7-11 GRASP MoM (TICRA) of Horn Antennas

We design horns initially using aperture theory by assuming a waveguide distribution in the aperture with a quadratic phase due to the flare of the horn. A mode-matching analysis for circular horns, for example CHAMP (TICRA), starts with an initial design and use optimization to design to a desired gain or beamwidth. The MoM analysis starts with a waveguide port using either rectangular or circular modes to excite currents in the horn walls. The method computes radiation from the wall currents instead of the aperture fields and sometimes combined with BOR-MoM outer wall currents excited by aperture fields of a mode-matching approach, i.e. CHAMP. CHAMP uses the combination of the aperture fields and the wall currents.

7-11.1 Rectangular Horns

The program RECHGRAT generates GRASP MoM TOR file edits in a GRASP MoM project for a pyramidal to a given gain or specified dimensions based on the program RHOPT. RHOPT designs an optimum (minimal material) horn with nearly equal beamwidths given gain at a particular frequency. RECHGRAT can be run using an input file that contains the values of the keyboard inputs.

```
C:\milligan\ANTENNA\HORN>rechgrat
File input? n
Rectangular Horn GRASP BOR-MoM geometry
Enter input waveguide X-axis, Y-axis, length 10.16,22.86,30
Enter length units: 1 in., 2 ft., 3 mm, 4 cm, 5 m 3
Enter design frequency (GHz) 10
Enter input: 1 Bell dimensions, 2 Gain dB 2
Enter design frequency gain (dB) 20
Enter S for E Plane, H Plane (0 Terminates) (0.26,0.4 opt) .26,.4
Enter Type Length Fixer: 1 E Plane, 2 H Plane 1

Actual Gain =   20.00

Horn Dimensions: mm
Aperture Width =  141.072    Height =   91.971
Axial  Length  =  163.474
Plate  Length  =  168.514    Length =  173.831

H Plane Radius =  207.447   E Plane Radius =  189.442
 3 dB beamwidths: E-plane:    17.1 H-plane:    17.0
10 dB beamwidths: E-plane:    30.5 H-plane:    33.6
Phase centers: E-plane:     46.88 H-plane:    105.43
Enter backwall distance of waveguide port (~3 mm) 3
Enter wall thickness (0 none) 0
Enter GRASP BOR-MoM TOR edit output file rechgra20t.txt
Enter bell mesh file (*.msh) rechgra20.msh
Enter frequency range (GHz) start,stop,number 8,12,41
Enter waveguide mode: (1 TE, 2 TM), X-axis, Y-axis 1,0,1
Enter Rectangular waveguiude modal expansion settings
X-axis max, Y-axis max 0,1
```

Above are the inputs for a 20-dB horn designed fed by an X-band waveguide. RECHGRAT generates a mesh file combining the bell and the input waveguide (rechgra20.msh). The mesh file includes a box behind the waveguide port 3 mm deep to confine port radiation to inside the waveguide and not behind the horn. The horn model can include outer walls where currents are excited by the horn radiation as currents flow out of the aperture and down the outside of the bell. The bell outer wall currents become significant for low gain horns. RECHGRAT writes an edit file for a "save as" project file of a former GRASP MoM project. Paste the mesh file (*.msh) into the "working" subdirectory of the new project. Replace every line in TOR file (*.tor) with output file of RECHGRAT above line: //DO NOT MODIFY OBJECTS BELOW THIS LINE.

An input file RECHGRAT1.TXT for the case above is as follows and contains input descriptors where the input is not a file name:

10.16,22.86,40	waveguide x-axis, y-axis, length
3	units: mm
10	design frequency (GHz)
2	enter gain
20	gain dB
0.26,0.4	S quadratic phase factor E, H planes
1	Use E-plane to determine axial length
3	waveguide port backwall distance
0.	wall thickness
rechgrat1t.txt	
rechgrat1.msh	
8,12,41	frequency start, stop, #
1,0,1	TE mode, x-axis mode, y-axis mode
0,1	modal expansion settings

This horn has its *E*-plane along the *x*-axis (narrow waveguide dimension) and the *H*-plane along the *y*-axis. The mode numbers are specified: 0 (no variation) along *x*-axis and 1: a single half cycle along the *y*-axis.

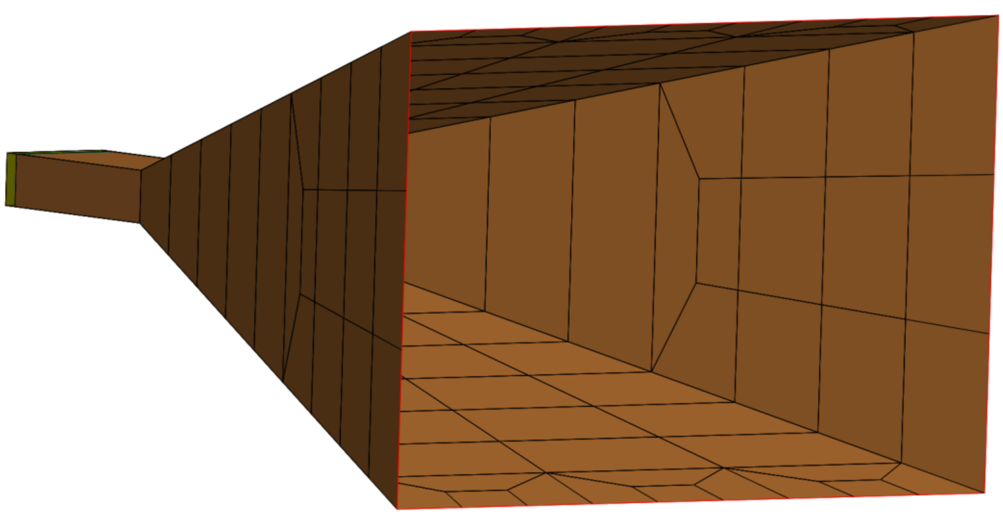

Figure 7-11.1 GRASP MoM model of 20 dB Gain @ 10 GHz Optimum Rectangular Horn

The green box denotes the waveguide input port with its closure box. The figure has its *x*-axis (*E*-plane) vertical and *y*-axis horizontal (*H*-plane). The four plates of the bell, the four plates of the waveguide walls, and the 5 plates of the waveguide port closure box are quadrilateral plates where only 4 nodes need to be specified for each one and these are stored in a single mesh file: rechgrat1t.msh in the example. The program handles subdivides the plates by meshing rules of GRASP MoM. Because the walls are plates, the MoM analysis replaces the metal plates with current sheets that radiate on both sides.

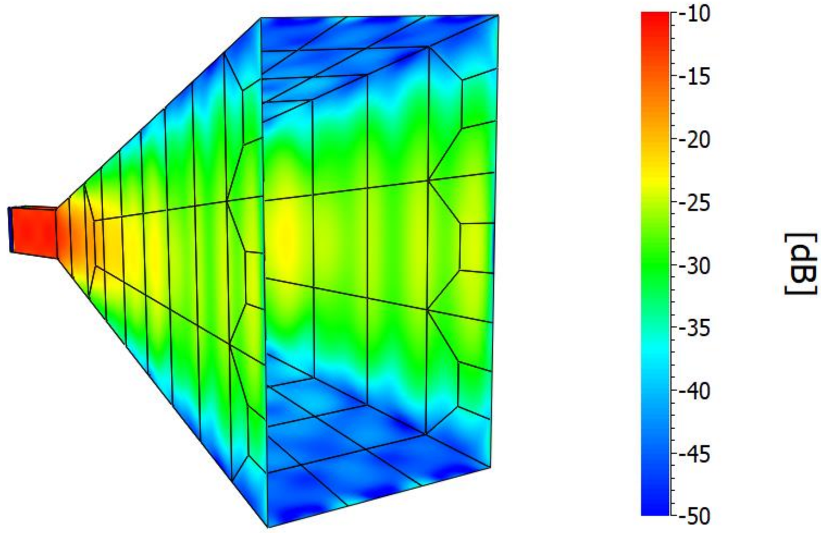

Figure 7-11.2 Wall currents in GRASP MoM model for the 20 dB gain horn at 10 GHz.

