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*Granger*

ARPA Cont. No. 3036

ELECTRONIC SYSTEMS

PROJECT VELA FINAL TECHNICAL REPORT

CONTRACT NO. AF 33(600)-43122

MARCH 6, 1962

Submitted To

Headquarters
USAF, (AFTAC)
Washington 25, D. C.

ARPA Order No. 159
Project Code No. 8200

GRANGER ASSOCIATES
974 Commercial Street
Palo Alto, California

# CONTENTS

# ILLUSTRATIONS

Headquarters
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Washington 25, D. C.

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# SECTION I

## INTRODUCTION

The objective of this portion of project VELA is the design of a prototype antenna system for use in detecting nuclear explosions by means of a backscatter technique. Background information provided by USAF covered the following points.

(1) As a part of a nuclear test ban control system discussed by the Conference of Experts at Geneva, the Technical Working Group 1 suggested the use of the backscatter radar technique for detection of nuclear explosions at high altitude and in space. Nuclear explosions which affect the ionosphere cause distinguishable changes in the return of the backscattered energy and thereby provide a means for detection.

(2) A backscatter detection station would be ground based at a fixed location. It would use a pulsed high frequency transmitter with a gated receiver which would look for backscatter returns from one or more hops along the propagation path during the idle period of the RF transmitter duty cycle. Changes in range illumination and number of hops of the RF pulse would be accomplished by changing the frequency of the transmitter and receiver. Changes in azimuth would be accomplished by changing the azimuth of the major lobe of the antenna.

(3) Work required under the project should lead to the development and design of a suitable antenna system for use with such a backscatter technique. The following broad tasks were outlined.

   (a) Study all antenna systems and techniques known to the art and determine what type of antenna should be used with a backscatter detection system. Separate antenna systems for transmitting and receiving may be necessary and will be permissible.

   (b) Construct a model or models and measure antenna characteristics.

   (c) Prepare drawings and specifications for a full scale prototype. Drawings and specifications are not intended for production but should be adequate for construction of a prototype by an antenna manufacturer.

On the basis of these points, system considerations were defined, and work was begun on formulation of antenna parameters and selection of configurations.

## SECTION II
## SYSTEM CONSIDERATIONS

### 2.1 General

As a starting point, the following antenna characteristics were given as desirable and were assumed indicative of the extent of system goals.

    (1) Operation from 3 to 30 megacycles with constant power and beamwidth.

    (2) Ability to scan 360 degrees in azimuth in about one minute.

    (3) Constant load presented to transmitter with change in frequency, azimuth, and elevation.

    (4) Side lobes reduced to the extent that possible backscatter returns from unknown directions are virtually eliminated.

    (5) Ability to control elevation angle of the major lobe from horizontal to approximately 45 degrees.

    (6) Transmitting antenna capable of withstanding 10 kw average power with peak power of 0.5 megawatt. Pulses about one millisecond long with PRF about 5 to 20 pulses per second.

    (7) Reasonable size and complexity.

Clearly, these are design goals which are not simultaneously achievable within a practical definition of "reasonable size and complexity." In view of this, an attempt has been made to better define the factors relating to the specific application which is the subject of this study. The general areas which required this further definition include:

    (1) desirable horizontal and vertical beamwidths;

    (2) maximum limits on horizontal and vertical beamwidths;

    (3) steerability; and

    (4) overall system gain.

The desirable antenna beamwidths are determined primarily by parameters relating to the ionosphere and to the area coverage required of the backscatter technique. Consideration of ray paths for ionospherically propagated signals leads to several conclusions which have

a bearing on the backscatter detection problem. Successful operation of a backscatter detection system, and in particular the meaningful interpretation of data, requires a detailed knowledge of the ionosphere conditions actually present on the path. Both geometric and time (in the use of pulsed emissions) focusing of energy in a particular region of the ionosphere may considerably enhance detection sensitivity. Conversely, defocusing (lessening of energy density in a particular volume) may reduce the detection sensitivity below an acceptable level. These focusing effects are illustrated in Figure 2-1, where it can be seen that geometric focusing may occur both on and above the ground. Clearly, the picture changes with frequency and with time. It is not possible therefore, on the basis of present knowledge, to define take-off angles and vertical beam-widths unambiguously to take advantage of focusing or to avoid defocusing loss. These conclusions are drawn from one-way ray path considerations alone. A complete discussion of what happens in the backscatter case employing pulsed systems is enormously complicated by time delay effects in addition to the two-way ray path geometry.

Discussion with several groups* engaged in ionosphere backscatter research, as well as a review of published reports, has not proven especially fruitful in regard to defining antenna performance goals. The various groups engaged in backscatter research are using a number of different antenna types, each of which has some desirable property and in general many undesirable properties.

The parameters discussed in the following sections have been deduced as hopefully achieving a suitable compromise between the ideal and practicality, and in the process providing adequate resolution and scanning rates for the backscatter detection of ionosphere perturbations induced by nuclear detonations.

Steering a highly directive broadband h-f antenna requires a relatively complex feed

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\* Stanford Research Institute, Stanford University, National Bureau of Standards (CRPL), and ACF, Electronics Division.

system (as compared to a simple dipole). Designing such a system for high power greatly complicates the mechanical design. Therefore, the receiving and transmitting antennas were considered separately with emphasis on the receiving antenna directed towards achieving as near an approximation to ideal as possible. The transmitting antenna system should provide maximum directivity within the constraints imposed by the intended application, the power level required, and practicality of switching at the 0.5 megawatt level.

The vertical angle of arrival of ionospherically propagated signals is not completely unknown. A reasonable estimate may be made of the highest elevation angle likely to be encountered, at a given frequency, based on standard ionosphere predictions. For example, the minimum range of an ionospheric backscatter radar might typically be about 400 km, a value set by transmitted pulse width plus recovery time (2 milliseconds and 0.3 ms respectively). At a 300-km height the secant $\emptyset$ factor ($\emptyset$ = angle of incidence on the ionosphere) is approximately 1.35 at a ground distance of 275 km corresponding to the minimum range of 400 km. Thus, an antenna array designed for 3 Mc would operate satisfactorily when the critical frequency is as low as 2.2 Mc if the antenna radiated energy at angles up to 45 degrees. Energy radiated at angles greater than 45 degrees would penetrate the ionosphere and be lost. Of course, ionosphere perturbations may increase the ionization in localized regions and thus permit direct backscattering or reflection if the disturbance is of sufficient magnitude.

If the critical frequency were on the order of 12 Mc, then the operating frequency would be on the order of 16.2 Mc for optimum detection sensitivity at a ground range of 275 km. Thus, the upper half-power point (UHPP) of the antenna would have to be at least 45 degrees over a frequency range of about 3 to 18 Mc.

At greater ranges, say for example 1100-km ground distance, a direct look at the ionosphere at a 300-km height would require radiation at an elevation angle of 10 degrees. For the same range of critical frequencies discussed above, the UHPP would have to be greater than 10 degrees over a frequency range of about 6.5 to 35 Mc.

These deductions are summarized in Figure 2-2 where the minimum UHPP for full coverage is plotted against operating frequency for various typical values of ionosphere critical frequencies. Curves are also included for a 100-km virtual height ionosphere reflection as well as for the 300-km height previously discussed. While multiple hop propagation is not ensured by matching radiation angles to the first hop, it is nevertheless true that the first hop must propagate before any consideration can be given to the multiple hops. Therefore, concentrating on the design for the first ionospherically propagated hop will provide satisfactory coverage for multiple hops if all elevation angles below the optimum are included.

It is apparent from Figure 2-2 that a single elevation plane pattern will not be optimum over the entire 3- to 30-Mc frequency range. Over the same frequency range, the variation in azimuthal beamwidth must be kept to a minimum. An antenna system consisting of two separate antennas, each with about a 6-to-1 bandwidth, and scaled such that one will cover 3 to 18 Mc and the other will cover 7 to 30 Mc, will provide complete coverage on a world-wide basis. A requirement for world-wide coverage, where vertical incidence critical frequencies will vary from less than 3 Mc to more than 16 Mc, is that the upper half-power point of the radiation pattern be at least 45 degrees. This requirement is, however, very unrealistic at high latitudes where the critical frequency may exceed 7 or 8 Mc very infrequently. At high latitudes it would be very desirable to restrict the upper half-power point of the high frequency antenna (7 to 30 Mc) to a maximum of about 25 degrees in order to maximize the system sensitivity.

Thus, two systems are envisioned here. One, for use at middle and low latitudes, where the UHPP is about 45 degrees in both the 3- to 18-Mc and 7- to 30-Mc bands, and the second for use in high latitudes where the UHPP of the low frequency band (3 to 18 Mc) is about 45 degrees and the UHPP of the high frequency band (7 to 30 Mc) is about 25 degrees. Ideally, this latter antenna (7 to 30 Mc) should have the UHPP decrease with increasing frequency from about 30 degrees at 7 Mc.

As the critical frequency varies in the vicinity of the station, both diurnally and seasonally

(and also with latitude and the solar cycle), the frequency where operation is switched from one array to the other would vary from 7 to 18 Mc. With low critical frequencies the change would occur near 7 Mc, and with high critical frequency the change would occur near 18 Mc.

## 2.2 Receiving Antenna Parameters

It has been assumed that the transmitting and receiving antennas would be separate systems. Thus, a discussion of horizontal beamwidth is somewhat more pertinent to the receiving antenna since that is where most of the directivity is obtained.

The normal ionosphere sets both an upper and lower limit on the horizontal beamwidth of a backscatter antenna system. The useful lower limit is set by the angular deviations of the transmission path from the great circle path induced by natural tilts, lateral gradients in electron density, and other perturbations present in the ionosphere. Such effects will normally produce angular deviations as great as five degrees, while unusual circumstances may produce deviations considerably in excess of five degrees. Thus, a horizontal beamwidth narrower than about five degrees will in general not produce a significant improvement in bearing determination.

The upper limit of a useful backscatter antenna system is determined by the normal azimuthal variations in backscatter which tend to become overlapping and ambiguous if the effective beamwidth (combined transmitting and receiving) is greater than about 40 degrees.

The desirable vertical beamwidth of the receiving antenna system is based on entirely different considerations. Since the backscattered energy from ranges just beyond the skip distance at any given frequency arrives in a relatively narrow spread of vertical angles, it would appear desirable to use a fan beam in the vertical plane to avoid the necessity of seeking the proper angle. Two factors, however, suggest a narrower vertical beamwidth. First, since the arriving energy from ranges corresponding to the skip distance and somewhat beyond does arrive in a relatively narrow angular segment, it is

desirable from a system gain standpoint to narrow the beam to include only this angular segment. At greater ranges beyond the skip distance, this technique would tend to reduce the upper or Pederson ray contribution to the backscatter echo and concentrate instead on the lower ray. From a detection viewpoint this may be undesirable since it concentrates on those ray paths which do not penetrate the ionosphere deeply and hence may be relatively unaffected by an ionospheric perturbation. Equally bad, when backscatter signals are received at low elevation angles, corresponding to one hop ranges greater than 3000 km, the majority of the backscatter energy may be received via the upper ray path. The angle of arrival of this energy is relatively unstable as compared with the angle of arrival of the lower ray, and it is therefore undesirable to use too narrow a beamwidth. The second factor suggesting a narrow vertical beamwidth is the potential reduction of susceptibility to jamming (either intentional or unintentional). However, other means (e.g., random frequency programming) are available to combat jamming.

Thus, except from a system gain viewpoint, a vertical fan beam appears to be most desirable for detection of ionospheric disturbances at all ranges and all azimuths. The maximum increase in system gain which might be realized by going to a pencil beam as compared to a fan beam is only about 6 db, and in taking this step the data processing load would be increased by a factor of about four.

A variation of azimuth beamwidth of not more than three to one over any frequency range (e.g., 3 to 30 Mc) would appear to be acceptable in terms of interpretability of the backscatter information.

The side lobe level on the receiving antenna must be reduced to the minimum possible to prevent spurious backscatter returns from being received. A combined side lobe level (transmitting and receiving) of not more than -25 db is acceptable, but -30 db is desirable for 0.5 megawatt transmitting power.

## 2.3 Transmitting Antenna Parameters

All of the previously discussed parameters applying to the receiving antenna would also

apply to the transmitting antenna. However, with present techniques it is not practical to transmit appreciable power through the phasing networks required to provide steering of narrow beams over wide frequency ranges and full 360-degree azimuthal coverage. Consequently, it is necessary to seek a compromise based almost completely on engineering considerations alone.

Since the receiving antenna system will provide a vertical fan beam (broad in elevation but narrow in azimuth), the transmitting antenna should also be broad in vertical coverage. The transmitting antenna cannot be steered and consequently must be broad in azimuth as compared with the receiving antenna system. In the limit, an omnidirectional (in azimuth) antenna might be used; however, such an antenna is inefficient not only in operation but also in terms of system directive gain. A much more desirable system would consist of a resonant (and consequently, more efficient) antenna with directive gain. A number of such antennas could be oriented in the required number of directions to obtain the full 360-degree azimuthal coverage. Minimum horizontal beamwidth is limited by size and switching requirements. It appears that transmitting horizontal beamwidths on the order of 40 to 60 degrees would be suitable.

# SECTION 3
## PROPOSED ANTENNA CONFIGURATIONS

### 3.1 General Considerations

As stated, it is desirable that the selected antenna configuration(s) possess a certain degree of directivity and be capable of 360-degree azimuth scan in about one minute. Because of the azimuth scan requirement and the large physical aperture needed to obtain some directivity at 3 Mc, it is obvious that the antenna configuration(s) must provide the scan capability by alternate excitation of different portions of an antenna system with azimuthal symmetry. Another basic consideration in the selection of antenna configurations is the frequency coverage requirements of the system, namely, 3 to 30 Mc.

With the above requirements in mind, the following types of antenna systems were considered:

- (a) Wire-Grid Luneberg Lens[1]
- (b) Arrays of Concentric Rhombic Antennas[2]
- (c) Arrays of Horizontally Polarized Log-Periodic Antennas
- (d) Arrays of Vertically Polarized Log-Periodic Antennas
- (e) Circular Arrays Utilizing the Wullenweber Principle[3], [4], [5], [6], [7], [8], [9], [10]

The wire grid Luneberg lens described in reference (1) does promise the bandwidth capability and azimuthal symmetry desired for the system. However, it appears that considerable development (e.g., in the feed system) is required, and full-scale performance data is not available. It should be noted also that the percentage variation in azimuthal beamwidth of such an array is just equal to its (percentage) frequency bandwidth.

The study reported in reference (2) was undertaken primarily as an attempt to improve the space utilization and pattern-versus-frequency characteristic of rhombic antennas. Results

of the study indicate that it may be possible to design a "nest" of concentric rhombics with improved performance over that obtained from separate antennas. However, it must be pointed out that the height-above-ground requirement for a specified take-off angle of radiation above the horizon is the same as for any other horizontally-polarized antenna. For example, for a 10-degree take-off angle at 6 Mc, the antenna height requirement is about 240 feet. At 3 Mc this height would have to be doubled to achieve the same radiation characteristics.

Arrays of horizontally-polarized log-periodic antennas have been considered; however, as remarked above, the height requirement for low take-off angles at low frequencies detracts considerably from the horizontally polarized type of antenna. In addition, to achieve an elevation plane pattern with a low take-off angle and reasonable side-lobe level requires arraying in the elevation plane at least two horizontally-polarized bays of radiating elements. For example, if only one horizontally-polarized bay is used to achieve a take-off angle on the order of 20 degrees, a side-lobe about 6 db below the main beam maximum is present at approximately 65 degrees above the horizon.

A considerable amount of design information and full-scale performance data are available on the types of antennas mentioned in (d) and (e) above. Although it is recognized that, in general, a highly conducting screen is required for proper operation of a vertically-polarized antenna operating against ground and it appears that in order to derive full benefit from the conducting radial system it should be placed on the surface of the ground*, the types of antennas listed in (d) and (e) above are well suited for the intended application.

The vertically-polarized log-periodic antenna is described in considerable detail in Section 4.1; however, a few general comments are in order at this point. For this antenna

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From an NEL report [11] "... It is recommended that if at all possible, extended ground radials be placed on the surface of the ground. Because of the low gain obtainable for buried radials under many conditions, it is recommended that consideration be given to the use of horizontally-polarized antennas if the ground radials cannot be placed on the surface."

type, maximum radiation is on the horizon for perfectly conducting earth, with the upper half-power point at approximately 30 degrees. Height requirement for this type of antenna is about $\lambda/4$ at the lowest operating frequency, with the maximum tower height being somewhat above this value in order to accommodate the radiator support structure.

The azimuth plane beamwidth from a single array element is about 110 degrees. Radiation patterns are essentially independent of frequency, and the VSWR (with respect to the antenna input impedance) is within 2:1 across the operating bandwidth. Various array configurations of this antenna type are possible and have been considered for the system. They include the following:

1) Four elements (or curtains) with each element covering a 90-degree sector in azimuth.

2) Arrays of two curtains, with each two-curtain array covering about 60 degrees in azimuth and with six such arrays located about a hexagon.

3) Arrays of three curtains, each three-curtain array covering 40 degrees in azimuth and nine such arrays located about a nonagon.

To obtain still narrower beamwidths in the azimuthal plane it is better to consider a circular array configuration. Because of its constant characteristics over a broad frequency range, it is natural to consider the log-periodic antenna as the elements of the circular array. However, due to the physical displacement of the phase center along the log-periodic structure as a function of frequency, a quite complicated feed system is required to properly phase the signals from the array elements. For this reason, the element considered for the circular arrays presented in Section 4.2 is the broad-band conical monopole. Performance data on this type of antenna is presented in Section 4.2.

For the reasons mentioned in Section 2, separate transmitting and receiving antennas are proposed for the system.

It should be mentioned that if the receiving function did not require higher directivity, the antenna described for the transmitting function could be employed for both modes.

Table 3-1 summarizes the previous comments on the various antenna configurations considered for the system.

TABLE 3-1

| ANTENNA TYPE | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| Wire-Grid Luneberg Lens | Azimuthal plane symmetry and bandwidth. | Requires considerable feed development and full-scale performance data not available. Variation of azimuth beamwidth. |
| Arrays of Concentric Rhombics | Bandwidth. | Height requirements for low take-off angles. |
| Arrays of Horizontally Polarized Log-Periodic Antennas | Bandwidth. Full scale performance data is available. | Height requirements for low take-off angles. |
| Arrays of Vertically Polarized Log-Periodic Antennas | Bandwidth. Height requirement much less than for horizontally polarized antenna with same radiation characteristics. Some full scale performance data available. | Ground screen requirements. |
| Circular Arrays Utilizing the Wullenweber Principle | Azimuthal plane symmetry. Considerable full scale performance data available. | Approximately 3.5:1 bandwidth. Because of feed mechanism design, adequate for receiving application only. |

## 3.2 Proposed Transmitting Antenna

The type of antenna proposed for the transmission mode consists of nine arrays located about a nonagon with each array consisting of three curtains of vertically-polarized log-periodic antennas. Azimuth plane beamwidth is about 40 degrees. Scan in the azimuthal

plane is achieved by switching the transmitter consecutively to the individual arrays in the system. Figures 3-1 through 3-4 depict the transmitting antenna system.

It should be mentioned that the proposed transmitting antenna system is one which offers the best compromise between technical requirements. Systems consisting of the arrays of fewer log-periodic antennas previously mentioned are feasible; however, resultant directivity in the azimuthal plane is less, and power handling requirements on the individual array elements are greater.

## 3.3 Proposed Receiving Antenna

The antenna selected for receive mode consists of the circular arrays of conical monopoles shown in Figures 3-5, 3-6 and 3-7.

The high-band array shown in Figure 3-6 is designed to provide higher directivity in the elevation plane than that obtained with the low-band array shown in Figure 3-5. However, due to the effect of the reflector on the elevation plane patterns when the system is operated over a bandwidth greater than about 3.5 to 1, the low-and-middle-latitude system (equal UHPP in both high and low bands) is somewhat better suited for high latitude installations because it provides more uniform elevation plane coverage. The low-and-middle-latitude receiving system would consist of one array such as that shown in Figure 3-5 operating over the frequency range 3 to 10 Mc and a second array operating from about 9 to 30 Mc. This second array would be a scaled (scale factor 1/3) version of the 3 to 10 Mc system. This results in the azimuthal plane beamwidth variation being held to about 3 to 1 because of the frequency coverage and array scale factors. As discussed in Section 4.2, the azimuth beamwidth variation for a circular array operating over a 6-to-1 bandwidth can be held to about 3 to 1, but not without adding some complication to the feed arrangement and introducing ripple in the main lobe.

With regard to side-lobe level (combined transmitting and receiving) it is appropriate to mention that although at some frequencies the side-lobe level of the receiving antenna is

only in the order of -10 db, due to the angular location of the receiving antenna side-lobes and the directivity of the transmitting antenna, the combined transmitting and receiving side-lobe level is on the order of -18 db.

## SECTION 4

## ELECTRICAL DESIGN

### 4.1 Transmitting Antenna

### 4.1.1 Array Element

An array element is a vertically polarized logarithmically periodic curtain as illustrated in Figure 3-1. Each array element is a complete radiating structure*, and all elements are identical in every respect except orientation. The operating frequency range is 3 to 30 Mc, and all following data apply to the full range unless otherwise indicated.

The curtain consists of vertically suspended triangular radiating wire forms grounded at the base of each triangle to the 2-inch diameter longeron pipe and the ground screen. A single unbalanced feed line excites the radiating elements through capacitors at each point where the feed line crosses a leg of a triangle.

Radiation Patterns and Gain. The E and H plane radiation patterns of an array element are given in Figure 4-1. The pattern is unidirectional with its maximum in the direction of the antenna vertex and on the horizon (for the case of a perfect earth). The half-power beamwidths are 30 degrees in elevation and 110 degrees in azimuth. This pattern is similar to that of an end fire array of three or four vertical monopoles above ground. The radiation pattern is constant with frequency; however, the phase center of an array element moves towards the apex as frequency is increased. The phase center is normally near a quarter-wave resonant tooth.

On the basis of radiation patterns obtained from imaged scale models of the array element, a gain of approximately 5 db relative to a quarter-wave monopole had been predicted for the log-periodic array element. The relative gain figure was confirmed by

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* The design described is that of the Granger Associates Model 726-2.5/30 Log-Periodic Array. This is a proprietary design, certain features of which are covered by patent applications pending. Other manufacturers offer designs which differ in some respects, but which are sufficiently similar to the Model 726-2.5/30 so that the conclusions and recommendations presented here are valid in the case of the use of the competitive products, also.

comparing the signal output from an imaged quarter-wave monopole and an imaged model of the log-periodic antenna, operating at about 250 Mc. When the Model 726-2.5/30 antenna shown in Figure 4-2 was erected as part of the acceptance inspection requirements on a contract, it was deemed desirable to perform relative gain measurements of the full scale antenna array element operating against ground. The radiation characteristics of the Model 726-2.5/30 antenna are identical to those of the array elements comprising the transmitting antenna. The following describes the antenna installation, instrumentation employed, and results of the measurements performed.

Figure 4-3 presents a plan view of the antenna installation employed for the relative gain measurements. For the sake of clarity the ground screen for the log-periodic antenna is shown separately in Figure 4-4. For reference purposes, the impedance measurements performed on the full scale Model 726 antenna are presented in Figure 4-5. The quarter-wave monopole was tuned to present a VSWR no greater than 1.4:1 relative to the 50-ohm characteristic impedance of the feed cable.

Azimuth and elevation plane radiation patterns for the log-periodic antenna were obtained from a scale model of the antenna when imaged over perfect ground, are presented in Figure 4-1. From these patterns a gain of 10.4 db over an isotropic radiator, or approximately 5 db over a quarter wavelength monopole is computed.

Figure 4-6 shows the instrumentation, circuit diagram, and signal sampling waveform employed for the collection of data. As indicated in Figure 4-6, collection of data consisted of periodically switching the input to the receiver to either the monopole or log-periodic antenna. Of course, the switch at the inputs to the dual channel recorder and the switch at the input to the receiver were synchronized; however, during a data run the inputs to the recorder were reversed periodically to cancel possible differences in recorder channel characteristics. Selection of the signal sampling period was affected by the desire to perform nearly simultaneous recording of the two signals and the need to have a sufficiently long (in terms of AGC circuit time constant) "on" and "off" times to prevent switching transients from significantly affecting the results.

Although a large quantity of data was taken and "reduced", at best inconclusive results were obtained. With the ground plane as originally installed, the data shown in Figures 4-7 through 4-9 were obtained. It is the contention of the investigating team that those cases where the whip exhibited higher gain on 15 Mc were due to the presence of WWVH signals to which the Model 726 did not respond because of its unidirectional radiation pattern and the orientation of the log-periodic antenna relative to WWVH. Figure 4-8 illustrates the rejection of the Model 726 to WWVH signals as measured when WWV was not transmitting. The contention regarding WWV and WWVH is further confirmed by the curves in Figure 4-7 which show higher whip gain on 15 Mc (WWV and WWVH) and higher Model 726 gain on 15.5 Mc (WWSI).

To summarize, the Model 726 log-periodic antenna generally has the expected gain relative to a quarter-wave monopole. No meaningful results were obtained that shed light on how antenna performance, particularly at low angles, is related to ground plane size and configuration.

Impedance and VSWR. Impedance of an array element is 150 ohms with 2:1 VSWR or less over the frequency band. The complex antenna impedance referred to the vertex theoretically rotates on the Smith Chart at a rate of one revolution per log-frequency period defined by the design ratio $\tau$. Thus $Z(f) = Z(\tau f)$. This is in accordance with the theory that the log-periodic antenna can be approximately divided into a transmission line zone (nearest the vertex), an active or radiating zone determined by frequency which extends over three to four vertical teeth in this case, and an inactive remainder portion. The antenna elements active at frequency f thus represent an exact scale model of the active elements at frequency $\tau$ f. Impedance plots of this and other log-periodic antennas have shown this periodicity in an approximate manner only. Figure 4-10 is an impedance plot of a scale model of a log-periodic curtain. The scale factor 4.4 indicates a low-frequency cutoff of 1.8 Mc for the antenna curtain with a 140-foot tower. However, a tower height of approximately 140 feet is required to support radiators long enough to insure radiation efficiency at 3 Mc. Capacitance values used in the feed line of the scale model are 10, 13, 17, 24, 32, 44 pf. Two each capacitors

were used at each tooth and a 150-pf capacitor fed the tower.

Power Handling Capacity.   Each array element must be capable of handling its proportionate share of the transmitter output, i.e., 167 kw peak and 3.3 kw average power.  Antennas similar to those described here, but of lower peak rating, have safely handled 10 kw average power.  The average power rating requirement is thus more than ample.

The peak power handling capability is limited by voltage breakdown.  This may be divided into two types, namely, direct arcing between metal parts and corona discharge.  The various parts of the antenna require separate consideration.  In that portion of the antenna near its vertex, a single conductor above ground feeds the antenna proper.  This short length of transmission line has 150 ohms characteristic impedance.  The maximum voltage during a pulse, at any point on the line, is of interest and is calculated from

$$E (max) = 1.4 \; [\; 1 + (S - 1)/ (S + 1) \; ] \; \sqrt{PR}$$

where    P = Peak power rating of source

R = Characteristic impedance of line

S = Voltage standing wave ratio

Here it is assumed that the source resistance of each array element is 150 ohms.  For a VSWR = 2 and P = 167,000 watts, the maximum voltage is 9400 volts.  In the event that the transmitter is tuned at any one frequency for maximum power transfer, the radiated power will be about 12 percent greater than in the case when the transmitter is matched to the characteristic impedance of the line, for the condition of maximum standing wave ratio (2:1).  The peak input line voltage will then be 6 percent greater or 10,000 volts maximum.

