An 8-antenna 4-channel microwave direction finder

Cairns, F. V.

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NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

AN 8-ANTENNA 4-CHANNEL MICROWAVE DIRECTION FINDER

F. V. CAIRNS

OTTAWA
FEBRUARY 1957

ABSTRACT

An experimental investigation of the performance of an eight-antenna system for the four-channel instantaneous microwave direction-finder (AN/UPD-501) was undertaken. Results for a number of frequency bands are given.

SUMMARY

Efforts to improve the performance of the AN/UPD-501, a four-channel instantaneous microwave direction finder, led to consideration of an eight-antenna system which could be used with the four-channel amplifier and display system. An investigation, largely experimental, of the performance of an eight-antenna system in which the outputs of the eight antennas are suitably resolved in a resistive network into the four inputs of the remainder of the system has led to the following conclusions:

1) The known advantages of increasing the number of antennas in the system are fairly easily realized in practice.

2) The advantages of increasing the number of antennas from four to eight seems to be relatively greater than that which would be obtained from further increases. For a system of limited accuracy, such as the AN/UPD-501, there is little advantage in increasing the number of antennas to more than eight.

LIST OF FIGURES

AN 8-ANTENNA 4-CHANNEL MICROWAVE DIRECTION FINDER

- F.V. Cairns -

INTRODUCTION

The AN/UPD-501 is an instantaneous microwave direction finder which indicates bearing by amplitude comparison of the amplified outputs of four antennas on the four plates of a cathode-ray tube (Fig.1(a)). It has been the objective in the development of this device to provide frequency coverage from 1000 mc/s to 20,000 mc/s for horizontal and vertical polarization with the minimum number of antenna systems. The wide frequency coverage has dictated the use of crystal video detectors and video amplifiers.

To give accurate bearings the system requires identical channels; that is, four amplifiers of equal gain, four crystals of equal sensitivity, and also four antennas whose radiation patterns P (θ) obey the condition

$$\frac{P(\theta) - P(180 - \theta)}{P(90 - \theta) - P(90 + \theta)} = \cot \theta. \qquad (1)$$

This condition can be readily derived from consideration of Figs. 1(a) and (b).

FREQUENCY COVERAGE LIMITATION

With four-antenna systems, coverage of both polarizations from 1000 to 11,000 mc/s has been achieved with six systems, three on each polarization. An antenna system suitable for operation at 11,000 to 20,000 mc/s with horizontal polarization has been developed, but it has been difficult to find crystals with sensitivities which track sufficiently well across this frequency band to keep errors low.

The criterion used in the development was a maximum bearing error of ±10° due to all causes, measured under laboratory conditions. This limited accuracy was achieved over a bandwidth of an octave, or slightly more on one polarization with one antenna system. For bandwidths greater than this, the error increases owing to excessive departure of the antenna radiation patterns from the ideal, lack of tracking of crystal sensitivities with frequency, or mismatch in the r-f components. It might be thought that moderate mismatches, VSWR's of, say, 3 or 4 to 1, might be tolerated since the loss introduced by them is not prohibitive. However, experience has shown that with mismatches of this order in two components separated by a length of

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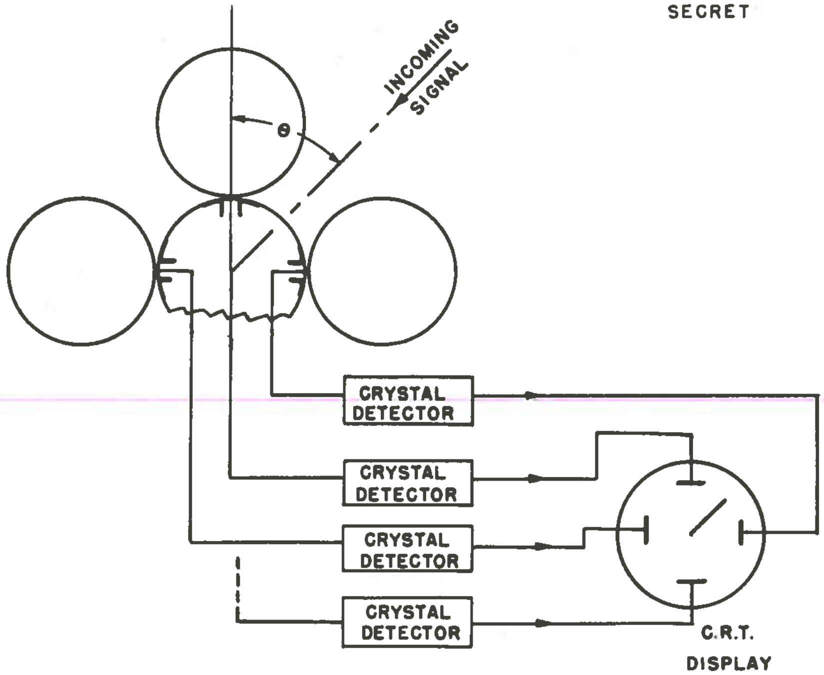

FIG. 1A 4-CHANNEL INSTANTANEOUS DIRECTION FINDER

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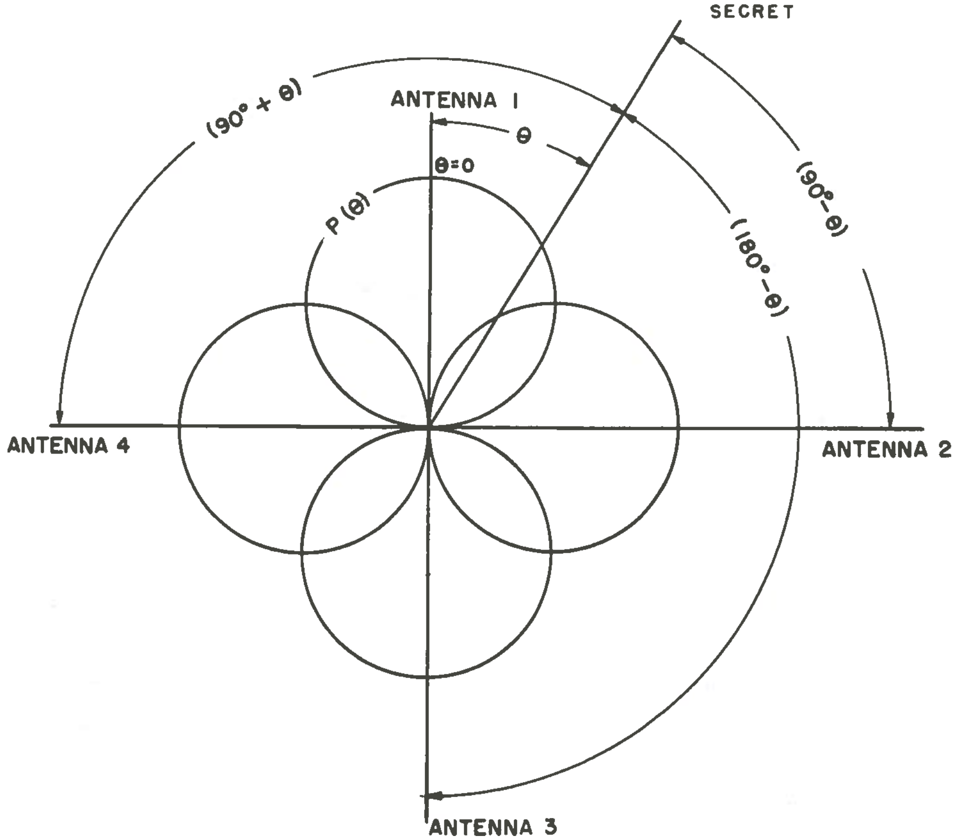

FIG. 1B ANGULAR RELATIONSHIPS IN 4-CHANNEL DIRECTION FINDER transmission line, small differences between components result in combination of the reflections in different phases in different channels, and hence the channels no longer maintain equal sensitivity as the frequency is changed.

DESCRIPTION OF 8-ANTENNA SYSTEM

It was thought that some of the limitations on the frequency coverage of the 4-channel antenna system could be overcome to a considerable extent by use of a larger number of antennas. Multiple antenna systems have been used in a number of related types of direction finders [1, 2], and the advantages are known.

The particular arrangement chosen for the AN/UPD-501 was an 8-channel antenna system which would be compatible with the existing 4-channel equipment. Consideration of size, complexity, and symmetry lead naturally to this choice. Furthermore, it is believed that the advantages that follow from the use of a larger number of antennas are realized sufficiently by the increase from 4 to 8 to make further increases of little interest in a system such as the AN/UPD-501.

The requirement for compatibility with the existing 4-channel equipment implies that the outputs of the 8-antennas must be suitably combined and fed to the four inputs of the amplifiers and thence to the plates of the cathode-ray display tube. A resolving network is therefore required between the antenna system and the amplifier system. Further, since resolving is to be done at the unamplified video level to allow operation with only four amplifiers and a four-plate cathode-ray tube, losses in the resolving network must be minimized.

RESOLVING NETWORK

Two forms of resolving network were considered and are shown in Figs. 2 and 3. Fig. 2 is similar to a resolving network developed at Melpar Laboratories [2].

These figures are drawn in schematic fashion; the four resistances R_a, represent the input resistances of four amplifiers (approximately 50 ohms) whose outputs are applied to the four plates of a cathode-ray tube. The outputs of the antennas numbered 1 to 8 are shown in positions corresponding to their azimuthal location in the antenna system, and a line drawn from the center of the figure through each numbered point indicates the direction of the peak of the radiation pattern from that antenna. From examination of Fig. 2 it can be seen that if R_1 and R_2 are chosen properly, the voltages

