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EXPERIMENTAL EVALUATION OF A 1000-WAVELENGTH ANTENNA

by

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Introduction

The recent demands of space surveillance and space communications have greatly increased the need for very high-gain, narrow-beam antennas. Until recently, this need has been fulfilled by increasing the physical aperture of reflectors operating at wavelengths of 3 cm or longer. However, the higher frequencies of the millimeter band can improve gain and beamwidth with relatively small structures, while simultaneously permitting extremely wide bandwidths, relatively unused spectrum, small size of waveguide components and reduced interference.

Following this reasoning, Lincoln Laboratory initiated a program of millimeter systems development. In conjunction with this effort, a 28-foot diameter antenna, operating at wavelengths of 8.5 mm, has been installed and tested. The reflector was formed by a technique known as "SPINCASTING" by the Kennedy Antenna Division of the Electronic Specialty Corporation.

This report describes the evaluation of the test range and the electrical testing of the antenna at a wavelength of 8.5 mm.

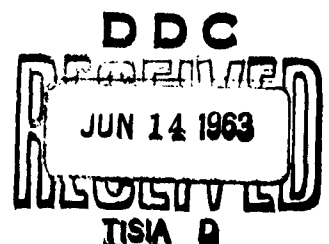
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Test Objectives

The present test series was initiated to determine the electrical characteristics more precisely than had been done in the initial tests performed shortly after installation, and to evaluate the effect of environmental conditions on these characteristics. A series of gain, pattern, and boresight shift measurements was taken to determine the effects of different ambient temperatures, nonuniform solar heating and wind conditions. On a typical daily run, measurements were taken at 1 - 1 1/2 hour intervals beginning before dawn and continuing until the late afternoon. Approximately 15 complete daily runs were made during various weather conditions which included winds up to 25 - 30 mph and ambient temperatures ranging from the mid 30's ($^{\circ}\text{F}$) to the high 80's.

The properties of a test range capable of measuring an antenna with a diameter of 1000 wavelengths poses special problems.⁽¹⁾ Some effects of terrain and propagation phenomena which are negligible in the measurement of antennas with smaller electrical apertures become serious obstacles, whereas in other instances, quite the reverse is true. For the range in question, the directivity of the 28-foot antenna at these frequencies is sufficient to virtually eliminate the influence of ground reflections from the measured patterns. However, these ground reflections can still cause errors in the gain measurement (the method used is comparison with a calibrated standard), and propagation phenomena can cause errors in all the major characteristics of the antenna (gain, patterns and boresight). The propagation phenomena of interest (refraction and signal scintillations), although only vaguely associated with site geometry, are considered as properties of the range.

An investigation of the range to determine the dependence of terrain and propagation effects on wind, sun, temperature, etc., was undertaken with a view towards separating these "range errors" from actual changes in antenna performance caused by the same changing environment.

Mechanical Description

Photographs of the antenna mounted on the roof of one of the Lincoln Laboratory buildings are shown in Fig. 1 and Fig. 2.

The reflector is supported by an aluminum-plate-girder-tangential-beam structure which is shown in Fig. 2. This back-up structure is attached to the mount adapter-stiffener at 6 hexagonally distributed points. The reflecting surface is supported by a total of 24 panels, individually attached to the back-up structure. Each panel is 6" thick and constructed of fiberglass over paper-core honeycomb. The precise spuncast paraboloid is formed over these panels. The actual reflecting surface is a thin flame-sprayed coating of zinc which is then weather protected by a thin coating of plastic. Figure 3 shows a cross section of the reflector construction.

The feed employed is a "rear feed" type supported by an aluminum column attached to the vertex and guyed at the feed end. The guy wires are attached to the extremities of the back-up structure as shown in Fig. 1.

The mount is a manually controlled elevation-over-azimuth type. Both the azimuth and elevation control points are provided with telescopes mounted on the elevation axis and directed through small apertures in the reflecting surface. One telescope is a 4-inch Cassegrainian type used for fine control. Rotation of the mount is limited to 345° in azimuth and from -2° to $+95^{\circ}$ in elevation. A two-speed synchro system provides information for remote readout and for the pattern recorder.

A more detailed mechanical description and an account of the "SPIN-CASTING" technique can be found in References (2) and (3).

Pattern Range

Figure 4 shows a vertical cross section of the test range used in the evaluation program. The transmitting antenna (Billerica) is a 4-foot paraboloid mounted on top of a 130-foot water tower located approximately 31,500 feet from the antenna under test. The power source is a reflex klystron (Varian VA-97) with 20 - 25 milliwatts CW output, remotely controlled with telephone-line relay circuits. The polarization of the transmitting antenna was horizontal throughout the test program.

The intensity with which the transmitter illuminates the terrain is as indicated. The 100 - 150-ft valley between the two sites minimizes the interference pattern observed at the receiving site. This interference pattern is of consequence only to the relatively low-gain standard horn used in the gain measurements. The angular discrimination of the main antenna (3-db beam-width $\approx .06^\circ$) is such as to almost completely discriminate against ground reflections. This is borne out experimentally by the excellent symmetry observed in vertical plane patterns even when the angle of declination is as great as 1° .

The distance separating the two sites is equivalent to $1.15 D^2/\lambda$, and consequently a slight amount of axial defocusing ($\approx 0.2 \lambda$) is required in the main dish to simulate the far-field patterns. (4)

Early in the program the interference pattern at the receiving site was investigated with a probe tower 38-ft high and a standard-gain horn (nominal 25 db) traversing the length of this tower. Numerous runs were taken for incremental changes in the elevation angle of the transmitting antenna, and the envelope of the interference pattern was adjusted to illuminate properly

the 28-ft main antenna. The final angular position of the transmitting antenna was such that the illumination of the 28-ft main antenna was slightly greater on top (i.e., the receiving aperture is located on the lower side of the transmitted beam). The amplitude taper is approximately 1/2 db which has a negligible effect on the pattern measurements. The gain standard is positioned at the mid-point of the vertical aperture so that the taper will not result in an error in the gain measurement.

In that one of our main objectives is to evaluate the effect of changing environmental conditions on the antenna characteristics, the measurement errors caused by an imperfect range take on added importance. The effects of changing propagation conditions over the test site with changing environment must be separated from actual changes in antenna performance. For purposes of analysis, the properties of the range can be separated into three categories which can be related to specific errors in the antenna measurements. These are:

- 1) The interference pattern resulting from ground reflections.
- 2) Refractive effects (angle-of-arrival variations) caused by the changing refractive index with height relationship.
- 3) Signal scintillations associated with atmospheric turbulence, etc.

The Interference Pattern

The measurement of gain by comparing the signal received from the antenna under test with that of a calibrated standard is based on the assumption that both antennas are placed in the same uniform field. Because of its high angular resolution, the main antenna receives only direct radiation from the transmitter (i.e., the free-space field). The signal received by the standard of comparison, however, because of ground reflections depends on its directivity and its vertical position.

A comparison of the interference patterns seen by the standard horn and an 8"-diameter paraboloid is shown in Fig. 5. The half-power beamwidth of the standard horn is approximately 8° as compared to a 3° half-power beamwidth obtained with the 8" dish. It is seen that the interference pattern of the 8" dish shows substantially larger angular separations between peaks and nulls and also much larger intensity variations.

It is well known that microwave propagation over rough terrain is characterized by poor specular reflection and results in a signal intensity near the free space level. ⁽⁵⁾ The integrated effect of a large number of reflected signals with a random phase relationship will alternately reinforce and be in phase opposition with the direct (free-space) field as the height is varied. It follows that the free-space level in relation to the interference pattern seen by the standard horn is the average of the loci of maxima and minima of the interference pattern. The free-space level in relation to the interference pattern seen by the 8" dish is doubtful, and, even if it were known, the error in gain measurement would be 2 db or more depending on the vertical position of the antenna. It is interesting to note that it does not necessarily follow that the error in the gain measurement due to ground reflections is decreased by increasing the directivity of the standard. In fact, if a gain standard directive enough to completely exclude ground reflections is not feasible, the best approach is to employ a very broad-beamed standard. This would include a large area of diffuse reflections and, hence, approach the desired free space condition. The 25-db standard horn was used in all the gain measurements. The error in the gain measurements as a result of interference can be as much as +0.5 db, although it is probably only a fraction of this.

