Technical Report # 4

June 1969

FROM: The Crawford Hill VHF Club - W2NFA

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SUBJECT: A Horn Antenna for EME Communication

This report will consider a horn antenna for 1295 mc EME work. Comparisons will be made with the more popular paraboloidal reflector antenna. The purpose of this report is to present all the characteristics of the most simple horn antenna in order that the reader may be better able to decide which antenna is more suitable for his requirements.

The particular horn antenna presented here is a square aperture pyramidal horn with a square waveguide feed. The square aperture and feed are chosen so that circular polarization of the radiated energy may be achieved at 1296 mc by the method of crossed linearly polarized feeds which are energized 90 degrees out of phase electrically by means of a quadrature hybrid.

The following information is for an optimum horn design. An optimum horn is by definition one in which the length is fixed and the horn is permitted to change in flare angle (aperture size) until the gain is maximum. The optimum condition is therefore a practical compromise which results in the minimum over-all length for a desired gain. This horn is therefore the most simple and practical case. Variations using focusing reflectors or aperture lenses are not simple and will not be considered here. Horns of different geometry such as conical horns or horns flared
with curved walls cannot improve the gain over the optimum design for the same length horn and so they are also omitted. Figure 1 shows the square aperture horn design considered here.

Any antenna for 1296 mc EME work may be characterized by the following factors, gain, radiation pattern, polarization, bandwidth, ,Impedance match at the feed, physical size, construction tolerances, noise, temperature, and cost. These factors will now be considered.

Bandwidth: Horn antennas are basically high pass filters by virtue . of the waveguide like construction and have a lower cut-off frequency determined by the smallest inside dimension of the waveguide feed. A horn is therefore a very broadband device and susceptable to out-of-band interference. With the 6 inch square waveguide feed shown in Figure 1, the cut-off frequency is 985 mc. A further modification of the bandwidth--characteristics is obtained from the method of-exciting the waveguide feed.

Impedance match: This is a circuit problem and does not belong to the antenna proper but since the waveguide must be excited by a device or other type of feedline with different characteristic impedance a suitable transition device or coupler must be employed. Our requirements at 1296 mc are very narrow band and so there are many ways to affect a matched coupler from a feeding to the dominant mode impedance of the waveguide. It should be done however in as low loss a manner as possible in order not to degrade the gain and noise temperature. A suitable coupler to go from coax line to waveguide will be described later.

Gain and size: These important factors are related by the design curves shown on Figure 1. For a desired gain, the horn length and aperture size are read directly from the curves. For example, a 30 db gain horn is 50 feet long and has an aperture size of 10 by 10 feet. These dimensions are strictly for 1296 mc. The gain values are referenced to an isotropic or point source radiator. Gain is simply defined as the ratio of radiation intensity (power if you like) in a particular direction usually. the main beam of a directive antenna, to the radiation intensity from an isotropic antenna with the same input power. An isotropic antenna is a fictitious antenna which radiates equally in all directions of, space:

Now a-slight digression will be made in aperture theory for those who desire more insight. For a particular aperture size (area), the maximum possible realizable gain which can be achieved is numerically equal to **4πA / λ*λ** where A is the aperture area in the same length units as **(λ),** Lambda the-free space wavelength, 9.13 inches or about 3/4 foot at 1296 mc. Furthermore, a term called aperture efficiency is used to indicate the ratio- between the actual realized gain of an aperture type antenna and the gain value computed from the above formula.

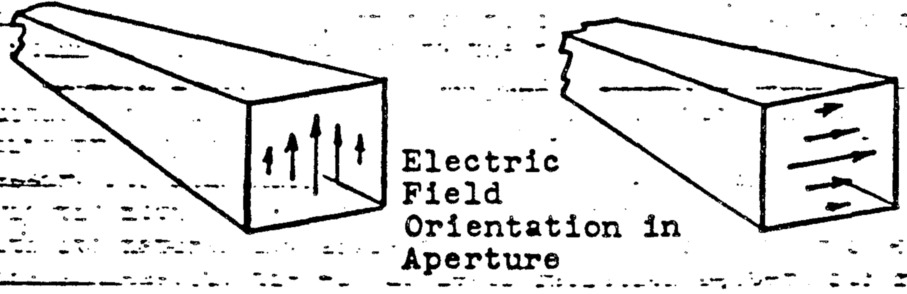
An optimum horn achieves just about 50 percent aperture efficiency for a wide range of. gain values. This value of aperture efficiency has already been included in the design curves of Figure 1. The optimum horn 50 percent aperture efficiency is due to both the distribution of energy over the aperture area resulting constraint of the dominant mode waveguide feed, and to_ the phase error over the aperture resulting from the horn flare angle.

If the phase error over the aperture were corrected by means of a. loss less lense or focusing-reflector, or the horn length increased many many times longer than optimum, the aperture efficiency would increase to a maximum of 80 percent, the remaining 20 percent loss in aperture efficiency is due simply to the amplitude distribution of the dominant mode field over the aperture.