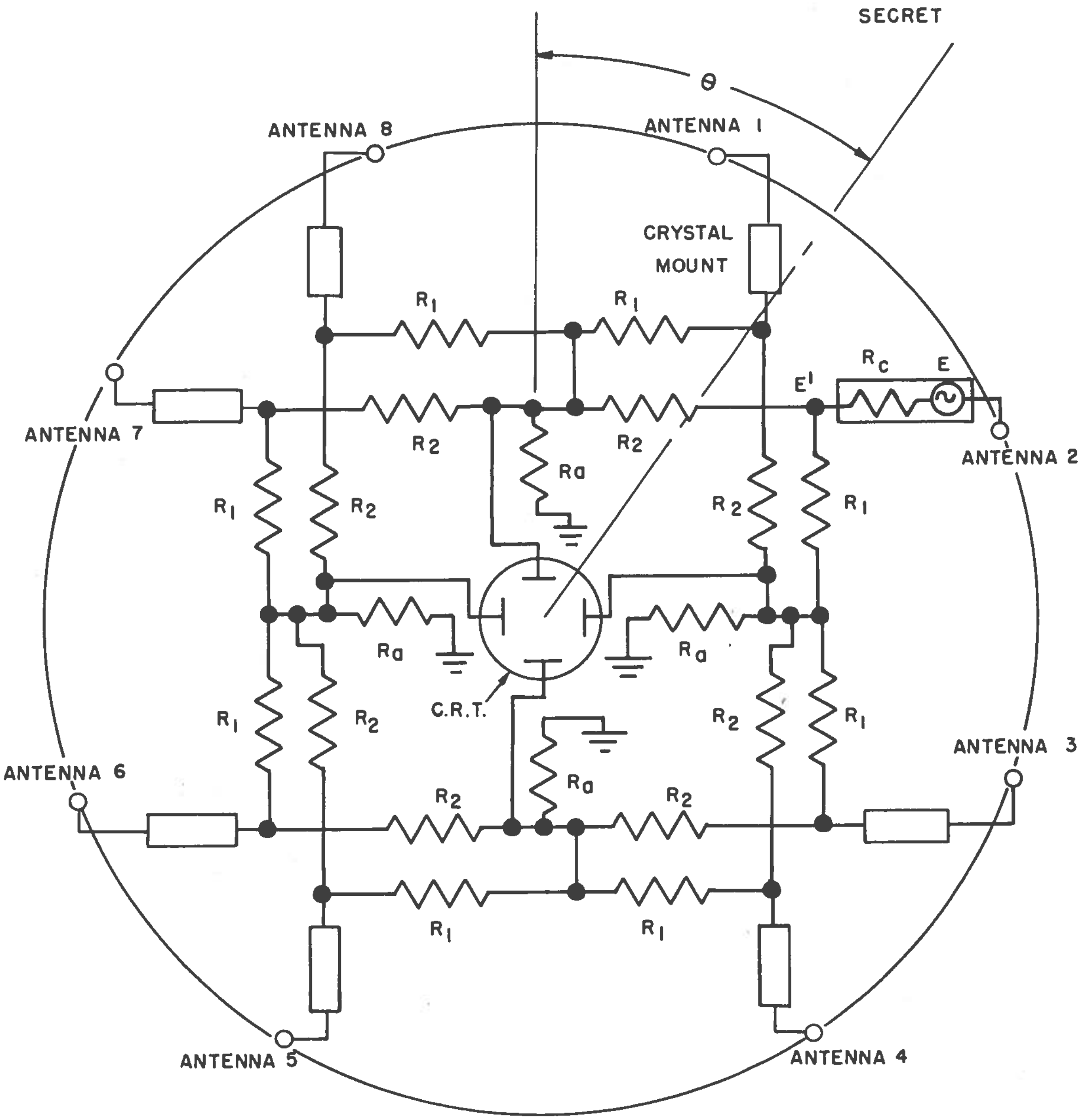

FIGURE 2

SCHEMATIC DIAGRAM OF
RESOLVING NETWORK TYPE I

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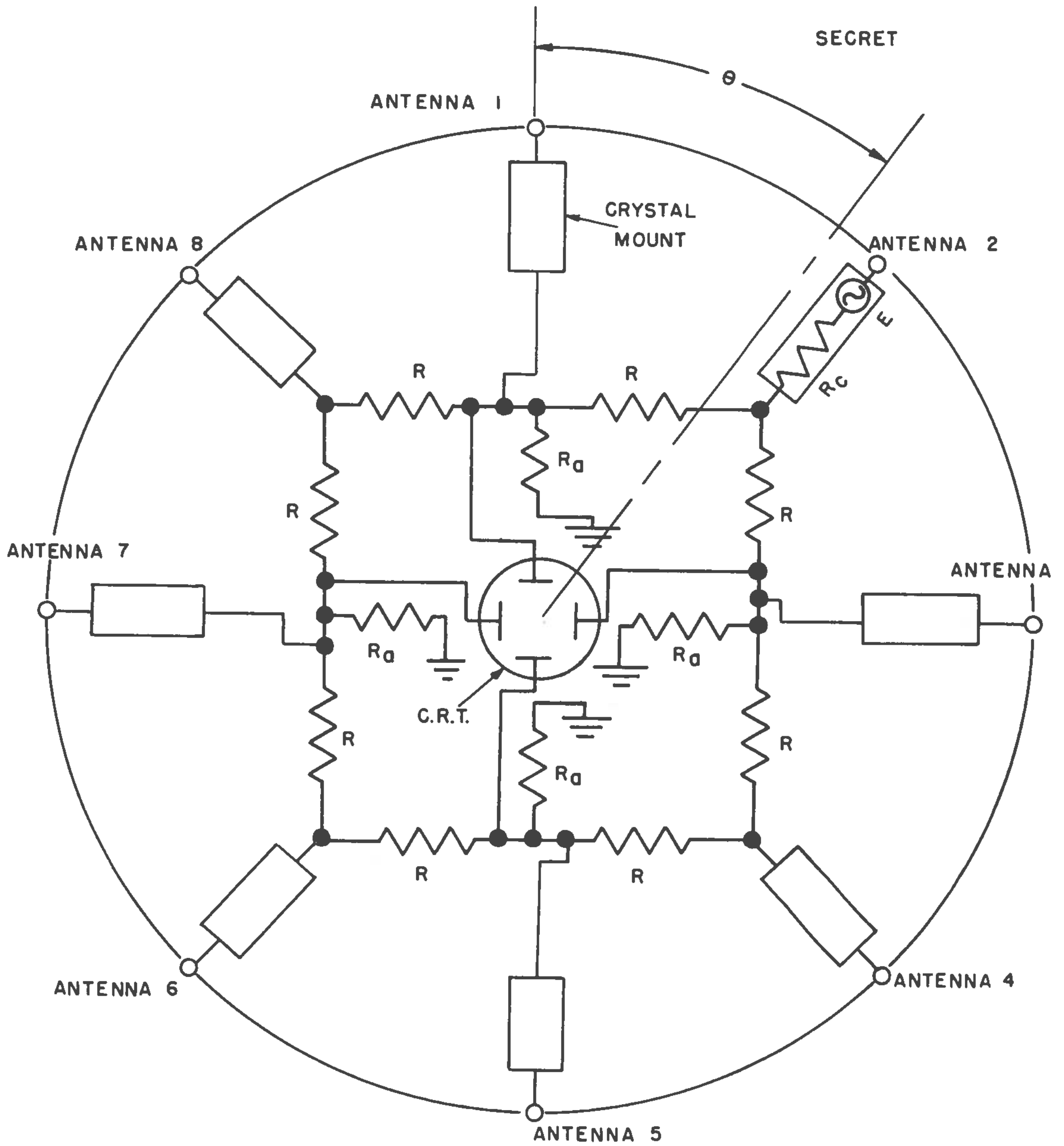

FIGURE 3
SCHEMATIC DIAGRAM OF
RESOLVING NETWORK TYPE II

applied to plates 1 and 2 of the cathode-ray tube from the output of antenna 1will deflect the spot on the display in the direction of θ. If the crystal associated with the antenna is represented by a generator of voltage E, and of internal impedance R_c (the video impedance of the crystal), the voltage at plate 1 will be $\frac{E' R_a}{R_a + R_2}$, and at plate 2 it will be $\frac{E' R_a}{R_a + R_1}$,

$$\text{where } E' = \frac{E\,(R_a + R_1)\,(R_a + R_2)}{(R_a + R_1)\,(R_a + R_2) + R_c(2R_a + R_1 + R_2)},$$

the voltage applied to the network. Values of R_1 and R_2 that satisfy the relation $\frac{R_a + R_1}{R_a + R_2} = \tan\theta_1$, where $\theta_1$is the angle between antenna 1 and reference or zero angle, should produce the required result. This is an oversimplified picture, however, because each antenna is coupled in varying degrees to all four amplifiers by a ring network and R_c may be small enough to load this network. Hence computation of R_1 and R_2 is complicated, and instead of carrying out the computation, R_2 was estimated and a network was constructed. R_1 was then adjusted by cut and try until the voltages applied to the cathode-ray tube display from an input to terminal 1 of the resolving network displaced the spot in the direction θ_1. The value chosen for R_2 is a compromise between two conflicting requirements. A large value of R_2 will reduce the coupling to adjacent plates of the cathode-ray tube (the voltages applied are subtractive and undesirable), but will increase the loss in the network. There will be an optimum which results in maximum net voltage applied to the plates of the cathode-ray tube. This optimum has not been determined. The value of 160 ohms chosen for R_2 results in a value of 70 ohms for R_1. This reduces the amplitude of the voltage applied to the display by approximately 50 percent.

Fig. 3 is an alternative and simpler form of the resolving network with the antennas in different azimuthal positions. In this case, since all the resistances are equal, the resolving is correct regardless of the value of R. If R is too small, however, the coupling of antenna 1, for example, to plates 3 and 4 will be excessive; if R is too large the outputs from antennas 2, 4, 6, and 8 will be small compared with the outputs from 1, 3, 5, and 7. Since this network is relatively simple , the computation was carried out, and it showed that there is a broad optimum of the value of R in the vicinity of 200 ohms where there is a net reduction in the voltage output from antennas 2, 4, 6, and 8 of about 40% and a reduction of about 10% in the output from antennas 1, 3, 5, and 7, due to the loss in R and the subtractive effects of coupling in the network. The difference between the contribution from antennas 1, 3, 5, 7 and that from 2, 4, 6, 8 can be equalized by a series resistance between antennas 1, 3, 5, and 7, and R in the network shown in Fig. 3. This series resistance can be chosen to reduce the contribution from antennas 1, 3, 5, and 7 to the level of that from antennas 2, 4, 6, and 8. A network with R = 170 ohms and a series resistance of 110 ohms, giving 40% reduction of amplitude has been found satisfactory.

The effect of loss in the network can be made unimportant if the resolving operation is done at a level where noise originating at the crystal is not a consideration; that is, by adding a suitable preamplifier between each antenna and its input to the resolving network. The values of R, or R_1 and R_2, can then be made sufficiently large to reduce the undesirable coupling to negligible level without loss of sensitivity. In the type of network shown in Fig. 3 this requires different gain for the preamplifiers for antennas 1, 3, 5, and 7 from that of the preamplifiers for antennas 2, 4, 6, and 8, and eliminates the need for series resistances.

It has been shown that the output of eight antennas can be resolved in a resistive network into a four-channel display so as to produce deflections in the display from each antenna in the appropriate direction. When this is done, the system is substantially equivalent to an eight-antenna system with eight amplifiers and eight plates on the cathode-ray tube. The use of four amplifiers instead of eight makes no difference provided the gains of the amplifiers are equal. However, because there is cross-coupling between channels in the ring network of the resolver, smaller departure from equality of gains can be allowed for a given amount of error than in the case of a true eight-channel system. When there is cross-coupling between plates the magnitude of the net voltage at any plate of the cathode-ray tube is the result of the addition and subtraction of voltages which have been amplified in different channels. Thus it can be seen that small differences in gain in different channels can lead to larger differences in the net voltage applied to a plate. This is not considered to be a serious drawback, since maintaining the required equality of gain has not been found significantly more difficult than it was for a four-channel system.

The discussion has been based on resolving of the output of eight antennas into a four-channel display for simplicity and concreteness in discussing the resolving network. However there is no difficulty in extending the results to antenna systems of 4n antennas for the networks shown in Figs. 2 and 3, and with some additional complication, to any number of antennas greater than two.

ADVANTAGES OF THE 8-ANTENNA SYSTEM

The advantages that follow from the use of more than four antennas in an instantaneous direction finder such as the UPD-501 are :

(1) Restrictions on the radiation pattern of the antenna for small error become less severe. This aspect of the problem has been investigated analytically by workers at Federal Telecommunications Laboratories [1]. Errors due to radiation pattern were computed and plotted for a number of types of radiation pattern against the number of antennas in the system. It was shown that for a variety of types of radiation pattern the error was less than 1° when the number of antennas was eight or more. An accuracy of ±1° is more than adequate for the AN/UPD-501; hence there would be no point in considering more than eight antennas to reduce error due to radiation pattern.

A qualitative presentation of the effect of increasing the number of antennas on the radiation pattern requirements is sufficient for our purposes.

In a four-antenna system there are eight azimuthal angles, one every 45°, for which the error due to radiation pattern is zero for any symmetrical pattern. For an eight-antenna system there are at least sixteen such points.

The radiation pattern of an antenna can be expressed as a Fourier series $P(\theta) = \sum_{K=0}^{\infty} A_k \cos K\theta$. If this expression is substituted in Equation (1), it can be shown by algebraic manipulation that for an error-free pattern, the restrictions on the Fourier coefficients are as follows :

For a four-channel system :

$$a_1 \neq 0, \qquad a_{4m-1} = a_{4m+1} \qquad m = 1, 2, 3 \ldots\ldots\ldots\ldots$$

and all other coefficients arbitrary.

For an eight-channel system :

$$a_1 \neq 0 \qquad a_{8m-1} = a_{8m+1} \qquad m = 1, 2, 3 \ldots\ldots\ldots\ldots$$

and all other coefficients arbitrary.

No attempt has been made to generalize these expressions since applications to the AN/UPD-501 antennas were confined to four and eight antenna systems.

It follows from the nature of the restrictions on the Fourier coefficients that there are many more error-free patterns for an eight- than for a four-antenna system. This, together with the fact that there are twice as many azimuthal points where the error is zero for any symmetrical pattern, leads to the conclusion that the requirements for a radiation pattern with small errors should be much less severe for an eight-antenna system than for a four-antenna system.

(2) A second advantage that is gained by increasing the number of antennas is a reduction in the accuracy of tracking of sensitivity with frequency between channels that is required for a given error. This can be seen from Fig. 4 where the maximum bearing error due to complete loss of one channel in an otherwise balanced system is plotted against n, the number of antennas. This curve was plotted on the assumption that in each case the antenna radiation pattern $P(\theta) = \cos \frac{n\theta}{4}$, for θ between $\pm\frac{360°}{n}$, and $P(\theta) = 0$ elsewhere. The curve for a loss of 3 db in one channel is shown on the same figure. Extension of these results to the practical case where the antenna radiation patterns are not the simple functions used above has not been made analytically. However, improvements of the order of those shown in Fig. 4 would certainly be expected.

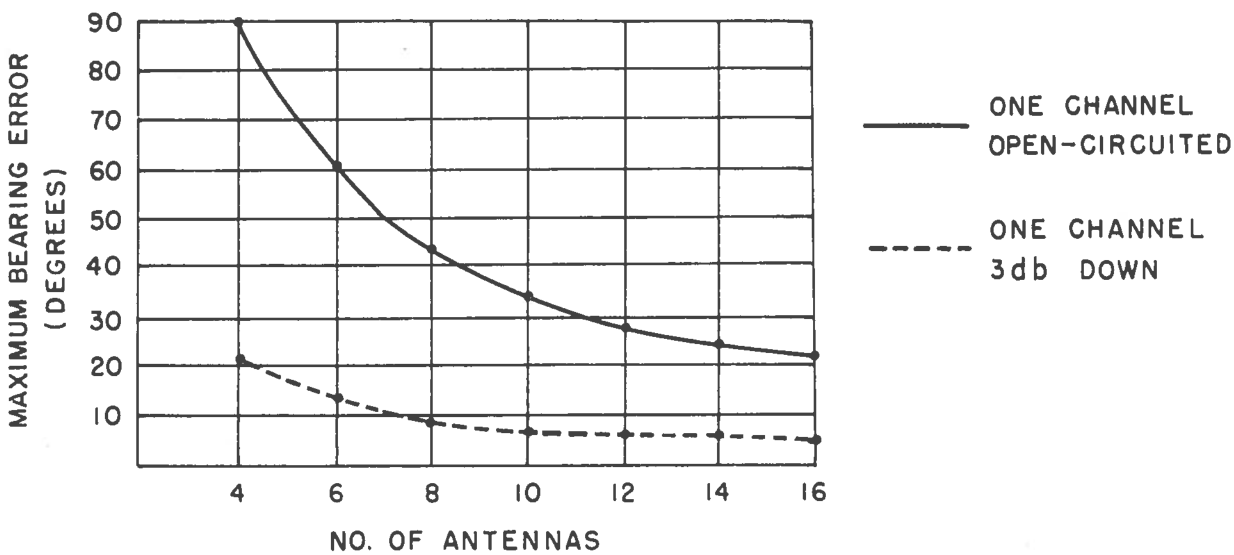

FIG. 4 MAXIMUM BEARING ERROR FOR VARIOUS NUMBERS OF ANTENNAS

(3) A third advantage of increasing the number of antennas is an increase in sensitivity. Increasing the number of antennas from four to eight, with no other change, will double the receiving cross section. However, since the antennas are spaced at 45-degree instead of 90-degree intervals, the gain of each antenna can be increased without increasing the bearing error. It is shown later that the gain of the antenna can increase enough to more than overcome the loss due to narrowing the radiation patterns. Hence, doubling the number of antennas may increase the sensitivity of the system more than 3 db. Similar increases in

sensitivity may be obtained for other increases in the number of antennas.

Since the advantage of increasing the number of antennas appears to be considerable, it was decided to investigate experimentally an eight-antenna system compatible with the existing four-channel UPD-501 equipment.

