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RESULTS OF TESTS ON THE AN/FPS-6 ANTENNA UNDER THE CW-396A RADOME

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OTTAWA

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ABSTRACT

An AN/FPS-6 antenna has been tested under a CW-396A radome, primarily to locate and measure off-axis scattered radiation produced by the radome. Two sets of side lobes have been found, lying in planes located ± 60° from the vertical. The largest of the side lobes is 22 db below the main beam in amplitude. These side lobes are produced by energy scattered from flanges which run at angles of ± 30° from the vertical. A third, but much smaller set of side lobes is located on the vertical plane.

Transmission tests indicate an average one-way loss of 1 db. This is twice that previously reported.

VSWR measurements show a variation ranging from 1.04 to 1.10, while the VSWR of the antenna alone is 1.08.

The maximum vertical boresight error was measured to be 0.23 milliradian.

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RESULTS OF TESTS ON THE AN/FPS-6 ANTENNA UNDER THE CW-396A RADOME

- W. Lavrench -

INTRODUCTION

When the CW-396A radomes were installed over AN/FPS-6 radars, some of the sites experienced a serious increase in ground clutter. In some cases the interference extended out to 50 or 60 miles and up to 60,000 feet. The geometry of the CW-396A radome, shown in Plate I is very uniform; three distinct sets of parallel lines are formed by the panel flanges and stiffeners. From past experience it was known that new side lobes could be formed by such parallel and equidistant discontinuities. It was thus felt that a new design with a much more random geometry would be useful.

If a prototype is built it will be subjected to a full set of electrical tests on our test range over an AN/FPS-6 antenna. The CW-396A radome has been tested elsewhere [1,2]; however, it was felt that more valid comparisons of the electrical properties of the two radomes could be made if the CW-396A radome were also tested at the same NRC site. Personnel from Rome Air Development Center, USAF, are very interested in this project, and it was arranged through their organization to borrow a CW-396A radome. The AN/FPS-6 antenna, which has been used here for previous tests, was also made available to us by RADC.

The main purpose of the random geometry is to avoid the formation of scatter side lobes. The CW-396A radome, as pointed out earlier, has three sets of parallel lines, and thus three sets of scatter side lobes were thought to exist. These side lobes were expected to lie along axes perpendicular to the lines in the radome. One of these sets of side lobes should lie on a vertical axis, and this set was shown in data taken at RADC [2]. Only principal plane patterns were taken at that time, and the other two sets of side lobes were not located.

In order to locate these side lobes extensive off-axis patterns were planned. This was the prime reason for testing the CW-396A radome; however, because the radome was to be available to us for several months, transmission, VSWR, and boresight tests were also planned.

TRANSMISSION TESTS

Radomes of this size (55 feet in major diameter) are tested in this Division by erecting two-thirds of the radome on a circular track, and then rotating it about the antenna to obtain measurements "with" and "without" the radome. (For a description of this test site see NRC Report ERB-507.)

Transmission tests are made by plotting the signal received from a distant transmitter as portions of the radome and the open section pass in front of the test antenna. Fig. 1 is a typical field-strength plot obtained in such a test. The three large dips in transmission efficiency are caused by three metal supports which are required when only a portion of a radome is erected, and these dips are to be ignored. The remainder of the plot shows a steady received signal when the open section is moving in front of the antenna, and a reduced, fluctuating signal when portions of the radome are in front of it. The loss in signal is 9% to 13%, or an average of 11% (1 db). This value is twice as large as that which had been accepted previously for this radome.

Transmission tests were repeated several times on different days. Each time the same result was obtained. Immediately before each transmission test, a system calibration was made to check the recorder.

There is a pronounced 18-degree period in the transmission plot. The basic geometry of the radome (icosahedron) repeats five times; that is, the basic pattern covers 72°. Examination of the radome itself shows that in each 72-degree segment there are four vertical rows of hubs, thereby producing a smaller pattern with an 18-degree separation. It was at first believed that this was the explanation for the 18-degree period in the transmission plot; however, by considering the amount of material and its distribution at the hub, it is very difficult to account for the magnitude of the variation in transmission.

The radome consists of diamond-shaped panels which have stiffeners bonded along the short diagonals, and at first glance the radome appears to consist of triangles. These discontinuities at the panel flanges scatter energy and account for a large part of the transmission loss. If the structure is considered as consisting of triangular panels, no explanation for the 18-degree period in transmission loss can be found.