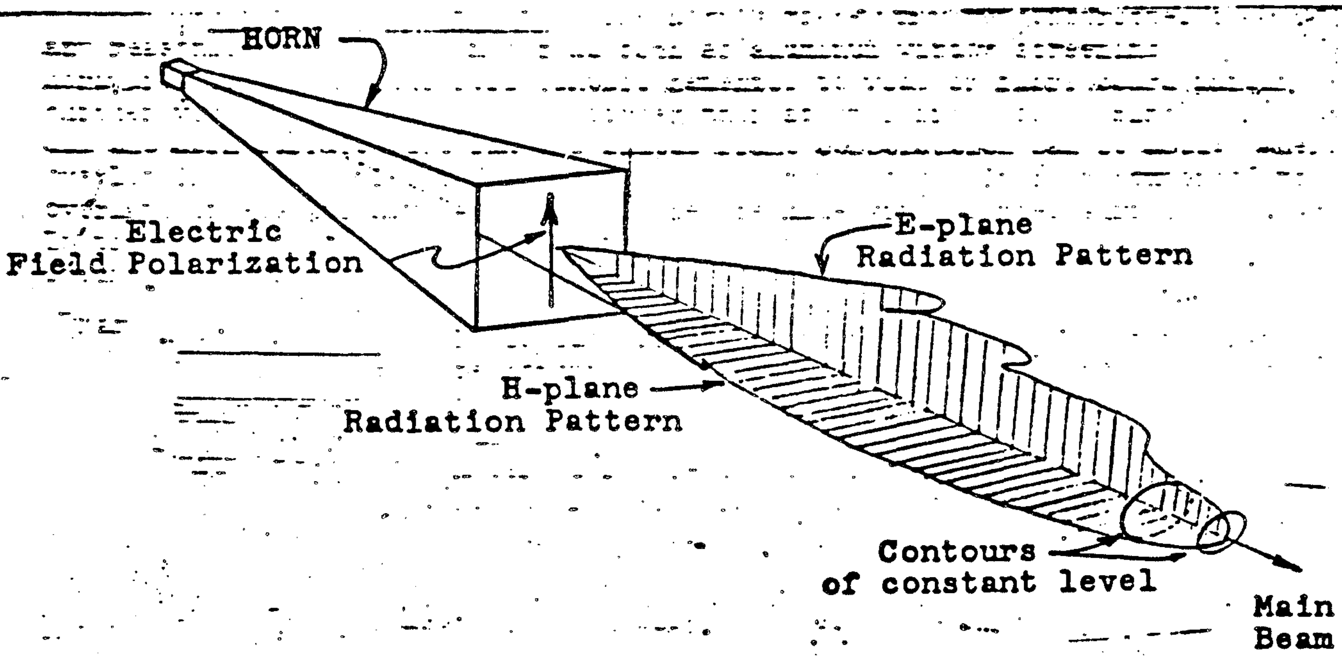
This report is too brief to consider other more complicated forms of higher order mode excitation-of-the-horn aperture. therefore, it is stressed here that this-entire analysis-is based =on constricting the smaller end of the horn so that only the fundamental or lowest order mode TE 0 is excited. Because of the complexity of exciting controlled higher order modes,-virtually all practical application handbooks treat this fundamental case-only.

Polarization: Let it be understood that the gain values read from the curves are the same for linear or circular, polarization provided that the antennas used for comparison are all consistent in polarization. It is desirable to use circular polarization for all ENE work, and this will be assumed for all practical cases. -However, it is sufficient to consider the linear polarization characteristics of an antenna and then by geometric construction arrange the antenna so that it will have the same characteristics when excited by a linearly polarized wave which is oriented 90 degrees from the first in space. This is why the square aperture was chosen. It is geometrically the same when rotated degrees about its axial center. The polarization scheme suggested in Technical Report #1 is implicit.

Radiation Pattern: Figure 2 shows universal radiation patterns normalized with respect to the aperture size. The patterns are for the two principal planes and for linear polarization. It is customary to refer to the principal-planes of radiation as those planes which are parallel with the electric and magnetic fields, E-plane and H-plane respectively. These planes are always at right angles to each other with their intersection line usually along the direction of the main radiation beam. The E-plane is also the reference plane of linear polarization and so the radiation planes are intimately-related to the'-aperture field orientation. For the square aperture horn considered here, the electric field orientation in the aperture can be either of the two cases shown as follows:



The principal planes E-plane and H-plane for which detailed radiation patterns are given by Figure 2 for linear polarization, are illustrated below. The actual radiation beam is sort of cigar shaped in volume while the drawing below only shows an axial slice of the pattern in the principal planes. Only half of the patterns are shown below and by Figure 2 since the full pattern is symmetric on either side of the center of the main beam.