The radius of the cylindrical conductors adequate to prevent corona may be computed from the balanced line formula for power handling capability.

$$P = \frac{E^2 d^2}{240S} \; cosh^{-1} \frac{D}{d} \quad watts$$

where    E = Breakdown gradient in volts per inch

d = Conductor diameter in inches

D = Center to center spacing of 150-ohm two-conductor line

The balanced line formula is used because It provides a conservative estimate of the peak power handling capability. The feed line employs a two-inch diameter pipe as ground return which is a less severe condition than equal diameter wires with respect to voltage breakdown, other things being equal. Thus d = 0.11-inch minimum. This is a considerably smaller diameter than desirable for reasons other than the corona problem. Also, allowance must be made for concentration of fields at junctions. Stranded 5/16-inch diameter cable consisting of seven copper wires of 0.097-inch diameter is more than adequate. Spacing for 150 ohms impedance above the two-inch pipe is approximately two inches center to center. Insulation is afforded by a polyethylene sheath 3/8-inch thick. The line is to be supported by suitable standoff insulators.

It has been calculated that the feed line capacitors will carry 15 amperes at 8 kilovolts rms when they are coupling peak power. Capacitors with this rating are available.

Beyond the section of uniform 150-ohm line, the line-to-ground spacing increases and thus tends to reduce voltage gradients. It is known, however, that voltage reaches a high value at the tip of a thin quarter-wave monopole. In order to obtain some quantitative idea of the severity of this problem the voltage gradient near the tip of the most active radiator was calculated. It was necessary, however, to make the following simplifying assumptions:

1) A triangular tooth is similar to two linear mutually coupled radiators.

2) A linear radiator may be treated here as a quarter-wave long transmission line of a certain average characteristic impedance terminated in a resistive load.

3) The voltage at the tip is that voltage across the load which is required to dissipate the equivalent amount of radiated power.

4) The voltage gradient at the tip is similar to that at the end of a conical transmission line of the same impedance and with the same tip voltage as above. Fringing fields are neglected here.

On the above basis it was calculated that an 8-foot long (30-Mc) quarter wave resonant elements, made up of 0.155-inch diameter wire in the form of a triangle that is radiating two-thirds of the input power to an array element (approximately 100,000 watts) would have

a tip voltage in the order of 19,000 volts rms and a voltage gradient of approximately 52,000 volts per inch peak. If this calculated value is arbitrarily increased 40 percent to allow for fringing fields one finds that this is probably sufficient to cause corona breakdown. Therefore, the radiating wire tooth tip is given the form of a 3-inch radius bend in place of the relatively angular bend. Comparative experimental studies of corona breakdown were made on the rounded tip end and an angular tip with supporting clevis and dielectric line by immersing these in a large, uniform r-f field between two parallel 24-inch square plates 18 inches apart. The antenna tip was connected to one plate at its lower end, and the floating tip end midway between plates tended to concentrate the field. Corona breakdown and deleterious dielectric support heating were observed for pointed tip shapes between 18 and 28 kv at 32 Mc. Dielectric heating was observed in the epoxy-Fiberglass link between the rounded tip and the support clevis. These test voltages are large enough to produce a field gradient greatly in excess of the above calculated gradient at the tip of an actual radiator.

The following conclusions were drawn from these high voltage experiments:

1) The radiating element (wire triangle) should have a rounded tip, of approximately 3 inches radius.

2) The clevis associated with the support member should be several inches above the rounded tip and should have no sharp edges.

3) The dielectric link between the tip and clevis should be designed so that the link does not concentrate the field in this region. The design drawing for the tooth tip was based on the above consideration.

Ground Screen. The ground screen of an array element is integral with that of the sub-array and will be more fully described under that heading. Each curtain has a 2-inch diameter pipe or longeron close to the ground that serves as the main return path for the antenna currents. Ground wires are electrically bonded to this pipe and to each other. Connections to the pipe are made at each point where a radiating tooth is grounded.

## 4.1.2  Sub-Array

A sub-array consists of three array elements having the same vertex with each two

adjacent elements forming a 40-degree angle, as shown in Figure 3-1.

Radiation Patterns and Gain. The E-plane (vertical) pattern of a sub-array is similar to that of an array element (30-degree beamwidth above perfect ground). The H-plane (azimuth) pattern is unidirectional with 40 degrees beamwidth. Directive gain of the sub-array is 15 db above an isotropic radiator. The increased directivity is due to the array factor of three elements. Side lobes are 10 db down at the low end of the band and approximately 15 db down over most the frequency range. Radiation pattern for a sub-array is shown in Figure 4-11.

Impedance and VSWR. The sub-array impedance is that of three 150-ohm array elements in parallel, or 50 ohms. All array elements are identical and therefore the VSWR of a sub-array will be the same as that of an array element, that is 2:1 or less.

Power Division. Power division between the three arrays is accomplished in a junction box at the apex of each sub-array. This junction box shields a three-output shunt connection and serves to anchor the array element feed lines. Each coaxial sub-array feed line terminates at the side of a junction box. As a corona preventive at the junction, the box· is filled with low-dielectric loss oil.

Ground Screen. The ground screen is formed of No. 10 copper wire arrayed on the surface to favor the principal direction of radiation as shown in Figure 3-1. The screen extends about 2000 feet in front of a sub-array. The ground screen thus extends about six wave-lengths forward of the phase center, at the lowest operating frequency. Antenna pattern coverage near the horizon is thus relatively unaffected by poorly conducting earth in the immediate vicinity of the antenna. The next section contains a discussion on ground screen requirements for vertically-polarized antennas operating against ground.

4.1.3 Complete Array for Full Azimuth Coverage

Feed Mechanism. Each of the nine sub-arrays is fed by 3-1/8 inch pressurized rigid

coaxial transmission line that extends radially from the array center to the apex of a sub-array. This line has a measured peak power rating of 2 megawatts with dry air at one atmosphere absolute pressure, 40°C ambient temperature, and unity VSWR. Since peak power rating is inversely proportional to line VSWR (under conditions of conjugate match at transmitter), and the square of the voltage safety factor and directly proportional to the square of relative pressure, it is readily calculated that a working VSWR of 2:1, a pressure of two atmospheres, and a power source rated at 0.5 Mw peak yield a safety factor of 2.8. A safety factor of this magnitude is not unreasonable here, and provision should be made therefore for two atmospheres of dry nitrogen pressurization.

The average power rating of 3-1/8 inch coaxial line is well in excess of the system average power requirements; hence, transmission line heating does not present a problem.

Attenuation at 30 Mc is theoretically 0.055 db per 100 feet. This amounts to nearly 0.3 db for the 530-foot radial run of transmission line. Interaction by the line VSWR of 2:1 will add 0.1 db. Oxidation might add 0.2 db. The end result is attenuation over the band varying from 0.2 db at 3 Mc to 0.6 db at 30 Mc. Finally, 0.5 db is added for reflection loss due to antenna VSWR. Total attenuation is 0.7 to 1.1 db yielding an overall efficiency of 80 percent at 3 Mc to 73 percent at 30 Mc.

Azimuth Scan Switching System. The transmitted beam must scan the full azimuth in one minute. Since there are nine positions, eight coaxial double-pole single-throw switches are arranged in a tree as shown in Figure 3-2. The tree arrangement provides equal delay from the transmitter output to all antennas and therefore allows the transmitter to be peaked at any frequency without suffering detuning when the antennas are scanned by the switching mechanism.

Minimum time between pulses is about 50 milliseconds. Since the high speed 3-1/8 inch vacuum coaxial relays presently available can be fully switched in 12 milliseconds or less, synchronous switching between pulses is feasible.

There are nine switch output positions labelled from A to I and eight coaxial SPDT switches labelled from 1 to 8 (in the form of a tree). In addition, there is one input labelled IN. In order for the input power to emerge from any specified output (output A excepted), at least four switches must be in the proper state, namely either left or right position (L or R). Then in order to switch to another output, one or more switches must change state. Analysis has shown that the switching operations can be apportioned in time so that no more than two switches need operate at each position change for continuous scanning. For example, suppose the instantaneous state of the tree is for an output at I. The next position is output at A. At the beginning of next scan position period a control pulse from unit A causes switch 1 to go into state R and switch 2 into state L. For an output at A the state of switch 1 only need be specified. There is now an output at position A, and in addition there is also advance provision for outputs at B, C, D, and E. For all positions except E and F each scan pulse causes one switch to change state and thus changes the power flow in an active path and causes another switch to change and thus helps to build up a path that will soon become active.

## 4.2 Receiving Antenna

The receiving antenna is a circular array of vertically-polarized omni-directional radiators arrayed around a circular reflector. Only a portion of the array is used at one time, and signals from the utilized elements are delayed to create a constant phase plane at a given azimuth. Due to the circular symmetry of this geometry, 360-degree scan is achieved with azimuth patterns that are essentially independent of the azimuth beam position. The antenna is steered in azimuth by connecting the required group of elements through the proper delay by means of a goniometer. Two arrays are employed to cover the 3- to 30-Mc frequency range.

### 4.2.1 Array Element

The array element is a conical monopole vertically-polarized omni-directional antenna. It consists geometrically of two truncated cones mounted base to base and supported with the axis vertical at a short distance above the ground plane. The external surfaces of

the cones form a monopole type of antenna with some effects of a true conic contributed by the lower cone particularly at the higher frequencies. The inner surface of the lower cone and the metal supporting tower form a short section of transmission line which is shunted across the antenna terminals. The tower forms the inner conductor of this section of line, the inner surface of the lower cone forms the outer conductor, and the spokes at the common plane of the two cones form the short circuit at the end of the line. This short section of line forms a broad-band matching stub that is in shunt with the antenna terminals and extends the low frequency range of the antenna.

Radiation Patterns and Gain. Figures 4-12 through 4-22 are elevation plane radiation patterns for the conical monopole. The azimuth plane pattern is essentially circular. The elevation plane patterns are for the antenna and its image and hence are the patterns that would be obtained for the antenna on an infinite perfectly-conducting ground plane. The element elevation plane patterns are of particular interest since they determine the elevation plane pattern characteristics of the circular array, over the frequency range $f_0$ to $3.5 f_0$. As can be seen from Figures 4-12 through 4-22, the elevation plane maximum is on the horizon for frequencies from $f_0$ to $3.5 f_0$ with an upper half-power point of approximately 30 to 45 degrees. At $4 f_0$ the pattern maximum occurs at 45 degrees and is down by 6 db on the horizon. Hence coverage of elevation angles below 45 degrees is provided over a 4:1 bandwidth. Over the remainder of the band the elevation plane maximum is 45 degrees with the upper and lower half-power points approaching 65 degrees and 25 degrees respectively.

Impedance and VSWR. The conical monopole radiator has a nominal impedance of 75 ohms. Figure 4-23 is a Smith Chart presentation of antenna impedance relative to 75 ohms in terms of relative frequency. The VSWR of the antenna is a maximum of 2.5:1.

4.2.2 Low-Frequency Band Array

The low-frequency band array could cover the frequency range of 3 to 18 Mc. A plan view of the array is shown in Figure 4-24. There are a total of sixty elements in the array, thirty of which are used at one time. The array is 2.5 wavelengths in diameter at the lowest frequency and the array elements are spaced 6 degrees apart or one-eighth wavelength.

Radiation Patterns and Gain. Due to the presence of the reflector, the vertical plane patterns of the array begin to differ significantly from the elevation plane patterns of the array element at frequencies in the order of $3.5 f_o$.

The horizontal plane patterns of the circular array are similar to those obtained from the projected linear aperture of the circular array. In fact for a uniform amplitude distribution, the beamwidth and first side-lobe level are essentially the same as that of the linear array. When an amplitude taper is used, the reduction in side-lobe level and the increase in beamwidth are not as great as for the linear array. Since the beamwidth is a function of the linear projected aperture, the beamwidth will vary inversely with frequency. Hence for an array having a 6:1 bandwidth, the beamwidth at the upper end of the frequency band will be one-sixth that at the low end.

Figures 4-25 through 4-28 are azimuth plane patterns for a one-hundredth scale model of 24 degrees of a circular array of conical monopole radiators. A picture of this scale model is shown in Figure 4-29. The measured beamwidth for the array and the beamwidth computed on the basis of the linear projected aperture are plotted in Figure 4-30 and are in good agreement. Clearly the expected 6:1 variation in azimuth beamwidth that would be observed for the full scale array phased in the manner pre-viously indicated is excessive, and the array design must provide for a reduction in the beamwidth variation. Several schemes were considered for reducing this variation.

First considered was the use of low-pass filters to decrease the number of array elements employed as a function of frequency. By proper selection of the filter cut-off frequencies, essentially constant azimuth plane beamwidth could be obtained over the 6:1 frequency band. Unfortunately since the number of elements is varied by a factor of approximately 6:1, the characteristic impedance of the array will vary by a similar amount.

The use of lossy transmission line in which the line loss increases with frequency was also considered. The longest lengths of this line would be used to feed the edge elements with the length of lossy line for each element decreasing from element to element to

IV - 11

zero for the center element of the array. The delay introduced by these sections of lines would be compensated for by the proper lengths of low loss delay line. This scheme would accomplish the required reduction in array aperture with increasing frequency without changing the characteristic impedance of the array. This results from the fact that as the loss in a length of transmission line is increased, the impedance at the input end of the line tends to the line characteristic impedance, and for a long line of high loss the input impedance becomes independent of terminating impedance. Unfortunately such a scheme would lower the efficiency of the array and degrade the signal-to-noise ratio.

Reduction in the azimuth beamwidth variation was achieved by splitting the circular array aperture into two sub-arrays. Each sub-array is phased to squint its beam a few degrees off boresight. One sub-array has its beam squinted to the left of boresight and the other sub-array the beam is to the right of boresight. The two sub-arrays are then combined in phase. The resultant array pattern will have a much wider azimuth beamwidth than if the array were fed in phase across the aperture. The amount of beam squint required is set by pattern considerations at 6 $f_o$ (18 Mc). A 6 db crossover at 6 $f_o$ was found to be optimum. This results in a beam squint of 4.6 degrees.

Since the beam squint will be produced by a time delay, the squint angle will be independent of frequency. Hence the sub-array beams will be squinted by 4.6 degrees at $f_o$ (3 Mc). The sub-array beamwidth at $f_o$ is 40 degrees, and the 4.6 degrees squint will have but a small effect on the array pattern at 3 Mc.

Figures 4-31 through 4-35 are computed azimuth plane patterns for the array fed in this manner. The variation in the azimuth plane of 3 db (half-power) beamwidth has been reduced from 6:1 to 3:1. The main lobe now exhibits a considerable ripple at the higher frequencies. However, since the purpose of the antenna is for detection, this causes no difficulty. Figure 4-36 shows the variation of antenna beamwidth and directive gain with frequency.

Since the computed patterns presented in Figures 4-31 through 4-35 show that in some cases considerable error would be involved by estimating directivity by considering only

the half-power beamwidth of the radiation pattern, the directive gain figures presented in Figure 4-36 were calculated by numerical integration of the radiation pattern to the region of the first side lobe.

Impedance and VSWR. The array will have a nominal impedance of 50 ohms. Suitable transformers are provided in the array goniometer to transform to this impedance level. The VSWR of the array will be nominally that of the array element as confirmed by model measurements. Figure 4-37 shows a Smith Chart presentation of the impedance for the nine-element model of a portion of the array. The impedance has been normalized to 8.35 ohms which is one-ninth the element characteristic impedance. The VSWR is less than 2.5:1 which is identical to the measured impedance variation for the array element.

Ground Screen. As discussed in the third monthly report, the actual surface over which h-f antennas operate is a significant factor in determining the antenna performance. For a vertically-polarized antenna, the angle of maximum elevation plane radiation and the radiation at low angles are influenced by the surface over which the antenna operates.

In operational practice the location of the antenna sites would probably be determined by factors other than the conductivity of the soil at the site. Assuming this to be true, then only the details of the ground wire system are available as design parameters.

For detection at long ranges, low take-off angles are desirable, and a ground system greater than five wavelengths in length is required. Figure 4-24 presents the plan view of the antenna, and the ground screen configuration for the antenna is also shown. There are 960 ground radials spaced three-eighths degree apart extending out from the reflector for 2000 feet. This provides a ground screen length of slightly over six wavelengths at 3 Mc. The elevation plane maxima with this ground configuration will be below 20 degrees at 3 Mc.

Selection of length of ground radials has been influenced by the graphs presented in

Figures 4-38 and 4-39. These figures show the results of measurements[12] of the elevation plane patterns of a quarter-wave monopole over a circular ground plane of various diameters. Ground constants beyond the ground plane were $\epsilon = 2.6$ and $\sigma = 4.6$ millimhos per meter. Figure 4-38 shows how the location of the elevation pattern maximum varies with the diameter of the ground plane. This is compared with the location of the maximum when the circular ground plane is in free space.

Figure 4-39 illustrates the relative gain at fixed angles $\psi$ as a function of ground plane diameter. The elevation angle to which each of the curves applies is also shown in the graphs. Minima occur in all cases at $d/\lambda = 1$ since the re-radiated signal from the edge currents are in phase opposition to the direct signal. On the basis of these results, two conclusions may be drawn. First, soil conductivity beyond the ground plane has at most a secondary effect on the elevation pattern. Second, improved low-angle performance can be achieved by extending the ground system five wavelengths or more in the direction of propagation. Confirmation of these predictions was obtained by Naval Electronics Laboratory personnel in field tests.[11] Comparison of signals received over long-haul circuits where low angle radiation is important indicate that, on the average, a quarter-wave vertical monopole antenna using $2.5\lambda$ radials will have a sensitivity some 5.5 db above that of the same antenna with $0.25\lambda$ radials. This value is appreciably higher than that predicted by the curves of Figure 4-39 if the $0.25\lambda$ points are extrapolated directly. It thus appears likely that the signal intensity at $\psi$ maximum is itself significantly increased by lengthening the ground radials.

With regard to the effects of burying the ground wires, two recommendations from an NEL report[11] should suffice. "Based on results of the recent model measurements it appears that burial of extended ground radials is not advisable under most conditions...". "It is recommended that if at all possible, extended ground radials be placed on the surface of the ground."

Azimuth Scan Mechanism and Time Delay Network. Azimuth scan of the circular array is accomplished by a capacitive goniometer. Its function is to provide the required

phase and amplitude distribution on the circular array to form the antenna beam in the desired direction. Figure 4-40 shows a schematic diagram of the goniometer. Its theory of operation can be understood if it is considered from a transmitting viewpoint. Since the input signal must be divided among thirty 950-ohm delay lines, the 50-ohm input impedance must be transformed to 31.7 ohms, the impedance of the thirty delay lines in parallel. The input power is divided equally among the thirty delay lines. The delay lines and input transformer are contained in the goniometer rotor assembly. The input transformer is connected to the input terminal through a coaxial rotary joint. The output of each delay line is capacitively coupled out of the rotor assembly. The goniometer coupling capacity is incorporated as a component of a broad-band impedance transformer. The 950-ohm impedance of the R665-A/U delay line is transformed to the 75-ohm impedance of the half-inch Foamflex cable that connects the goniometer to the array elements. Each of thirty delay cables is connected to a rotor plate. Each of the stator plates is connected to an array element through a transformer. At a given position of the goniometer rotor, thirty of the array elements are fed with the proper phases to provide a beam in a direction normal to the diameter through the edge elements that are being fed. Rotation of the goniometer rotor steers the array maximum through 360 degrees.

By designing the rotor plates to be smaller than the stator plates, more continuity in antenna performance is obtained as the rotor scans. In addition, by incorporating this design the coupling from two array elements to a single rotor plate is minimized.

The required delay line length for each of the sixty elements is

$$L = R \cos \left( \left| \phi \right| -4.6° \right)$$

where

$L$ = delay line length

$R$ = radius of circular array (reflector radius)

$\phi$ = angular position of array element measured from center of semi-circle

The lengths computed using the above provide for squinting the beam 4.6 degrees for each sub-array.

Antenna Efficiency. Components introducing significant loss into the system are the Foamflex cables used to connect the array elements to the goniometer and the delay cables contained in the goniometer. The Foamflex cables would introduce a loss of 0.57 db at 3 Mc increasing to 1.44 db at 18 Mc. The delay cable loss would vary from 0.64 db to 1.92 db over the frequency range.

Figure 4-41 shows feed system losses as a function of frequency.

## 4.2.3 High Frequency Band Array

The high frequency band array could cover the frequency range of 7 to 30 Mc. A plan view of the array is shown in Figure 4-42. In general it is similar to the low band array and only the differences will be discussed.

Radiation Patterns and Gain. The high band array is designed to provide increased vertical plane directivity since it is the lower elevation angles that are of importance at these frequencies. Two conical monopoles are arrayed vertically in the manner shown in Figure 4-43. This provides an elevation pattern with a half-power beamwidth of 33 degrees at 7 Mc decreasing to 10 degrees at 30 Mc. Figure 4-44 shows the variation of elevation and azimuth plane beamwidth with frequency.

Impedance and VSWR. Since the array element is a balanced antenna for the high-band array, a broadband balun is used to feed the antenna and transform its input impedance from 150 ohms to 75 ohms.

Ground Screen. The ground screen will in general, be similar to that employed with the low band array except for the length of ground radials. Due to the importance of low angle coverage at these frequencies the ground radial length has been increased to ten wavelengths.

Azimuth Scan Mechanism and Time Delay Network. Other than different delay line lengths and component values, the goniometer is identical to that of the low band array.

Antenna Efficiency.   Figure 4-45 shows efficiency versus frequency for the high band array feed system.

Synchronization with Low Frequency Band Array.   Both the low and high band array goniometers will be controlled by servo systems that slave each goniometer to the display drive motor.   Figure 4-46 is a block diagram of the rotation control system. The motor driving the display is controlled electrically at the display console to provide CW or CCW rotation.   Manual control can be included.

Electrical direction information is obtained from a synchro geared to the display and is transmitted to synchros at the low band and high band goniometers.   The synchro at the goniometer provides an error signal input to the servo amplifier which drives the servo motors.   Both goniometers are thus locked in rotation with the display.

## SECTION 5

## MECHANICAL DESIGN

### 5.1 General Considerations

This section outlines the considerations involved in the mechanical design of the previously described antenna systems. The recommendations on types of materials to use in the construction of the antennas are based on experience in the design and fabrication of similar types of radiating systems.

### 5.1.1 Assumed Environmental Conditions

Wind and Ice Loads. Transmitting and Receiving Antennas: 1/2-inch radial ice with 125 mph winds, simultaneously.

Corrosive Environment Considerations. Both transmitting and receiving arrays are designed to be more than adequately corrosion resistant under normal environmental conditions. The transmitting vertical curtain antenna components include such corrosion-resistant materials as: Fiberglass catenaries; 6061-T6 aluminum alloy catenary and drop fittings; calsun bronze wire radiating elements; galvanized longeron pipe; and corrosion-resistant hardware.

The receiving conical monopole antennas are fabricated of such corrosion-resistant components as: 6061-T6 aluminum alloy radial spokes; calsun bronze wire radiating elements; a copper ring at the bottom end of the radiators; and corrosion-resistant hardware. The reflector material, along with its support catenaries is calsun bronze wire.

Both the transmitting and receiving array ground screens are of No. 10 solid copper wire, and all support towers in each array are constructed of hot-dip galvanized steel. Under extremely corrosive conditions, aluminum towers should be provided.

### 5.1.2 Material Selection and Miscellaneous Mechanical Considerations

**Electrical Requirements, Transmitting Antenna.** The seven-strand No. 15 calsun bronze radiating elements, the 3-1/8 inch coaxial transmission line, and the No. 2 insulated stranded feed line were all chosen in order to satisfy the electrical requirements of conductivity and peak and average power handling capability.

**Electrical Requirements, Receiving Antenna.** The seven-strand No. 15 calsun bronze vertical and peripheral radiating elements, along with the copper peripheral rings, were chosen for their conductive capabilities and corrosion resistance.

**Mechanical Requirements, General.** Materials for both the transmitting and receiving array systems were chosen and sized in order to provide a good, positive margin of safety, stress-wise, and to afford more than adequate structural integrity of the antenna systems under the assumed environmental loads and corrosive conditions.

**Mechanical Requirements, Transmitting Antenna.** Fiberglass was selected for the catenary and drop materials since it exhibits a minimum of creep under load, a high ultimate tensile strength (140,000 psi), and good dielectric properties. Aluminum alloy (6061-T6) catenary and drop fittings provide a 35,000 psi tensile yield capability. The longeron pipe, used as an accurate method of locating and attaching the radiators and ground screen centerline points, is galvanized and periodically supported on concrete piers. Coaxial transmission lines to each three-curtain antenna array power divider include a 50-foot loop to absorb linear thermal expansion of the line under normal operating conditions, as advised by the Prodelin Corporation, the coaxial manufacturers. Pressurizing equipment for the line can be contained in the building at the center of the array circle, as is the scanning switch and its operating equipment.

**Mechanical Requirements, Receiving Antenna.** Radial spokes at the middle and one end of each conical monopole are of 6061-T6 aluminum pipe and provide a good margin of safety under the assumed loadings. Wooden poles were considered in place of the steel antenna support towers; however, excessive weight and cost of the poles rendered them

impractical. Vertical reflector wires and their supporting catenaries are of seven-strand No. 15 calsun bronze wire. Reflectors are tensioned from ground level by means of a turnbuckle mounted on each reflector support pole.

### 5.1.3 Methods Employed in Structural Analysis

Detailed calculations show ample margins of safety on the larger components of the antennas, such as catenaries, towers, spokes, etc., and the detailed structural items, such as tower joints, have been designed to be compatible with the rest of the structure.

Transmitting Antenna. The vertical load transmitted to the supporting tower for each curtain was found by determining the vertical component of the load (at the tower) induced in the catenary as a result of 1/2-inch radial ice on all effective elements, vectorially combined with the "toggle effect" of a 125-mph wind applied horizontally against the iced radiators. A 3.87 margin of safety was calculated based on the column allowable strength of the tower. The catenary would be subject to a maximum load of 4790 pounds.

Receiving Antenna. The supporting conical monopole tower for the 3- to 18-Mc conical monopole antenna was analyzed using the "three moment" equation to determine the maximum positive moment in the bottom, most critical span. This moment, combined with the effect of the guy cables, and tower and ice weights, was then implemented to determine the compressive and flexural loads on the tower. The capability of the radial spokes was determined from their "column allowables", as dictated by their "length to radius of gyration" ratios. The 7- to 30-Mc conical monopoles were assumed to withstand the loading conditions with a good margin of safety by comparison with the 3- to 18-Mc conical monopole antennas. A 1.52 margin of safety was calculated based on the column allowable strength of the tower.

### 5.2 Transmitting and Receiving Antennas

Load calculations have been performed and adequate and detailed instructions for antenna installation and erection can be provided.

## 5.3 Results of Structural Tests

The Fiberglass catenary (transmitting antenna) 1/4-inch in diameter has been tested and found to have an ultimate tensile strength of 7000 pounds; the clevis fittings were tested in conjunction with the catenary and were structurally compatible.

The monopole radiator assemblies with the terminal end fittings have been tested in tension and found to show a positive margin of safety under the given loading conditions.

# SECTION 6

## REFERENCES

(1) Final Report, Part I, "investigation of Methods of Scanning the Beam of Large Antennas", March, 1961, Contract AF 19(604)-2240, issued by Stanford Research Institute.

(2) Technical Report 67 "A Study of Possibilities for Improving Space Utilization and Performance of Rhombic Antennas", By Angel Martin-Coloto, July, 1959, Contract AF 19(604)-3458, issued by Stanford Research Institute.

(3) R. C. Benoit, Jr. and W. M. Furlow, Jr., "Wullenweber Type UHF Radio Direction Finder", IRE National Convention Record, 1955, Part 5, pp. 109, 114.

(4) "Interim Engineering Report No. 3 Wullenweber Type Antenna Array".

(5) "Interim Engineering Report No. 4 Wullenweber Type Antenna Array".

(6) "Interim Engineering Report No. 5 Wullenweber Type Antenna Array".

(7) "Interim Engineering Report No. 6 Wullenweber Type Antenna Array".

(8) "Interim Engineering Report No. 8 Wullenweber Type Antenna Array".

(9) Final Engineering Report "High Frequency Steerable Antenna 3.8 Mc to 14.4 Mc", June, 1955, Contract AF 33(038)-23700, issued by Andrew Alford Consulting Engineer.

(10) Final Engineering Report "High Frequency Steerable Antenna 8.8 Mc".

(11) Private Communications.

(12) From a private communication with Dr. Tetsu Morita, Stanford Research Institute.