Further examination of the radome shows that there is considerably more material at the panel flanges than at the stiffeners, and that the scattering from the latter can be ignored. Viewed in this manner, the radome consists of diamond-shaped panels, and since the antenna in question is quite narrow (7.5 feet) there are times when essentially only horizontal flanges are situated in front of the vertical center line of the antenna, and other times when flanges at ±30° from the vertical are in front. Tests elsewhere [3] indicate that the amount of scattering from flanges which are parallel to the polarization (vertical in this case) is about twice the scattering obtained from flanges perpendicular to the polarization. This was verified when scatter side lobes were being measured. When only the diamond configuration of flanges is considered, there is an 18-degree pattern in the radome geometry, and this then is almost certainly the cause of the fluctuations in transmission.

REFLECTION MEASUREMENTS

Reflections from the radome wall, which are received by the antenna, were monitored by a directional coupler mounted at the back of the feed horn. The signal from the directional coupler was plotted as the radome was rotated about the antenna. The plot so obtained is a measure of reflection coefficient, but can be readily converted to give the VSWR of the antenna. The recorder is first calibrated in two steps. First, a flat load is substituted for the AN/FPS-6 antenna, and tuning screws at the directional coupler are adjusted to give a zero reflected signal. This step makes it unnecessary to have a perfect directional coupler, as any reflections or inadequate directivity in the coupler are compensated for by the tuning screws. Next, a short circuit is connected to the directional coupler. This provides a reflection coefficient of one, and the recorder gain is adjusted to place the pen at full scale on the plotting chart. The antenna under test is next connected to the directional coupler, at which time the output signal is increased by 20 db. This final step places a reflection coefficient of 0.1 at full scale.

It was anticipated that some reflections would be received from the test stand and nearby trees when the elevation angle of the AN/FPS-6 antenna was near zero. A preliminary plot of reflection coefficient was made by positioning the open section of the radome in front of the antenna and scanning the antenna in a vertical plane. Fig. 2 shows the plot obtained. It can be seen that over an elevation angle from -2° to 0° there are indeed reflections picked up by the antenna, whereas above 0° no reflections are evident. It is possible that at angles above 0°, a reflection of constant phase and amplitude is received by the antenna, but this is very unlikely.

Reflections from the radome were plotted with the antenna positioned at intervals of 5° in elevation, ranging from 0° to 30°. These plots are shown in Fig. 3. The VSWR of the antenna alone was found to be 1.08. With the radome wall in front, the VSWR varied between 1.04 and 1.10.

BORESIGHT ERRORS

While boresight errors of this radome-antenna combination were not of immediate interest, measurements were made nevertheless.

The AN/FPS-6 antenna was modified by the addition of a dual horn to simulate an amplitude-comparison monopulse system in elevation. Signals received by the two horns from a distant transmitter are individually detected, and then one is subtracted from the other. This provides a zero output on the electrical axis of the antenna.

A shift of the antenna beams in elevation increases the output from one horn and reduces that of the other. The difference is now no longer zero and has a polarity determined by the direction of beamshift. The system is calibrated by either of two methods. One method consists of moving the distant transmitting antenna along a vertical track, and noting the recorder pen deflection. The other consists of rotating the AN/FPS-6 antenna in elevation and noting the deflection. Both methods were used and very good agreement was obtained. The first one is far easier to perform and is usually employed.

As the initial elevation setting is determined by the height of the distant transmitter, only one boresight plot can be made. The results of such a test are shown in Fig. 4. As the open section of the radome moves in front of the antenna, there is very little fluctuation in the plotted signal; however, when portions of the radome are in front, the received signal varies, indicating that the beams are shifting in elevation.

The maximum beamshift from the free space position is 0.23 milliradian. If only fluctuations about a mean value are considered, the boresight variation is ±0.16 milliradian.

ANTENNA PATTERNS

This part of the test was by far the most important. Previous antenna pattern tests [1,2] were made only on the principal axes and showed small scatter side lobes which did not account for the amount of interference experienced at the actual radar sites. It was therefore necessary that a large number of off-axis patterns be plotted to locate and measure the off-axis scattered energy. The matter is further complicated because there are many different radome-antenna orientations possible, even in the basic radome pattern of 72°. Fig. 5 shows the layout of a triangle from the icosahedron on which the radome is based. All hubs, flange joints, and panel stiffeners have been marked. Also shown is the width of the antenna to the same scale. It can be seen that there are four different rows of hubs and four different inter-hub spaces. Hub row No. 4 is a mirror image of row No. 2, and the inter-hub spaces C and D are mirror images of B and A, respectively. However, the antenna is not symmetrical about a vertical axis, and all rows and spaces were considered as being different.

In order to minimize the number of off-axis patterns which would be required without losing any important information, several exploratory patterns were plotted. Normal elevation patterns were plotted with each of the hub rows and inter-hub spaces in front of the antenna center line. Examination of the results showed that:

1) patterns through rows 2 and 4 were similar,
2) patterns through spaces A and D were similar, and
3) patterns through spaces B and C were similar.

