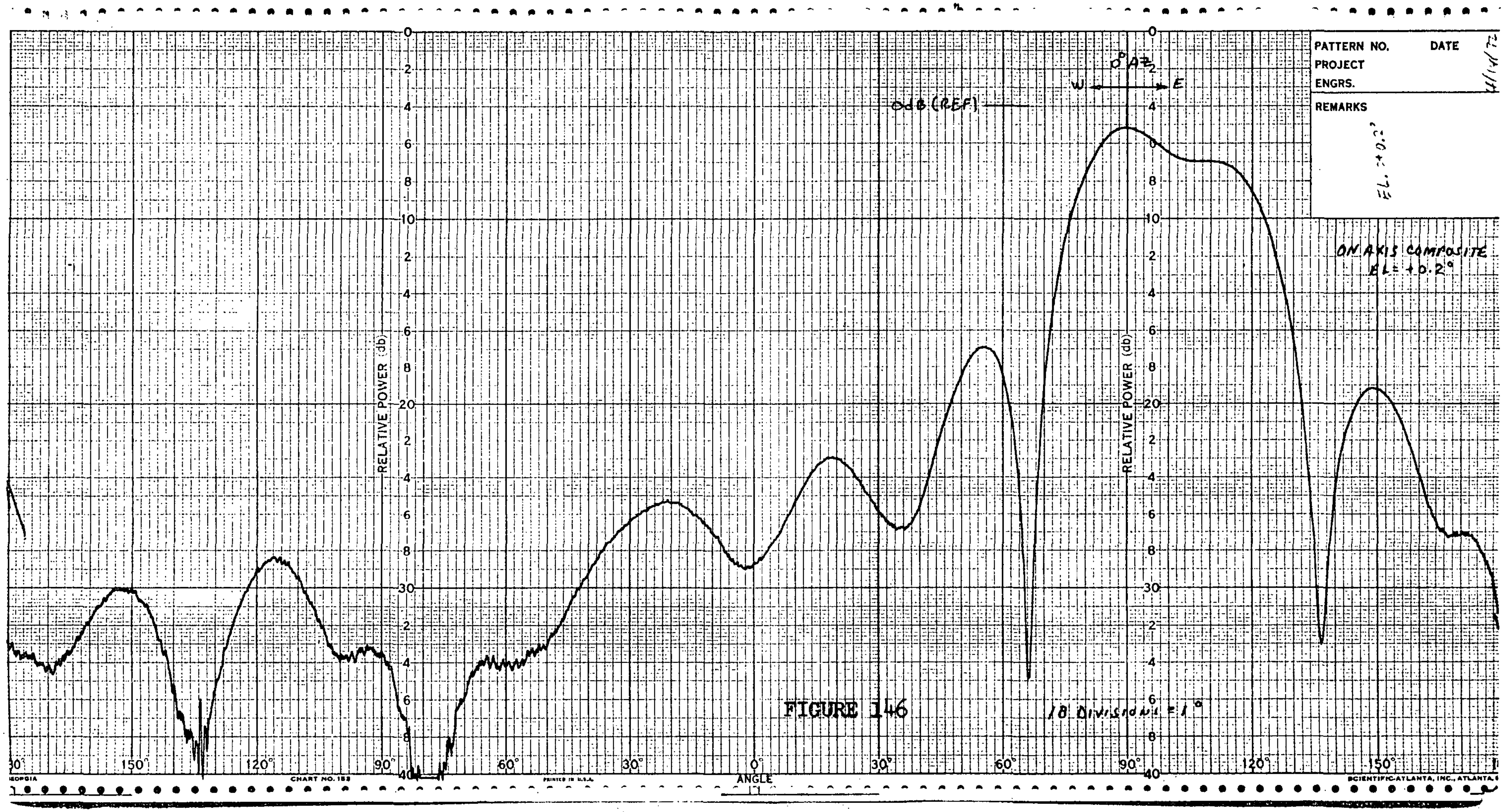

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0° AZ
W
E
0dB (REF)
ON AXIS COMPOSITE
EL = +0.2°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 152
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 146

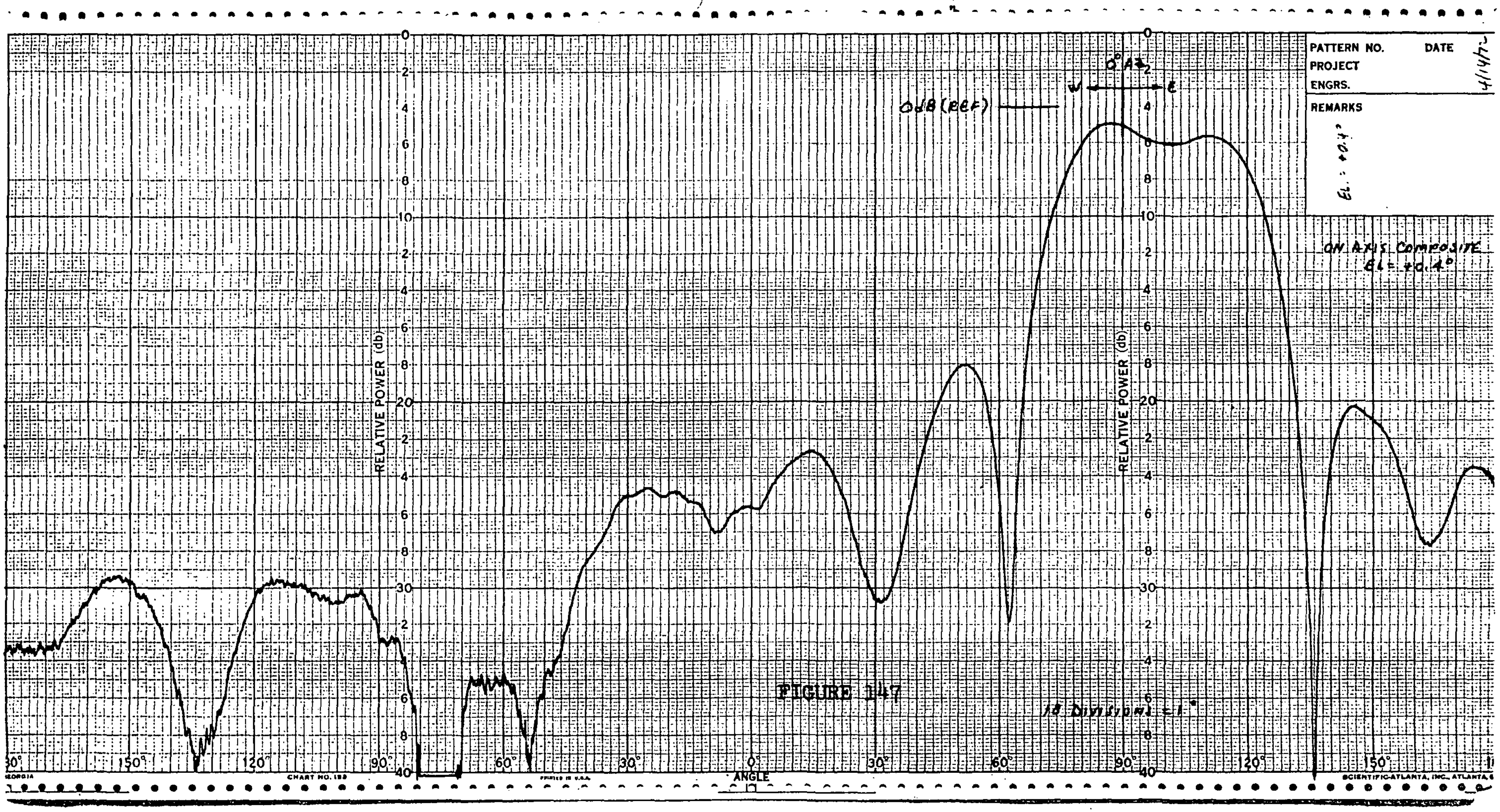

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0° AZ
W
E
0dB (REF)
ON AXIS COMPOSITE
EL = +0.4°
RELATIVE POWER (db)
RELATIVE POWER (db)
18 DIVISIONS = 1°
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 147

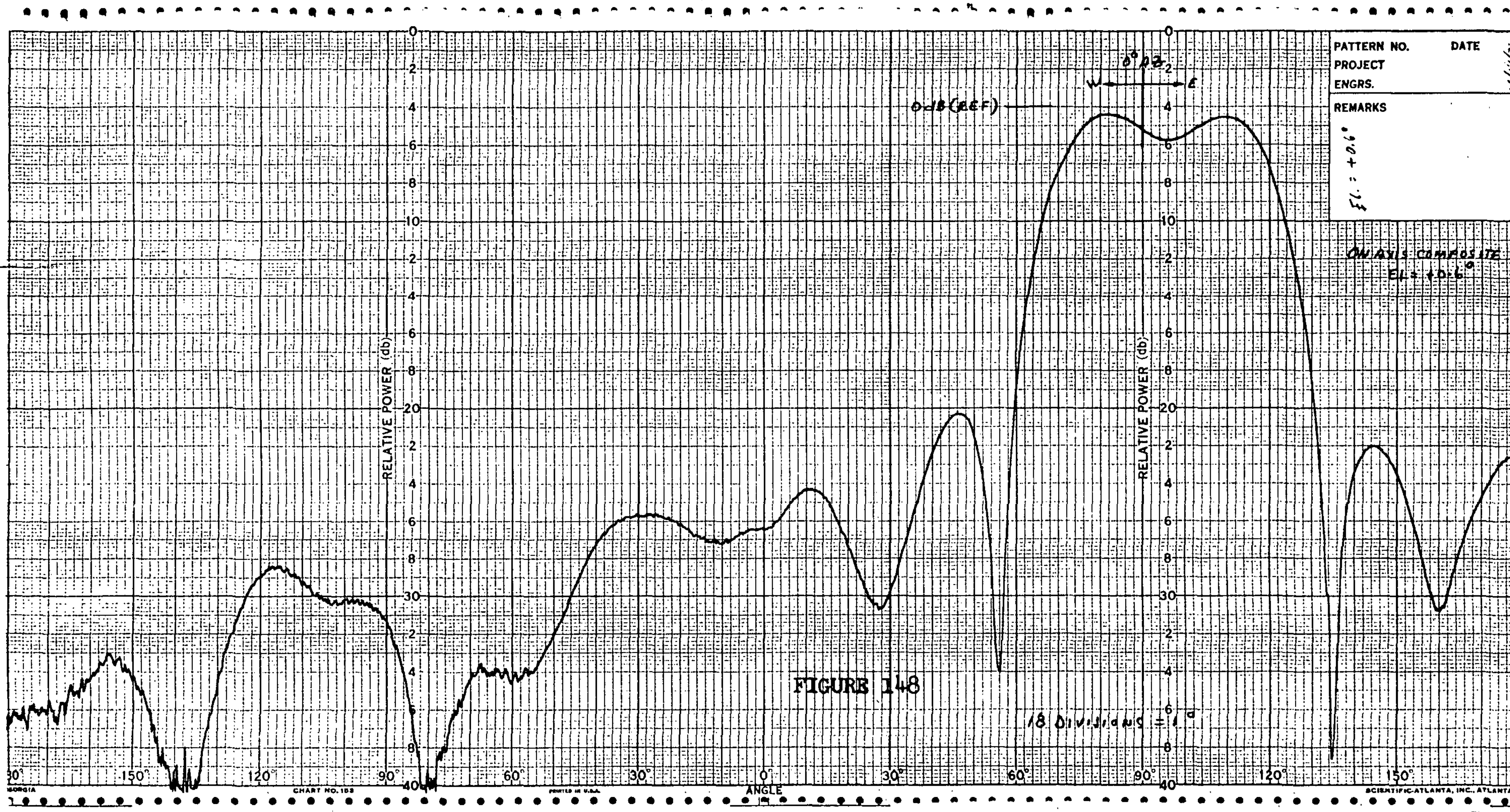

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
0 dB (REF)
W
E
ON AXIS COMPOSITE
EL = +0.6°
18 DIVISIONS = 1°
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA,
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°

FIGURE 148

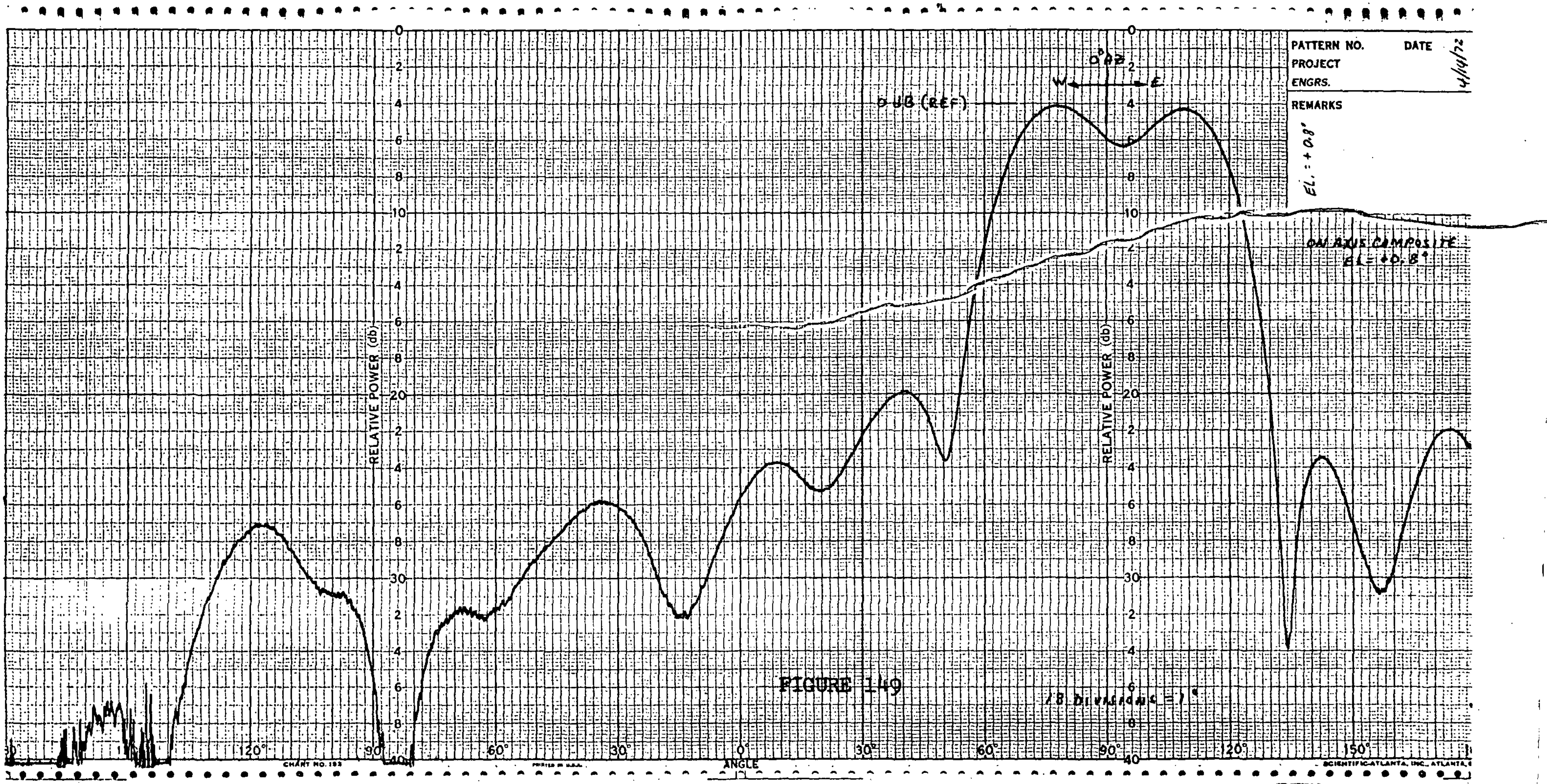

PATTERN NO.
DATE
4/14/72
PROJECT
ENGRS.
REMARKS
EL: +0.8°
0°AZ
W
E
0 dB (REF)
ON AXIS COMPOSITE
EL = +0.8°
RELATIVE POWER (db)
120°
90°
60°
30°
0°
ANGLE
150°
CHART NO. 153
18 DIVISIONS = 1°
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 149

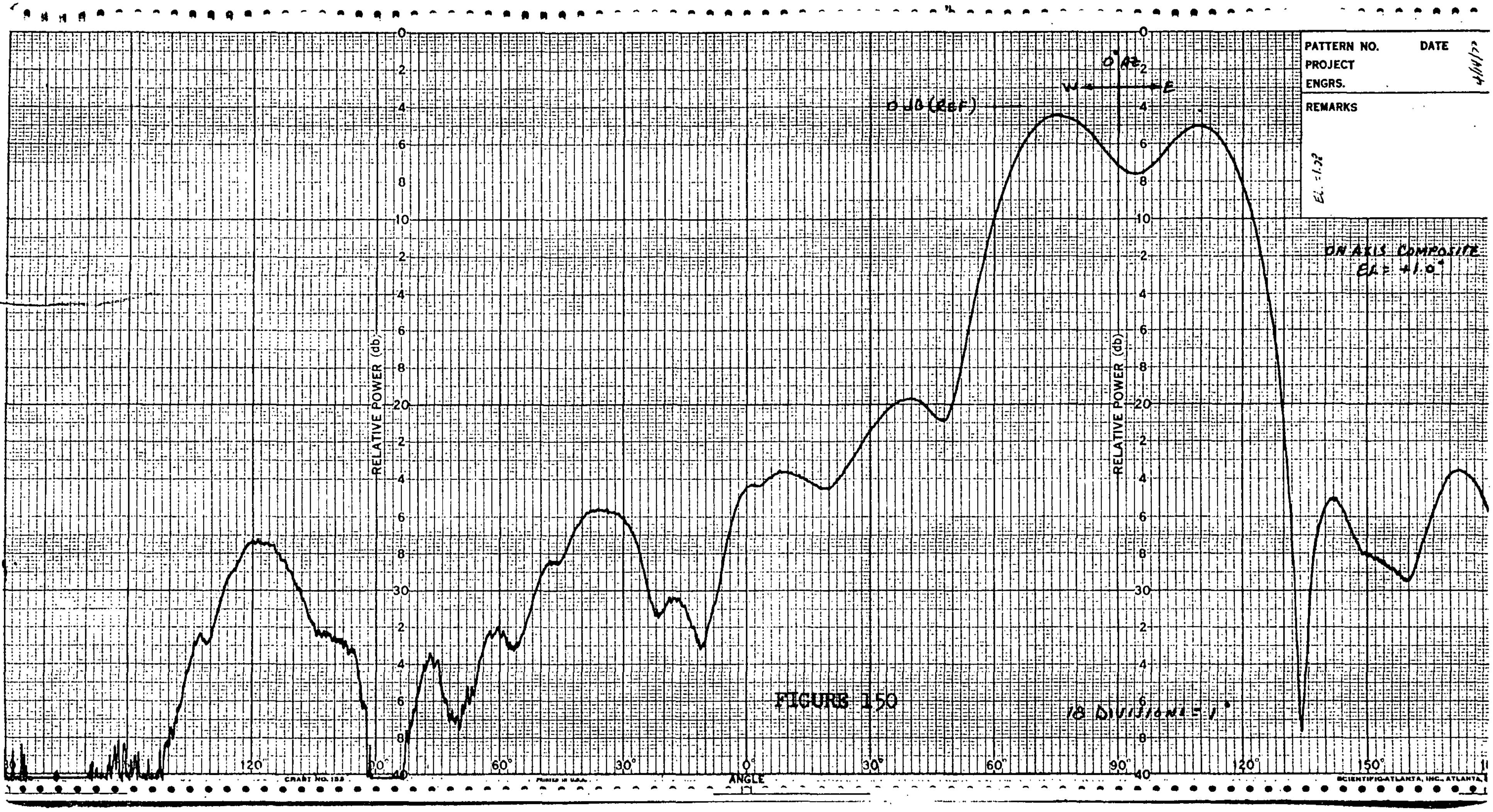

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (Ref)
0° AZ
W
E
ON AXIS COMPOSITE
EL = +1.0°
18 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 150