## SECTION 7

## IDENTIFICATION OF GRANGER ASSOCIATES TECHNICAL PERSONNEL

The following individuals from the engineering staff of Granger Associates contributed to the project.

Mr. William A. Alfano

Mr. Ross L. Bell

Dr. Raymond D. Egan

Dr. John V. N. Granger

Dr. William G. Hoover

Dr. Raymond Justice

Mr. Charles A. Lucero

Mr. Charles E. Phillips

Mr. Bernard M. Schiffman
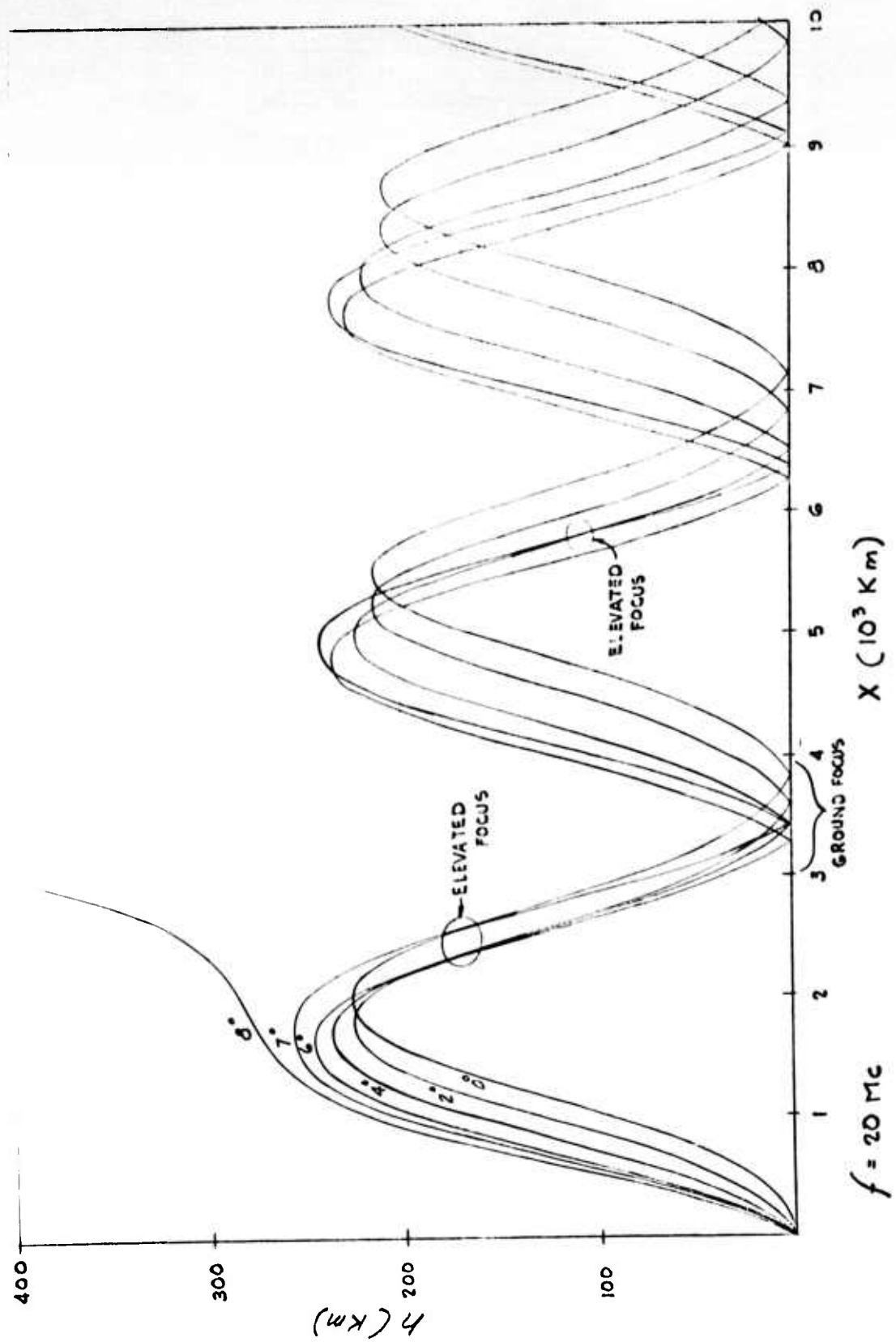
FIG. 2-1 RAY PATH DIAGRAM
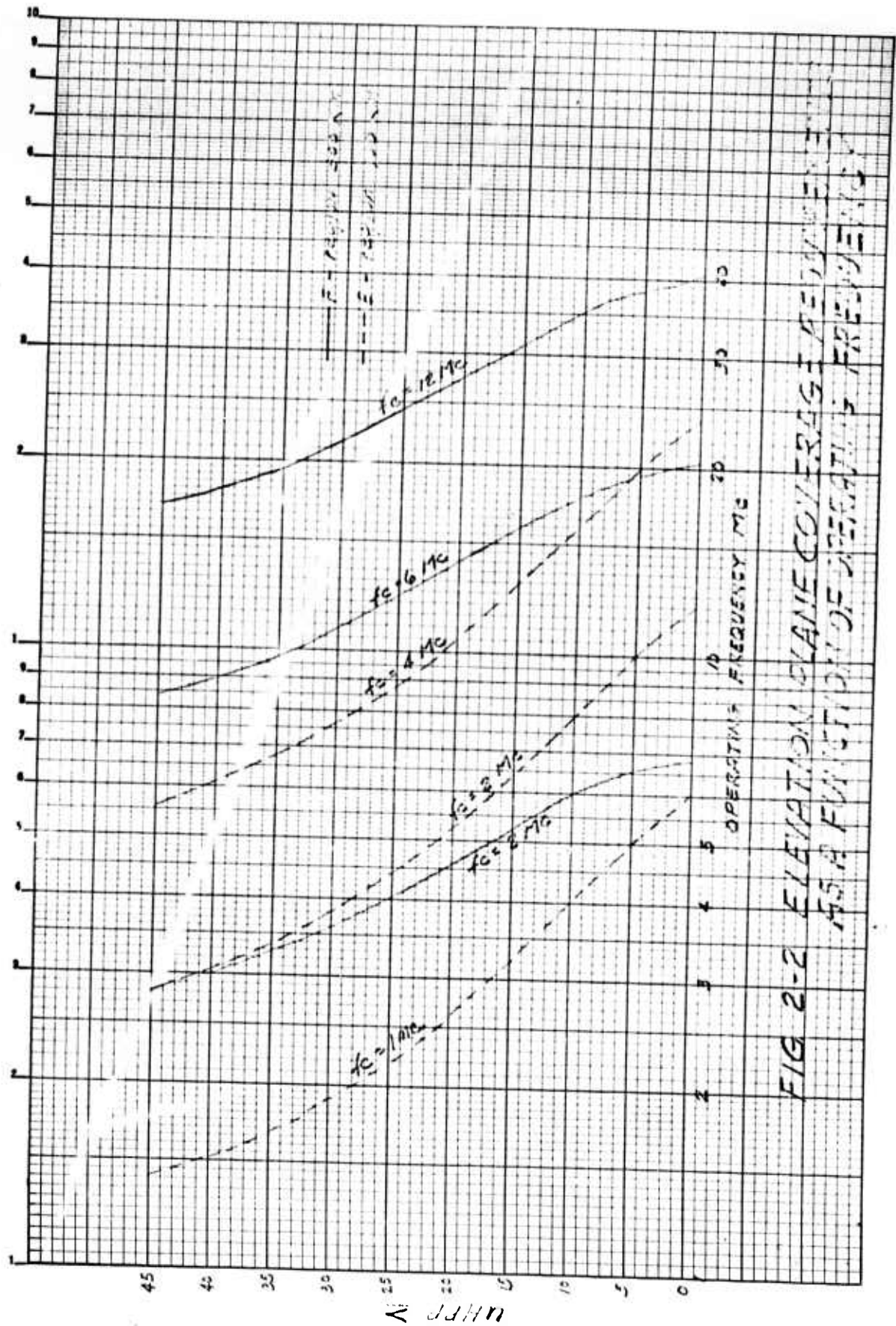
FIG. 2-2 ELEVATION PLANE COVERAGE fₑ IN
AS A FUNCTION OF OPERATING FREQUENCY

LONGERON PIPE

40°(REF)

40°(REF)

APEX OF ARRAY

INSULATING SPACER

POWER DIVIDER

SILICONE RUBBER
POTTING COMPOUND TYP

RADIATOR

LUMP CAPACITOR

INSULATED FEED LINE

LONGERON PIPE (REF)

GROUND WIRE

RADIATOR

INSULATED MOUNTING

LUMP CAPACITOR (REF)

INSULATED FEED LINE

LONGERON PIPE (REF)

GROUND WIRE

**1**

VIEW

LONGERON PIPE

HEIGHT ADJUSTING SCREW

CONCRETE PIER

VIEW
TYP LONGERON / PIER ABBUT

ELECTRICAL HEIGHT LINE (REF)

30° (REF)

RADIUS (REF) TYP

VIEW
TYP 9 PLACES

INSULATING SPACER

RADIATOR

SILICONE RUBBER
POTTING COMPOUND TYP

LUMP CAPACITOR

INSULATED FEED LINE

LONGERON PIPE (REF)

GROUND WIRE

VIEW

FIBERGLASS

RADIATOR

LUMP CAPACITOR (REF)

MOUNTING
BRACKET

INSULATED FEED LINE

RON PIPE (REF)

GROUND WIRE

VIEW

FEED

RADIA

FEED

VIEW A-A
ANTENNA CURTAIN TYP 27 PLACES
GUY CABLE LOCATION AS SHOWN IS TYP
9 PLACES ONLY

**2**

GROUND WIRE

2" PIPE LONGERON

3" ... FOR FUTURE ATTACHMENT
RADIATOR

FLAG TERMINAL 2 REQ'D
C-TAP 2 REQ'D

JUMPER

VIEW **13-13**
TYP. RADIATOR-GROUND WIRE-LONGERON ATTACHMENT

ELECTRICAL HEIGHT LINE (REF)

3" RADIUS (REF)-TYP
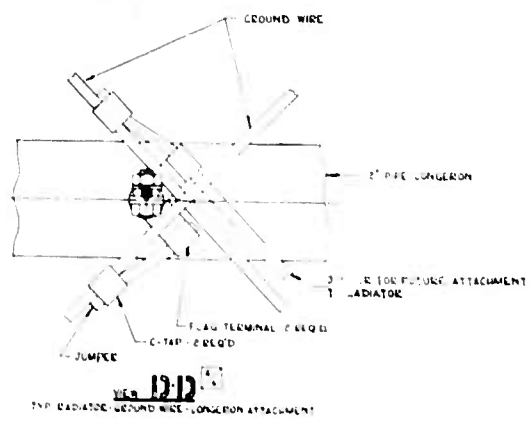
FIBERGLASS CATENARY

FIBERGLASS DROP

RADIATOR

GROUND SCREEN ARRANGE-
MENT-TYP 360°

FEED LINE (REF)

VIEW **A-A**
ANTENNA CURTAIN TYP 27 PLACES
GUY CABLE LOCATION AS SHOWN IS TYP.-
9 PLACES ONLY

**3**

GROUND WIRE

2' PIPE LONGERON

R FOR FUTURE ATTACHMENT
RADIATOR

FLAG TERMINAL - 2 REQ'D
C-TAP - 2 REQ'D

JUMPER

VIEW **B-B**

RADIATOR-GROUND WIRE-LONGERON ATTACHMENT

FRONT POLE TYP 9 PLACES

POLE TYP 27 PLACES

BUILDING TO HOUSE
ANTENNA SCANNING SWITCH &
AMPLIFIER EQUIPT

COAXIAL TRANSMISSION LINE (9Ω)
TYP 9 PLACES SHOWN 1 PLACE ONLY
SEE NOTE 1

GUY CABLE - TYP
SHOWN 9 PLACES ONLY

GROUND SCREEN ARRANGE-
MENT - TYP 360°

SEE B
TYP

5000'
TYP

210 FT (TYP)

45° (TYP)

531.9 FT RADIUS (REF)
TYP

PLAN VIEW

PLAN VIEW
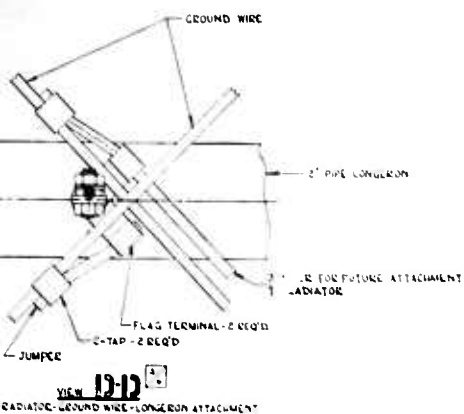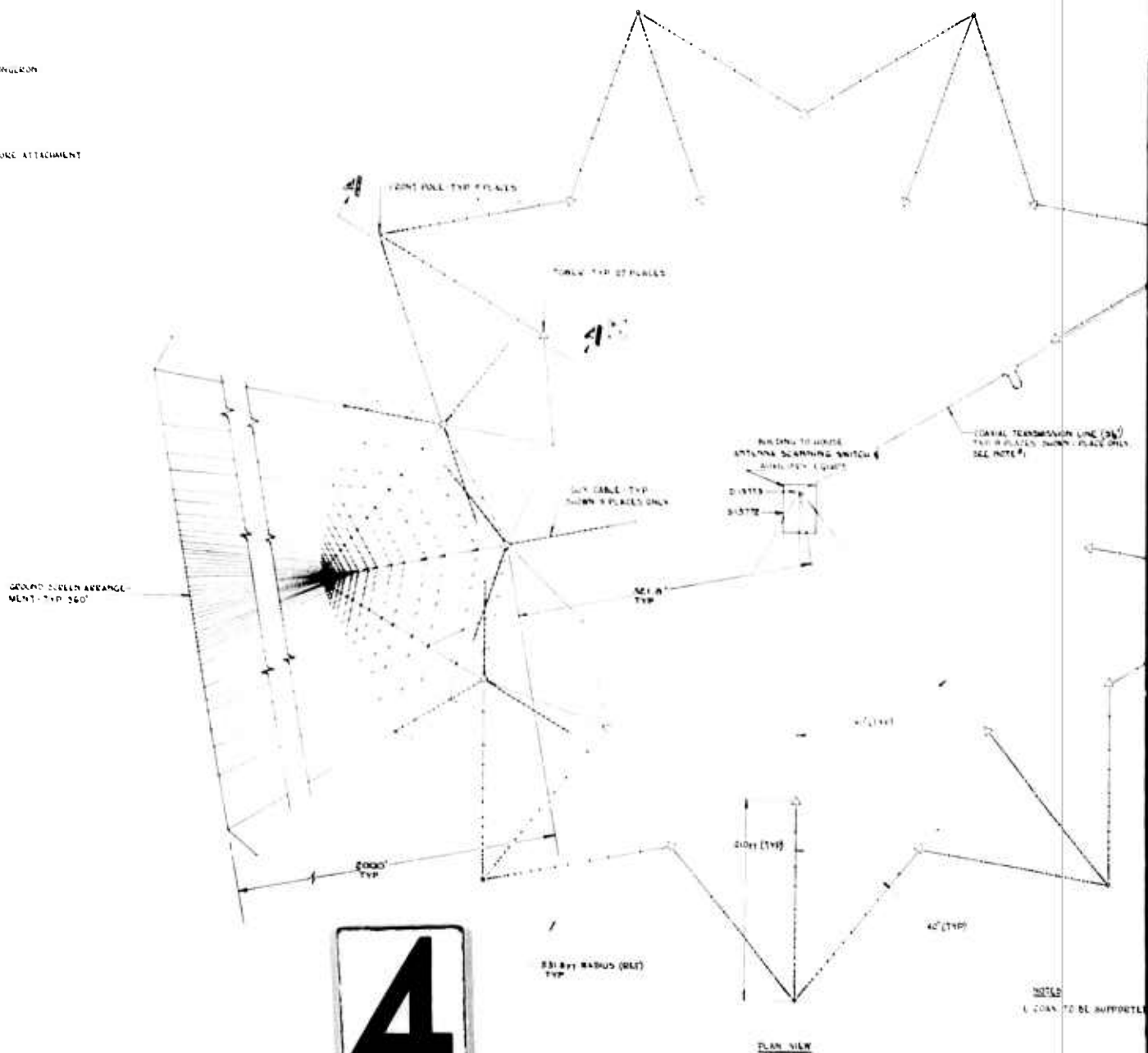
NOTES:
1. COAX TO BE SUPPORTED APPROXIMATELY EVERY 10 FT

BUILDING TO HOUSE
ANTENNA SCANNING SWITCH
AUXILIARY EQUIPT

D 13773
91377E

COAXIAL TRANSMISSION LINE (36')
TYP 6 PLACES SHOWN 1 PLACE ONLY
SEE NOTE #1

40' (TYP)

40' (TYP)

210 FT (TYP)

**5**

FIG 3-1

INPUT

E     F

D     G

80° TYP

40° TYP

10° TYP

9' RAD.     40' - TYP.

C     H

B

A

SYMMETRICAL

INPUT
FARSIDE →

G H

GROUND LINE (REF)

**1**

ELECTRICAL SCHEMATIC
o - 90° COAXIAL SWIVEL ELBOW
△-COAXIAL RELAY · "T" JOINT

FIG. 3-2

D13773

| | | | | PART NO | | PART NAME | STOCK SIZE | MATERIAL DESCRIPTION | | SPEC | ITEM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | DRAWN C-A-L | DATE | TITLE | | | | | |
| | | 1 | PER ASS'Y | CHECKED BMS | DATE 2-19-62 | ASSEMBLY, SCANNING | | | | | |
| | | R 13771 | NEXT ASS'Y | STANDARD BMS | DATE 2-14-62 | SWITCH | | | | | |
| | | | MODEL | APPROVED | DATE | | | | PALO ALTO CALIFORNIA | | |
| FINISH | | | | | SCALE | LIMITS ON DIMENSIONS — EXCEPT AS NOTED | | | | | |
| | | | | | NONE | DECIMAL .000 .00 | FRACTION | ANGULAR LIMITS | SIZE | D13773 | REV |

CONTROL PULSE SHAPING

INPUT SELECTOR (MAIN INPUT, — MANUAL OR TEST)

COAXIAL SWITCHES CONTROL UNIT

COAXIAL SWITCHES (8) 10 MS OPERATE TIME

NINE-POSITION SCAN PULSES

MAIN INPUT

FROM 9 POSITION SCAN COMMUTATOR

OPEN RELAY INTERLOCK

TO TRANSMITTER

1

INPUT
SELECTOR
(MAIN INPUT, —
MANUAL OR TEST)

COAXIAL
SWITCHES
CONTROL
UNIT

COAXIAL
SWITCHES
(8)
IO MS
OPERATE TIME

IN
UT

OUTPUT TO ANTENNA
FEEDERS

$3\frac{1}{8}$ COAXIAL LINE

SPDT COAXIAL
SWITCH

COAXIAL SWITCH
TREE SCHEMATIC

SKC 6675

OPEN RELAY
INTERLOCK

TO TRANSMITTER

FIG. 3-3

2

| | | | PART NO | PART NAME | STOCK SIZE | MATERIAL DESCRIPTION | SPEC. | ITEM |
|---|---|---|---|---|---|---|---|---|
| | | DRAWN C·A·L | DATE 12\|20\|61 | TITLE | | | | |
| | PER ASS'Y | CHECKED BMS | DATE 2-14-62 | ANTENNA SCANNING | | | | |
| | NEXT ASS'Y | APPROVED BMS | DATE 2-14-62 | PROGRAMMER (TRANSMIT) | | | | |
| | MODEL | APPROVED | DATE | LIMITS ON DIMENSIONS — EXCEPT AS NOTED | | PALO ALTO CALIFORNIA | | |
| FINISH | | SCALE NONE | | DECIMAL .000 .00 | FRACTION | ANGULAR LIMITS | SIZE | DRAWING NO. SKC 6675 | REV. |

DRY NITROGEN CYLINDERS (112 cu ft)
3 REQ'D, 1 RESERVE

ELECTRONIC CONTROL CIRCUIT
FOR VACUUM COAXIAL RELAYS

PLATFORM
10'×6' (REF)

MANIFOLD -
10 PORT

SCANNING SWITCH
ARRANGEMENT

20 FT (REF)

9 FT DIA (REF)

14 FT (REF)

1

ELECTRONIC CONTROL CIRCUIT
FOR VACUUM COAXIAL RELAYS

SCANNING SWITCH
ARRANGEMENT

9 FT DIA (REF)

**2**

D13772

FIG. 3-4

| | | | | PART NO | PART NAME | STOCK SIZE | MATERIAL DESCRIPTION | | SPEC | ITEM |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | DRAWN C·A·L 12/15/61 | TITLE | | | | | |
| | 1 | FOR ASS'Y | | CHECKED BM5 2-14 62 | BUILDING, | | | | | |
| R 13771 | | NEXT ASS'Y | | APPROVED BMS 2-14-62 | SCANNING SWITCH | | | | | |
| | | MODEL | | APPROVED DATE | | | PALO ALTO CALIFORNIA | | | |
| FINISH | | | SCALE | LIMITS ON DIMENSIONS — EXCEPT AS NOTED | | | | | | |
| | | | NONE | DECIMAL .000 | FRACTION | ANGULAR LIMITS | SIZE | DRAWING NO D13772 | | REV |

NICO-PRESS SLEEVE
420 REQ'D

CALSUN
BRONZE REFLECTOR-420 REQ'S.

DOUGLAS FIR POLE - 20"DIA X 100'LG
TYP. 60 PLACES

REFLECTOR SUPPORT
CATENARY CABLE ASS'Y 60 REQ'D

R4'6" TYP

JAW & EYE TURNBUCKLE
60 REQ'D

EYEBOLT
60 REQ'D

VIEW **B-B**

240' RAD
OUTER EDGE OF GR

NICO-PRESS SLEEVE
420 REQ'D

THIS ANCHOR ARRANGEMENT
IS TYP 30 PLACES

THIS ANCHOR ARRANGEMENT
IS TYP 30 PLACES

SECTION **C-C**

SEE D13759 FOR TYP BASE & ANCHOR INSTALLATION

**1**

DOUGLAS FIR POLE - 20"DIA X 100'LG
TYP 60 PLACES

820' DIA
REFLECTOR POLES

SUPPORT
ASS'Y - 60 REQ'D

TYP

TURNBUCKLE

VIEW 13-13

2410 RAD
OUTER EDGE OF GROUND WIRE

THIS ANCHOR ARRANGEMENT
IS TYP 30 PLACES

13

13

2

A                    A

820' DIA
FLECTOR POLES

CONICAL MONOPOLE ANTENNAS

3-18 MC CONICAL
MONOPOLE - RQ'D

B

B

A

C

C

VIEW A-A
PORTION OF REFLECTORS SHOWN ONLY

**3**

NTENNAS



VIEW **A-A**
PORTION OF REFLECTORS SHOWN ONLY

**FIG 3-5**



RECEIVING ANTENNA
ARRAY ASSEMBLY
3-18 Mc

PALO ALTO, CALIFORNIA

R-13774

C

NICO-PRESS SLEEVE
300 REQ'D

CAL SUN
BRONZE REFLECTOR-300 REQ'D

DOUGLAS FIR POLE - 20" x 100' LG
TYP 60 PLACES

REFLECTOR SUPPORT
CATENARY CABLE ASS'Y 60 REQ'D

75'-0 TYP

JAW & EYE TURNBUCKLE
60 REQ'D

EYEBOLT
60 REQ'D

B-B

B

NICO PRESS SLEEVE
120 REQ'D

300 TYP (REF)
TYP 60 PLACES

THIS ANCHOR ARRANGEMENT
IS TYP 30 PLACES

THIS ANCHOR ARRANGEMENT
IS TYP 30 PLACES

A

# 1

SECTION C-C

SEE 113759 FOR TYP BASE & ANCHOR INSTALLATION

DOUGLAS FIR POLE - 20" x 100' LG
TYP 60 PLACES

SUPPORT
ASS'Y 60 REQ'D

75'-0 TYP

7.5 Mc CONICAL
MONOPOLE - 60 REQ'D
ON 193' RADIUS

REFLECTOR POLE
ON 193' RADIUS
60 REQ'D

TURNBUCKLE

13-13

THIS ANCHOR ARRANGEMENT
IS TYP 30 PLACES

C

**2**

REFLECTOR POLE
IN ITS RADIUS
40 REQ'D

C TIP
40 PLACES

45.84
(REF)

7.50 M. CONICAL
MONOPOLE  40 REQ'D

C                                                                          C

VIEW A-A
PORTION OF REFLECTORS SHOWN ONLY

# 3

43.84
(REF.)

7-30 Mc CONICAL
MONOPOLE 4 REQ'D

VIEW A-A
PORTION OF REFLECTORS SHOWN ONLY

FIG 3-6

A

**4**
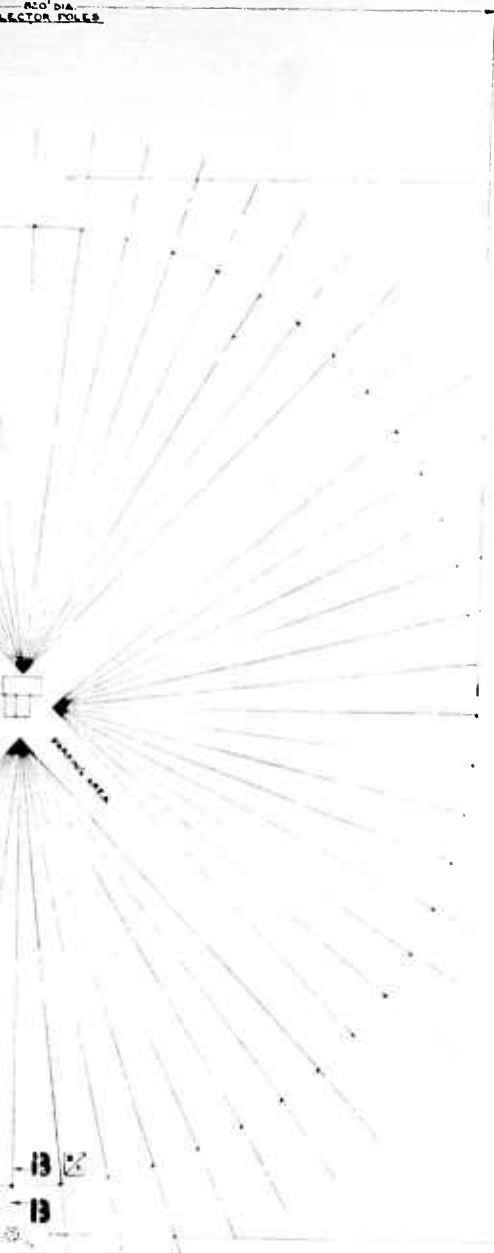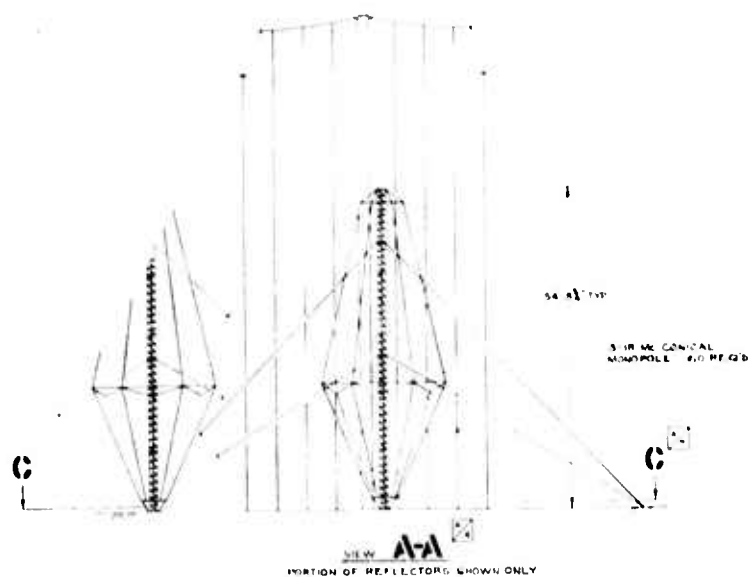
| ASSEMBLY APPLICATION | TOTAL QUANTITY | ITEM | PART NUMBER | DESCRIPTION | MATERIAL AND SPECIFICATION | | |
|---|---|---|---|---|---|---|---|
| UNLESS OTHERWISE SPECIFIED TOLERANCES | | NEXT ASSEMBLY | | TITLE | | | |
| | | | | RECEIVING ANTENNA ARRAY ASSEMBLY 7-30 Mc | PALO ALTO, CALIFORNIA | | |
| MACHINED SURFACES EXCEPT AS NOTED | | | | | DRAWING NUMBER REV R - 15923 | | |
| | | | | SCALE NONE WEIGHT | SHT 1 OF 3 SIZE | | |

23¾" DIA. (REF)

STATOR/ROTOR CIRCLE (REF)
19½" DIA. NOM.

