Low Cost Horn Antennas for 23 cm EME

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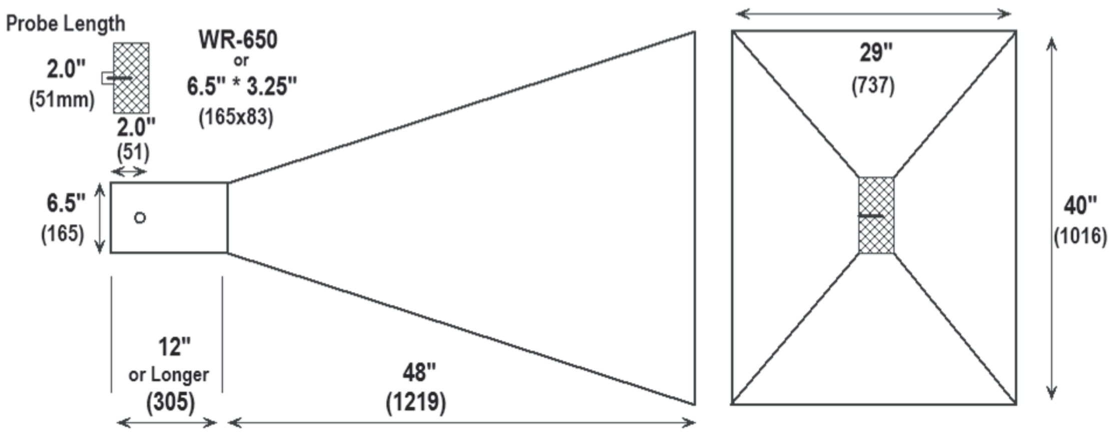
“What is the best antenna for EME?” is an online topic that crops up from time to time. “Lowest cost”, was added to another posting. The band of interest is 23 cm. Looking at the station log sheets, the most commonly used antenna for this band is the parabolic reflector (dish) followed by the yagi. Common is not quite accurate as out of the hundreds of earth-moon-earth (EME) contacts on this band only a couple were made with yagi stations. The only other antenna tested for 23 cm EME, in the receive mode only, was a mid size 15 dBi horn. It appears then the dish wins out and with a high efficiency feedhorn it is tough to beat. So which is the easiest, lowest cost antenna to construct? Value analysis of each the antennas noted above was made. A starting point would be to determine the antenna gain needed to make EME contacts. Over fifty 23 cm EME stations have excess gain and power levels to communicate with low power stations. This includes the small, commonly used 3 m dish. Over a dozen of those high gain/power stations will have over 10 dB gain to spare when communicating with the 3 m dish. This would place a minimum receiving antenna gain targeted around 20 dBi. At this gain level, reception of larger EME stations should be possible and with 250 W or more of power, contacts could also be made. For a 20 dBi gain antenna to have a higher EME success rate though, the ability to use circular polarization would be desirable. Communication from linear to circular polarized antennas encounters a loss of about 3 dB which cuts into our margin of success.

The prime focus dish is well understood. With advancements in feedhorn designs, efficiencies up to 67% are possible with antenna temperatures (Ta) in the range of 30°K as calculated and measured on a 20λ diameter dish(1). With a dish diameter of 10λ (about 2.4 m on the 23 cm band), gain is approximately 28 dBi. At a diameter of 1m, the dish offers about 20 dBi of gain which is the planned target. As the dish’s diameter is reduced though, Ta will rise due to a higher percentage of feedhorn blockages. Building and mounting the dish is where the labor and cost come into play. Despite the added mechanical construction, if a small used dish is available, then the dish is the value winner. Yagis were also analyzed. The antenna temperature for the yagi was much higher than other antennas tested, but its lightweight and portability has advantages. Student’s success was noted in building 70 cm yagi’s for the EME test with Arecibo last year. A 23 cm test yagi was built but it was determined that this was not the way to go for the beginning builder. Construction and tuning yagis on 70 cm is far easier than 23 cm. Besides, one criterion is for the antenna to be converted easily to circular polarization with low losses which is where the yagi falls short at higher frequencies. The horn is one of the oldest antenna designs to choose from. The horn antenna is known for having a low noise temperature but lower efficiency for its size and material usage as compared to a properly illuminated dish. A look at optimum gain charts for a 20 dBi horn illustrates a horn size of 4 feet long and an aperture of approximately 3 feet square. This gain is assuming 50% efficiency. Noting this is about the same gain per aperture size as a 1m dish although more surface material is needed for a horn. After further research, it was decided to build and analyze two large horn antennas.