The interference pattern is surprisingly constant. Probe measurements taken intermittently over a period of three months in a variety of environmental conditions showed but negligible changes in the interference pattern.

Refraction

Although we were unable to measure changes in the angle of arrival of the incident signal or at least unable to separate this effect from the beam scan and boresight errors of the system, published accounts of angle-of-arrival measurements suggest that it may give rise to a significant error in the boresight measurements. Reference (6) describes angle-of-arrival measurements taken at a wavelength of 1.25 cm. The test range is a 12.6-mile overland path with an average height of 155 ft above ground level. The results indicate that the angle-of-arrival changes in the horizontal plane are slight, the maximum observed being 1.8 angular minutes. In the vertical plane, however, the variation is from -2.4 minutes to +6.6 minutes relative to the line of sight. The present test range is about half as long (≈ 6 miles) but otherwise similar to the one described. Using the reported results as a rough guide, we are led to conclude that anomalous propagation conditions might cause a number of minutes' variation in the RF angle of arrival. The reported 9-minute variation represents the maximum observed over a 2-month period. Also, the range used was on the New Jersey coast, much closer to the ocean than the present test site, which may result in quite different propagation conditions. In any event, the beamwidth of the antenna under test is only 4.2 minutes; hence, 1 to 2 minutes of boresight error is serious. The possibility of errors this large or larger, as a result of refraction, cannot be overlooked.

Optical refraction is the cause of still more uncertainty in the boresight measurements. Under "normal" conditions optical and electrical refraction on passage through the atmosphere are approximately the same at these frequencies.⁽⁷⁾ Over a short horizontal transmission path the relationship between the variation of optical and electrical refraction is unknown.

Signal Scintillation

Probe tower measurements taken with the 8" dish on a typical daily run are shown in Fig. 6. The central section of these traces (marked descending) corresponds to the field variation over the height of the tower which is the superposition of the interference pattern and the signal scintillation. The regions marked top and bottom show the signal scintillation with the probe antenna held fixed at these positions. The amplitude of these scintillations varies from a negligible amount (before dawn) to approximately ± 0.6 db (early afternoon) with rates on the order of 1 cps. Signal fluctuations of approximately the same rate and amplitude are observed on both the 28-ft main antenna and the broader beamed standard-gain horn. This indicates that the scintillations are independent of ground reflections.

This effect has been reported elsewhere⁽⁸⁾ and is generally attributed to scattering due to atmospheric turbulence. Numerous runs of this type were taken, and it is apparent that the scintillations are negligible when fog is present and that they are generally much more severe in the daylight hours (especially early afternoon) than in the predawn hours.

The period of these fluctuations is comparable to the time required to manually swing the 28-ft antenna through the beam when taking a pattern. As a result, a slight lack of repeatability is noticed when patterns are taken at times of large signal scintillation. Measured sidelobes can be in error by as much as 1 db and beamwidths by some 0.2 minutes of arc.

These scintillations have a negligible effect on the gain measurement as the signal is effectively "averaged" out by rapid switching.

The errors in the antenna measurements which may be attributed to the range are summarized as follows:

Interference Pattern - because of the extreme angular discrimination of the antenna under test, pattern and boresight measurements are unaffected by ground reflections. The interference pattern seen by the relatively broad-beamed standard-gain horn can cause errors only in the gain measurement. The error will not exceed and is probably less than ± 0.5 db.

Refraction - changes in the angle of arrival are of consequence only in the boresight measurements. The amount of error here is not known, although during periods of anomalous propagation conditions it may be large.

Signal Scintillations - These intensity fluctuations affect only the pattern characteristics. At times of high scintillation (usually early afternoon) the measured beamwidths and sidelobes may be in error by .2 minutes and 1 db respectively.

It may seem like an oversimplification to associate the interference pattern exclusively with the gain measurement, refraction exclusively with boresight measurements, and scintillations exclusively with pattern information, but the extreme directivity of the antenna and, to a lesser extent, measurement techniques indicate that this breakdown is quite accurate. In fact, this analysis of measurement errors caused by the test site appears to be generally applicable to the measurement of electrically large apertures.

These discrepancies in the range are not independent of each other; for example, conditions which might cause large refractive effects are certainly related to scintillation. However, the interdependence is of little significance

when identifying each of the three propagation phenomena with a specific antenna characteristic.

References (6) and (12) have reported multiple-path transmission caused by refraction rather than reflection. Two, three, and sometimes more signal components were found to arrive at differing angles in the vertical plane. If such an effect were present on our test site, it would cause serious errors in pattern, gain, and boresight measurements. Fortunately, no evidence of multiple-path transmission has ever been observed.

Gain

The gain measurement is accomplished by the method of direct comparison with a calibrated gain standard. The standard used is a nominal 25-db Microwave Associates pyramidal horn.

The standard horn is mounted on one side of the main reflector and at the mid-point of the vertical aperture. The feed line to the standard is a long waveguide run (~ 26 ft) which is connected to one port of a waveguide switch mounted in the equipment cab just inside the vertex of the antenna. The main feed line consists of a waveguide run of approximately 15 ft and two calibrated attenuators. This line is attached to the second port of the waveguide switch. The function of the attenuators is to reduce the signal in the main line to the level of the signal in the standard horn. The common port of the switch is connected to the receiver and a level meter.

This arrangement enables rapid switching from the main antenna to the standard. Measurement errors as a result of the aforementioned scintillations are effectively averaged out.

Line Losses

A most important part of the gain measurement is the accurate determination of the losses in the main and standard horn feed lines. It was attempted

initially to use a reflex klystron as a source for this measurement. However, a millimeter tube is subject to output power variations with physical handling, ambient temperatures, wind, etc. (The measurement must ultimately be performed outdoors.) This approach was found to be incapable of sufficient accuracy. A 'Tucor' gas-discharge noise source was used as the signal generator. The noise source proved to be unaffected by the above disturbances.

The experimental setup for the loss measurement consists of the noise source and an isolator connected to the extreme end of the line to be measured (i.e., substituted for the standard horn or the main feed, as the case may be). The rear end of the line in question is attached to the receiver. The receiver output is directed through a precise IF attenuator to a level meter.

With the noise source on, the IF attenuator is adjusted to equate this level to that which is obtained with the noise source off. The expression is:

$$T_o + T_m = \left[T_s (1 - L) + T_o L + T_m \right] A$$

where:

L = Fractional loss of the line length in question.

A = Fractional transmission of IF difference attenuation
which is required to equate levels.

T_m = Effective receiver noise temperature.

T_s = Effective source noise temperature.

Solving for L :

$$L = 1 - \left(\frac{1 - A}{A} \right) \frac{\left(\frac{T_m}{T_o} + 1 \right)}{\left(\frac{T_s}{T_o} - 1 \right)}$$

This can be shown to be:

$$L = 1 - \left(\frac{1 - A}{A} \right) \left(\frac{1}{\frac{N_{on}}{N_{off}} - 1} \right)$$

The quantity $\frac{N_{on}}{N_{off}}$ is determined by connecting the source directly to the receiver input terminals. It is then the ratio of the noise power output with the source on and off and can be read directly from the precision IF attenuator.

The result of these measurements shows the standard horn line loss to be 4.7 db and the main line loss to be 2.9 db. The main line loss includes insertion loss of the two calibrated RF attenuators and the waveguide of the pattern receiver. Repeated measurements check to within .1 db.

An alternate method was used to measure the relative attenuation of the two lines. Again, the noise source was connected successively in place of the standard horn and the feed. The calibrated attenuator in the main feed line was adjusted to give equal levels of output from the receiver. The results of this method checked with those of the former to within $\pm .1$ db.

The standard horn, as per the manufacturer's curves, has a gain of 25.05 db at 8.5 mm. The calculated value is 24.61, which should be accurate to $\pm .2$ db. ⁽⁹⁾ Using the more conservative figure of 24.6 db for the standard horn, the measured gain of the main antenna is 67.3 db. This represents an efficiency of $\approx 53\%$.

Considering all the possible causes of error, namely, the interference pattern seen by the horn, line losses, calibration of the rf attenuators, beam alignment, etc., the error could be 1 db or more. It is felt, however, that the above figure is accurate to within $\pm .5$ db.

