SCALAR FEEDS

FOR PRIME FOCUS DISH ANTENNAS

 

Measured Results from Two
Ku Band Horns Tested at 10.368 GHz

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Purpose

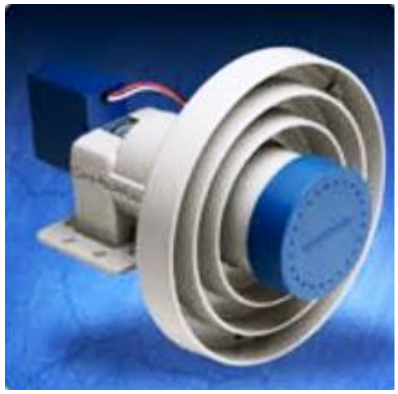
Upgrading my Amateur 10 GHz system has been an ongoing project since 2009. Having obtained a 48-inch dish antenna, I wanted to use the best feed horn I could find. Ku band horns designed for 12 GHz satellite TV reception are available from surplus sources. I performed feed pattern tests to determine if the horns I had would be suitable for my antenna. The test range, equipment, methods, data and feed horn patterns are presented in this paper.

Background on Scalar Feeds

Early parabolic dish antennas used rectangular waveguides or pyramidal feed horns. These feeds inherently created unwanted side lobes resulting from edge currents at the open mouth of the horn. Affordable scalar feeds appeared on the satellite TV market in the late 70s to early 80s. The advertised features of these horns were low sidelobes and a more round, symmetrical pattern of illumination for a circular dish antenna, resulting in lower noise than conventional feed systems.

Receiving watchable TV signals was a technical challenge. The programming came from geo-stationary satellites at a distance of 22,300 miles above the equator. The satellite TV was down-linked to earth on the C-Band at 3.7 to 4.2 GHz microwave channels. From satellite to earth, the typical signal loss was 196 dB. Most local cable TV companies used large commercial reflector antennas on the order of 18 to 25 feet in diameter, but hobbyists and consumers were obtaining watchable TV on 12-foot or 10-foot dish antennas. The smaller consumer antennas needed high performance to pull in acceptable TV pictures. This meant minimizing the noise of the smaller dishes was important. Scalar feeds were used to accomplish this.

Prof. Taylor Howard

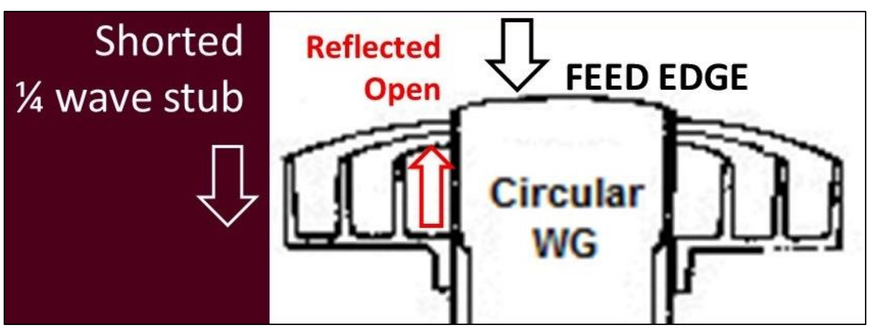


Chaparral C–Band Super Feed

Chaparral Ku–Band Scalar Feed

Radio Amateurs and electronics hobbyists were among the first to design, build and operate home satellite TV receive systems for personal use and entertainment. Consumers followed in the ensuing years as home satellite TV became popular and systems were made available for sale. Electrical Engineering Professor Taylor Howard, at Stanford University, was one of the pioneers in home satellite TV and a radio Amateur (SK–W6UGL). He invented the "scalar" feed for C-Band (Above) and co-founded Chaparral Communications.

How a Scalar Feed Works



The main features of a scalar feed are side lobe suppression and a more symmetrical, circular radiation pattern. Without the rings, the radiation pattern would be oval shaped, having different radiation angles in the E-plane vs. the H-plane. So, the scalar rings re-shape the feed horn pattern, creating a circular pattern for a circular dish. Side lobe suppression is accomplished by cancelling the feed horn edge currents. As seen in the illustration above, waveguide theory tells us that a shorted ¼-wave stub reflects an open circuit with minimum current flow at the open end of the stub. This effectively cancels the feed edge currents, reducing sidelobes.