SUMMING JUNCTION
CONNECTOR (REF)

COAX ROT. JOINT
SAGE 505

SUMMING JUNC.
BOX

TYPE "N" CONNECTORS
TYP. 30 PLACES-12" APART

TYPE "N" CONNECTORS
TYP. 30 PLACES-12" APART
CONNECTED TO ROTOR PLATES

RG 65 DELAY CABLE-TYP.
30 REQ'D. OF VARYING LENGTHS

TOP COVER LEFT OUT FOR CLARITY INSIDE THIS AREA

ROTOR PLATE-TYP. 30
PLACES-12" APART-
IMBEDDED IN DIELECTRIC

TYPE "N" CONNECTOR
TYP. 60 PLACES-6" APART

STATOR PLATE-TYP. 60
PLACES-6" APART
IMBEDDED IN DIELECTRIC

FERRITE CORES-2 REQ'D.
TYP. 60 PLACES-6" APART

1

24" (REF)

3 STATOR PLATES SHOWN, ONLY
NOT LOCATED TO SCALE

DELAY CABLE (REF)

SUMMING JUNCTION
CONNECTOR (REF)

VIEW A-A
ROTATED 90°

SKD 6805

Y CABLE - TYP
VARYING LENGTHS

FT OUT FOR CLARITY INSIDE THIS AREA

FIG. 3-7

2

| PART NO | PART NAME | STOCK SIZE | MATERIAL DESCRIPTION | SPEC | ITEM |
|---------|-----------|------------|----------------------|------|------|

| DRAWN | C·A·L | DATE 2/14/62 | TITLE | | |
| PER. ASS'Y | | ANSWERED DATE | ASSEMBLY, GONIOMETER | | |
| NEXT ASS'Y | | APPROVED DATE | | | |
| MODEL | | APPROVED DATE | | PALO ALTO CALIFORNIA | |
| | | | LIMITS ON DIMENSIONS — EXCEPT AS NOTED | | |
| FINISH | SCALE NONE | DECIMAL .000 .00 | FRACTION | ANGULAR LIMITS | SIZE | DRAWING NO SKD 6805 | REV |

FIG. 4-1     ELEVATION AND AZIMUTH PLANE PATTERNS
OF TRANSMITTING ANTENNA ARRAY ELEMENT
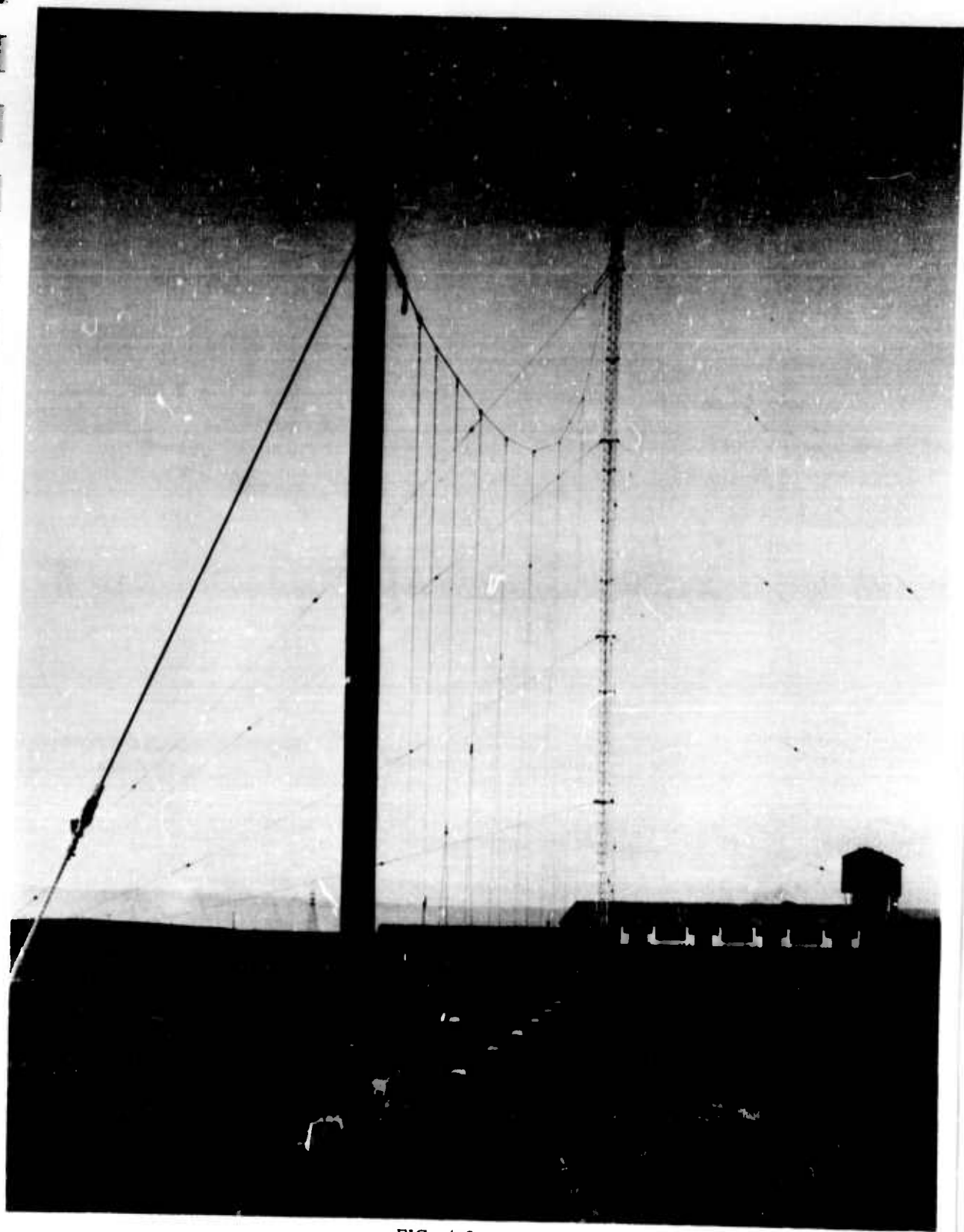
FIG. 4-2

G/A MODEL 726-2.5/30 LOG-PERIODIC ANTENNA

300'

Direction of
Maximum Radiation
from Log Periodic
Antenna at 58°

8 Radials each
130 ft long

λ/4 Monopole Antenna

Model 726-2.5/30
Log Periodic
Antenna
Ground Plane
Shown in Fig.

200 ft of RG-17/U
Coaxial Cable

300 ft of RG-17/U
Coaxial Cable

Instrumentation
Van

Tower
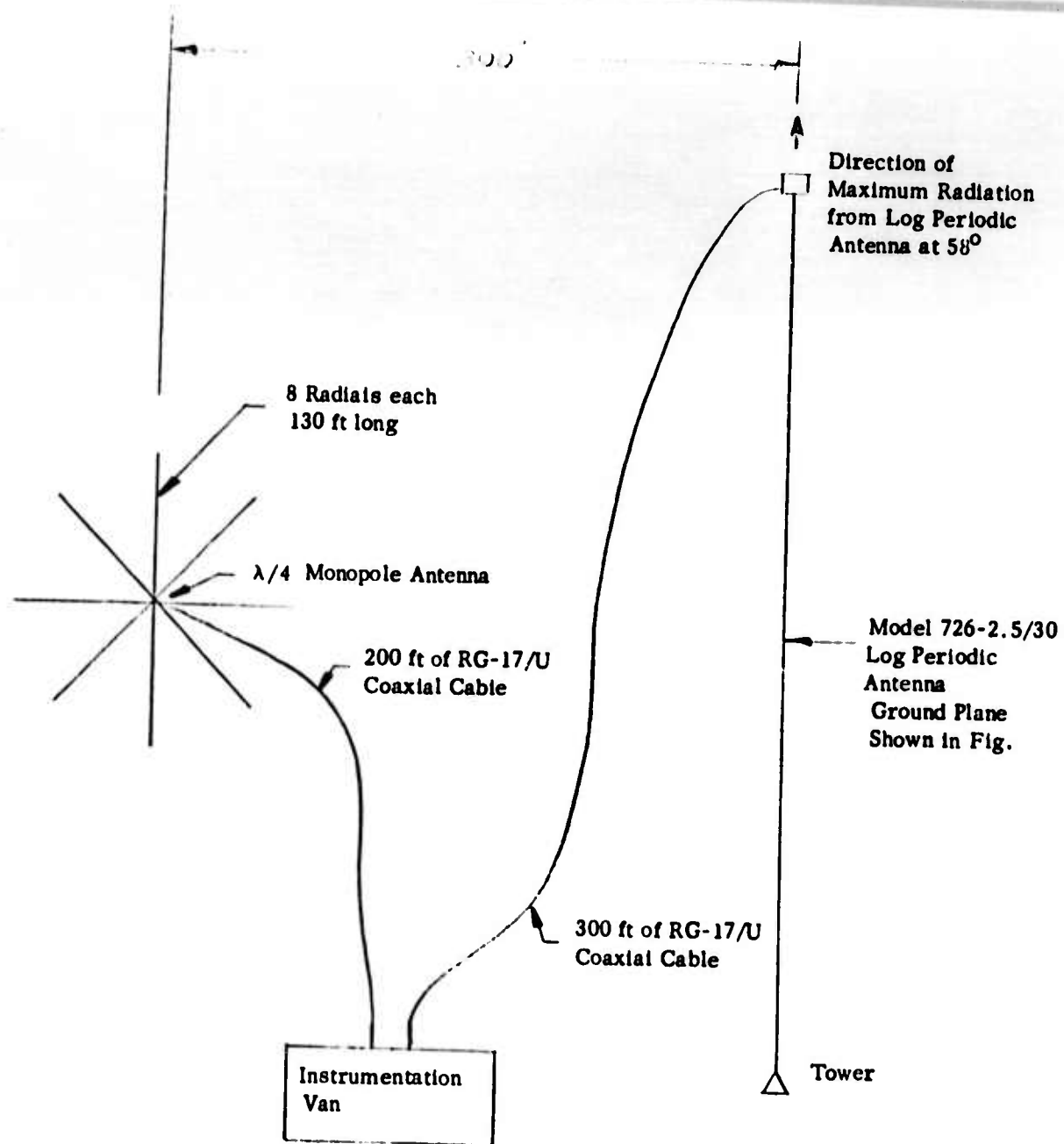
FIG. 4-3 - Plan View of Antenna Installation for Relative Gain Measurements

FIG. 4-4 - Ground Screen for the Model 726-2.5/30 Antenna

IMPEDANCE          COORDINATES

$Z_0$ = 50 ohms
(through transformer)

2.0:1 VSWR Circle
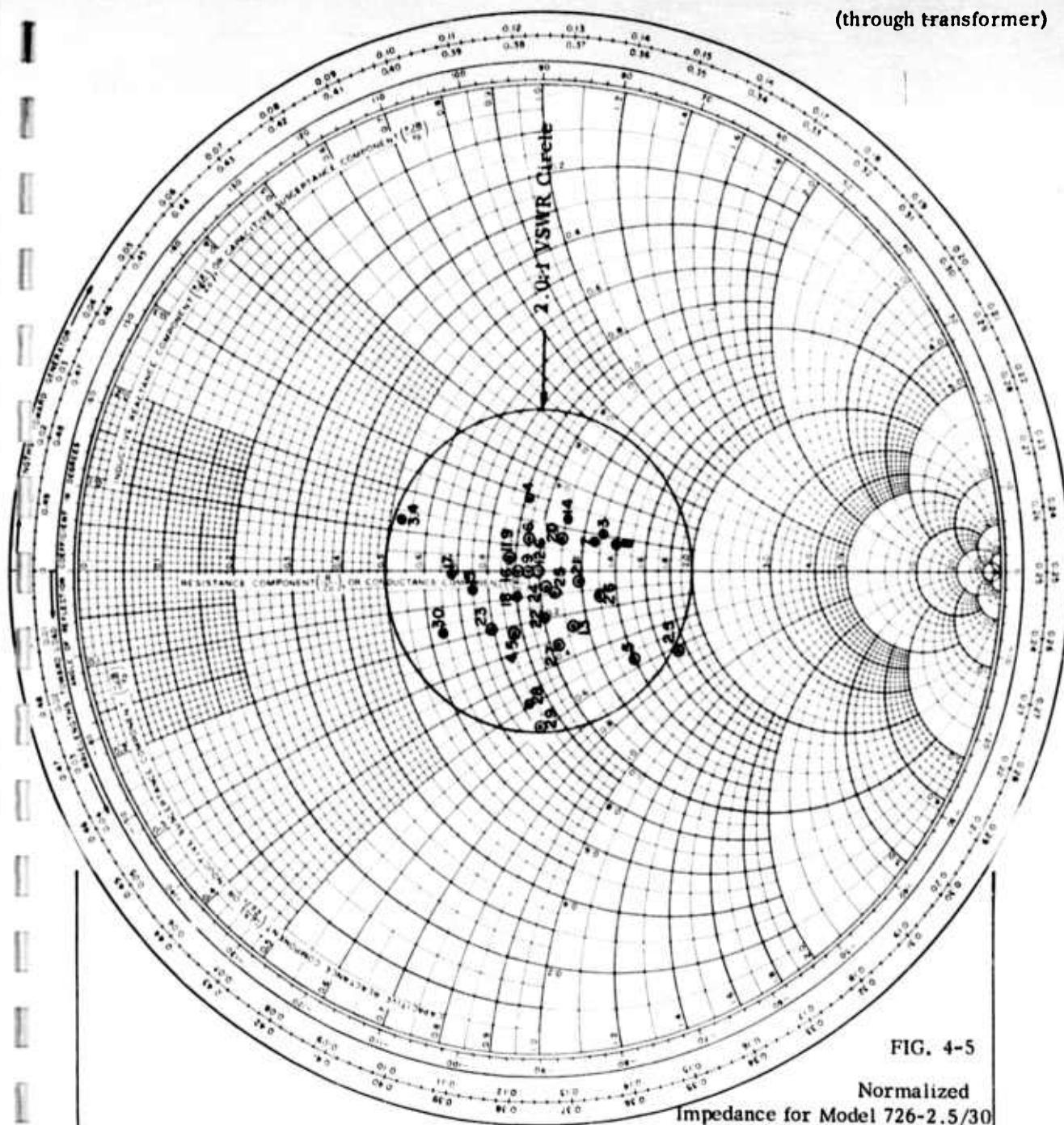
FIG. 4-5

Normalized
Impedance for Model 726-2.5/30
Antenna

RADIALLY SCALED PARAMETERS

TOWARD GENERATOR →          ← TOWARD LOAD

CENTER

FIG. 4-6 Instrumentation Used for Relative Gain Measurements and Waveform of Data Collection Sequence

System calibrated with H-P 606 Signal Generator into RF input of Receiver.

Input to Recorder switched periodically during measurements to cancel possible differences in channel characteristics.

* On time approximately five time greater than AGC circuit time constant

WWV = 15 Mc     Washington, D. C.

WVSI = 15.5 Mc     Washington, D. C. = Voice of America



WWV $\left\{\begin{array}{l} \text{M.P.} = \text{------} \\ \text{LP} = \text{--·--} \end{array}\right.$   Average MP + 2.64 db

WVSI $\left\{\begin{array}{l} \text{MP} = \text{--·--} \\ \text{LP} = \text{------} \end{array}\right.$   Average LP + 4.13 db

12/18/61
9:05 to 9:45
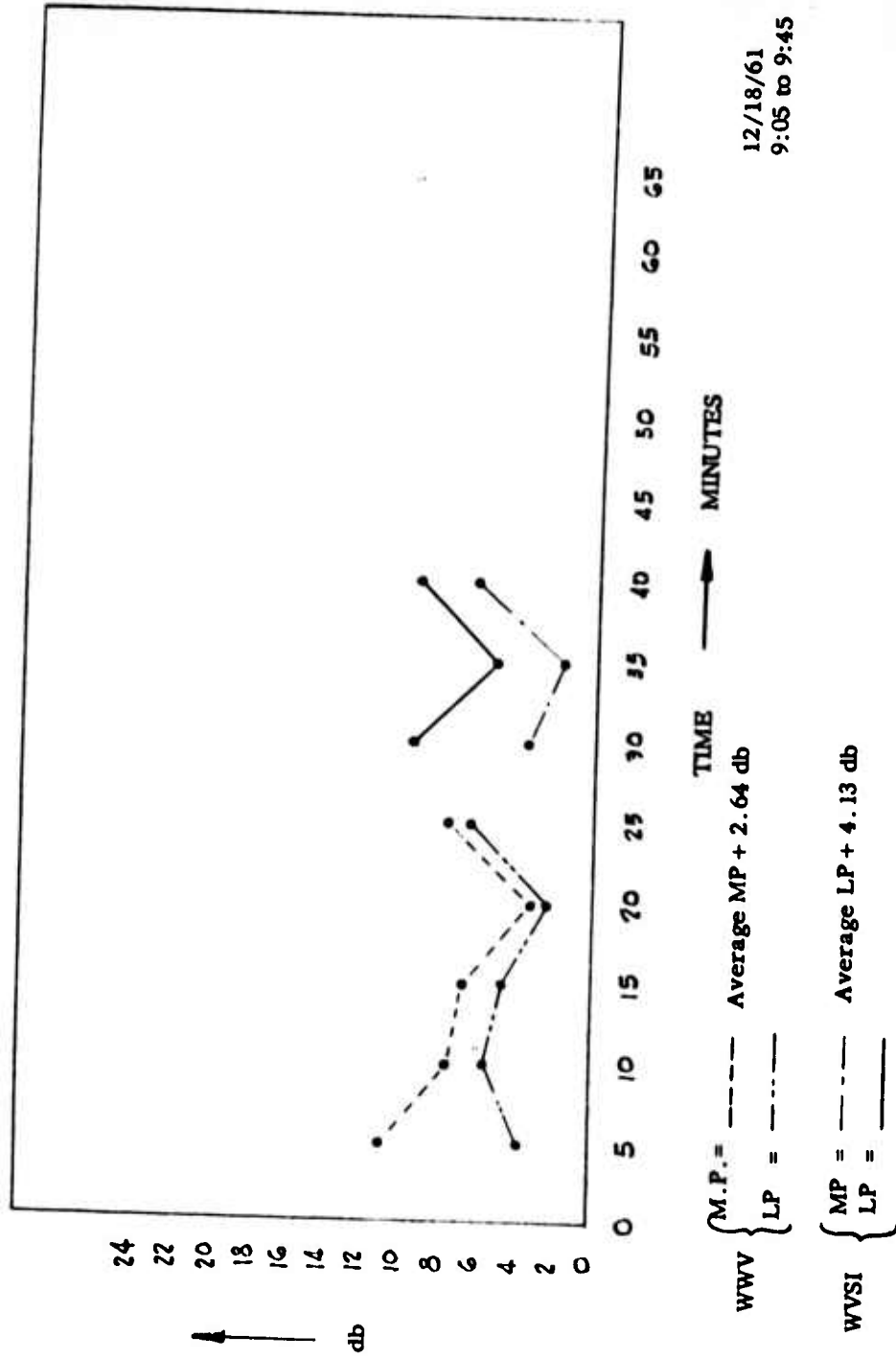
FIG. 4-7 - Reduced Relative Gain Data
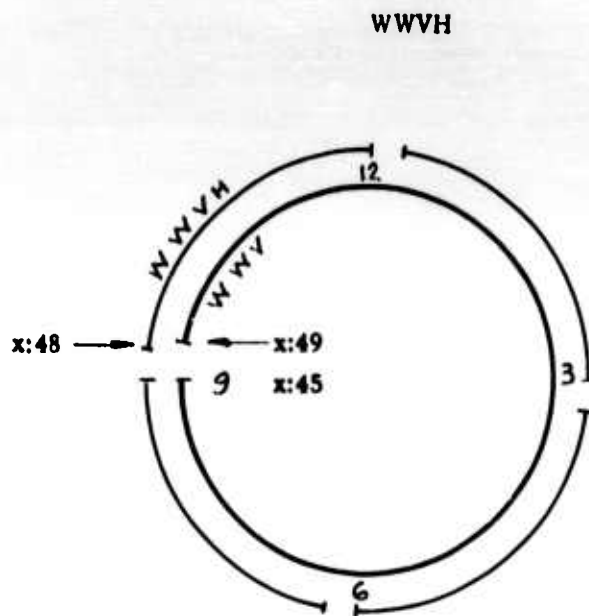
WWVH



WWVH on only
x:48 to x:49 hours
During these periods
the Whip exhibited
15+ db higher gain
than the 726

FIG. 4-8 - WWV and WWVH Data
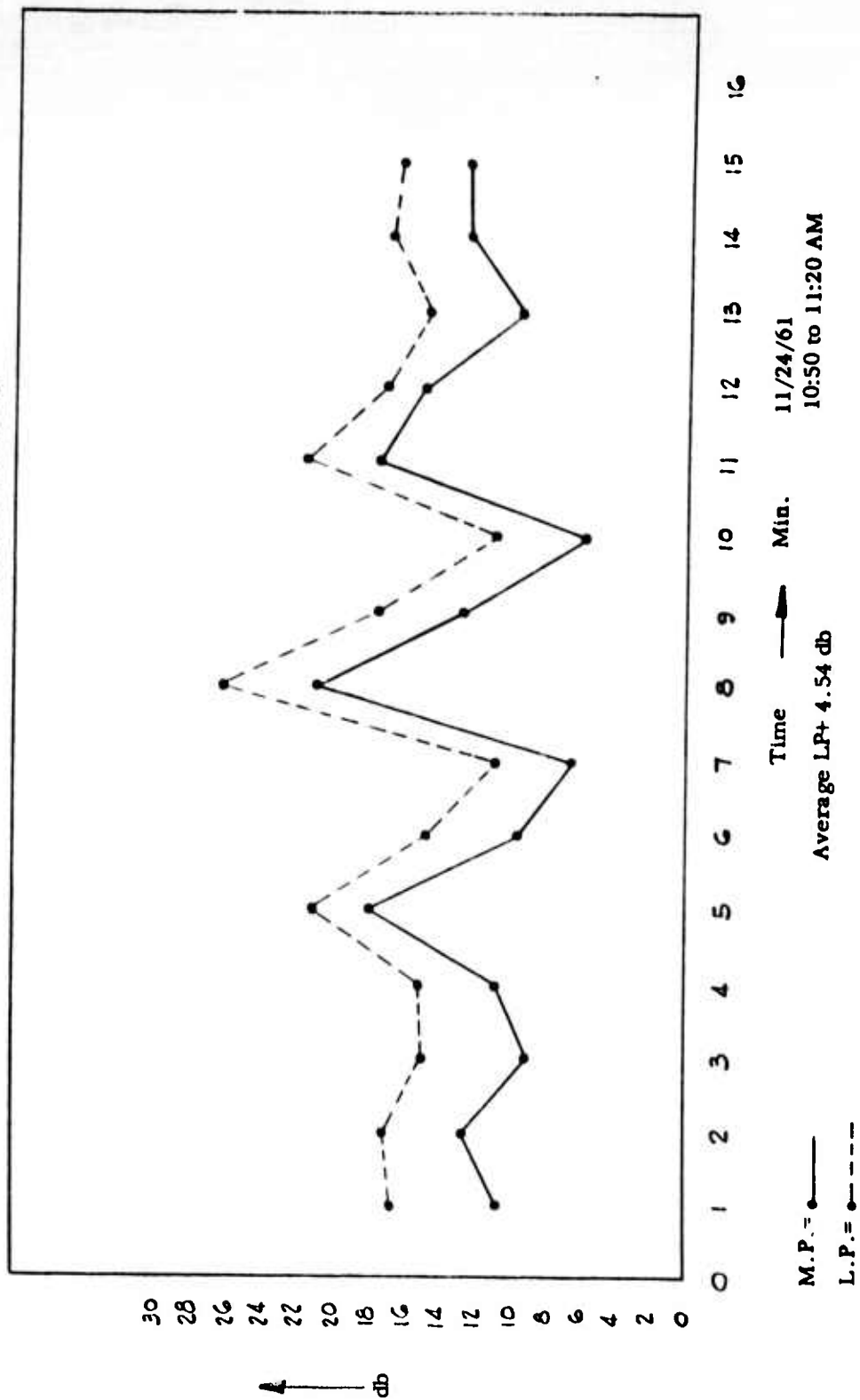
FIG. 4-9 - Relative Gains on WWV

IMPEDANCE OR ADMITTANCE COORDINATES

*SCALE FACTOR 4.4
(PARTIAL FREQ. RANGE)