Figure 7-11.2 shows high currents in the waveguide walls that peak in the *E*-plane (center of wide plates) of bell and diminish in the *H*-plane due to the cosine distribution of the internal waveguide mode. The wall currents radiate the pattern below at the center frequency of 10 GHz.

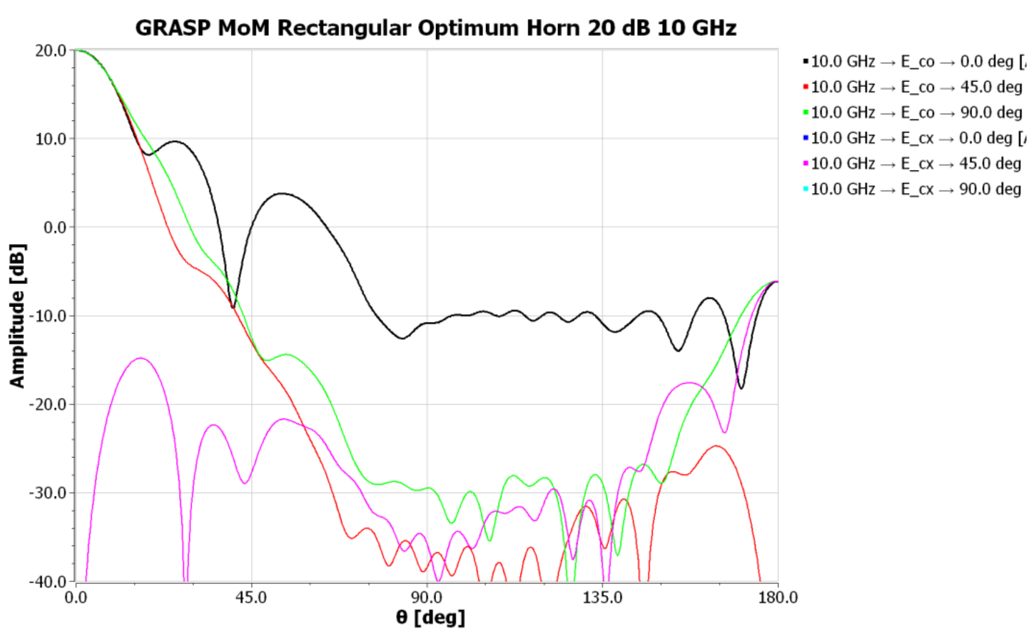

Figure 7-11.3 Pattern of 20 dB Optimum Pyramidal Horn at 10 GHz (design frequency)

Figure 7-11.3 has nearly equal beamwidths in all planes and has the characteristic high sidelobes (black curve) in the *E*-plane (uniform distribution) and low sidelobes in the *H*-plane (cosine distribution) (red curve). The aperture method generated dimensions for a 20-dB gain horn at 10 GHz and the analysis predicts 19.98 dB, an insignificant difference. The designs based on aperture methods in this section may not match the gains computed by GRASP or CHAMP. You can easily redesign the horn after modifying the design gain by the difference, but often the difference is less than measurement error.

The radiation from the bell wall currents, which replace the metal plates, will excite currents on the outside of the bell that add to the total radiated pattern. A second model contains a set of mesh plates spaced from the inner bell by the wall thickness and connected to inner bell plates by 4 thin connection aperture plates. The model also contains four plates around the input waveguide. The mesh file includes these shielding plates. Figure 7-11.4 shows the distribution of currents on the outside of the bell and waveguide. We see that these currents are very small compared to the inner wall currents shown below.

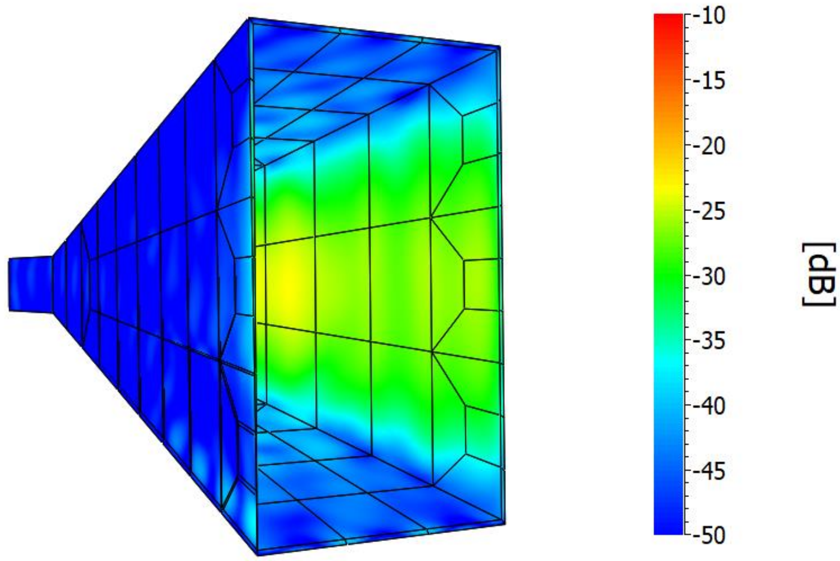

Figure 7-11.4 Outer wall currents of 20 dB gain horn at 10 GHz

The MoM analysis patterns include the radiation from both set of the currents of Figures 7-11.2 and 7-11.4 outside. The radiated pattern looks the same as Figure 7-11.3 because the changes are small. The boresight gain of this model is 20.02 dB or 0.04 dB difference when the outer wall currents are included. Adding the outer wall currents increased the runtime 4 times and not worth the extra time.

The aperture method predicts a smooth gain curve over frequency because there is no interaction with the finite length bell. Both the aperture size and quadratic phase change slowly. However, the aperture method predicts gain within tenths of a dB of the other method, a variation less than can be accurately measured. The MoM analysis incorporates the finite size of the bell plates and we see this prediction oscillating about the aperture method prediction. Adding the currents induced on the outside of the bell nearly uniformly increases gain about 0.04 dB, another insignificant change. The currents on the inside surface determines most of the radiation variation shown in Figure 7-11.5.

The next case uses a lower 15 dB gain design and we will see that the extra outer wall currents have greater effect. If we use the same quadratic phase factors $S_e = 0.26$ and $S_h = 0.4$, the bell is short and flares with a large angle transition from the waveguide to the bell Figure 7-11-6 and its gain falls short at 14.7 dB for 10 GHz.