The gain figure of 67.3 db does not include the losses of the main feed line. This figure is the gain from the feed and is quoted as being an indication of the quality of the reflecting surface. Operationally, the main line losses can be reduced to 1.4 db (measured); hence, the true or operational gain of the antenna is 65.9 db.

Gain measurements were taken during the daily runs to evaluate environmental effects. The previously described extremes of wind, temperature, etc., were encountered. The variation in measured gain was within $\pm .25$ db for 90% of all the readings taken. There was no recognizable trend in this variation which could be identified with time of day, solar heating, wind conditions, etc.

Feed

The feed developed for this antenna⁽¹⁰⁾ is a "rear feed" type consisting of an open-ended circular waveguide operating in its dominant mode (TE_{11}) with a circular reflecting disk positioned approximately 3-1/2 wavelengths in front of the open guide. A small hemispherical radome serves to hold the reflecting disk in position and also provides weather protection. Figure 7 shows the feed in a 4-foot paraboloid. This feed has proven highly satisfactory in that it provides dual polarization capability, wide bandwidths, and nearly equal beamwidths in the principal planes. However, it does have the small disadvantage of not offering a point center of phase.

A similar type of feed with the splash plate in close proximity to the open-ended guide is described in the literature.^(9, 11) This feed behaves more like a ring source rather than a point source, and consequently it is considered not suitable for use with a reflector having a point focus.

The present feed differs from this "ring focus" feed in that the reflecting disk is well into the far-field of the open-ended waveguide. The result is a

configuration which is Cassegrainian in behavior. The hyperboloid degenerates into the flat plane with equal focal lengths. The image is placed at the focal point of the paraboloid.

The phase error with this arrangement is reduced to within tolerable limits. Figure 8 indicates the principal plane patterns taken in a 4-foot paraboloid with the axial setting of the feed such as to optimize the H-plane patterns. The difference between the effective phase centers in the two principal planes is approximately 0.3 wavelengths. The compromise feed setting results in similar principal plane patterns with the sidelobes clearly distinguishable from the main beam (i.e., the sidelobes are not integrated into the main beam as in the E-plane pattern of Figure 8). This slight de-focusing has no appreciable effect on gain or beamwidths.

A more detailed description of the feed can be found in Reference 10.

Patterns

Typical azimuth and elevation plane patterns of the 28-foot antenna with the feed positioned such as to focus the elevation plane patterns are shown in Figure 9. There is a close similarity between these patterns and those taken in the proven 4-foot paraboloid. The amount of de-focusing in the E-plane patterns of both sets is comparable. With the exception of the sidelobe structure in the E-plane, the beamwidths and sidelobes for both antennas check exceptionally well when expressed in terms of λ/D . This is a good indication of the excellent performance of the 28-foot antenna as well as the quality of the test site. In both cases, the difference in axial setting corresponding to the different focal points in the principal planes is approximately 0.3λ .

It is apparent that the inability to obtain perfectly focused patterns in both planes for a single axial setting of the feed is a characteristic of the

feed itself and not the result of a distorted reflecting surface.

Figure 10 shows azimuth and elevation plane patterns with the feed in the compromise position. The main beams of these patterns are almost identical, the only difference in the two being in the sidelobe structure. Patterns showing the far-out sidelobe structure are shown in Fig. 11.

In the pattern measurements described below, which are primarily to determine the effects of solar heating, the axial position of the feed was set at the elevation plane focal point. This was done because the effects of solar heating are more pronounced in the elevation plane (the vertical temperature gradients are larger than the horizontal) and, hence, will be more easily distinguishable if the elevation plane is focused.

Thermocouples were attached to the aluminum backup structure to measure temperature gradients. The results indicate a maximum vertical temperature gradient (in the early afternoon) of approximately 30° F. The horizontal gradient is about half this figure. The antenna is directed almost due north to receive a signal from the transmitter and, consequently, the late summer sun swings across the back of the reflector.

Figure 12 shows the effect of solar heating on the elevation plane pattern. The high asymmetrical sidelobe varies from a level of $17 \frac{1}{2}$ db to a condition of symmetry with both sidelobes at 24 db. The $17 \frac{1}{2}$ -db sidelobe is the maximum experienced in all the patterns taken to evaluate the solar heating effect. On the particular day in question, the sun became obscured in the early afternoon and, as seen in the figure, the pattern reverted back to the predawn condition. A close correlation between asymmetry and solar heating was consistently observed.

The guy wires which support the feed column are attached to the ends of the aluminum girder panels. One result of the higher temperatures on

the top of the backup structure is believed to be a relaxing of tension in the top guy wire. This causes a downward motion of the feed column and an upward scan of the beam. The high asymmetrical sidelobe appears on the proper side of the scanned beam to be identified as the "coma" lobe associated with beam scan. As the beam is scanned off-axis, due to a lateral motion of the feed, the "coma" lobe appears on the axial side of the main beam. The sidelobe variation in Fig. 12 shows the asymmetrical sidelobe high in the predawn pattern and decreasing with solar heating. This "reversed scan" is the result of positioning the feed for best elevation plane focus at a time of maximum thermal gradients (afternoon). The up-and-down designations in the figure refer to the position of the transmitter relative to the peak of the elevation plane pattern.

A relaxing of tension in the top guy wire must certainly be accompanied by some thermal distortion of the upper portion of the reflecting surface which would also result in asymmetry. The obvious approach to determine how much pattern asymmetry is the result of motion of the feed column and how much is the result of reflector distortion would be to measure the beam shift. The pattern asymmetry which would result from reflector distortions would be accompanied by a negligible amount of beam scan. Unfortunately, the accuracy of the boresight shift measurements (described below) is not sufficient for the amount of beam scan involved. Pattern measurements, however, do indicate that the asymmetry due to distortion of the reflecting surface is negligible in comparison to the "coma" lobe.

Consider the case (Fig. 12) where the predawn position of the beam is presumed to be downward and is scanned upward by the effects of solar heating to a condition of symmetry. In view of the excellent patterns obtained with the maximum temperature gradient (symmetrical; well-focused, etc.)

associating the change in sidelobe structure with thermal distortion of the reflecting surface leads to the highly unlikely situation of the surface becoming more paraboloidal as the temperature gradient increases. Further, patterns were taken with the feed position adjusted such that the predawn position of the beam is on axis and is scanned upward with solar heating to an asymmetrical condition. Comparison of the predawn asymmetrical pattern (negligible temperature gradient) of the former with the early afternoon asymmetrical pattern (maximum temperature gradient) of the latter shows them to be mirror images. This is the case with patterns representing equal amounts of scan in opposite directions and can be true only if the asymmetry caused by thermal distortion of the reflector is negligible.

During the initial focusing period, it was found that a lateral displacement of the feed amounting to approximately 1/16" changed the pattern from a condition of symmetry to a typical off-axis pattern with the "coma" lobe at the 17-18 db level. The 1/16" motion of the feed, which has about the same effect as the maximum temperature gradient, corresponds to a beam scan of approximately 1.4 angular minutes.

Figure 13 shows the effect of solar heating on the azimuth patterns. It is seen that the asymmetry is slight. Presumably this is due to:

1. The thermal gradient from left to right (15° - 20° F) is on the order of half the top to bottom gradient.
2. The slight defocusing in the azimuth plane serves to mask asymmetrical effects caused by temperature gradients.

The only consequence of nonuniform solar heating on the radiation patterns is the beam scan in the vertical plane amounting to approximately 1.4 angular minutes. This amount of scan corresponds to the maximum asymmetry observed during the test period although on clear days the "coma" lobe

consistently reaches the 17-18 db level. Thermal distortion of the reflecting surface has a negligible effect on pattern asymmetry relative to the effects of beam scan.

These solar heating effects were observed with the antenna directed almost due north and the late summer sun swinging across the back of the dish.

Ambient Temperatures

Measurements were taken in ambient temperatures which ranged from the mid 30's ($^{\circ}$ F) to the high 80's. No noticeable changes of the electrical characteristics were observed.

It might be mentioned here that the antenna was left unprotected on the roof of one of the Lincoln Laboratory buildings for the winter prior to the present series. Pattern and gain measurements taken before the winter are in close agreement with the present results.