$f_c = 8.0$

RADIALLY SCALED PARAMETERS

TOWARD GENERATOR →          ← TOWARD LOAD

CENTER

FILE NO. _____



FIG. 4-11  AZIMUTH PLANE  PATTERN OF
TRANSMITTING  ARRAY ANTENNA
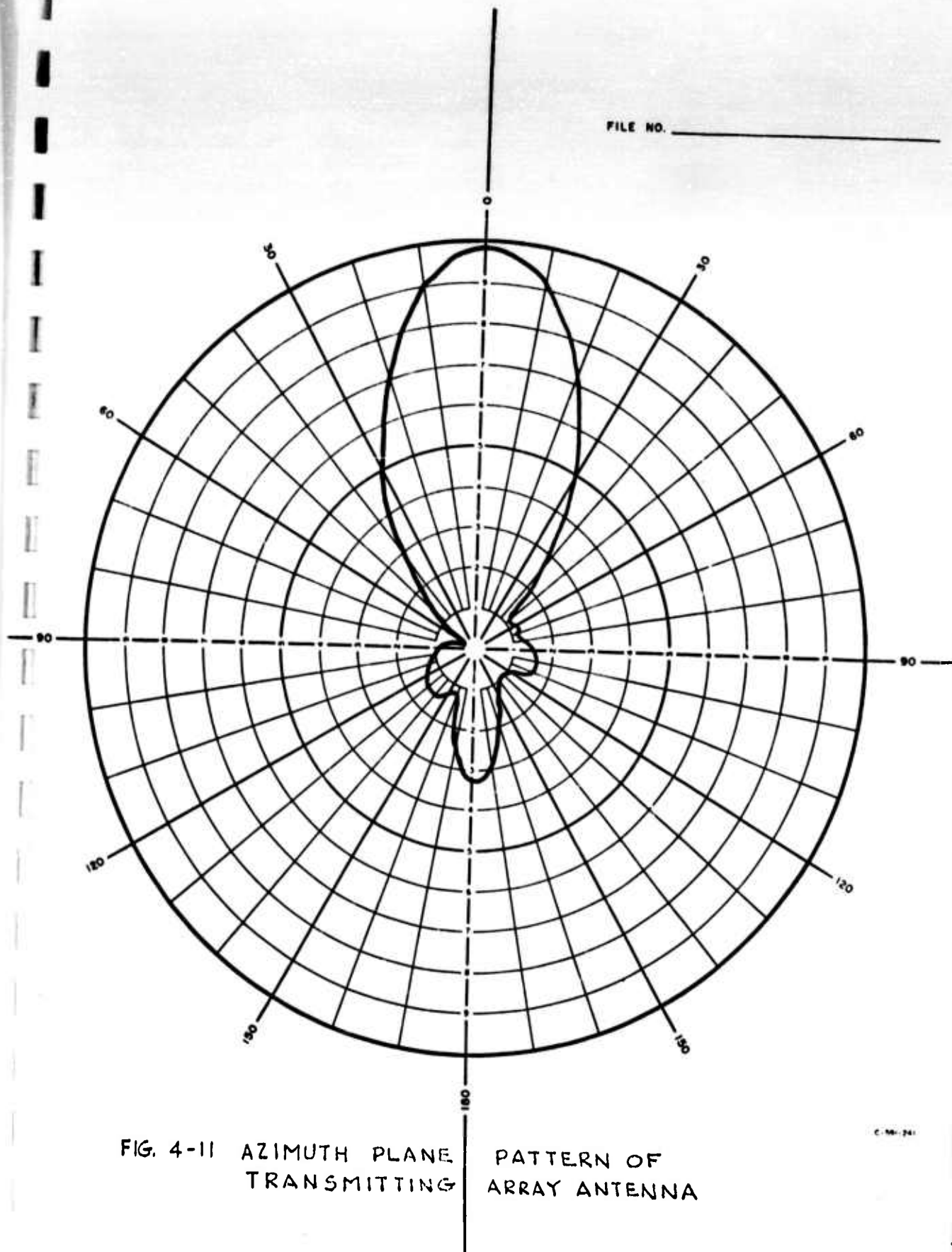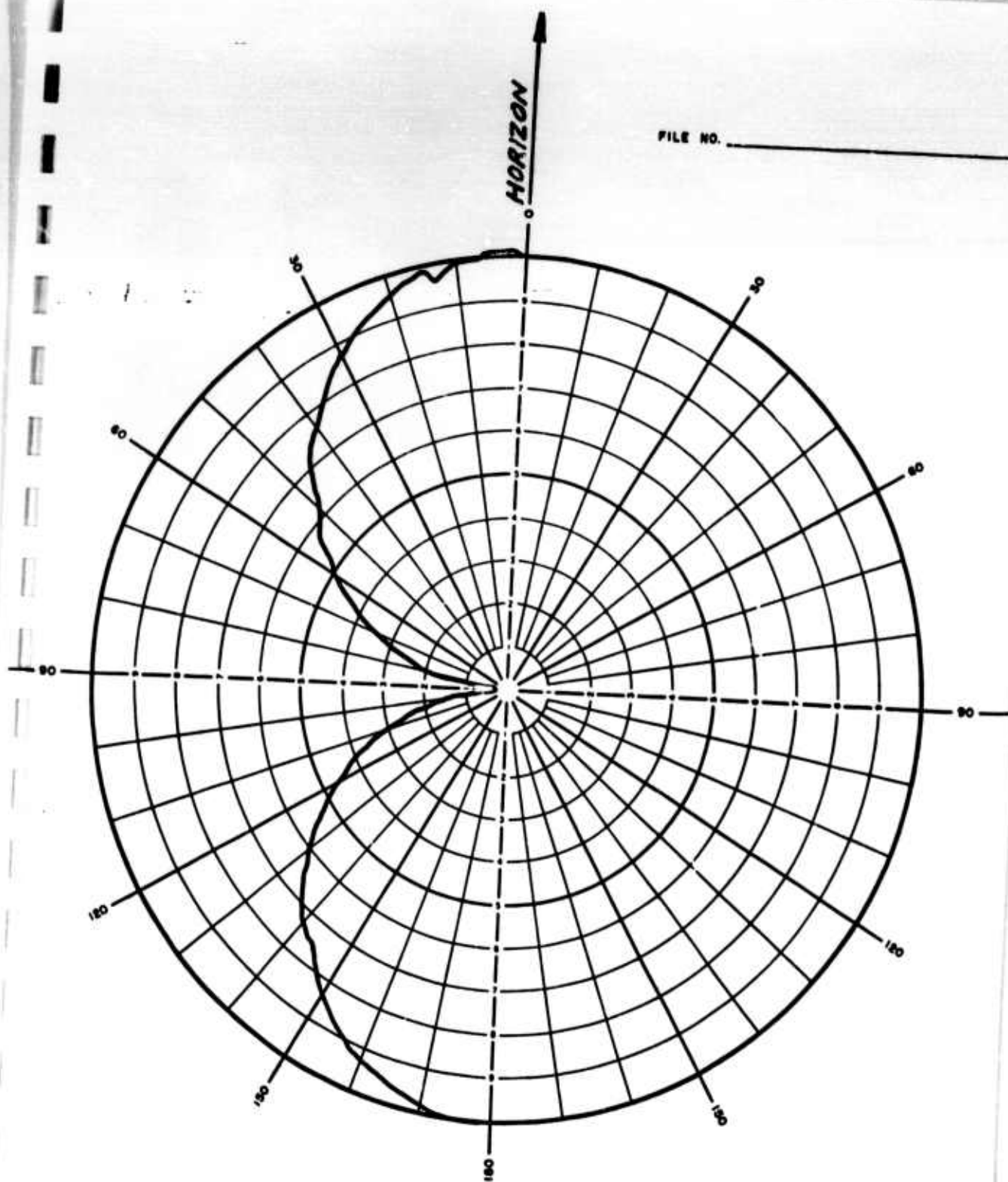
FIG. 4-12 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT $f_0$

FIG. 4-13 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT 1.5 $f_o$

FIG. 4-14   ELEVATION PLANE   RADIATION PATTERN FOR
CONICAL MONOPOLE   ARRAY ELEMENT AT 2.0 $f_0$
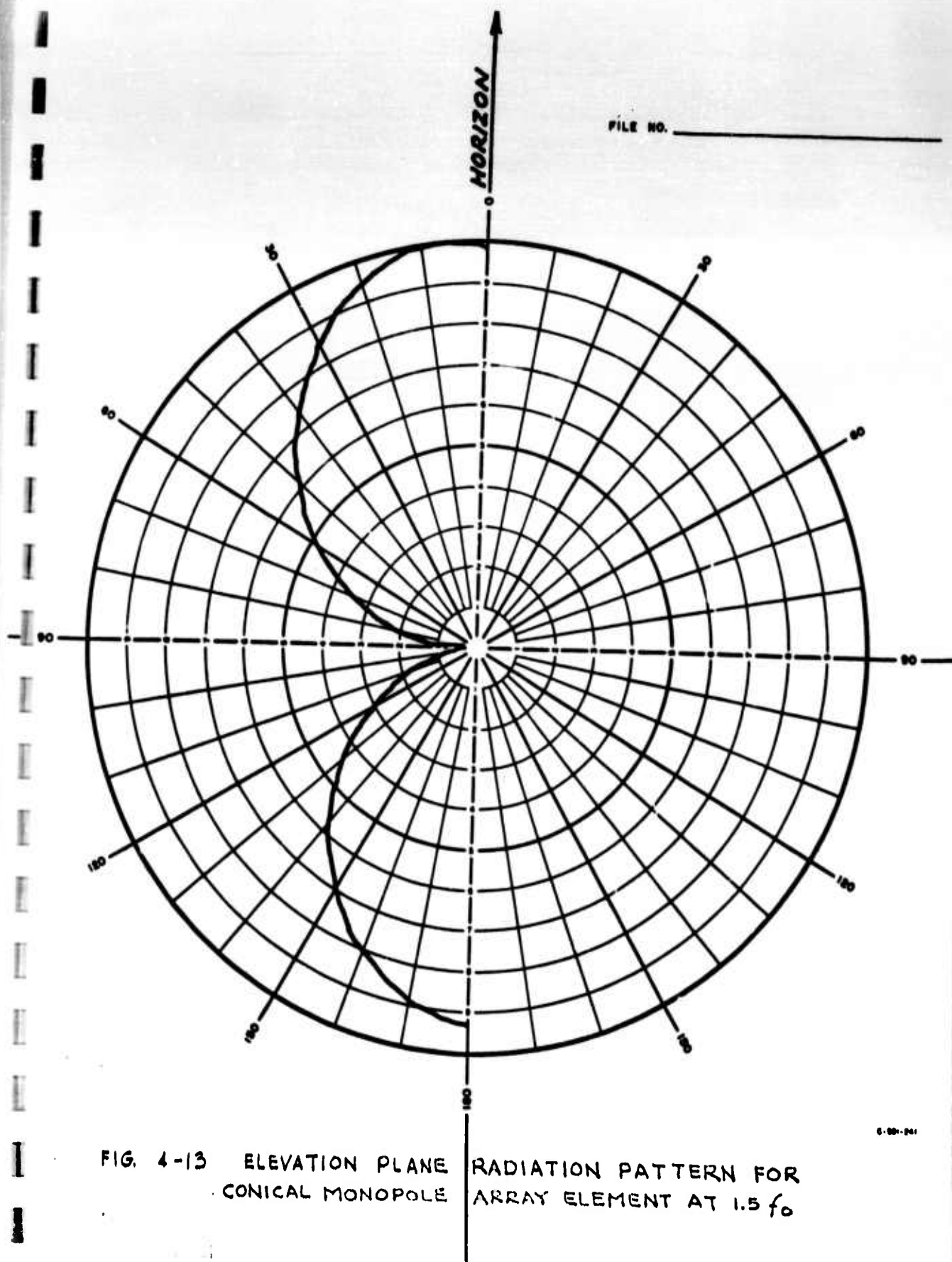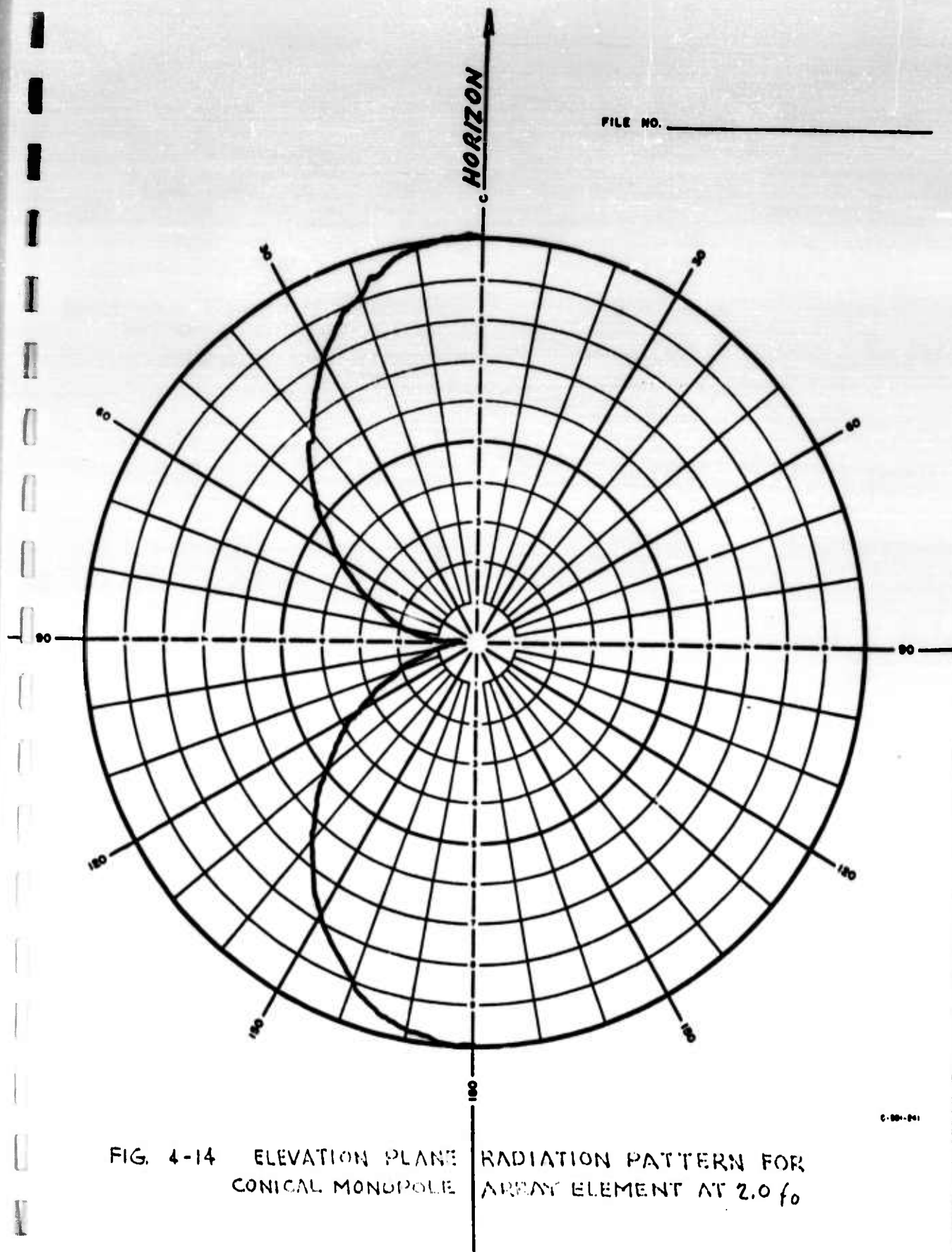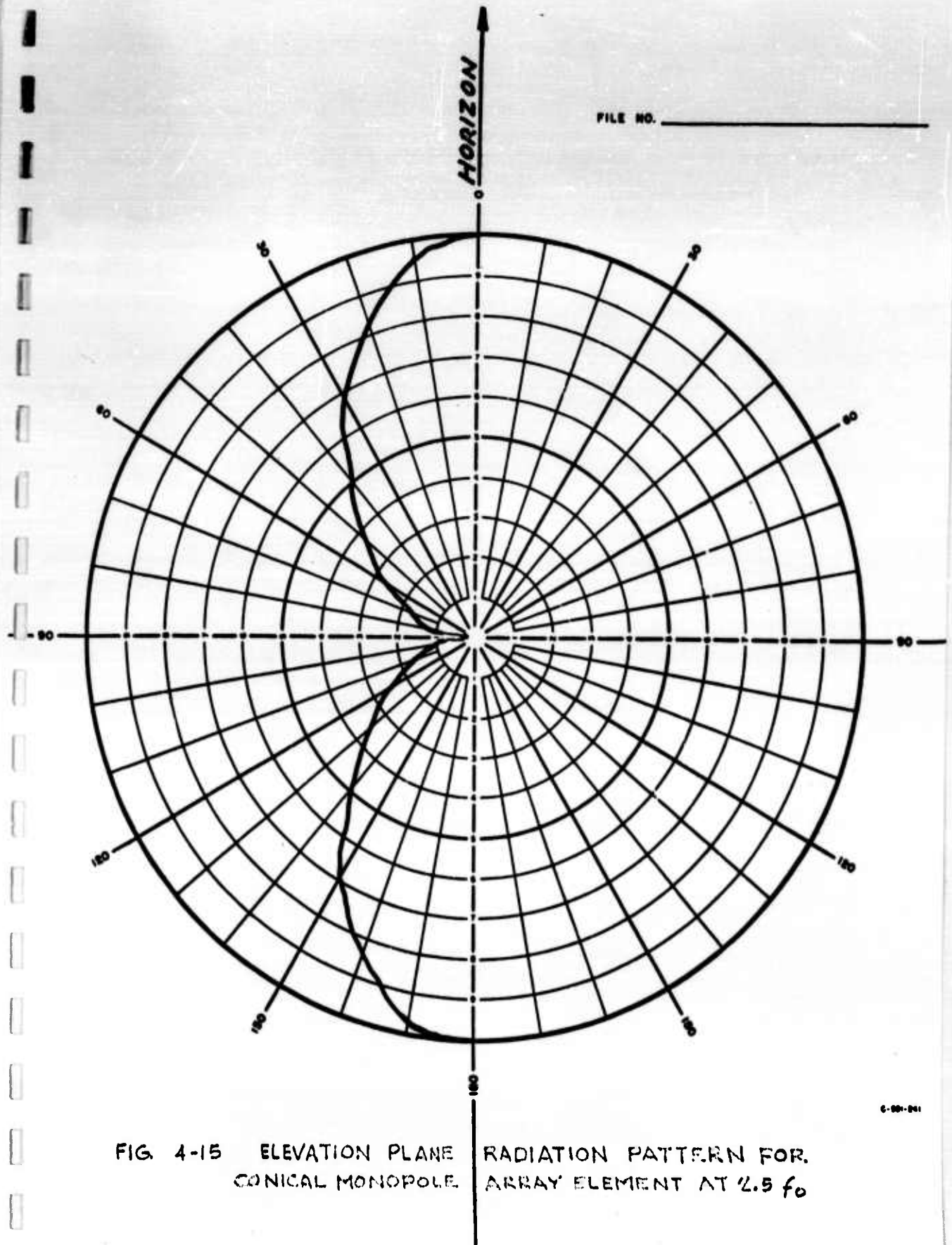
FIG 4-15   ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT 2.5 $f_0$
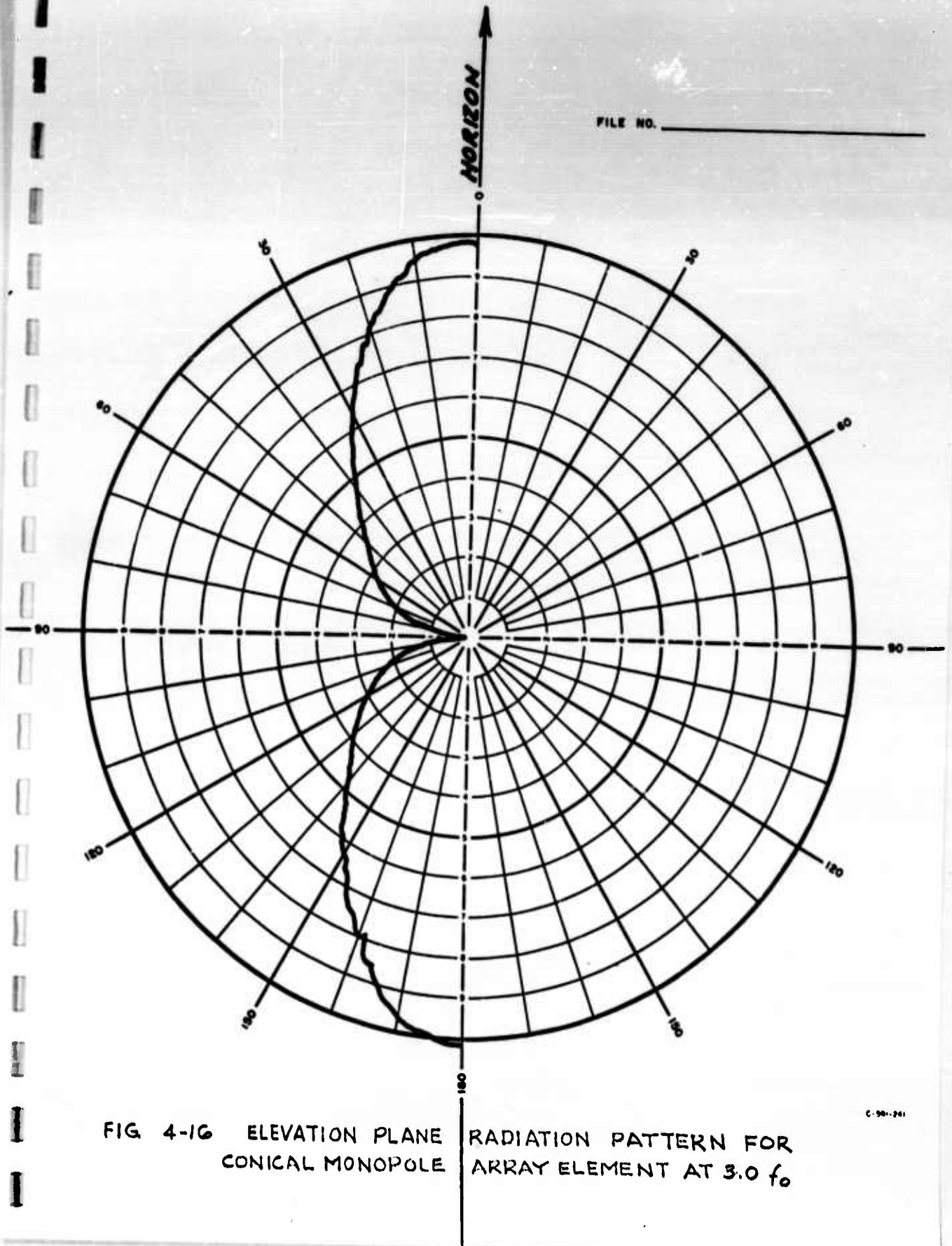
FIG 4-16   ELEVATION PLANE   RADIATION PATTERN FOR
CONICAL MONOPOLE   ARRAY ELEMENT AT 3.0 $f_0$
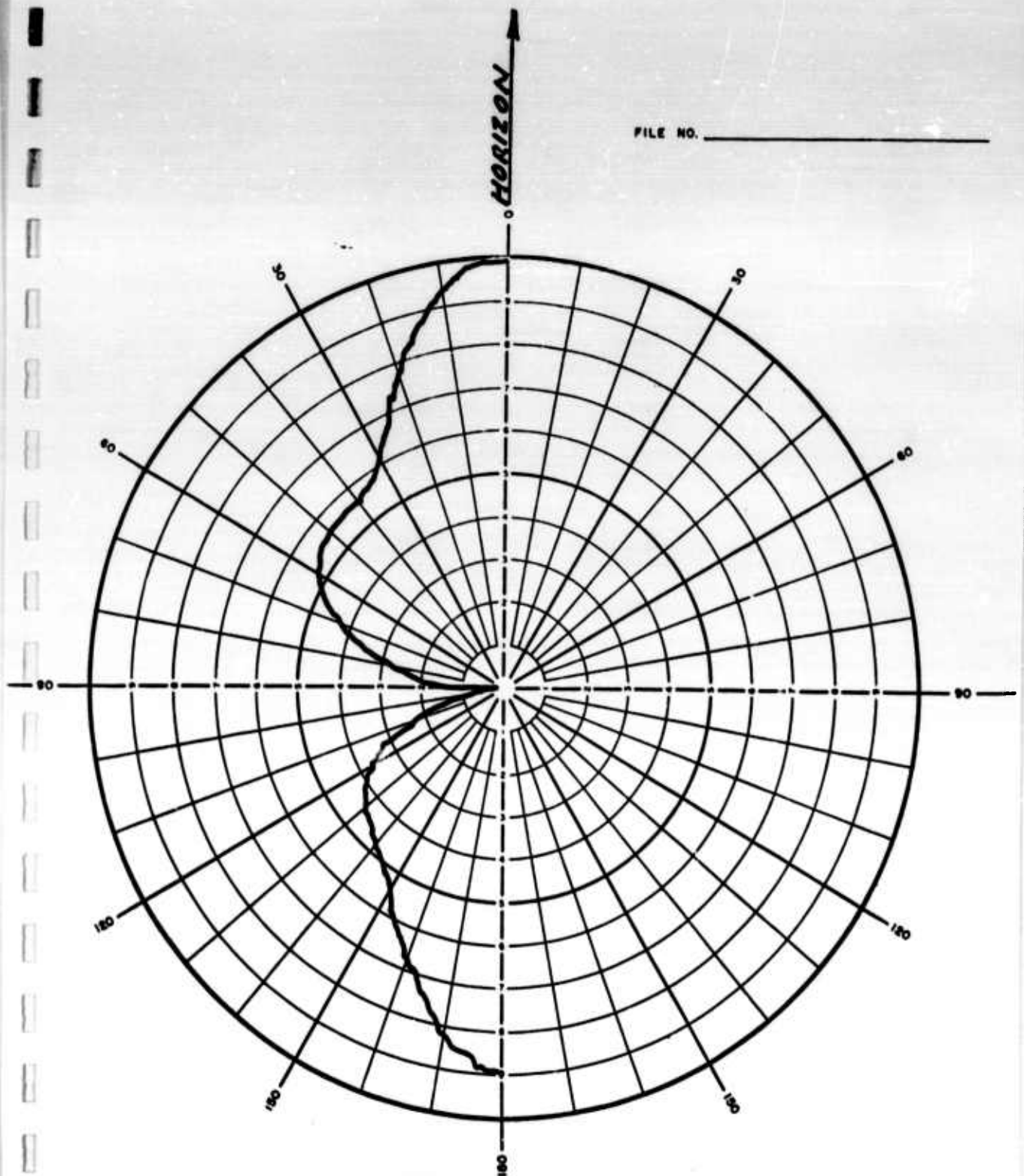
FIG 4-17 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT 3.5 $f_o$

FIG 4-18 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT 4.0 $f_0$

FIG. 4-19 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE. ARRAY ELEMENT AT 4.5 $f_0$

FIG. 4-20 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT 5.0 $f_0$

FIG. 4·21 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT $5.5 f_0$

HORIZON

FILE NO. _____

FIG. 4.22 ELEVATION PLANE RADIATION PATTERN FOR CONICAL MONOPOLE ARRAY ELEMENT AT 6.0 fₒ

| NAME | TITLE CONICAL MONOPLE IMPEDANCE | DWG. NO. 4-23 |
|---|---|---|
| SMITH CHART FORM 82BSPR (2-49) | KAY ELECTRIC COMPANY, PINE BROOK, N.J. ©1949 PRINTED IN U.S.A. | DATE |

IMPEDANCE          COORDINATES



VSWR 2.5:1

$Z_0 = 75\,\Omega$

RESISTANCE COMPONENT ($\frac{R}{Z_0}$) OR CONDUCTANCE COMPONENT ($\frac{G}{Y_0}$)

RADIALLY SCALED PARAMETERS

TOWARD GENERATOR → ← TOWARD LOAD

CENTER

A MEGA-CHART

REFLECTOR POLE
ON 820' DIA.
TYP. 60 PLACES
AT 6° ANGLES

PARKING AREA

OUTER 2410' RADIUS
EDGE OF GROUND WIRE

3-18 Mc CON...
MONOPOLE - ...
ON 902' DIA.

