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SUMMARY

A Cassegrain subreflector has been designed which permits prime-focus feeding of the paraboloidal reflector by a feed looking through the hyperboloidal subreflector. This subreflector is frequency sensitive and reflects the frequency band 6.0 to 16.0 Gc while passing the frequency band 4.0 to 6.0 Gc. Resonant objects on the subreflector are effective for all polarizations. Reflection properties are equivalent to that obtained with a solid metallic subreflector. Transmissivity is equivalent to that obtained with no subreflector in place.

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INTRODUCTION

The basic concept of a Cassegrain subreflector having the property of being transparent to some radio frequencies and opaque to others is covered in a patent issued to C. A. Cochran.[1] This idea was expanded by Hannan,[2,3] who developed a practical model. These investigators considered only those reflector surfaces which are polarization sensitive, that is, those transparent to one polarization and reflecting another. The experimental effort described in this report pertains to a frequency-sensitive reflector surface which passes all polarizations at a low frequency and reflects all polarizations at a high frequency.

BACKGROUND

Because of the high cost of large-aperture, paraboloidal reflector antennas used for space data acquisition, each of these antennas must be capable of supporting a maximum number of flight programs. This requirement has led to the development of multifrequency, multipurpose feed systems. These systems usually consist of four crossed dipoles clustered about the focal region of the reflector so that monopulse following can be achieved at selectable polarizations. Since three or more frequency bands usually are covered, three or more groups of these monopulse feeds are used. At best, this arrangement is a poor compromise because the parabola has only one focal point and the phase centers of all the feed elements cannot occupy the same spot.

A Cassegrain dual-reflector antenna[4] utilizes a prime reflector (paraboloidal) and a subreflector (hyperboloidal), providing two foci. One of the foci, that of the hyperbola, is the true focal point of the system and is located at the center of the feed; the other is a virtual focal point and is located at the focus of the parabola. Ordinarily the subreflector is constructed of solid metal, making the virtual focal point unavailable for use in illuminating the paraboloid. Techniques can be applied to the design of the subreflector to permit use of the virtual focal point. Hence, prime focus feeding as well as Cassegrain feeding can be done in the same reflector at the same time, thereby greatly relieving the number of feed elements crowded about a single focus system. The success of such an antenna depends on the synthesis of a material for use in constructing the subreflector to enable it to "discriminate" between the electromagnetic energy to be reflected (from the true focus) and to be passed (from the virtual focus). One technique for achieving this would be to construct the subreflector as a grating, thereby providing polarization discrimination. However, since most satellite polarizations are circular, an antenna restricted to operation at linear polarizations cannot be used. A more versatile means of allowing the subreflector to discriminate between the two impinging fields is to design it to be frequency sensitive. A reflector of this type is referred to as a "dichroic" reflector.

DICHROIC SUBREFLECTORS

A Cassegrain reflector can be made to be dichroic provided that the range of frequencies to pass through the subreflector material is separated sufficiently from the range of frequencies to be reflected. Fortunately the NASA operational frequencies can be so grouped; the 136- and 400-Mc bands can pass through the subreflector (prime focus feeding) and the 1.7-, 2.3- and 4.0-Gc bands can be reflected (Cassegrain feeding). In order to develop a subreflector material having these properties, it was planned to scale to higher frequencies for experimentation in an r-f anechoic room. The band 4.0 to 6.0 Gc was selected as the pass band and the band 8.0 to 16.0 Gc was selected as the reflection band. This choice of frequencies was based on availability of equipment rather than on frequency scaling of any operational system.

Two techniques are generally available for constructing a dichroic subreflector: construct it of r-f transparent plastic material in which tuned, reflective objects are imbedded, or construct it of r-f reflective metal in which tuned openings are cut. The equivalent performance of each approach is discussed by Booker,[5] who demonstrates the application of Babinet's principle. This principle states that two screens are complimentary if the opaque parts of one exactly replace the transparent parts of the other and that complimentary screens produce identical diffraction patterns.

A decision was arbitrarily made to confine this investigation of dichroic reflectors to that class being transparent to radio frequencies and containing tuned, reflective objects. Although glass cloth laminate is somewhat lossy for r-f, it was readily available and selected as the base material. Tuned objects were located by means of photo-etching a copper deposition on the material.

DESIGN THEORY

The reflecting, or back scattering, cross section of a re-radiating dipole was measured by Sevick[6] and found to be at maximum when the dipole length was 0.475λ. The scattering area for this resonant condition was observed to be $0.36\lambda^2$ for a thin wire dipole. This cross section applies only to an r-f field polarized parallel to the dipole. Two orthogonally crossed dipoles have the same cross section for orthogonal linear polarizations. Circularly polarized energy would see the same cross section, but the sense of circularity would be reversed on reflection. It was first suggested by Watson[7] that a dispersion of closely spaced resonant dipoles would perform like a reflecting screen. This theory was exhaustively investigated by Mack[8] in support of U.S. Air Force Project West Ford.

In consideration of the fact that the effective cross section of a resonant half-wave dipole is approximately $0.3\lambda^2$, it follows that the dipoles forming a reflecting screen matrix should be spaced approximately 0.6λ apart. This initial assumption was made. A length-to-width ratio for the dipoles was chosen which would optimize frequency bandwidth. It is shown by Thourel[9] that bandwidth of a dipole increases as its characteristic impedance decreases, and that the characteristic impedance is reduced by making the length-to-width ratio small. Smith[10] determines the optimum value for this ratio to be 0.25; it was decided therefore to design for a ratio of 0.20 to compensate for dielectric loading by the fiberglass.

REFLECTIVITY EXPERIMENTS

The dielectric material readily available for this experiment was an epoxy resin glass laminate. Values for the dielectric constant and loss tangent of material of this general class are listed by von Hippel[11] as $\epsilon/\epsilon_0 = 4.0$ to 4.2 and $\tan\ \delta = 2.0 \times 10^{-2}$, for a frequency of 1×10^{10} cycles per second. In order to measure the transmission loss through this material, a 2-foot square sheet, 1/8-inch thick, was located between a transmitting horn and a receiving horn spaced 20 feet apart in an anechoic chamber. It was observed that a normally incident r-f field was attenuated from 20 to 50 percent (1.0 to 3.0 db) over the frequency band 4.0 to 12.0 Gc when the sample under test was located 2 to 3 feet in front of the receiving horn. A similar dielectric material was available with a copper surface bonded to one side. This copper was suitable for use in photo-etching tuned resonant shapes on the dielectric surface.

Equipment was arranged as shown in Figure 1 for measuring experimental dichroic Cassegrain subreflectors. A Cassegrain feed horn* was located at the real focal point of the system, 34.5 inches from the hyperboloid. This entire assembly could be rotated in an r-f field generated 20 feet away. In this manner, the primary pattern which would illuminate a paraboloidal prime reflector was observed. Figure 2 shows angles subtended by the hyperboloidal subreflector.

*7.9x5.9-inch aperture, with 12-degree E-plane and 13-degree H-plane beamwidth at 8.0 to 12.4 Gc., 6.14x5.07-inch aperture, with 9-degree E-plane and 10-degree H-plane beamwidth at 12.4 to 16.0 Gc.

Elements were etched on copper backed dielectric as shown in Figure 3. To simplify construction, flat sheets were initially used instead of hyperboloidal shapes. It was expected that the arrangement of crossed dipoles shown in Figure 3(a) would resonate at 9.5 Gc; however, the loading effect of the dielectric produced resonance at 7.3 to 7.5 Gc. A second crossed dipole matrix, shown in Figure 3(b), was fabricated and was found to resonate at the desired frequency, 9.5 Gc. Reflectivity from these crossed dipole matrices was compared to that received from a solid (un-etched) copper sheet. It was observed that the crossed dipoles provided the same reflectivity as a solid copper sheet; however, for 45-degree (diagonal) polarization, a 3-db loss was observed. Accordingly, the matrix of circular spots shown in Figure 3(c) was fabricated. This device also resonated at 9.5 Gc and provided reflectivity equivalent to a solid sheet for all polarizations. Figures 4, 5, and 6 are photographs of the copper elements on the dielectric.

Reflectivity was observed by rotating the primary horn and subreflector assembly and thereby plotting the effective primary Cassegrain pattern. The flat sheet can be considered to be a degenerate form of a hyperboloid and was found to produce a primary pattern similar to that which would be derived from a hyperboloid. Figure 7 is the primary H-plane pattern obtained with the flat sheet with circular spots as elements. The characteristics of this pattern, as well as subsequent patterns obtained with hyperboloidal reflectors, displayed all of the six characteristics of a Cassegrain primary pattern discussed by Rusch:[12] (1) an isotropic region from 0 degree to about 50 degrees, (2) a region of monotonic decrease from 50 degrees to 70 degrees, (3) a highly oscillatory region from 70 degrees to the hyperboloid edge angle (which occurs at approximately 157 degrees in this case), (4) a local maximum at the hyperboloid edge angle, (5) an oscillatory region between the edge angle and 180 degrees, and (6) a maximum at 180 degrees. Each of these features is a well-known phenomenon from physical optics and is discussed in standard texts on physical optics. The oscillations in the isotropic region are diffraction contributions. The steepness of the monotonic decay determines the amount of rearward spillover in a Cassegrain system. The oscillations in the region on each side of the edge angle are due to diffraction and the maximum at the edge angle is also a diffraction effect. Finally, the maximum at 180 degrees is Poisson's diffraction. An increase in the subreflector diameter-to-wavelength ratio increases the spatial frequency of the diffraction oscillations and reduces their amplitude. It should also be observed that a null exists in the vicinity of 0 degrees, as a result of blockage by the primary horn. The angle subtended by a 40-foot prime paraboloidal reflector ($f/D = 0.42$) is indicated as 64 degrees on all patterns. All of these Cassegrain primary pattern characteristics were observed and recorded by Potter[13] in developing a Cassegrain system.

The problem of fabricating a copper clad plastic hyperboloid was a difficult one, and the problem of designing a matrix of resonant elements for this three-dimensional surface was even more complex. Figure 8 is a conic section of the hyperboloidal subreflector selected. This subreflector is a 5:1 scale model of that required for a 60-foot paraboloidal prime reflector (f/D = 0.42). Figure 9 is a photograph of the copper clad hyperboloid before etching; Figure 10 shows the circular resonant spots etched on this surface.

Figures 11 through 15 show primary H-plane patterns obtained with the hyperboloidal, dichroic subreflector for various frequencies from 9.0 to 16.5 Gc. Each pattern is compared with that received with the solid copper hyperboloid. In every case the performance of the surface with the copper spots is equivalent to that of the surface with the solid copper. Figures 16 and 17 show E-plane primary patterns obtained with the hyperboloidal, dichroic subreflector also compared with solid surface reflection. The increased diffraction oscillations are a result of the sidelobes that characterize the E-plane pattern of a horn.

TRANSMISSIVITY EXPERIMENTS

The dichroic Cassegrain subreflector must permit illumination of the paraboloidal reflector by a horn located at the virtual focus (behind the hyperboloid) and looking through the hyperboloid. Hence it was necessary to measure the effective transmissivity of the dichroic subreflector at the pass band frequency 4.0 to 6.0 Gc. The arrangement of equipment for this purpose is shown in Figure 18. H-plane patterns are shown in Figure 19 for 4.0 and 6.0 Gc with the dielectric alone, the dielectric with copper spots, and with nothing in front of the receiving horn. The H-plane patterns are remarkably similar for all three cases, indicating the practicality of the dichroic subreflector concept. Figure 20 shows E-plane transmissivity patterns for the same three cases with the same excellent results.