Wind

Measurements were taken during periods when the wind velocity reached 25 mph with gusts of approximately 30 mph. The wind direction varied from the front to the back of the dish. No first-order effects were observed in gain or pattern measurements. The only noticeable effect of the wind was a slight oscillation in the level of the received signal, indicating some vibration in the antenna or more probably in the feed column. This amounted to not more than .2 - .3 db superimposed on the "wind-free" pattern.

Boresight Measurements

The variation in the alignment of the boresight optics and the position of the RF beam as a function of solar heating and wind conditions proved to be most difficult to evaluate. The most significant

contribution to this difficulty is believed to be refractive effects, both the electrical and optical angle-of-arrival or ray path curvature variations.

Seven consecutive daily runs were taken, during which time no adjustments were made on either the feed position or the synchros. The boresight measurements over this period, although not as accurate as might be desired, give some indication of the magnitude of both the electrical and optical refraction encountered.

A total of about 50 measurements was made during these seven daily runs. Each measurement consisted of optical line-of-sight and RF beam position on both azimuth and elevation synchro readouts. The range of variation of these quantities experienced during this measurement period is as follows:

Azimuth:

optical	1/2 - 1 minute
electrical	1 - 1-1/2 minute

Elevation:

optical	3 - 3-1/2 minutes
electrical	3 - 3-1/2 minutes

There is no clear relationship between the relative optical and electrical variations in either plane. Initially, the optical and electrical boresights were aligned parallel and at times during the measurement period they are separated by $\approx 1\text{-}1/2$ minutes in the azimuth plane and more than 2 minutes in the elevation plane. Possible errors in these measurements are: the synchro readout (as much as 1/2 minute), human errors in optical alignment, and errors in aligning the RF beam. Hence, the azimuth-optical variation of 1/2 - 1 minute is about as constant an angle as the system is capable of measuring.

Clearly, there is more variation of both the optical and electrical boresights in the elevation plane. There is no reason to suspect that any of the above sources of error would be more pronounced in the elevation plane over the azimuth plane. The variation of the elevation plane quantities may simply be positional shifts of the entire mount because of flexible mount supports or lack of rigidity of the base. A second possibility is the presence of both optical and RF refraction. References (6) and (12) indicate that angle-of-arrival variations of a number of minutes might be expected. If we assume that the basic accuracy of the mount is adequate, the amount of optical refraction for the period in question would appear to be in the vicinity of 2-3 minutes. The RF refraction is at least the same, probably more. It is thought that an appreciable part of the variation in the elevation plane can be attributed to refraction if it is not the prominent cause.

Another important characteristic to be evaluated is the effect of elevation angle on boresight and patterns. Changes in gravitational loading could give rise to beam scan and pattern distortion. Although actual measurements have not been made, there are indications that boresight and patterns are preserved with elevation angle. The reflector is fabricated while pointing at zenith, and hence, the horizontal position probably represents the "worst case" of gravitational loading. In that the recorded patterns were taken in the horizontal position and show no evidence of pattern distortion, it can be assumed that pattern distortion at the higher elevation angles is slight. The beam can be held to the optical reference to at least a beamwidth, probably better.

Conclusions

It is clear that the antenna performs quite satisfactorily at a wavelength of 8.5 mm. The exceptional aperture efficiency ($\approx 53\%$) and patterns obtained indicate that the reflecting surface is paraboloidal to a high degree of accuracy and retains its shape in the environmental conditions encountered.

The only measured change in electrical characteristics resulting from the wind, non-uniform solar heating and ambient temperatures experienced is a lateral motion of the feed column with non-uniform heating, causing the beam to scan. The amount of scan is less than 1.5 angular minutes. There is no evidence of any significant distortions of the reflecting surface as a result of these environmental conditions.

It was shown that with proper precautions, the test range does not introduce appreciable errors into the gain and pattern measurements. The influence of refraction, however, is believed to appreciably affect the boresight measurements although the amount which might be expected during various weather conditions is not clear.

While there is still some uncertainty in regard to performance at high angles, in addition to the uncertainty in the boresight characteristics, recent radiometric experiments involving optical tracking of celestial sources indicate that the optical control of the beam is quite satisfactory.

Acknowledgements

We take this opportunity to express our appreciation to Mr. J. Freedman and Dr. J. W. Meyer who were not only instrumental in the initial conception of the project, but whose continued interest and support has made this work possible.