Many of the features of the eight-antenna system become clear if it is realized that it is in reality two four-antenna systems oriented at an angle of 45° in azimuth with respect to each other. Each four-antenna system produces a deflection on the cathode-ray tube display which can be considered as a vector indicating the bearing of the signal received. The sum of the two vectors for the two four-antenna systems is the vector which would be produced by the eight-antenna system. The two four-antenna systems need not be at 45° to each other, although it can be shown that this gives the greatest benefit. Further, the two four-antenna systems need not be in the same physical location, as has been implied. For example, two four-antenna systems might be located on different parts of a ship or aircraft. The eight-antenna system can also be divided with the two parts mounted fore and aft or on the wingtips of an aircraft to reduce the bad effect of reflections, as has been done with the four-channel system [3].

An interesting feature of the eight-antenna system, which can readily be understood from this point of view, is the removal of the requirement for equal sensitivity in all channels for zero bearing error, in some circumstances. When the radiation pattern of the individual antennas is free of error in an ideal four-channel system the vector produced by each four-channel system is correctly oriented and the vector sum must be correct regardless of the relative amplitudes. The sensitivities of channels 1, 3, 5, and 7 can then be different from those of 2, 4, 6, and 8 without causing error. This is the simplest and most easily explained case of unequal sensitivities which do not cause error. Others can be derived by substitution of $P(\theta) = \cos\theta$ or $P(\theta) = 1 + \cos\theta$ (well known examples of error-free patterns for four-channel systems) in Equation 1. It is possible, since the radiation patterns of some of the antennas used for experimental work are relatively free of error in a four-antenna system, that this is a factor in the improved performance of the eight-antenna system.

EXPERIMENTAL RESULTS

An eight-antenna system for operation on K_u-band (11,000 mc/s to 21,000 mc/s) was constructed and is shown in Fig. 5. Each horn has an aperture of 0.622 × 2.00 inches and tapers to a section 0.622 inches square. Both horizontally and vertically polarized signals incident on the horns will be propagated to the square section for the frequencies involved. Crystal mounts with waveguide sections tapering from 0.622 × 0.622 inches to 0.622 × 0.125 inches were mounted to accept vertical polarization and then rotated to accept horizontal polarization. Eight type-1N26 crystals with sensitivities which tracked within ±2 db across the frequency band were used, and bearing errors were measured across the frequency band, using the resolving network shown in Fig. 2 and a four-channel amplifier and display. Results for the two frequencies at the ends of the band and one near the center are shown in Figs. 6, 7, 8 for horizontal polarization, in Figs. 9, 10, 11 for vertical polarization. Measurements were taken at intervals of 1000 mc/s across the frequency band and the curves were substantially the same as those shown. The performance of the antenna on both polarizations across a frequency band of almost an octave is satisfactory. To convert it to a dual-polarized antenna, a transforming section from square waveguide to rectangular waveguide at 45° to the square waveguide is required so that both polarizations can propagate to the crystal mount independently. A transforming section of this type has been built. Measurement of its performance is not complete, but the principle appears to be sound.

An eight-antenna dual-polarized S-band (2350- 5500 mc/s) antenna is shown in Fig. 12. In this case dual polarization has been obtained in a different fashion, by mounting the horns at 45° to the vertical. This method has the disadvantage that independent control of vertical and horizontal radiation patterns is not possible without additional structures of some kind. The bearing errors of this antenna were measured on both polarizations across the frequency band, and typical results are shown in Figs. 13 to 18.

Both of the dual polarized eight-antenna systems described above are more accurate than a single-polarization four-antenna system in their respective frequency ranges. It has been inferred from this that the advantages expected from an eight-antenna system are realized, and that they are great enough to be of considerable practical importance.

To determine experimentally the effect of different sensitivity levels in different channels, a video attenuator was inserted on one channel of the K_u band antenna system. Bearing error was measured as the attenuation was increased in steps of 1 db, and a final measurement made with the channel open-circuited. It should be remembered that because of the square-law detector, 1-db attenuation in the video circuit represents $\frac{1}{2}$ db in the r-f circuit. The significant results are shown in Figs. 19 to 22.

It can be seen that the expected independence of crystal sensitivity has been realized. Also, it is evident that the errors for an open-circuited channel are smaller than predicted on the basis of the particular radiation pattern assumed in Fig. 4. The reason for this is that the horizontal radiation pattern of the experimental antenna is wider than that assumed in the calculation. It appears, therefore, that the extent of the independence of crystal sensitivity in an eight-antenna system is influenced by the radiation pattern of the individual antennas.

The extent of the relaxation on the type of radiation pattern required for low error was demonstrated by the measurements plotted in Figs. 23 and 24. Fig. 23 shows the radiation patterns of a K_u-band horn mounted in a cylinder, and of the same horn with a vertical post in front of the horn in two different positions. Fig. 24 shows the bearing error measured when each of the three types of horn was used in an eight-antenna system for direction finding. Most of the error on these curves is due to differing sensitivities of the crystals in different channels. The differences between the curves are caused by the different radiation patterns of the antennas. It can be seen that widely differing radiation patterns have a surprisingly small effect on the amount of bearing error.

CONCLUSIONS

Two of the advantages of an eight-antenna system over a four-antenna system in an instantaneous microwave direction finder, viz.:

1) greater freedom from the requirement of close tracking of the sensitivity of channels across a frequency band, and,

2) much less restriction on the radiation patterns of the individual antennas for low bearing error,

have been justified on philosophical grounds and demonstrated experimentally.

Measurements of the relative sensitivity of four- and eight-antenna systems are not so conclusive because of the difficulties involved in this type of measurement and because of the relatively large effect of the individual antenna radiation patterns on the sensitivity of the system. The relative sensitivities of some ideal systems with simple radiation patterns have been computed and are tabulated on page 10.

It is believed that four-antenna systems are usually somewhere between cases 1 and 2, and that eight-antenna systems are likely to be between cases 3 and 5. Therefore an increase of sensitivity of 4 to 5 db should be expected. In the experimental antenna systems there is a loss of approximately $2\frac{1}{2}$ db in the resolver, and for dual polarized antennas there is a further loss of 3 db in the antenna. Measurements which have been made do not disagree, but at the present time they are not sufficiently precise to provide positive confirmation.

The use of eight antennas will, we believe, make possible the design of dual-

TABLE I

RELATIVE SENSITIVITY OF SIX DIFFERENT ANTENNA SYSTEMS

	No. of Antennas	Radiation Pattern	Free of Pattern Error	Equal Sensitivity for all θ.	Relative Sensitivity at $\theta = 0$ (db)
1	4	$P(\theta) = \cos\theta \quad -\frac{\pi}{2} \geq \theta \geq \frac{\pi}{2}$ $P(\theta) = 0 \quad \lvert\theta\rvert > \frac{\pi}{2}$	Yes	Yes	0
2	4	$P(\theta) = 1 + \cos\theta$	Yes	Yes	-1.95
3	8	$P(\theta) = \cos\theta \quad -\frac{\pi}{4} \geq \theta \geq \frac{\pi}{4}$ $P(\theta) = 0 \quad \lvert\theta\rvert > \frac{\pi}{4}$	Yes	Yes	+3.00
4	8	$P(\theta) = \cos 2\theta \quad -\frac{\pi}{4} \geq \theta \geq +\frac{\pi}{4}$ $P(\theta) = 0 \quad \lvert\theta\rvert > \frac{\pi}{4}$	small error	Minimum at $\theta = 0$	+3.00
5	8	$P(\theta) = \cos\theta - \sin\theta, -\frac{\pi}{4} \geq \theta \geq \frac{\pi}{4}$ $P(\theta) = 0 \quad \lvert\theta\rvert > \frac{\pi}{4}$	Yes	Yes	+3.85
6	8	$P(\theta) = \cos\theta \cos 2\theta, -\frac{\pi}{4} \geq \theta \geq \frac{\pi}{4}$ $P(\theta) = 0 \quad \lvert\theta\rvert > \frac{\pi}{4}$	Yes	Minimum at $\theta = 0$	+3.25

polarized eight-antenna systems with sensitivity approximately 1 db less than the four-antenna single polarized systems previously built. The accuracy of the eight-antenna systems has been found to be better on both polarizations over the same frequency range, and they are much less dependent on relative crystal sensitivities in the different channels. The increase in size and weight, although not yet accurately determined, is expected to be small.

The extent to which the advantages of multiple antenna systems are realized in practice by the rather modest increase in the number of antennas from four to eight, is surprising and indicates that this type of antenna system has greater application in the instantaneous microwave direction-finder than was previously realized.

Development of eight-antenna direction-finding systems is continuing in this laboratory. This is a preliminary report and is issued in this form to permit early dissemination of the information to interested organizations.

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ACKNOWLEDGMENT

The author wishes to acknowledge the many valuable suggestions that arose out of numerous discussions with W.L. Haney and A. Staniforth during the course of the work reported here.

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FIG. 5 EIGHT-ANTENNA DUAL-POLARIZED K_u BAND ANTENNA SYSTEM

8-ANTENNA DUAL POLARIZED
KU-BAND ANTENNA SYSTEM
BEARING ERROR CURVE

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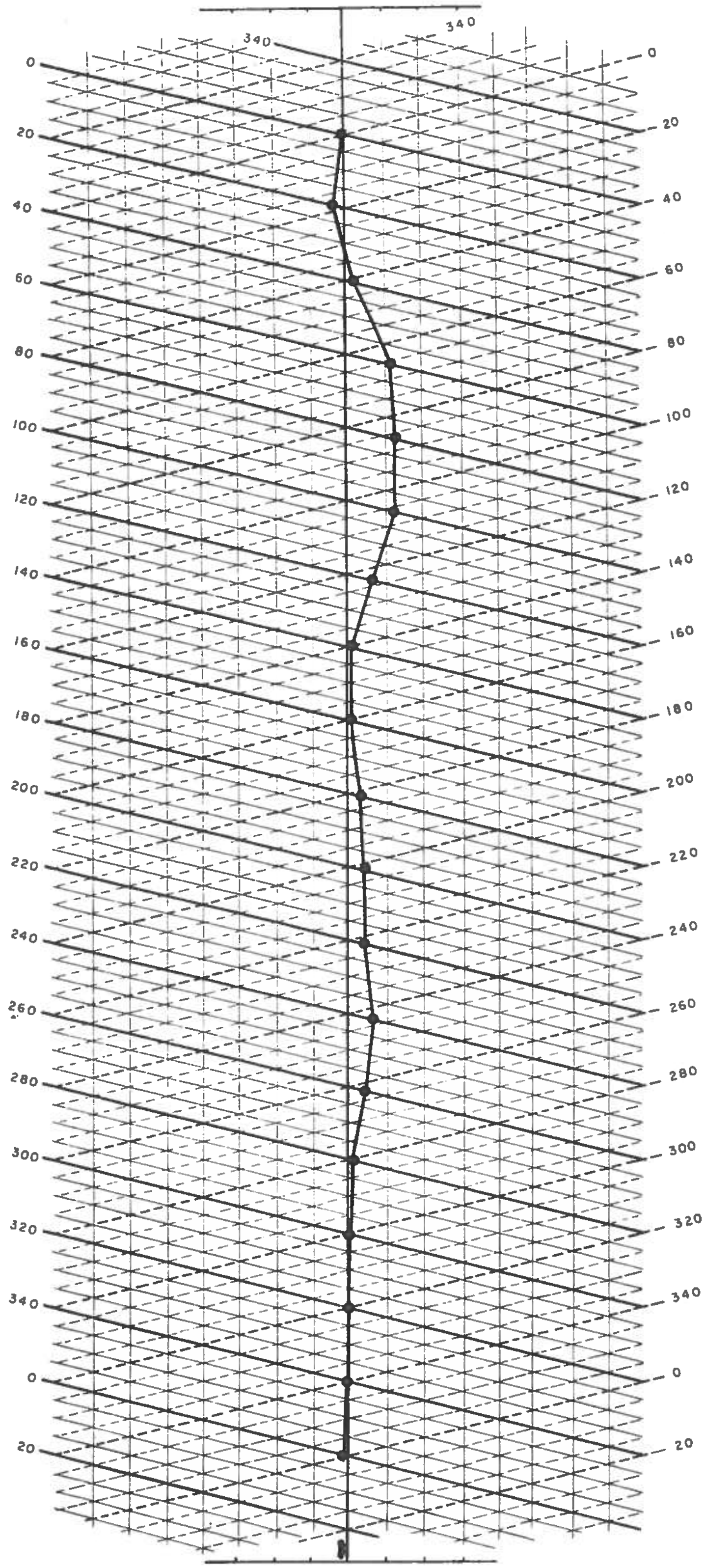
DATE JAN.16,1957