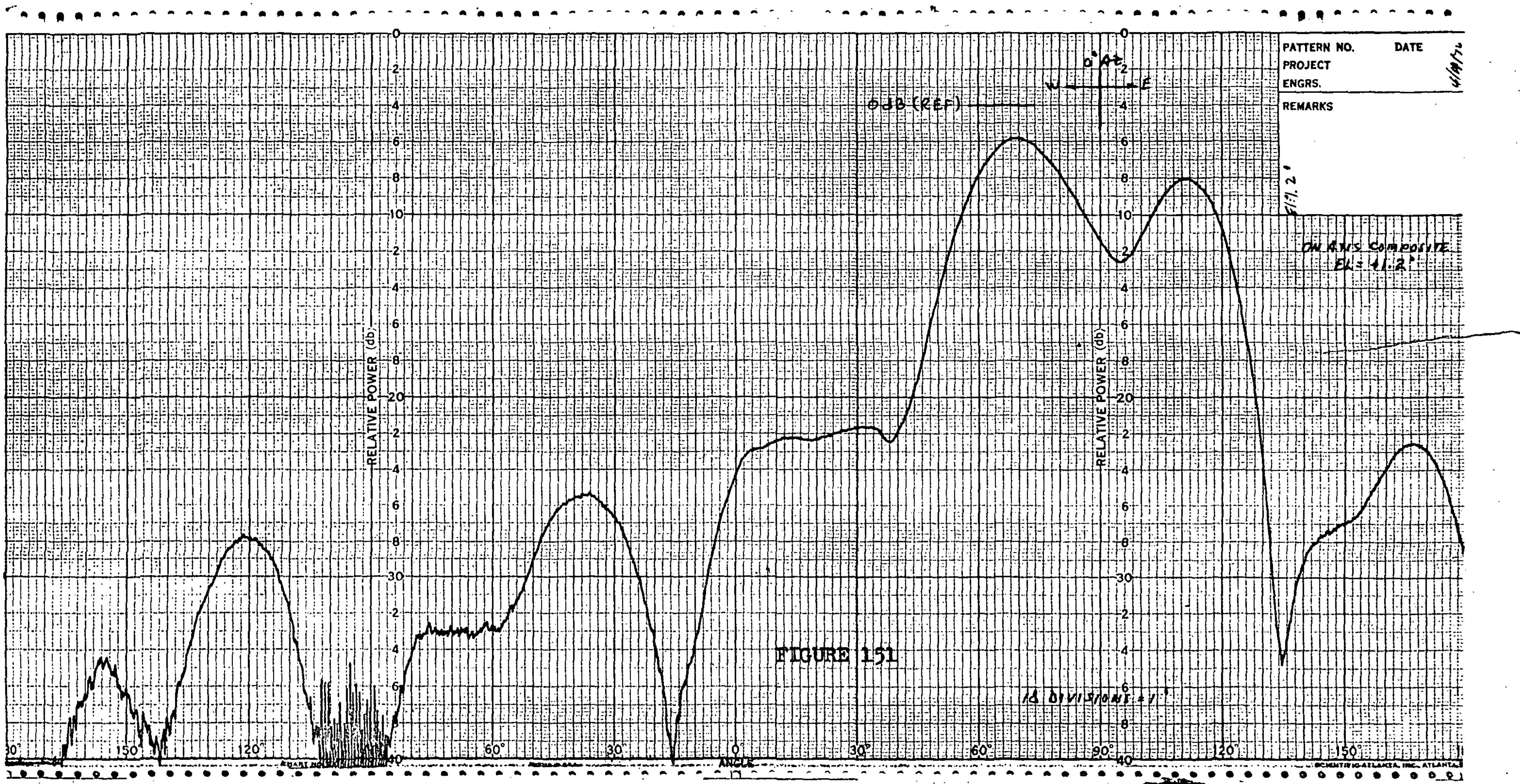

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0dB (REF)
W
E
ON AXIS COMPOSITE
EL = +1.2°
10 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
SCIENTIFIC-ATLANTA, INC. ATLANTA

FIGURE 151

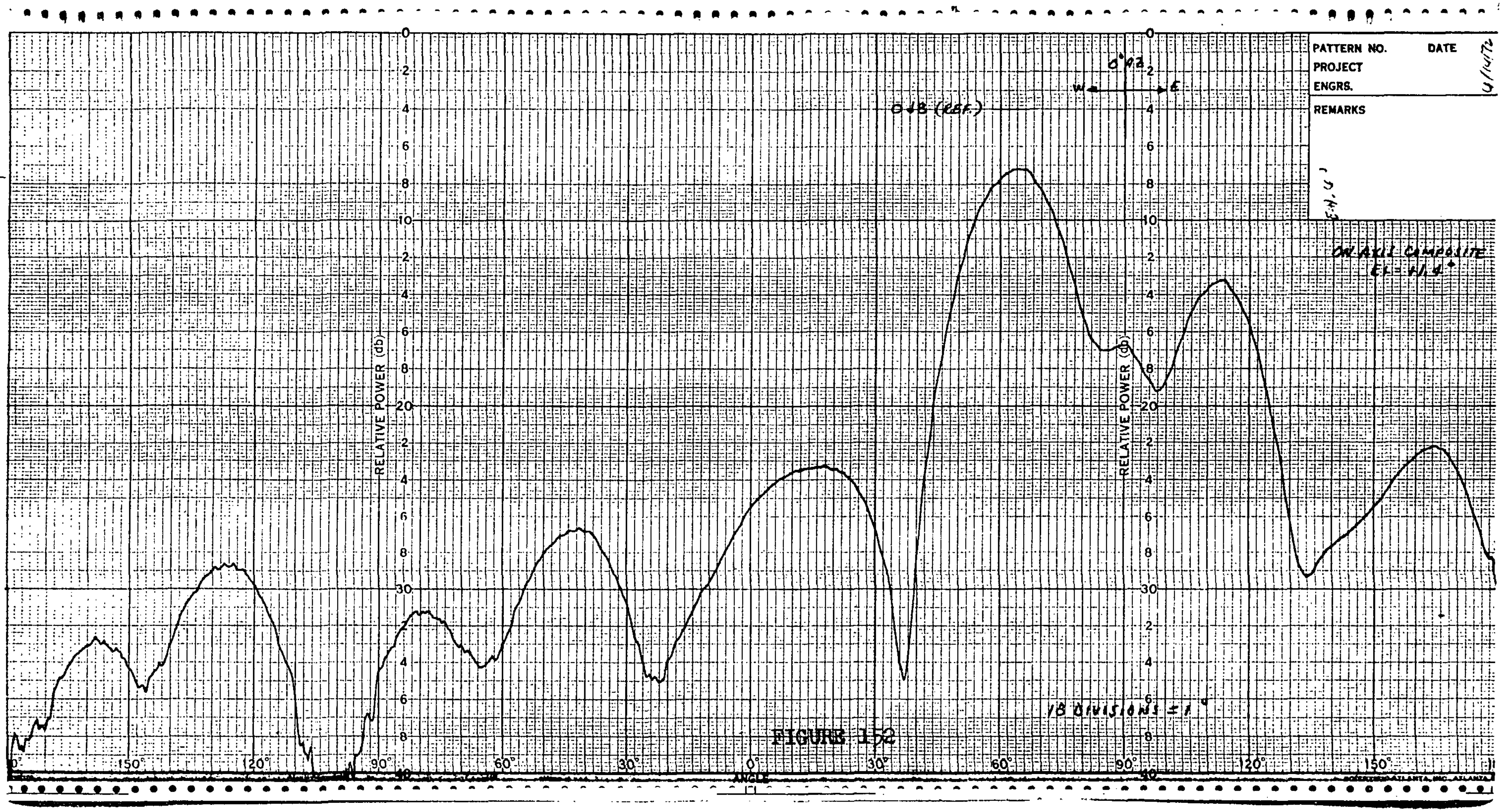
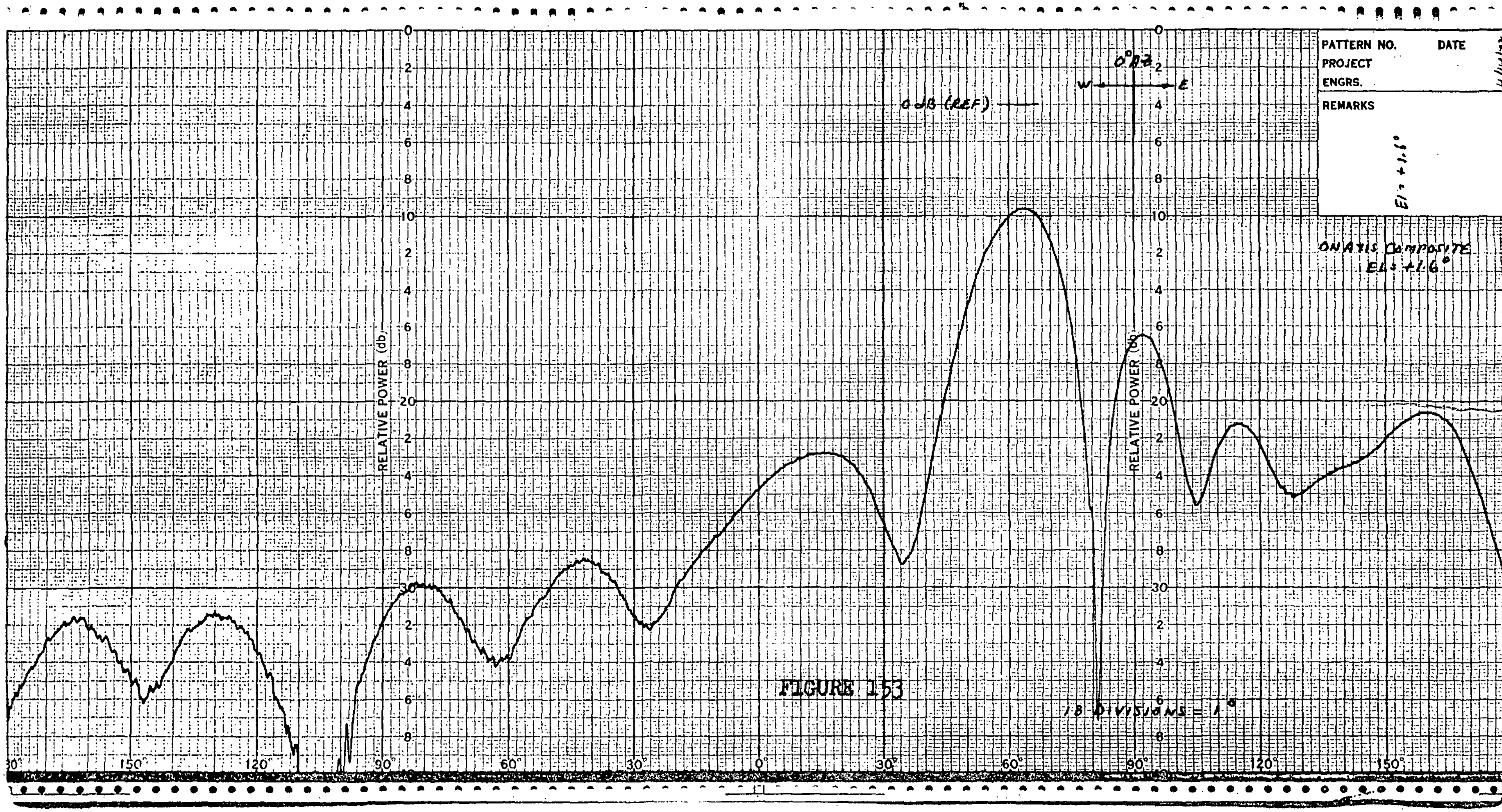

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
ANGLE
ON AXIS COMPOSITE
0 dB (REF.)
W
E
18 DIVISIONS = 1°

FIGURE 152



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
ON AXIS COMPOSITE
EL = +1.6°
0 dB (REF)
W
E
RELATIVE POWER (db)
18 DIVISIONS = 1°
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°

FIGURE 153

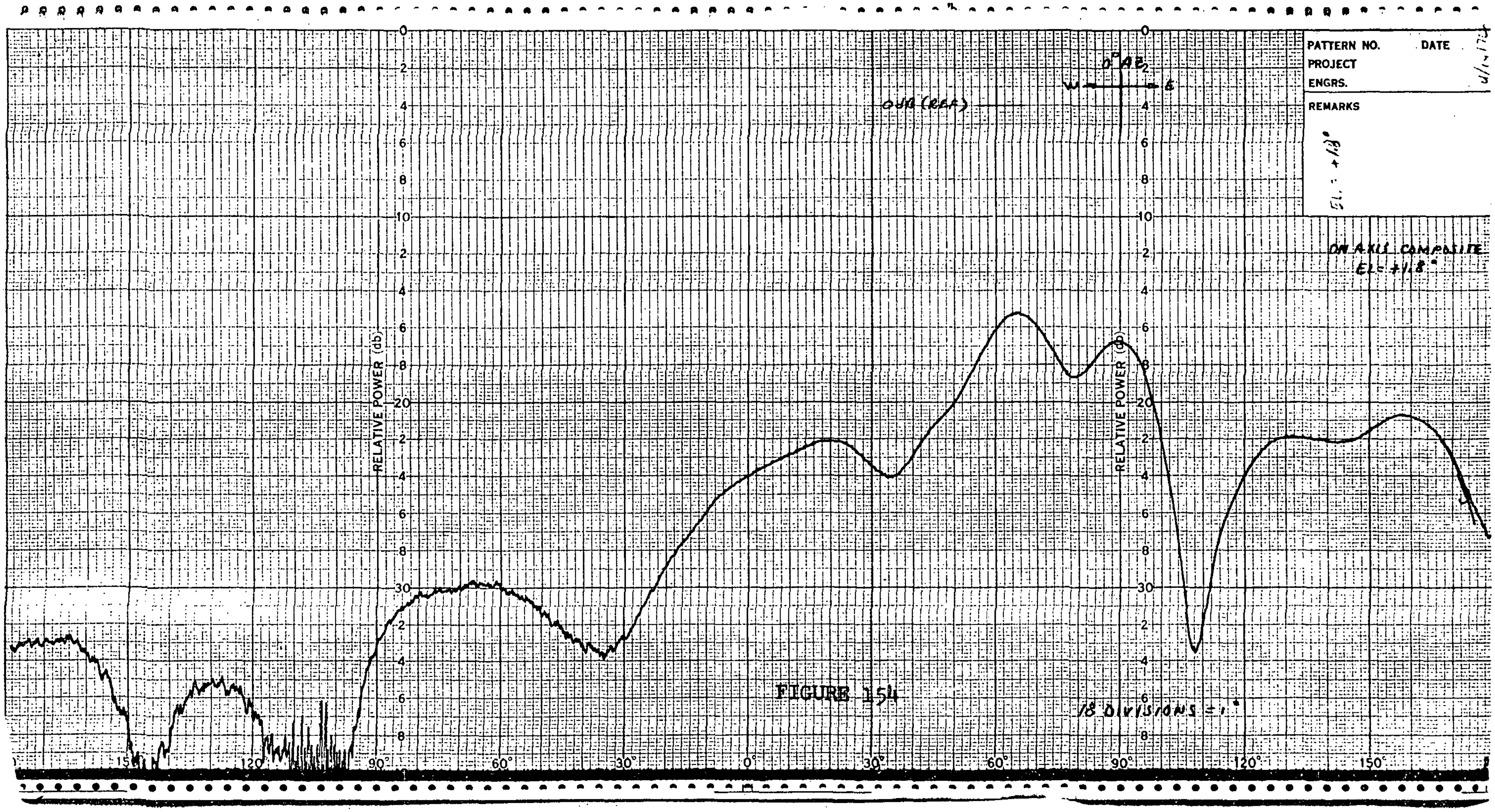

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
RELATIVE POWER (db)
ON AXIS COMPOSITE
EL = +1.8°
18 DIVISIONS = 1°

FIGURE 154

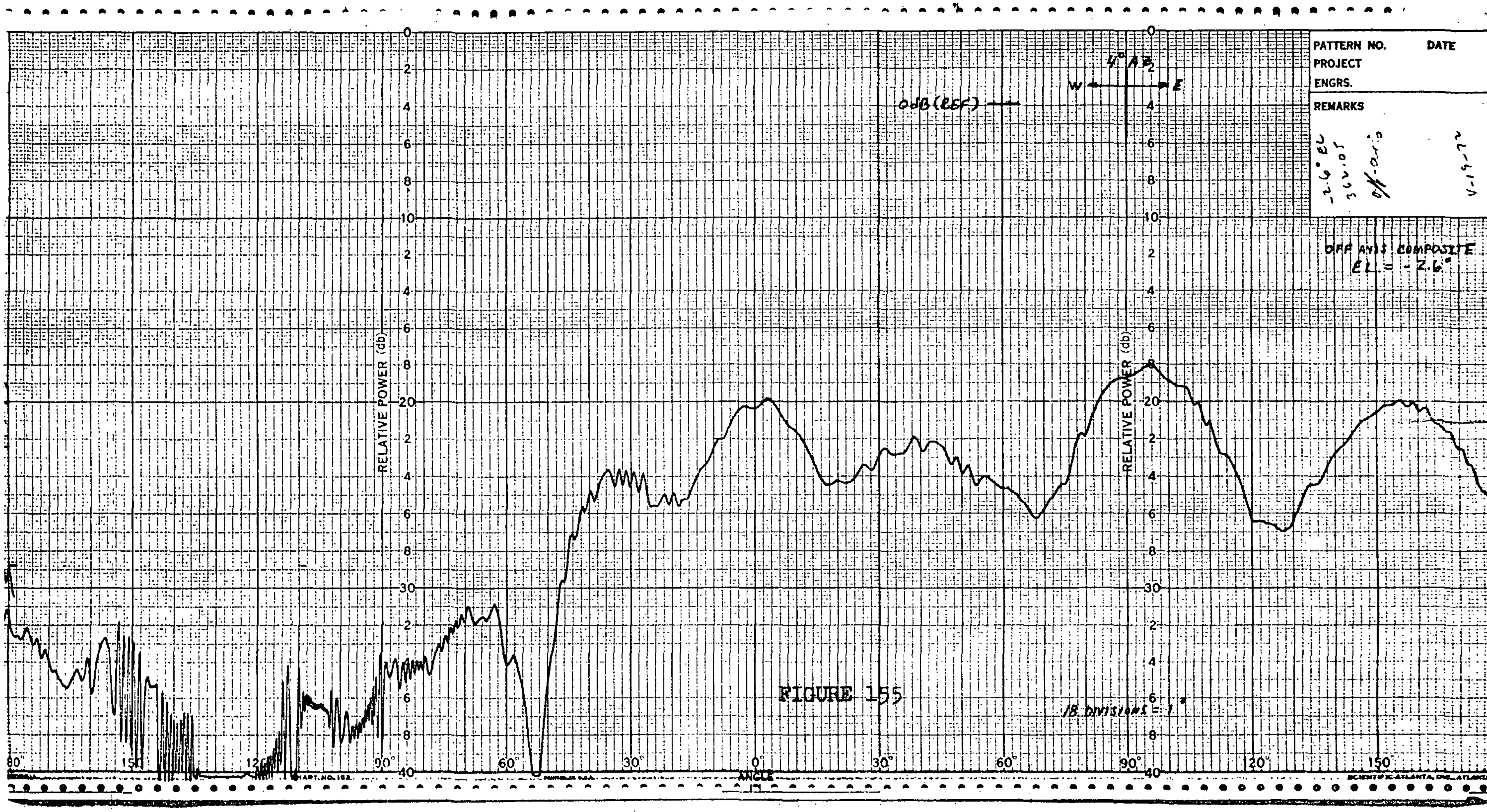
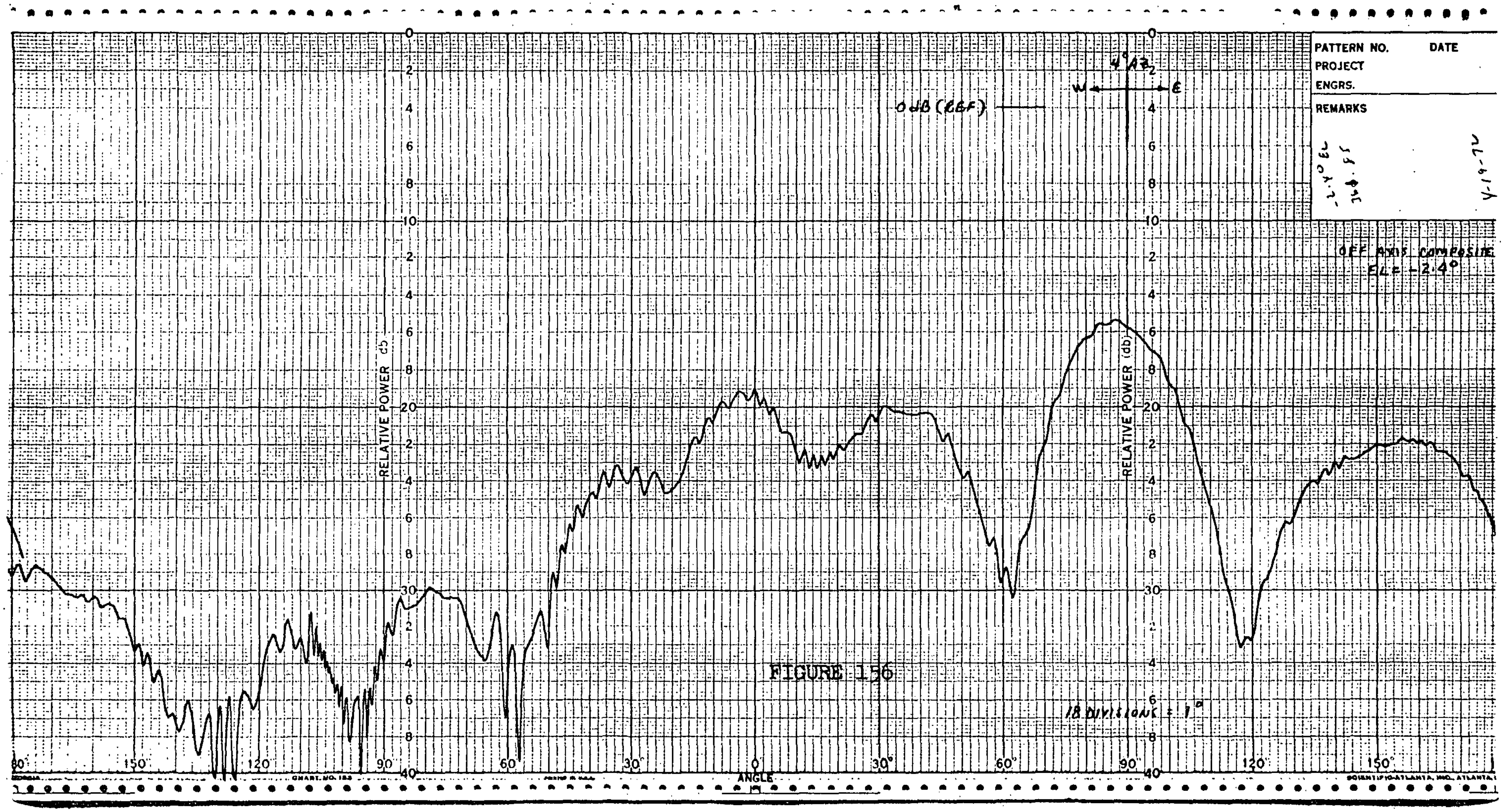