The worst case of scatter side lobes occurred when the antenna was looking through row 3. This is not too surprising because at this position the large triangle above the one shown (XYZ) provides a continuation of the periodic pattern found in row 3. About one-third of the antenna extends above line XY. On the other hand, when row 1 is in front of the antenna, two large triangles meet above point X and the geometric pattern is quite different from the pattern found below point X. This then produces scattering of a more random nature, and thereby smaller scatter side lobes. In retrospect, it must be admitted that the existence of bad scatter lobes in the vertical plane in no way guarantees bad scatter lobes in any other plane. This is so, because each set of lobes is produced by a separate set of panel flanges. However, since row 3 contains a maximum number of inclined flanges and a regular geometric pattern exists over the full antenna aperture, it was considered that this position produced the worst scatter lobes in the inclined planes.

All subsequent off-axis patterns were plotted with row 3 in front of the center line of the antenna.

The search for off-axis scatter side lobes was carried out in the following manner. A normal elevation pattern through the peak of the main beam was first plotted. The AN/FPS-6 antenna was then rotated 1° in azimuth and another elevation pattern was plotted. This procedure was repeated every 1° in azimuth for a total swing of 40° (20° on each side of the main beam). Each pattern covered an elevation angle of 20°. Only the space below the main beam was investigated, since the antenna would have to be pointed into the ground to explore the region above the beam. This is neither advisable nor mechanically feasible.

The resultant 41 patterns contain a great deal of information, but do not facilitate rapid assessment of the results. It is believed that the best way to present the information is in the form of a three-dimensional model. Each of the patterns was traced on a sheet of cardboard and the cardboard cut along the plotted line. Forty-one saw-cuts were made in a sheet of plywood, one-half inch apart, and the cardboard cutouts placed in the slots in proper sequence, with zero signal level flush with the top of the plywood. A one-half inch spacing was used because the original scale in the elevation pattern was $\frac{1}{2}'' = 1°$. The spaces between the cardboard were filled with plasticene to give a best fit at the cardboard edges and the whole model was given a spray coat of flat white paint. Plate II(a) is the finished model. The height of the pattern above the base is proportional to field strength. The main beam has been cut off at the 10% (-20 db) level.

As expected, two families of side lobes are situated in planes which are ±30° from the horizontal axis. These side lobes are produced by energy scattered by the panel flanges situated at angles of ±60° from the horizontal axis. A horizontal set of flanges produces a considerably smaller set of side lobes, thereby indicating that scatter from flanges at right angles to the polarization (vertical in this case) is much less than from flanges which lie near the plane of polarization. The largest of the scatter side lobes is 22 db below the peak of the main beam. The spacing of the side lobe is about 4°, which correlates quite well with the flange spacing.

It is thus evident that when the antenna is tilted back, to place the main beam 5° to 10° above the horizon, there are several sizable lobes hitting the ground.

A further set of 41 off-axis patterns was plotted with the antenna looking through the open section of the radome. A three-dimensional model of the result is shown in Plate II(b). It can be seen that very little radiation appears off the axes.

One further test was made on the scatter side lobes. The polarization of the radiation from the antenna is vertical, whereas the flanges which produce the large scatter side lobes are ±30° from vertical; therefore, there was some question as to the actual polarization of the side lobes. To resolve this problem, the AN/FPS-6 antenna was positioned so that one of the side lobes pointed at the receiver. The receiving antenna was next rotated about the line-of-sight and the received signal monitored. It was found that the scattering was also vertically polarized.

CONCLUSION

The most significant portion of this work has been the location and measurement of off-axis side lobes which heretofore had not been plotted, but whose existence was almost a certainty. It is very likely indeed that these side lobes are responsible for the increase in ground clutter observed on many operational sites when a CW-396A radome is placed over an AN/FPS-6 antenna. The results obtained point out quite definitely that a radome with a geometry of parallel equidistant flanges is to be avoided.

A byproduct of the testing has been the discovery that the transmission loss is higher than was formerly believed.