FIG. 4-24
PLAN VIEW
LOW BAND ARRAY
3-18 Mc
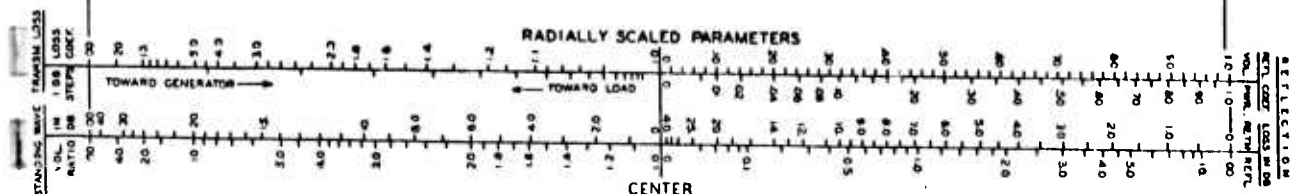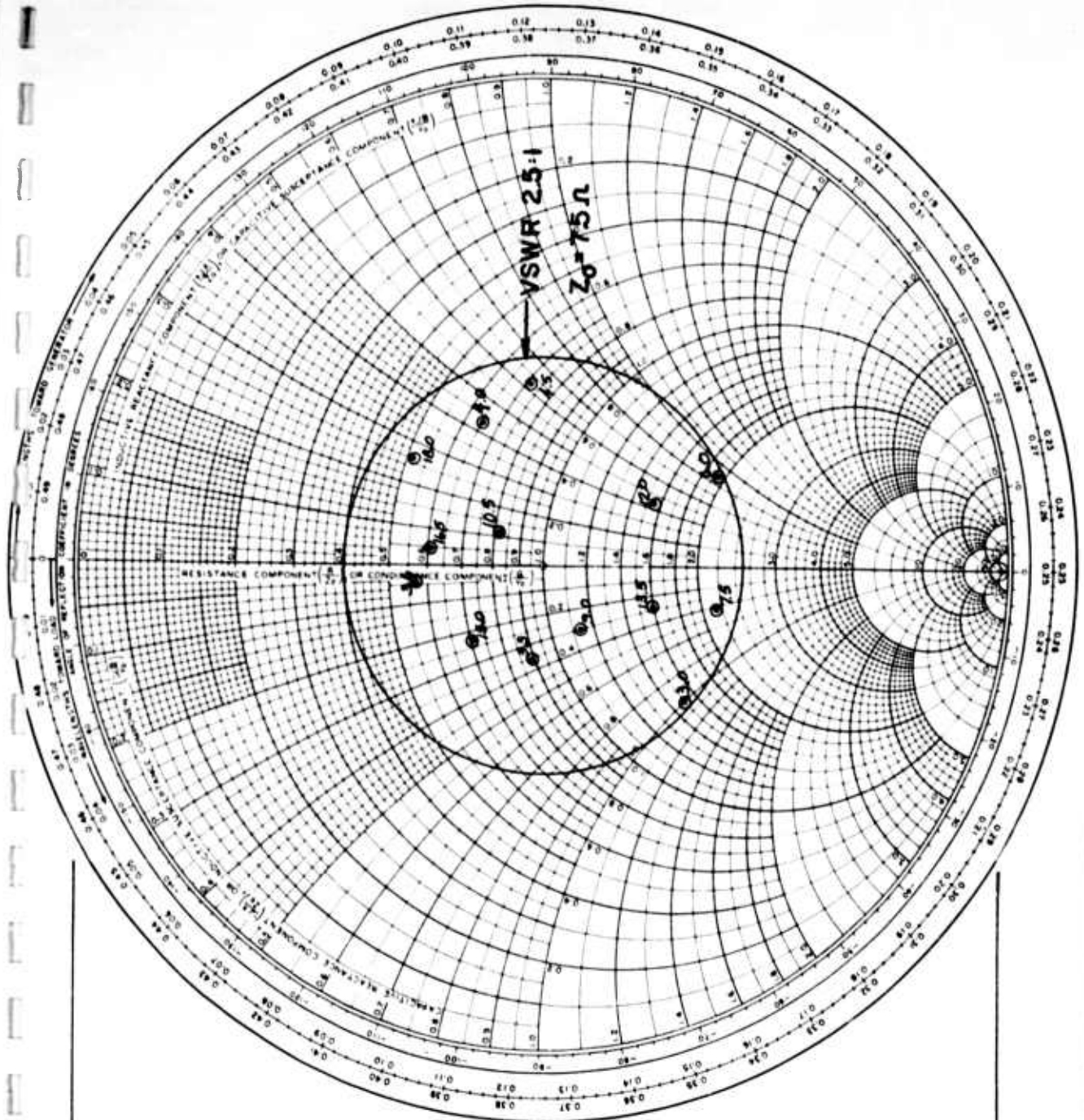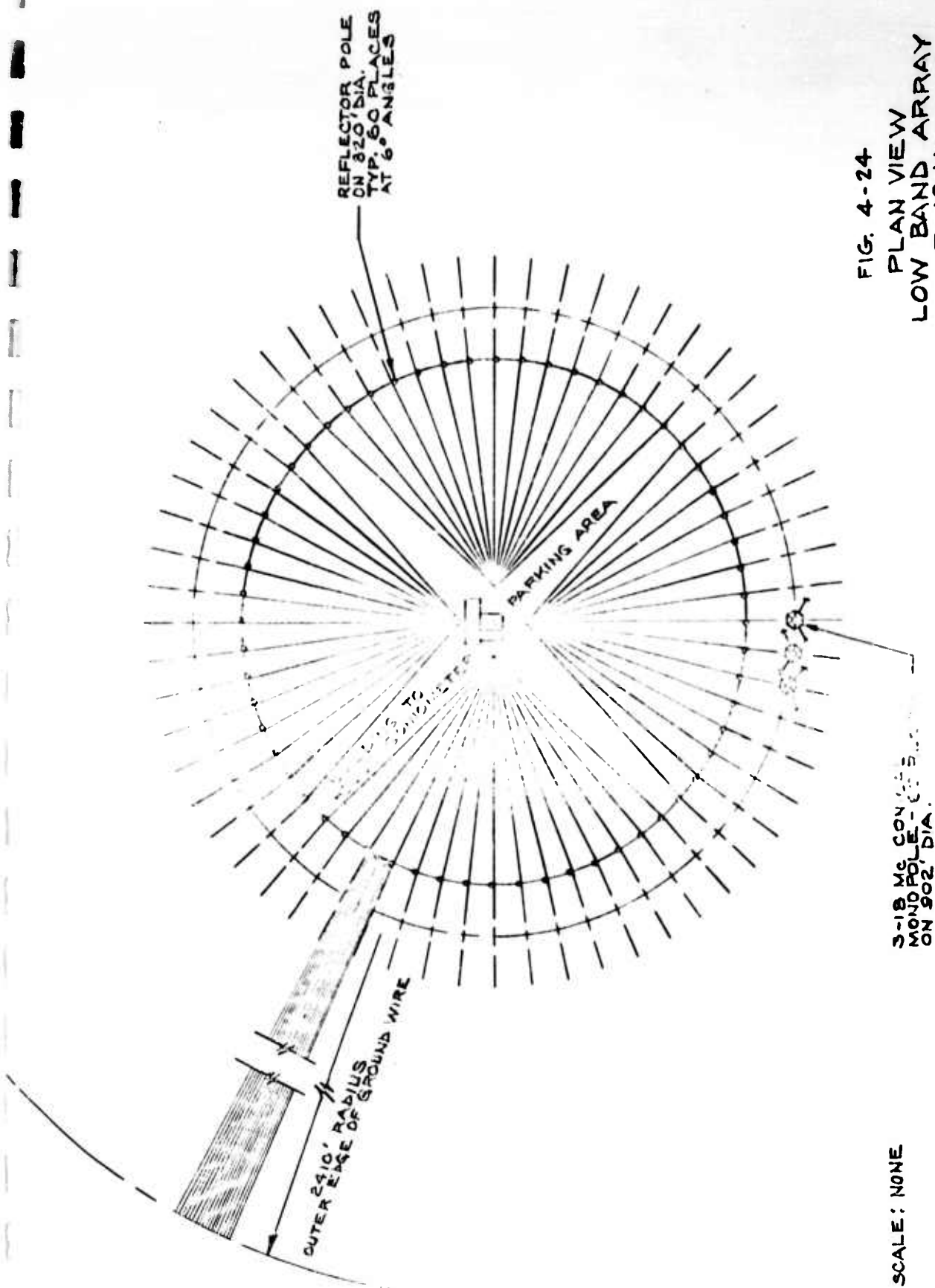
SCALE: NONE
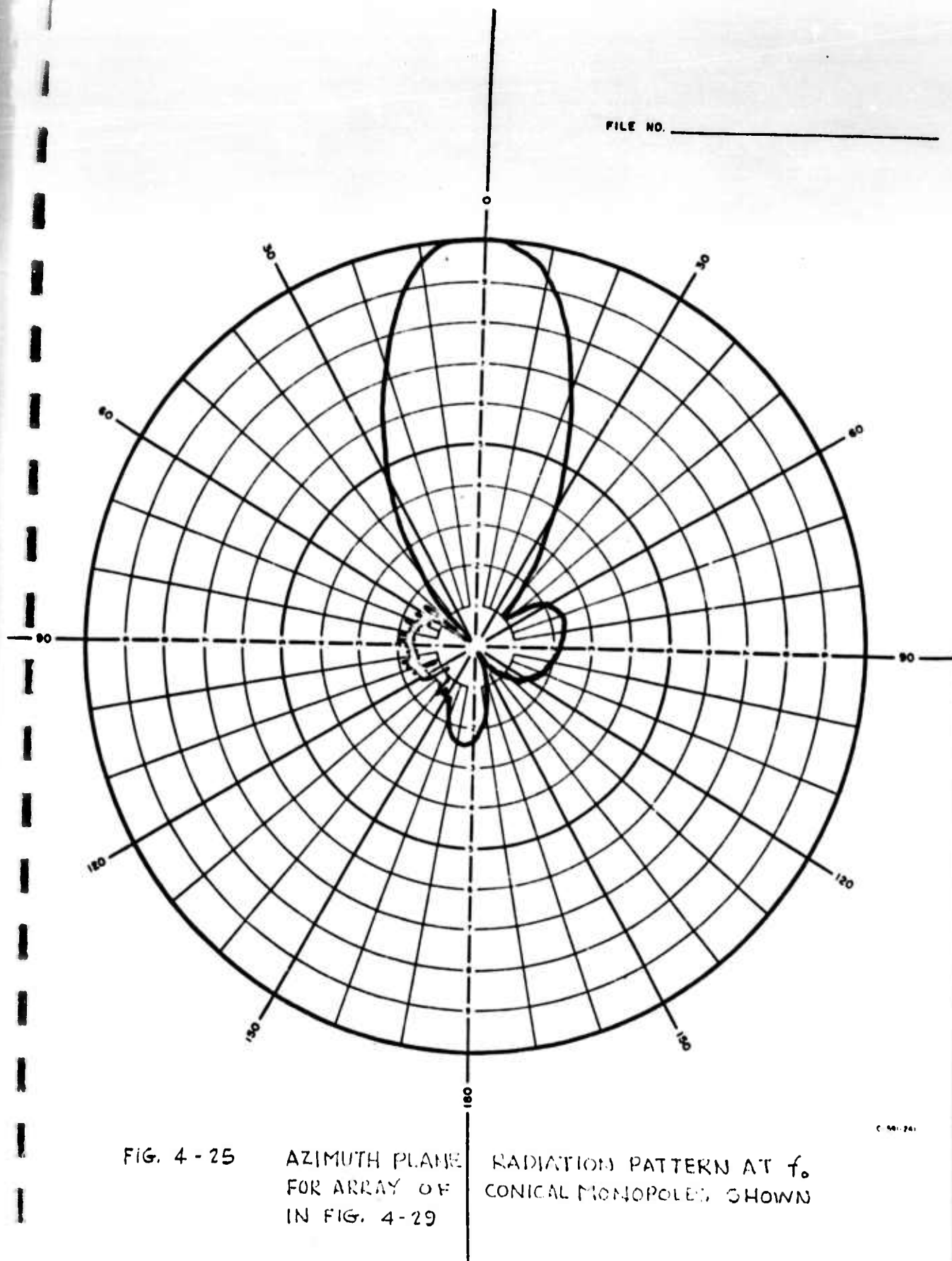
FIG. 4-25    AZIMUTH PLANE   RADIATION PATTERN AT $f_0$
             FOR ARRAY OF    CONICAL MONOPOLES SHOWN
             IN FIG. 4-29

FILE NO._____

FIG. 4-26    AZIMUTH PLANE   RADIATION PATTERN AT 1.5 $f_0$
FOR ARRAY OF   CONICAL MONOPOLES SHOWN
IN FIG. 4-29
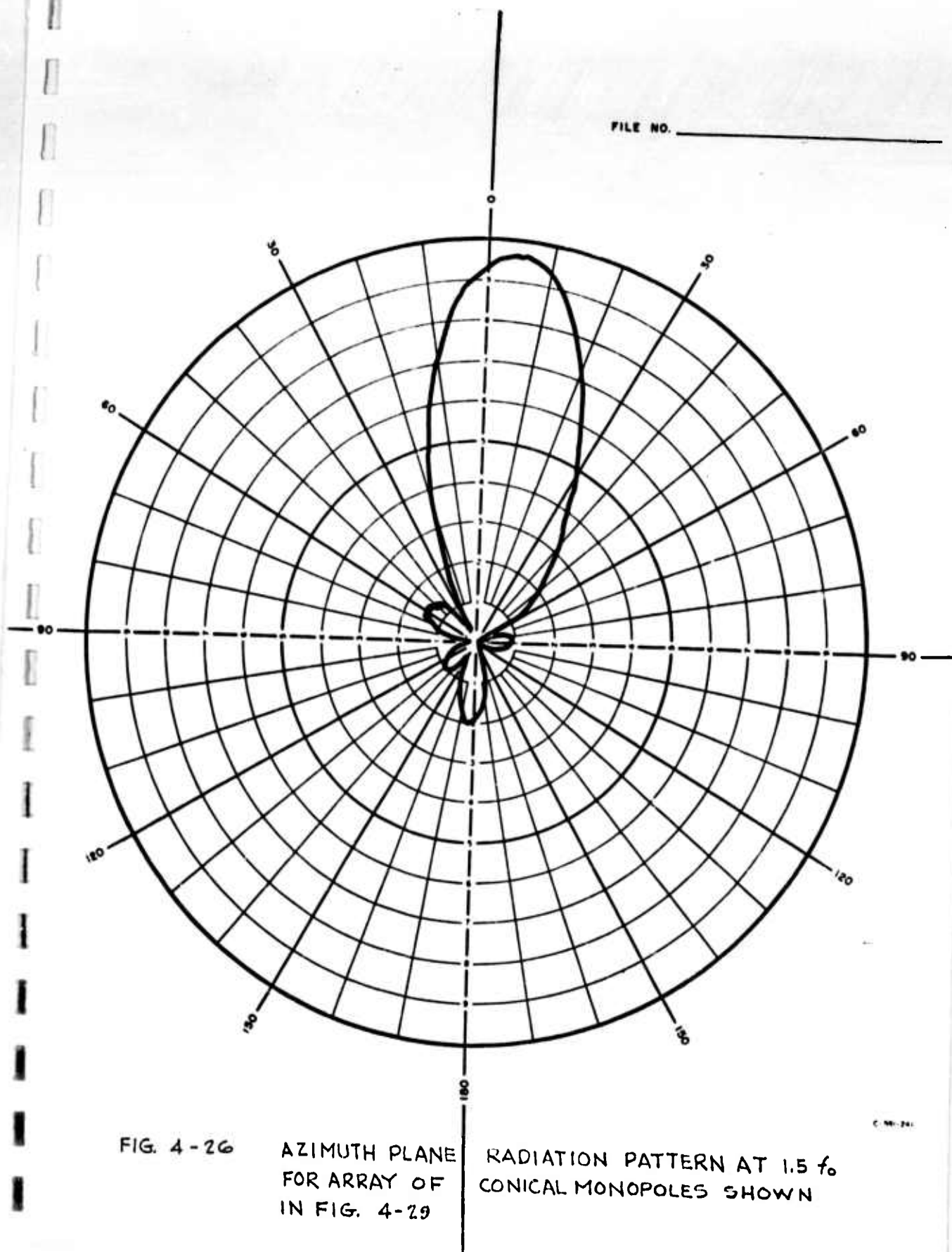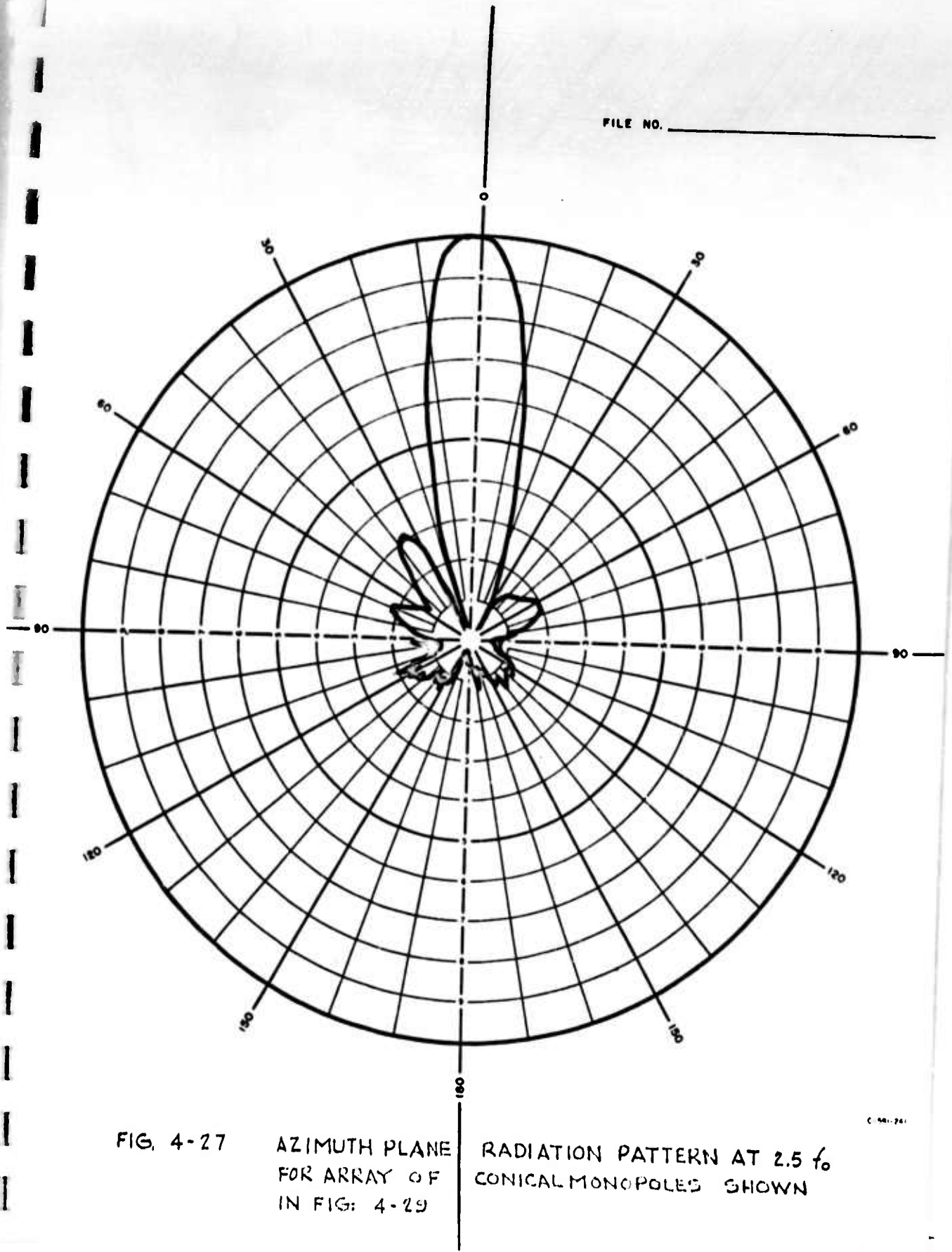
FILE NO. _____

FIG. 4-27    AZIMUTH PLANE | RADIATION PATTERN AT 2.5 $f_o$
             FOR ARRAY OF | CONICAL MONOPOLES  SHOWN
             IN FIG: 4-29
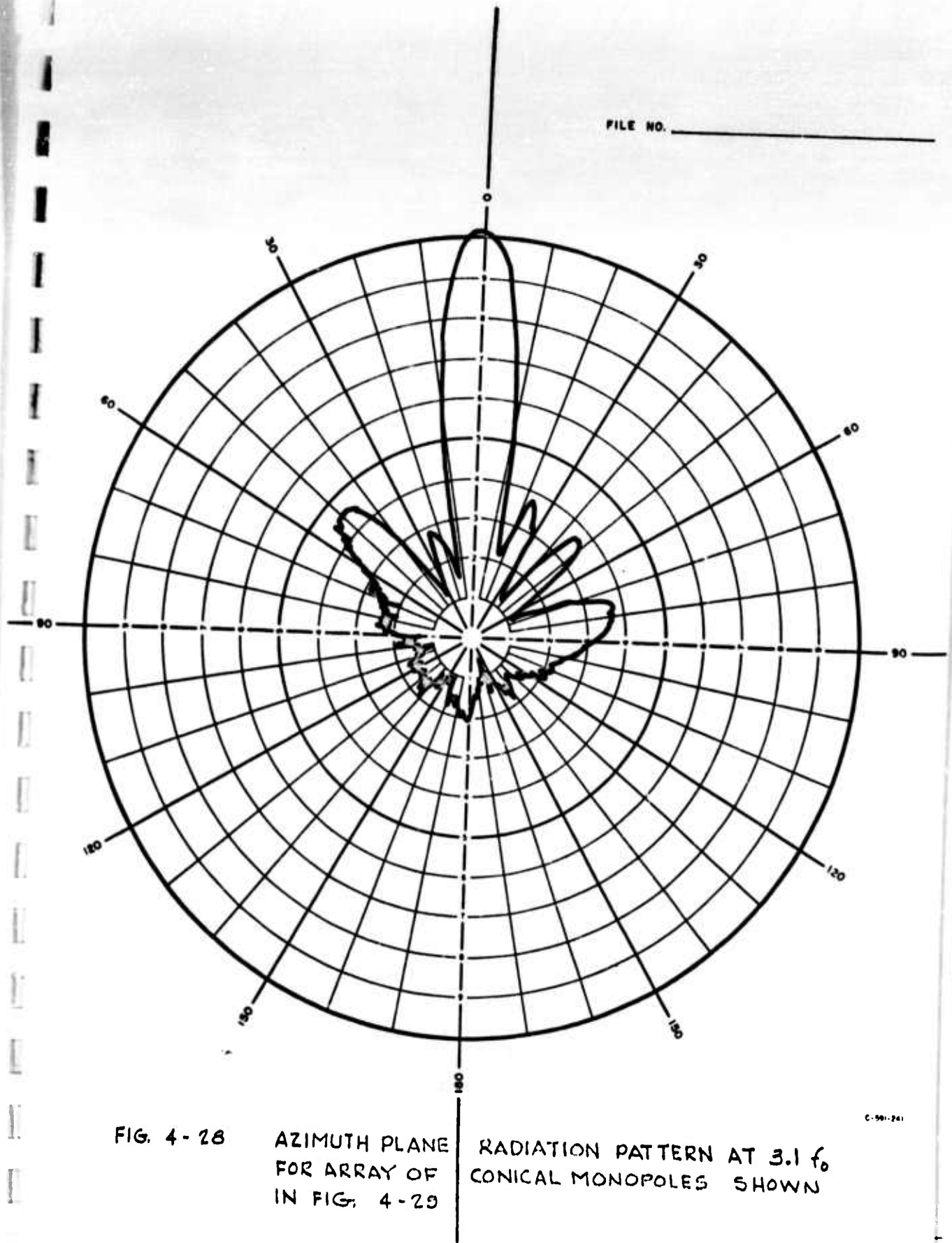
FIG. 4-28    AZIMUTH PLANE  RADIATION PATTERN AT 3.1 $f_0$
FOR ARRAY OF  CONICAL MONOPOLES  SHOWN
IN FIG. 4-29
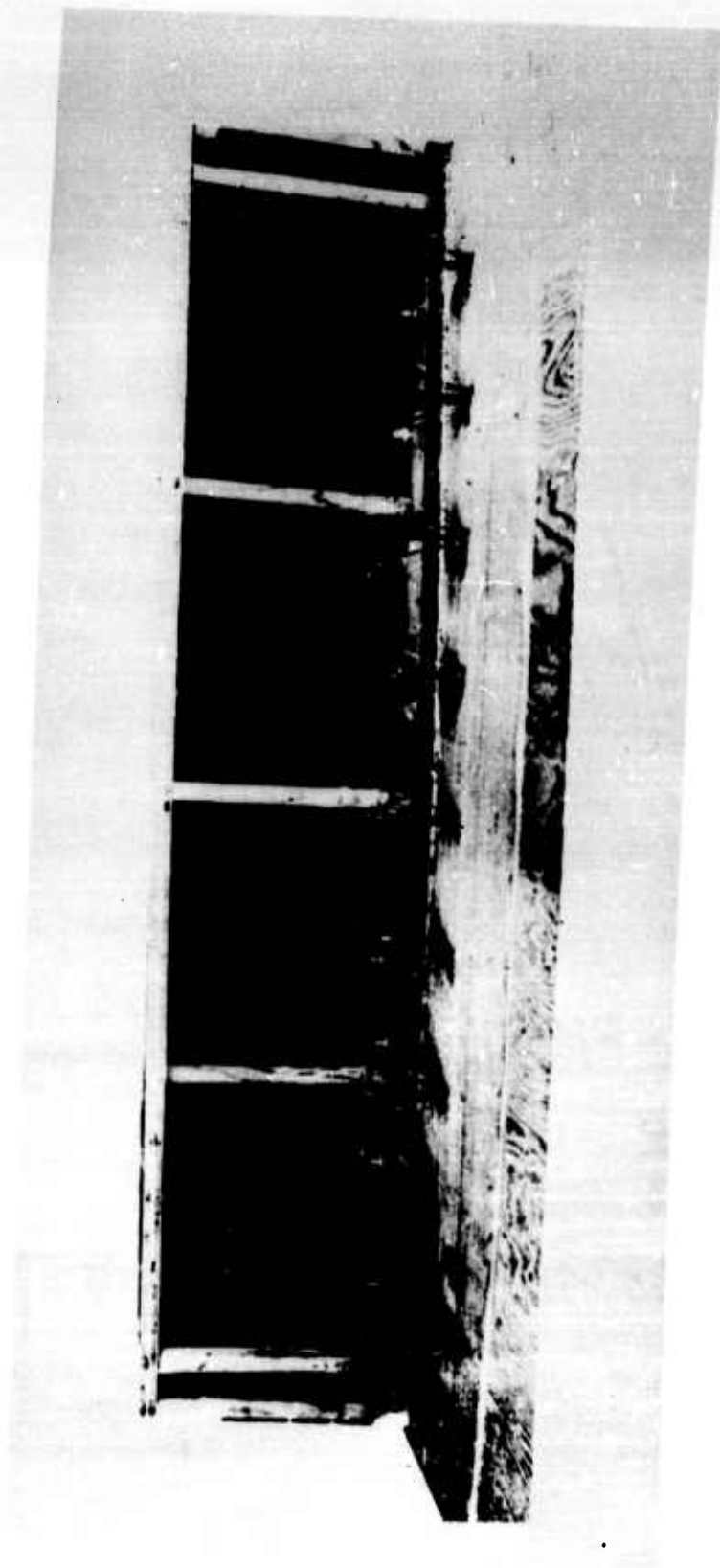
FIG. 4-29