The first horn was constructed by students with design goals of simplicity and low cost construction. To keep the horn simple, linear polarization was utilized therefore allowing nearly any horn shape to be used. After evaluating the horn length versus construction techniques of round, square, and rectangle waveguide sizes, the rectangular horn was favored. This is also known as a pyramidal horn. A set of dimensions for an optimized 20 dBi gain horn were given(2)(3). Suitable material ideas to be used for the horn ranged from plywood coated with a conductive paint to galvanized hardware cloth (cage mesh wire). The lowest cost and easiest approach though was to use a single 48 in * 96 in sheet of foam siding-insulation backed with aluminum film. The sheet cost under $15. The original horn aperture dimensions were adjusted in order to cut four complete patterns from the single sheet. The new dimensions (Fig. 1 – 2 shown in inches and (mm)) should produce a gain of about 20 dBi. A $10 roll of aluminum tape from the same home improvement store was used to hold the seams together with the aluminum film placed on the inside of the horn (Fig. 3). Duct tape was used to reinforce the outside edges (Fig. 4). The project took less than one hour to complete.

Fig 1 -2



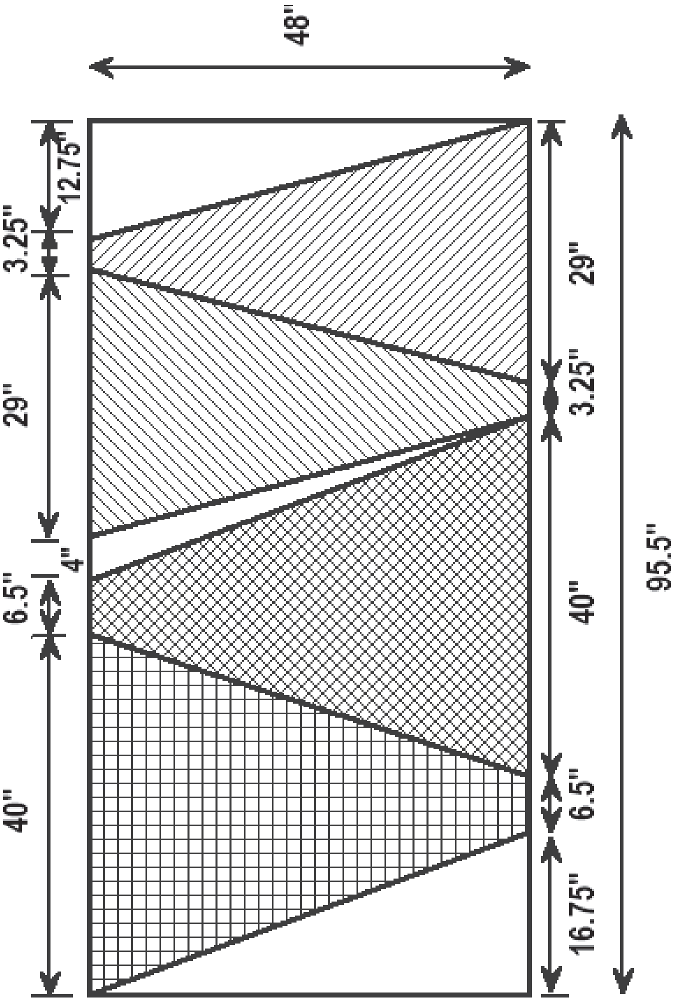


fig 3

fig 4

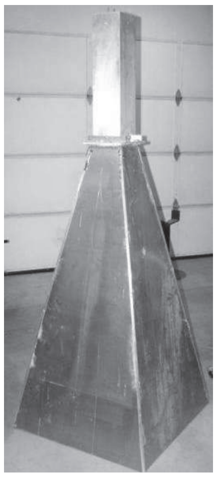
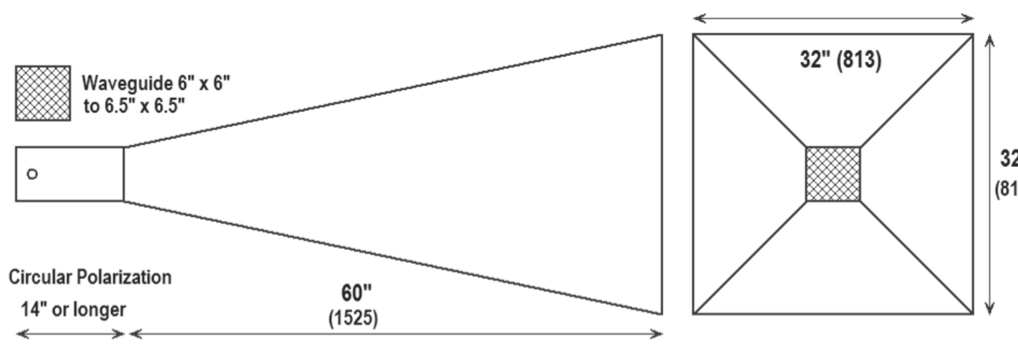