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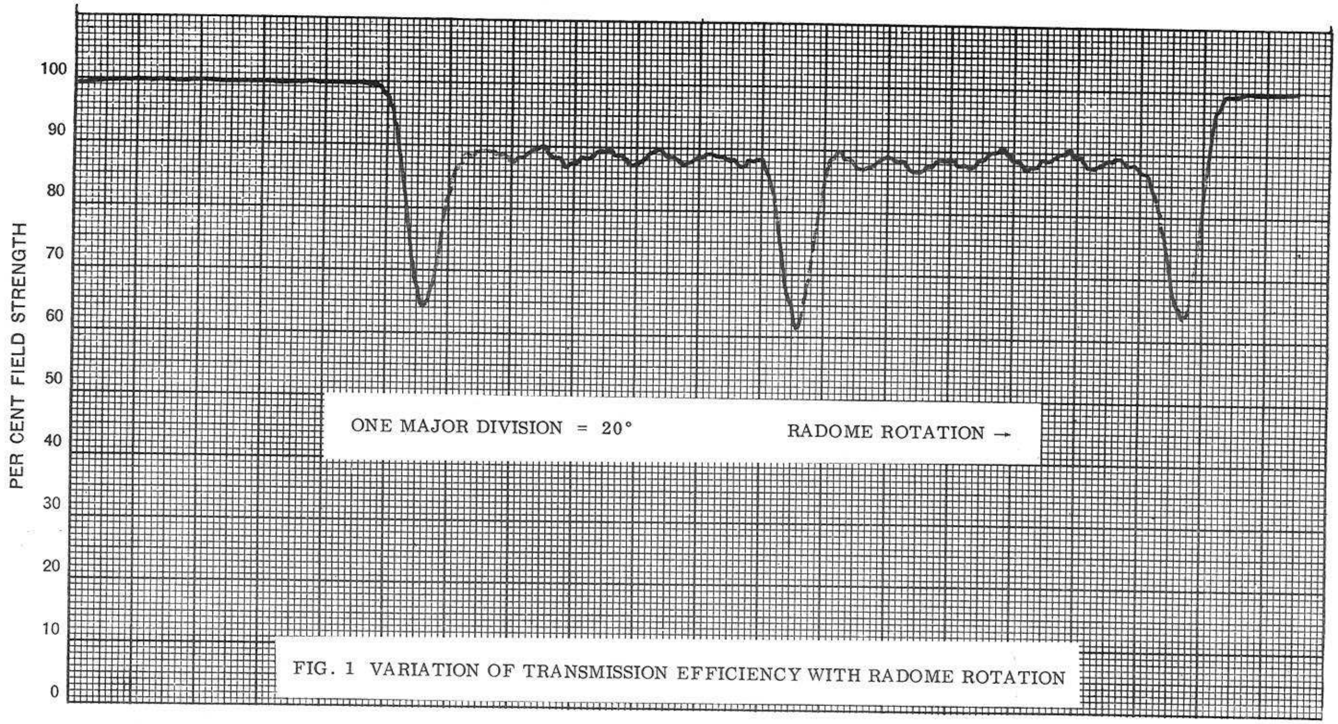