CONCLUSIONS

A dichroic Cassegrain subreflector can be built which performs like a conventional solid metallic hyperboloidal reflector over the frequency band 8.0 to 16.0 Gc, and yet permits prime focus feeding of a paraboloidal reflector with a horn looking through this subreflector. Losses for the prime focus feeding arrangement are only those due to the dielectric loss of the dichroic subreflector. Continued research to find a low-loss dielectric is indicated to be needed and is in progress. Teflon loaded fiberglass appears to be suitable for this purpose.

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13 Potter, P. D., "A Simple Beamshaping Device For Cassegrainain Antennas," JPL Technical Report 32-214, January 1964, pp. 21-30

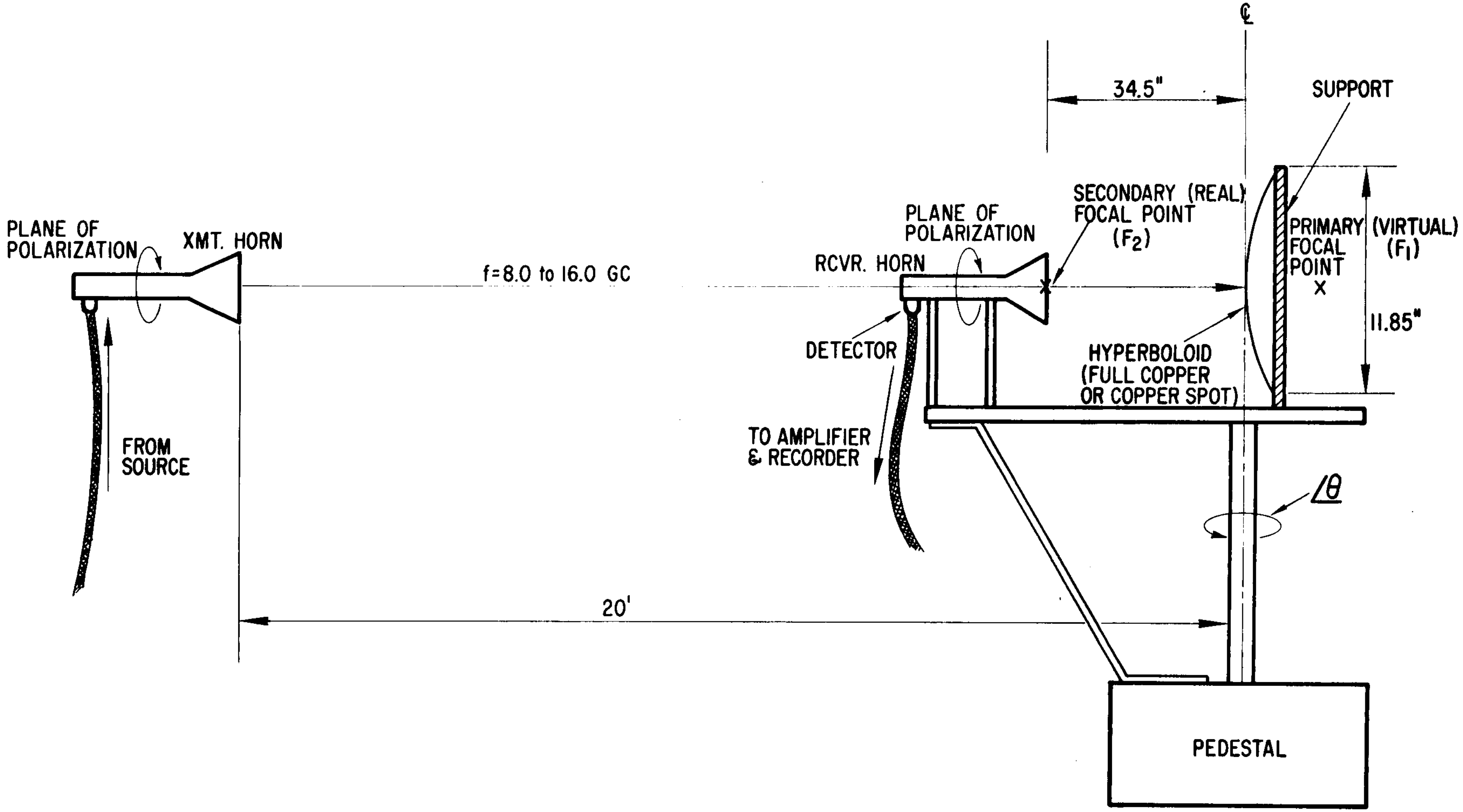


Figure 1 – Instrumentation for Reflectivity Measurements

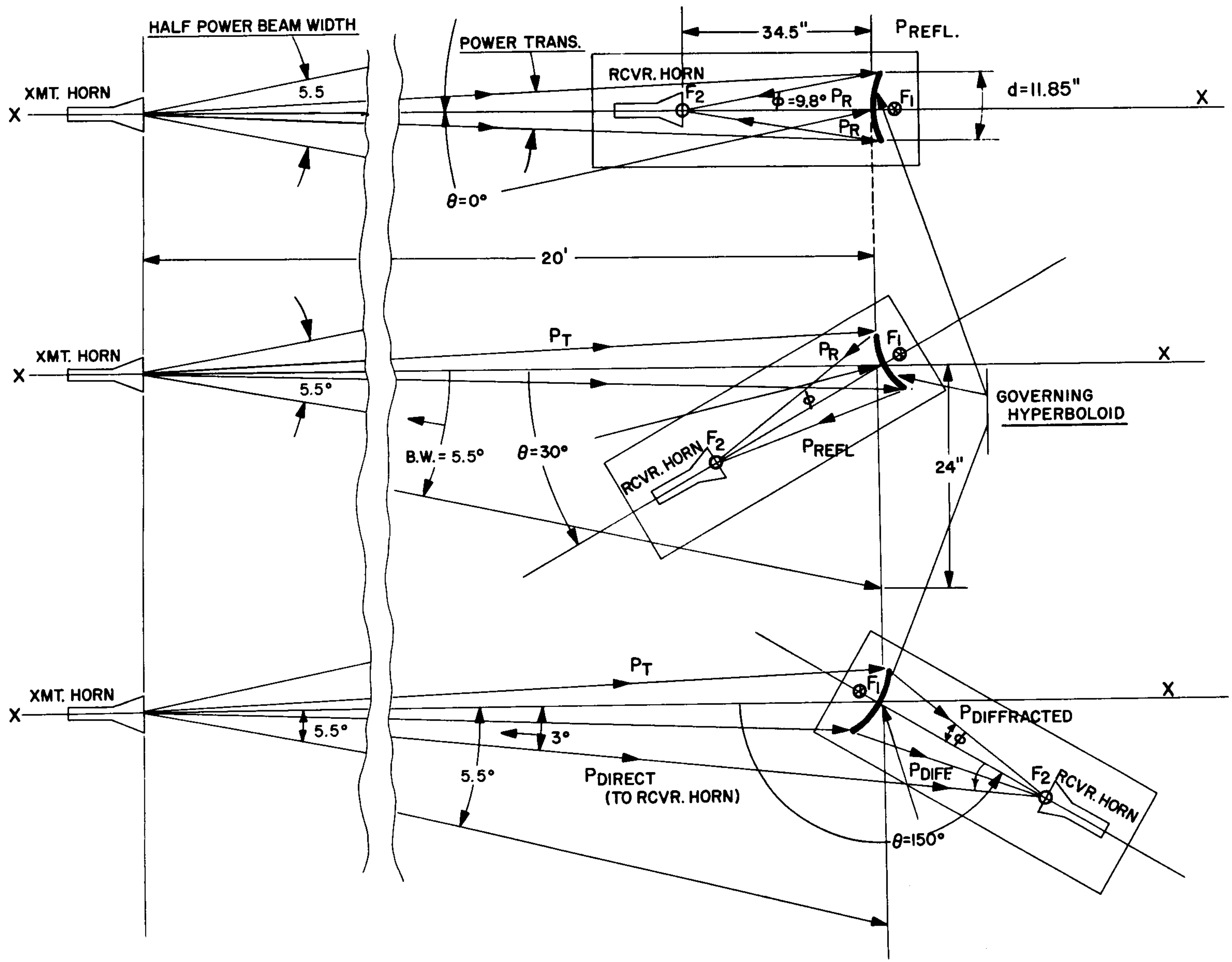


Figure 2 – Geometrical Relationship for Reflectivity Experiment

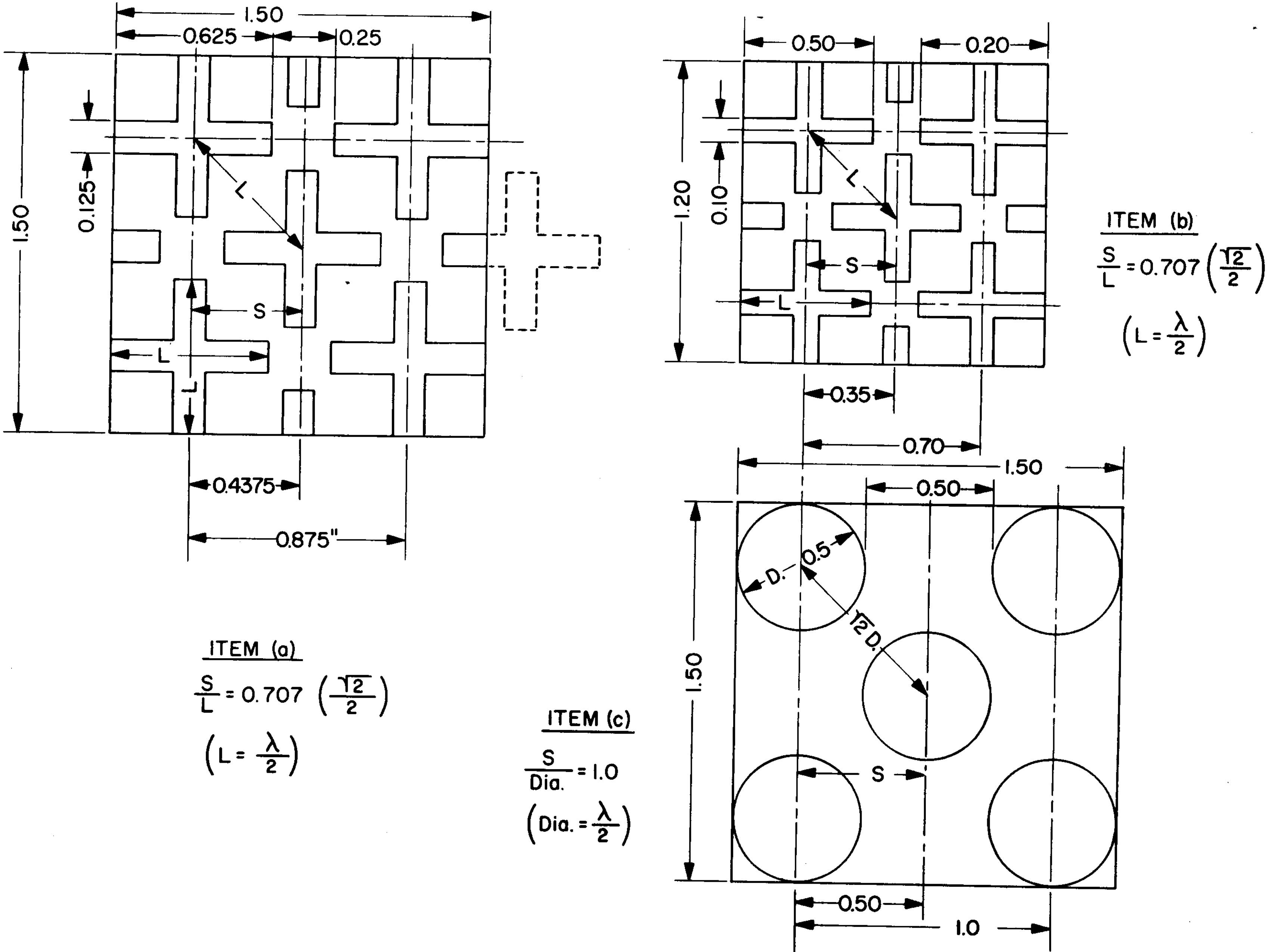


Figure 3 – Arrangement of Copper Plated Elements

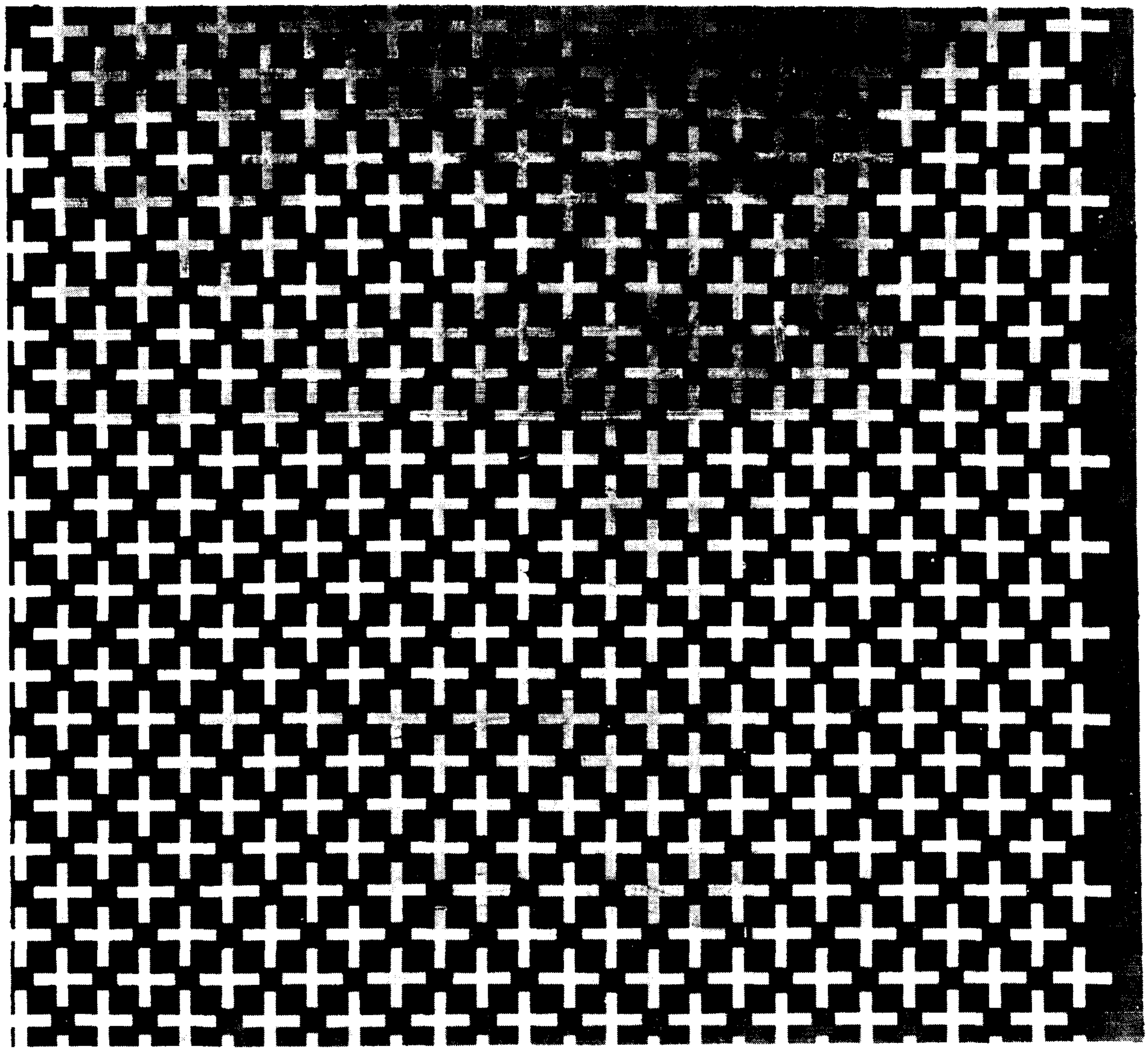


Figure 4 – Crossed Orthogonal Dipoles (First Experiment with Flat Sheet)

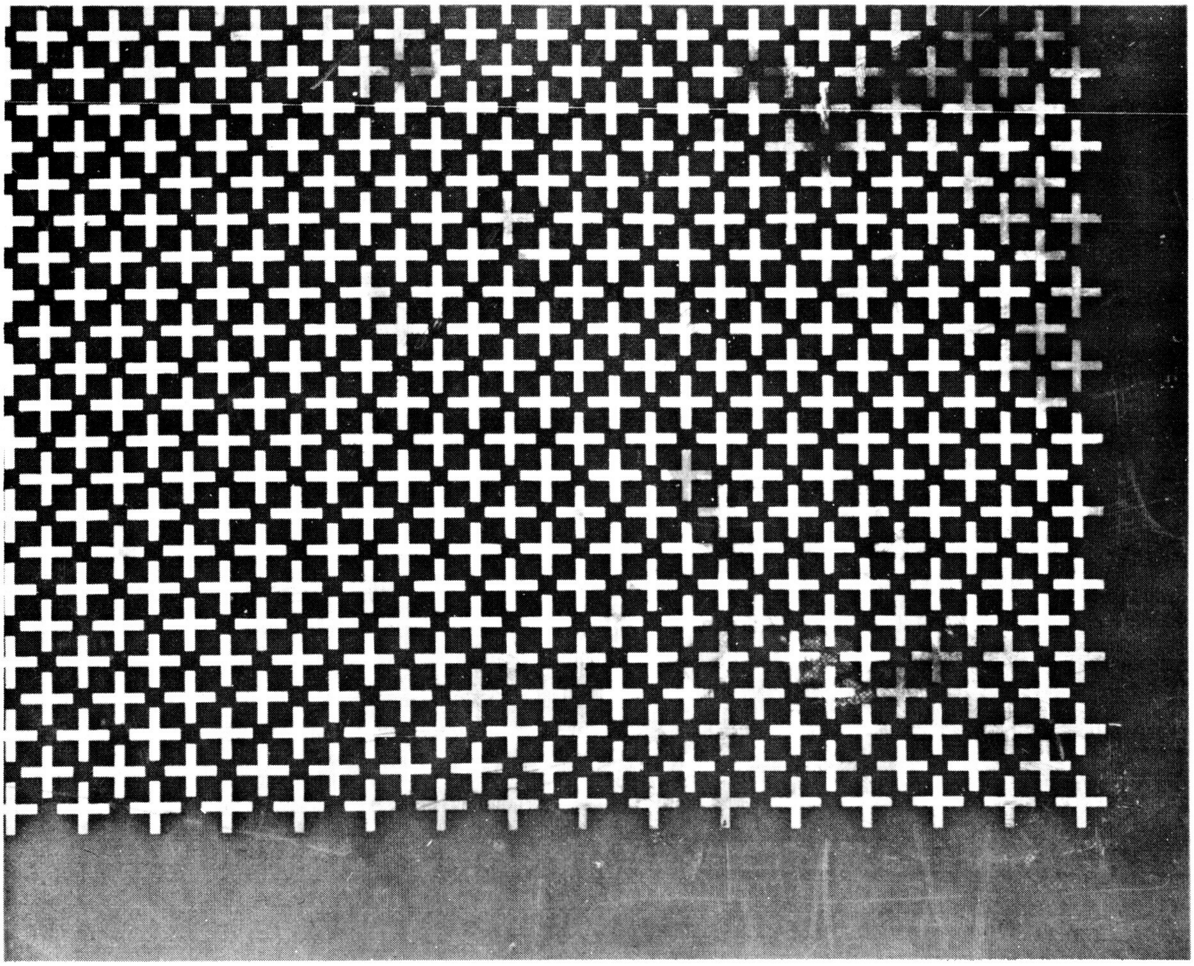


Figure 5 – Crossed Orthogonal Dipoles (Second Experiment with Flat Sheet)

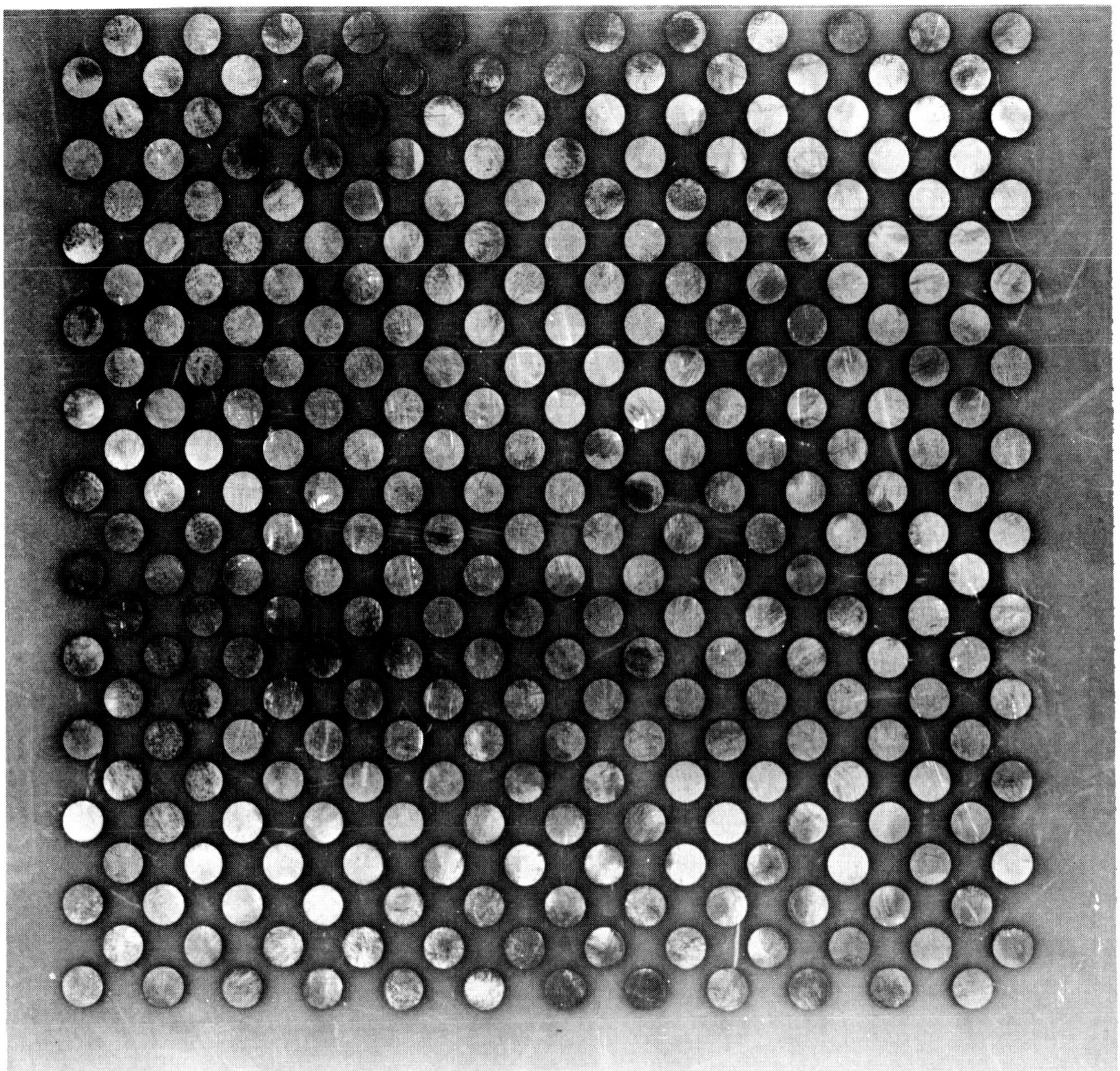


Figure 6 – Circular Copper Spots (Third Experiment with Flat Sheet)