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
OFF AXIS COMPOSITE
EL = -2.6°
0dB (REF)
W
E
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 155



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (REF)
4° AZ
W
E
OFF AXIS COMPOSITE
EL = -2.4°
RELATIVE POWER (db)
18 DIVISIONS = 1°
ANGLE

FIGURE 156

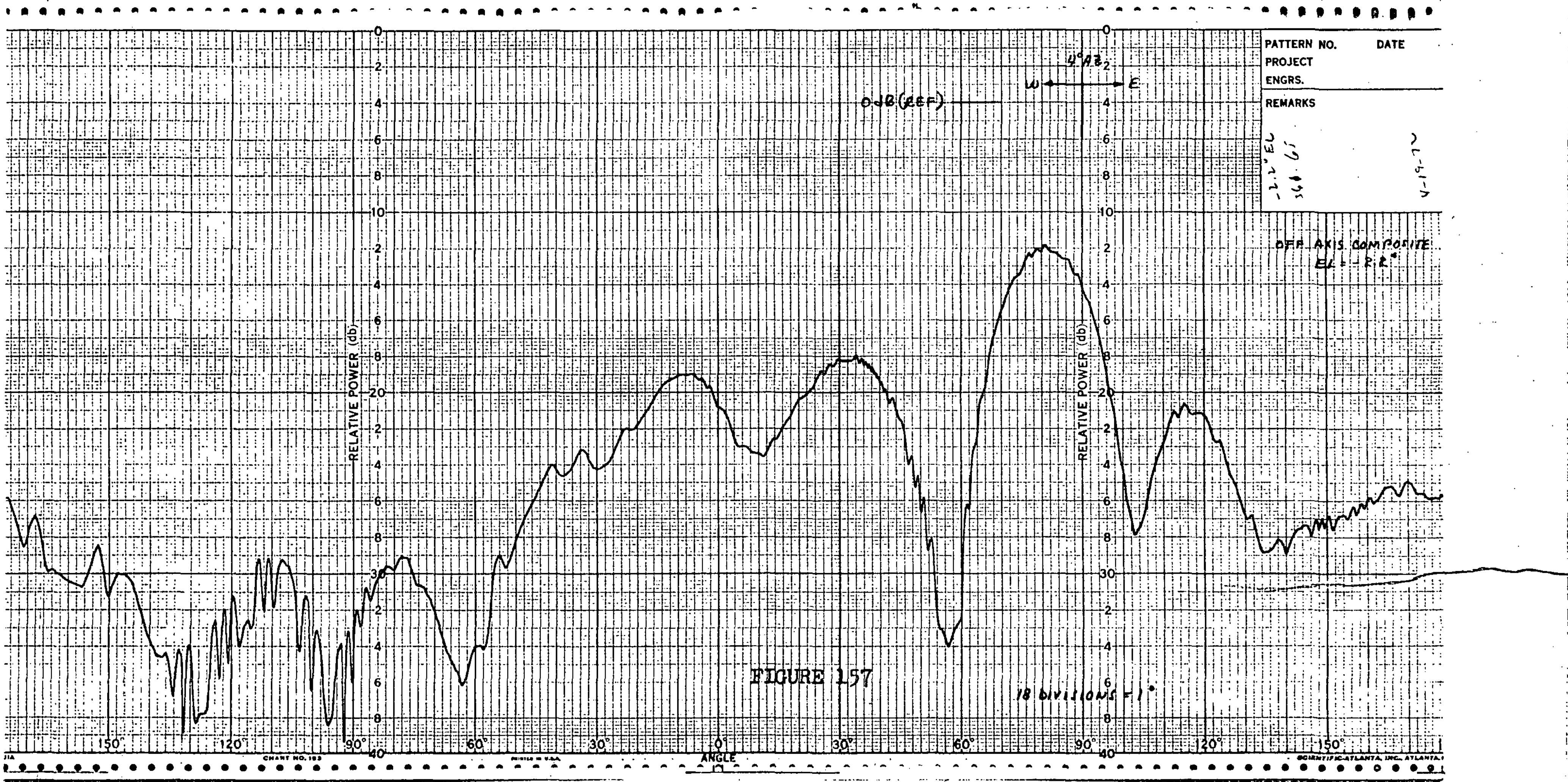

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
ANGLE
OFF AXIS COMPOSITE
0 dB (REF)
W
E
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 157

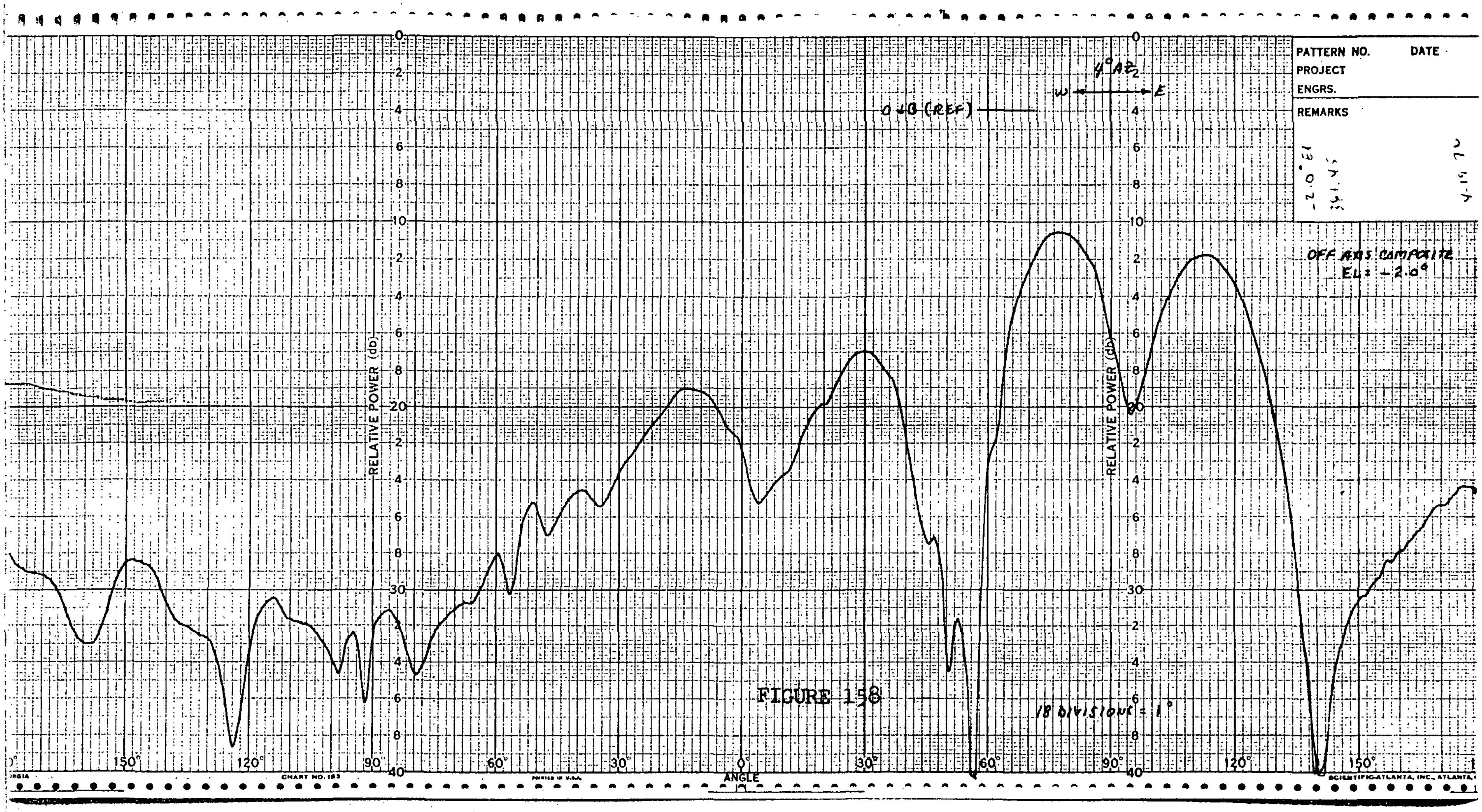

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (REF)
4° AZ
W E
OFF AXIS COMPOSITE
EL = +2.0°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 158

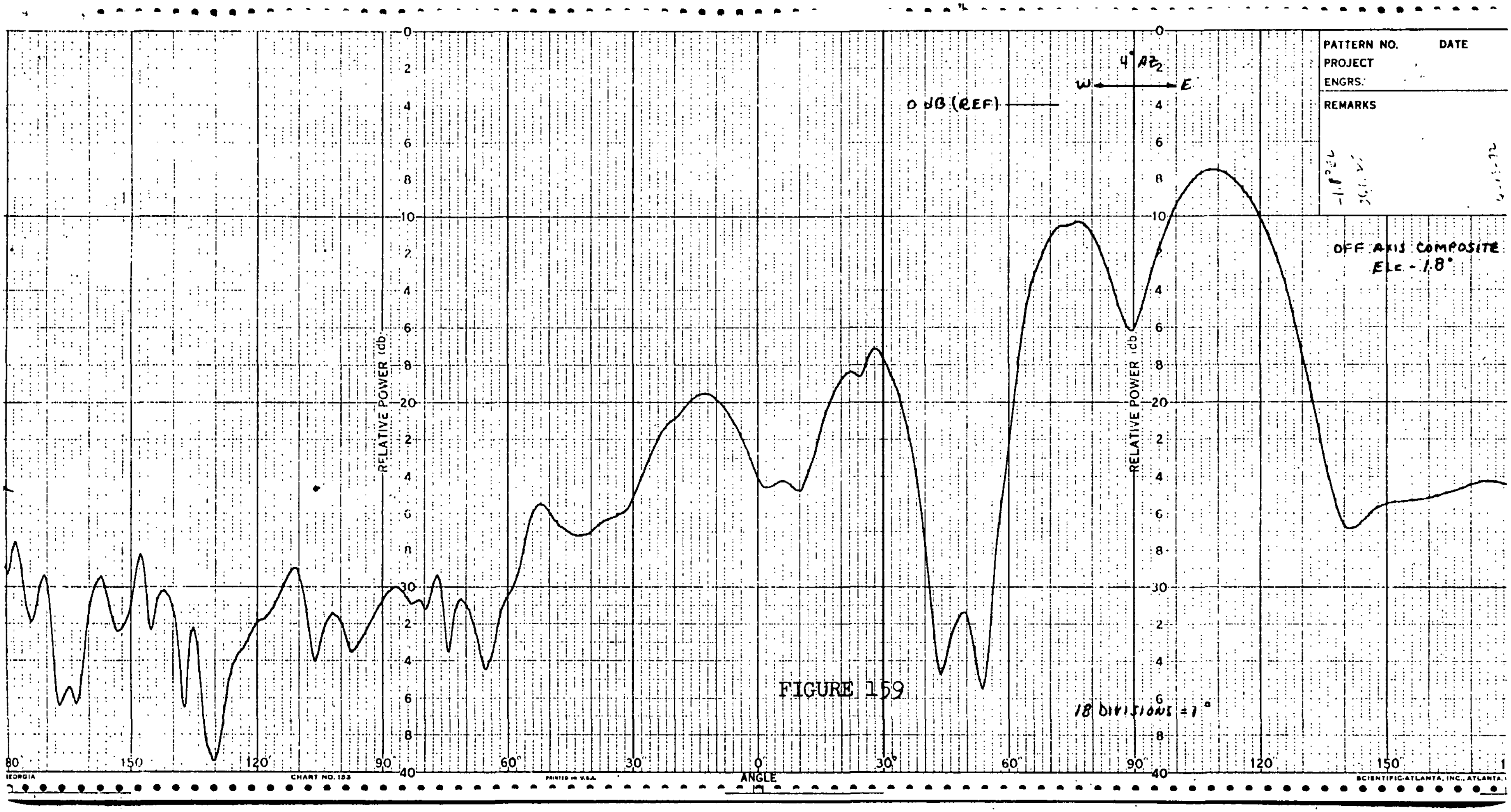
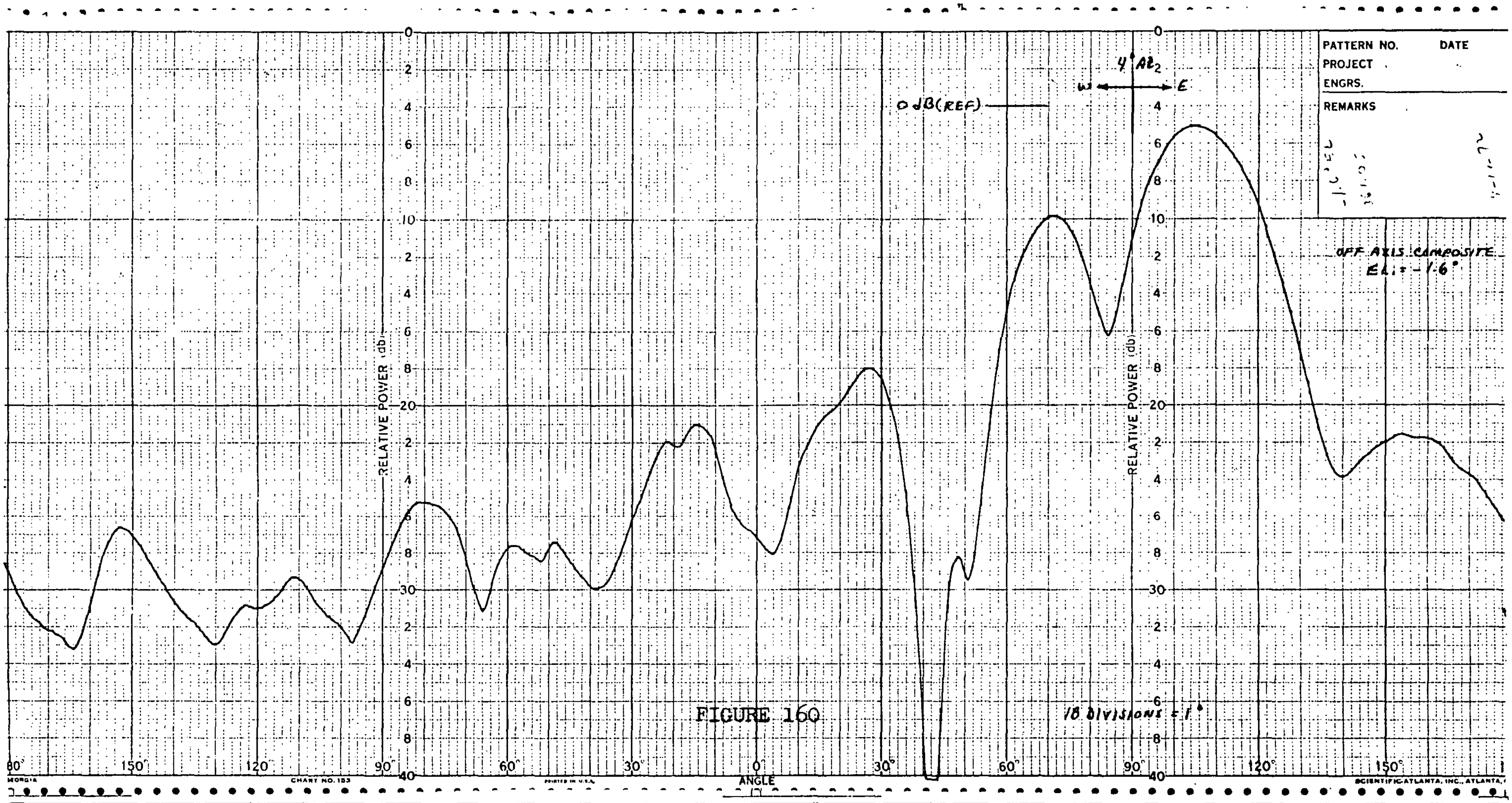

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
4° AZ₂
W ← → E
0 dB (REF)
OFF AXIS COMPOSITE
Elc - 1.8°
18 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 159



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
4' AZ2
W
E
0 dB(REF)
OFF AXIS COMPOSITE
EL: -1.6°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA,

FIGURE 160

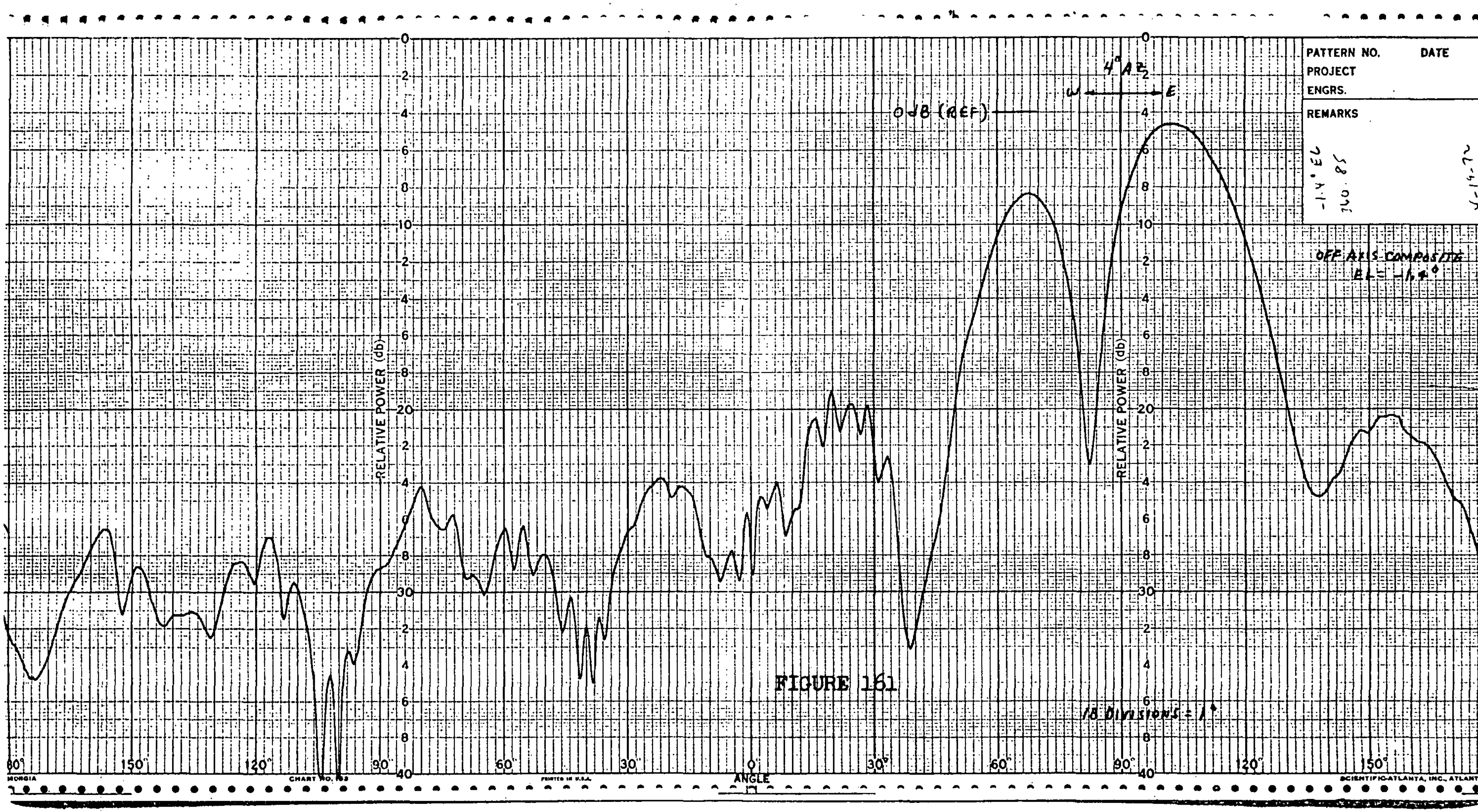
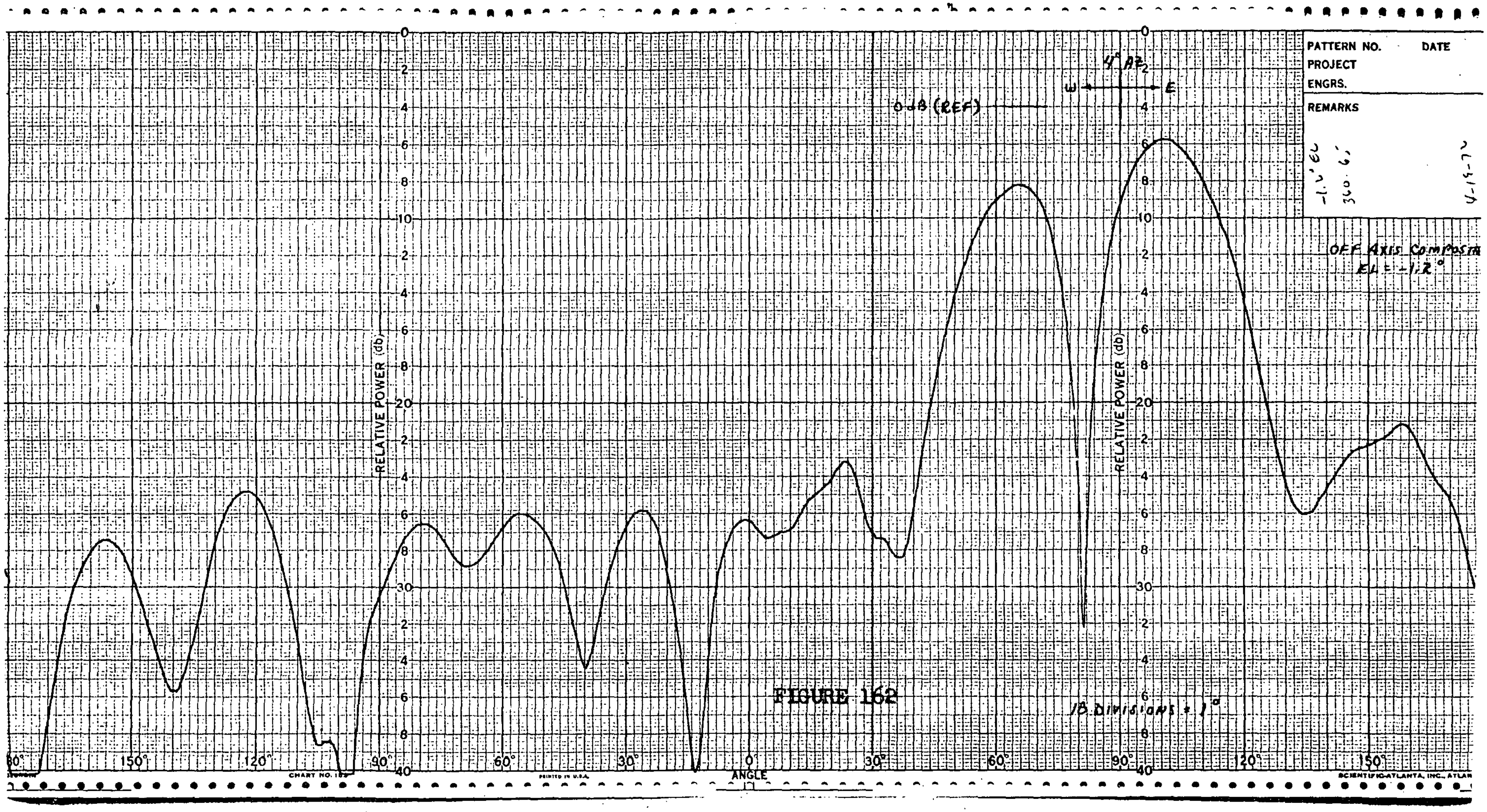