My Driveway Microwave Feed Horn Range

I had the test gear and experience to set up a compact test range, so I decided to do radiation pattern tests at 10 GHz. The range can be seen in the following photo. Hopefully, the data could help me choose the best horn for my new system.

My Driveway Feed Horn Range

Is a 1–Meter Test Range Long Enough?

Some of us may have done gain testing of microwave reflectors that required a very long test range. The question comes up about how this kind of testing could be done on a compact range. Earlier in my professional career, I set up and qualified a 3-meter open-area test range many times. As an EMI Test Engineer, I made measurements of RF and microwave signals for FCC and European regulations. Radiated emissions tests were required to be performed at a minimum distance of 3 meters to ensure the RF wave fronts were sufficiently flat, or “planar,” resulting in more accurate readings. (R3) This is an important design aspect of any RF or microwave test range.

So, in setting up my compact 10 GHz range, I had to think about what the appropriate measurement distance would be. Antenna pattern testing is usually done in the “far field” of the antenna at the frequency of interest. The larger the antenna, the longer the distance required to be in the “far field.” Far field is defined as the distance from an antenna where the radiated wave front is essentially flat. (R4, R5) This distance is determined by the following equation:

$$D_{ff} = 2A^2 / \lambda$$

where: D_{ff} = Distance to far field
A = antenna aperture
λ = wavelength

Wavelength at 10.368 GHz is 28.9 mm (1.14 inches). The largest feed horn width I tested was the 3-channel Chaparral, at 54 mm. Applying the equation above at 10.368 GHz, the far field for this horn begins at about 7.9 inches. Far field distances for the scalar horns under test are shown in the following table.

Aperture	Far Field Distance Dff = $2A^2 / \lambda$	Horn Type
20.6 mm	29 mm = 1.2 inches	¾-inch copper pipe
44 mm	144 mm = 5.3 inches	Chaparral 2-Channel
54 mm	202 mm = 7.9 inches	Chaparral 3-Channel

Table A – Calculated Far Field Distances

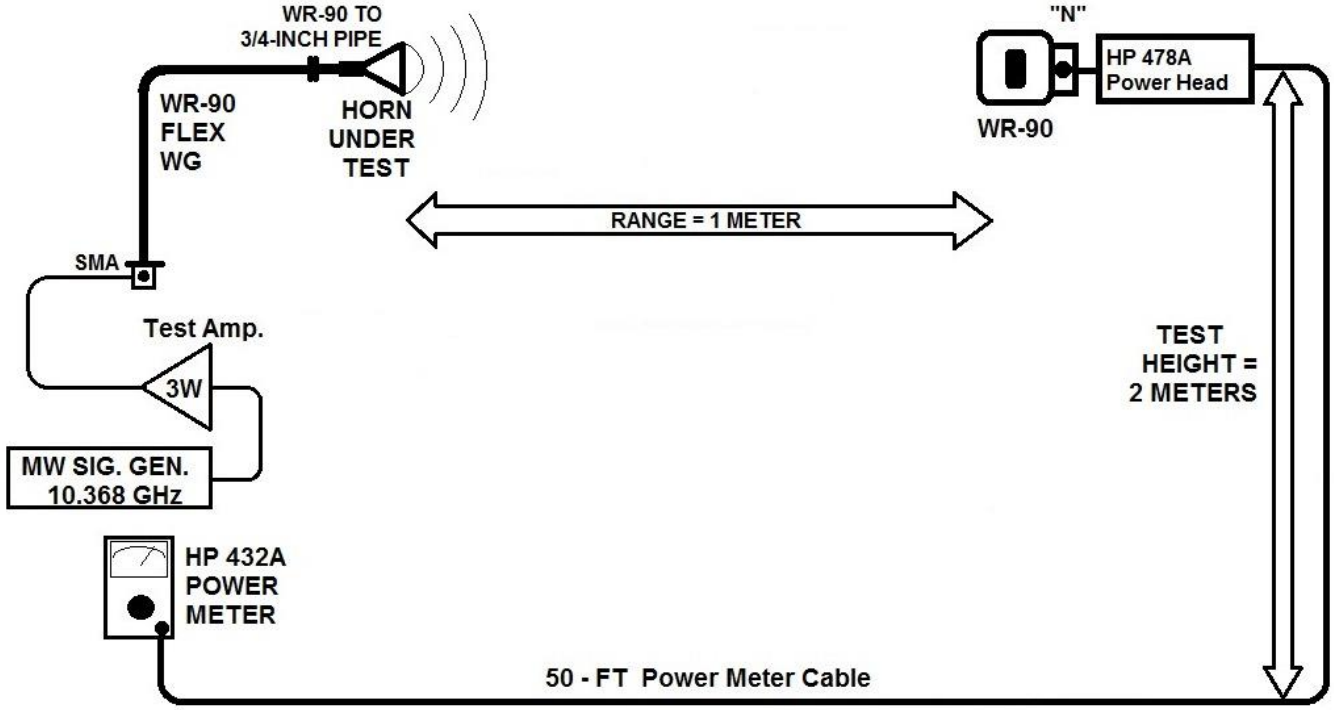
With the small aperture sizes associated with feed horns and open waveguide, a 1-meter test distance puts all the horns tested in the far field. For the largest horn, a one meter range would be nearly five times the minimum far-field distance. So I set up the test range for a measurement distance of 39-3/8 inches (1 meter).