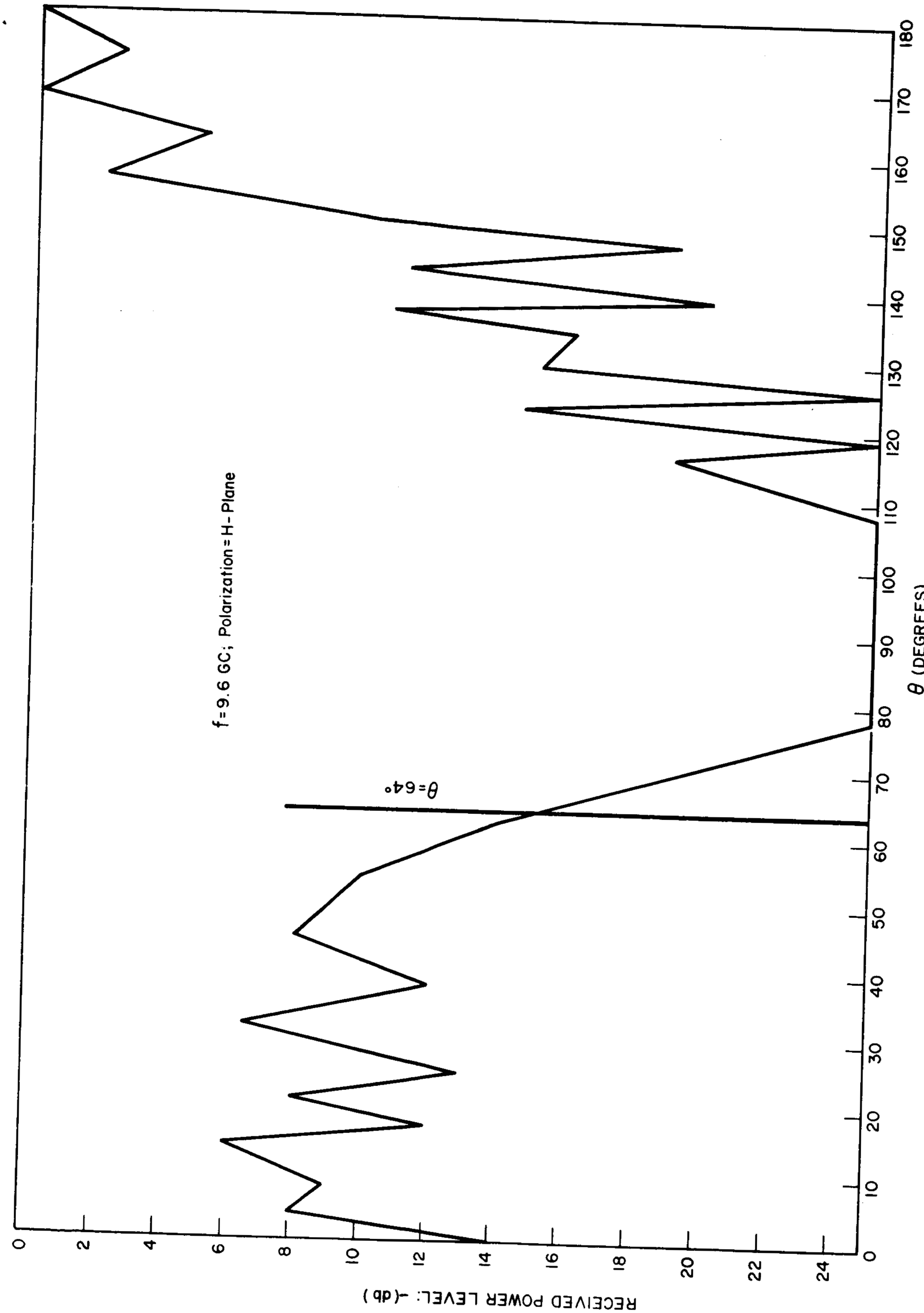
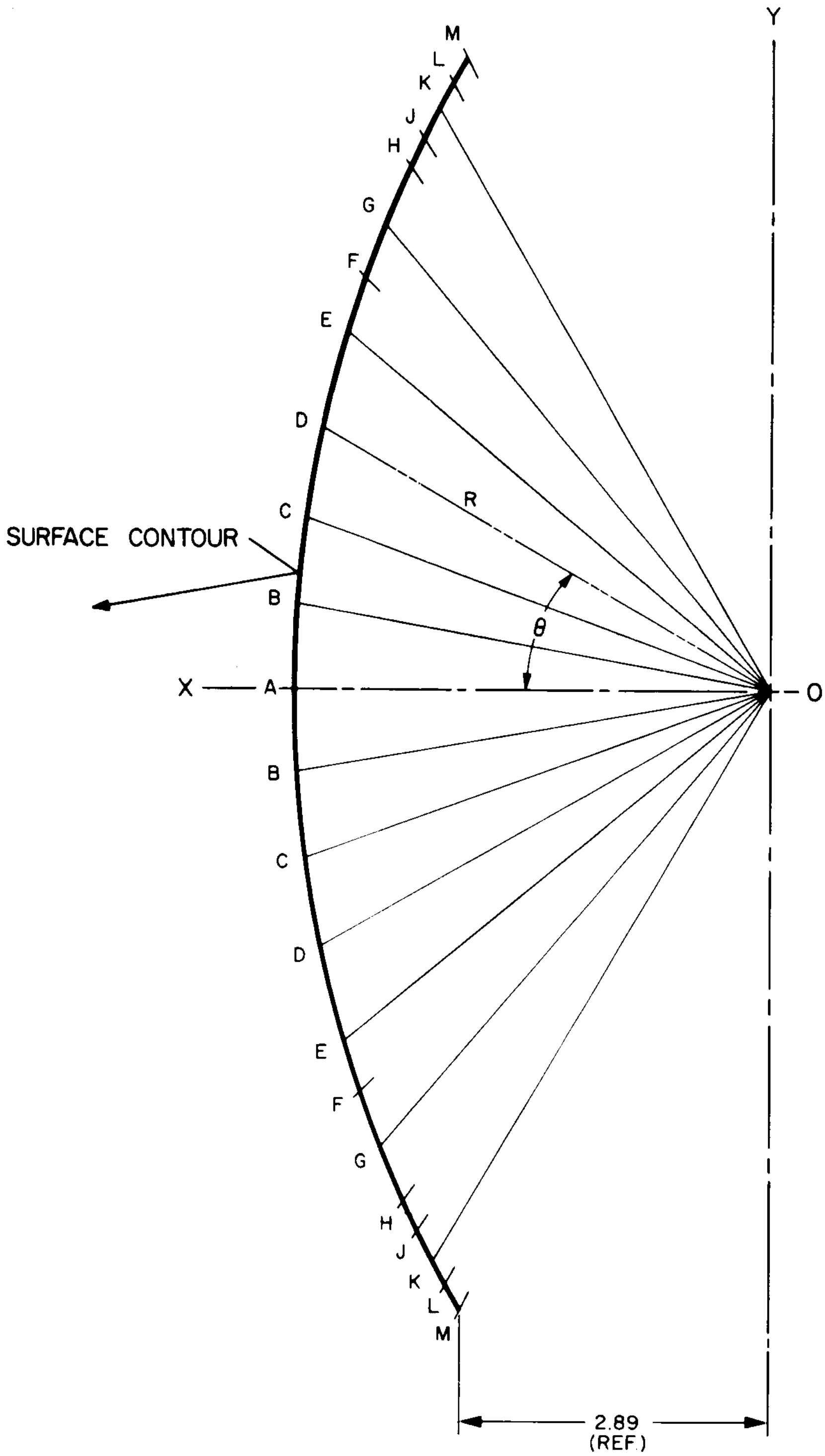


Figure 7 – Antenna Patterns (Envelope) of Flat Sheet with Copper Circles



SECTION A-A

	A	B	C	D	E	F	G	H	J	K	L	M
θ (Deg)	0°	10°	20°	30°	40°	45°	50°	55°	57°30'	60°	62°	64°
R	4.500	4.539	4.659	4.869	5.186	5.393	5.638	5.929	6.094	6.273	6.427	6.593
X	4.500	4.470	4.378	4.216	3.972	3.813	3.624	3.401	3.274	3.137	3.017	2.890
Y & Z	0	0.789	1.593	2.434	3.334	3.813	4.319	4.857	5.140	5.432	5.674	5.926