PATTERN NO. DATE
PROJECT
ENGRS.
REMARKS
-1.4° EL
340.85
5-19-72
4° AZ
W E
0 dB (REF)
OFF AXIS COMPOSITE
EL = -1.4°
18 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 161



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
ANGLE
0 dB (REF)
W
E
OFF AXIS COMPOSITE
18 DIVISIONS = 1°
CHART NO.
PRINTED IN U.S.A.
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 162

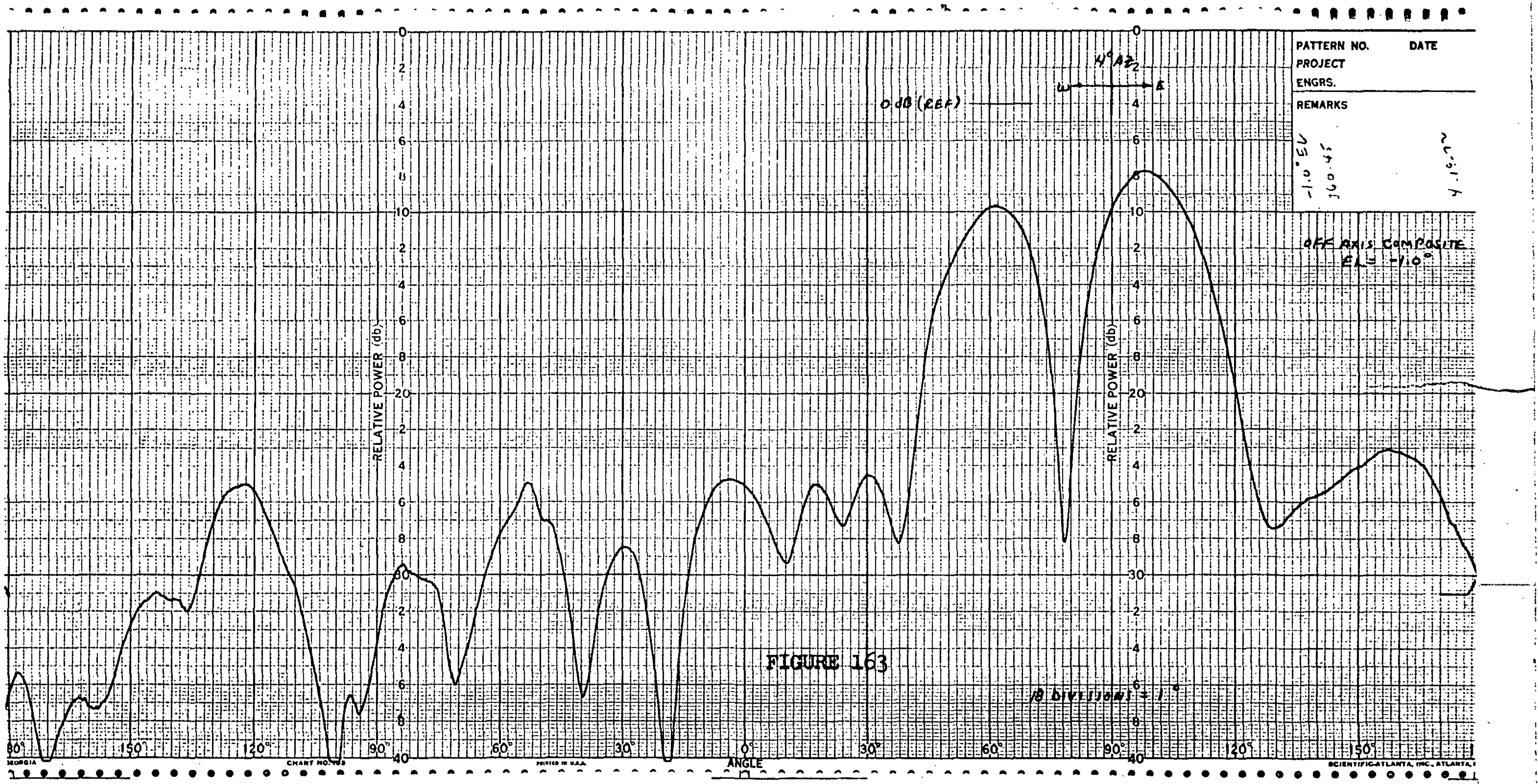

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
OFF AXIS COMPOSITE
EL = -1.0°
0 dB (REF)
W
E
RELATIVE POWER (db)
ANGLE
10 DIVISIONS = 1°

FIGURE 163

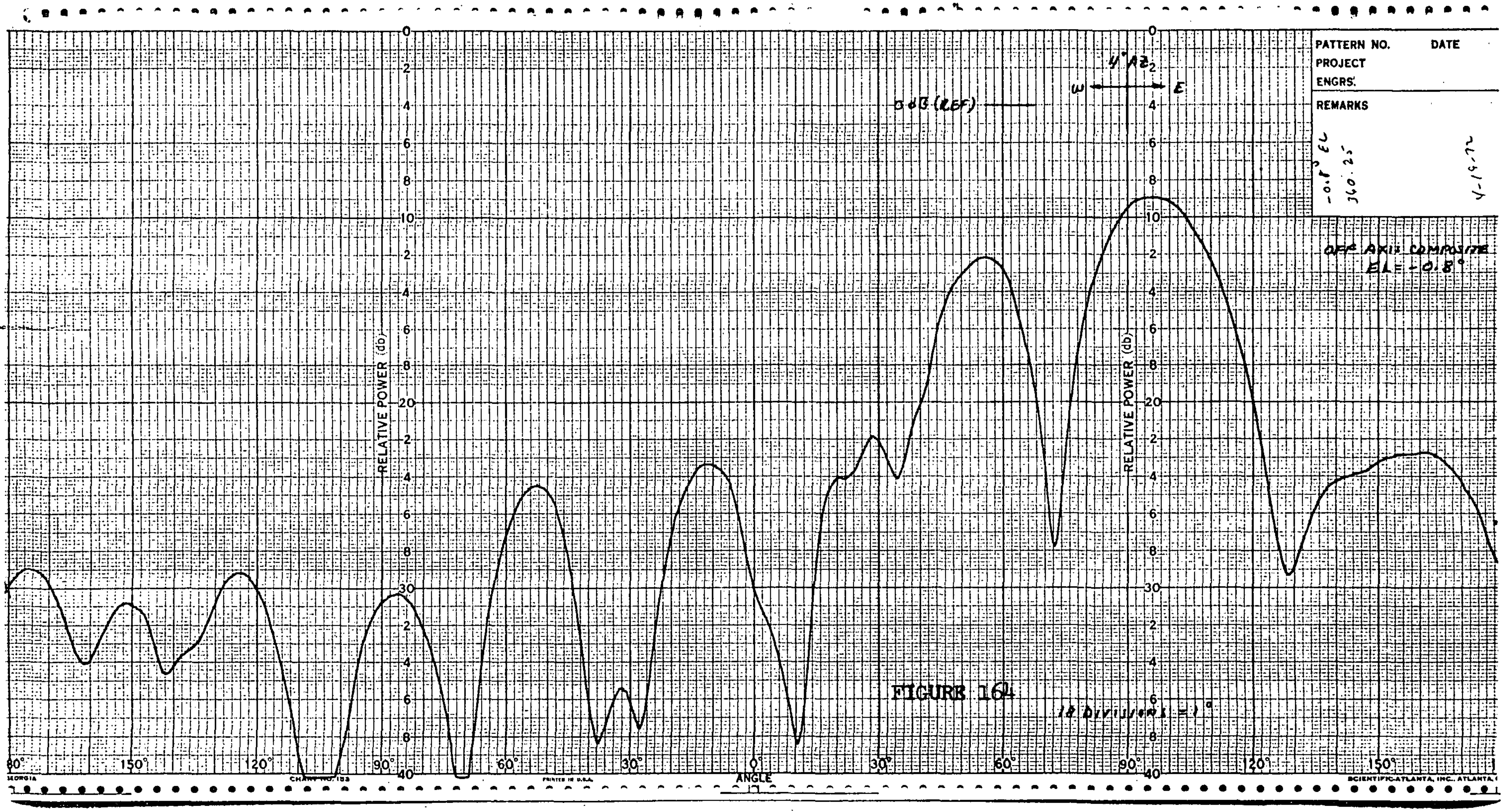

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
-0.8° EL
360.25°
4-19-72
4° AZ
W
E
0 dB (REF)
OFF AXIS COMPOSITE
EL = -0.8°
RELATIVE POWER (db)
RELATIVE POWER (db)
ANGLE
18 Divisions = 1°
180°
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 164

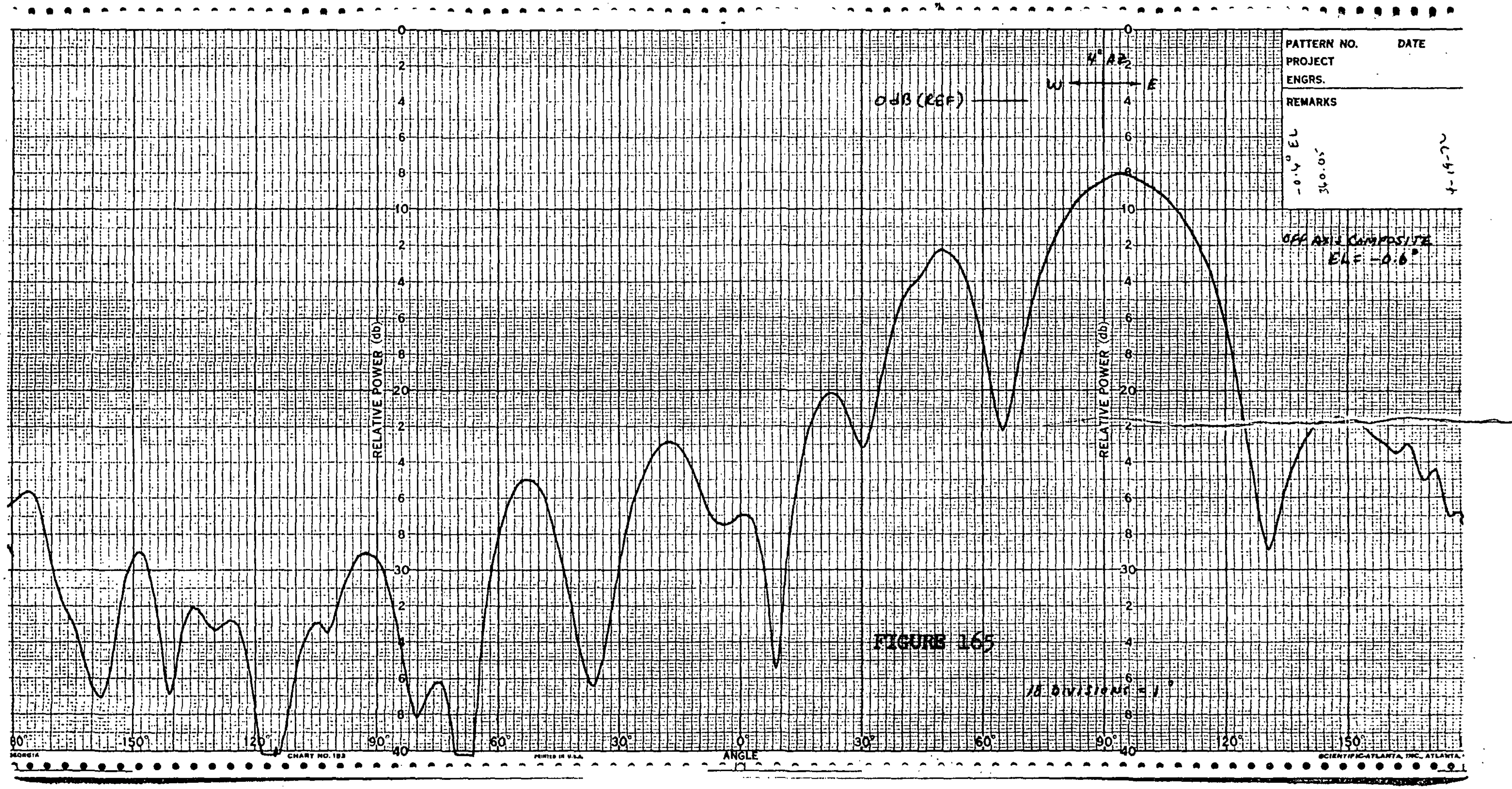

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
-0.4° EL
360.0°
0dB (REF)
4° AZ
W
E
OFF AXIS COMPOSITE
EL = -0.6°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 165

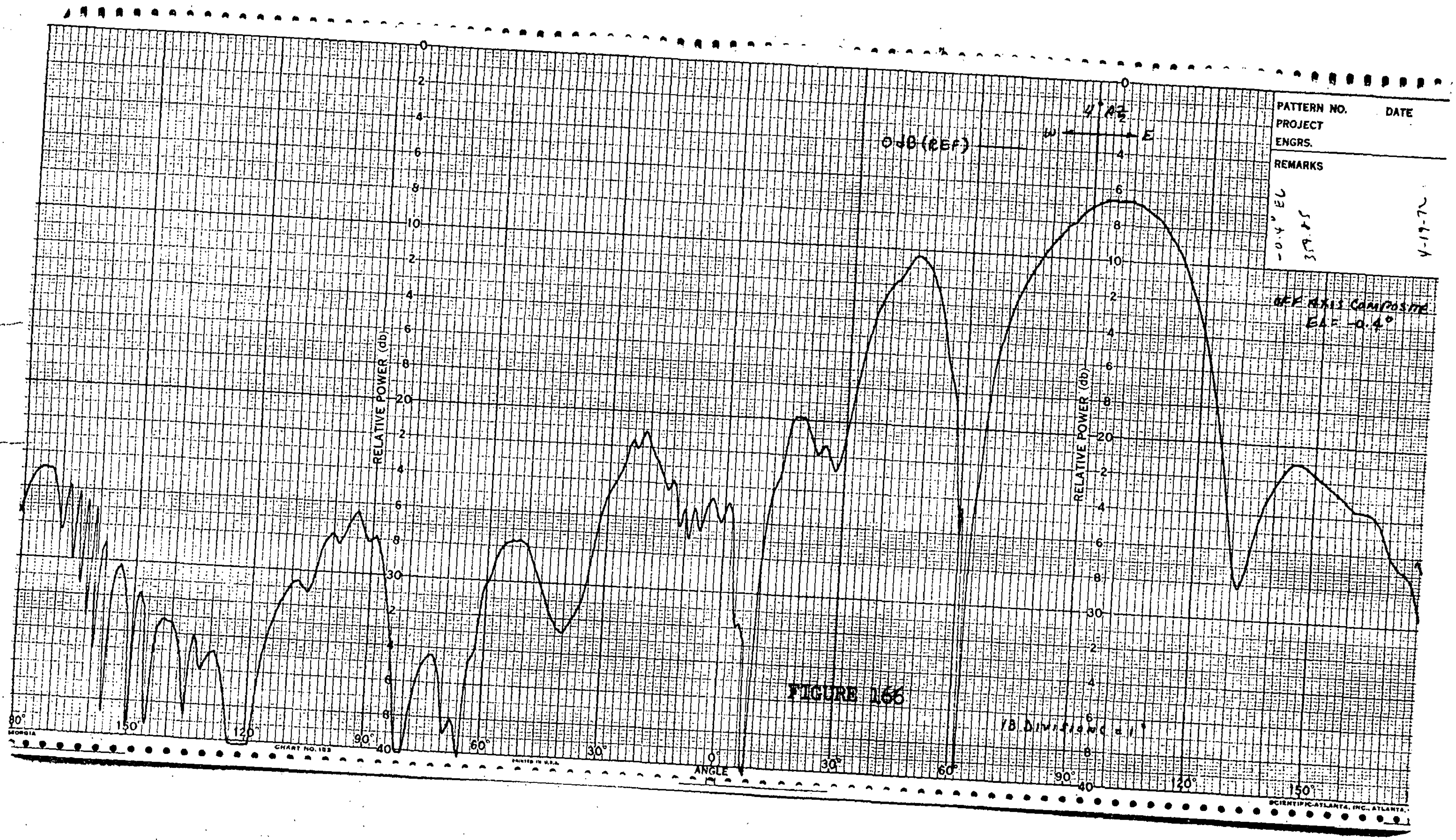
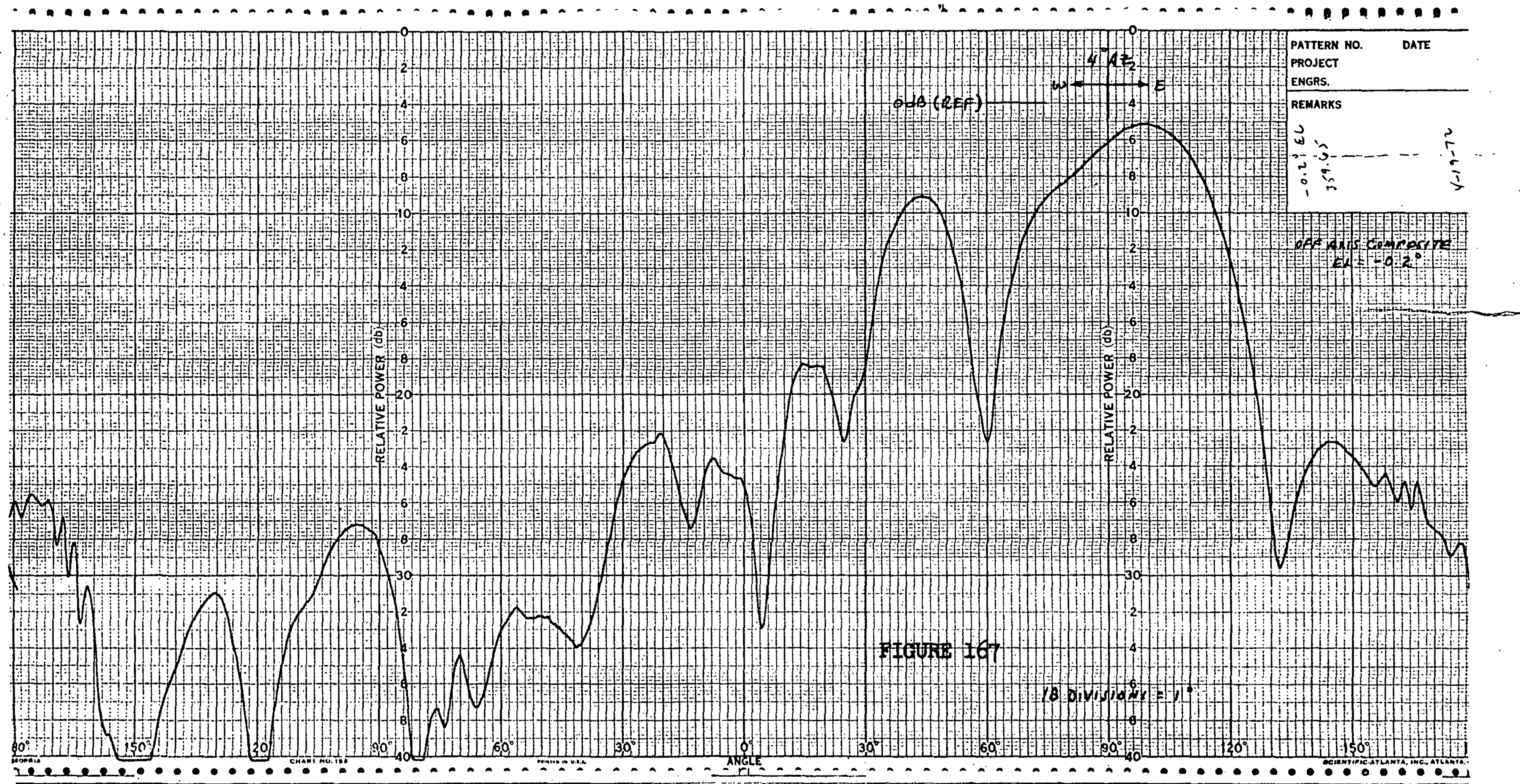
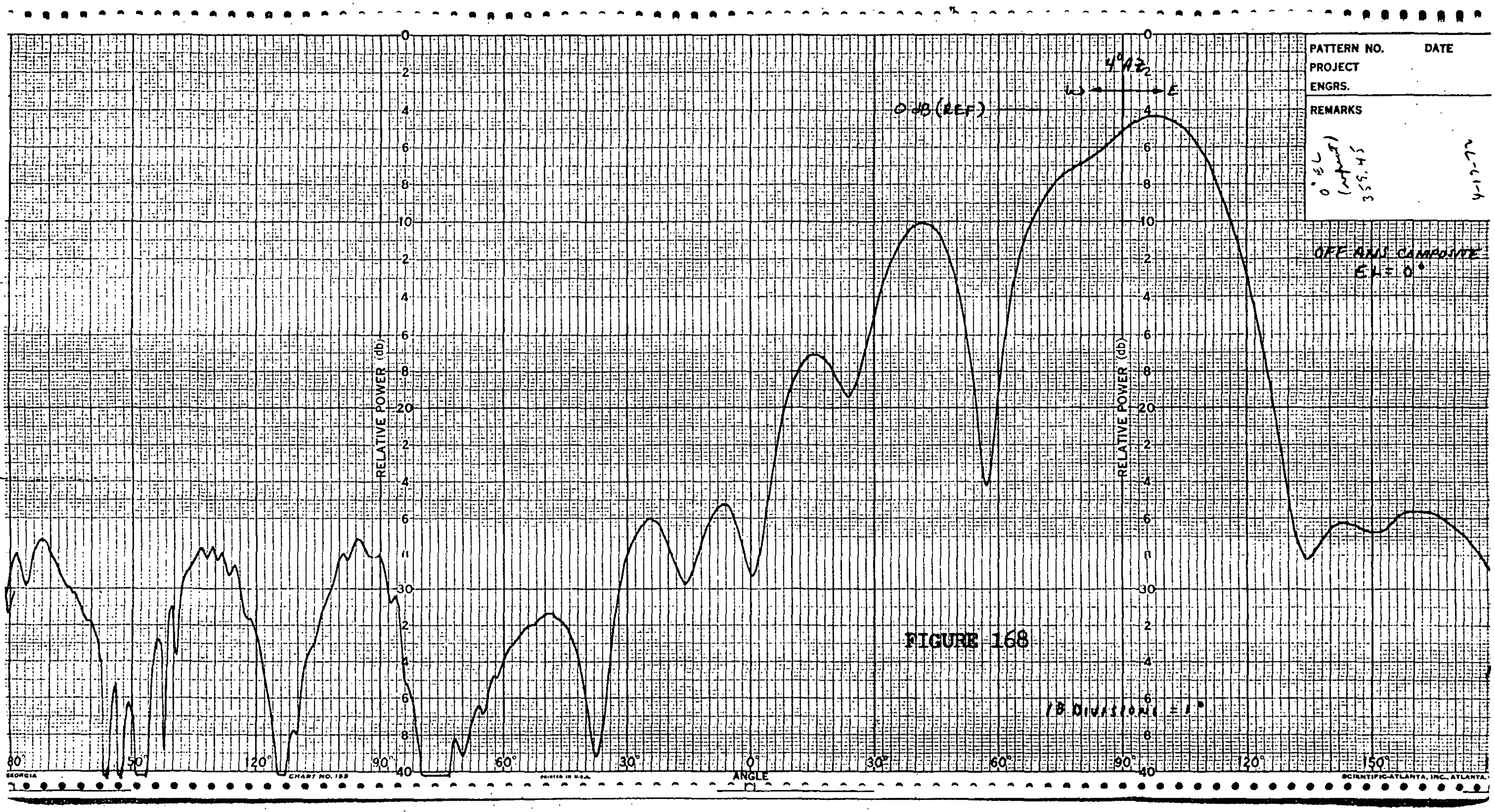