Test Equipment and Fixtures

While my test instrumentation was not "state of the art," it was still functional and more than adequate for the testing. A list and diagram follows:

- HP 8620C Sweep Oscillator (in CW mode)
- DEMI 3WPA 3-Watt Amplifier (10.368 GHz)
- HP 5350 B Microwave Frequency Counter
- HP 432A Power Meter
- HP 478A Thermistor Power Head
- HP X281B Adapter (WR-90 / "N")
- WR-90 Flex Waveguide (24")
- WR-90 Right Angle Bend
- Quickset "Hercules" Tripod
- 12 V Power Supply

As can be seen in the following block diagram, the measurement system uses an analog power meter with a 50-foot power head cable. This enables power level changes to be seen immediately, faster than “real time” as defined by digitized systems.



Feed Horn Test Equipment Setup

A 3-Watt amplifier was used to compensate for the 1-meter range loss and present a measurable signal to the power meter. System dynamic measurement range is about 35 dB. While the frequency counter is not in the diagram, the generator output frequency was checked at the beginning, midpoint and after the data collection to ensure the frequency was stable within about 3 kHz.

The HP 8620 C sweep oscillator is not a “rock–solid” stable frequency instrument. It will drift in frequency by several hundred Hz. I checked this instrument with the power meter before the testing. Even though the frequency may drift a bit, the output level stays pretty constant within 10ths of a dB. It has an automatic level control circuit, so I believe it is working on this instrument.

The Horns Under Test

I have obtained two Chaparral Ku band feed horns over the past few years of collecting parts for my Amateur 10.368 GHz systems. One has two channels, the other has three. Measuring the patterns helped me decide which one to use. I also measured an open copper pipe to provide a contrasting pattern for comparison.

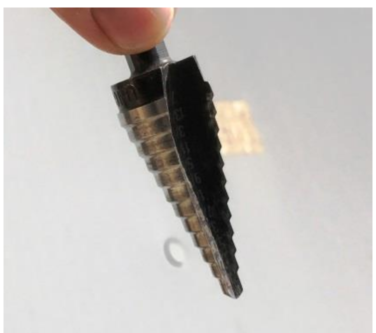
2–Channel Scalar

3–Channel Scalar

Open 3/4–Inch Copper Pipe

I expected before the testing that the two scalar horns would be pretty similar in their patterns. I include the results from an open ¾-inch copper pipe waveguide to illustrate the advantage of the scalar horn design. Also, there were two variations on the 3-channel horn. One was drilled out to fit a ¾-inch pipe using a combination bit. The combination bit leaves a couple of steps in the horn waveguide between the copper pipe and the horn inside diameter. I had questions about whether this double step transition affected the radiation pattern. So I had a friend machine out a second 3-channel horn for comparison. The results of this comparison are included in the data that follows.