One of the most important characteristics of an antenna radiation is its half power (-3 db) beamwidth. This is the angle within which half of the total radiated power is contained. This angle is important because it is a measure of the antenna gain for high gain antennas especially.

For circular polarization an approximate half power beamwidth angle related to aperture size is given under Figure 2.

A logical question which may arise is of what use are the linearly polarized radiation patterns when the antenna will in all probability be used only in the circularly polarized mode. The reason for not including circularly polarized radiation patterns is that they are not available for this particular horn geometry and are difficult to compute exactly. However, for practical purposes the approximate circularly polarized mode radiation patterns can be assumed to be similar to the E-plane case for linear polarization. The radiation can only be circularly polarized over a limited region of space when the proper feed conditions are met to obtain circular polarization at the center of the main beam. For the optimum horn as with most other beam antennas, circular polarization with tolerable ellipticity can be obtained from the center of the main beam to where the E and H plane linear polarized radiation patterns differ in amplitude. This occurs at about -5 db level for the case considered here. At other directions in the space pattern all degrees of ellipticity are possible. This bit of information is of little practical significance for EME since the target (moon) will be illuminated by only a small portion of the main beam and so will be totally illuminated by circularly polarized radiation.

Antenna Noise Temperature: Since a large horn has very low side and rear lobe, radiation, the noise temperature of the antenna will be essentially the temperature of the region into which the main beam is pointed. Therefore, at 1296 mc, a large aperture optimum horn will have an effective temperature of no greater than about 20 degrees Kelvin when pointed away from the warm earth. This is very small when compared with a typical paraboloidal antenna which may have a noise temperature of 75 to 100 degrees Kelvin when aimed in the same direction. The reason for the higher noise temperature of a paraboloidal antenna is that the feed for the paraboloid is looking in the opposite direction which is towards the warm earth and spillover or radiation beyond the outer periphery of the paraboloid will be directed towards the warm earth and so contribute noise. In the horn the feed is essentially imbedded in the horn and can contribute nothing extra to the antenna noise.

It should be kept in mind, however, that unless a very low noise receiver is employed with the horn, the system operating temperature may not be significantly improved. See Technical Report #3. For instance, a typically well constructed parametric amplifier will have a noise temperature of about 100 degrees Kelvin. The improvement in sensitivity using a horn with 20 degrees as compared with a paraboloid with 100 degrees will be the ratio of 100° + 100°/100° + 20° or 2 decibels.
When the horn antenna is directed parallel with the surface of the earth, half of the radiation beam will be directed toward the warm, 300 degrees Kelvin, earth and the other half into a relatively cold background temperature at 1296 mc. This means that the effective antenna temperature for this - particular pointing direction can be no less than 150 degrees.

Comparison between Optimum Horn and Paraboloidal Reflector Antenna: It is interesting and coincidental that the aperture efficiencies of both the optimum horn and paraboloidal antennas are about the same, 50 percent. Because of this, some useful comparisons can be drawn since both antennas will have the same physical aperture size for a given value of gain. Although one is circular in aperture and the other square, each will have the same number of square feet in area.
The paraboloidal surface must be constructed with great accuracy and maintained accurate whereas the walls of the horn may be constructed an order of magnitude (10 times) less accurate without impairing the

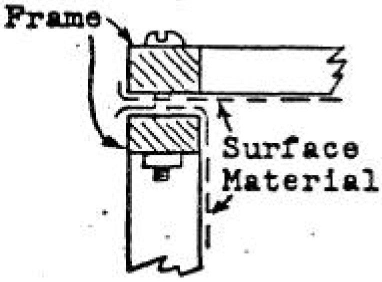
horn efficiency. However, for the same gain, about 8 times more surface material is required with the horn. Since conductive material (screening, etc) is relatively expensive, the horn may be more expensive but permits more simple construction techniques to be employed. Another consideration is the volume or space occupied by the horn as compared with a paraboloid.

A horn lends itself to low angle radiation while a paraboloid is most suitable for high angle pointing. This latter consideration presents a mounting problem but has interesting implications. Low angle radiation is necessary for long haul DX work but does not restrict short haul or local paths via the moon. High angle radiation restricts the long haul path, the horn with its natural low angle mounting must also have good foreground clearance at least to the -10 db level radiation pattern for reasonably low noise performance.

One of the greatest advantages of the horn is that the feed point is readily accessible near the ground so that equipment may be mounted directly at the feed with little or no feedline losses. Although feed mounted equipment can be physically realized with a front fed paraboloid, the equipment is directly in the aperture area causing blockage and scattering in addition to being difficult to reach for adjustment.