Nº_____

TRUE BEARING

INDICATED BEARING



TRANSMITTER TYPE
X-12 KLYSTRON

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
HORIZONTAL
POLARIZATION

FREQUENCY

11000 mc/s

RECEIVER TYPE
U.P.D. 501

LOCATION
ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

FIGURE 6

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

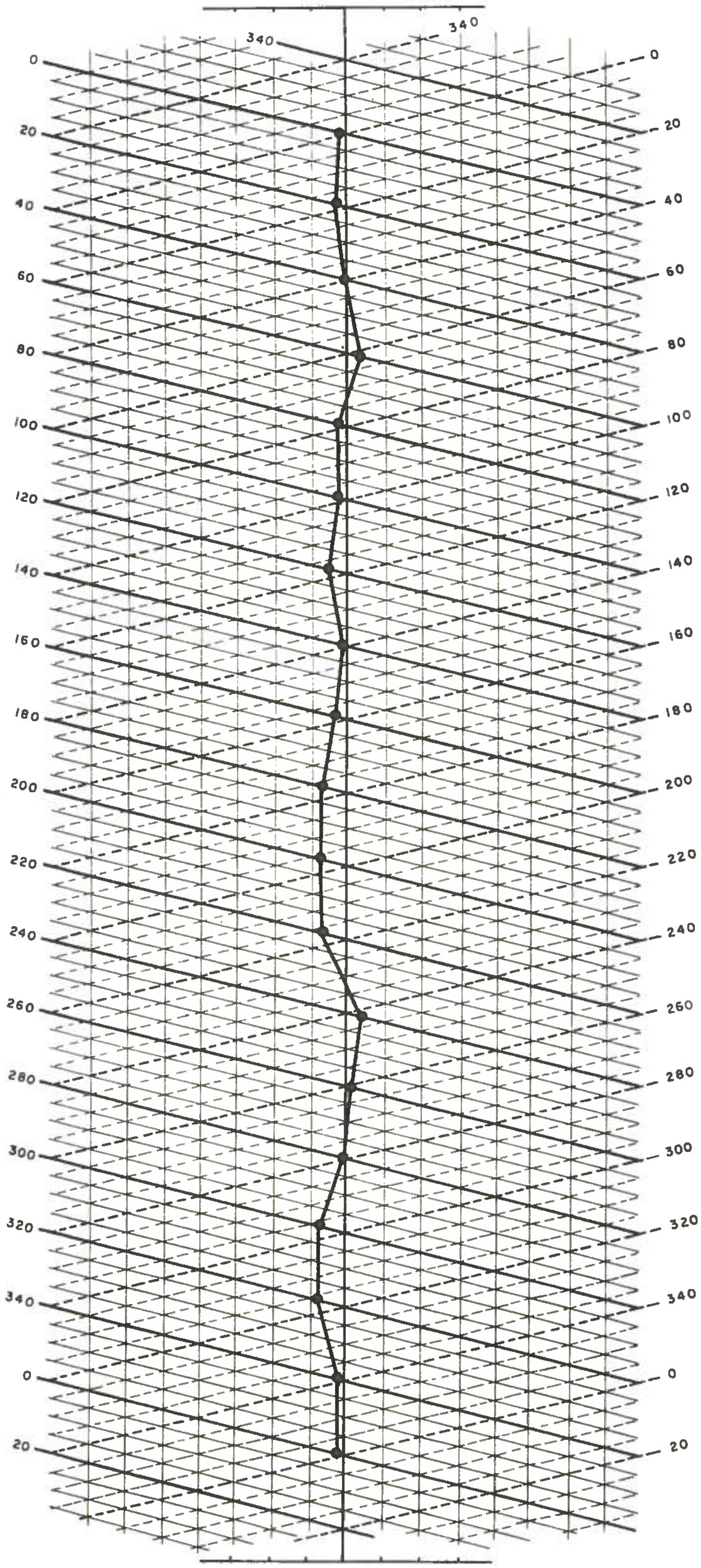
SECRET

DATE DEC. 19, 1956

№_____

TRUE BEARING

INDICATED BEARING



TRANSMITTER
TYPE
X-12 KLYSTRON

RECEIVER
TYPE
U. P. D. 501

LOCATION
ROOF
TEST SITE

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
HORIZONTAL
POLARIZATION

ANTENNA

FREQUENCY

15000 mc/s

BIAS

ADJUSTMENT

FIGURE 7

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

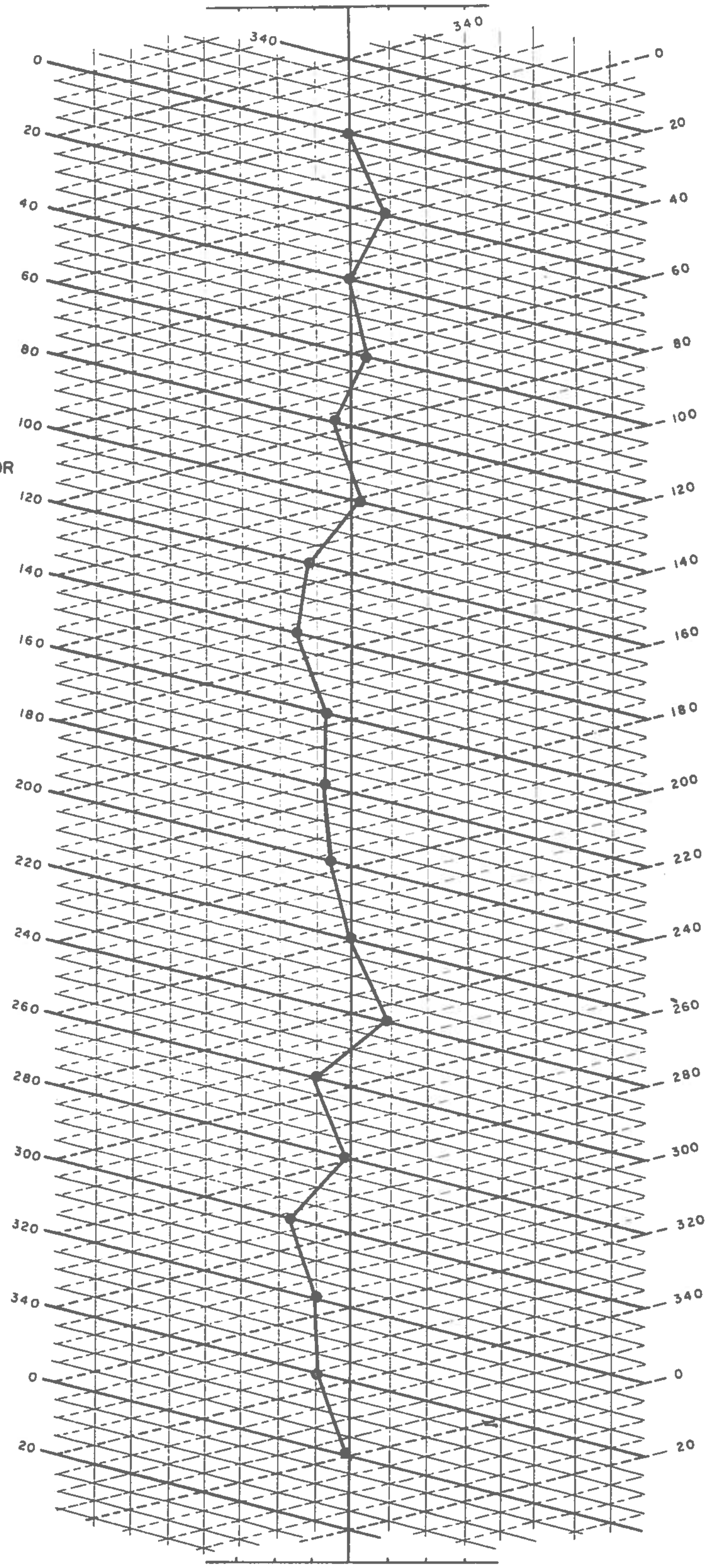
SECRET

DATE DEC. 19, 1956

№ -----

TRUE BEARING

INDICATED BEARING



TRANSMITTER
TYPE
SIGNAL GENERATOR

RECEIVER
TYPE
U. P. D. 501

LOCATION
ROOF
TEST SITE

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
HORIZONTAL
POLARIZATION

ANTENNA

FREQUENCY

21000 mc/s

BIAS

ADJUSTMENT

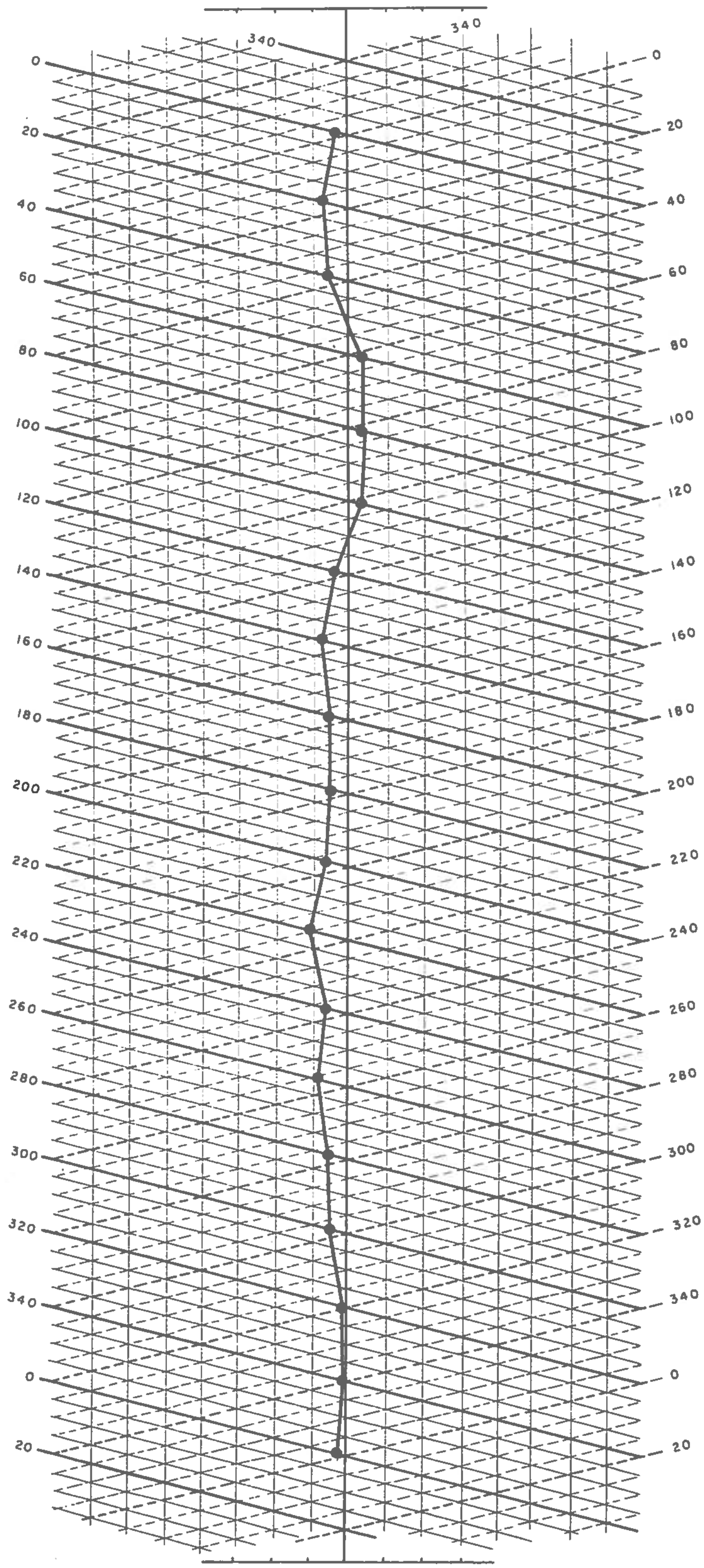
FIGURE 8

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM
BEARING ERROR CURVE

SECRET

DATE DEC. 13, 1956

№ _____



TRANSMITTER
TYPE
X-13 KLYSTRON

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
VERTICAL
POLARIZATION

FREQUENCY

11000 mc/s

RECEIVER
TYPE
U. P. D. 501

LOCATION
ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

FIGURE 9

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

SECRET

DATE DEC.13,1956

Nº_____

TRUE BEARING

INDICATED BEARING

TRANSMITTER TYPE X-12 KLYSTRON

RECEIVER TYPE U.P.D. 501

LOCATION ROOF TEST SITE

LOCATION ROOF TEST SITE

ANTENNA HORN VERTICAL POLARIZATION

ANTENNA

FREQUENCY 15000 mc/s

BIAS

ADJUSTMENT

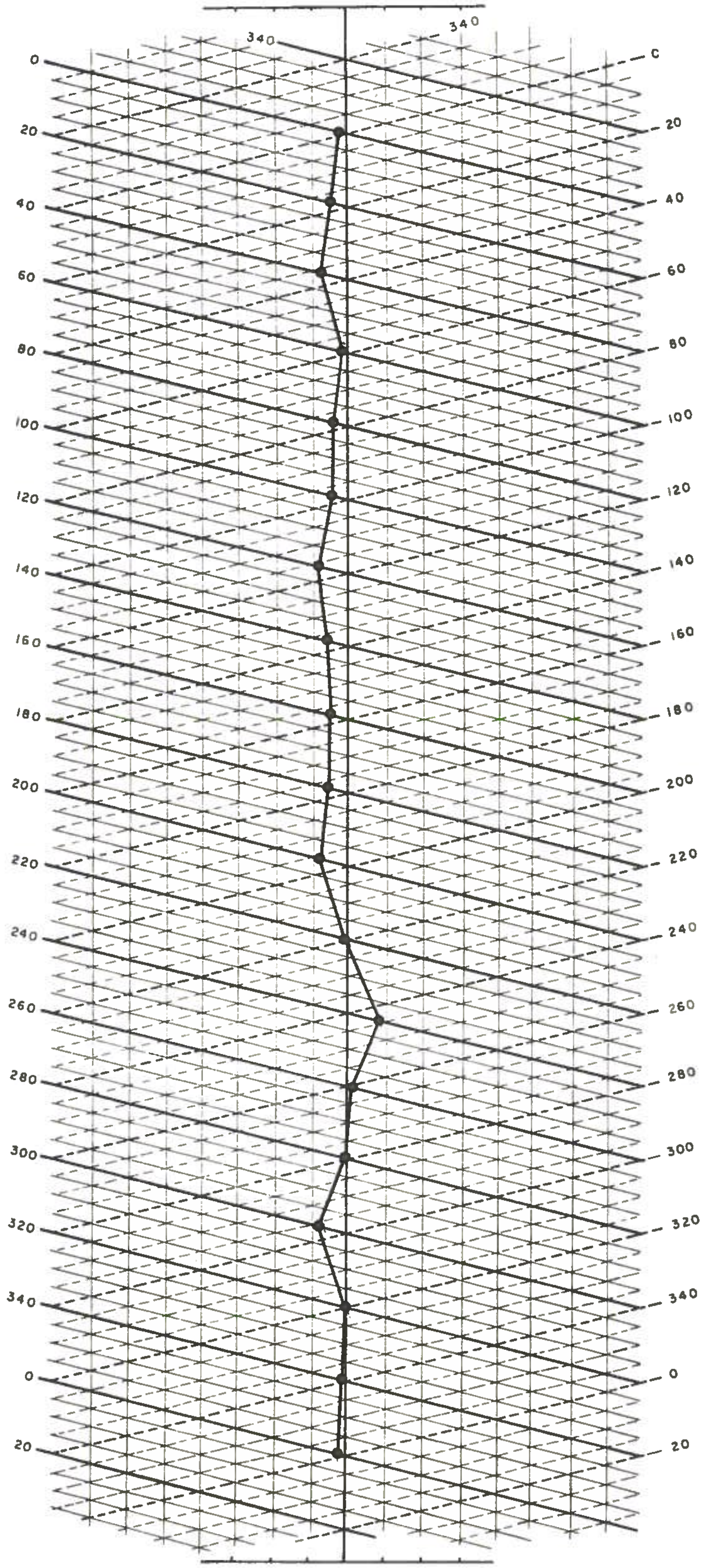


FIGURE 10

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM
BEARING ERROR CURVE

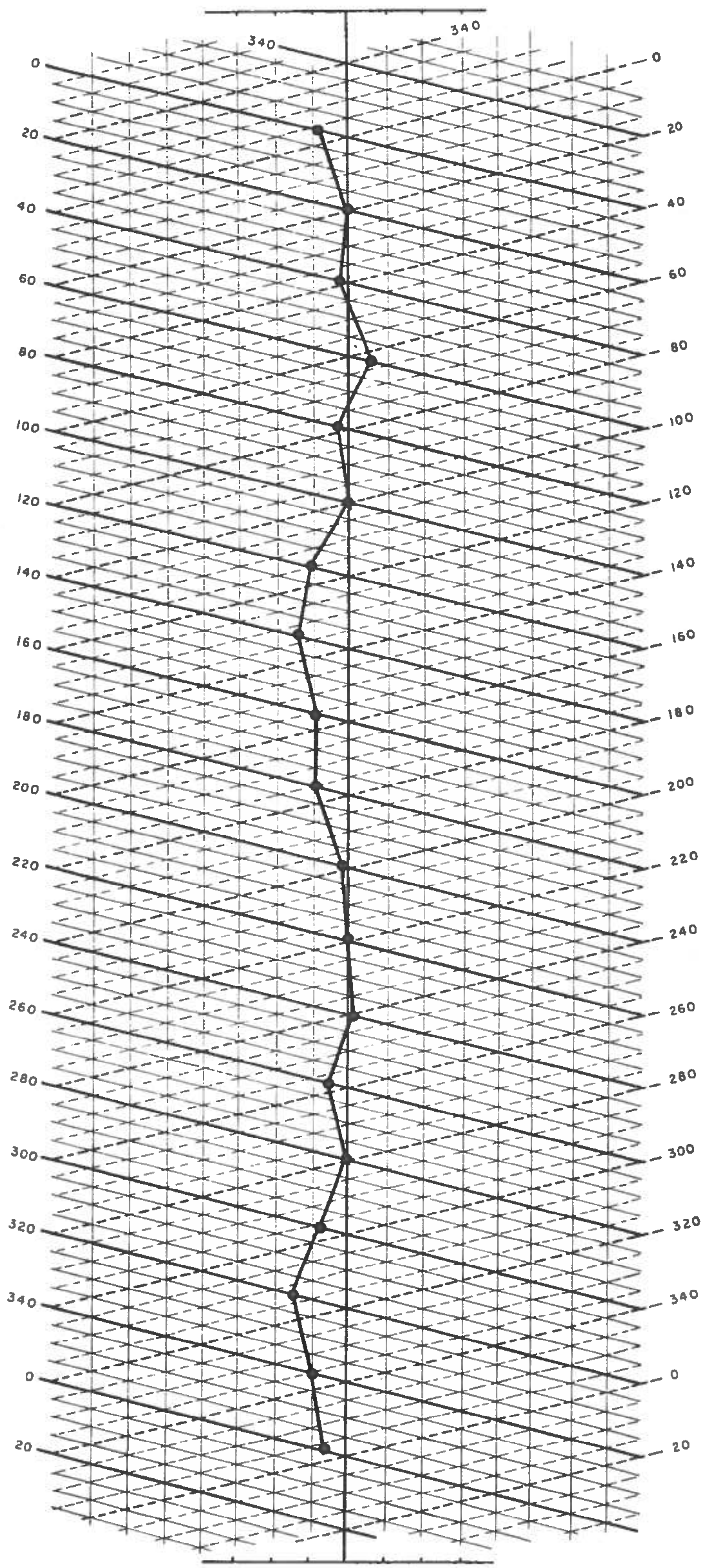
SECRET

DATE DEC. 19, 1956

№ ____

TRUE BEARING

INDICATED BEARING



TRANSMITTER
TYPE
X-12 KLYSTRON

RECEIVER
TYPE
U.P.D. 501

LOCATION
ROOF
TEST SITE

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
VERTICAL
POLARIZATION

ANTENNA

FREQUENCY

21000 mc/s

BIAS

ADJUSTMENT

FIGURE 11

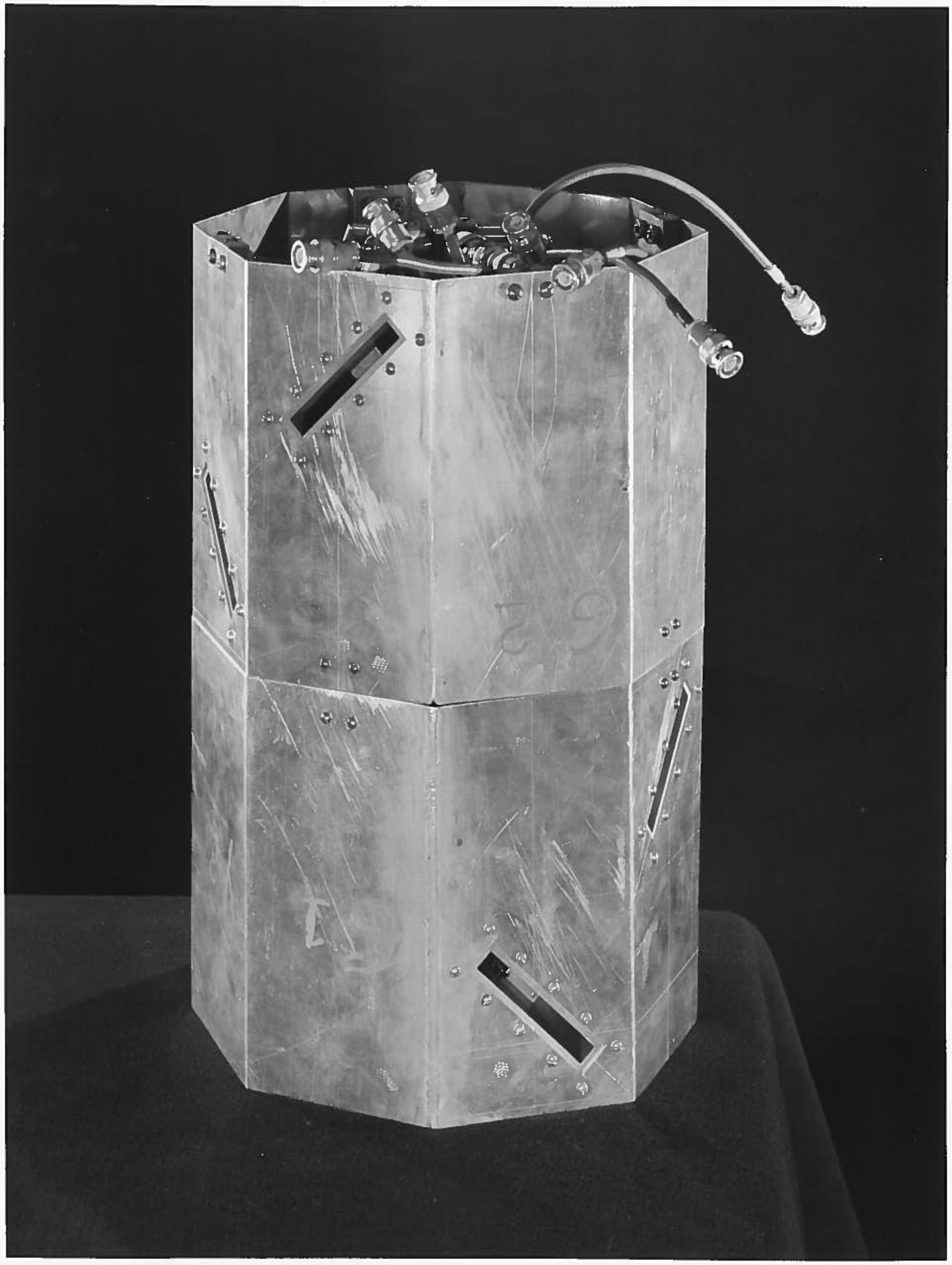


FIG. 12 EIGHT-ANTENNA DUAL-POLARIZED S-BAND ANTENNA SYSTEM

SECRET

SECRET

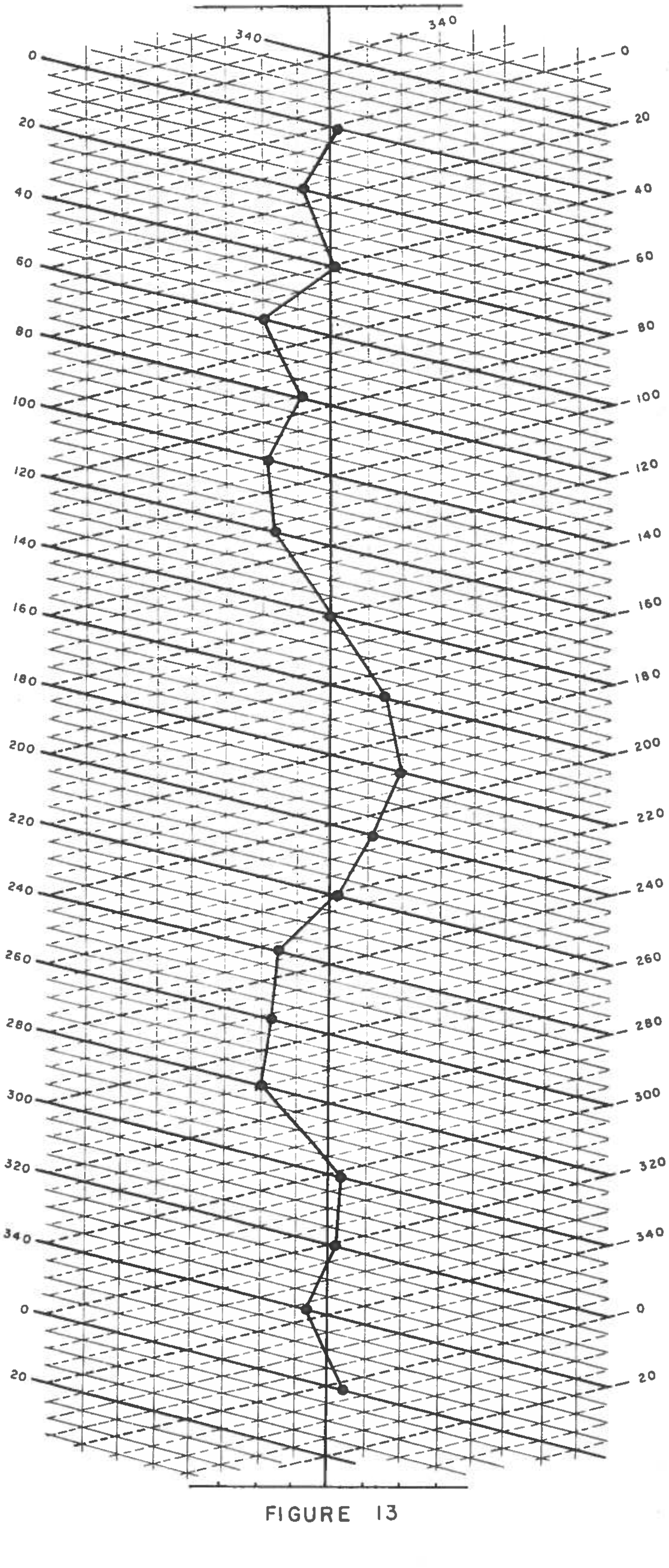
DATE JAN.2,1957

№ _____

8-ANTENNA DUAL-POLARIZED

S-BAND ANTENNA SYSTEM

BEARING ERROR CURVE



TRUE BEARING

INDICATED BEARING

TRANSMITTER TYPE
SIGNAL GENERATOR AND T.W.T. AMPLIFIER

RECEIVER TYPE
U.P.D. 501

LOCATION
ROOF TEST SITE

LOCATION
ROOF TEST SITE

ANTENNA
HORN
HORIZONTAL POLARIZATION

ANTENNA

FREQUENCY

2350 mc/s

BIAS

ADJUSTMENT

FIGURE 13

8-ANTENNA DUAL-POLARIZED