Drilled Horn



Combination Bit

Machined Horn

The other variable in the testing was that I used tan-colored packing tape over the mouth of the horns to see if it made a difference in the patterns. Tan packing tape is what I use to keep dust and insects out of the waveguide feed system.

Test Procedure

While it may seem as though some of the steps are unnecessary, all the steps are for the purpose of measurement accuracy and repeatability. Note that the abbreviation AZ means azimuth and the rotation begins at the 10 deg. AZ position through 90 deg. AZ. Negative degree positions (-10 through -90) on the graphs that follow indicate positions beginning at 350 deg. AZ through 270 deg. AZ.

1. Zero the power meter.
2. Enable the 3W P.A. and turn on the generator output.
3. Point the tripod–mounted horn at the power meter head.
4. Adjust the tripod up and down until a peak indication is obtained on the power meter.
5. Lock down elevation position.
6. Swing the fixture right and left until a peak reading is obtained on the power meter.
7. Position the angle pointer so it points at the current position (zero degree mark).
8. Zero the power meter.
9. Adjust the generator output until the power meter indicates the 0 dB reference level. (Any level can be used as the reference, but it should be as high as is practical)
10. Swing the tripod left (CCW) to the 10 degree AZ mark and record the meter reading.
11. Repeat for 20 and 30 degrees AZ.
12. Swing back to the center (peak) position and re-check for 0 dB.
13. Zero the power meter and adjust the generator output for 0 dB reference.
14. Swing the tripod left (CCW) to the 40 degree AZ mark and record the meter reading.
15. Repeat for 50 and 60 degrees AZ.
16. Swing back to the center (peak) position and re-check for 0 dB.
17. Zero the power meter and adjust the generator output for 0 dB reference.
18. Swing the tripod left (CCW) to the 70 degree AZ mark and record the meter reading.
19. Repeat for 80 and 90 degrees AZ.
20. Swing back to the center position and re-check for 0 dB.
21. Zero the power meter.
22. Repeat steps 9 through 19 for 9 positions to the right (CW) of the center 0 degree mark.

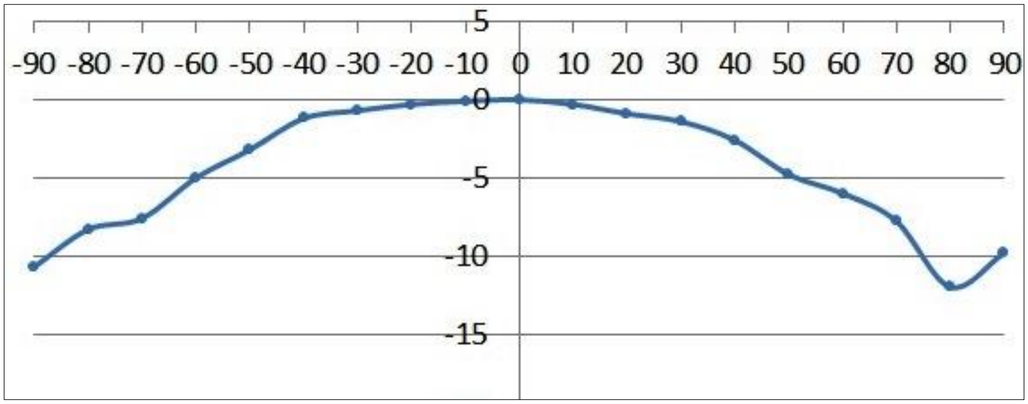
Controlling possible sources of error in radiated RF & microwave measurements is important for valid data. The two most significant potential error conditions were wind and power amplifier output level changes. When the wind was blowing, sometimes the power sensor would move, causing variations of about + and – 1 dB. In most cases when "wind wobble" was present, I simply waited out the wobble and took the data point when the power sensor was stable.

The 3-Watt power amp output power decreased when it got hot, so the temperature was controlled by removing power from the amp when measurements for one horn were completed. I also ran the (3-Watt) amp at 1.5 Watts output to reduce the heating.