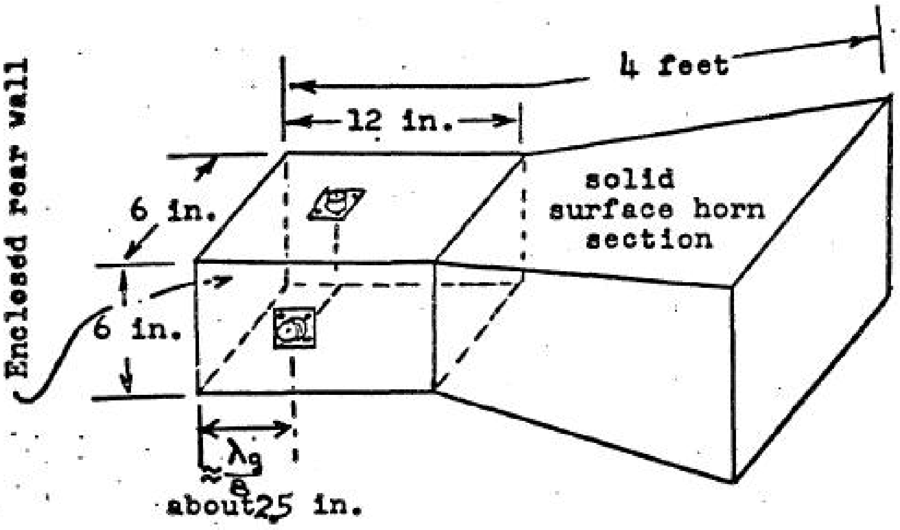
Construction Comments: The horn surfaces may be constructed of any reasonably conductive material such as aluminum window screening,
hardware cloth, aluminum foil contact cemented to wood or fiber board panels, chicken wire with hole sizes no longer than about 1 inch, etc. Since all the horn surfaces are fiat, a simple frame construction can be used. Where overlapping of material is necessary and at frame joints it is recommended that overlaps of essentially λ/4 or 2.25 inches be made with clamped surfaces. In the horn corners the surfacing material may be brought over the framing around the frame so that the overlap is compressed between frames.

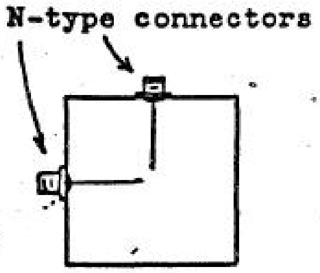
It is also suggested that the small end of the horn be constructed entirely of sheet material well bonded at all seams and joints with similar overlapped and clamped areas where joints between sheet and other Surface material is required. The length of this first
Material solid sheet section should be at least several wave-length, or perhaps a minimum of about 4 feet long. See frame below:



It is also suggested that the small end of the horn be constructed entirely of sheet material well bonded at all seams and joints with similar overlapped and clamped areas where joints between sheet and other material are required. The length of this first solid sheet section should be at least several wavelengths or perhaps a minimum of about 4 feet long

The Square waveguide or feed section should be made of heavier since in all probability a transition from waveguide to coax line will be required.
The heavier wall permits direct mounting of a type-N receptacle for probe excitation or the guide. This is the simplest form of transition and is illustrated
below:


4 feet
12 in.
6 in.
solid surface horn section
Enclosed rear wall
6 in.
≈ λg/e
about 2.5 in.


N-type connectors

Front View

The probes may be number 10 wire or larger diameter rod soldered directly to the connector.
Type-N panel receptacles have captive pins so that no further support will normally be required to maintain the probe mechanically fixed in position. The length of the probe and the position with respect to the short-circuit or rear wall should be adjusted for minimum S W R on the coax line.
Although for best matching results the complete horn should be available only the first solid section will be adequate for initial adjustments.
The rear-or-short.-circuit wall should be well bonded electrically to the waveguide. In making impedance matching adjustments the horn must be aimed into a region free of obstacles or straight into the sky.

The-two-probes are in the same transverse plane in the guide and their tips may became close together. Nevertheless, the coupling between the two probes should be -20 db or less. Should this not be the case by direct measurement, the probes may be carefully bent or skewed slightly until minimum coupling exists. Under these conditions the two probes will be mutually independent and permit circular polarization to be implemented as indicated earlier.

Concluding Remarks: Although the optimum horn has same appealing land useful characteristics, the primary ones being construction intolerance and low noise, the required gain of a single horn for EME work results in a very large space consuming structure which will be difficult to steer. .A more practical solution to the use of the horn design is in an array of perhaps four -24 db gain horns all fed in parallel through a suitable low loss-interconnecting feedline harness.

Careful consideration should be given to all the advantages and disadvantages of the horn antenna with respect to your individual situation before construction. It is this author's opinion that while the horn has great merit for EME work, the paraboloidal reflector type antenna is more practical.
This report has been presented in response to requests for horn design information.
As an addendum to this report, a one page design sheet for optimum horns of 15 and 20 db gain at both 1296 and 2390 mc has been included.
The dimensions are accurately computed in order that these horns when accurately -constructed and impedance matched will serve as standard gain horns with gain tolerance of +/- 0.2 db for comparison measurements with higher gain antenna’s.
For best gain accuracy, the horn should be made of conductive material s-material with all joints well bonded.