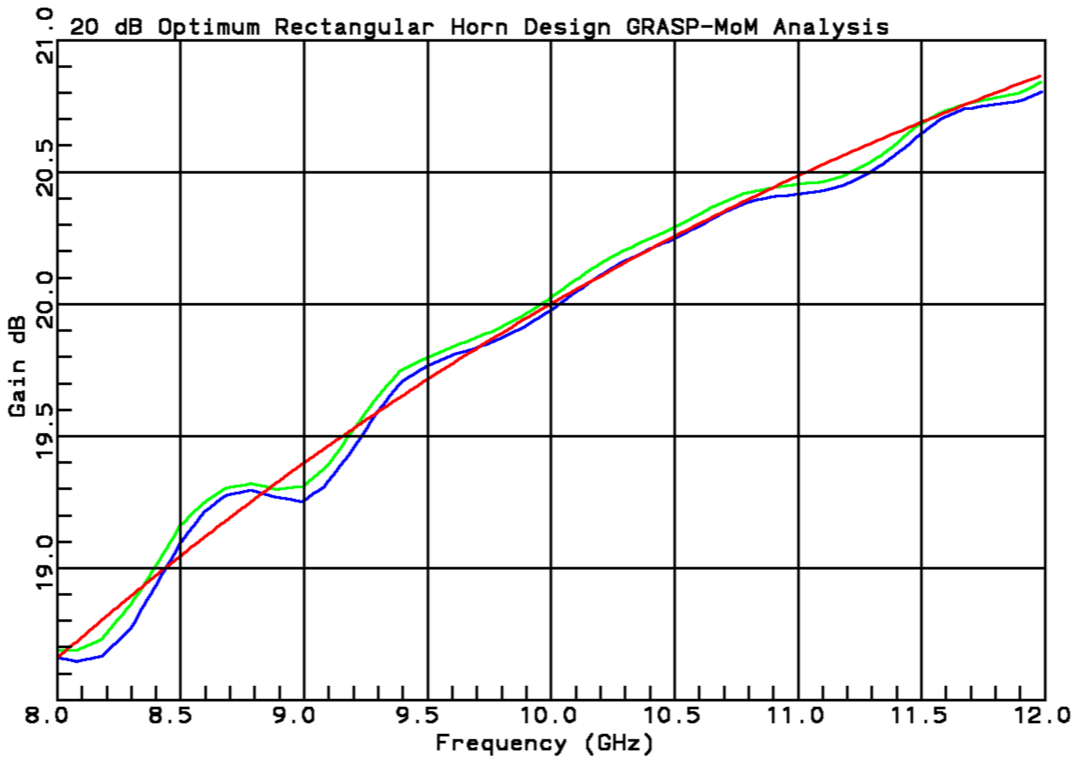

Figure 7-11.5 Predicted gain of Aperture method (red), MoM model (blue), and MoM model including bell and waveguide outer wall currents (green)

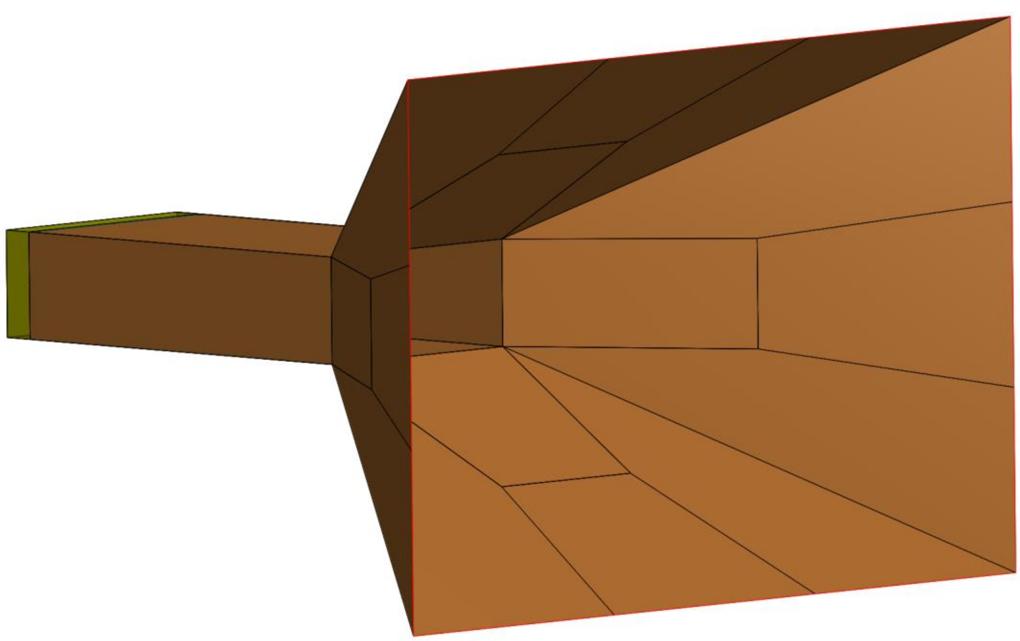

Figure 7-11.6 15 dB gain design using S_e = 0.26 and S_h = 0.4

The answer is to lower the quadratic phase factors to S = 0.1 which generates a longer bell and produces an acceptable waveguide to bell flare angle Figure 7-11.7. The center frequency pattern Figure 7-11.8 has a gain of 15.06 dB which means the aperture theory design over designs slightly.