FIG. 1 VARIATION OF TRANSMISSION EFFICIENCY WITH RADOME ROTATION

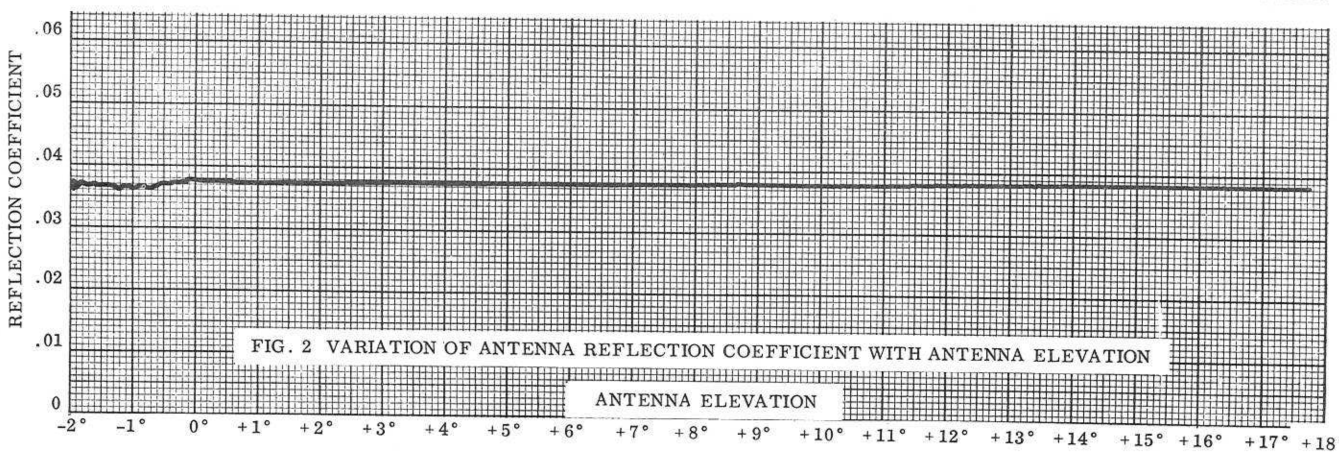


FIG. 2 VARIATION OF ANTENNA REFLECTION COEFFICIENT WITH ANTENNA ELEVATION