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
ANGLE
0dB (REF)
W
E
OFF AXIS COMPOSITE
EL = -0.4°
18 Divisions = 1°

FIGURE 166



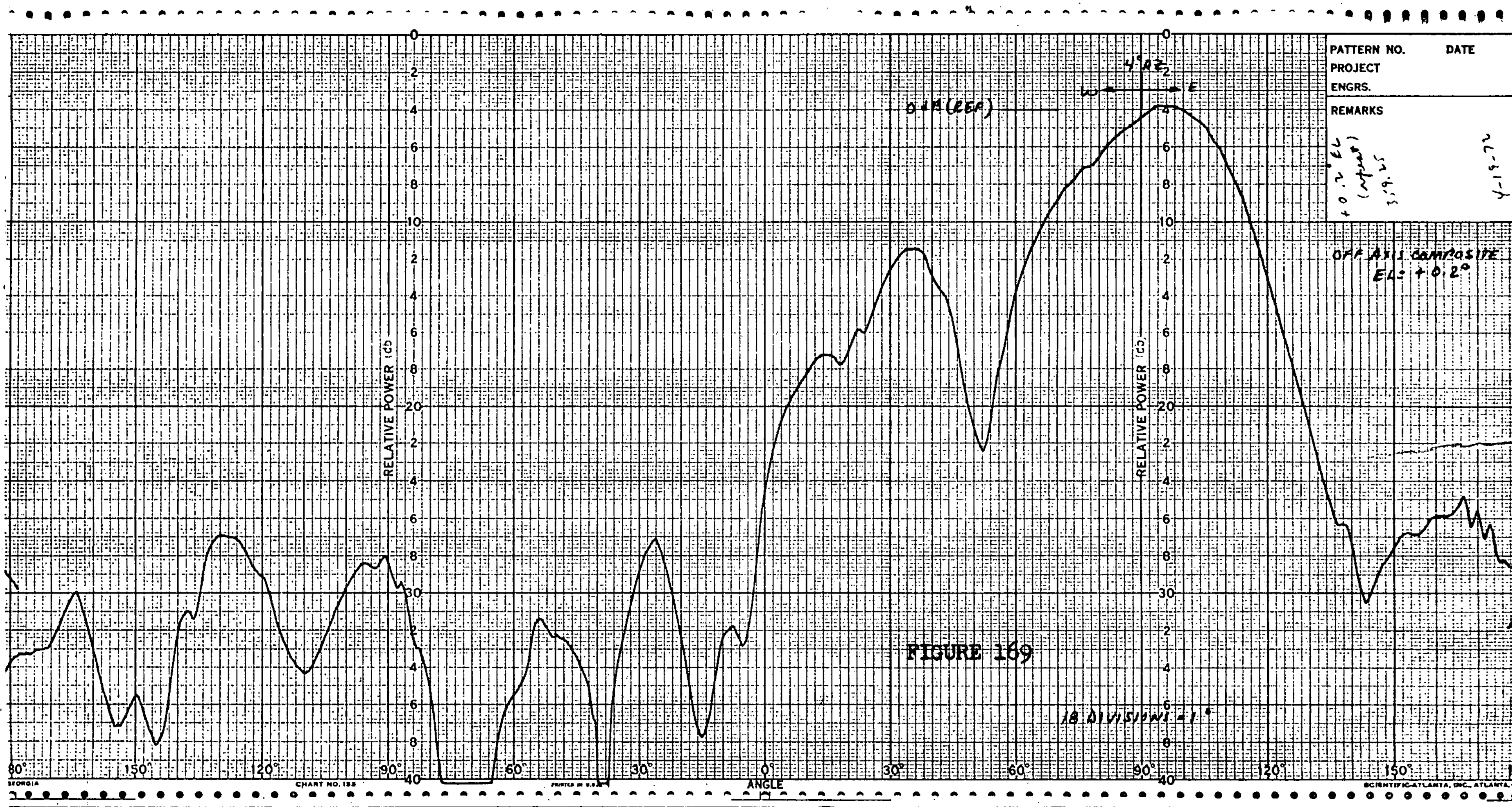
PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
-0.2° EL
359.65
4-19-72
4° AZ
W
E
0dB (REF)
OFF AXIS COMPOSITE
EL = -0.2°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 167



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
ANGLE
0 dB (REF)
W
E
OFF AXIS COMPOSITE
EL = 0°
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 168



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA,
OFF AXIS COMPOSITE
EL: +0.2°
4° AZ
W
E
18 DIVISIONS = 1°

FIGURE 169

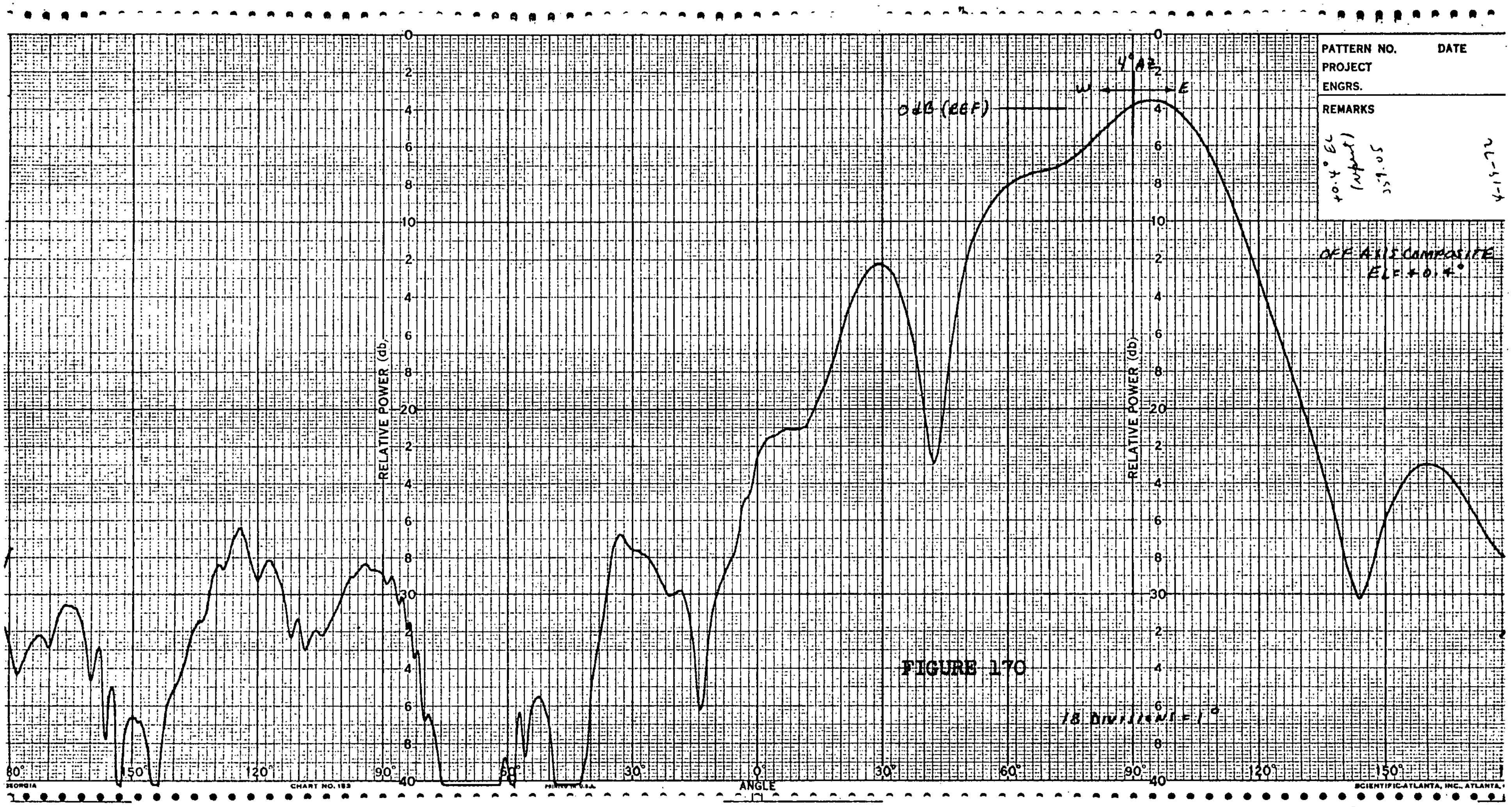

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0dB (REF)
W
E
OFF AXIS COMPOSITE
EL=+0.4°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 170

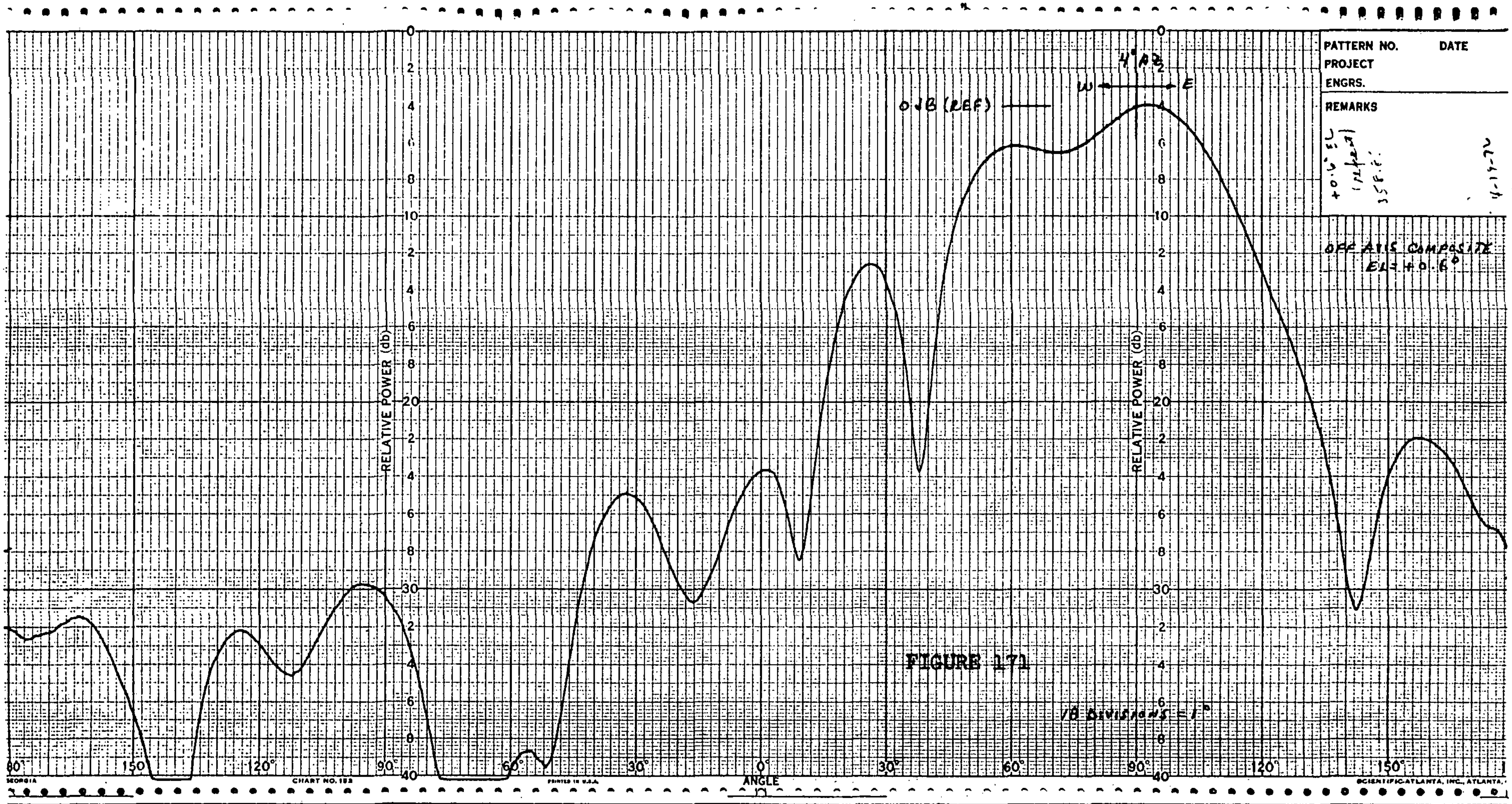
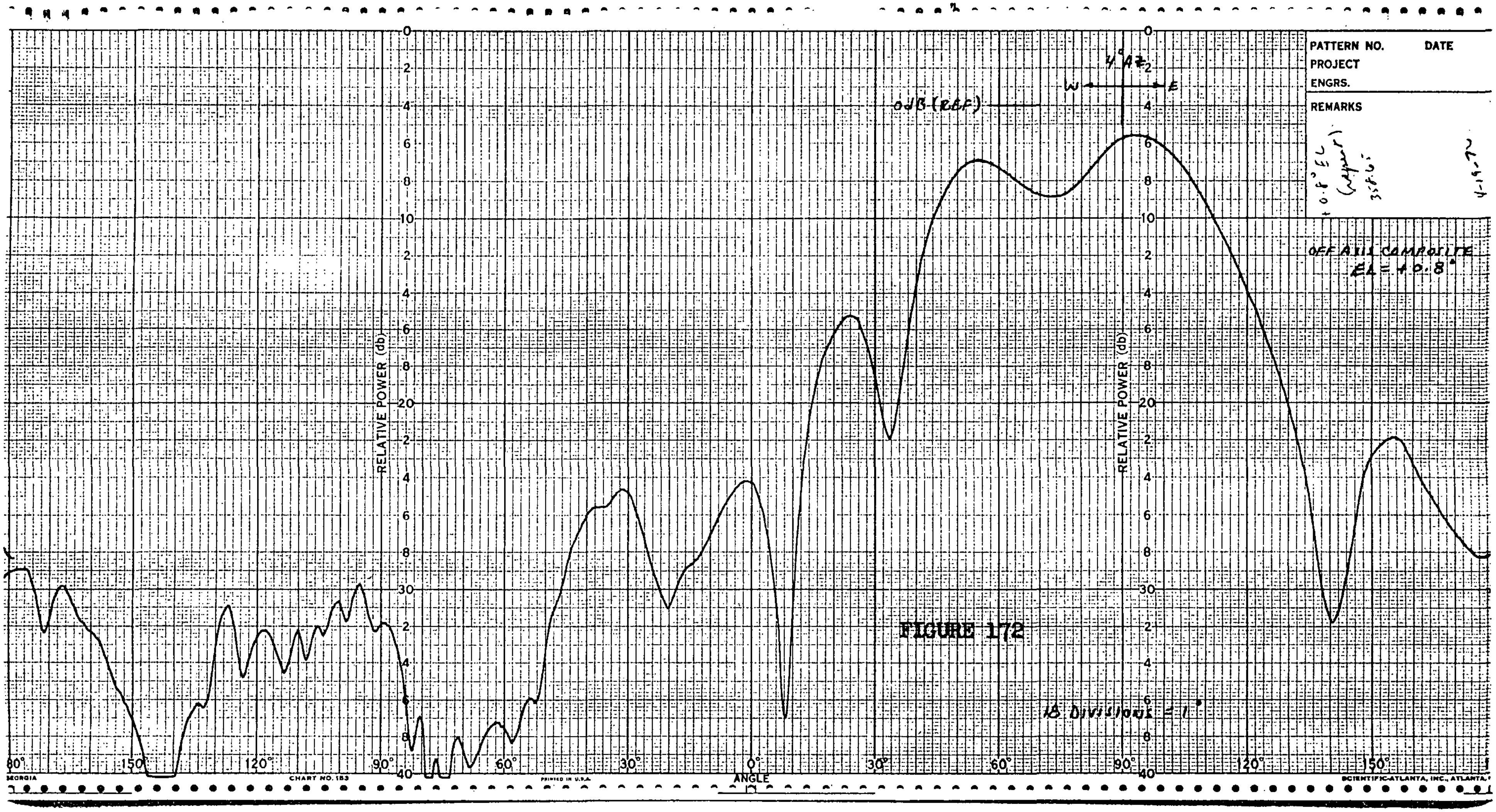

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA
0 dB (REF)
W
E
OFF AXIS COMPOSITE
EL = +0.6°

FIGURE 171


PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0dB (REF)
W
E
OFF AXIS COMPOSITE
EL = +0.8°
18 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
CHART NO. 183
PRINTED IN U.S.A.
SCIENTIFIC-ATLANTA, INC., ATLANTA,
GEORGIA
FIGURE 172