Figure 8 – Conic Section of Hyperboloid

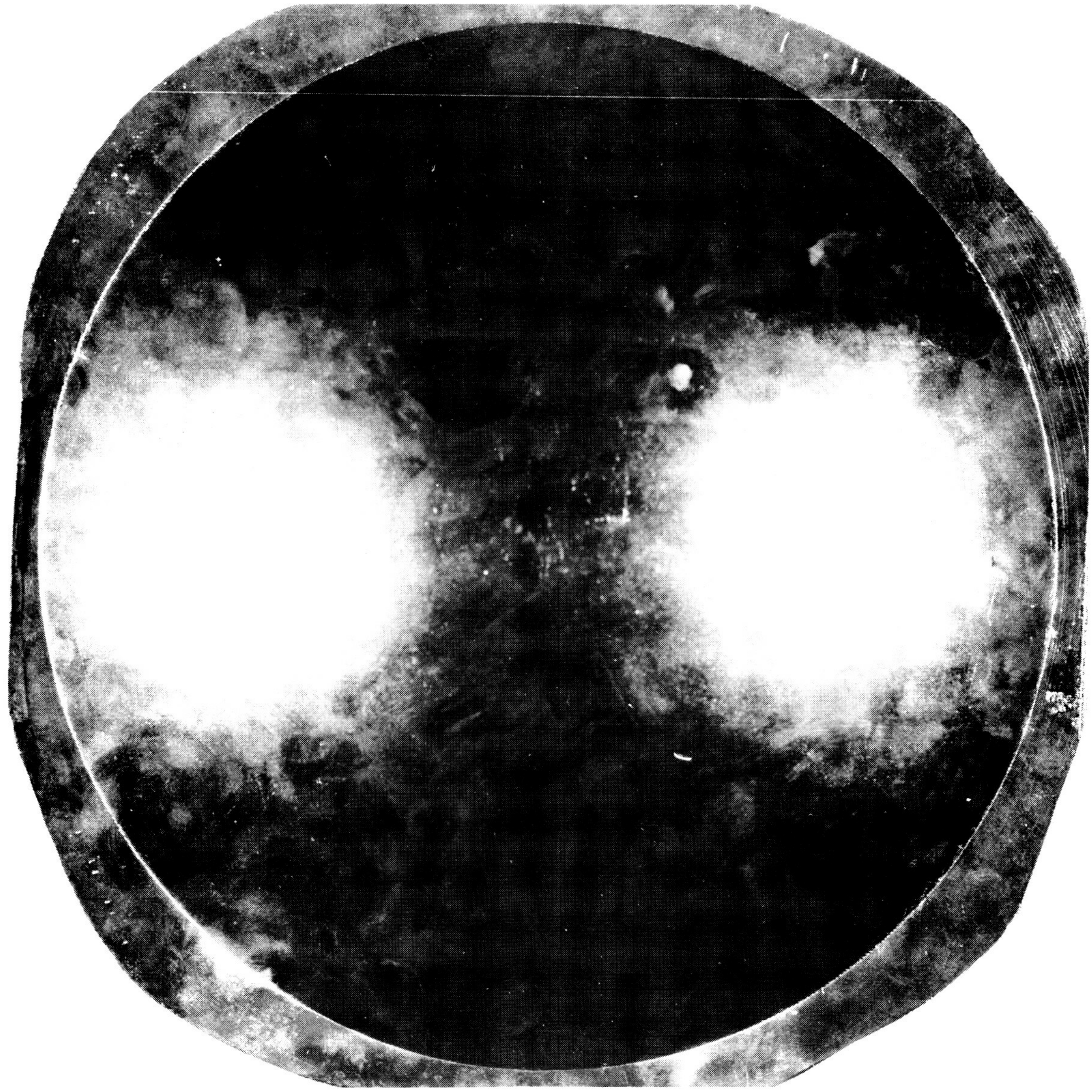


Figure 9 – Copper Plated Hyperboloid Surface

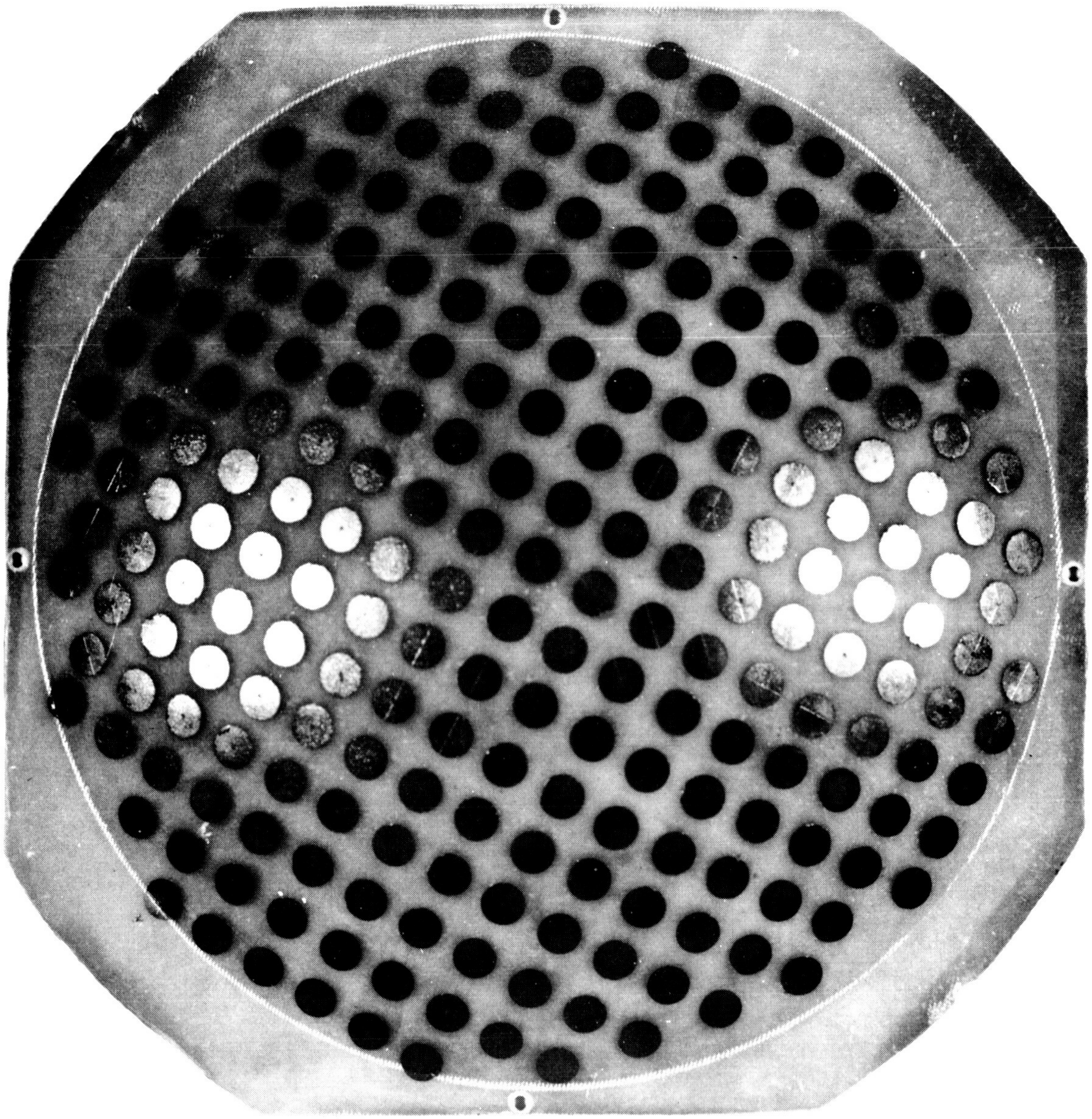


Figure 10 – Hyperboloid with Copper Plated Circular Spots

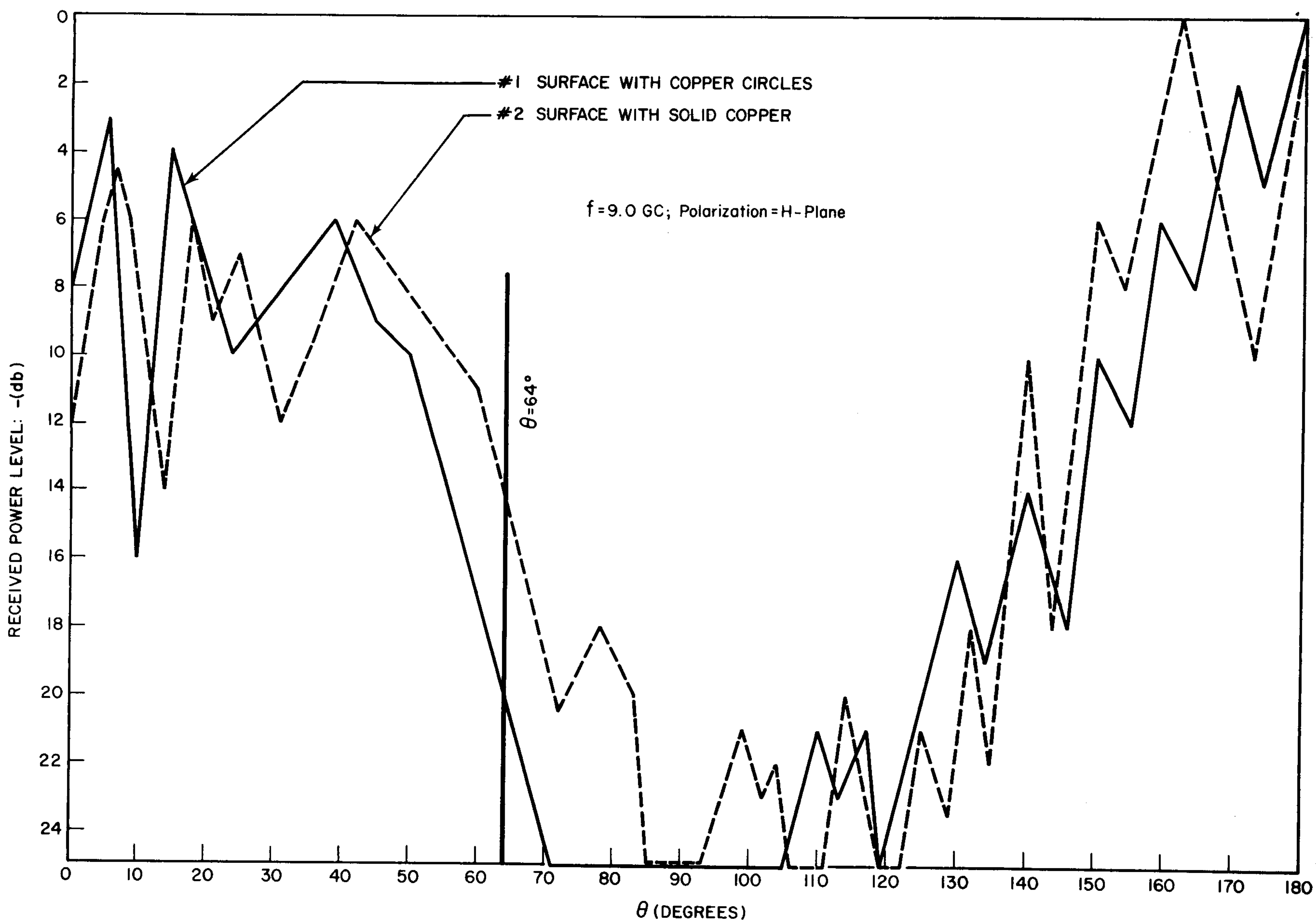


Figure 11 – Antenna Patterns (Envelope) of Hyperboloid Reflectors