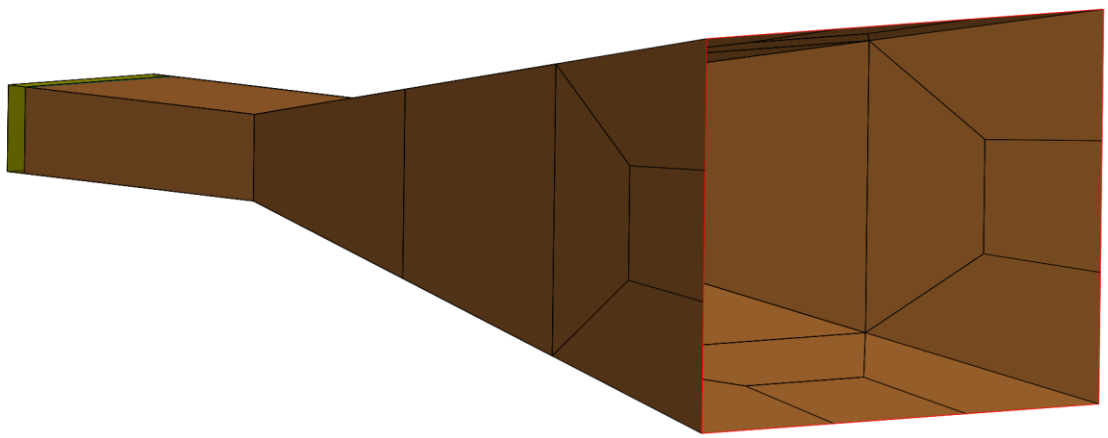

Figure 7-11.7 15 dB gain design using S_e = 0.1 and S_h = 0.1

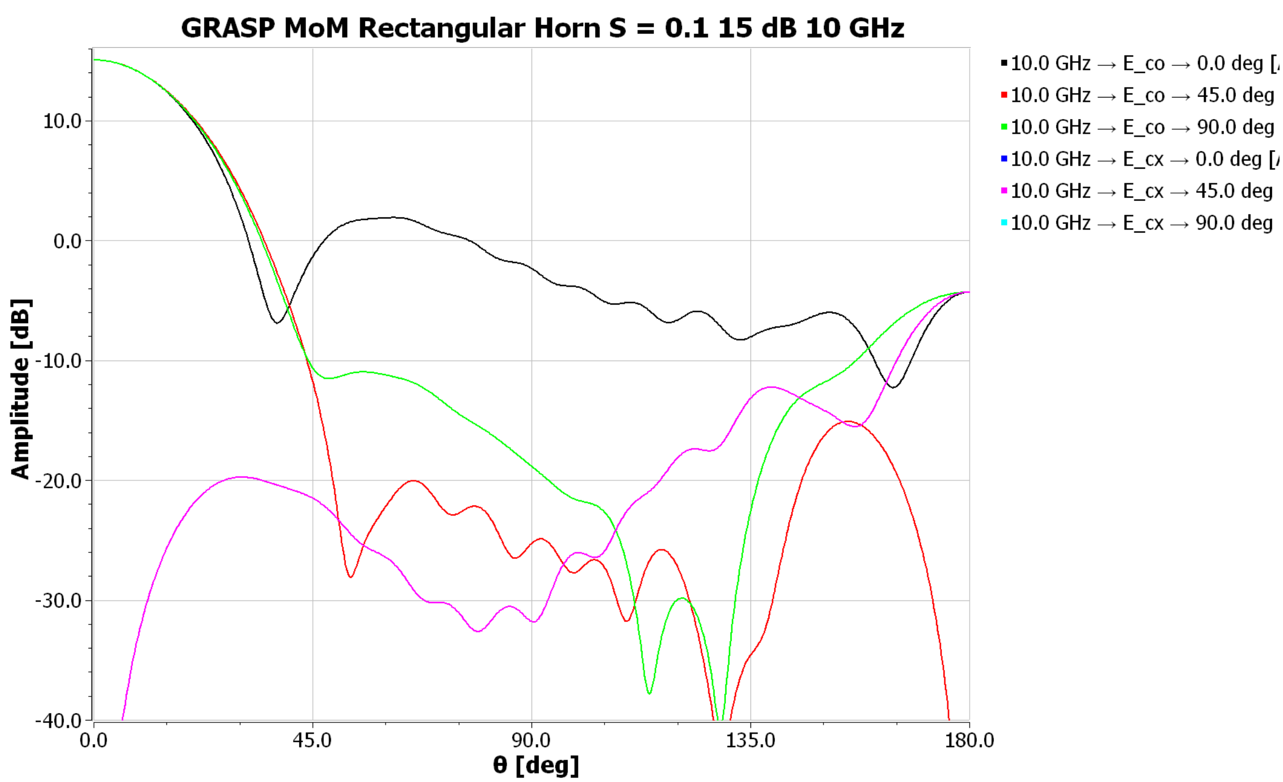

Figure 7-11.8 Pattern of 15 dB S_e = 0.1 and S_h = 0.1 Pyramidal Horn at 10 GHz (design frequency)

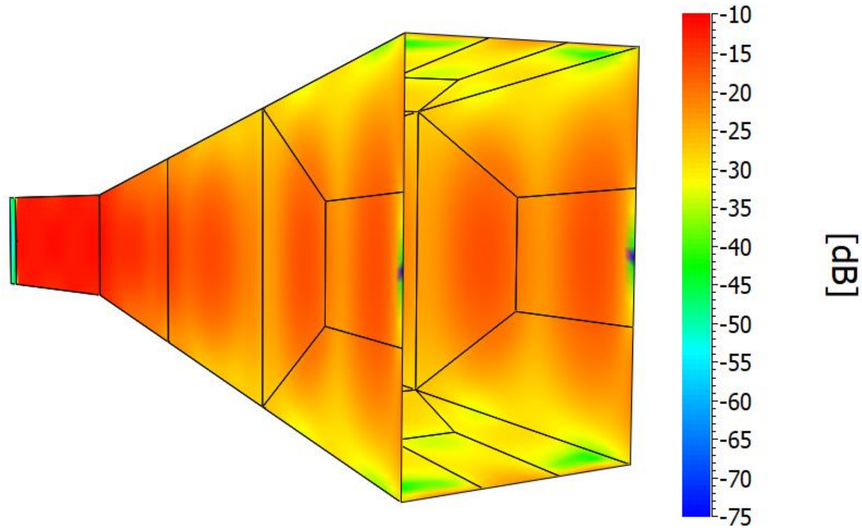

Figure 7-11.9 Wall currents of 15 dB S_e = 0.1 and S_h = 0.1 Pyramidal Horn at 10 GHz (design frequency)

The narrow wall currents are much higher than the 20 dB horn by comparing Figures 7-11.2 and 7-11.9. Figure 7-11.10 illustrates the GRASP MoM model when the outer walls are added and the altered meshing generated by GRASP.

The outer wall currents, Figure 7-11.11, for the 15 dB gain design are larger those of the 20 dB design and we can expect a greater affect on the overall radiated pattern. However, we see little difference in the pattern when comparing Figure 7-11.8 and Figure 7-11.12. The gain has increased to 15.14 dB when the outer wall currents are added. The 20 dB horn design increased gain by 0.04 dB when the outer wall currents are included and the 15 dB increased by 0.08 dB. The small changes do not justify extra walls analysis.

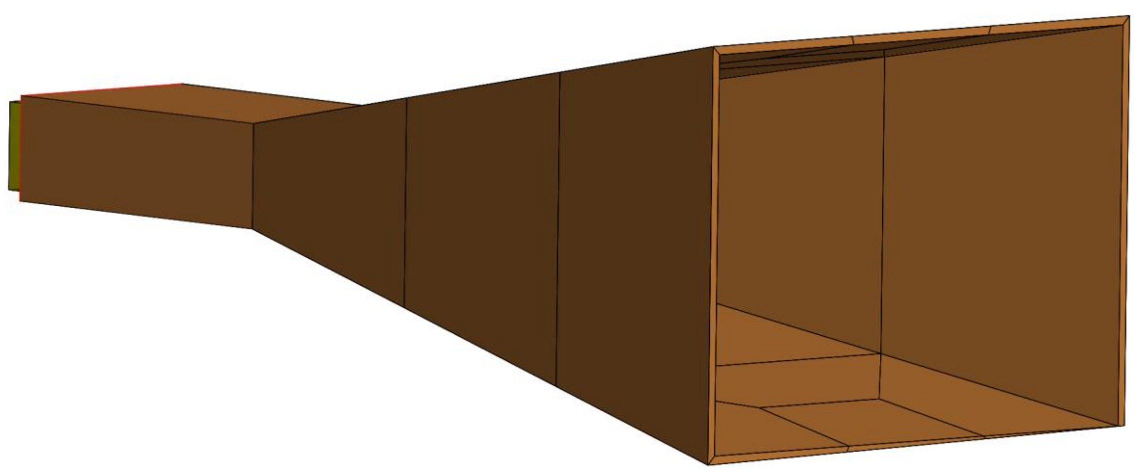

Figure 7-11.10 15 dB gain design using S_e = 0.1 and S_h = 0.1 horn model with outer walls

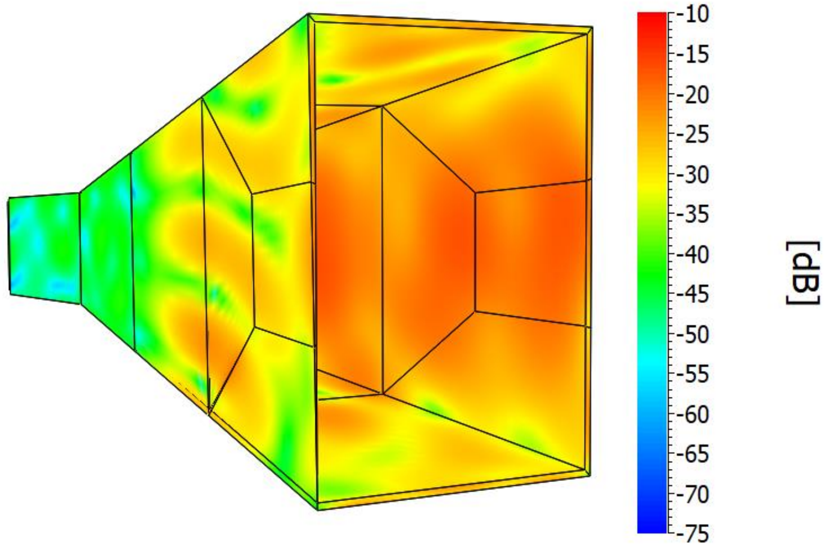

Figure 7-11.11 Outer Wall currents of 15 dB S_e = 0.1 and S_h = 0.1 Pyramidal Horn at 10 GHz (design frequency)