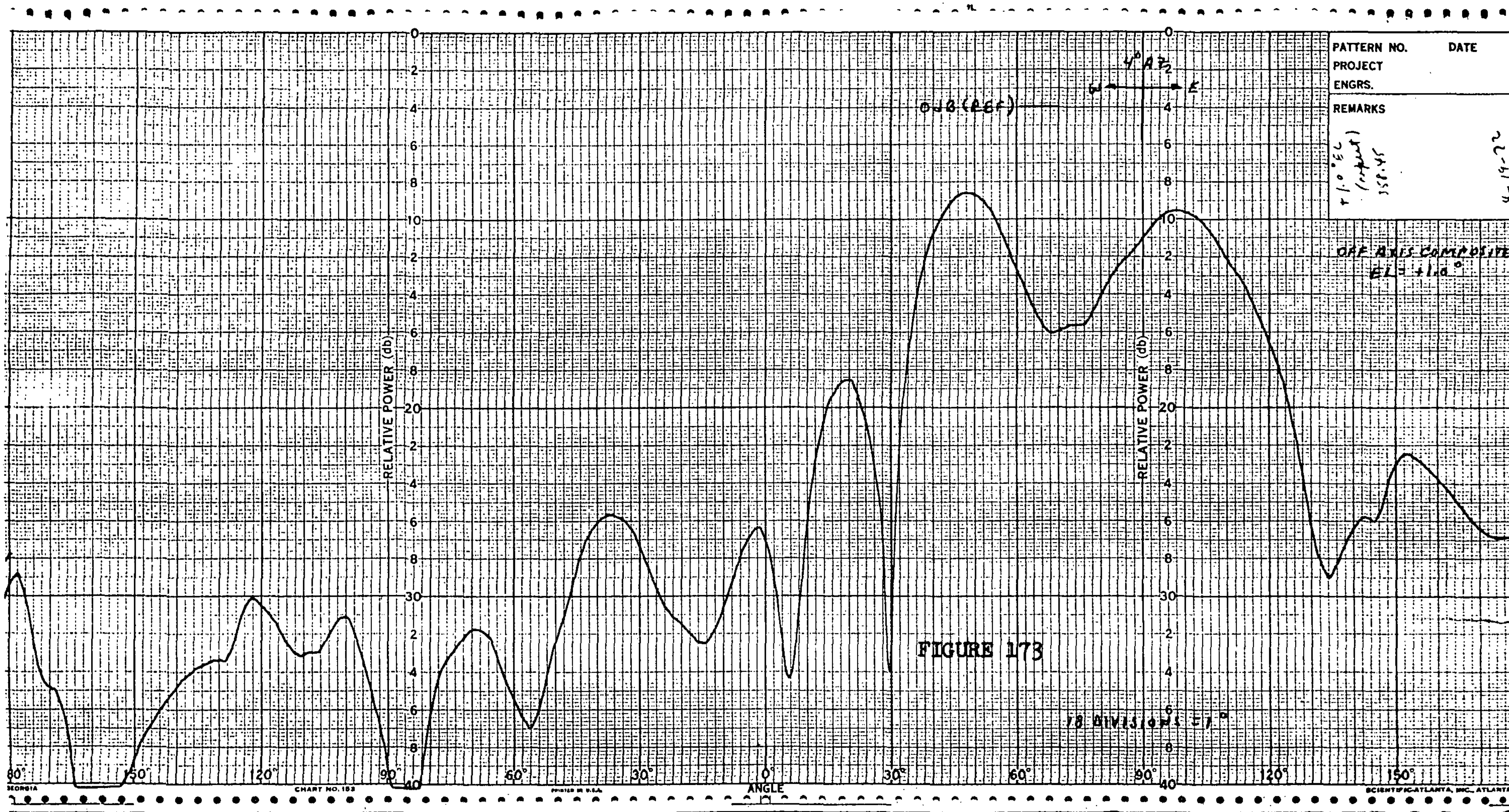
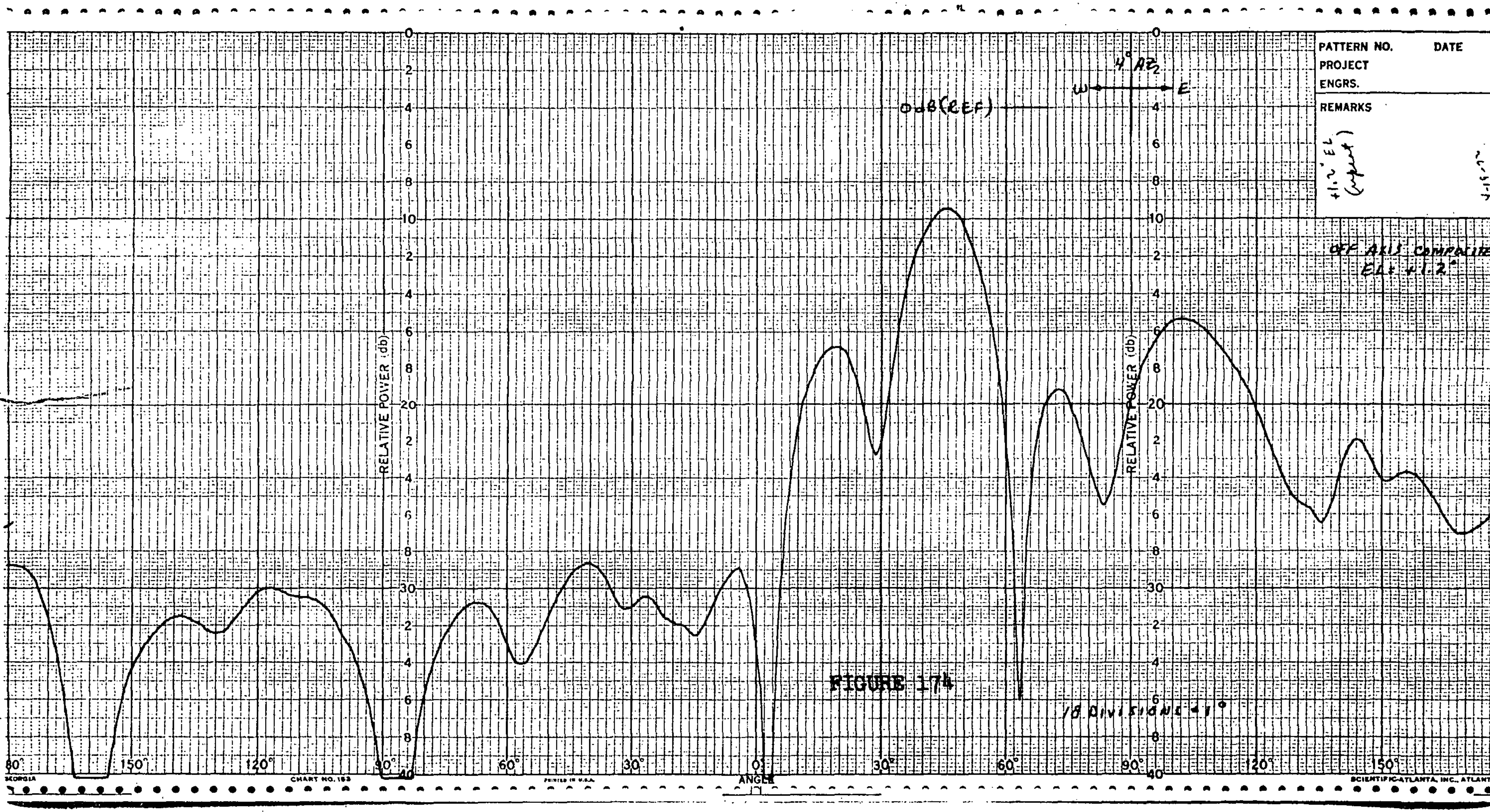

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
4-19-72
OFF AXIS COMPOSITE
EL = +1.0°
OJB (REF)
W
E
RELATIVE POWER (db)
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 173



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
4° AZ
W
E
0 dB (REF)
OFF AXIS COMPOSITE
EL: +1.2°
RELATIVE POWER (db)
ANGLE
18 DIVISIONS = 1°
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 174

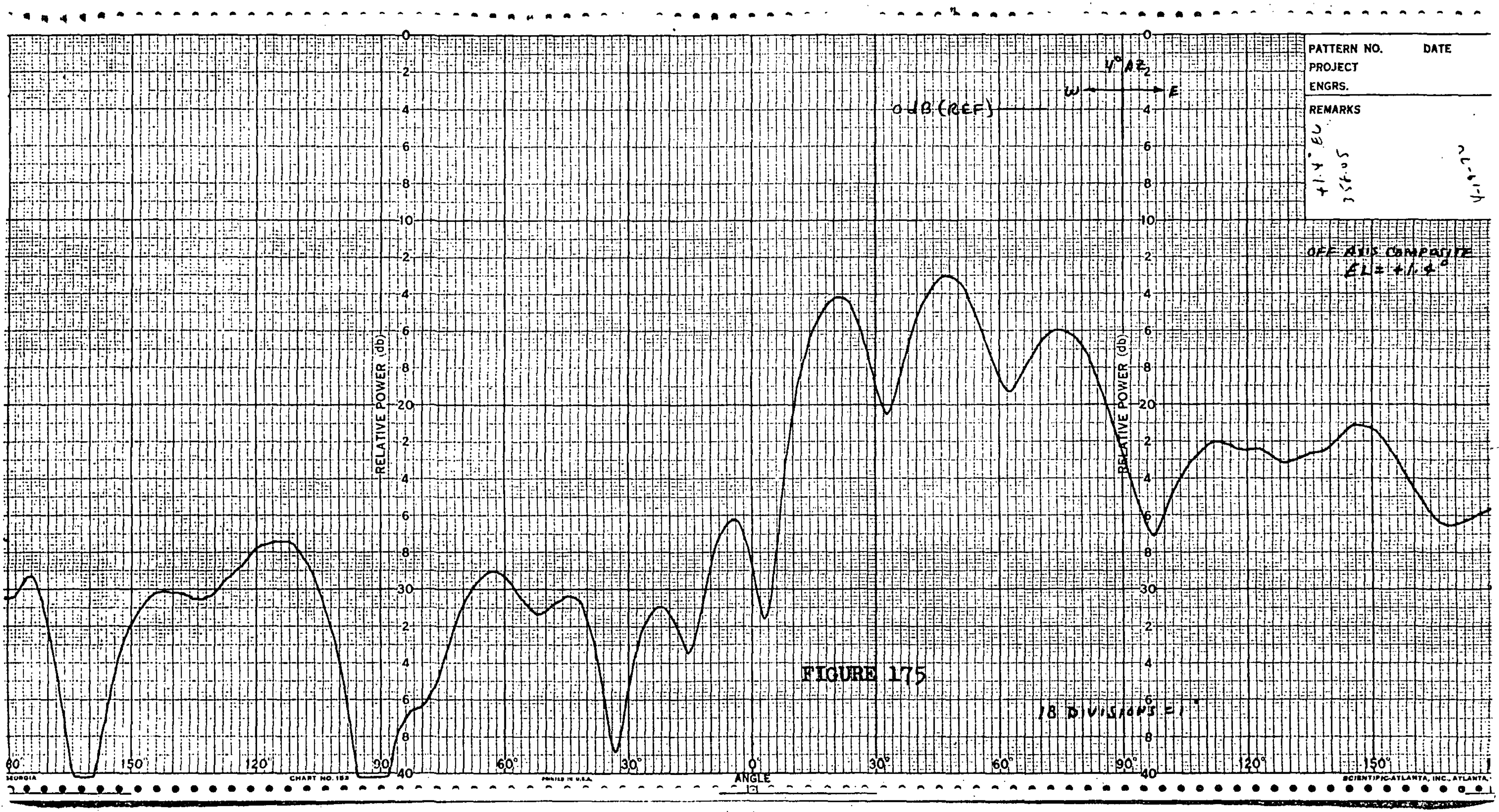
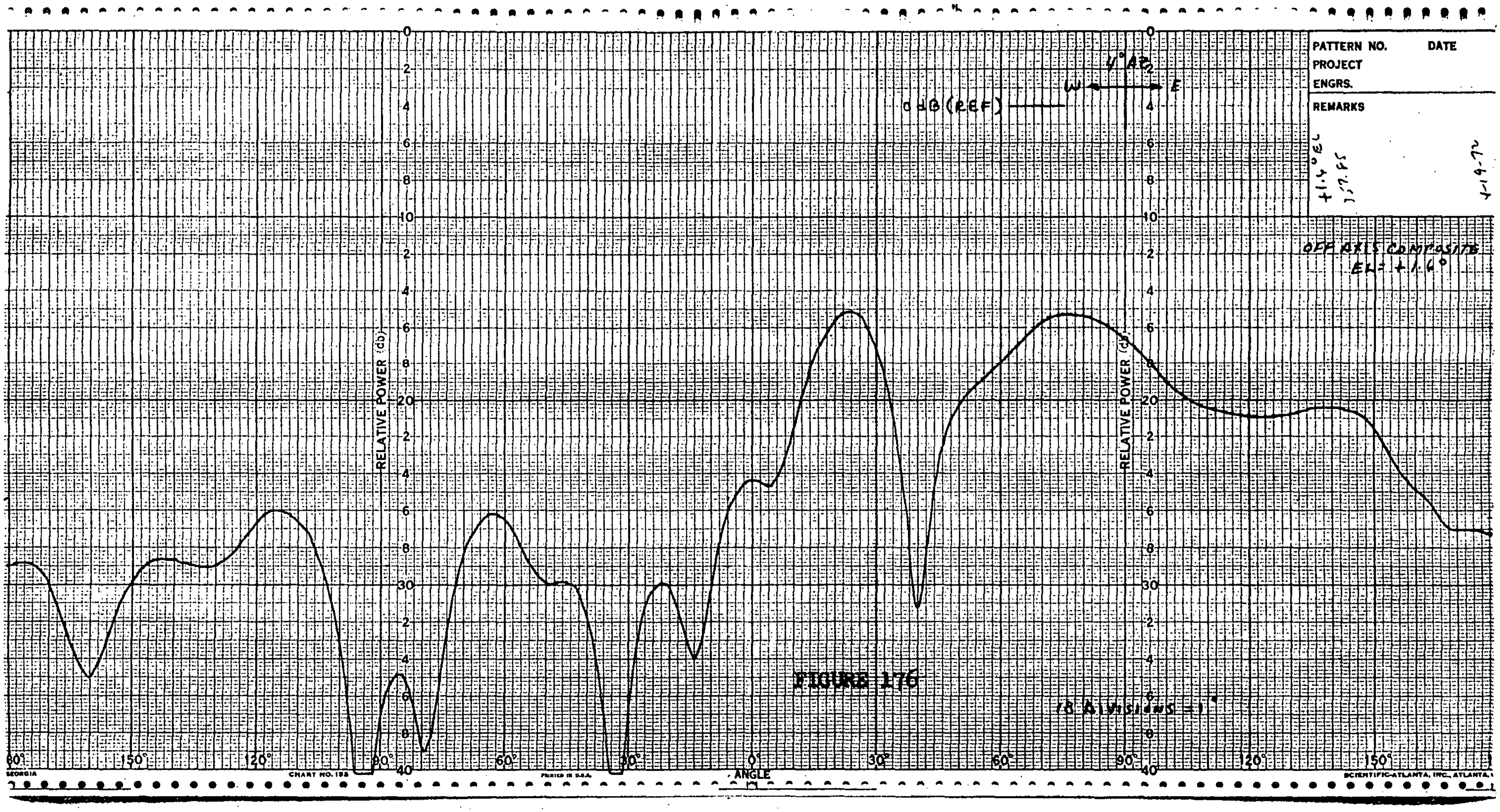

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (REF)
4° AZ
W
E
OFF AXIS COMPOSITE
EL = +1.4°
RELATIVE POWER (db)
RELATIVE POWER (db)
18 DIVISIONS = 1°
ANGLE
CHART NO. 153
SCIENTIFIC-ATLANTA, INC., ATLANTA,

FIGURE 175



PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
0 dB (REF)
W
E
OFF AXIS COMPOSITE
EL = +1.6°
18 DIVISIONS = 1°
RELATIVE POWER (db)
ANGLE
CHART NO. 183
SCIENTIFIC-ATLANTA, INC., ATLANTA

FIGURE 176

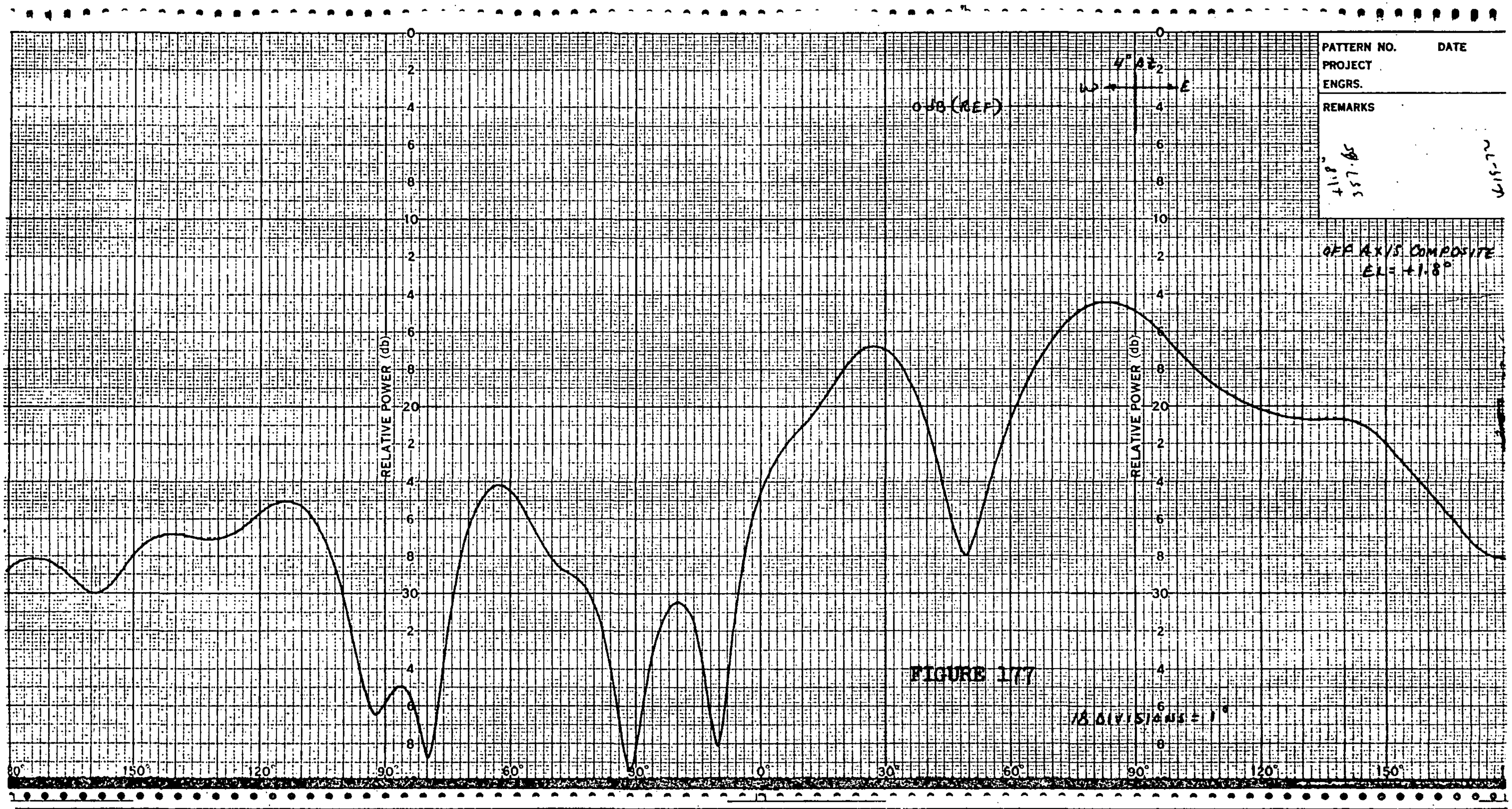

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
0dB (REF)
4° AZ
W
E
OFF AXIS COMPOSITE
EL = +1.8°
18 DIVISIONS = 1°
180° 150° 120° 90° 60° 30° 0° 30° 60° 90° 120° 150°

FIGURE 177

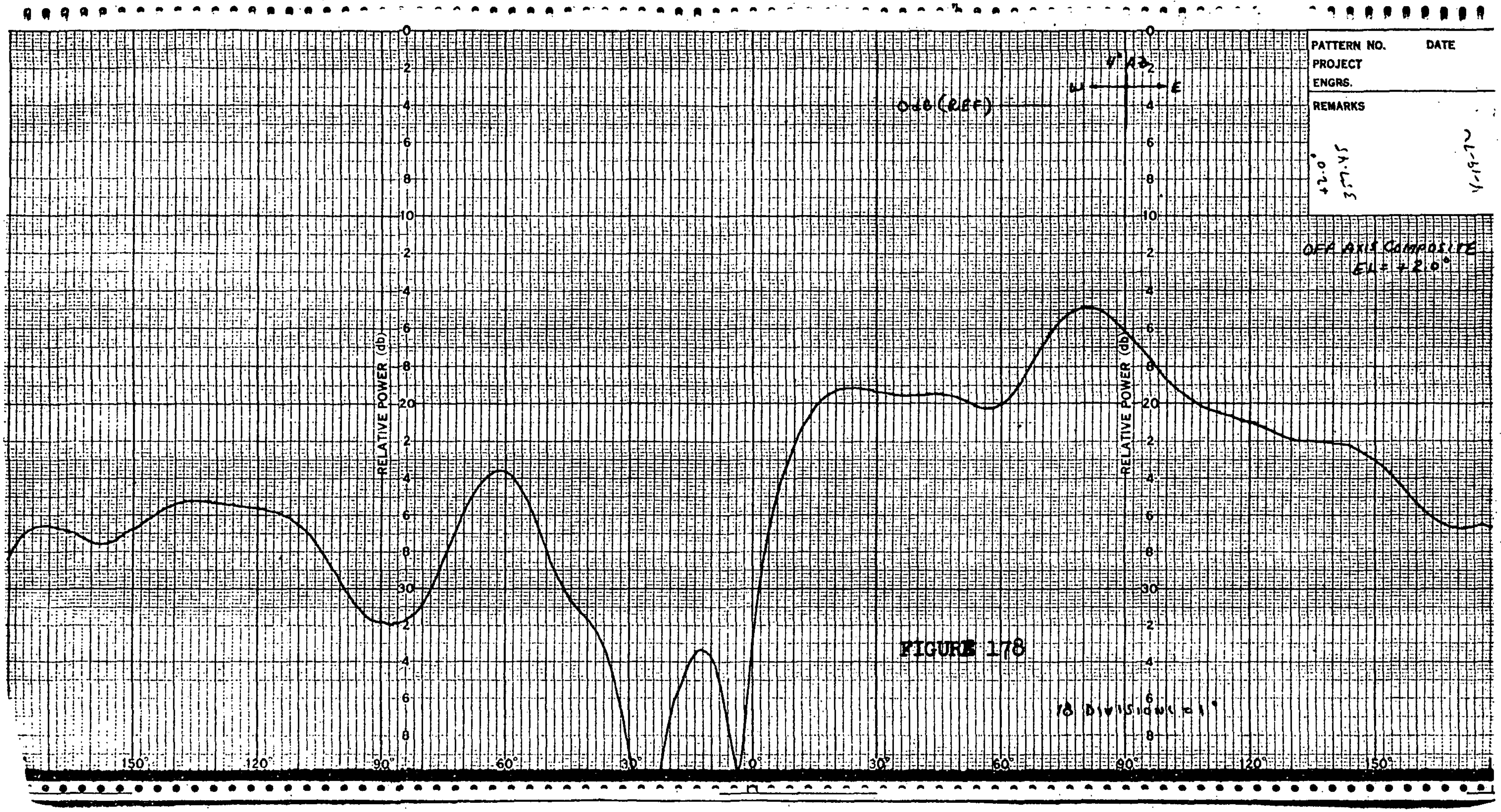

PATTERN NO.
DATE
PROJECT
ENGRS.
REMARKS
RELATIVE POWER (db)
0 dB (REF)
W
E
OFF AXIS COMPOSITE
EL = +2.0°
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
150°