S-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

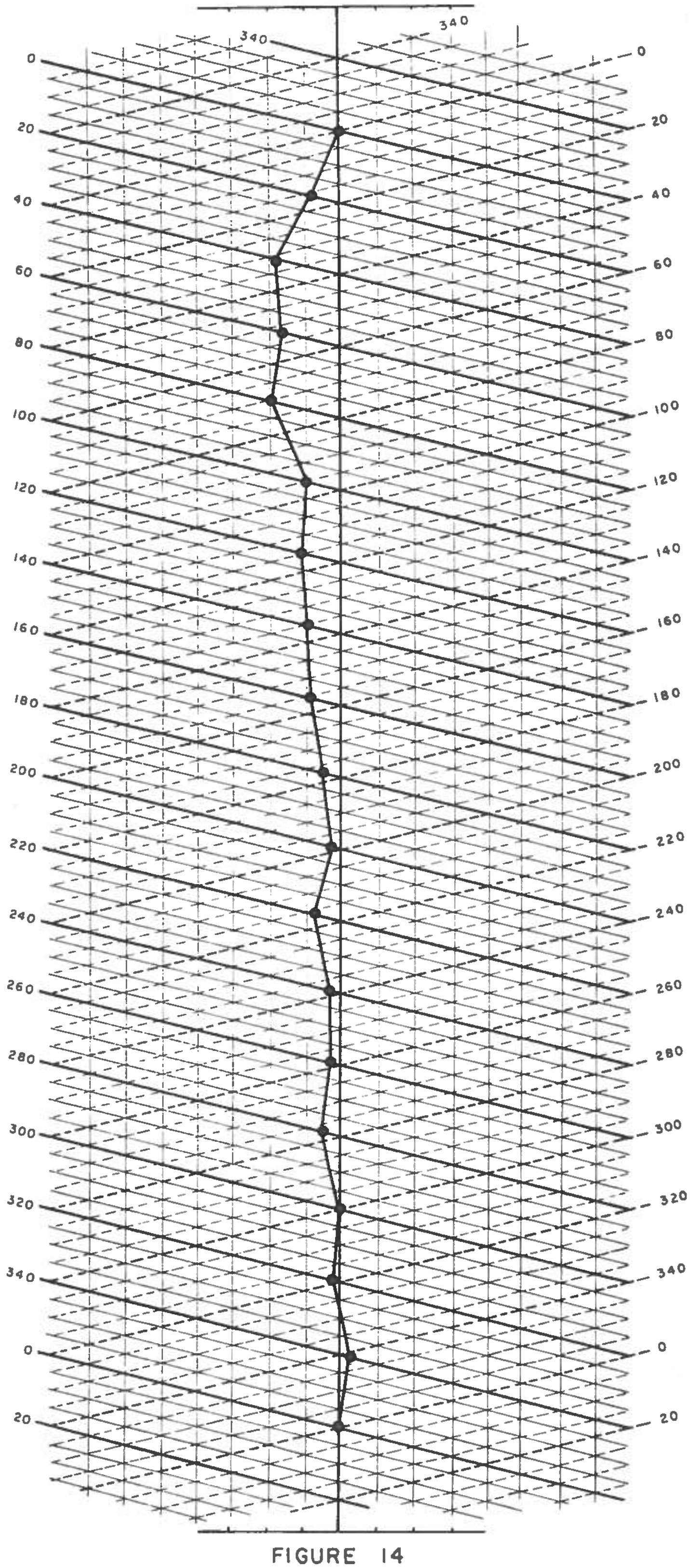
SECRET

DATE JAN. 2, 1957

№ _____

TRUE BEARING

INDICATED BEARING



TRANSMITTER

TYPE

SIGNAL GENERATOR
AND T.W.T. AMPLIFIER

LOCATION

ROOF
TEST SITE

ANTENNA

HORN
HORIZONTAL
POLARIZATION

FREQUENCY

4000 mc/s

RECEIVER

TYPE

U.P.D. 501

LOCATION

ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

FIGURE 14

8-ANTENNA DUAL-POLARIZED
S-BAND ANTENNA SYSTEM
BEARING ERROR CURVE

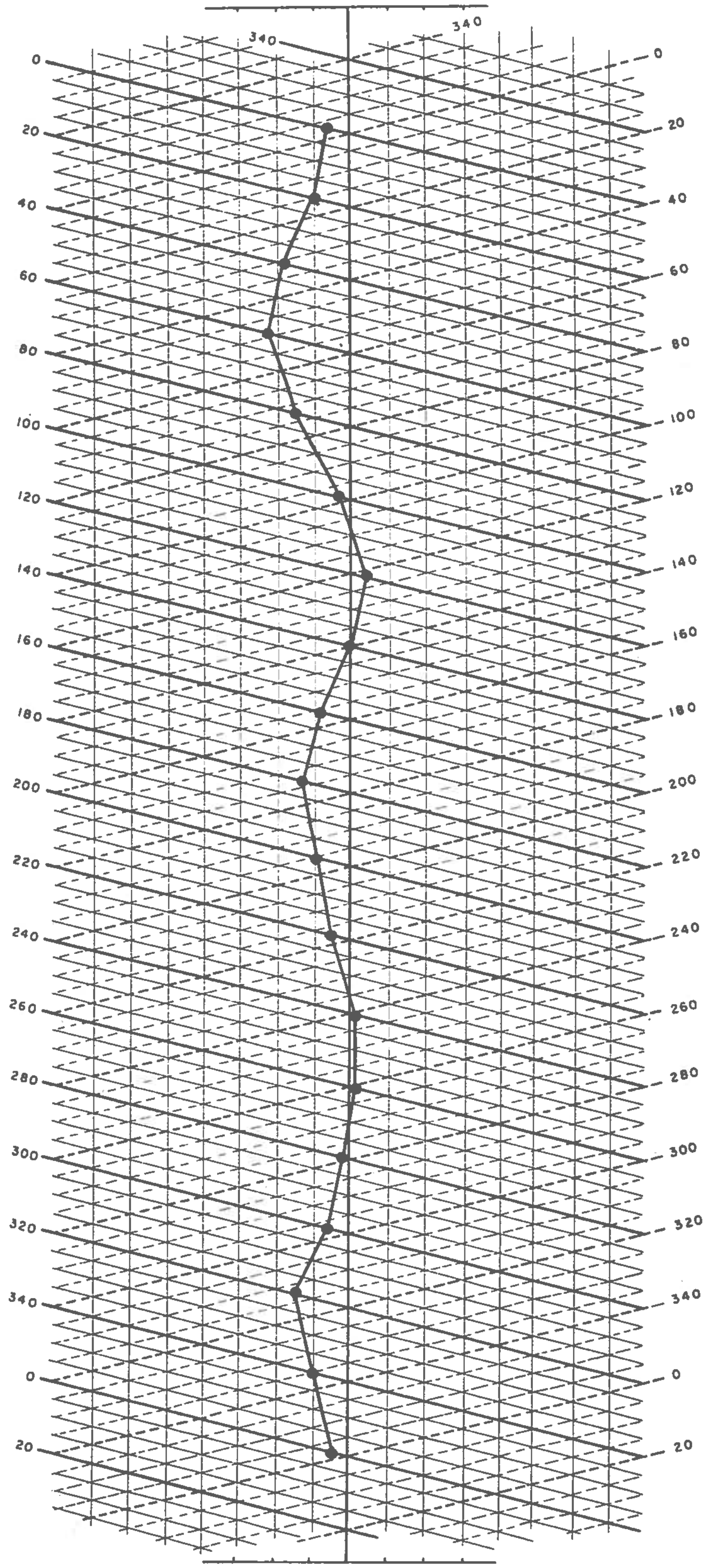
SECRET

DATE JAN. 2, 1957

№ _____

TRUE BEARING

INDICATED BEARING



TRANSMITTER
TYPE
SIGNAL GENERATOR
AND T.W.T. AMPLIFIER

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
HORIZONTAL
POLARIZATION

FREQUENCY

5500 mc/s

RECEIVER
TYPE
U.P.D. 501

LOCATION
ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

FIGURE 15

8-ANTENNA DUAL-POLARIZED
S-BAND ANTENNA SYSTEM

SECRET

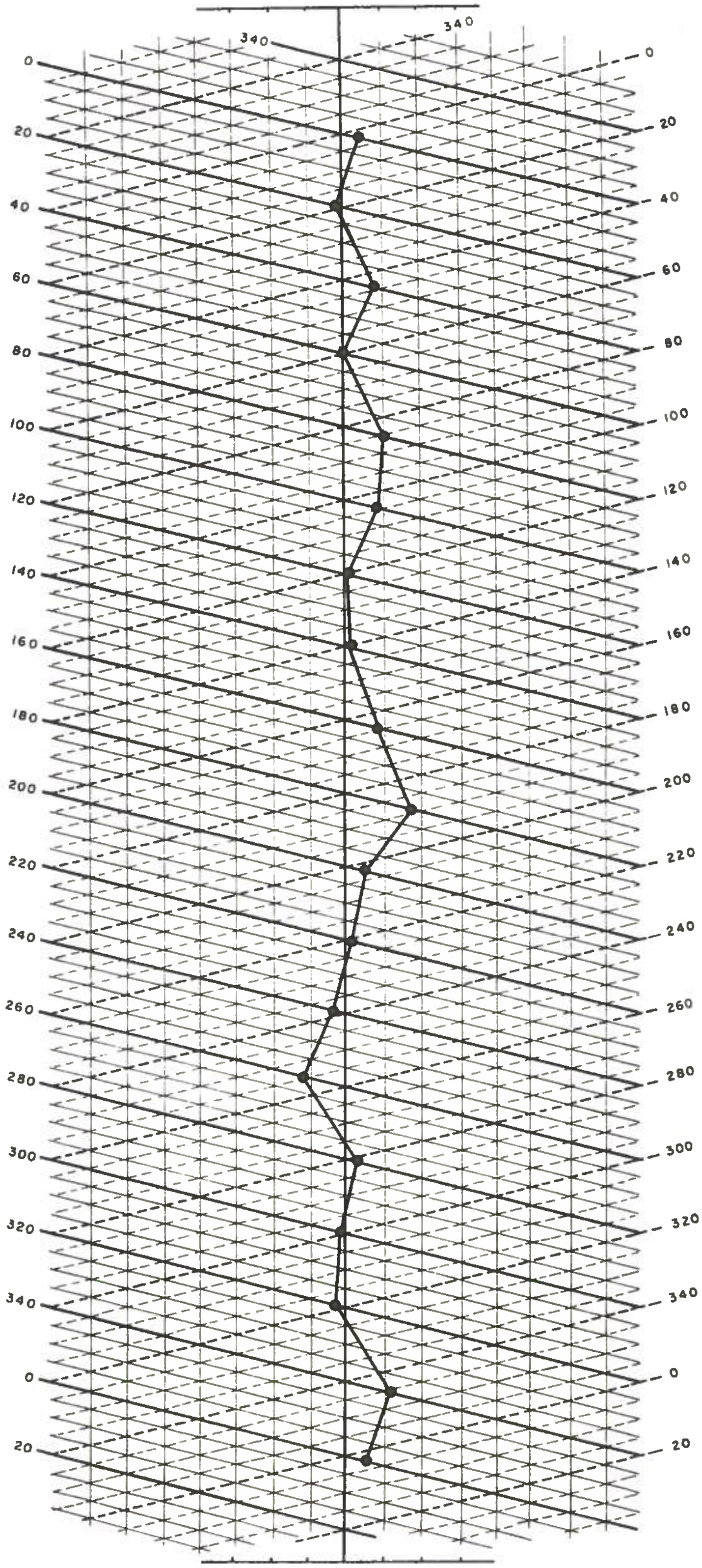
BEARING ERROR CURVE

DATE JAN. 3, 1957

No. ____

TRUE BEARING

INDICATED BEARING



TRANSMITTER
TYPE
SIGNAL GENERATOR
AND T.W.T. AMPLIFIER

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
VERTICAL
POLARIZATION

FREQUENCY

2350 mc/s

RECEIVER
TYPE
U. P. D. 501

LOCATION
ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

FIGURE 16

8-ANTENNA DUAL-POLARIZED

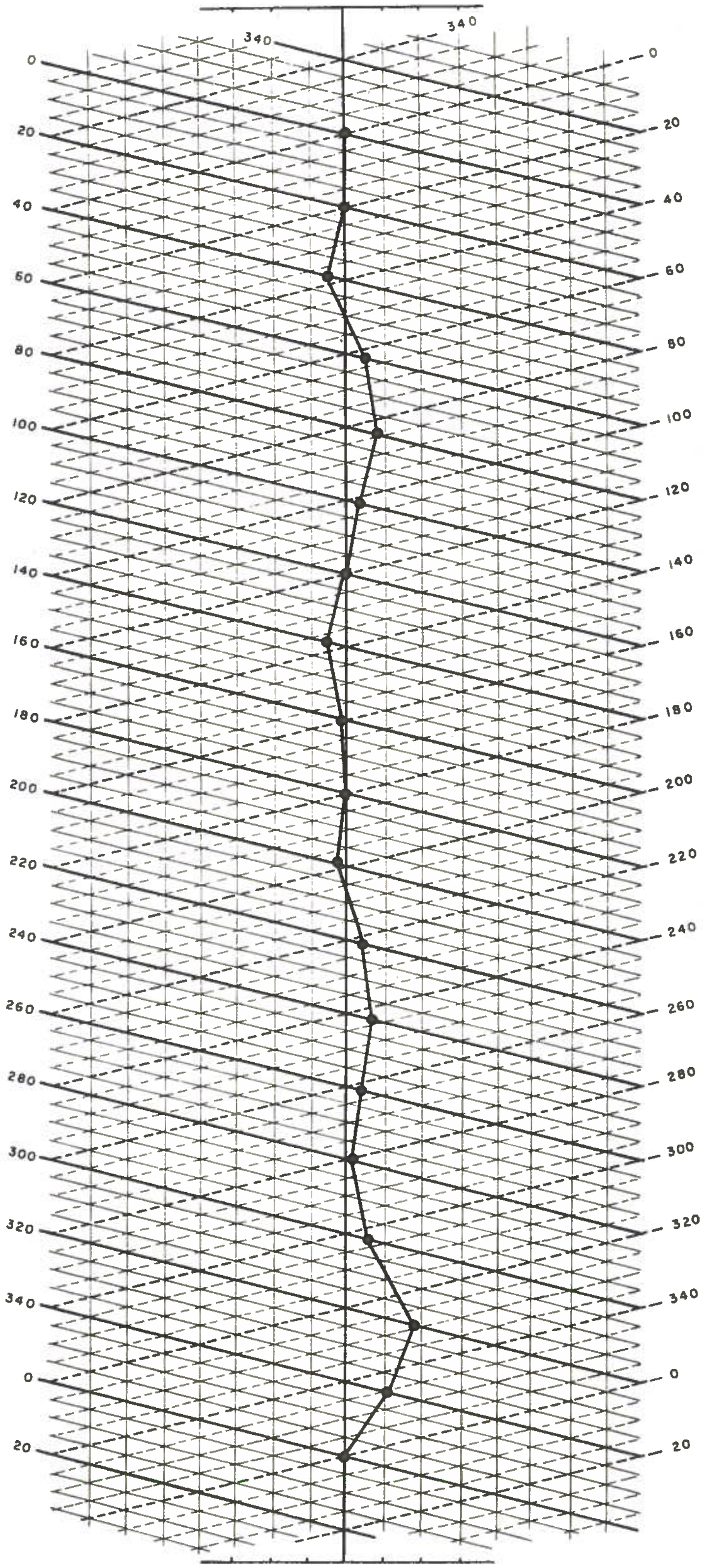
S-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