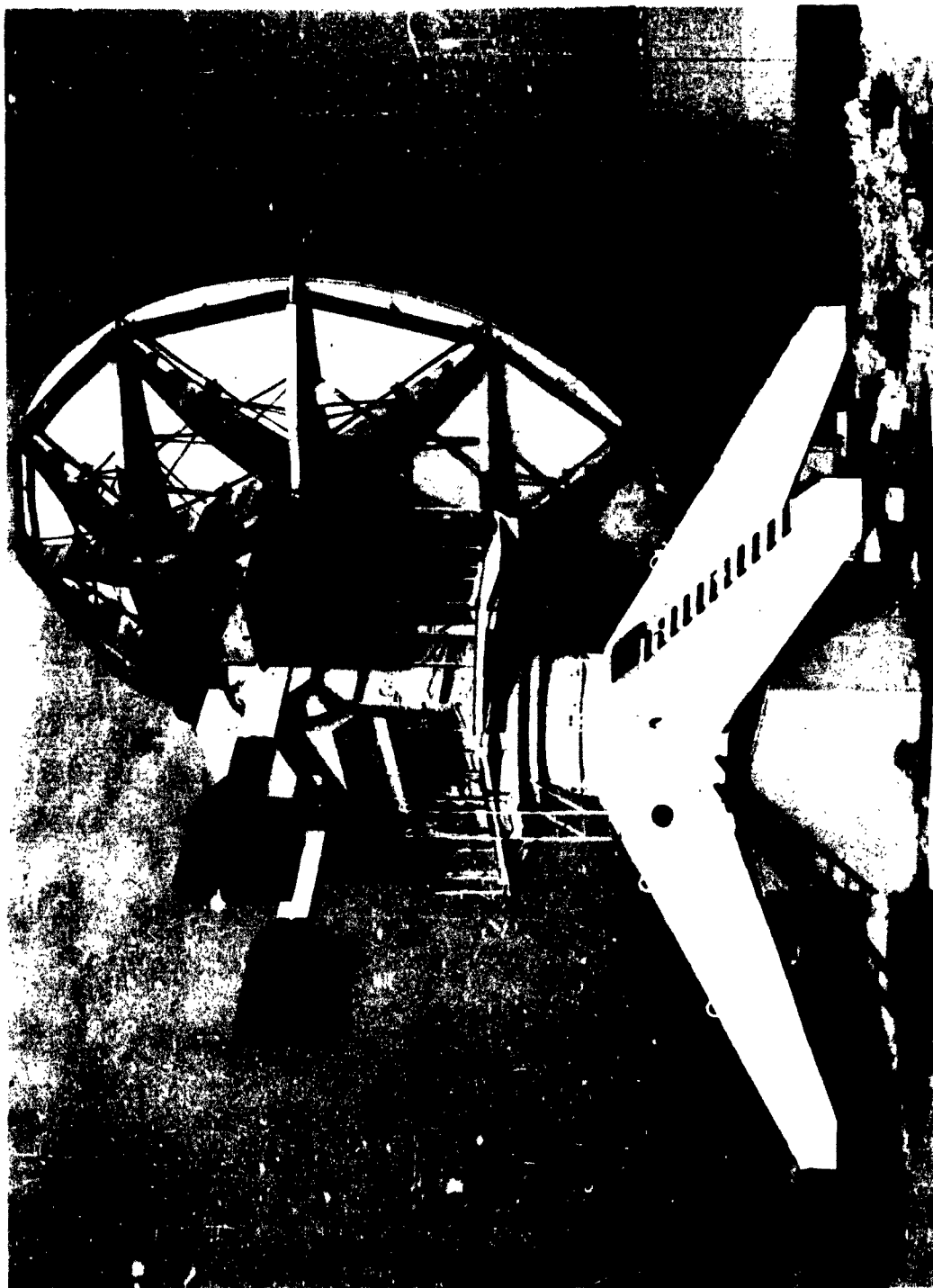


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28-Foot Millimeter Antenna

Front View

Figure 1



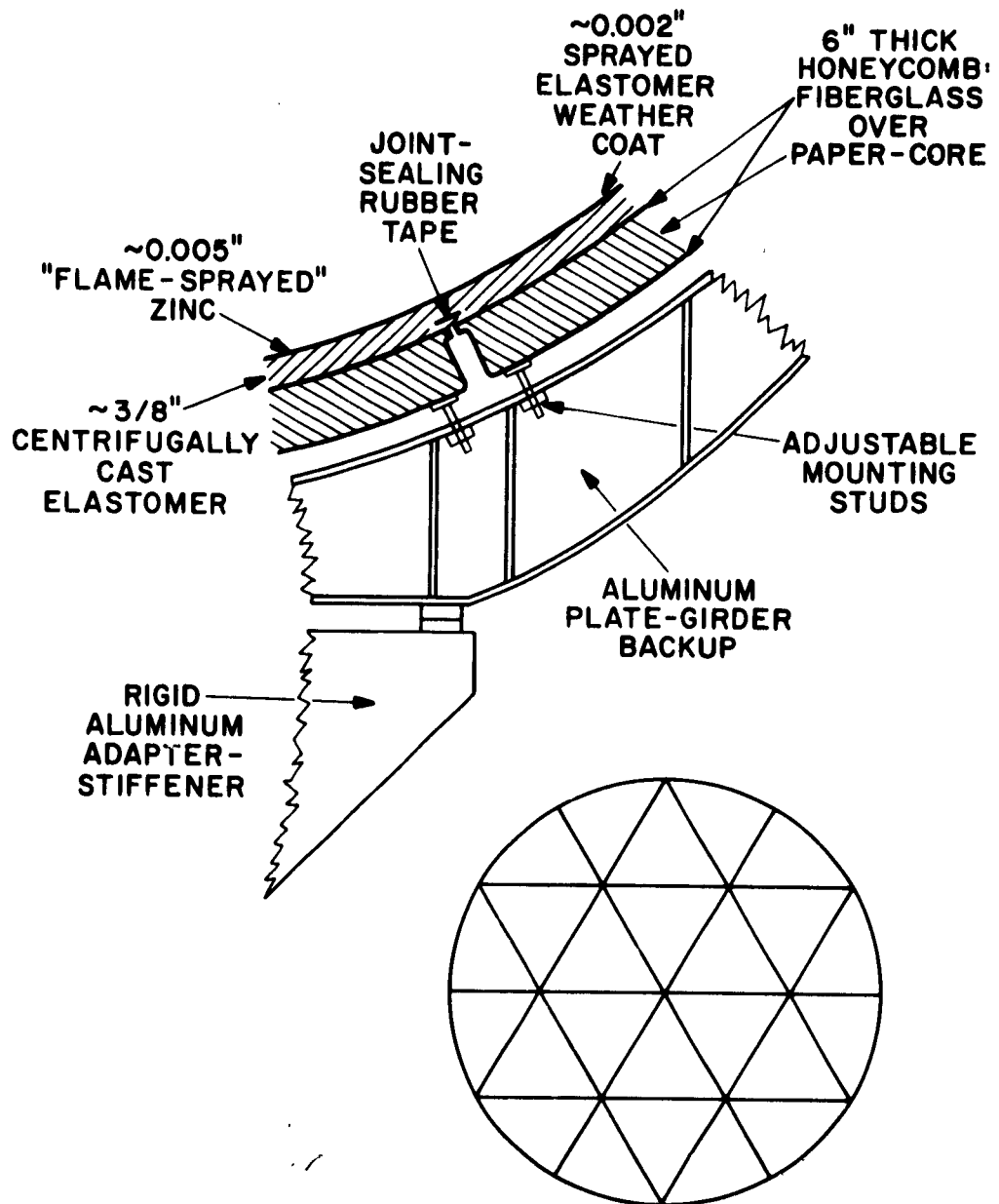
28-Foot Millimeter Antenna

Rear View

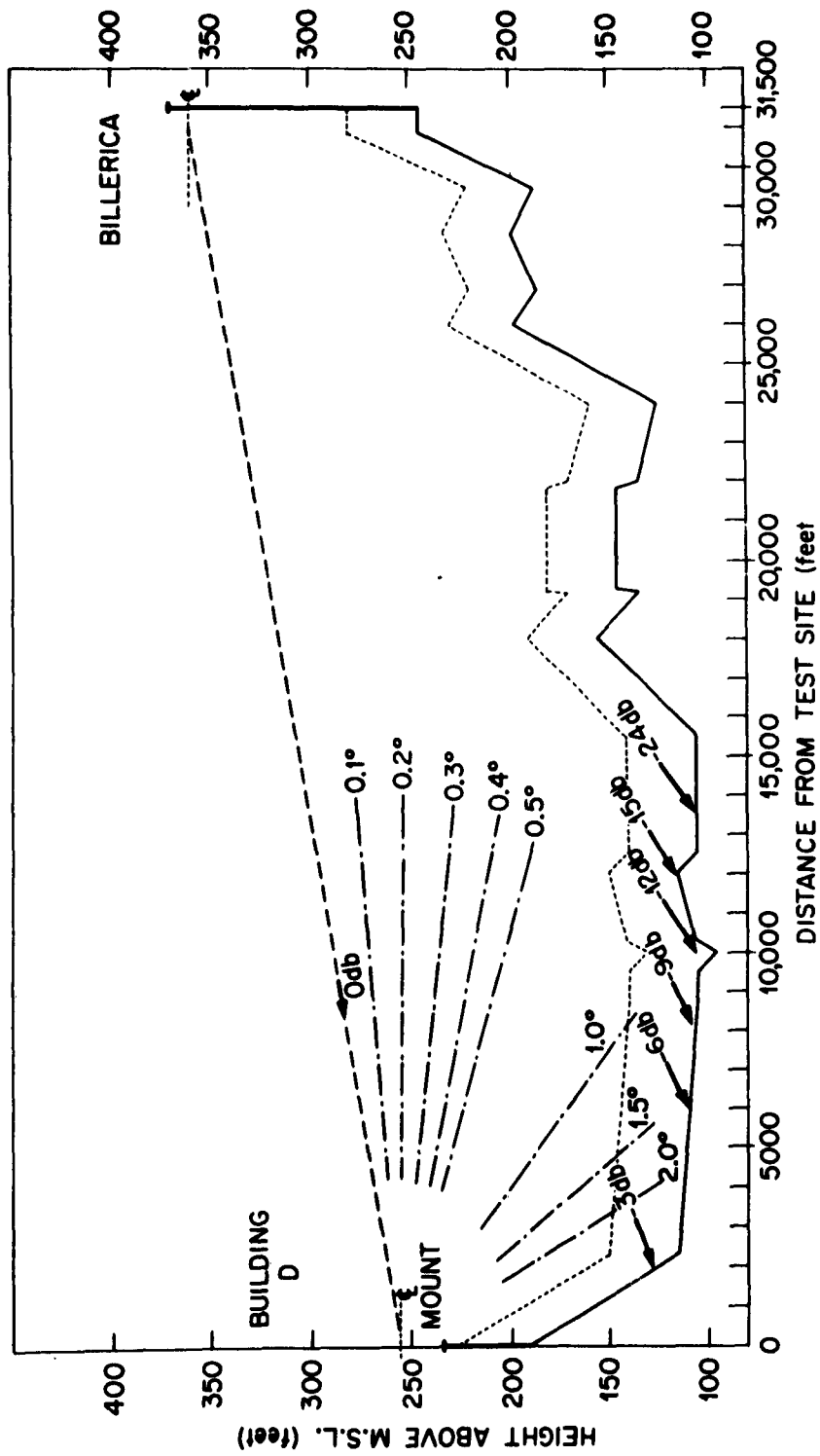
Figure 2

P67-100

CROSS-SECTION OF ANTENNA STRUCTURE (NOT TO SCALE)