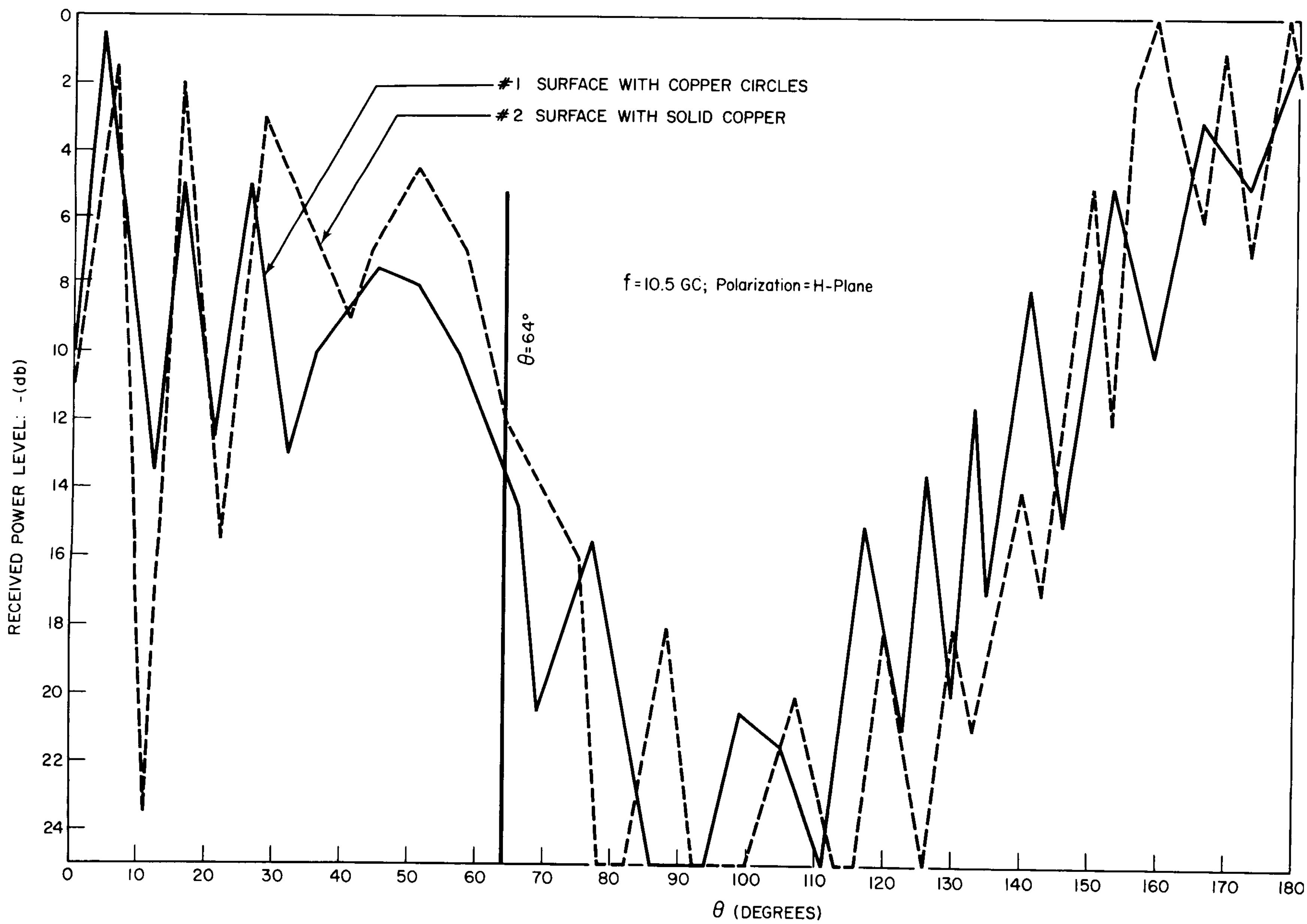


Figure 12 – Antenna Patterns (Envelope) of Hyperboloid Reflectors

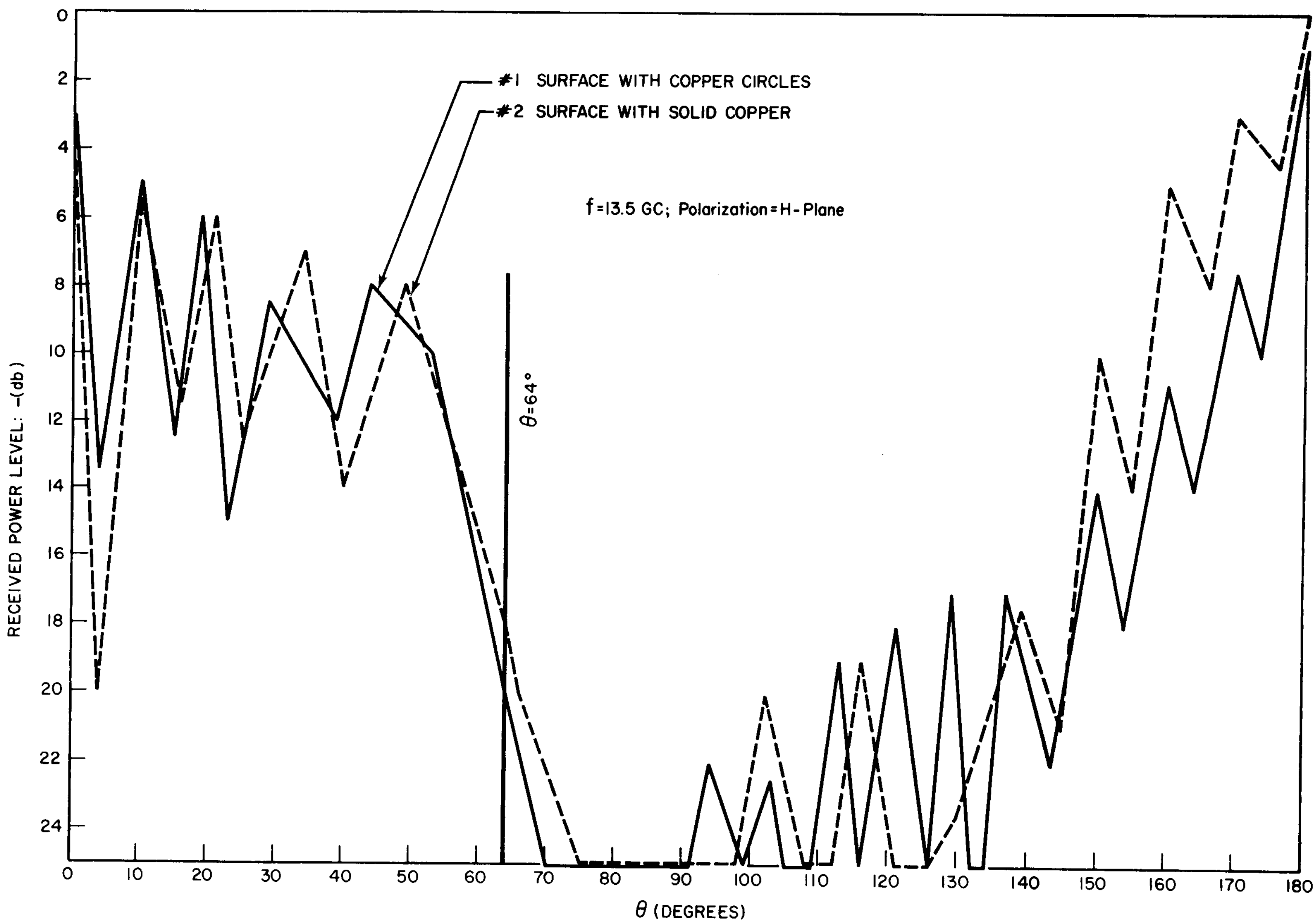


Figure 13 – Antenna Patterns (Envelope) of Hyperboloid Reflectors

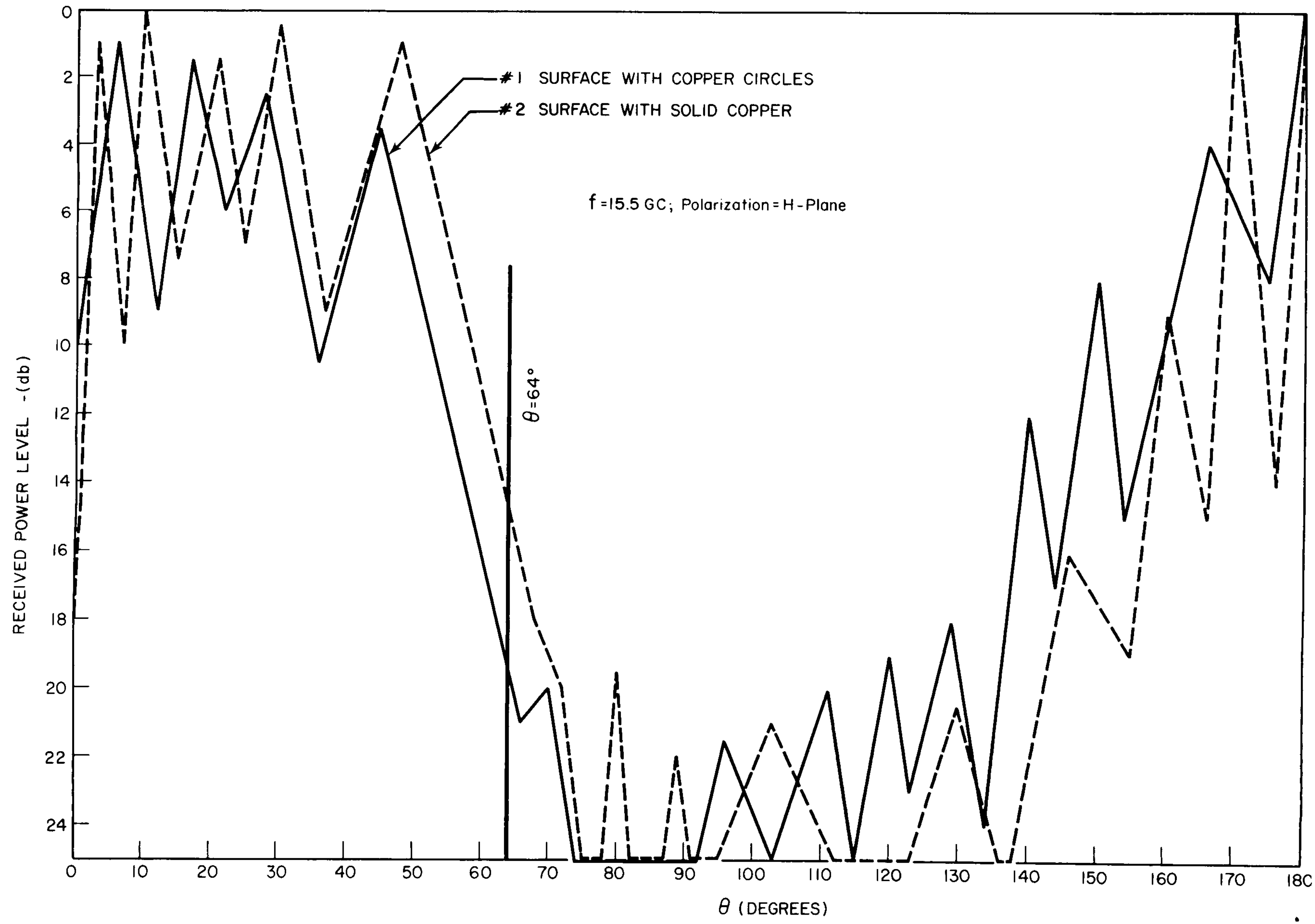


Figure 14 – Antenna Patterns (Envelope) of Hyperboloid Reflectors