SECRET

DATE JAN.3, 1957

Nº_____



TRANSMITTER

TYPE
SIGNAL GENERATOR
AND T.W.T. AMPLIFIER

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
VERTICAL
POLARIZATION

FREQUENCY

4000 mc/s

RECEIVER

TYPE
U.P.D. 501

LOCATION
ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

FIGURE 17

8-ANTENNA DUAL-POLARIZED
S-BAND ANTENNA SYSTEM

SECRET

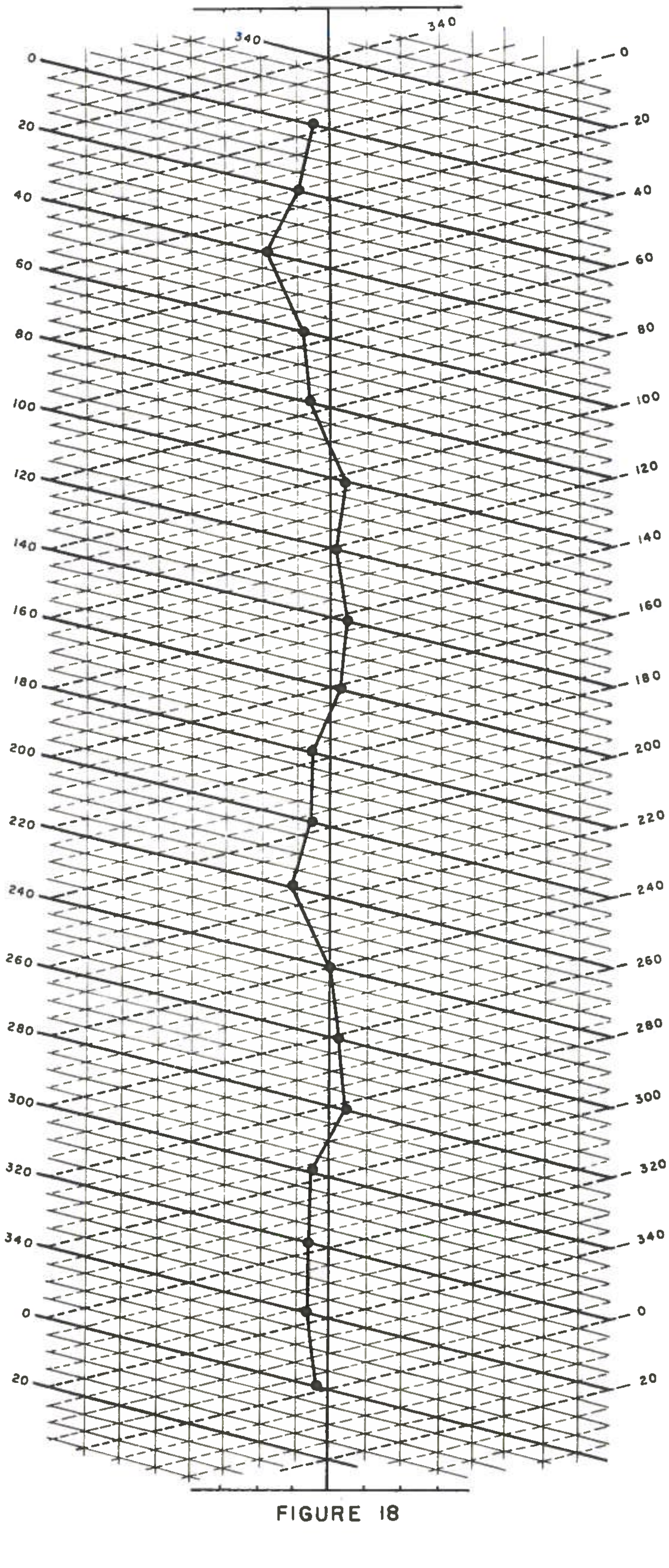
BEARING ERROR CURVE

DATE JAN.3,1957

Nº_____

TRUE BEARING

INDICATED BEARING



TRANSMITTER

TYPE

SIGNAL GENERATOR
AND T.W.T. AMPLIFIER

LOCATION

ROOF
TEST SITE

ANTENNA

HORN
VERTICAL
POLARIZATION

FREQUENCY

5500 mc/s

RECEIVER

TYPE

U.P.D. 501

LOCATION

ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

FIGURE 18

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

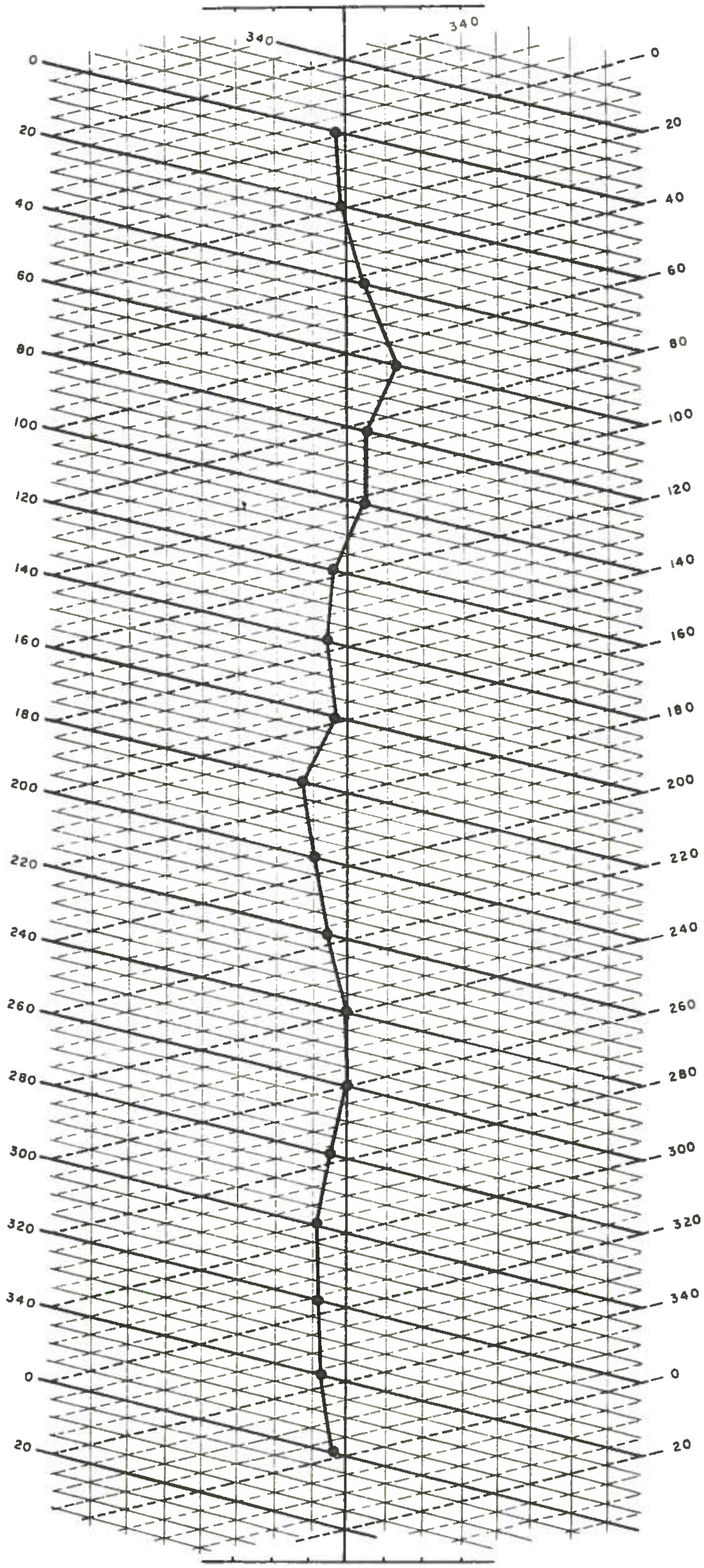
SECRET

DATE DEC. 20, 1956

Nº_____

TRUE BEARING

INDICATED BEARING



TRANSMITTER TYPE
X-12 KLYSTRON

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
HORIZONTAL
POLARIZATION

FREQUENCY

15000 mc/s

RECEIVER TYPE
U.P.D. 501

LOCATION
ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

I db VIDEO
ATTENUATION
IN CHANNEL # 1

FIGURE 19

8-ANTENNA DUAL-POLARIZED KU-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