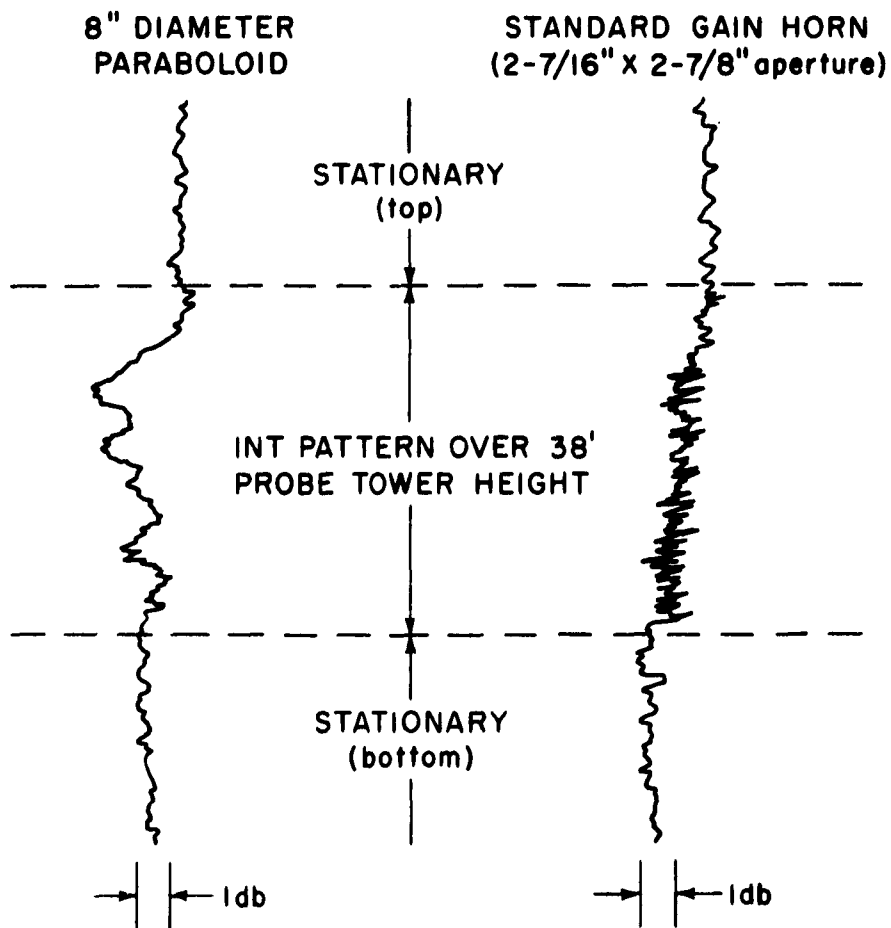
BASIC GEOMETRY OF PANELS AND BACKUP



Topology of Pattern Range

Figure 4

3-46-6036



Comparison of Interference Patterns

Figure 5

SEPTEMBER 14, 1962

RECEIVING ANTENNA - 8" dia. PARABOLA

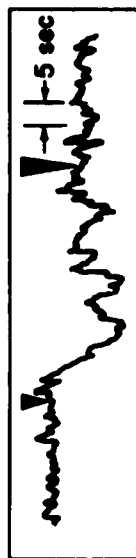


TIME: 0600

WEATHER: GROUND FOG

TIME: 0840

WEATHER: OVERCAST



TIME: 1030

WEATHER: OVERCAST OCCASIONAL
HAZY SUNLIGHT

TIME: 1200

WEATHER: CLEAR
SLIGHT HAZE



TIME: 1330