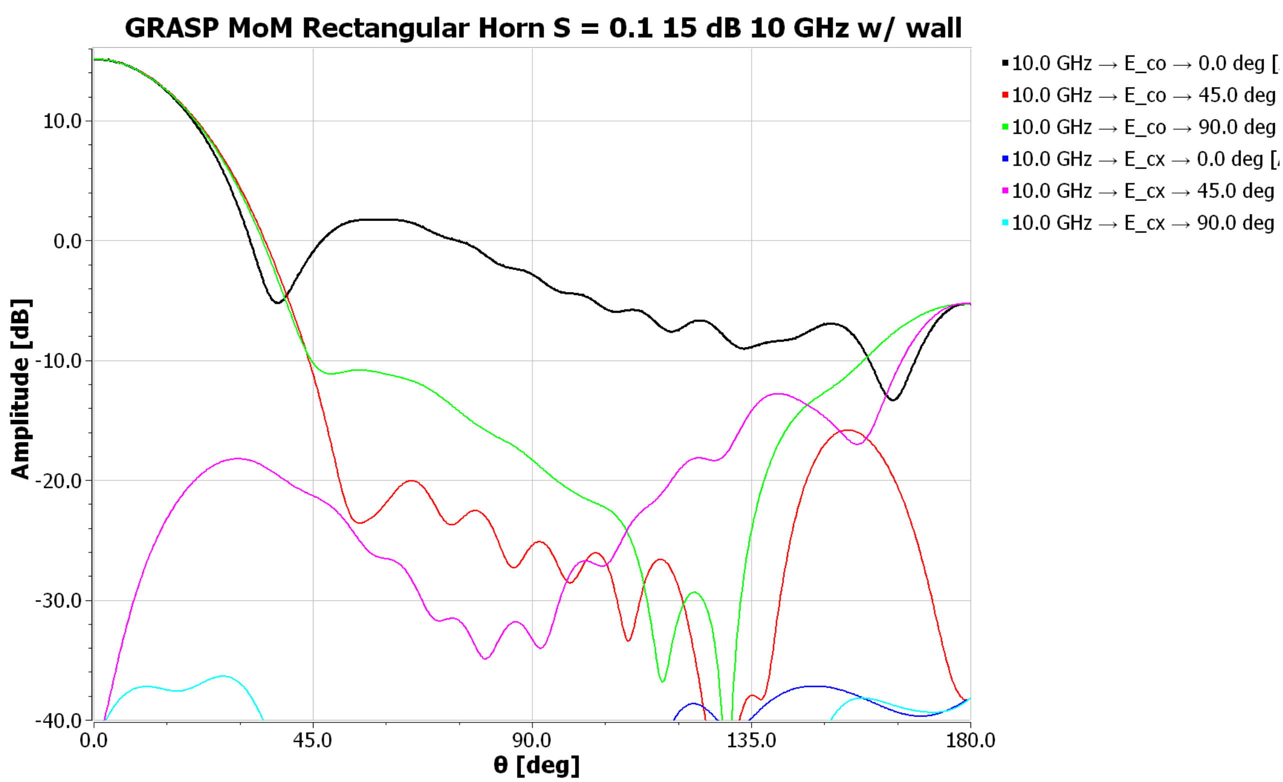

Figure 7-11.12 Pattern of 15 dB S_e = 0.1 and S_h = 0.1 Pyramidal Horn including induced outer wall currents at 10 GHz (design frequency)

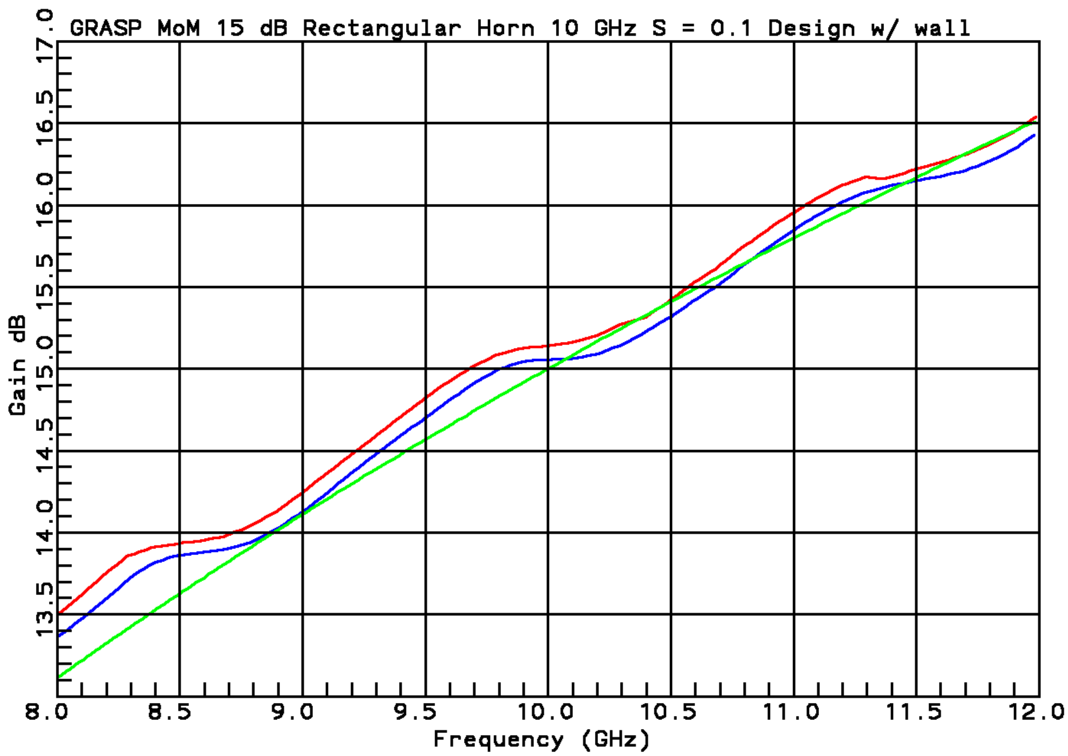

Figure 7-11.13 Predicted gain of Aperture method (green), MoM model (blue), and MoM model including bell and waveguide outer wall currents (red)

7-11.2 Circular Horns

GRASP MoM models for circular horns involve BOR elements using piecewise_linear_bor objects. This section considers smooth wall, Potter stepped, corrugated wall, and axially corrugation horns. Each antenna can be independently analyzed using the mode-matching program CHAMP that can include external BOR-MoM elements, such as, outer wall currents. Generally speaking CHAMP analyzes these antenna with drastically reduced runtimes compared to the full MoM expansion of GRASP. All models include the exterior wall and generate closed objects which reduce the terms in the MoM model.

7-11.2.1 Smooth Wall Circular Horn

The program CIRHGRA writes an edit file which we use to modify an existing TOR file to alter the geometry and parameters for a new project. No external elements like mesh files are required, but the whole geometry resides in the TOR file.

We start with a 20 dB gain horn designed for 10 GHz using the aperture method of CIRHDN contained in CIRHGRA. Figure 7-11.14 shows the simple design. The radiation pattern of Figure 7-11-15 illustrates that a circular horn will have different *E*- and *H*-plane beamwidths, but a lower first *E*-plane sidelobe than the rectangular horn. The aperture method dimensions produce slightly higher gain in the GRASP MoM analysis, 20.13-dB. The wave reflection between the waveguide to bell juncture and bell aperture produces the gain variation seen in the GRASP MoM analysis of Figure 7-11.16.