These designs are for linear polarization only and the feed sections are standard size rectangular wave guides. These horns also serve very well as relatively easy to construct low gain antennas for terrestrial communications. A thin sheet of polyethylene, vinyl, or Mylar sheet covering the aperture can be used for weatherproofing the horn.

SQUARE APERTURE OPTIMUM HORN DESIGN FOR 1296 MC

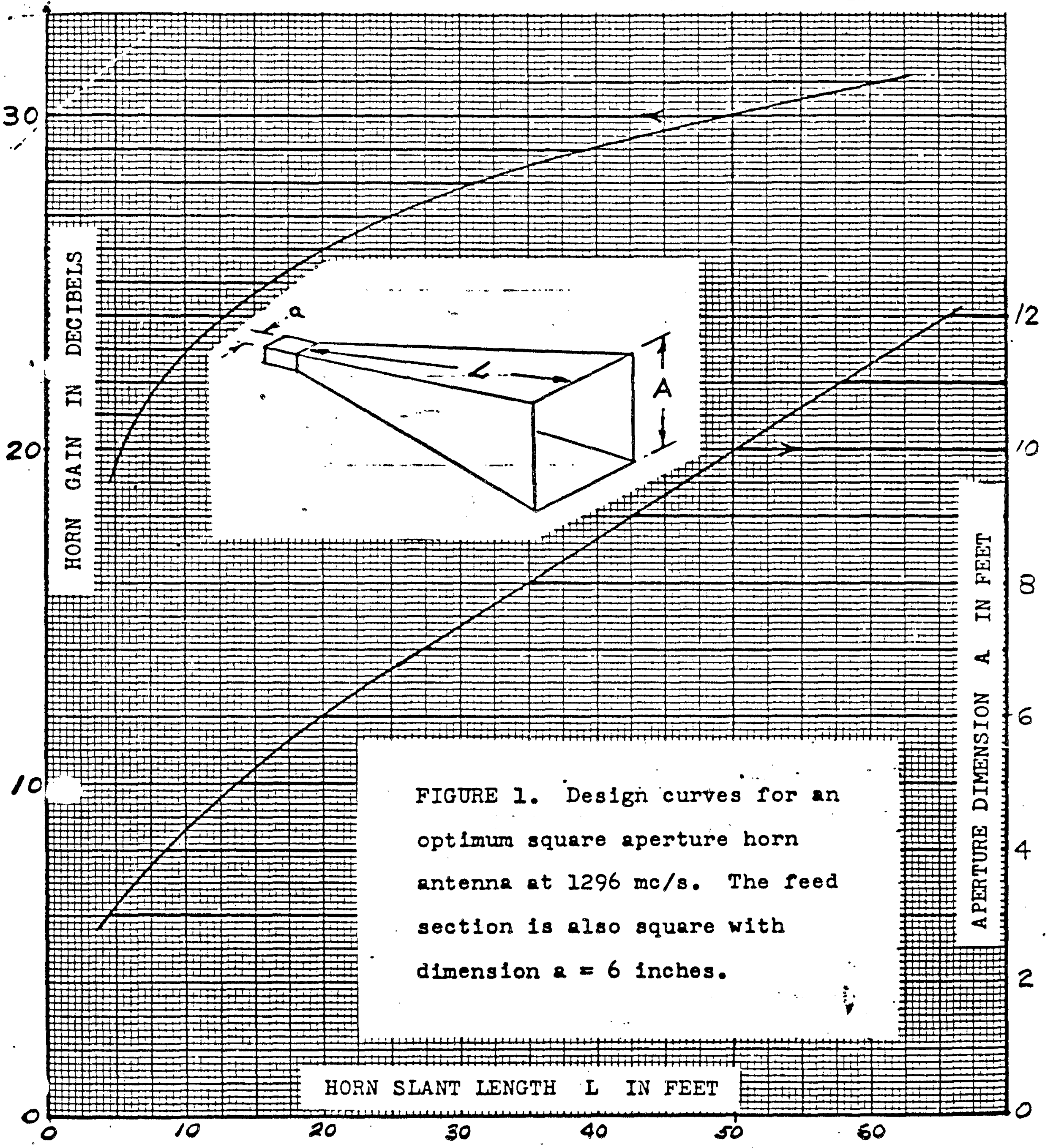
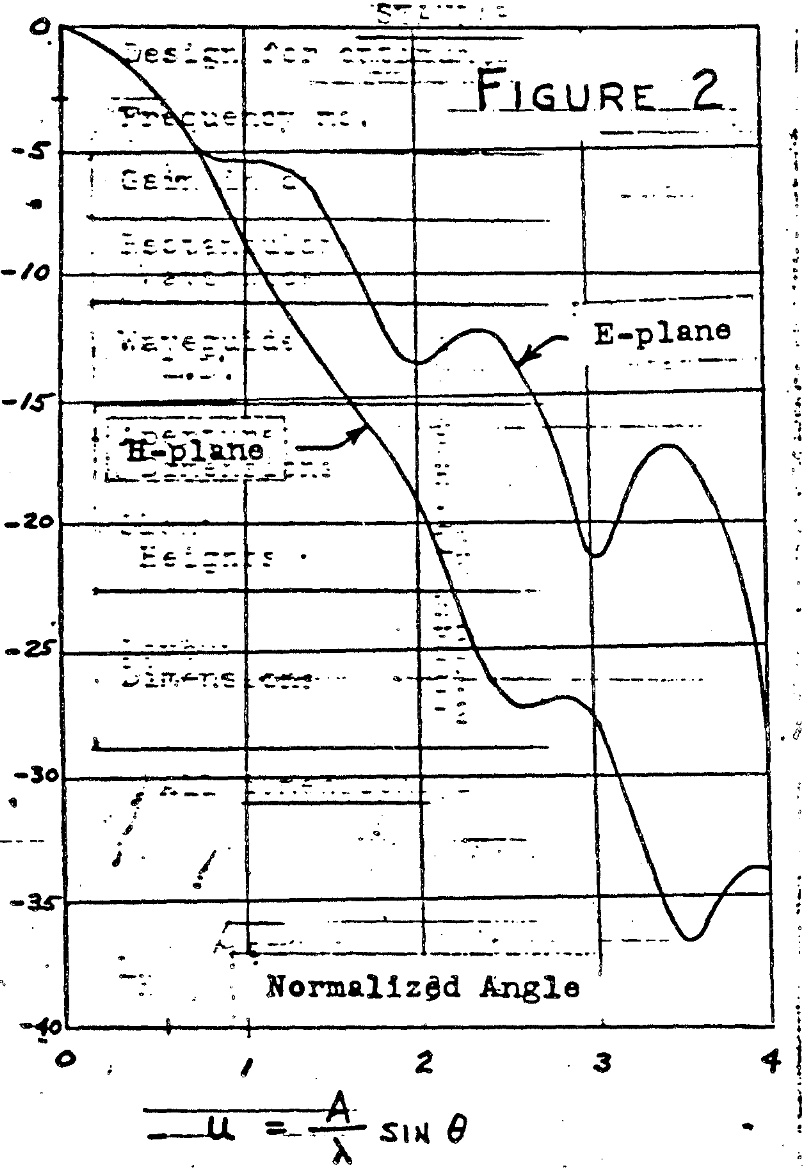
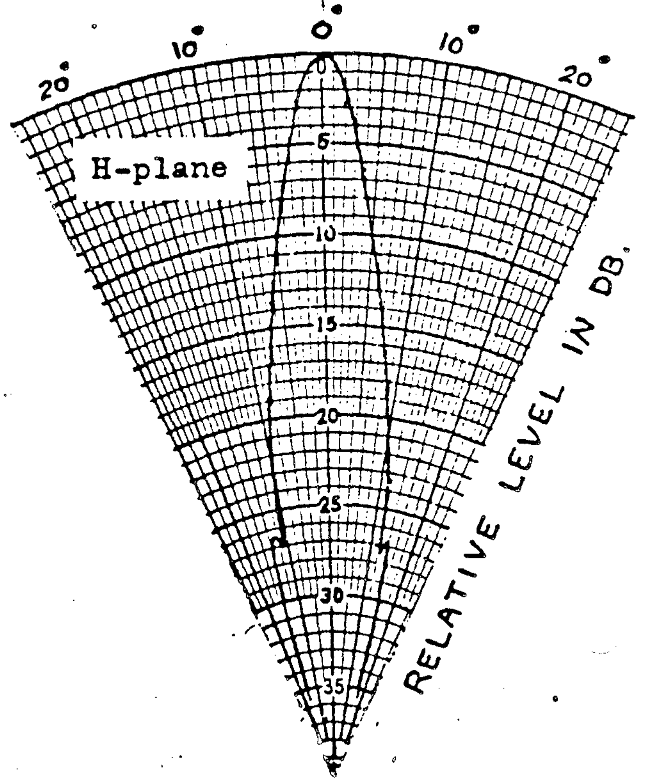
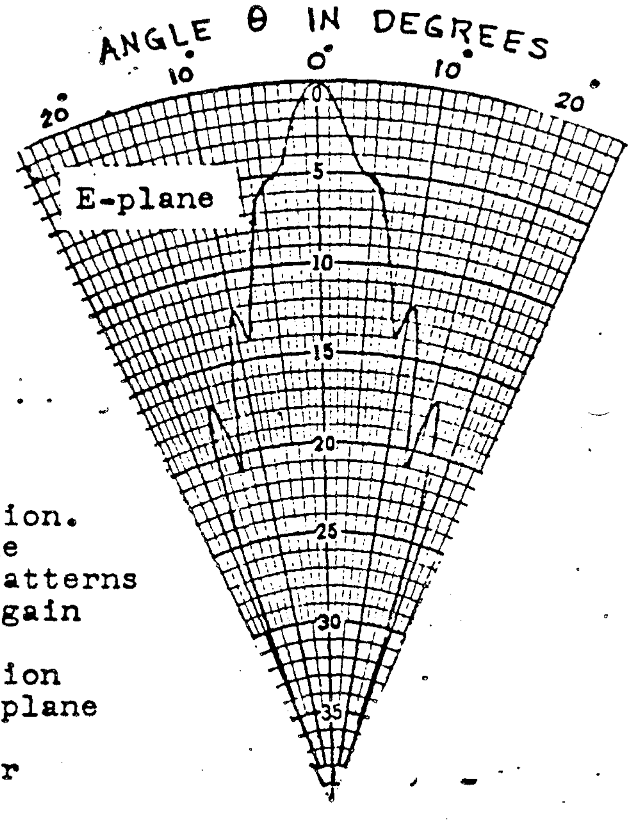