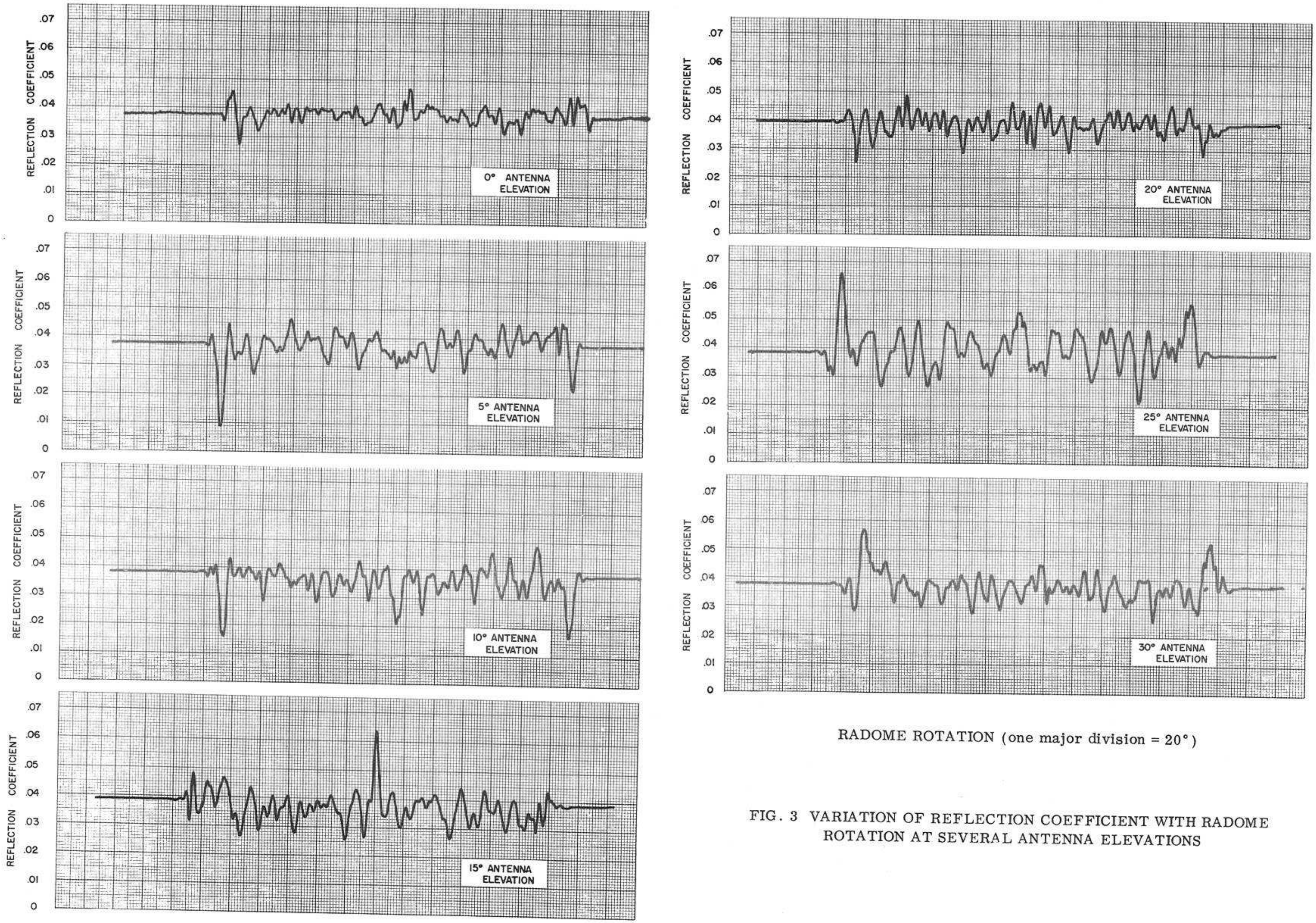


FIG. 3 VARIATION OF REFLECTION COEFFICIENT WITH RADOME ROTATION AT SEVERAL ANTENNA ELEVATIONS

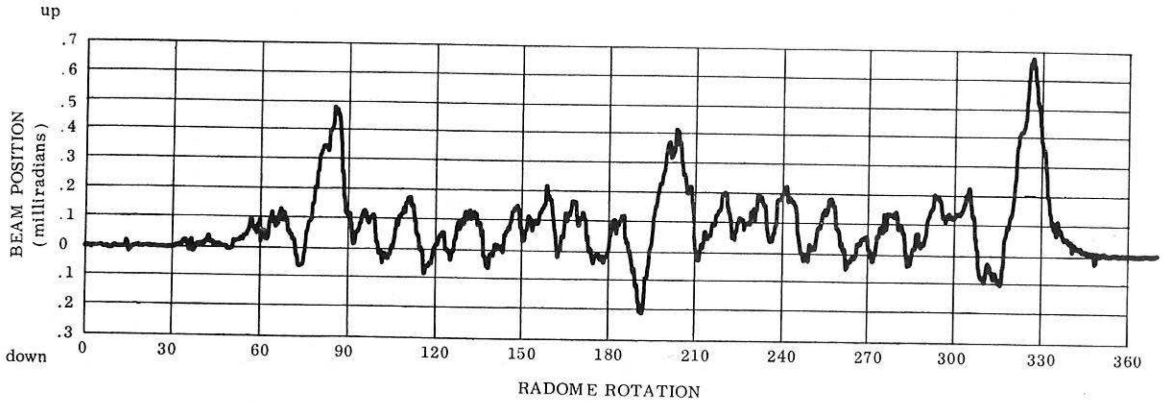


FIG. 4 VARIATION OF VERTICAL BORESIGHT