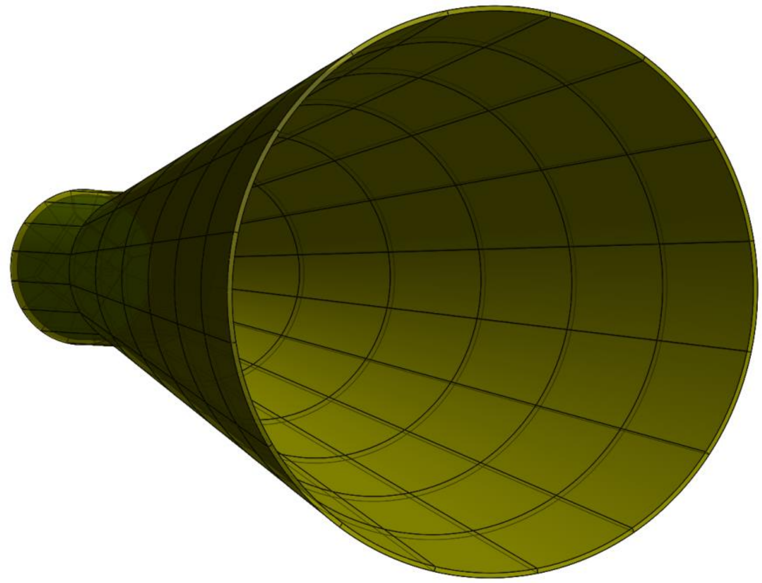

Figure 7-11.14 Circular Horn Designed at 10 GHz for 20 dB gain using S = 0.2

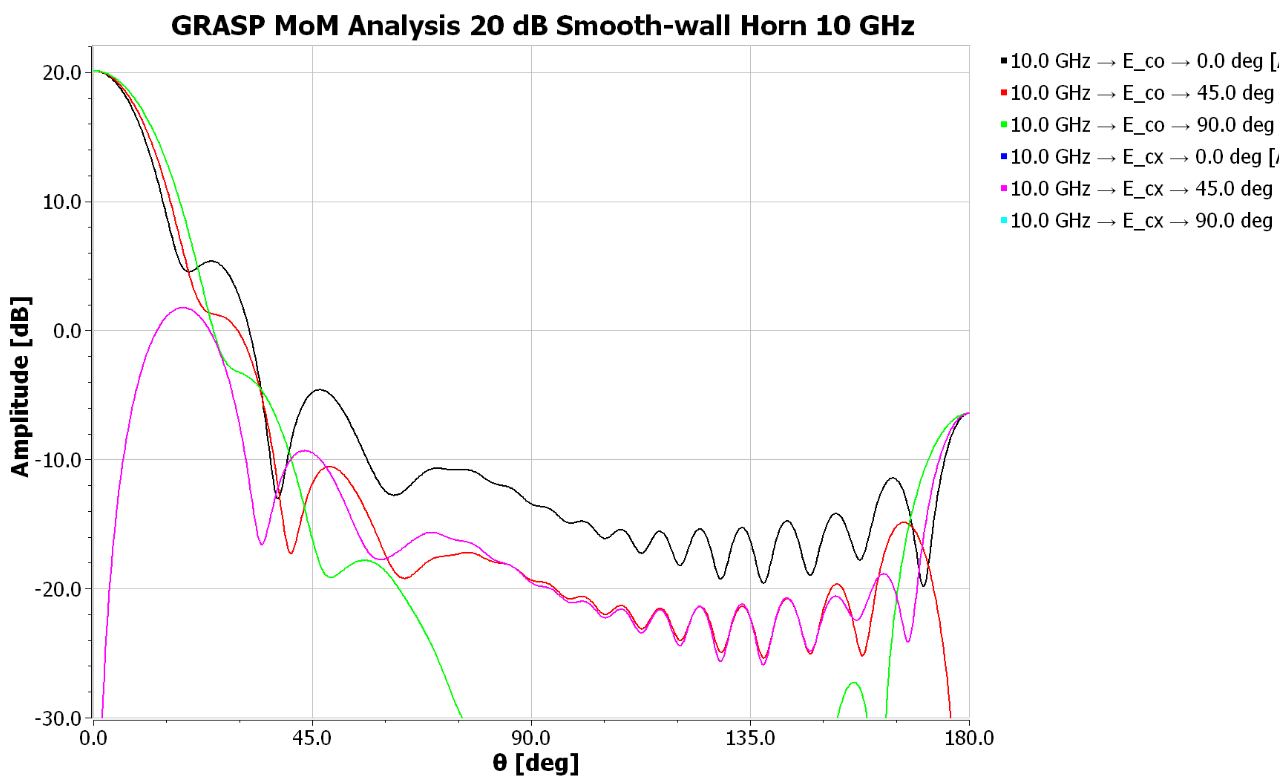

Figure 7-11.15 Smooth-wall circular horn designed for 20 dB gain at 10 GHz

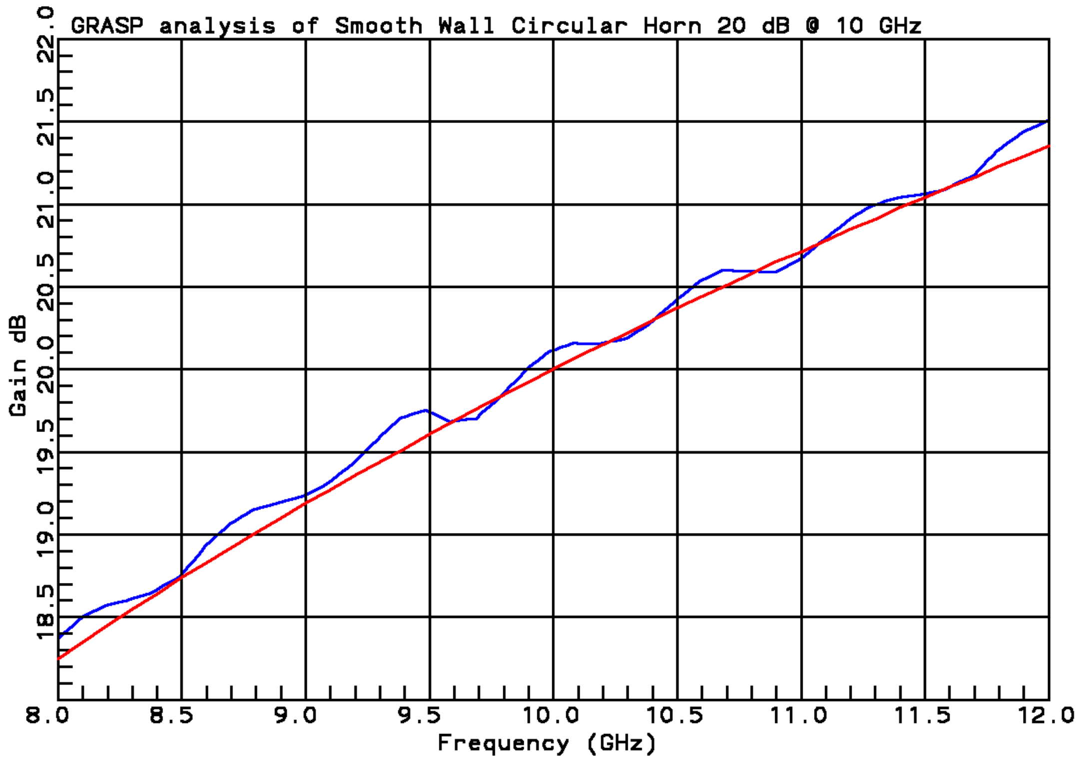

Figure 7-11.16 Predicted gain in 20 dB design circular smooth-wall horn: Aperture (red), GRASP MoM (blue)