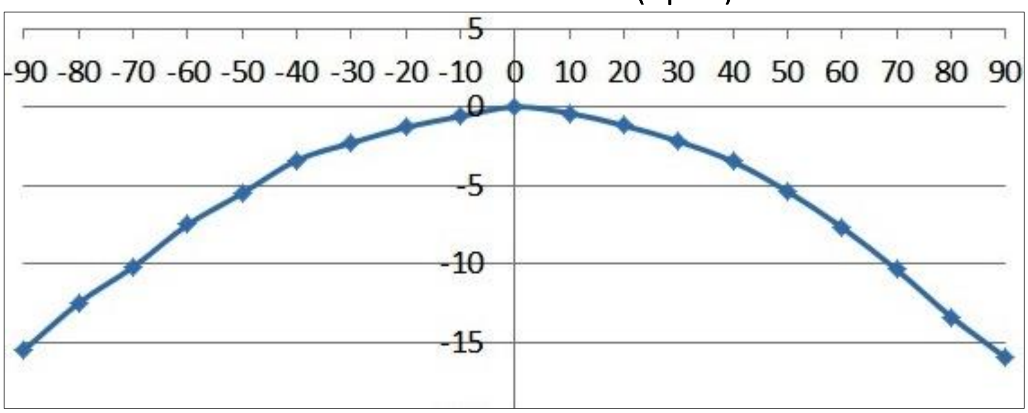
Data and Results

Data points were taken at 10 degree intervals 90 degrees right and left of the direction of the maximum power axis. My prime focus reflector has illumination angle of about 135 to 140 degrees. So, data collection between the angular values of + / - 90 degrees should include the most important values for my limited evaluation.

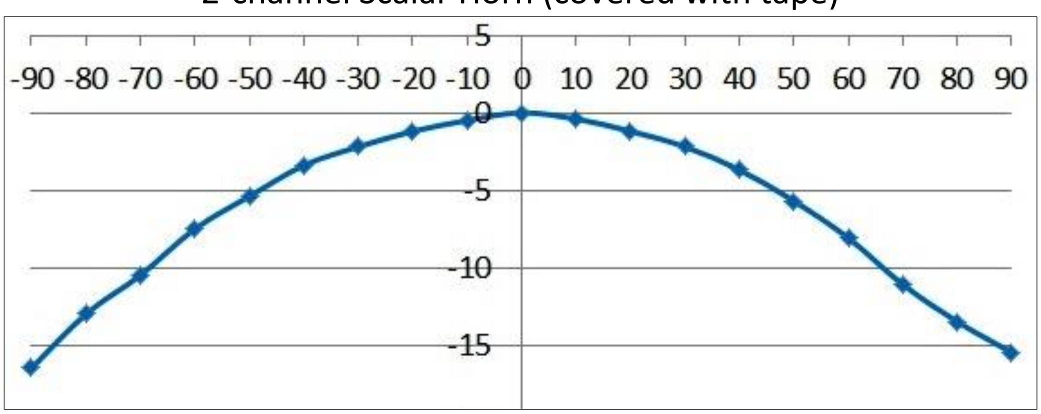
Open ¾-inch copper pipe (open)



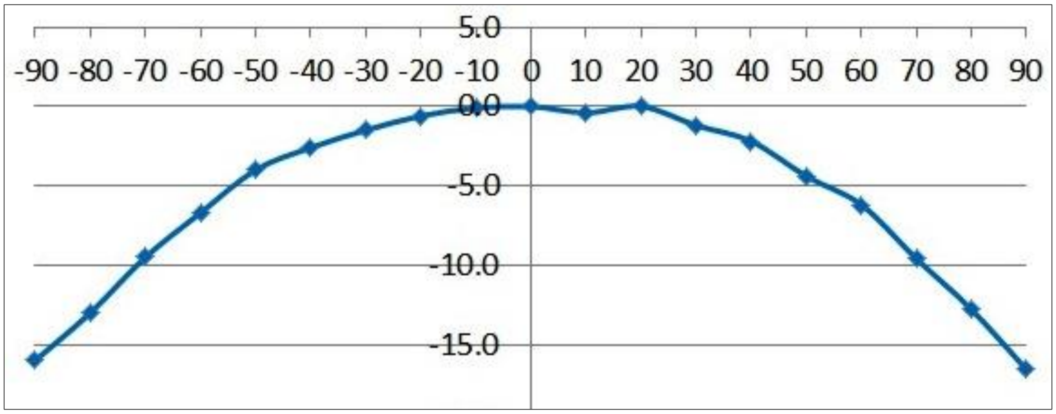
2-channel Scalar Horn (open)