FIGURE 178

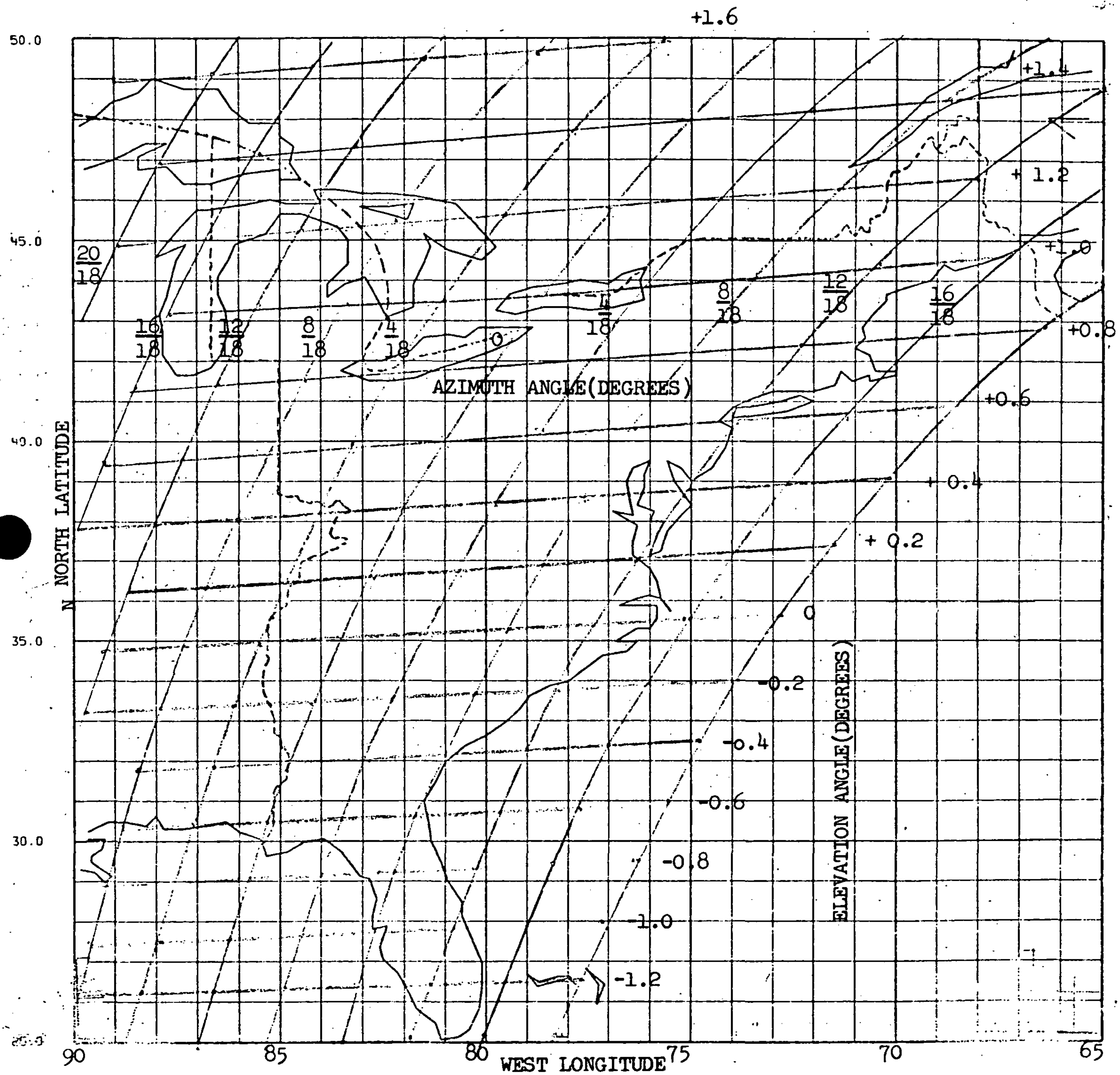


FIG. 17.9 CONSTANT AZIMUTH AND ELEVATION OVERLAYS

SATELLITE LOCATION____ 112 DEG. W. LONG.

REFLECTOR BORESIGHT____ 35 DEG. N. LAT.

83.5 DEG. W. LONG.

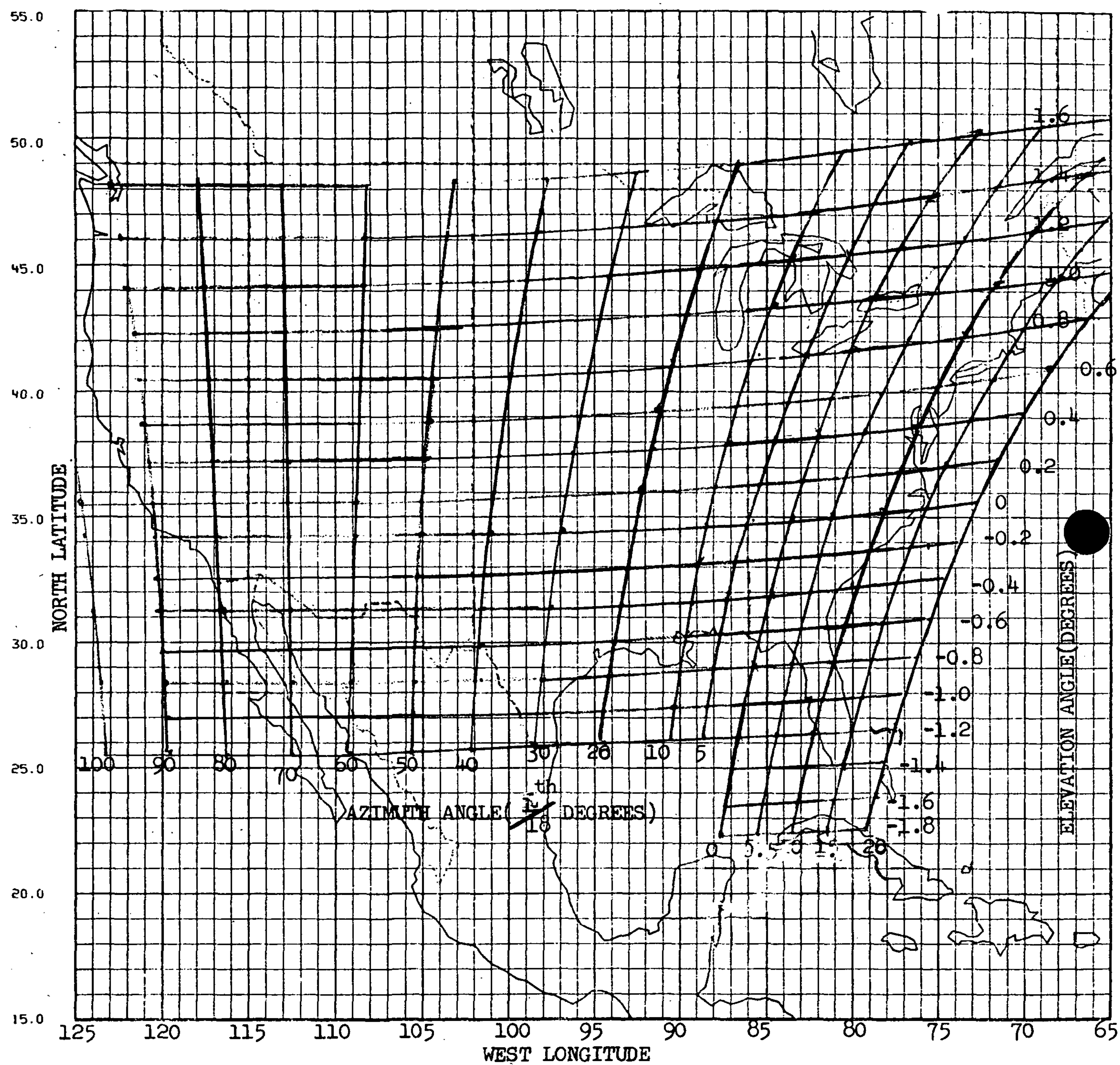


FIG. 180 CONSTANT AZIMUTH AND ELEVATION OVERLAYS

SATELLITE LOCATION ______ 112 DEG. W. LONG.

REFLECTOR BORESIGHT ______ 35 DEG. N. LAT.
83.5 DEG. W. LONG.

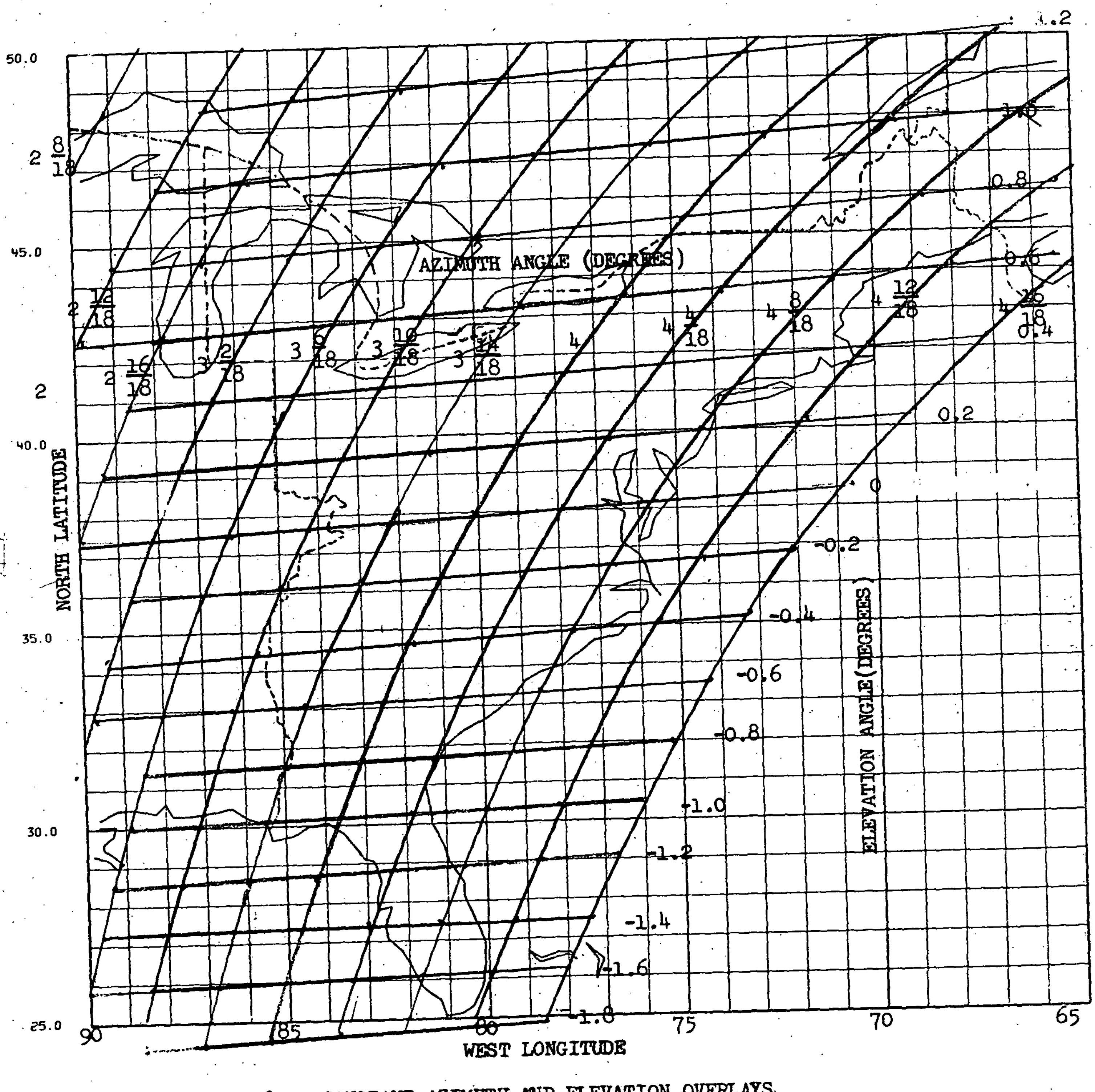


FIG. 181 CONSTANT AZIMUTH AND ELEVATION OVERLAYS

SATELLITE LOCATION_____ 112 DEG. W. LONG.

REFLECTOR BORESIGHT_____ 37 DEG. N. LAT.
112 DEG. W. LONG.

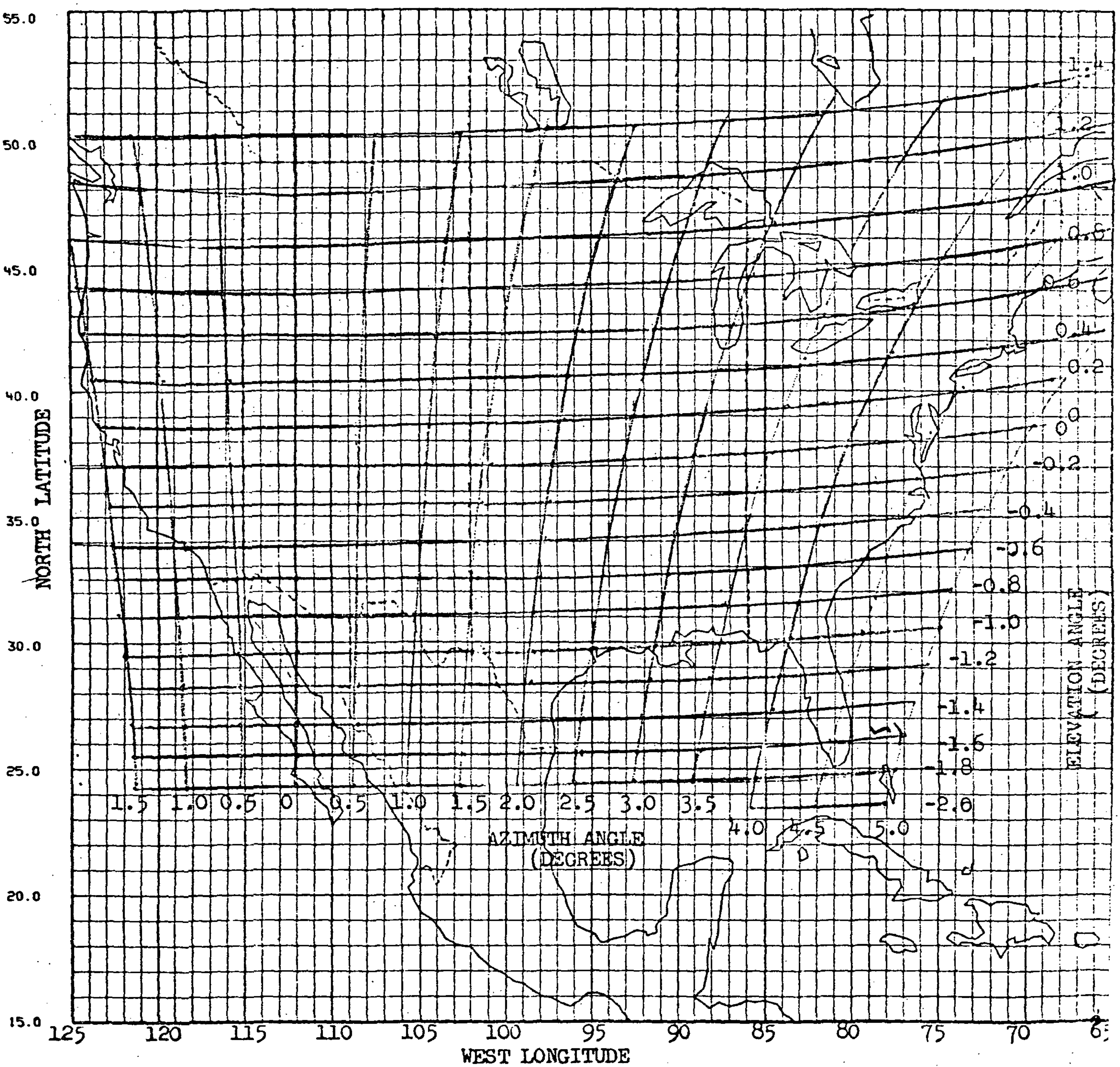


FIG. 182 CONSTANT AZIMUTH AND ELEVATION OVERLAYS

SATELLITE LOCATION _____ 112 DEG. W. LONG.

REFLECTOR BORESIGHT ____ 37 DEG. N. LAT.

112 DEG. W. LONG.

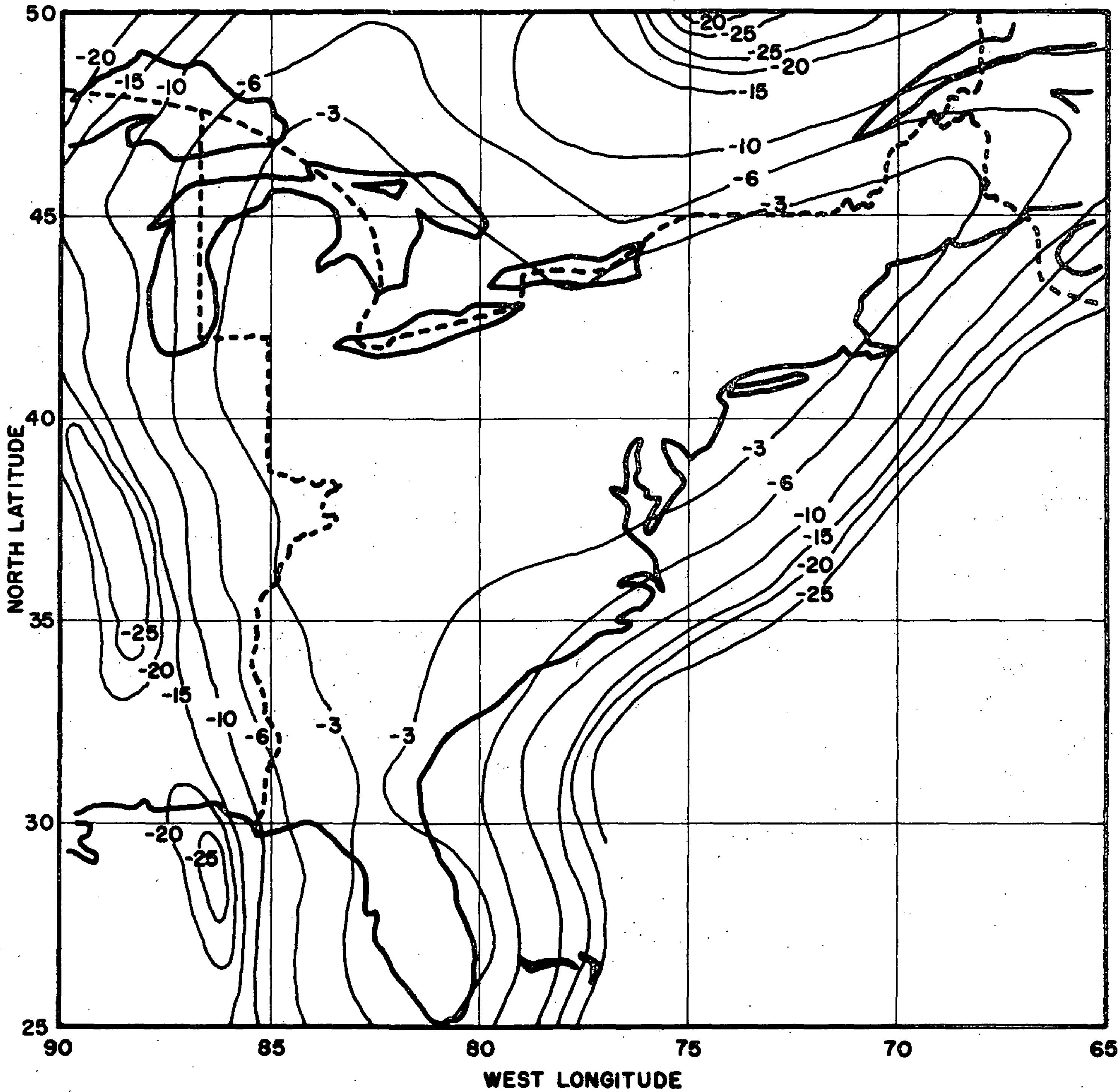


FIG. 183 COMPOSITE AMPLITUDE CONTOURS ON AXIS FEED CLUSTER
12 FT. DIAMETER REFLECTOR 10 GHZ.