7-11.2.2 Stepped Multimode Potter Circular Horn

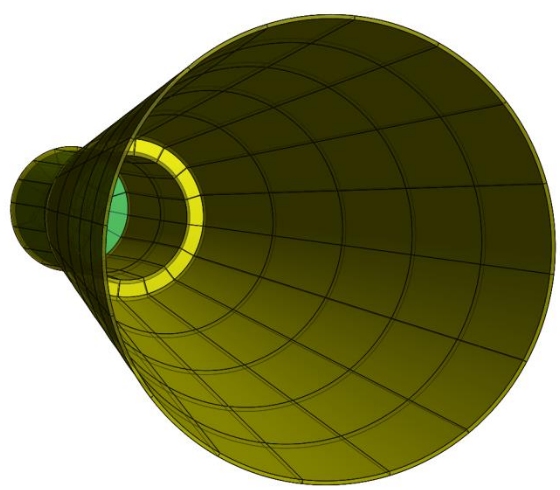

Figure 7-11.17 Potter horn designed for 20 dB gain at 10 GHz

A step of radius in the throat of the Potter horn excites the TM_{11} mode which combines in the aperture with the remaining TE_{11} power from the input waveguide whose phase has been adjusted by the length of the bell to produce the hybrid mode HE_{11} found in a corrugated horn. The horn radiates corrugated horn type patterns over a narrow frequency range. See section 7-9.1 for more details.

The program POTHGRA writes GRASP TOR file edits for a Potter horn given gain at the design frequency. You start with an existing GRASP project and save it as a new project. POTHGRA runs using keyboard inputs or from an input file, for example:

```
10              design frequency GHz
3               units: mm
14.314,30       waveguide radius, length
1               wall thickness
2               design to gain
20              gain dB
pothgra1t.txt   output TOR file edit text file list
9,11,21         frequency start, stop, #
1,1,1           TE, 1, 1
1,1,1           modal expansion M_min, N-Max, M_max
```

Use the output file POTHGRA1T.TXT to replace the top portion of the new project TOR file located in the "working" subdirectory. Below is an example edit using a text editor to copy the entire file: POTHGRA1T.TXT and replace all lines while keeping the lines shown in red below. The object potter_cir_horn contains the entire geometry of the horn including the outer wall. The less interesting lines have been removed below.

```
potter_cir_horn  piecewise_linear_bor
(
 nodes         : table
  (
   -2.36396E+02   1.43140E+01
   -2.06396E+02   1.43140E+01
   -1.85545E+02   1.52894E+01
   -1.85545E+02   1.94865E+01
    5.72205E-06   5.68347E+01
    5.72205E-06   5.78347E+01
   -1.86545E+02   2.04865E+01
   -1.86545E+02   1.62894E+01
   -2.06396E+02   1.53140E+01
   -2.37396E+02   1.53140E+01
   -2.37396E+02   0.00000E+00
  ),
.
.
.
mom_horn  mom
(
```

```
 frequency       : ref(frequency),
 scatterer       : ref(potter_cir_horn),
 expansion_accuracy : enhanced,
 waveguide_ports  : sequence
  ( struct(waveguide_port: ref(port), coor_sys: ref(coor_sys_horn), x: 0. m, y: 0. m, z: -2.36396E+02 mm,
 normal: Z-axis)
 ),
 file_name       : mom_horn.cur,
 colour_plot_file : " "
)

//DO NOT MODIFY OBJECTS BELOW THIS LINE.
//THESE OBJECTS ARE CREATED AND MANAGED BY THE
//GRAPHICAL USER INTERFACE AND SHOULD NOT BE
//MODIFIED MANUALLY!
view_1  view
(
```

Save the edited TOR file and restart the GRASP project which will now contain the Potter horn. The program POTHGRA asks for the frequency range as input but writes a spherical_cut object which you might want to edit in the GRASP GUI. The example above designs a 20-dB gain horn for 10 GHz with the aperture located at Z = 0.

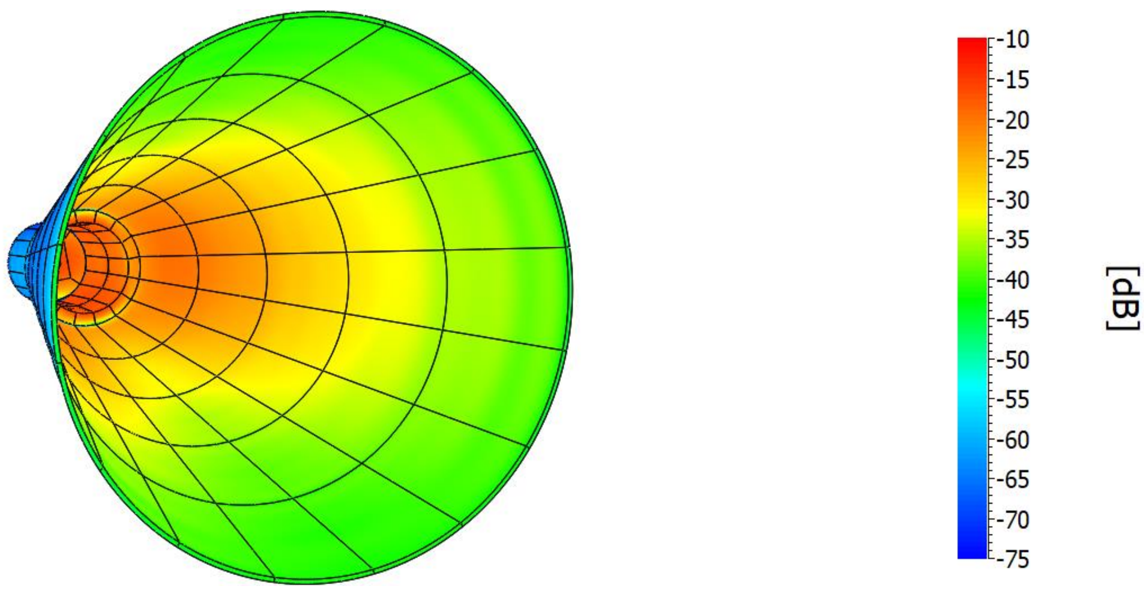

Figure 7-11.18 Wall currents of Potter horn designed for 20 dB gain at 10 GHz

Figure 7-11.18 plots the surface currents of the Potter horn. Note that the relatively high gain of the horn induces little current on the outside of the horn. The sum of the surface currents inside and outside replaces the metal bell and waveguide for the computation of radiation.