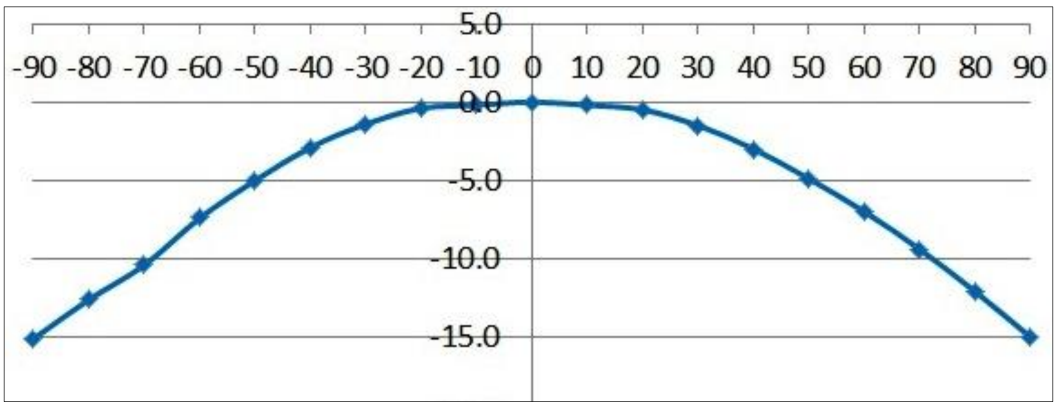
2-channel Scalar Horn (covered with tape)



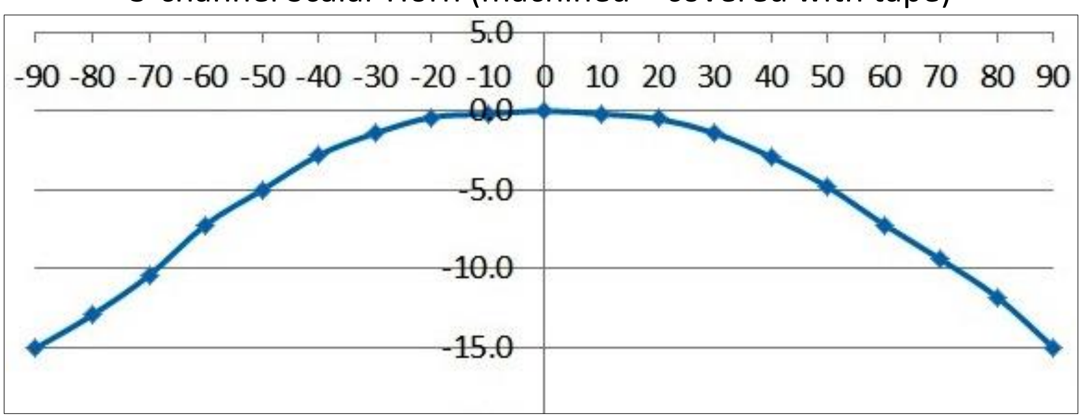
3-channel Scalar Horn (drilled – open)



3-channel Scalar Horn (machined – open)



3-channel Scalar Horn (machined – covered with tape)



Discussion / Conclusions

- The test results show that the scalar horns tested perform as they are intended to. Comparing to an open ¾-inch copper pipe, the radiation patterns of both the 2-channel and 3-channel horns have more smooth patterns, and they show a sharper drop-off of the microwave power beyond the 130-degree illumination angle point.

- It can also be seen by close inspection of the graphs, that there is a slightly wider pattern for the 3-channl horn vs. the 2-channel. This would put more power on the reflector surface and possibly result in better efficiency and gain.