fig 5

The second horn antenna design goal was to use circular polarization (CP). A horn with symmetry is needed. Round and square horn proto types were constructed. There are round, dual mode horn designs which have very low antenna temperatures. After constructing round proto types, noting once above an aperture size of 20 inches, a larger square horn was easier to construct. In an effort to test and analyze antenna temperature, the square CP horn was made slightly longer than the standard optimized sized pyramidal horn. The horn input is 6 x 6 inches to match the CP section. Some gain is added by using a longer horn with the same aperture so the aperture was reduced to 32 inches. This horn also has approximately 20 dBi of gain. The large CP horn was designed to be used more as a test instrument using welded and bolted joints built from 64 and 125 mil, 6061-T6 aluminum. With a square septum CP waveguide section bolted to the input the total weight is 55 lbs (Fig. 5). It would take two sheets of aluminum/foam insulation to build this horn. Figure 6 is the horn dimensions in inches and mm.

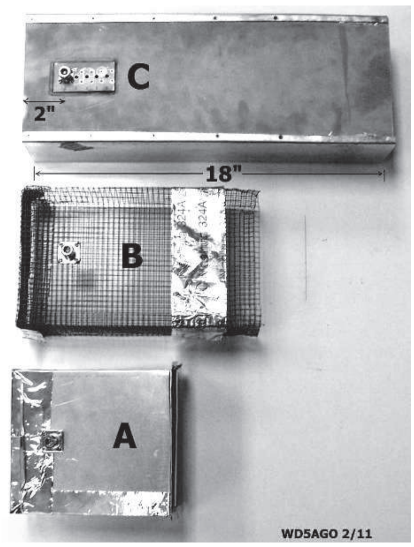
Transition Construction: The 6.5 * 3.25 inch waveguide input was chosen as it is a standard waveguide size number, WR-650. Trying to find this waveguide size though may be a problem. Several different rectangular coax to waveguide transition sections were built to feed the horn (Fig. 7). The first waveguide transition built used a 7 inch wide by 20 mil thick aluminum folded into an open box (Fig 7-A). The 7 inch long transition measured the poorest return loss of the lengths tested for WR-650.