100-1 SCALE MODEL OF CONICAL MONOPOLE ARRAY
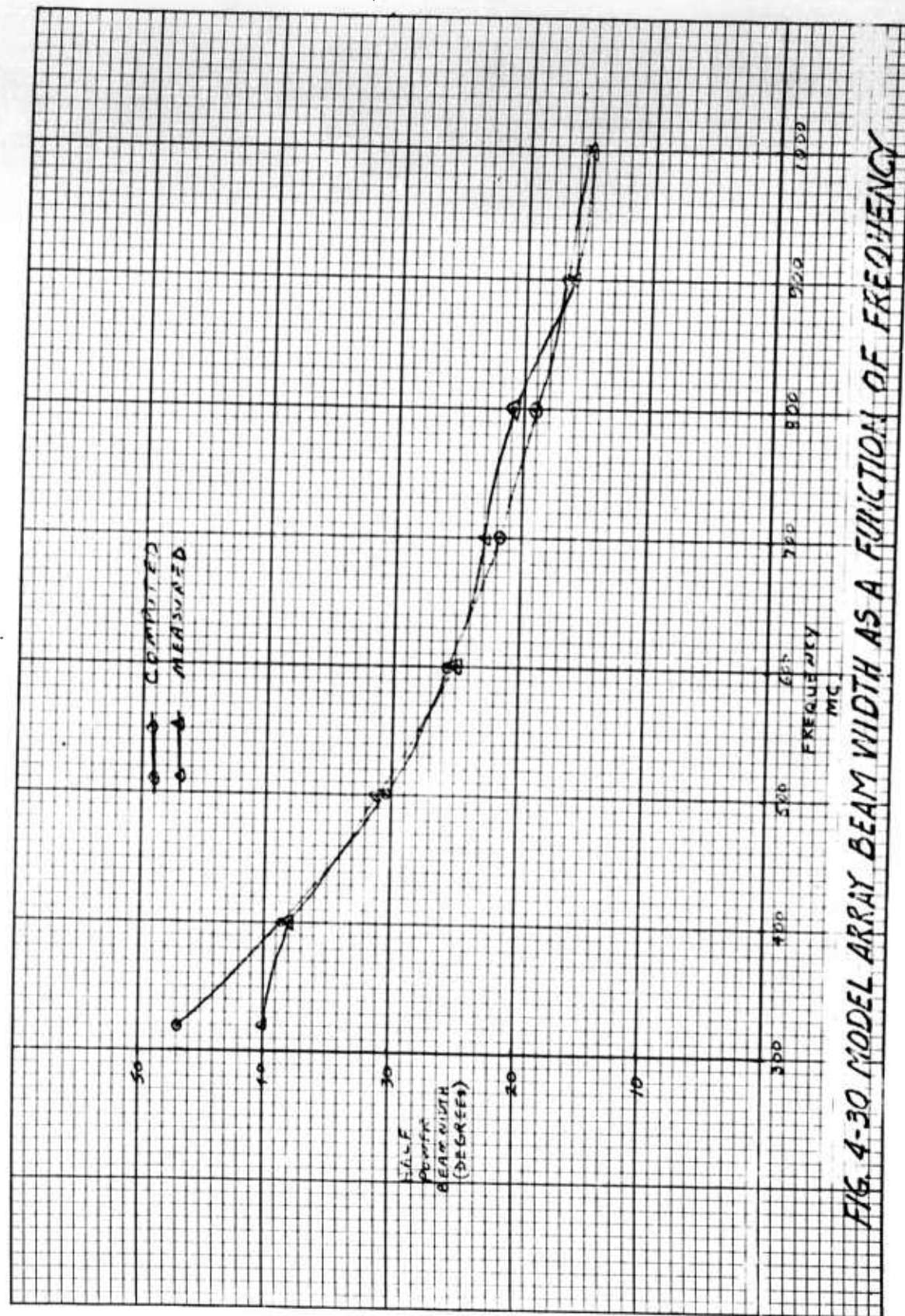
FIG. 4-30 MODEL ARRAY BEAM WIDTH AS A FUNCTION OF FREQUENCY
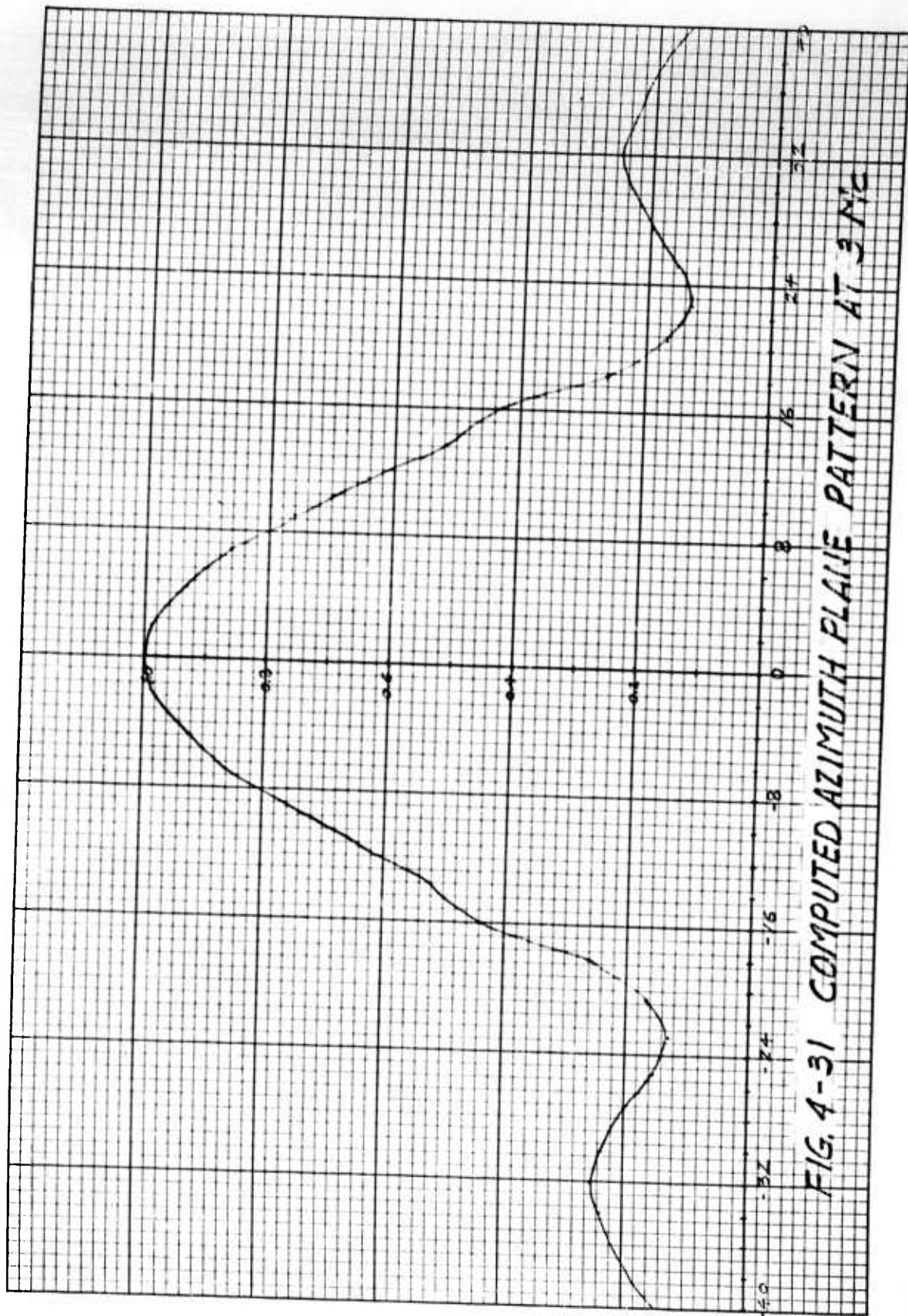
FIG. 4-31 COMPUTED AZIMUTH PLANE PATTERN AT 3 Kc
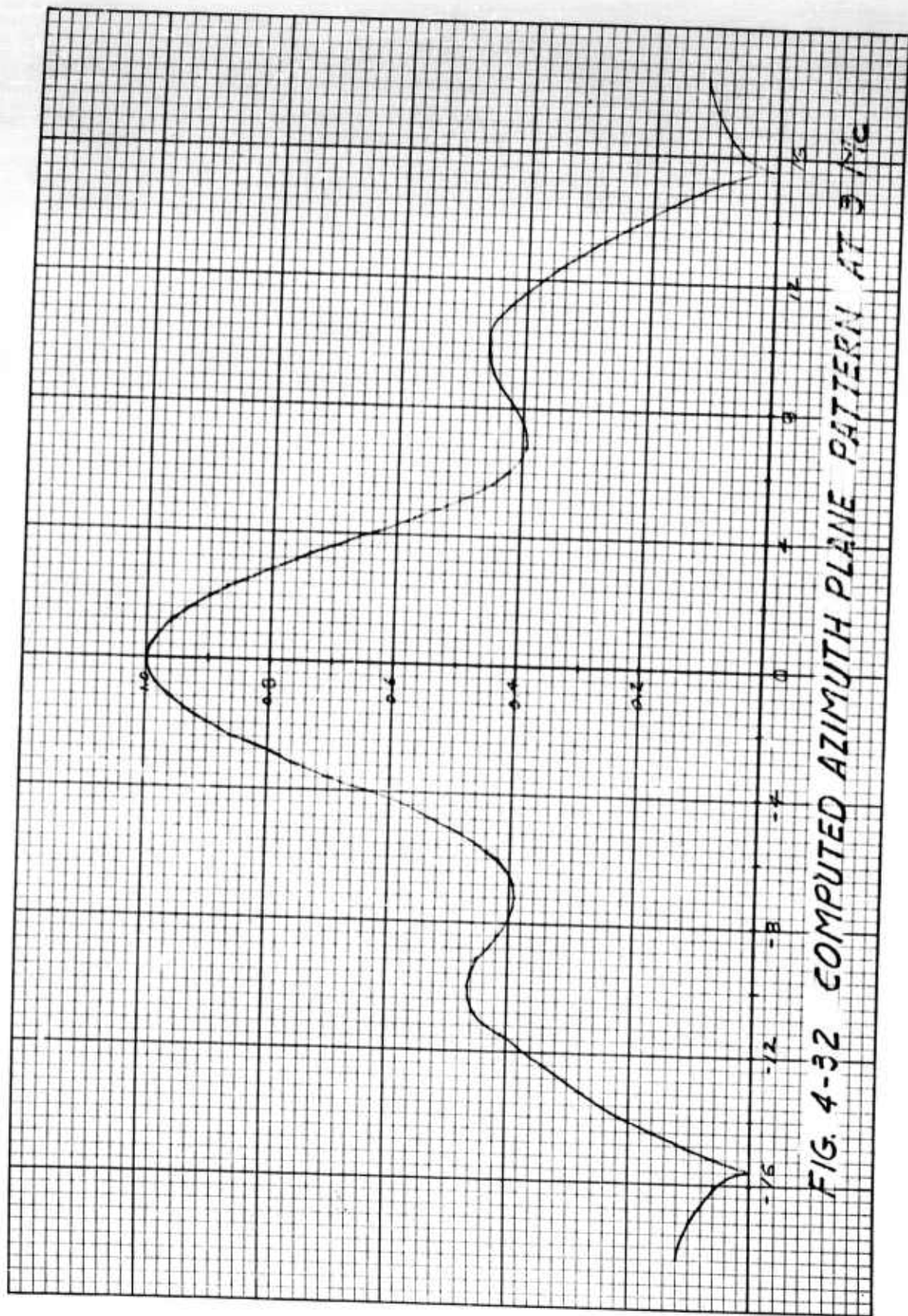
FIG. 4-32  COMPUTED AZIMUTH PLANE PATTERN AT 9.1 kc
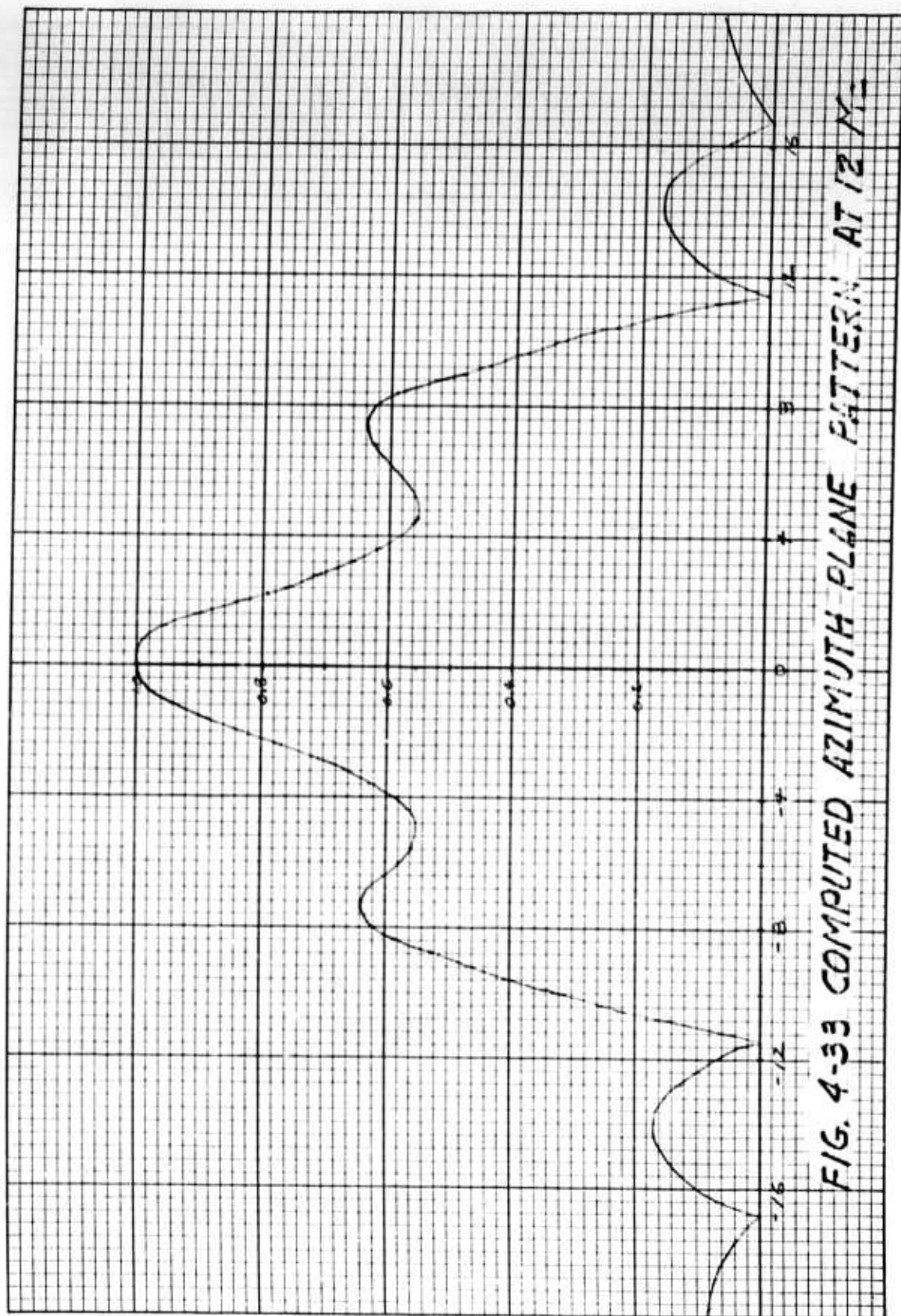
FIG. 4-33 COMPUTED AZIMUTH PLANE PATTERN AT 12 Hz
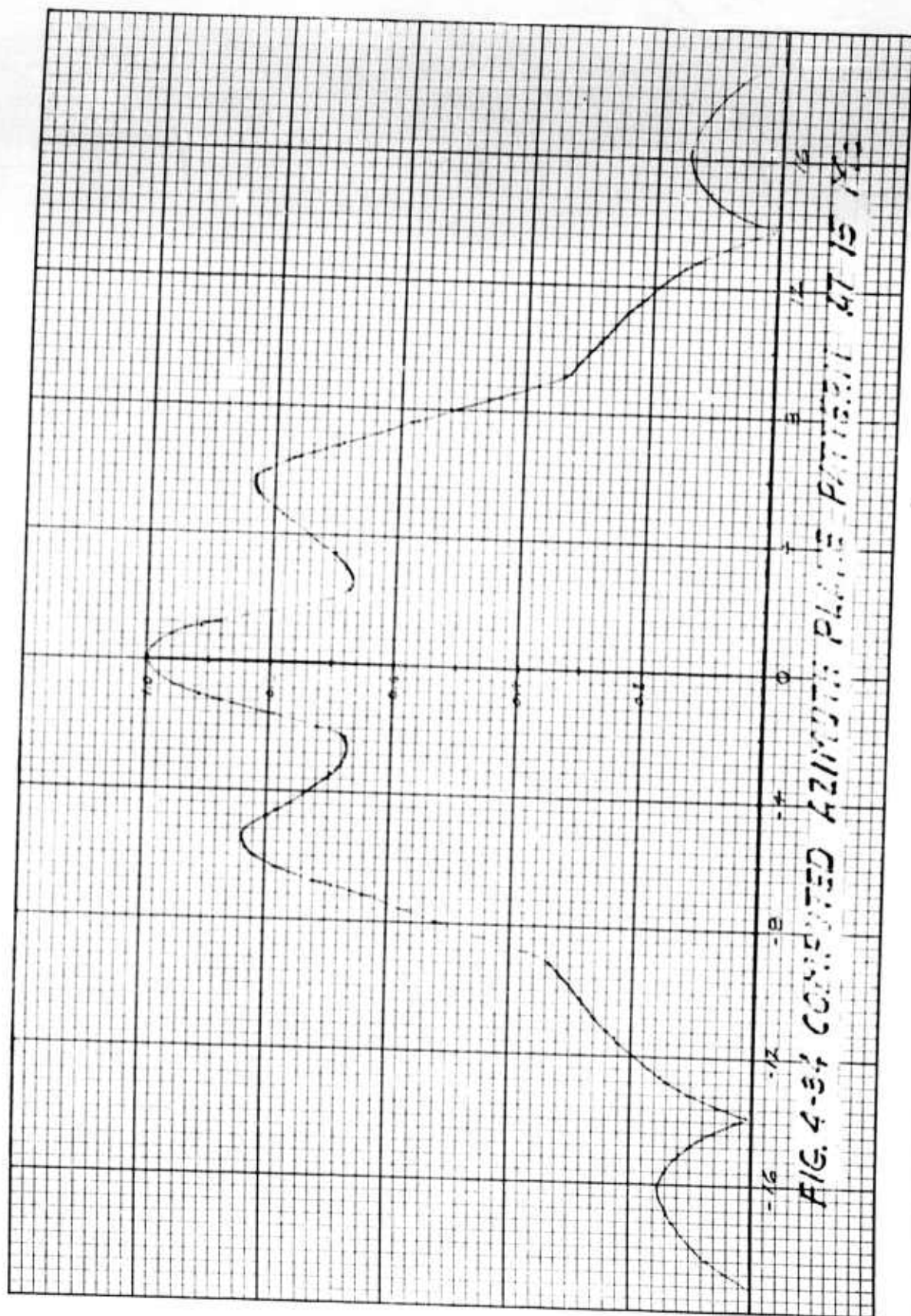
FIG. 4-34 COMPUTED AZIMUTH PLANE PATTERN AT 15 Kc
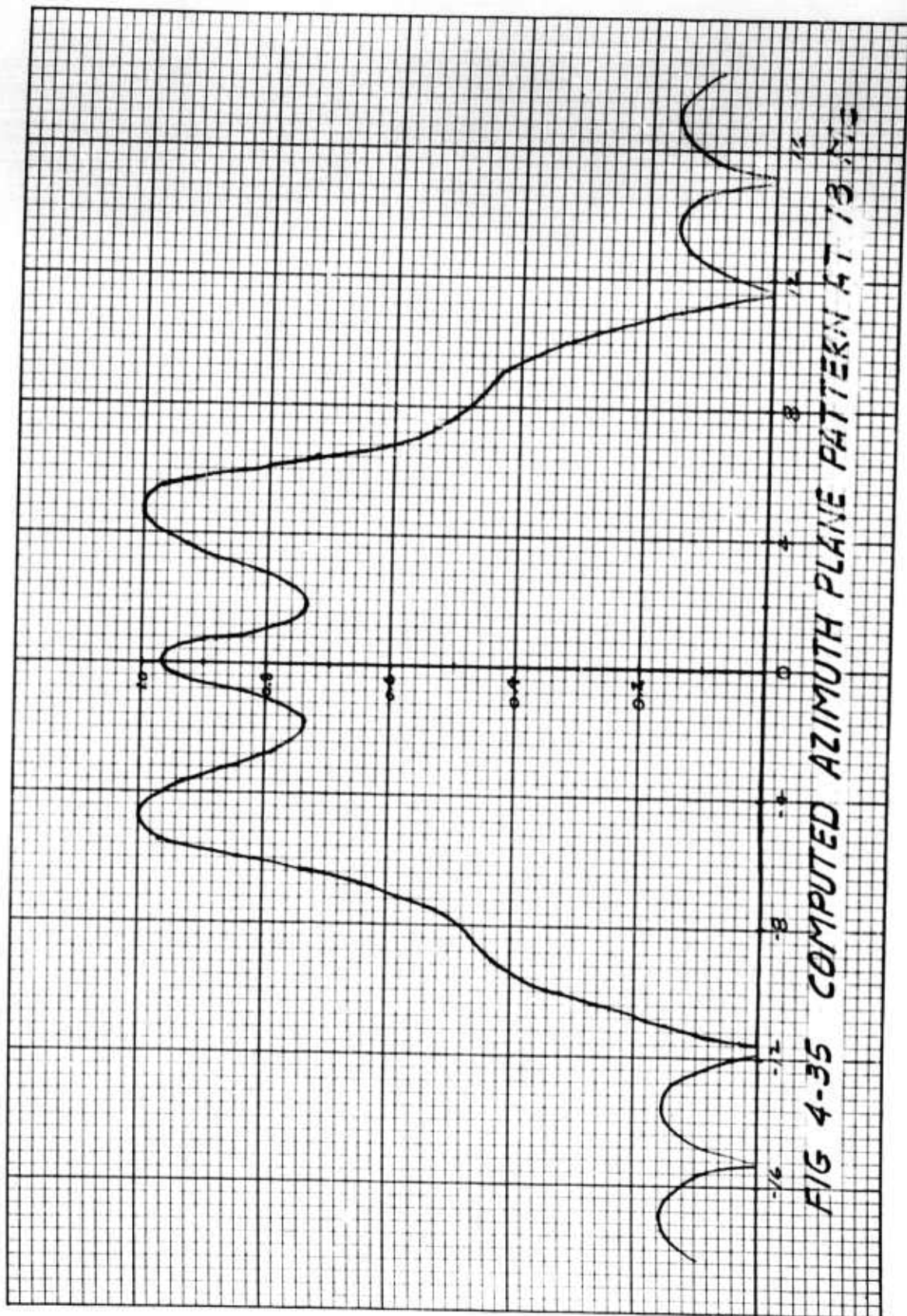
FIG 4-35 COMPUTED AZIMUTH PLANE PATTERN AT 73 MHz
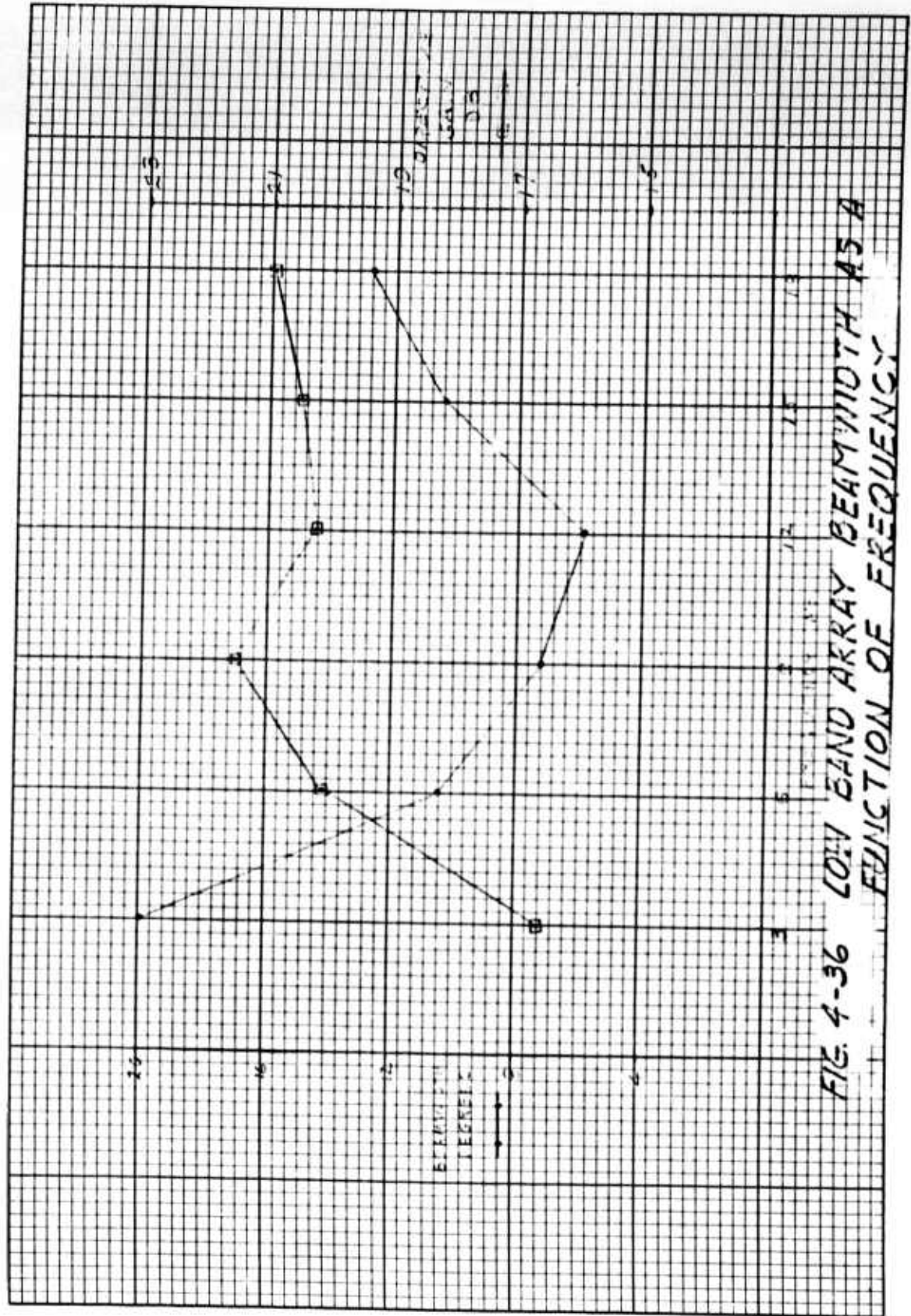
FIG. 4-36  LOW BAND ARRAY BEAMWIDTH AS A
FUNCTION OF FREQUENCY

IMPEDANCE COORDINATES

VSWR 2.5:1
$Z_0 = 8.35 \Lambda$

RADIALLY SCALED PARAMETERS

TOWARD GENERATOR →

← TOWARD LOAD

CENTER

A MEGA-CHART

FIG. 4-38

Effect of Ground Screen Diameter (in Wavelengths) on Angle
of Maximum Elevation Plane Radiation ($\psi$)
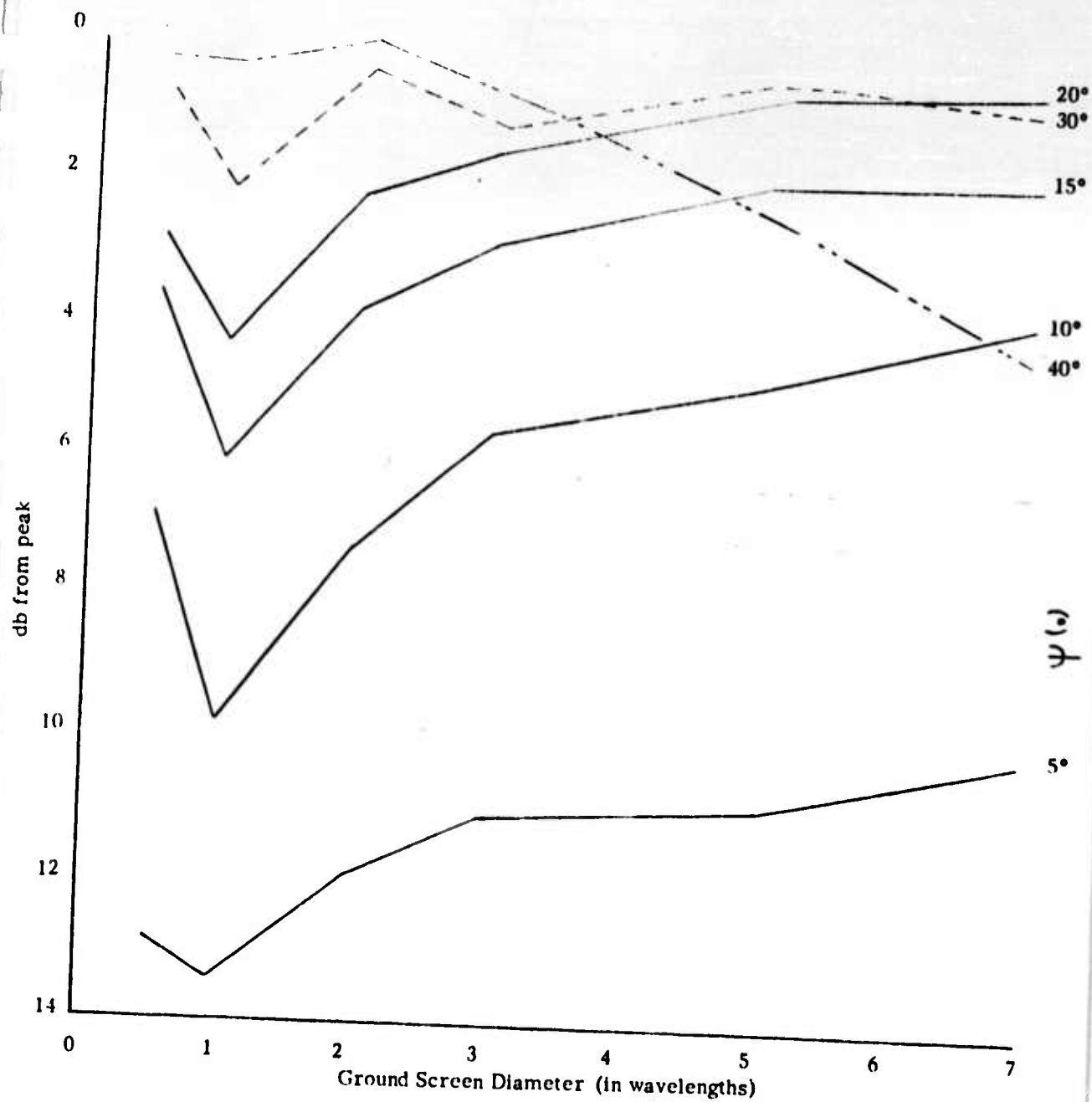
FIG. 4-39

Effect of Ground Screen Diameter (in wavelengths) on
Elevation Plane Signal Intensity

DELAY LINES
TYPE RG-65-A/U
(TYP. 30 REQ'D.)