SECRET

DATE DEC. 20, 1956

Nº_____

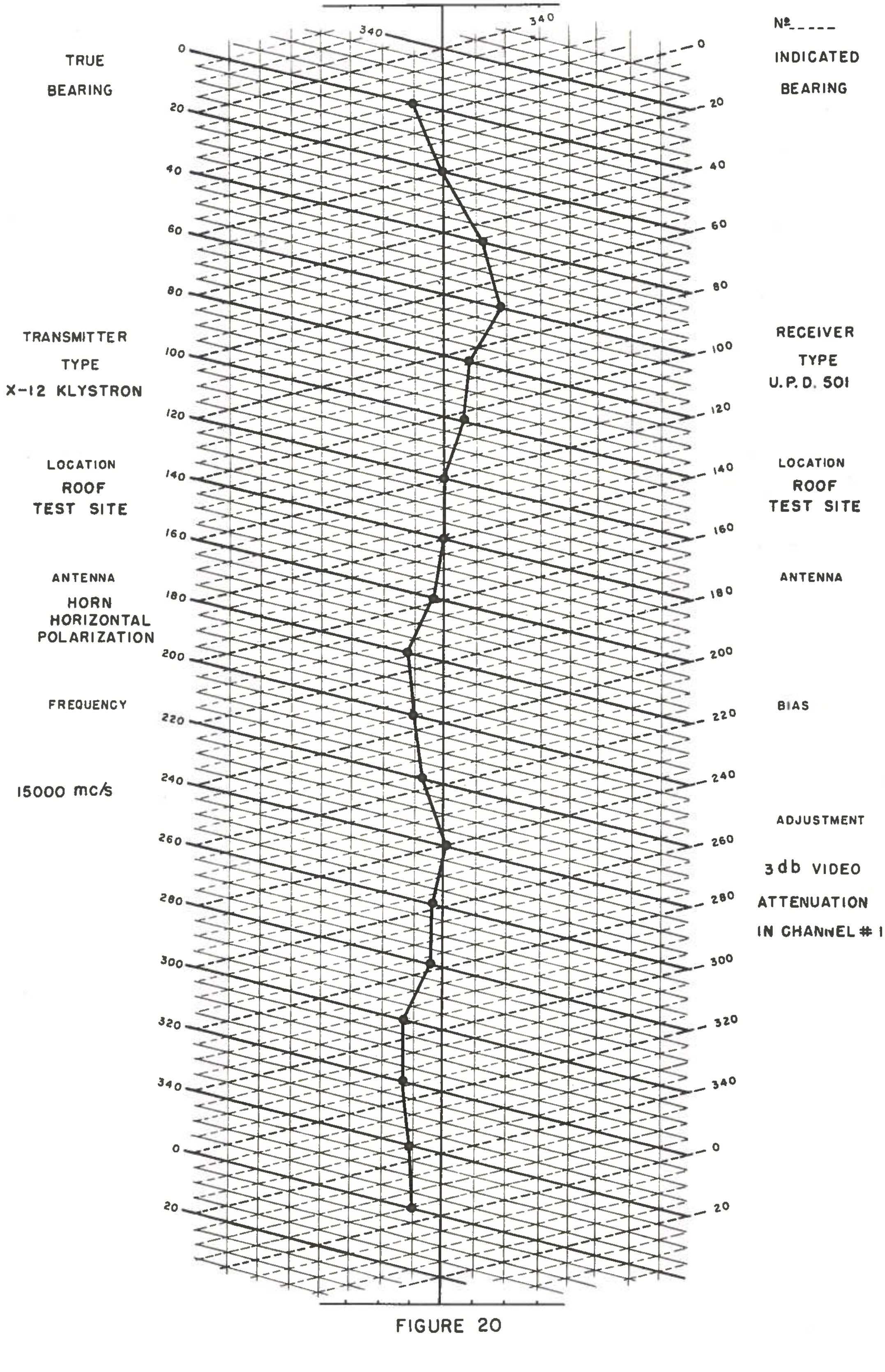


FIGURE 20

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

SECRET

DATE DEC. 20, 1956

№ _____

TRUE BEARING

INDICATED BEARING

TRANSMITTER TYPE
X-12 KLYSTRON

RECEIVER TYPE
U.P.D. 501

LOCATION
ROOF
TEST SITE

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
HORIZONTAL
POLARIZATION

ANTENNA

FREQUENCY

15000 mc/s

BIAS

ADJUSTMENT

6db VIDEO
ATTENUATION
IN CHANNEL # 1

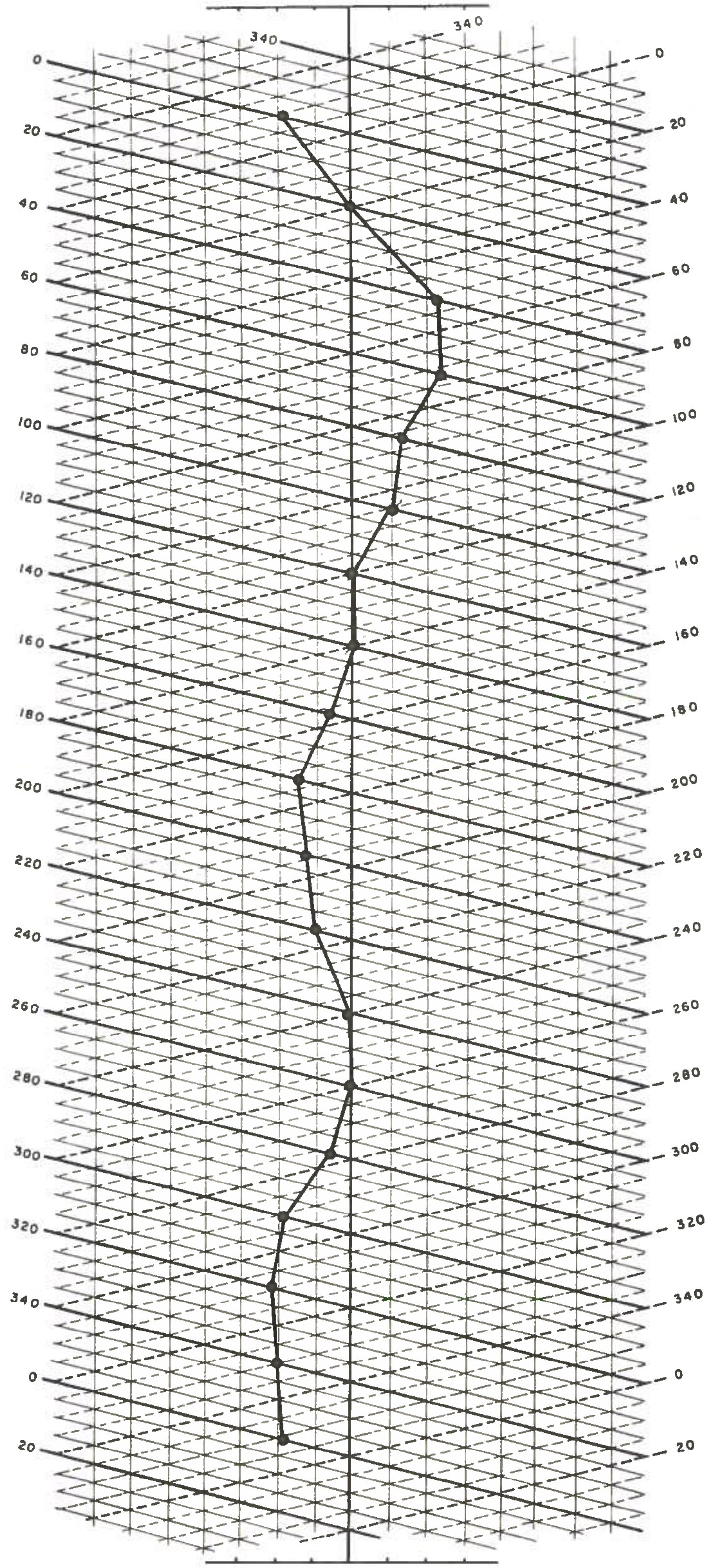


FIGURE 21

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM
BEARING ERROR CURVE

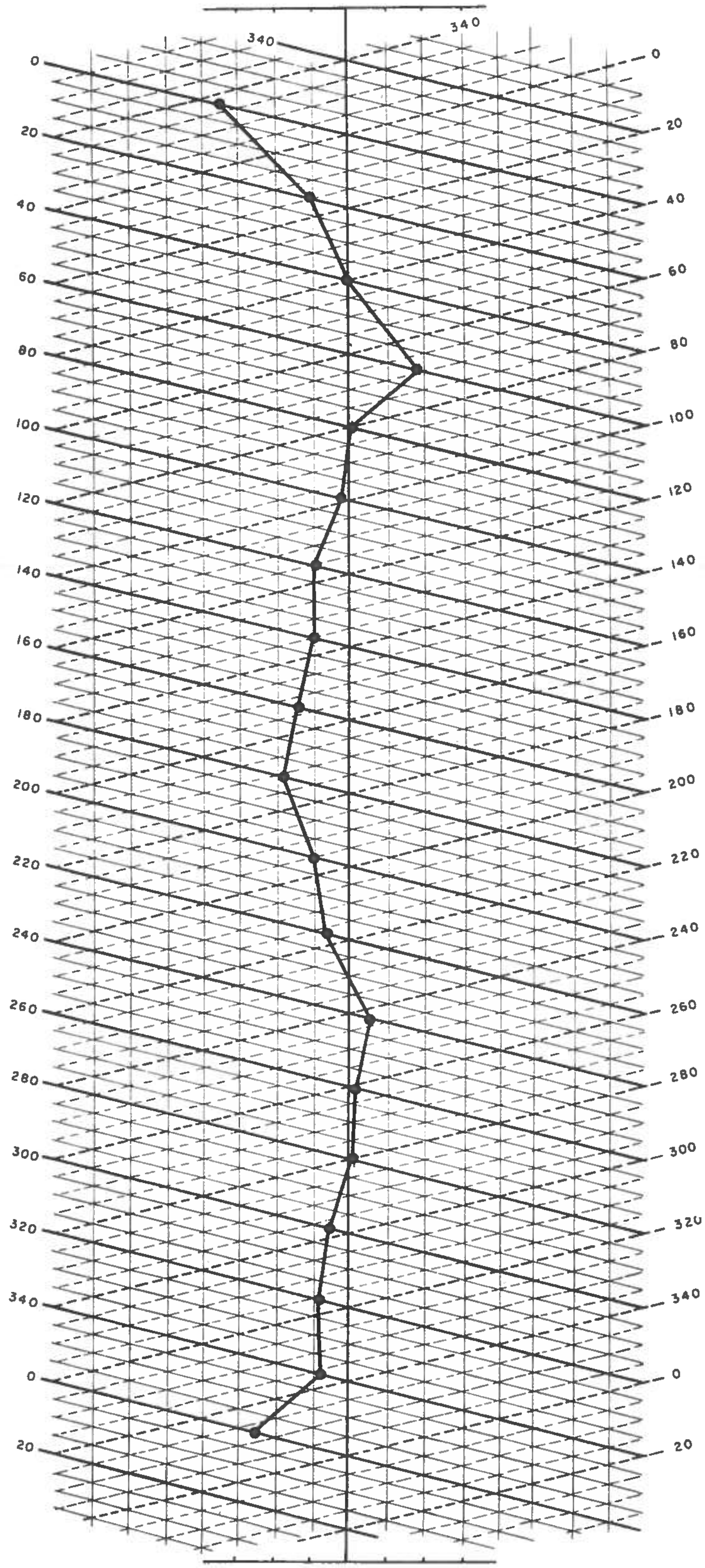
SECRET

DATE DEC. 20, 1956

№_____

TRUE BEARING

INDICATED BEARING



TRANSMITTER TYPE
X-12 KLYSTRON

RECEIVER TYPE
U.P.D. 501

LOCATION
ROOF
TEST SITE

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
VERTICAL
POLARIZATION

ANTENNA

FREQUENCY

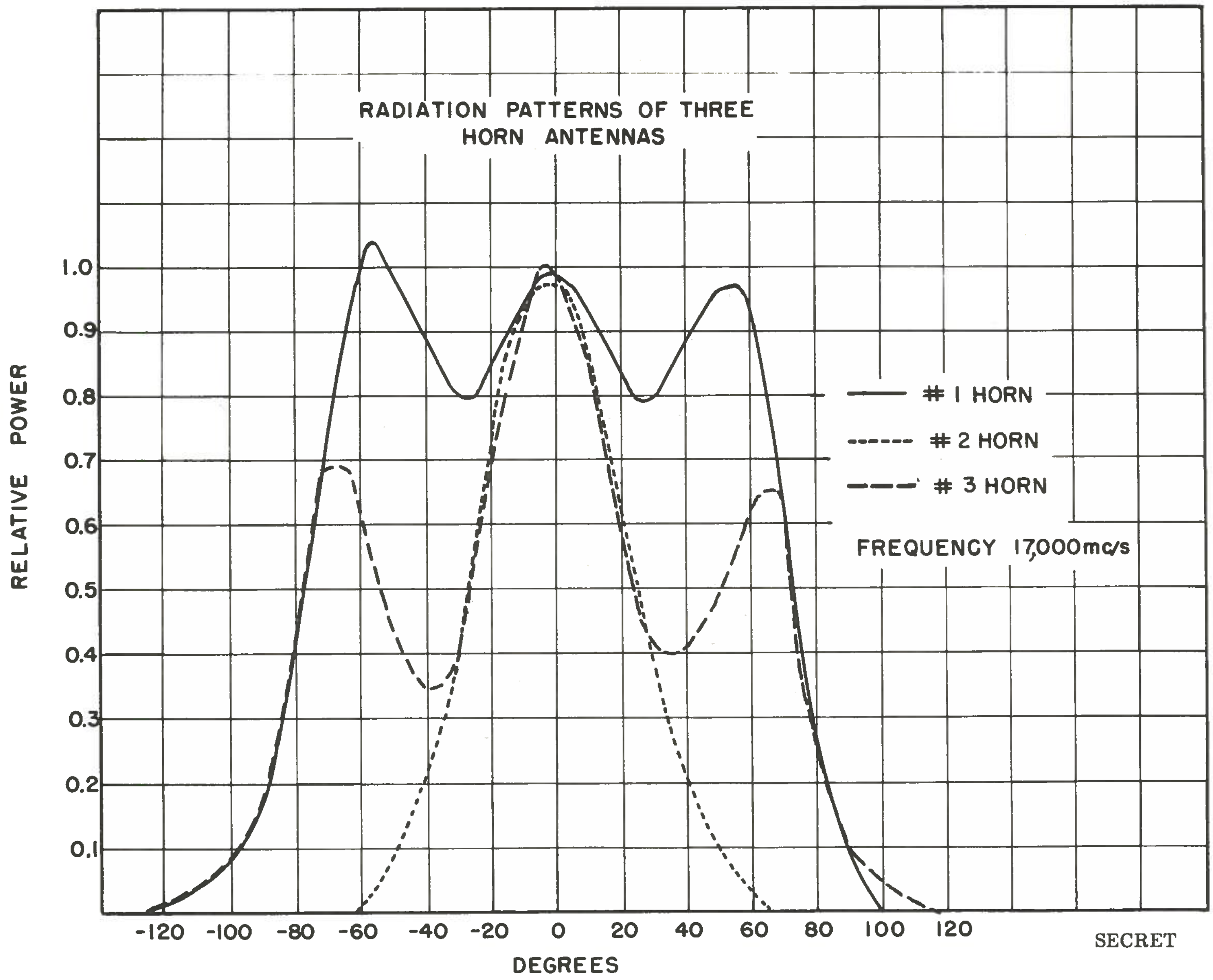
15000 mc/s

BIAS

ADJUSTMENT

1 CHANNEL
OPEN – CIRCUITED

FIGURE 22



SECRET

FIGURE 23

8-ANTENNA DUAL-POLARIZED
KU-BAND ANTENNA SYSTEM

BEARING ERROR CURVE

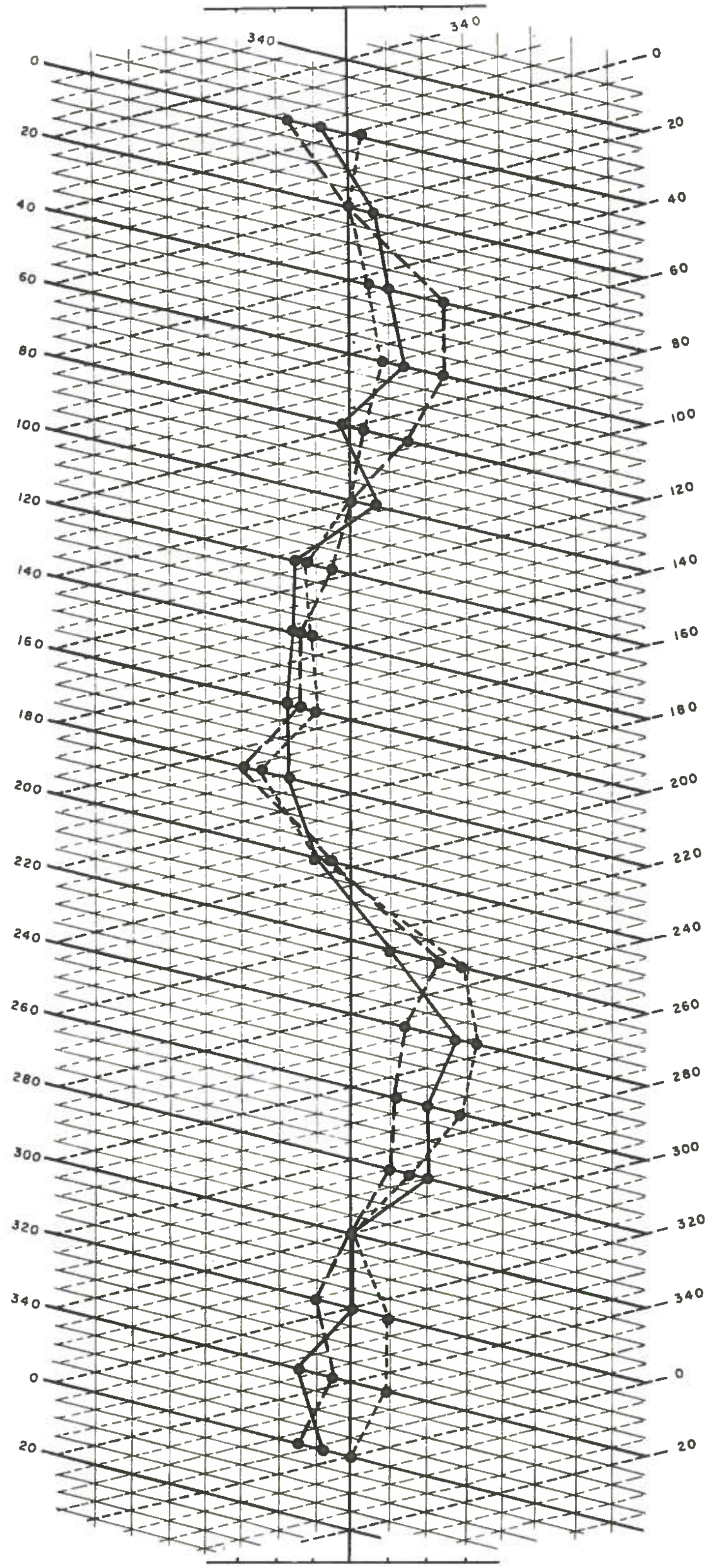
SECRET

DATE DEC. 1 ,1956

№ _____

TRUE BEARING

INDICATED BEARING



TRANSMITTER
TYPE
X-12 KLYSTRON

LOCATION
ROOF
TEST SITE

ANTENNA
HORN
VERTICAL
POLARIZATION

FREQUENCY

17000 mc/s

RECEIVER
TYPE
U. P. D. 501

LOCATION
ROOF
TEST SITE

ANTENNA

BIAS

ADJUSTMENT

—— # 1 HORNS
- - - # 2 HORNS
— — — # 3 HORNS

FIGURE 24