- The crudely drilled out horn seemed to have some pattern irregularities, not as smooth of a pattern as the one that was machined to fit.

- The patterns of the 2-channel feedhorn with and without tan packing tape covering the opening were very similar; too close to determine if the tape had any effect. That is good news to me, meaning I don't have to spend any significant money or time to find a plastic cap that passes microwaves freely.

Numeric data tables are presented below.

Test Data:

Horn Type: 3/4-in. copper   Aperture (mm): 20.6
Flare Angle (deg.): n/a   No. of Channels: n/a

deg.	dB
90	-9.8
80	-12
70	-7.8
60	-6
50	-4.8
40	-2.6
30	-1.4
20	-0.9
10	-0.3
0	0
-10	-0.1
-20	-0.3
-30	-0.7
-40	-1.2
-50	-3.2
-60	-5
-70	-7.6
-80	-8.3
-90	-10.7

Test Data:

Horn Type: 11GHz Chaparral Aperture (mm): 19
Flare Angle (deg.): 180 No. of Channels: 2

deg.	dB
90	-16
80	-13.4
70	-10.4
60	-7.7
50	-5.4
40	-3.5
30	-2.2
20	-1.2
10	-0.4
0	0
-10	-0.6
-20	-1.3
-30	-2.3
-40	-3.4
-50	-5.5
-60	-7.5
-70	-10.2
-80	-12.5
-90	-15.5

Horn Type: 11GHz Chaparral Aperture (mm): 19 **/w/ tape**
Flare Angle (deg.): 180 No. of Channels:2

deg.	Db
90	-15.5
80	-13.5
70	-11.1
60	-8.1
50	-5.7
40	-3.7
30	-2.2
20	-1.2
10	-0.4
0	0
-10	-0.5
-20	-1.2
-30	-2.2
-40	-3.4
-50	-5.4
-60	-7.5
-70	-10.5
-80	-13
-90	-16.5

Test Data:

Horn Type: 11GHz Chaparral – **drilled out** Aperture (mm): 19
Flare Angle (deg.): 180 No. of Channels: 3

deg.	dB
90	-16.6
80	-12.8
70	-9.6
60	-6.2
50	-4.4
40	-2.2
30	-1.2
20	0.0
10	-0.4
0	0.0
-10	-0.1
-20	-0.6
-30	-1.5
-40	-2.6
-50	-4.0
-60	-6.7
-70	-9.5
-80	-13.0
-90	-16.0

Test Data:

Horn Type: 11GHz Chaparral - **Machined** Aperture (mm): 19 w/ Tape
Flare Angle (deg.): 180 No. of Channels: 3

deg.	dB
90	-15.0
80	-12.1
70	-9.4
60	-7.0
50	-4.9
40	-3.0
30	-1.5
20	-0.5
10	-0.2
0	0.0
-10	-0.2
-20	-0.4
-30	-1.4
-40	-2.9
-50	-5.0
-60	-7.4
-70	-10.4
-80	-12.6
-90	-15.1

Horn Type: 11GHz Chaparral - **Machined** Aperture (mm): 19 w/ Tape
Flare Angle (deg.): 180 No. of Channels: 3

deg.	dB
90	-15.0
80	-11.8
70	-9.4
60	-7.2
50	-4.8
40	-2.9
30	-1.4
20	-0.5
10	-0.2
0	0.0
-10	-0.2
-20	-0.4
-30	-1.4
-40	-2.8
-50	-5.0
-60	-7.2
-70	-10.4
-80	-12.9
-90	-15.0

References:

- R1: Paul Wade W1GHZ - High-Efficiency Feedhorns for Prime-focus Dishes - VE4MA and Chaparral feeds with Septum Polarizers - ©2006 w1ghz@arrl.net

- R2: Paul Wade, W1GHZ, *Online Microwave Antenna Handbook Chapter 6 – Feeds For Parabolic Dish Antennas,* 1998 http://www.w1ghz.org/antbook/contents.htm

- R3: *American National Standard for Methods of Measurement of Radio Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz*, ANSI C63.4, 2009

- R4: Krauss, *Antennas*, 1988

- R5: ITT, *Reference Data for Radio Engineers*, 1956