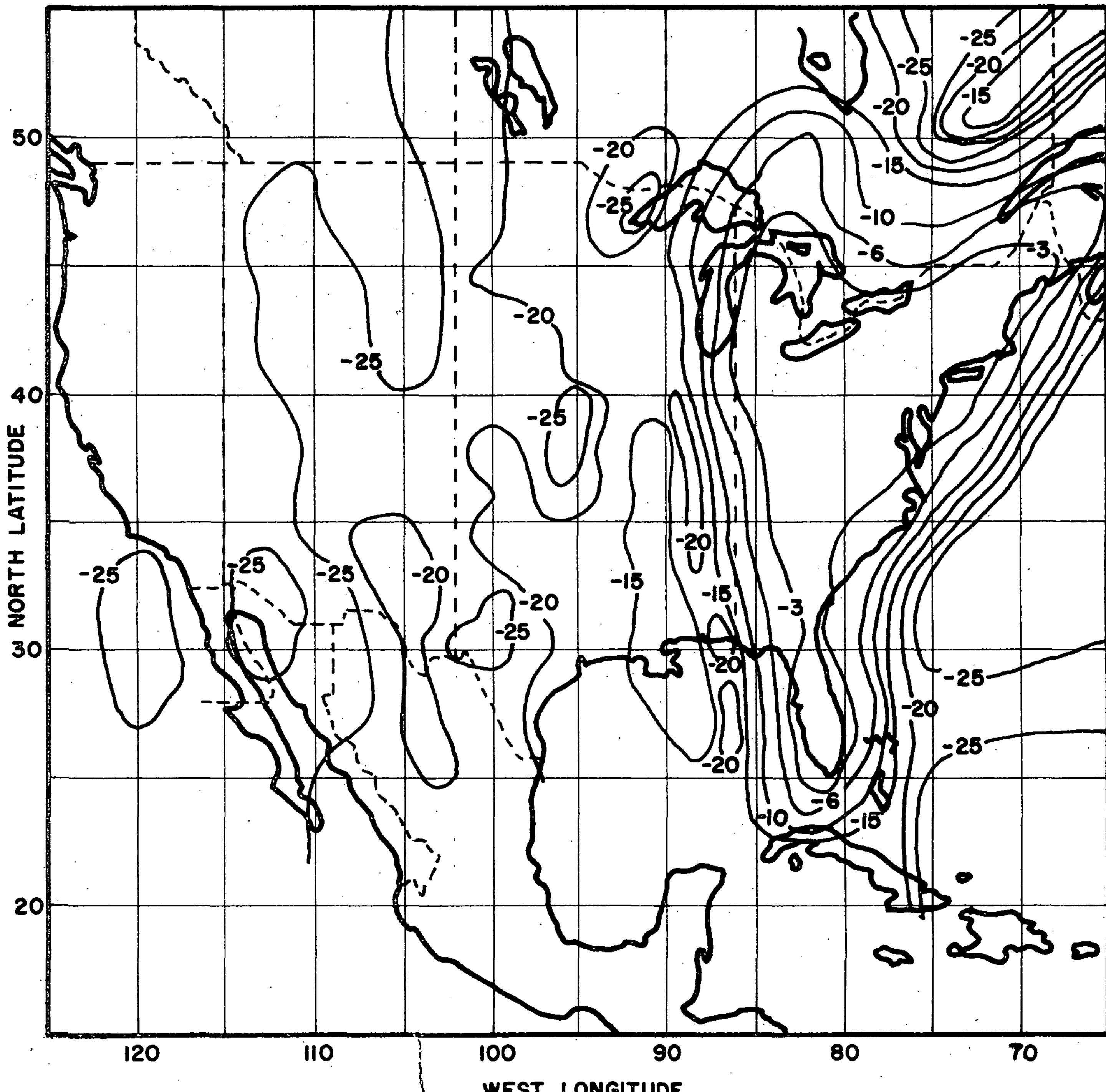


FIG. 184 COMPOSITE AMPLITUDE CONTOURS ON AXIS FEED CLUSTER
12 FT. DIAMETER REFLECTOR 10 GHZ.

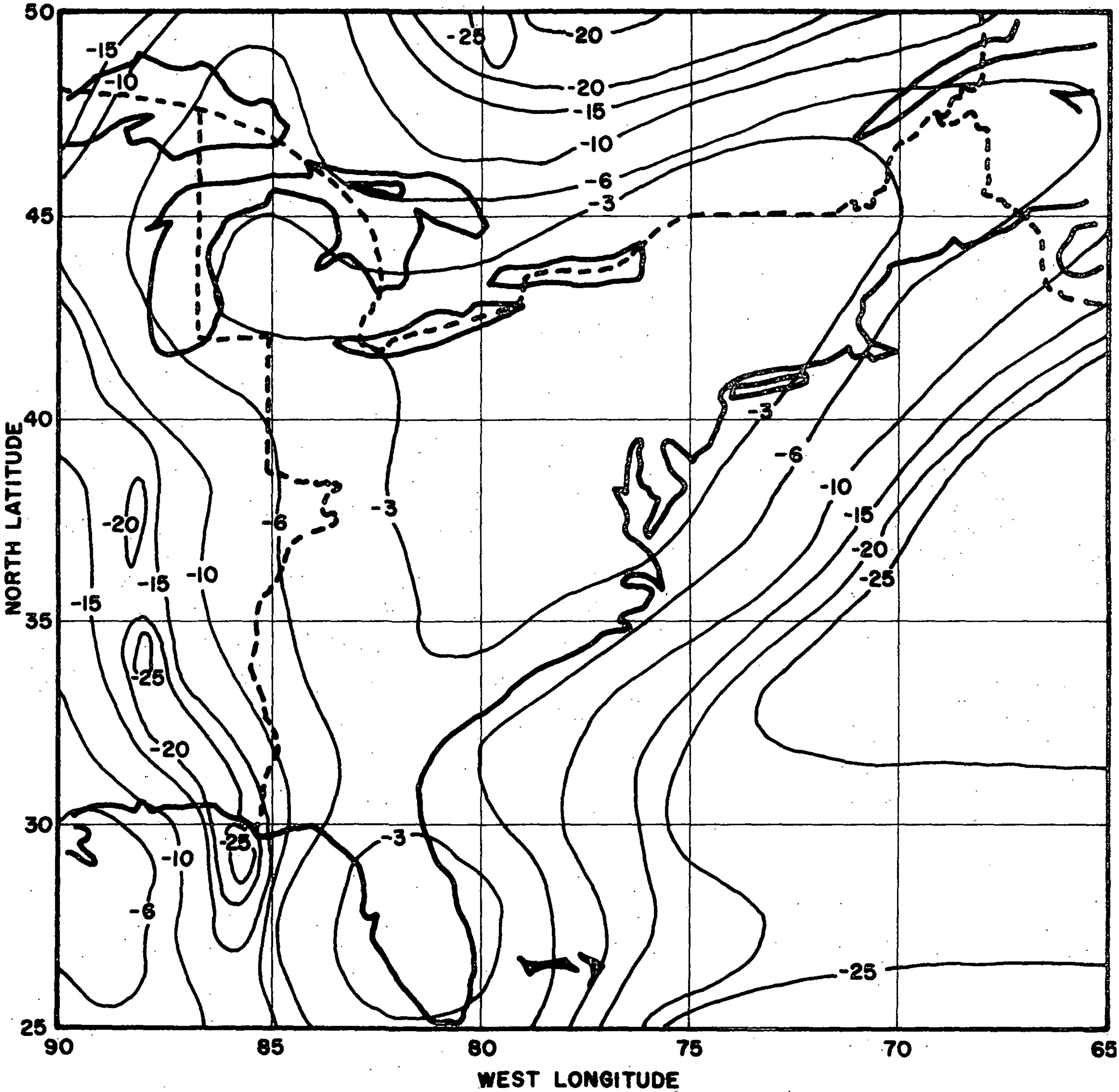


FIG. 185 COMPOSITE AMPLITUDE CONTOURS OFF AXIS FEED CLUSTER

12 FT. DIAMETER REFLECTOR 10 GHZ.

/F6

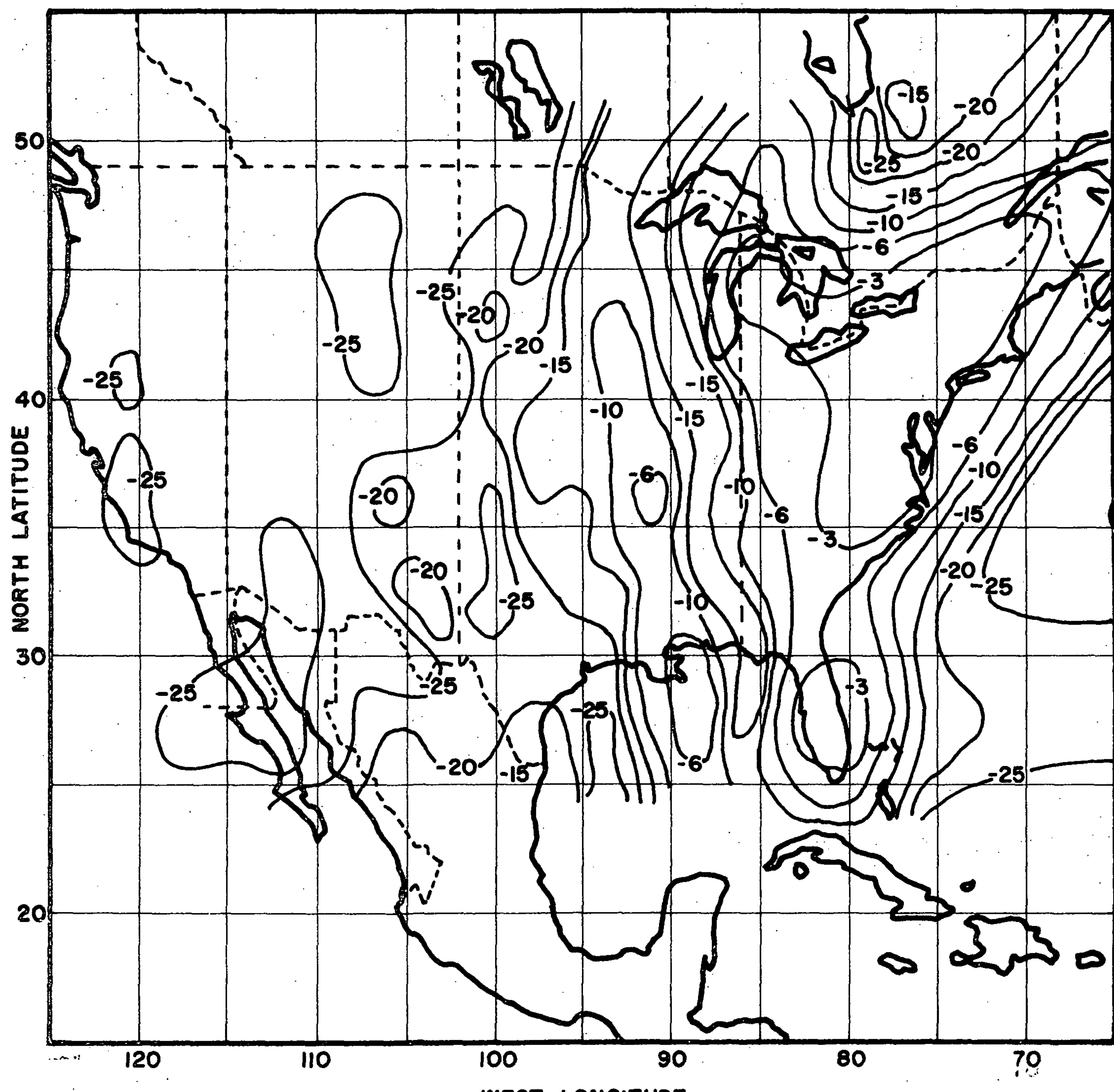


FIG. 186 COMPOSITE AMPLITUDE CONTOURS OFF AXIS FEED CLUSTER

12 FT. DIAMETER REFLECTOR 10 GHZ.

10

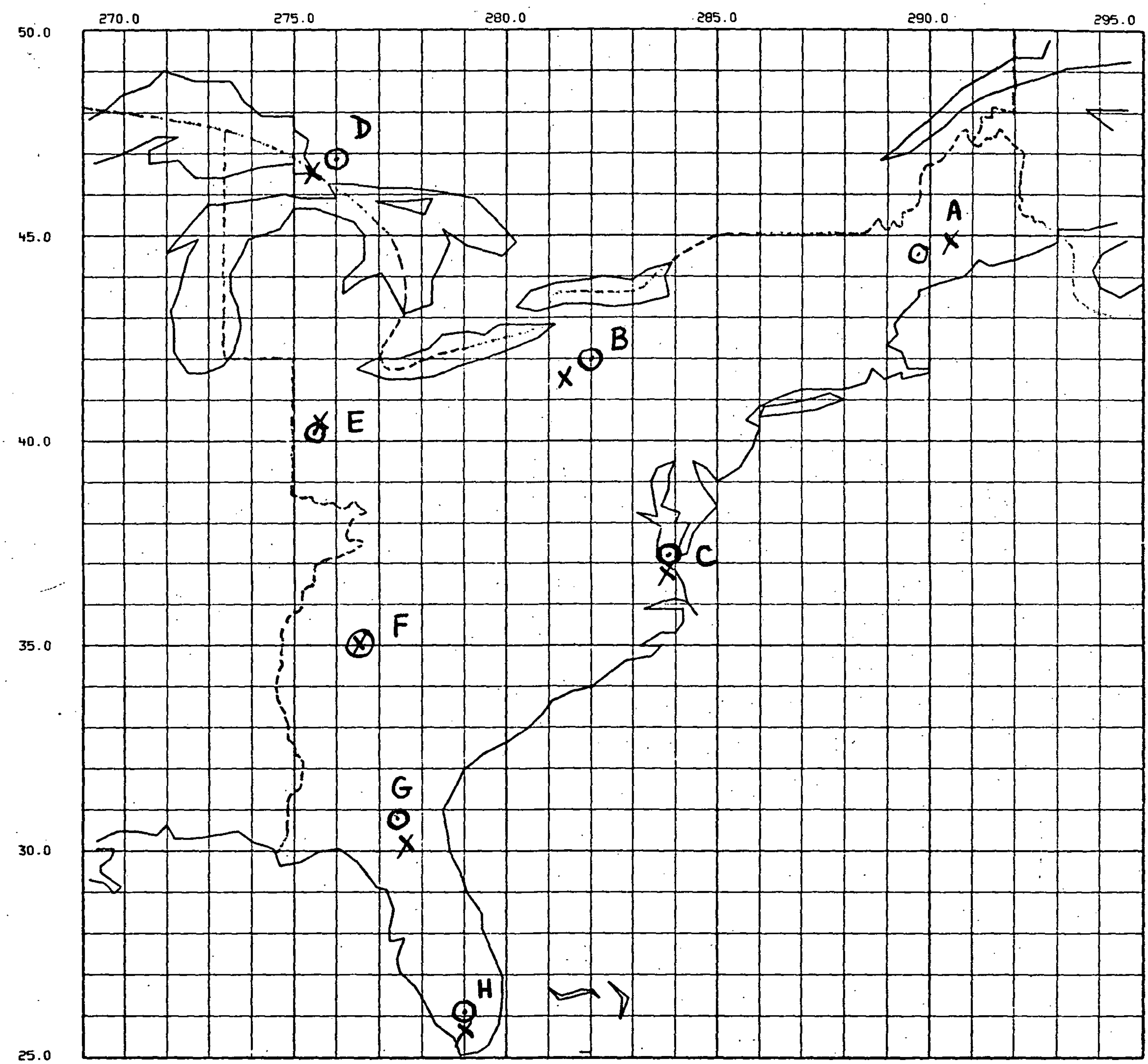


FIG. 187 SECONDARY BEAM BORESIGHTS ON_ AXIS CLUSTER

X CALCULATED ⊙ MEASURED

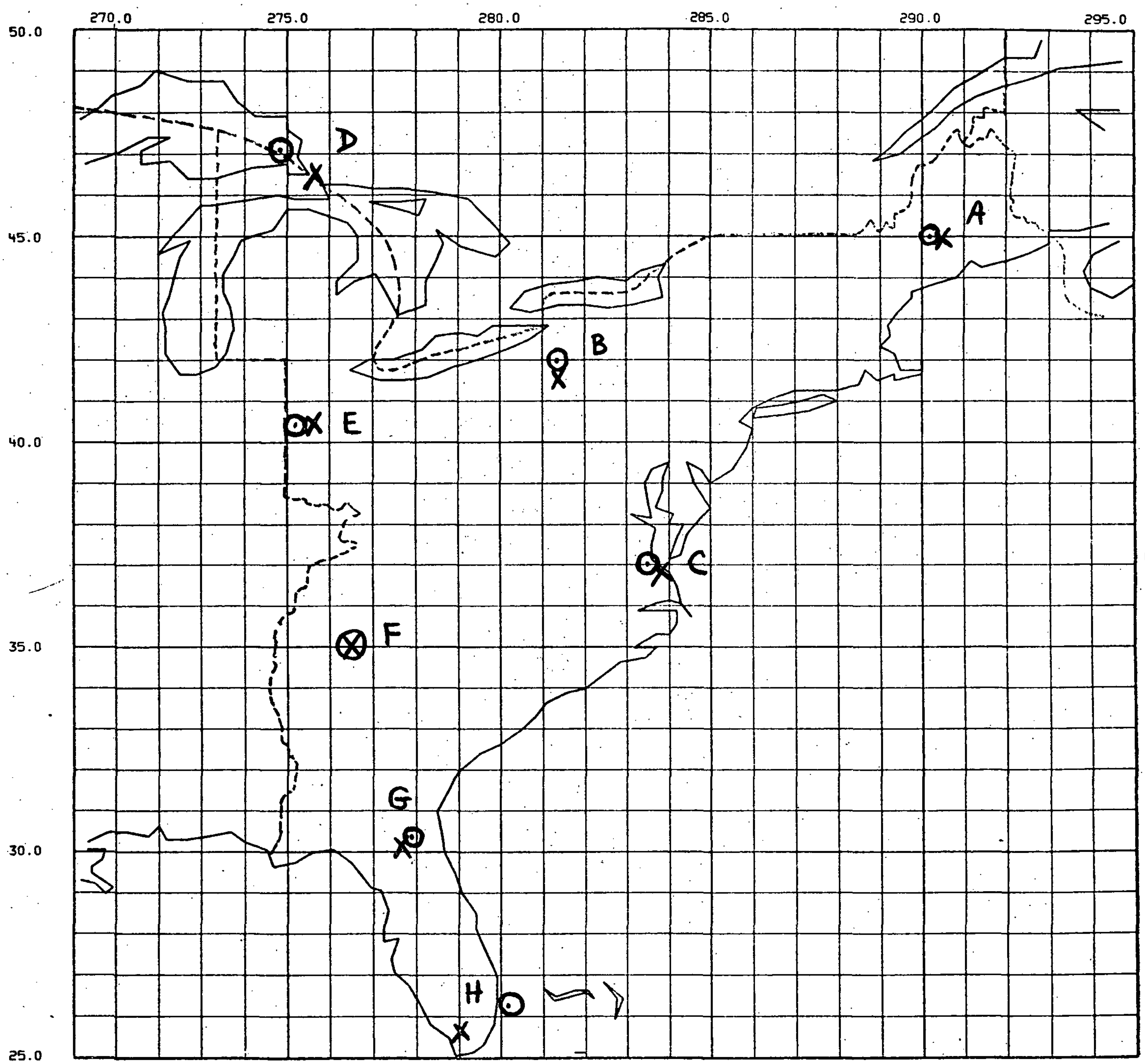


FIG. 188 SECONDARY BEAM BORESIGHTS OFF AXIS CLUSTER

X CALCULATED ⊙ MEASURED

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The following conclusions are made regarding this study effort:

(1) A 30 ft. diameter reflector operating at a frequency of 4 GHZ, and with 8 feeds, fed with equal amplitude and phase, was designed to produce a composite pattern whose shape followed the irregular outline of the Eastern United States Time Zone when the antenna was located on a synchronous orbit satellite.

(2) A reduced physical size feed was designed and proved successful which allowed the eight feeds to be spatially located in their proper relative positions to achieve the required composite beam.

(3) Eight feeds and the required feeding network were fabricated and tested in a 12 ft. diameter paraboloid at 10 GHZ (2/5 scale). Two separate focal plane feed cluster locations were used; one, on-axis, to simulate the situation when multiple reflectors would be used to cover the four time zones (each reflector bore sighted to the applicable time zone) and, the second, off-axis, to simulate the situation where one reflector would be used to cover all four time zones (the reflector would be bore sighted to Salt Lake City and the 4 feed clusters would be offset accordingly for the particular time zone to be covered).

(4) The measured composite patterns followed the outline of the irregularly shaped Eastern United States Time Zone.

(5) The measured composite patterns agreed with the patterns predicted from the analysis.

8.2 Recommendations

This study involved a large proportion of analysis compared to the experimental work completed. A large effort dealt with making the basic selection of an appropriate antenna approach, and with developing analytical tools and computer programs to aid in the analysis of possible candidate systems and to facilitate evaluation of the experimental results.

It is recommended that a follow-on program be initiated which would reverse the apportionment of effort into analytical and experimental areas. The analytical tools developed here would be used to predict beam bore sights and feed positions appropriate for achieving shaped beams required for the Central, Mountain, and Pacific Time Zones (feeds for coverage of Hawaii, Alaska, and the Caribbean could be included). Computer programs developed here would also be used to provide the necessary grids that have allowed us to display and interpret experimental results.

The reflector and feeds designed in this study could be used, or, as part of a more detailed investigation into pattern coverage limitations attributable to feed interaction, an improved feed could be designed.

Additional feeds would be fabricated during the proposed follow-on program, such that when used with the appropriate parabolic reflector, time zone (and other desired coverage area) beams could be synthesized. Patterns would be measured and displayed for a complete system in both the dominant and the orthogonal polarization modes so as to provide information on both the coverage provided and the potential interference with other beams.