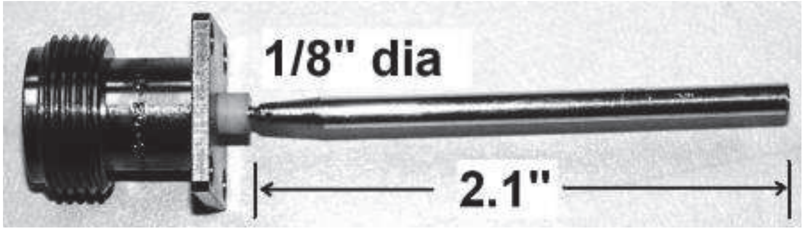
Fig 6

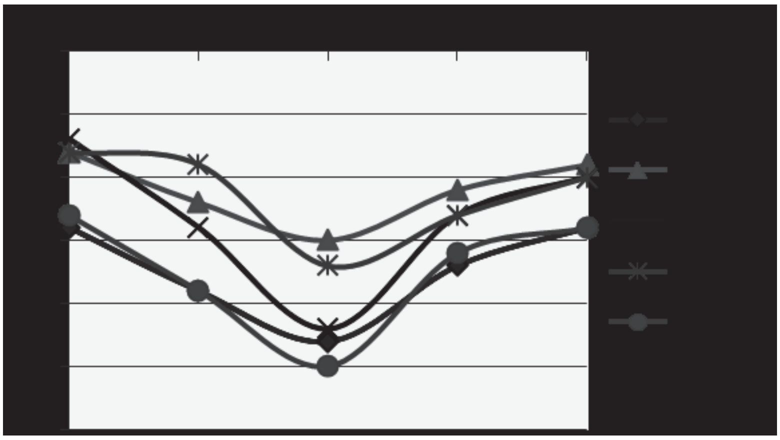


Several probe positions and lengths were tested. It was determined that a longer waveguide section should offer greater performance. Using some ¼ inch hardware cloth (Fig 7-B) we formed a new transition which measured a lower return loss. The small holes in the hardware cloth do not hinder the waveguides operation as they are smaller than 1/10th the operating wavelength. A fun experiment with the hardware cloth waveguide is to move the location of the coax coupling probe and note the changes in return loss. Highest performance was observed with probe placements from 2 to 2.7 inches away from the closed section of the waveguide using a probe 2 inches long. About 1 inch of the hardware cloth waveguide was used to fold and tape down to the inside of the horn. Total cost for the waveguide transition was under $15 including the N connector and #12 wire probe. One advantage of the low cost horn antenna project was that it is light, weighing in at only 5 lbs; but the antenna becomes a kite on windy days. The hardware cloth flexed too much. A third waveguide transition was made which would have more strength. Waveguide (Fig. 7-C) was made by wielded and bolting aluminum together which provided a mechanically stable transition. This coax to waveguide transition was made 18 inches long to test effects on return loss as compared to the shorter transition sections. With the waveguide open, the best return loss (-30 dB) was with the probe 2.5 inches from the back. With the waveguide connected to the pyramidal horn, the best return loss favored the probe to be 2 inches from the back (went from -17 to -25 dB). A plate with holes tapped allowed the probe to be moved in ½ inch steps. Probe length should start at 2.2 inches and trim down to about 2.1 inches as measured from the inside waveguide wall (Fig. 8). A larger diameter probe may offer broader bandwidth were a smaller diameter may offer lower return losses at a given frequency. AWG #12 to 1/8 in brass will work fine. The CP, 12, and 18 inch transitions performed satisfactory with the winner going to the 18 inch transition. Graph 1 illustrates a swept frequency response of the coax transitions from 1.2 – 1.4 GHz. A linear 15dBi horn was also built based on the W2IMU notes, except a common 6 x 3 inch OD 6063 aluminum (5.625 x 2.625 ID) stock was used for the transition. Cut to 6 inches long and a probe placed 2 inched from the back at 1.8 inches long, the measured return loss was 26 dB (append 1).

Fig 7



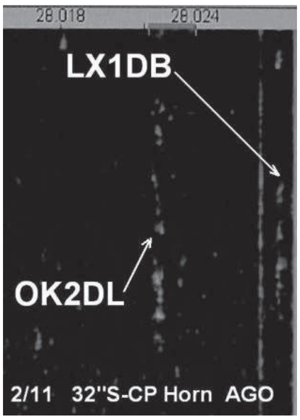

1/8" dia
2.1"

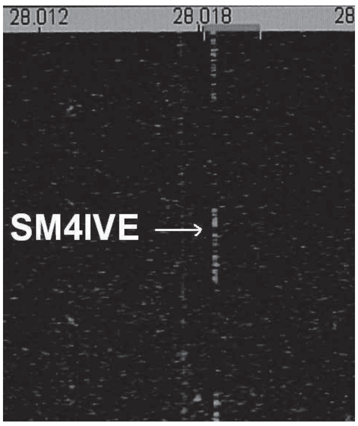


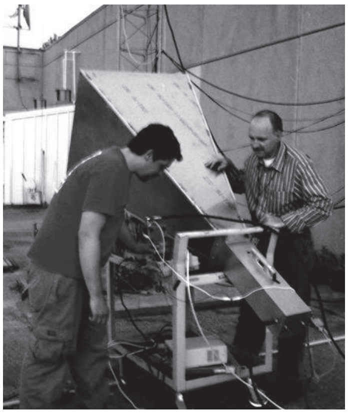
There are several methods to obtain circular polarity for EME. Assuming receiving and transmitting is desired, transmitting is right hand circular when the wave leaves the antenna and receiving is left hand circular. There are commercially available square septum polarizer's which can be used for the transition section for the horn. Another alternative, with slightly higher insertion losses is to use a 90 degree hybrid combiner as in figure 9. Note if a coaxial port on a commercial CP section used for EME is marked as TX or RX then these ports are normally designated for usage in a parabolic reflector. When a dish is using the CP feedhorn CP changes therefore TX is actually connected to the Left Hand port. The ports will reverse in CP usage as a horn antenna is used for EME. Of course for the linear polarized horn it is just plug-and-play.