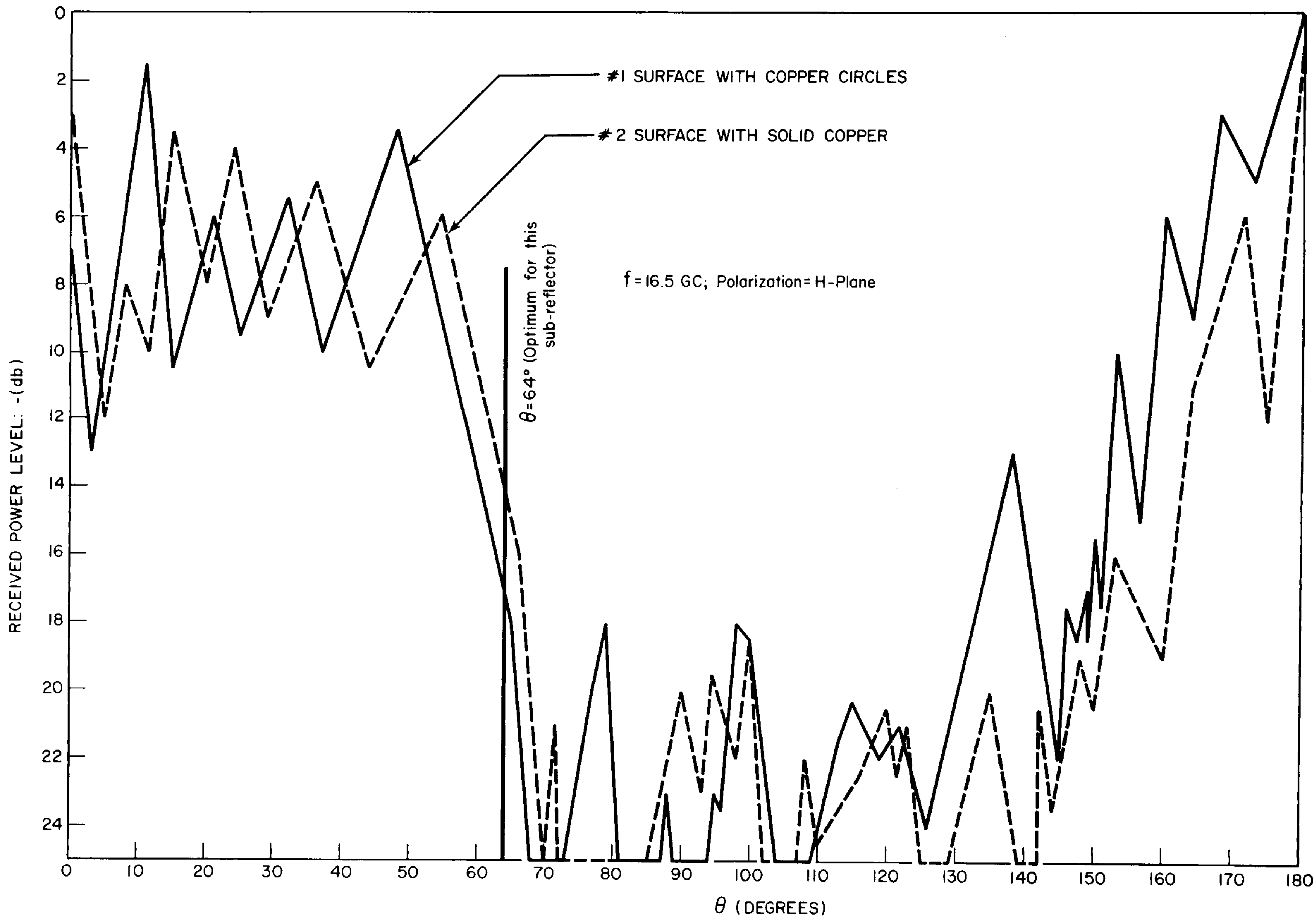


Figure 15 – Typical Envelope Antenna Pattern of Hyperboloid Reflectors

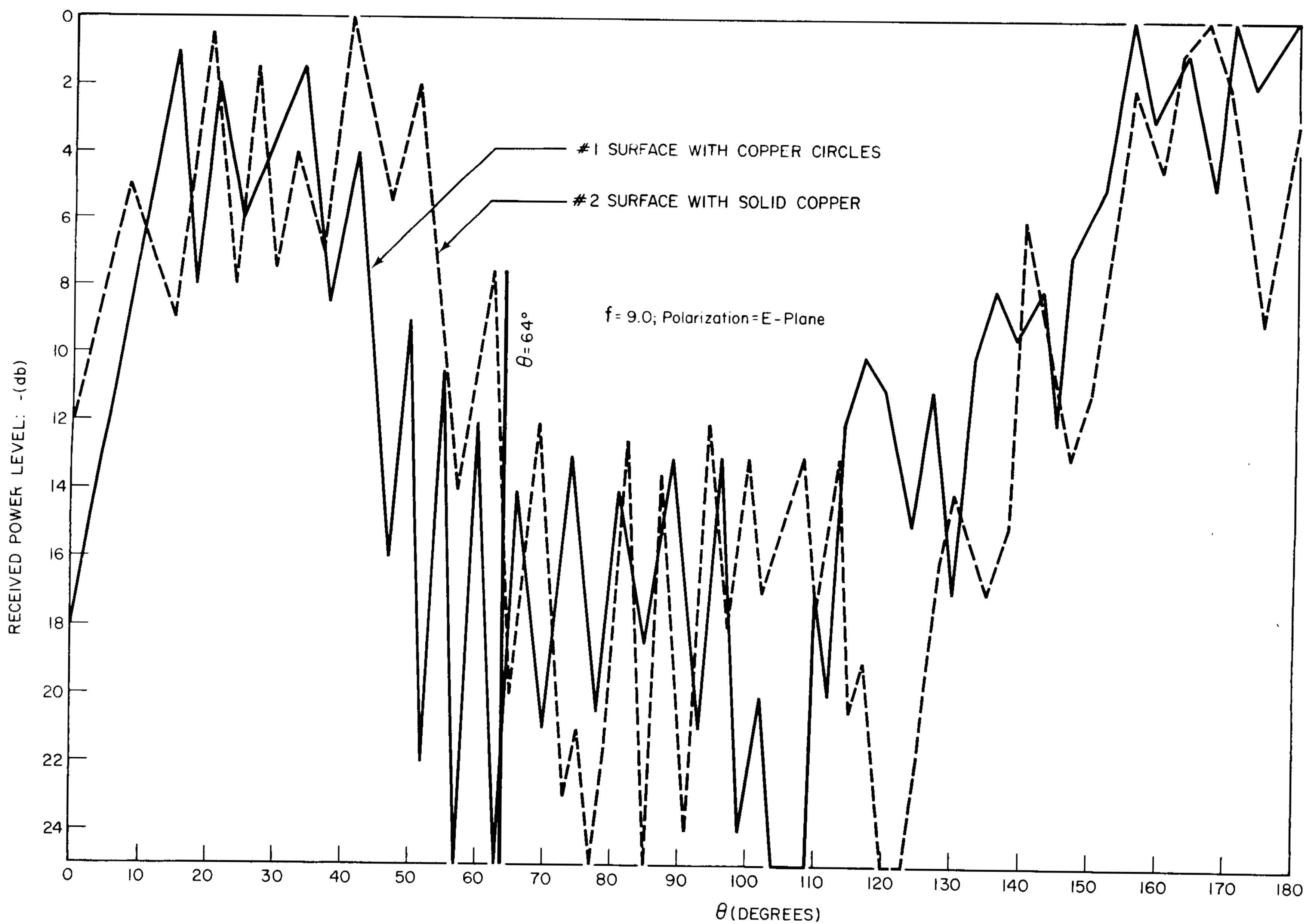


Figure 16 – Antenna Patterns (Envelope) of Hyperboloid Reflectors

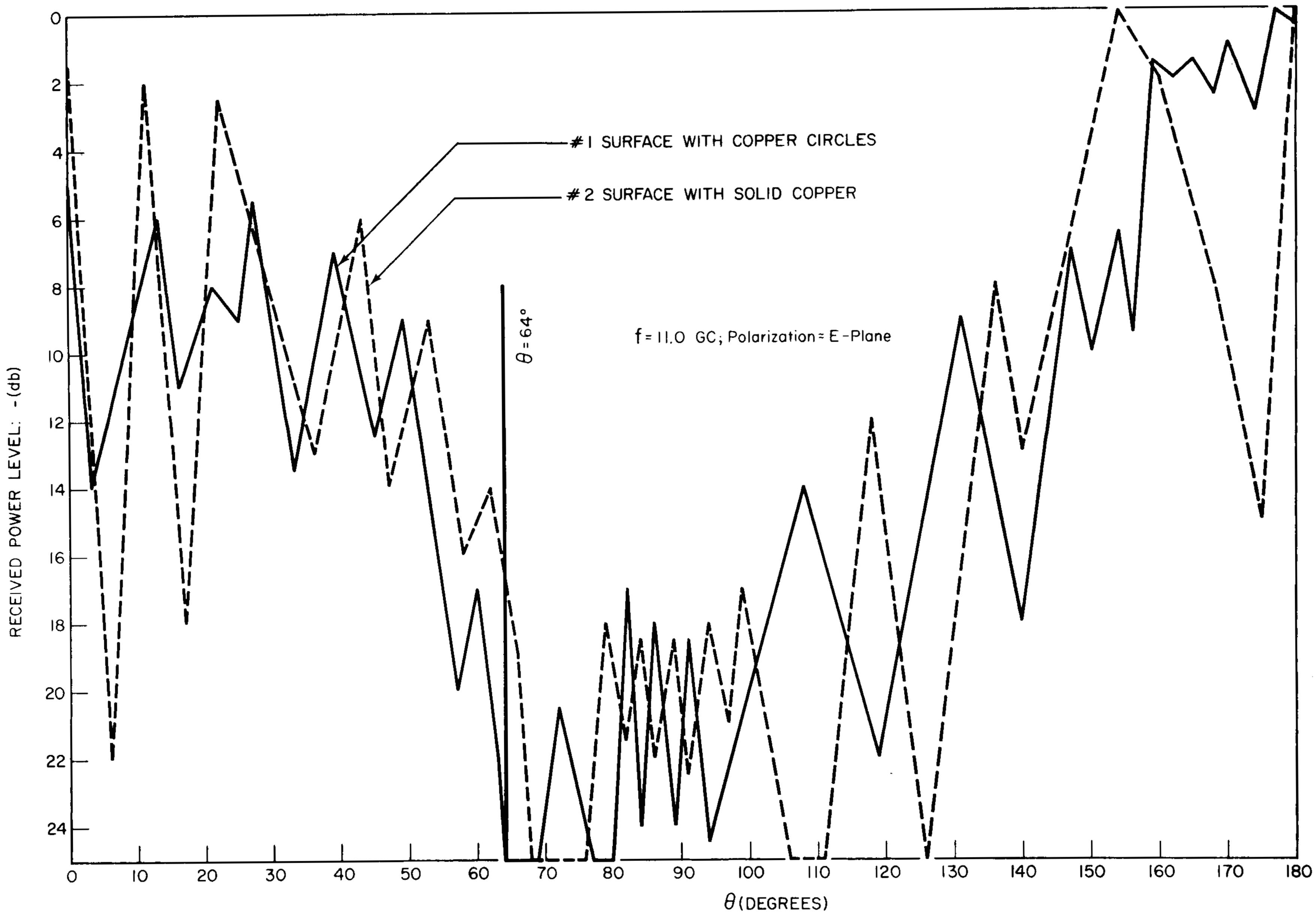