ERROR WITH RADOME ROTATION

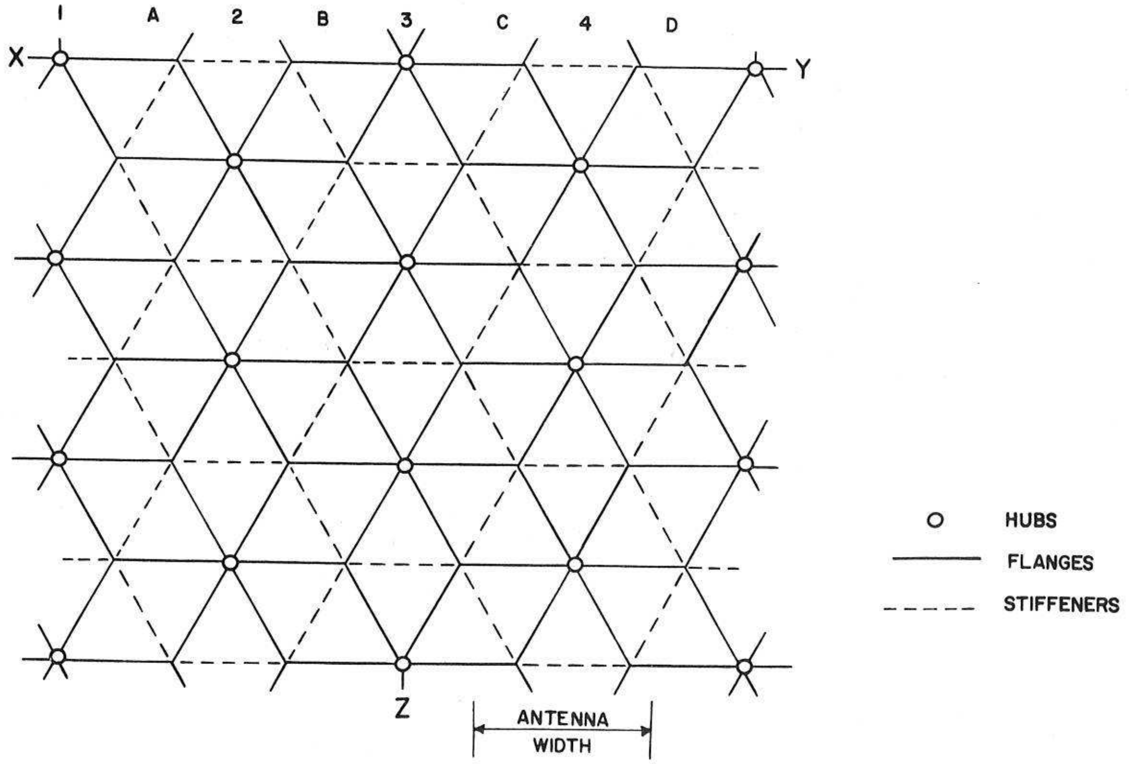


FIG. 5 PANEL GEOMETRY OF CW-396A RADOME

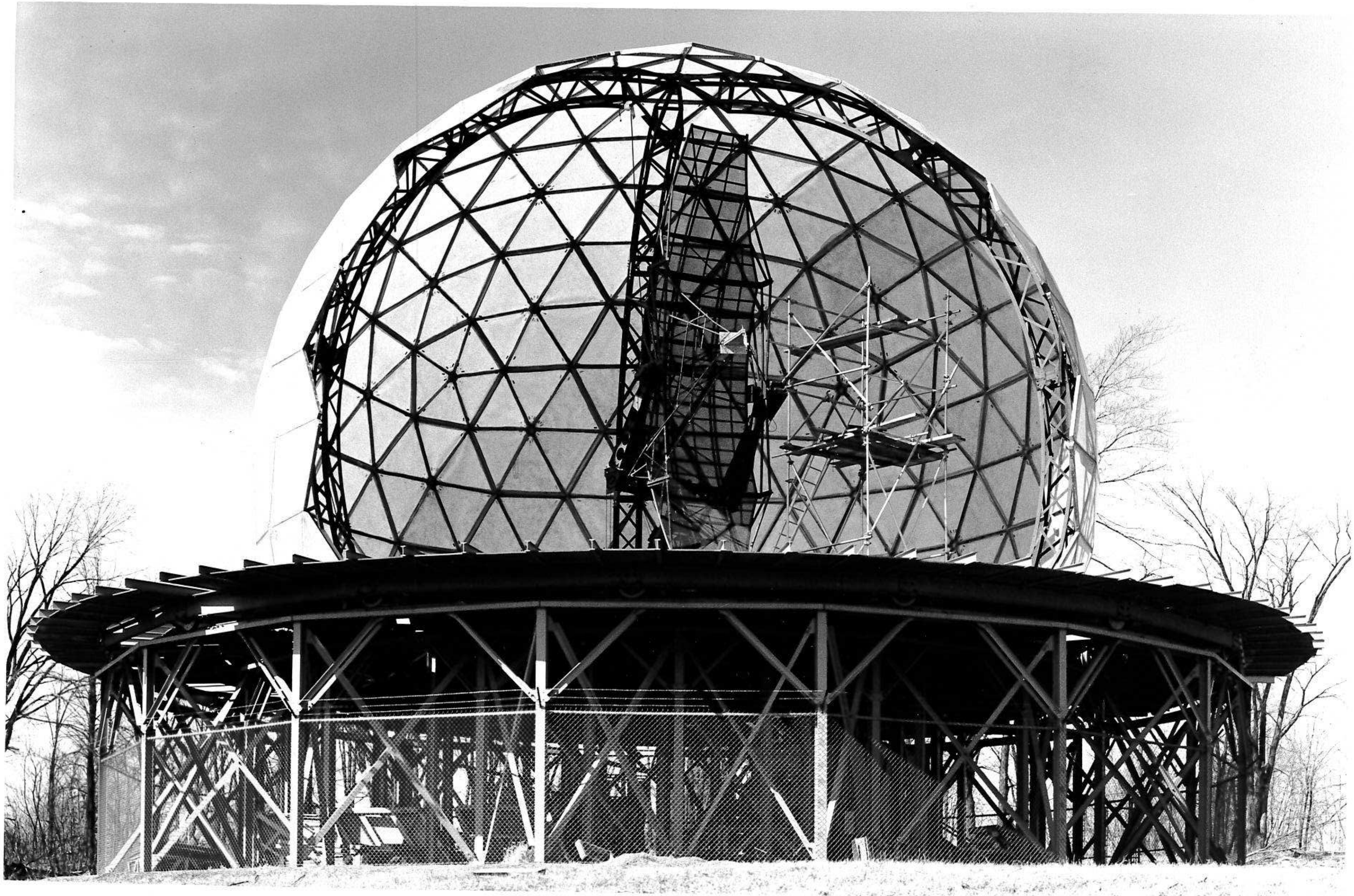
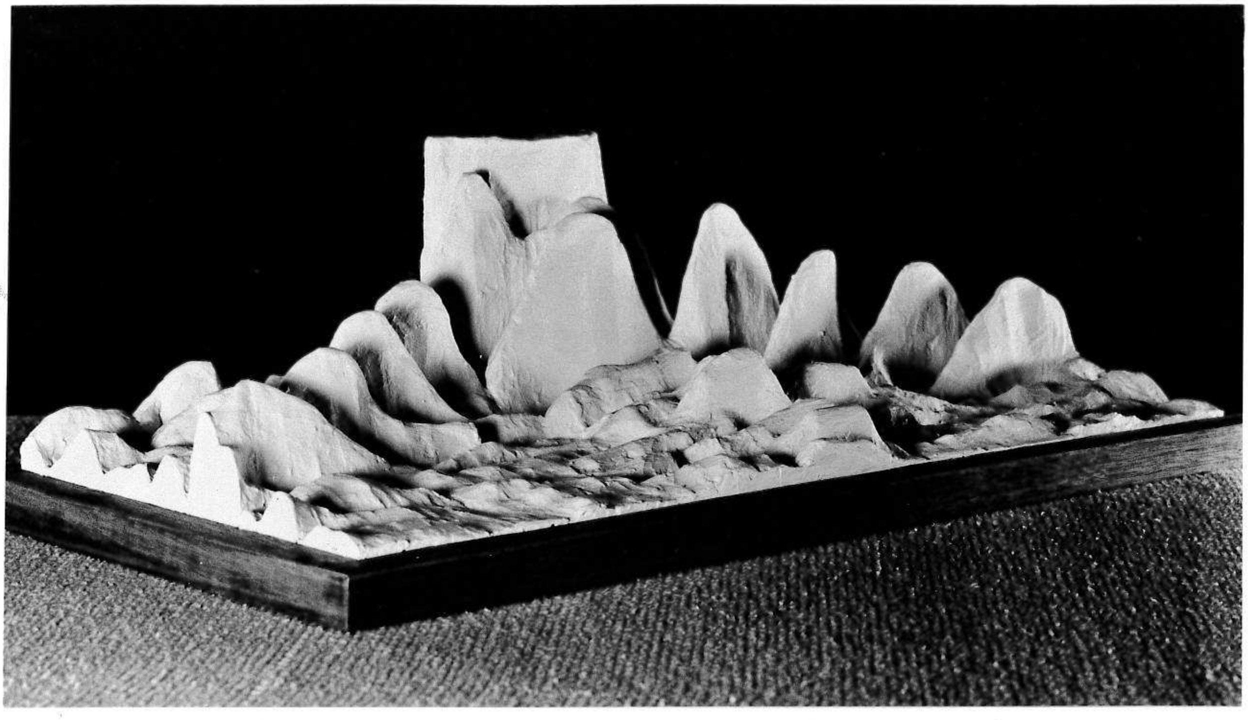