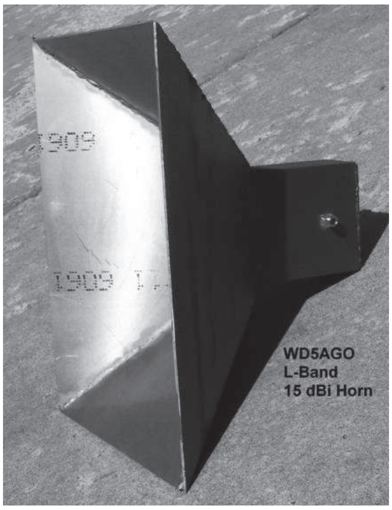
Fig 9 Table 1 Horn Antenna	Long CP	Standard Linear
Gain Calculated	20.0 dBi	20.0 dBi
Gain Measured	19.8 dBi	19.3 dBi
Beam width Calculated	16.5°	16.5°
Sun Noise Calculated	5.8 dB	5.0 dB
Sun Noise Measured	5.0 dB	4.0 dB
CS/G Measured	10 dB	9.2 dB
CS/50Ω	9.9 dB	9.9 dB
Ta	11.0°K	16.0°K

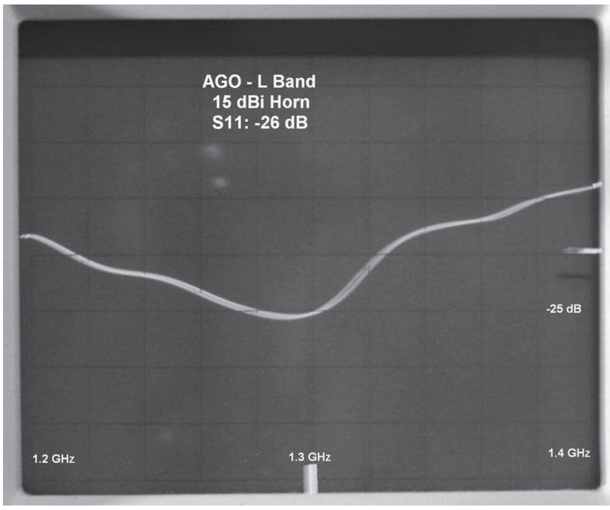
Results: Both horns were tested over a two month period (Fig. 10). Sun noise and cold sky to ground (CS/G) measured results were close to calculated for each horn shown in table 1. Measurements varied over the testing period by +/- 0.2 dB. The low cost linear horn did average about 0.5 dB less gain than the CP horn but both horns were successful in receiving EME signals. The smallest CW station detected was using a 5 m dish and 500 watts. During the *432 MHz and Above EME Newsletters* 23 cm SSB contest, several stations were received on SSB (Fig. 11). Figure 12 is SM4IVE's CW signal received on the linear horn. Both of these signals were heard after down conversion on an IC-706 and SDR-IQ receiver. The CP horn was 2 to 4 dB better on receive which should be expected with transmitting stations using CP. The LNA designed and used measures 14°K (0.2 dB n/f) at 40 dB gain. The measured Ta is 16°K for the linear horn and 11°K for the CP horn(4). The VK3UM system calculator is a valuable tool in comparing measured and calculated results. These horns were also compared to a low noise, round, dual mode horn which measured approximately 8°K Ta(5). For a club or student organization, the linear, less than $50, horn antenna should offer plenty of 23cm EME and radio astronomy signals to be received. All that is needed is a low noise amplifier and receiver. If EME communications are desired, adding circular polarization to a square or round horn should help reduce the power needed to be successful. Shown in figure 13 is our CP set-up for several completed random CW EME contacts during the month of April. Stations worked included K1RQG (559), G4CCH (339), LX1DB (559) and SM4IVE (339). Another 10 stations were copied and called. The system was as noted above with a 300W solid state power amplifier at the horn. I want to thank Justin Owen, KF5JBE, who helped with the linear horn antenna construction which was under $30 and Joe, K1RQG (SK) with the on air testing. As illustrated in this paper the total cost including the CP transition section for the aluminum horn antenna was under $200. This amount could be reduced by using the construction methods as described for the linear horn antenna.











Appendances: Optimum 15 dBi pyramidal standard gain horn using smaller rectangular (2.6 x 5.6) waveguide, which cutoff is around 1.1 GHz (TE10). 6061 Al all wielded construction. This waveguide size (6 inches long) as shown above provided one of the better broad band return loss of the transitions tested. This illustrates that a variety of waveguide sizes from 5.6 to 8 inches wide can be tuned to work all measured better than -18 dB return loss.

References:
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