FIGURE 1. Design curves for an optimum square aperture horn antenna at 1296 mc/s. The feed section is also square with dimension a = 6 inches.







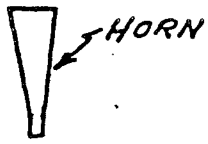


Figure 2. Shown above are the principal plane, E and H plane, radiation patterns for an optimum horn with linear polarization. The angle scale has been normalized to the aperture dimension A, which makes these patterns universal for any size optimum horn with gain greater than 10 db.

For circular polarization the radiation pattern will more closely resemble the E-plane linearly polarized pattern shown above.

The half-power beamwidth for circular polarization is in degrees approximately

$$\theta^\circ = 2\ \arcsin\left(\frac{0.44}{A}\right) \quad \text{for 1296 mc.}$$

where A is the square aperture size in feet.

The linearly polarized patterns to the right are shown in polar form and are for a specific horn having 30 db gain and a 10 X 10 foot aperture.

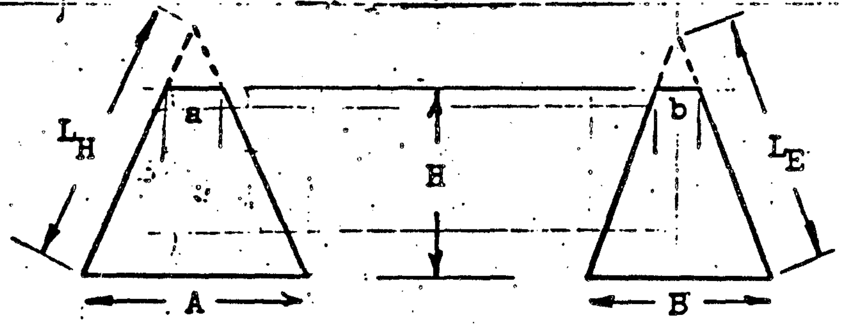
March 28, 1967
W2IMU

STANDARD GAIN HORN DIMENSIONS

Design for optimum gain pyramidal horn is 3.1 db below area gain.

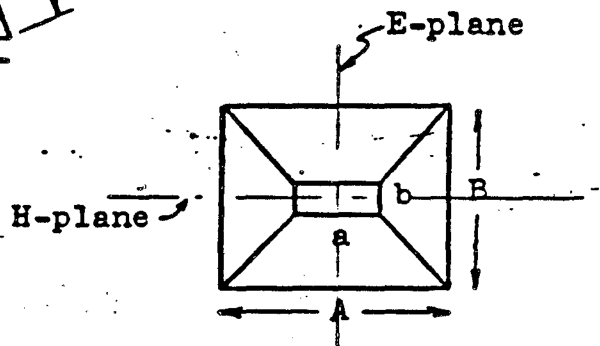
Frequency mc.		1296	1296	2390	2390
Gain in db		15	20	15	20
Rectangular Waveguide		WR650	WR650	WR340	WR340
Waveguide I.D.	a	6.50	6.50	3.40	3.40
	b	3.25	3.25	1.70	1.70
Aperture Dimensions	A	21.47	41.67	11.62	22.56
	B	15.78	32.52	8.55	17.62
	H	8.19	47.45	4.49	25.83
Slant Heights	L_E	12.99	55.17	7.05	29.91
	L_H	15.92	59.96	8.60	32.44
Layout Dimensions	H_1	10.31	49.66	5.65	27.03
	H_2	11.10	50.60	6.09	27.55
	D_1	14.79	58.83	7.99	31.83
	D_2	13.98	56.22	7.59	30.49