Figure 17 – Antenna Patterns (Envelope) of Hyperboloid Reflectors

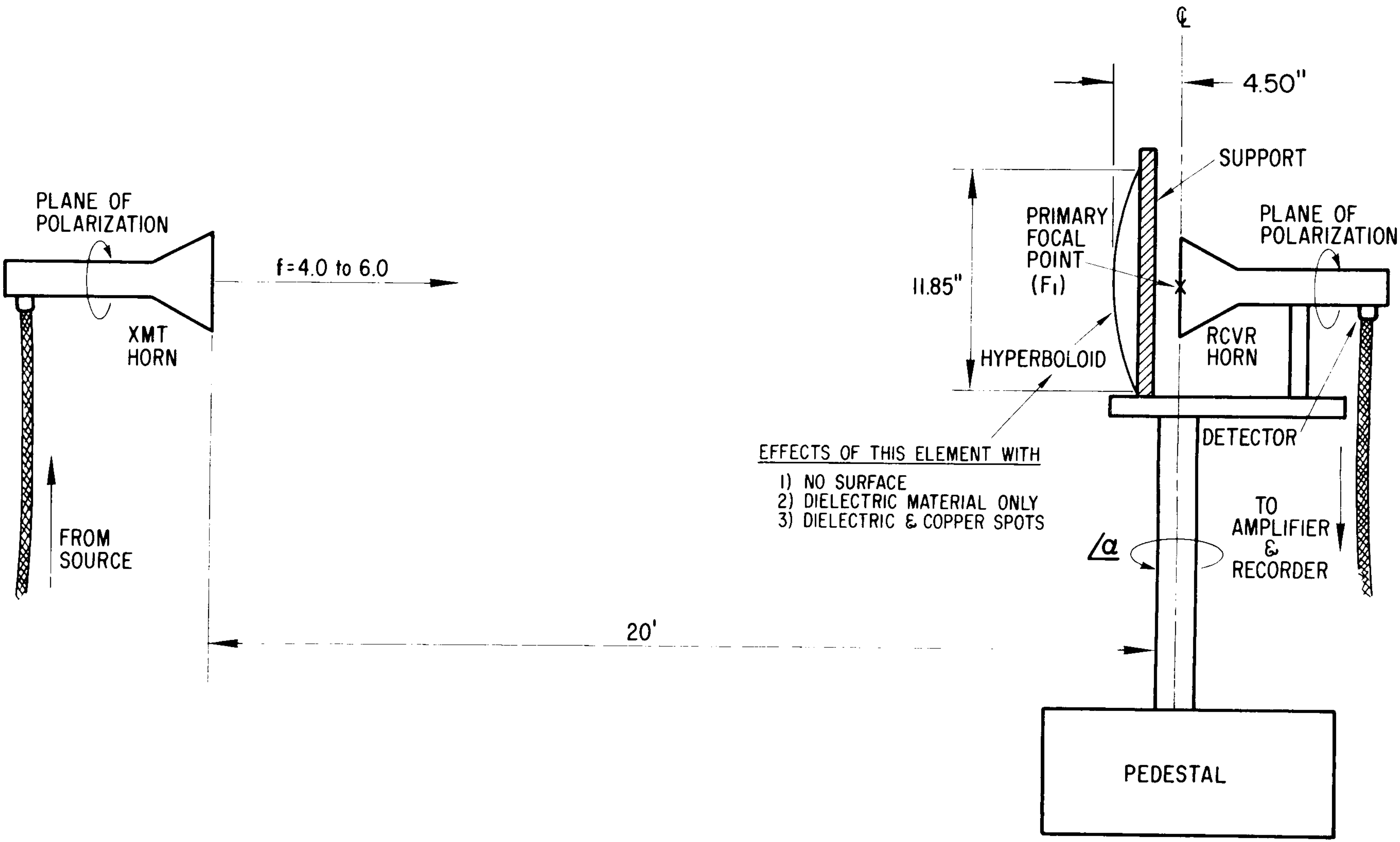


Figure 18 – Instrumentation for Transmissivity Measurements

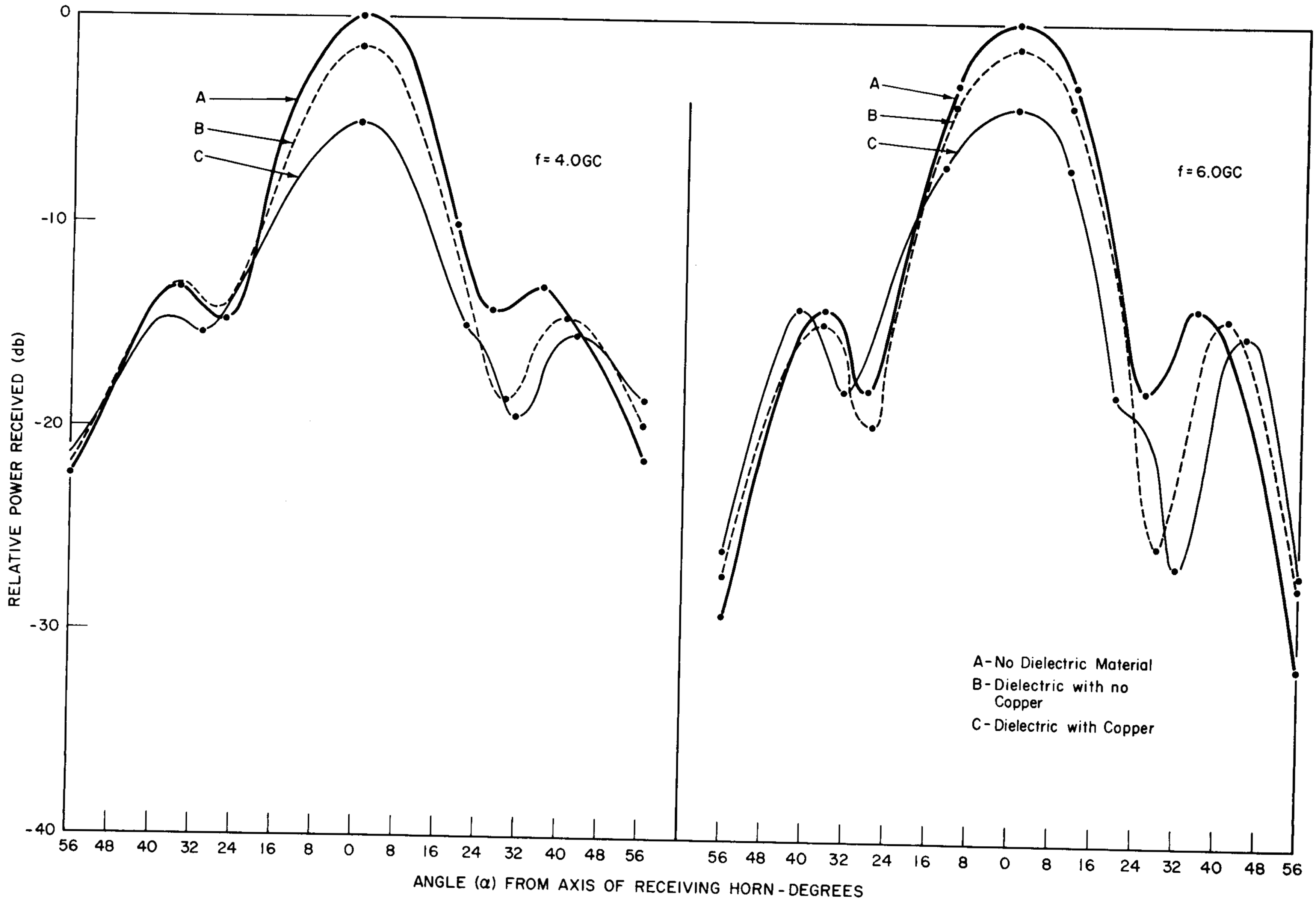


Figure 20 – E-Plane Transmissivity Pattern

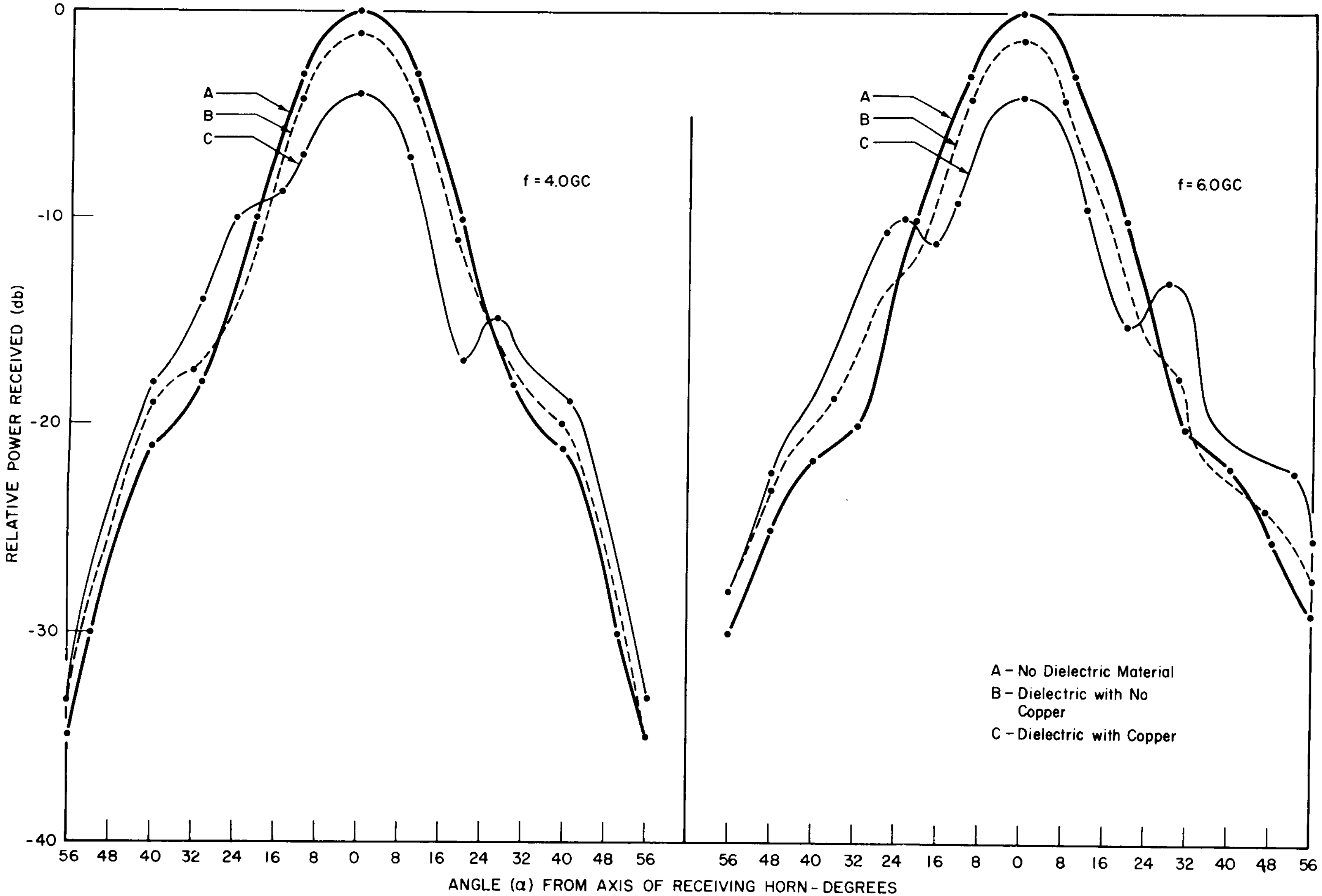


Figure 19 – H-Plane Transmissivity Pattern