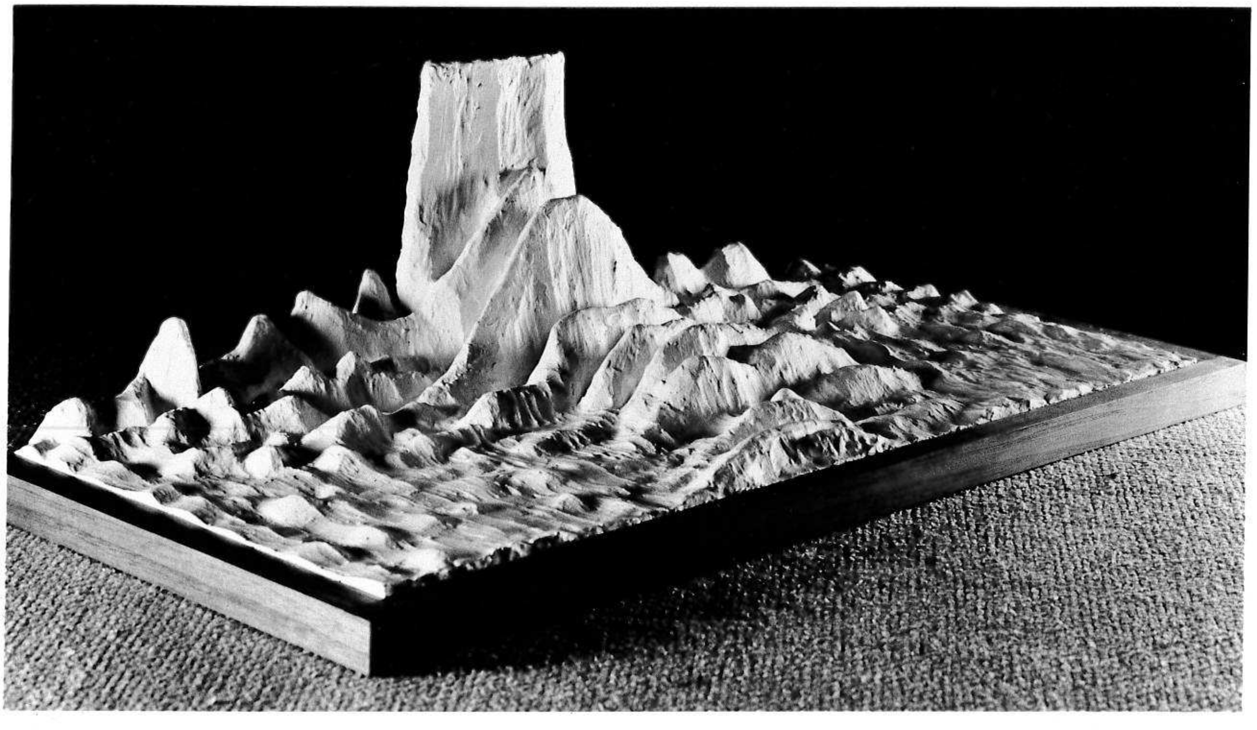


PLATE I — AN/FPS-6 ANTENNA UNDER CW-396A RADOME



(a) with radome



(b) without radome

PLATE II — THREE-DIMENSIONAL RADIATION PATTERNS OF THE AN/FPS-6 ANTENNA