All dimensions are in inches to inside surfaces

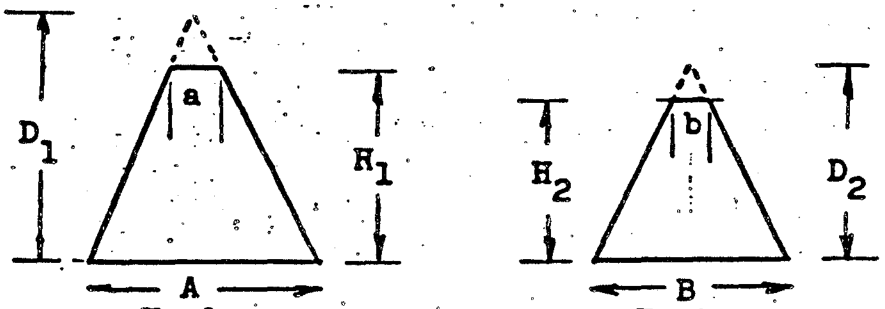


H-plane E-plane

Cross-section Dimensions



Front View

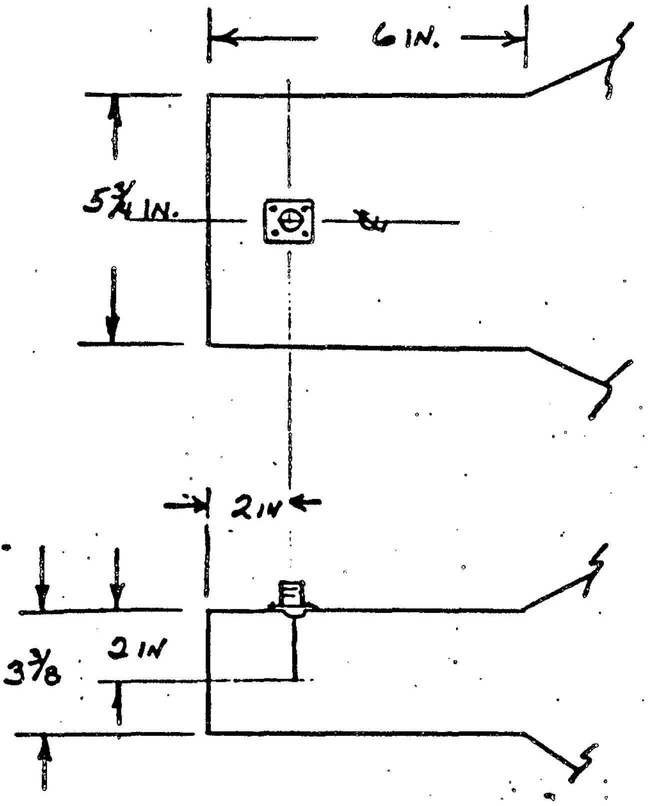


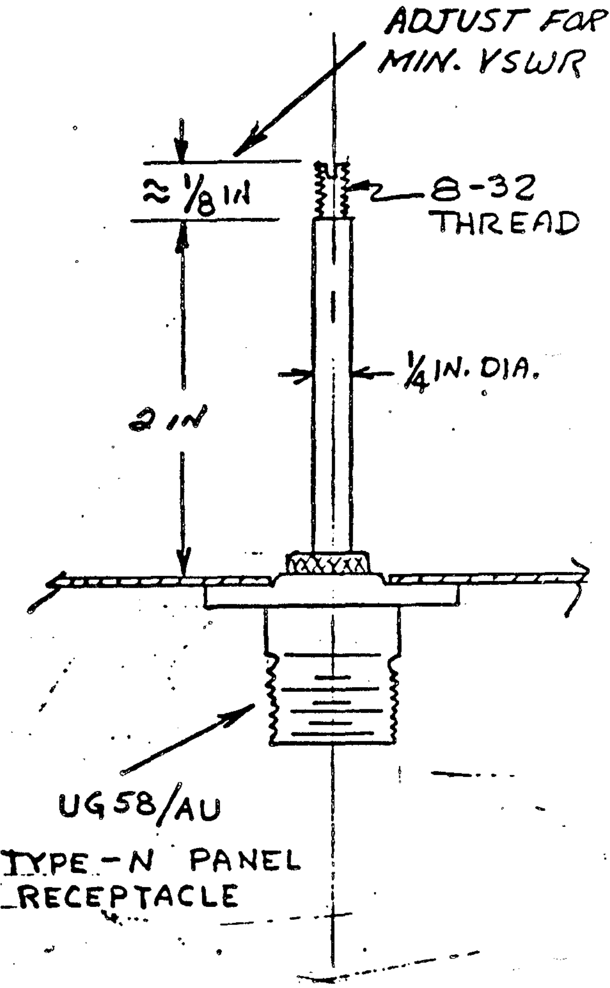
H-plane E-plane

Layout Dimensions of actual sides of horn

Coaxial Line (50 ohm) to Rectangular Waveguide Transition

W2CCY





This coax to waveguide transition is suitable for the standard gain horn design at 1296 mc only. The short section of rectangular guide inwhich the coax probe is located may be fabricated of sheet material or from a standard minibox with one end removed and all joints thoroughly bonded with screws every inch or two.

These dimensions do not correspond exactly with the standard rectangular waveguide size and allowances must be made at the interface between horn and transition. The dimensions shown above are inside dimensions in inches.