WEATHER: CLEAR - SLIGHT HAZE

TIME: 1500

WEATHER: CLEAR - SLIGHT HAZE

PROBE TOWER MEASUREMENTS

046-495

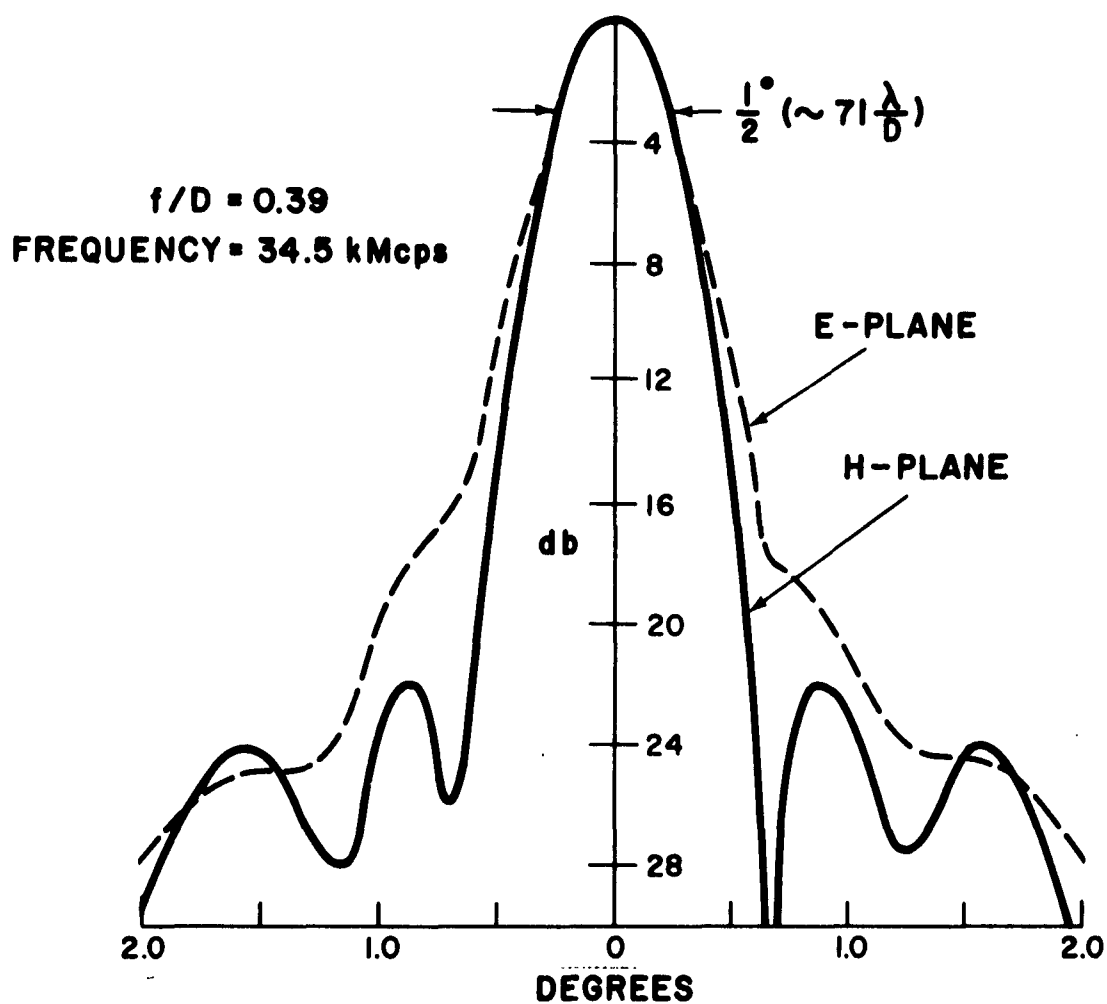
Figure 6



P67-44

Modified Cassegrain Feed in 4-foot Paraboloid

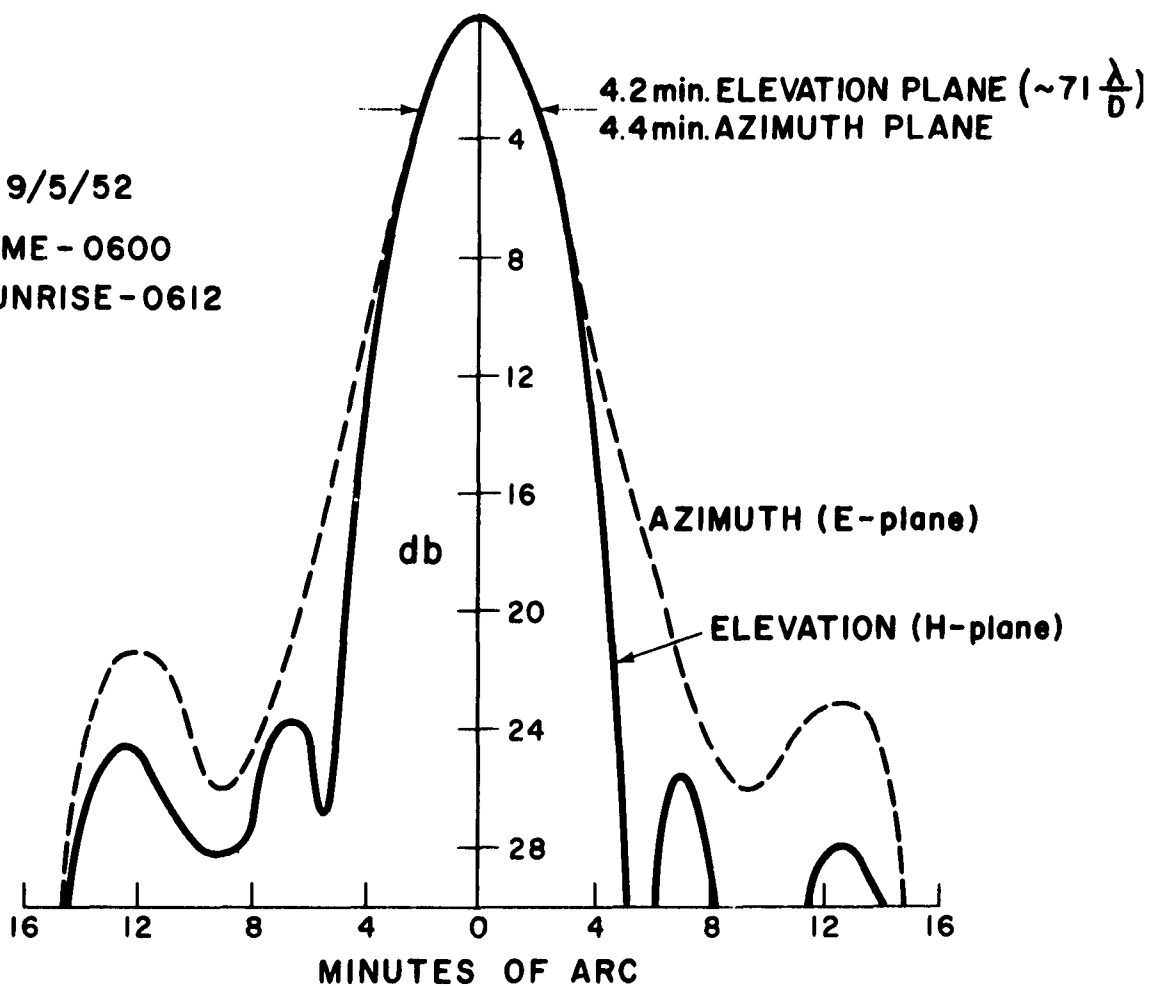
Figure 7



MODIFIED CASSEGRAIN FEED WITH 4-FOOT PARABOLA

Figure 8

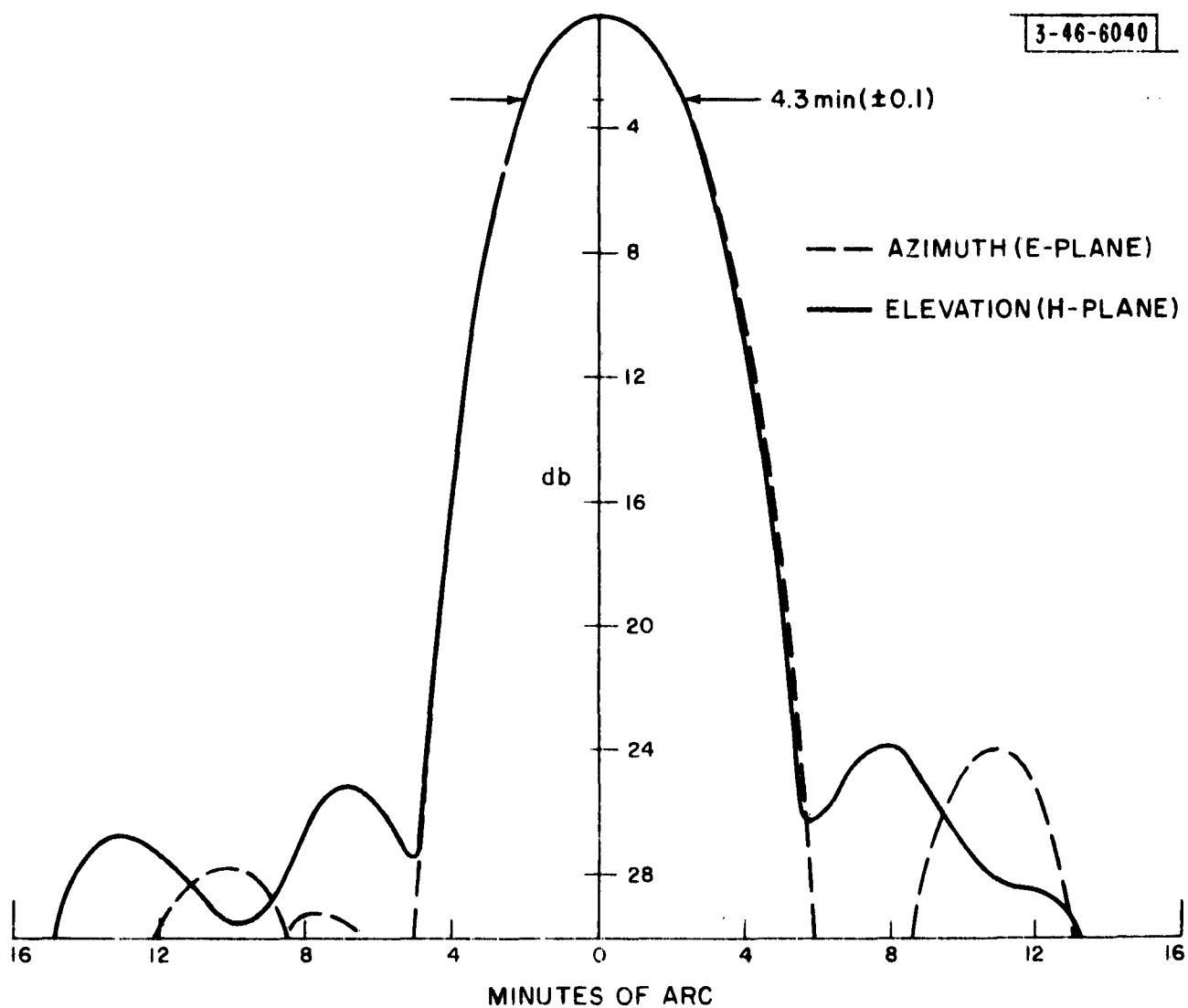
9/5/52
TIME - 0600
SUNRISE - 0612



TYPICAL AZIMUTH AND ELEVATION PATTERNS
WITH ELEVATION PLANE FOCUSED