50 Ω

950 Ω

75 Ω

ROTOR PLATE
(30 REQ'D)

STATOR PLATE
(60 REQ'D)
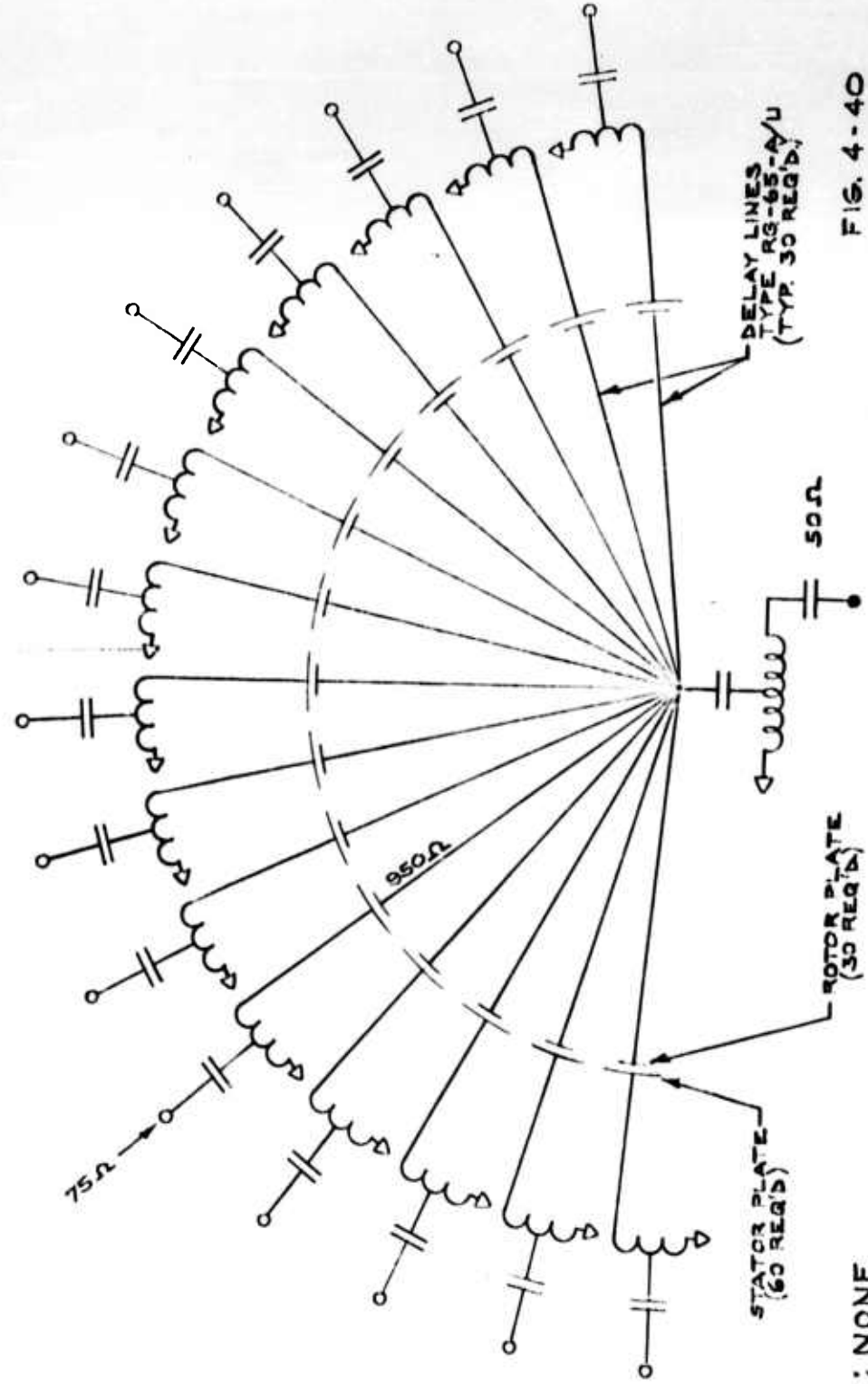
FIG. 4-40

GONIOMETER
SCHEMATIC

SCALE : NONE
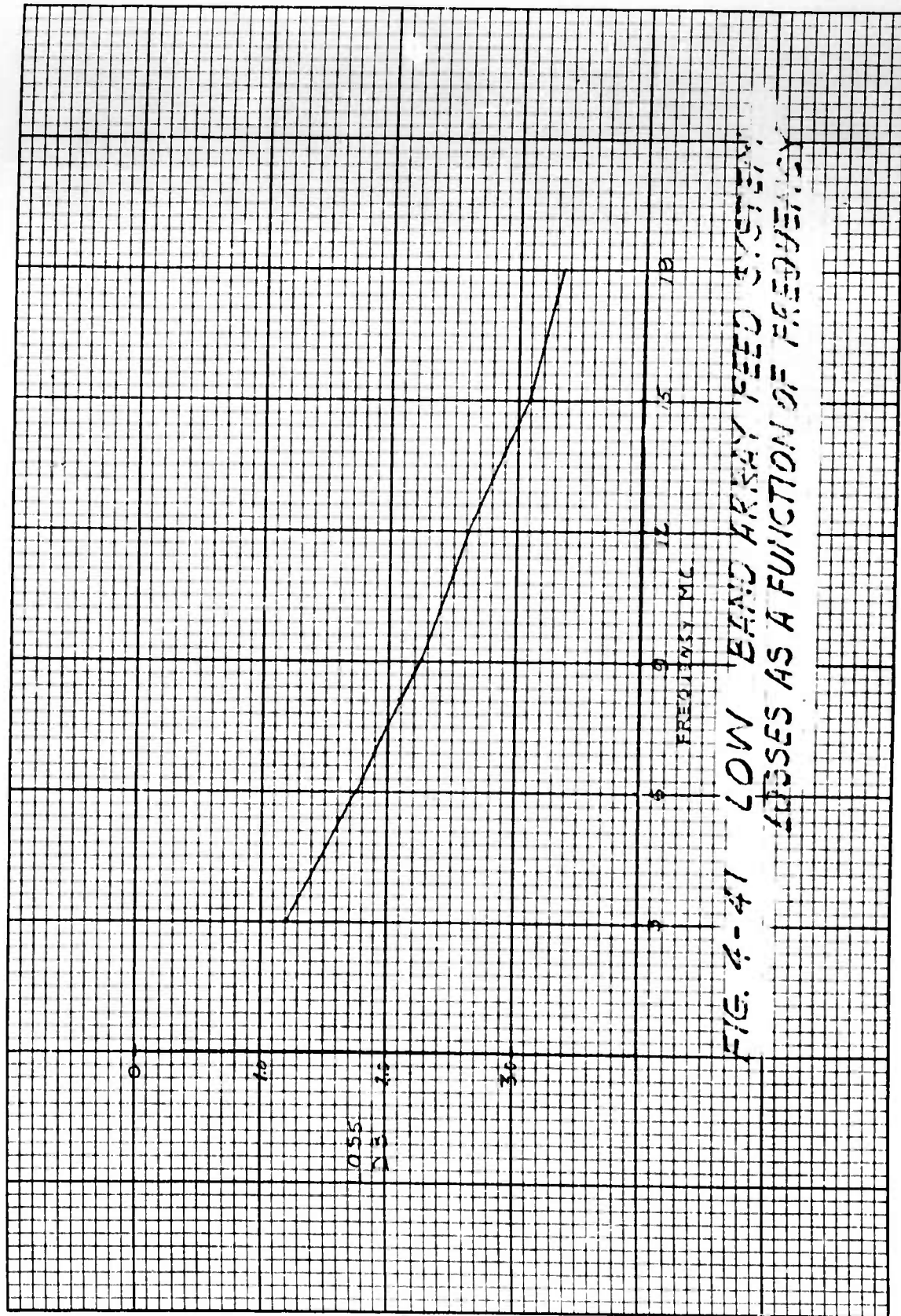
FIG. 4-41  LOW BAND ARRAY FEED SYSTEM
LOSSES AS A FUNCTION OF FREQUENCY

REFLECTOR POLE
ON 175' RADIUS
60 REQ'D.

7-30 Mc CONICAL
MONOPOLE - 60 REQ'D.
ON 193' RADIUS

6° TYP.
60 PLACES

PARKING AREA

BUILDING TO HOUSE
GONIOMETER

OUTER EDGE
GROUND WIRE GRID

157.5' RADIUS
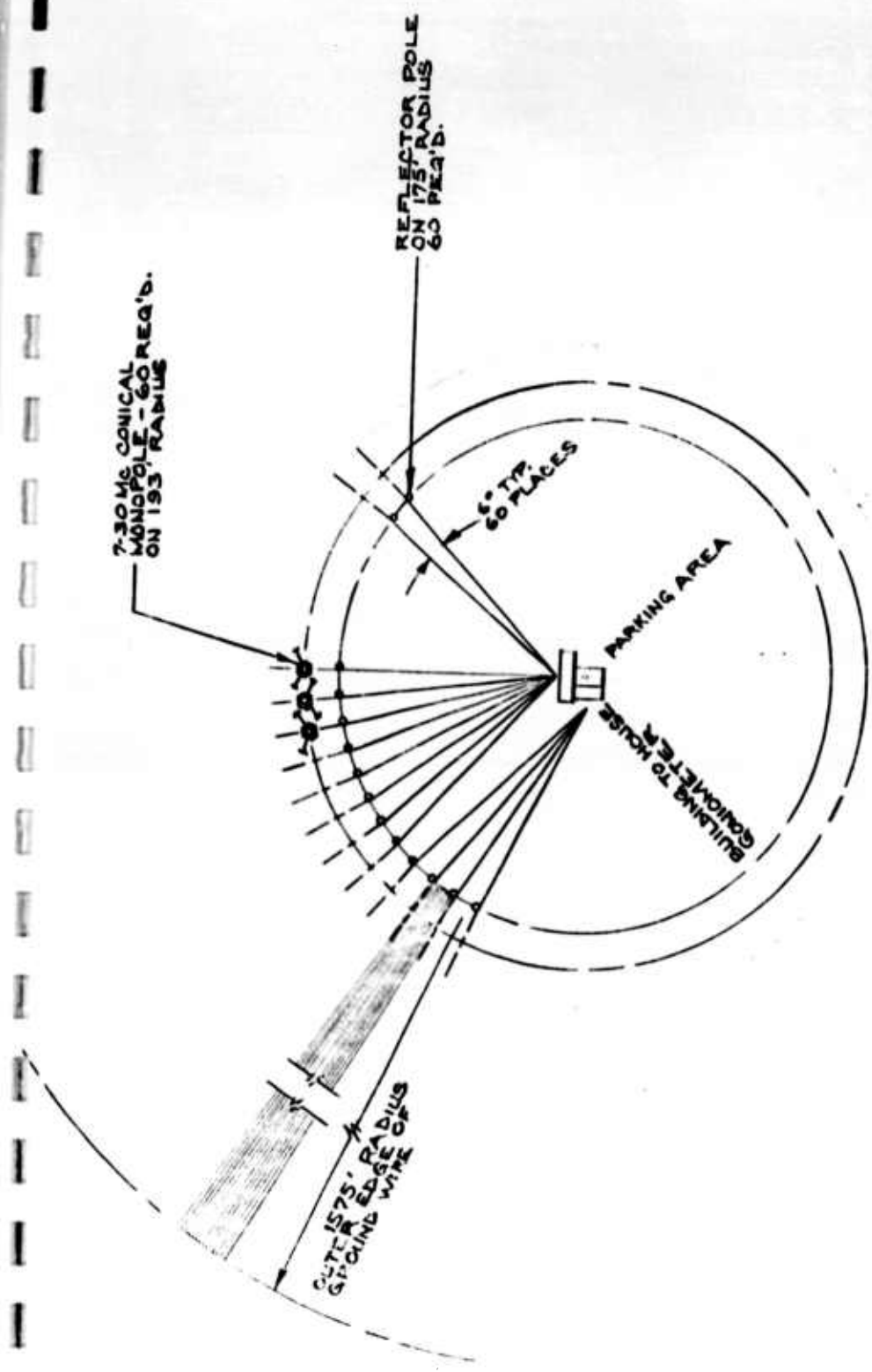
FIG. 4-42
PLAN VIEW
HIGH BAND ARRAY
7-30 Mc

SCALE: NONE

43.84'(REF)

ROHN 25G TOWER
SECTIONS IN THIS AREA

ROHN 45G TOWER
SECTIONS IN THIS AREA
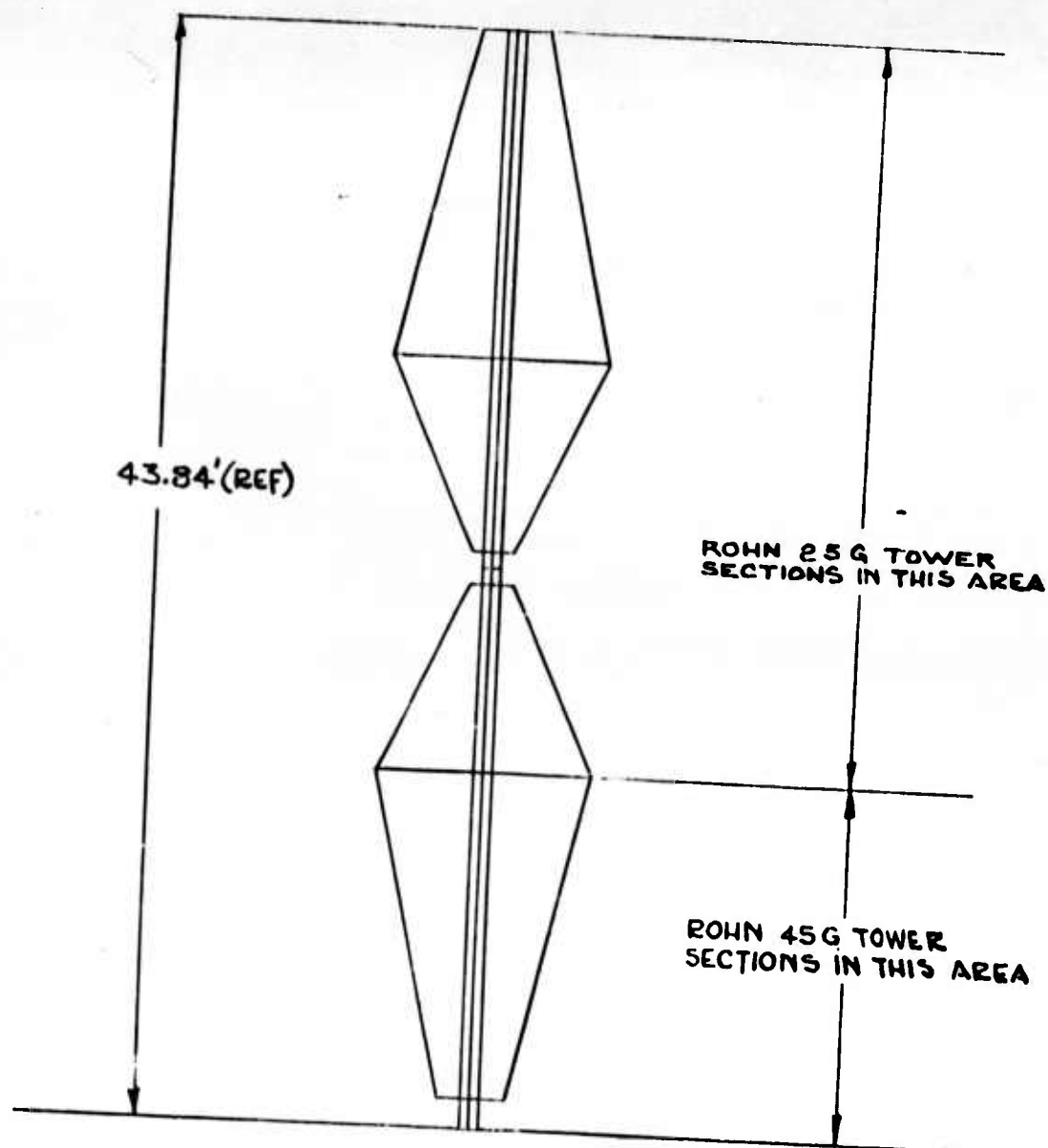
SCALE : NONE

FIG. 4-43
HIGH BAND
ARRAY ELEMENT
(7-30 Mc)
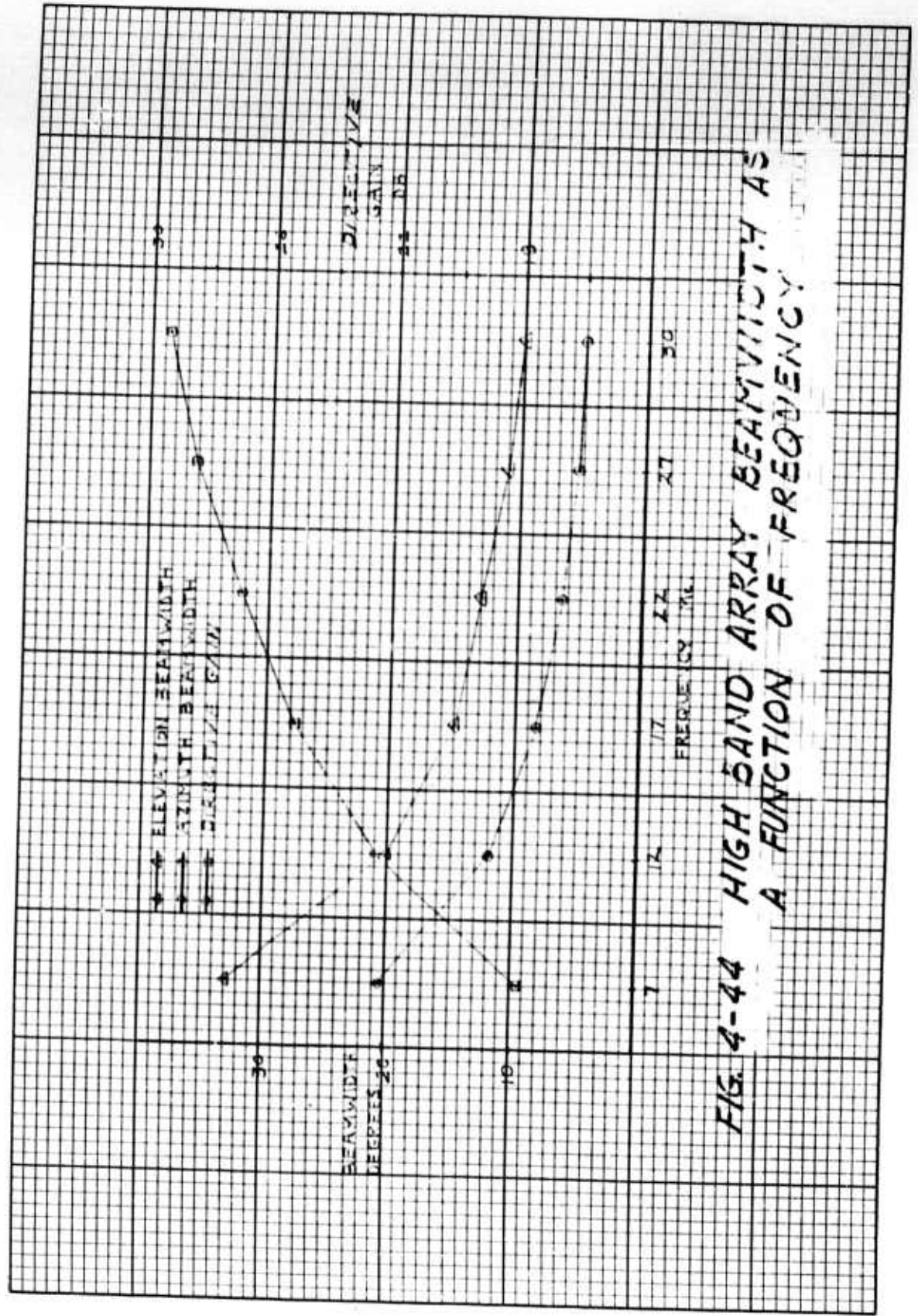
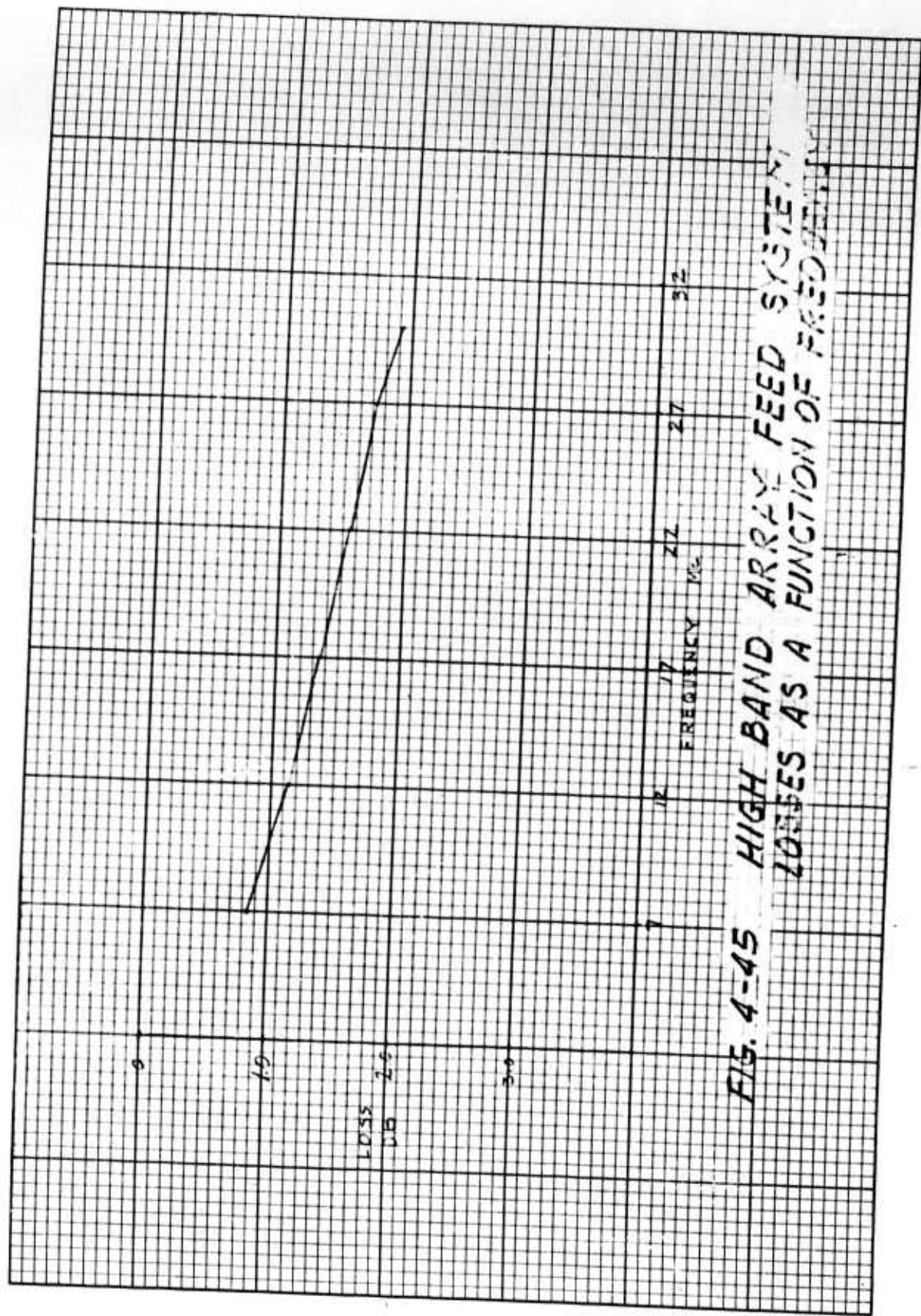FIG. 4-44   HIGH BAND ARRAY BEAMWIDTH AS A FUNCTION OF FREQUENCY

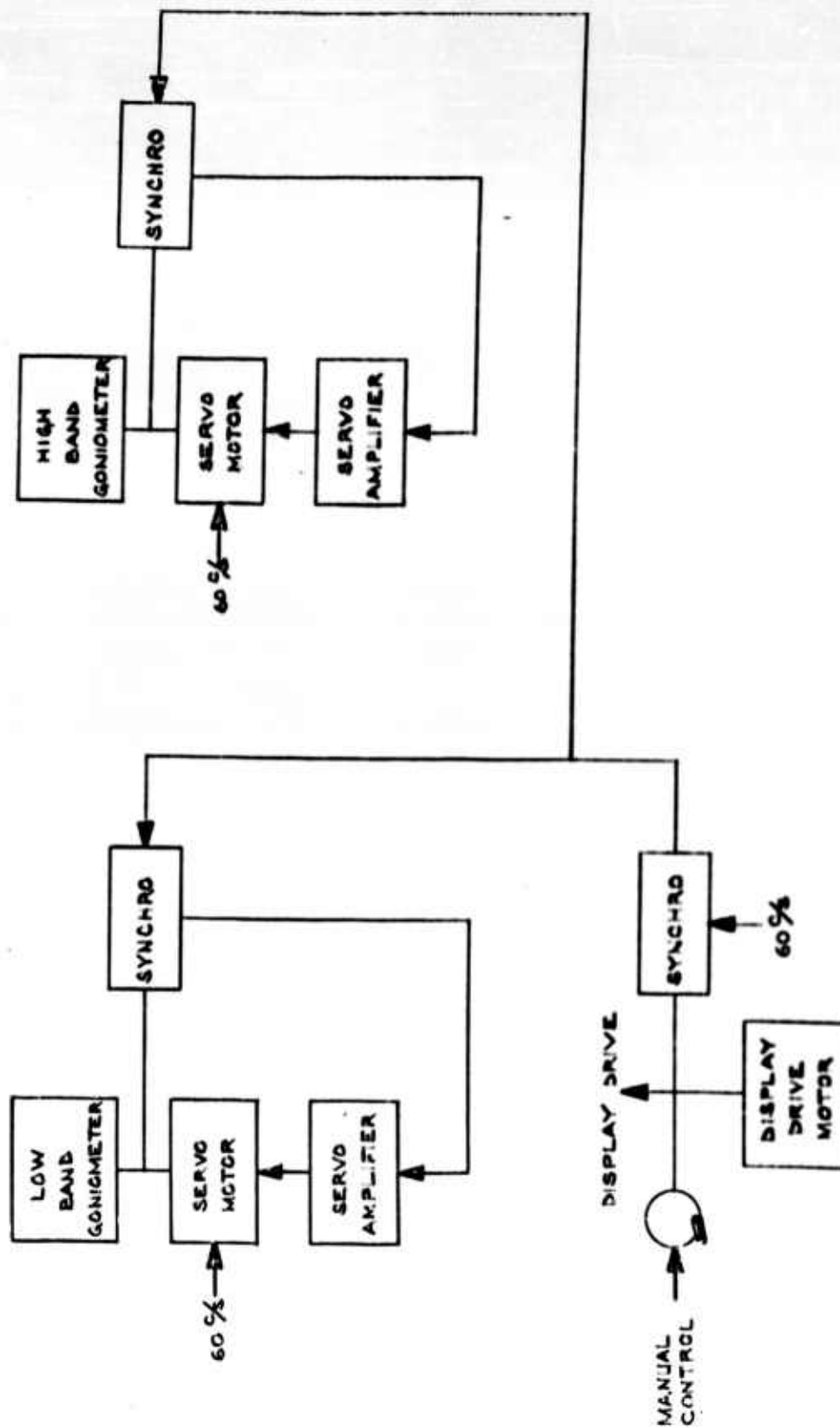FIG. 4-45   HIGH BAND ARRAY FEED SYSTEM
LOSSES AS A FUNCTION OF FREQUENCY

FIG. 4-46
ROTATION CONTROL
SYSTEM

SCALE : NONE

# UNCLASSIFIED