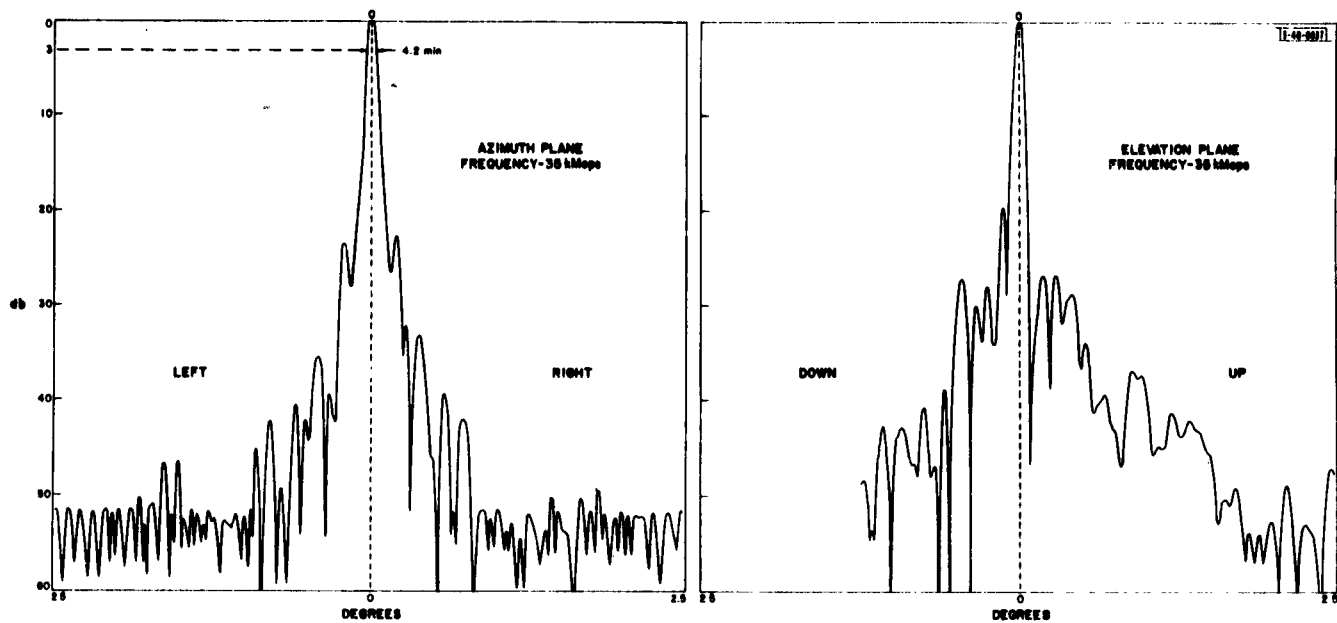
(146-494

Figure 9



Azimuth and Elevation Plane Patterns with Feed in Compromise Position

Figure 10



Azimuth and Elevation Plane Patterns

Figure 11

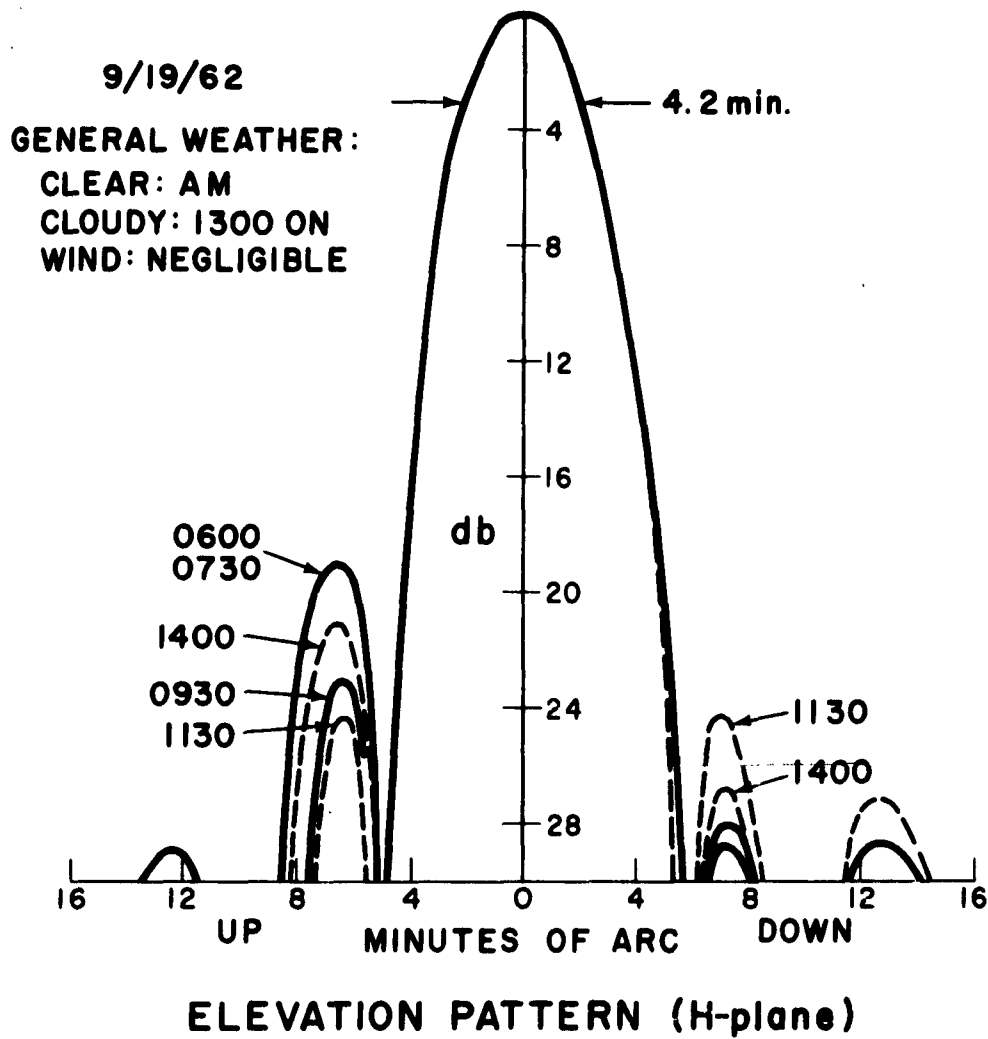
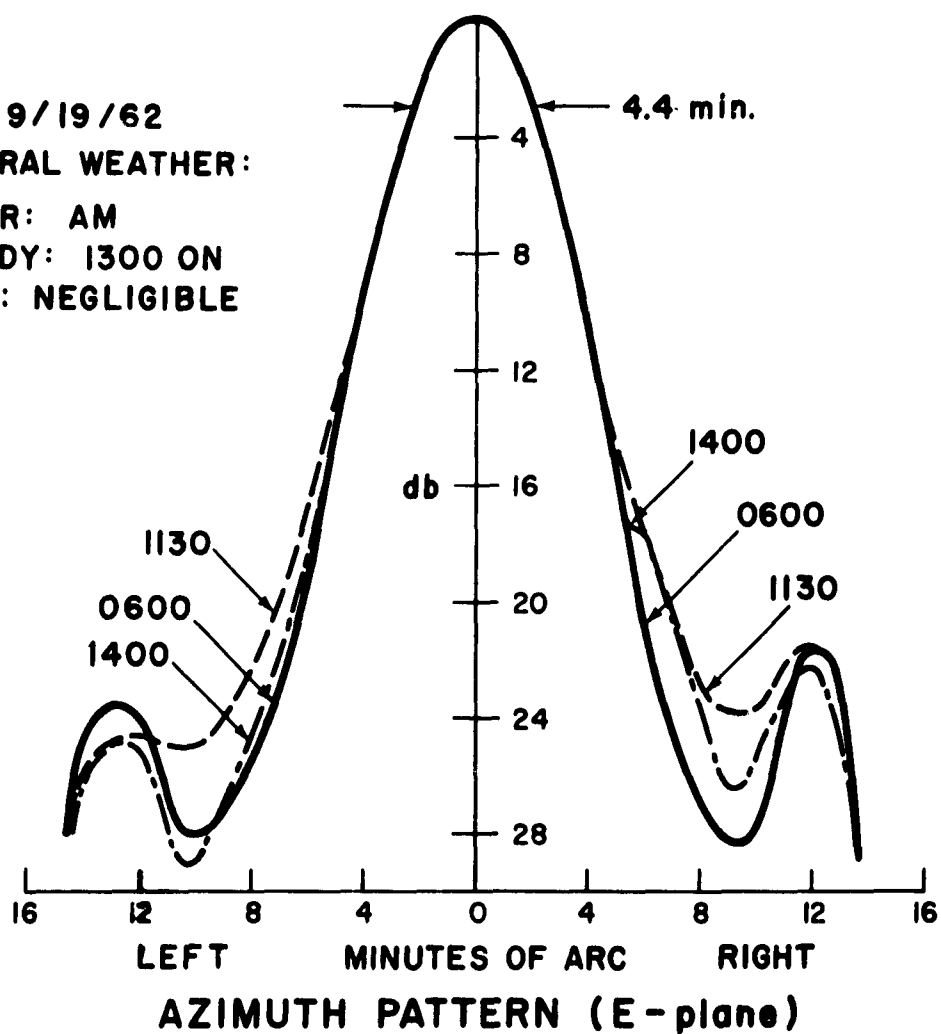


Figure 12

C46-491

9/19/62
GENERAL WEATHER:
CLEAR: AM
CLOUDY: 1300 ON
WIND: NEGLIGIBLE



046-492

Figure 13

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