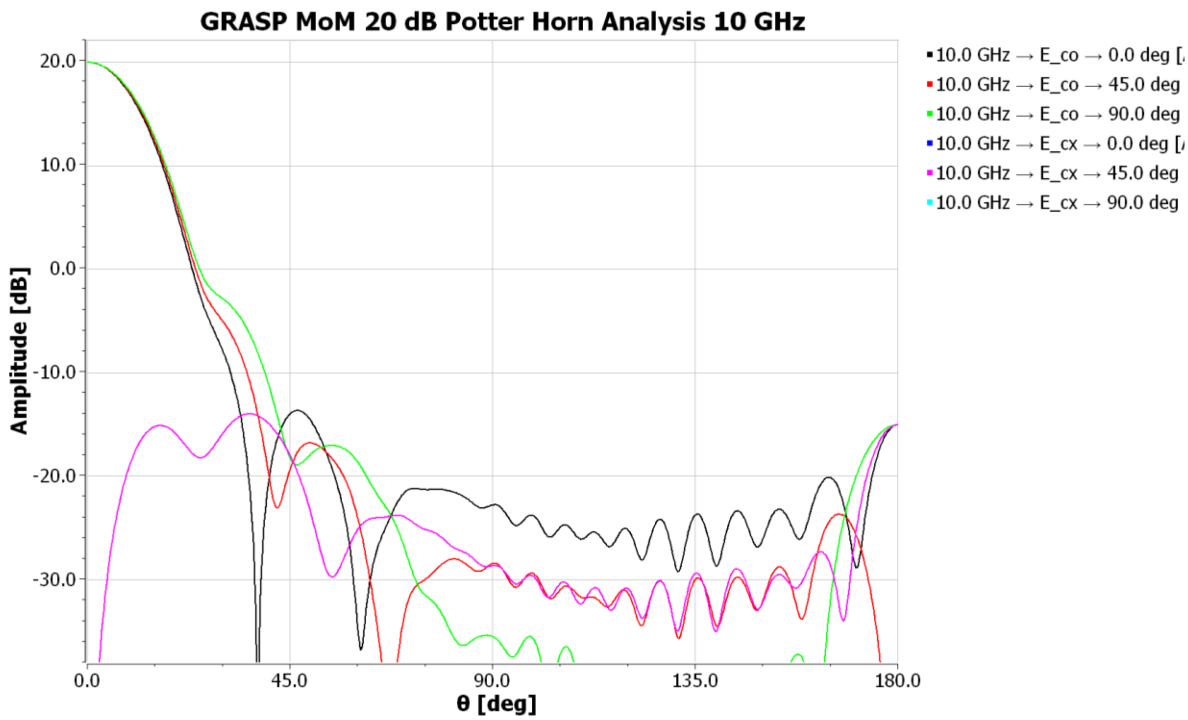

Figure 7-11.19 Radiation pattern of Potter horn designed for 20 dB gain at 10 GHz

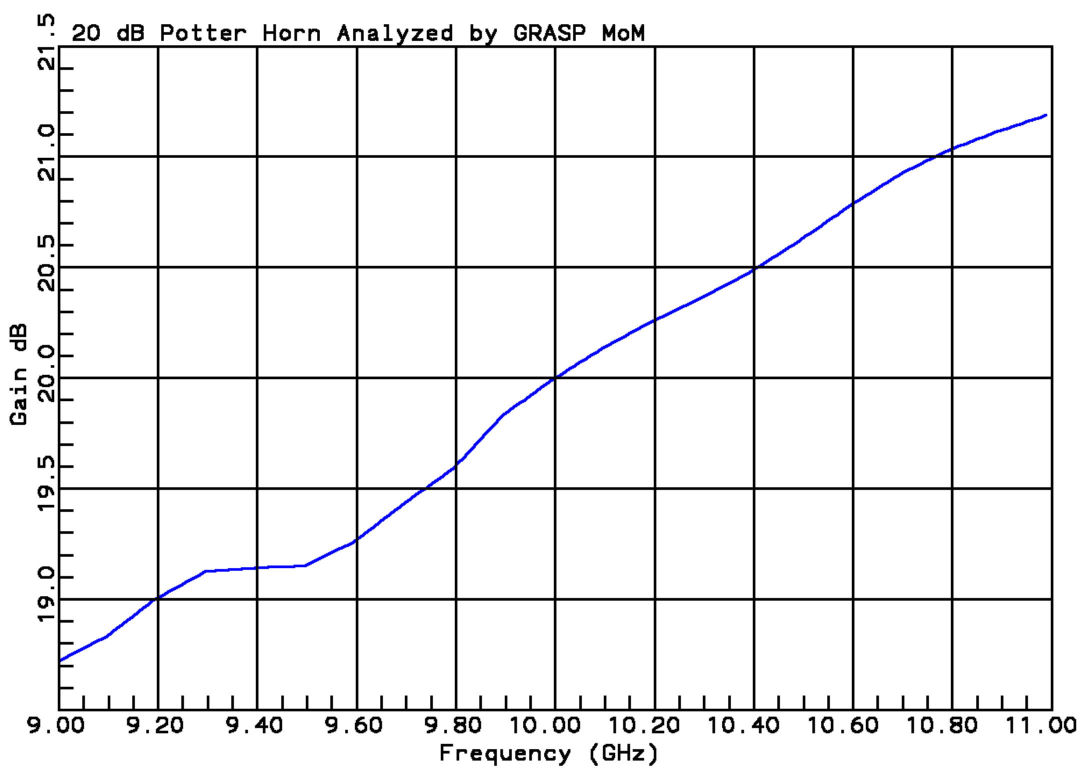

Figure 7-11.20 Gain response of Potter horn designed for 20 dB gain at 10 GHz

The horn designed by POTHGRA has the specified gain at center frequency. Figure 7-11.20 shows that the horn gain response has small variations from a smooth curve which would be predicted from an aperture method analysis. The horn has a limited frequency range of good cross polarization response illustrated by Figures 7-11.21 and 7-11.22.

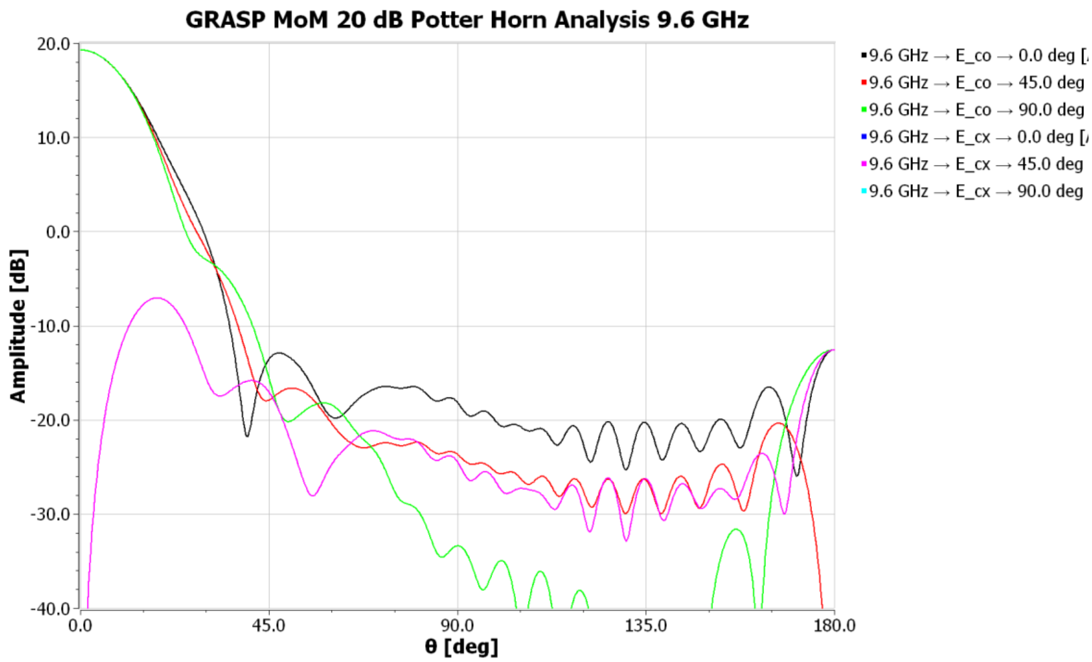

Figure 7-11.21 Radiation pattern of Potter horn designed for 20 dB gain at 10 GHz @ 9.6 GHz

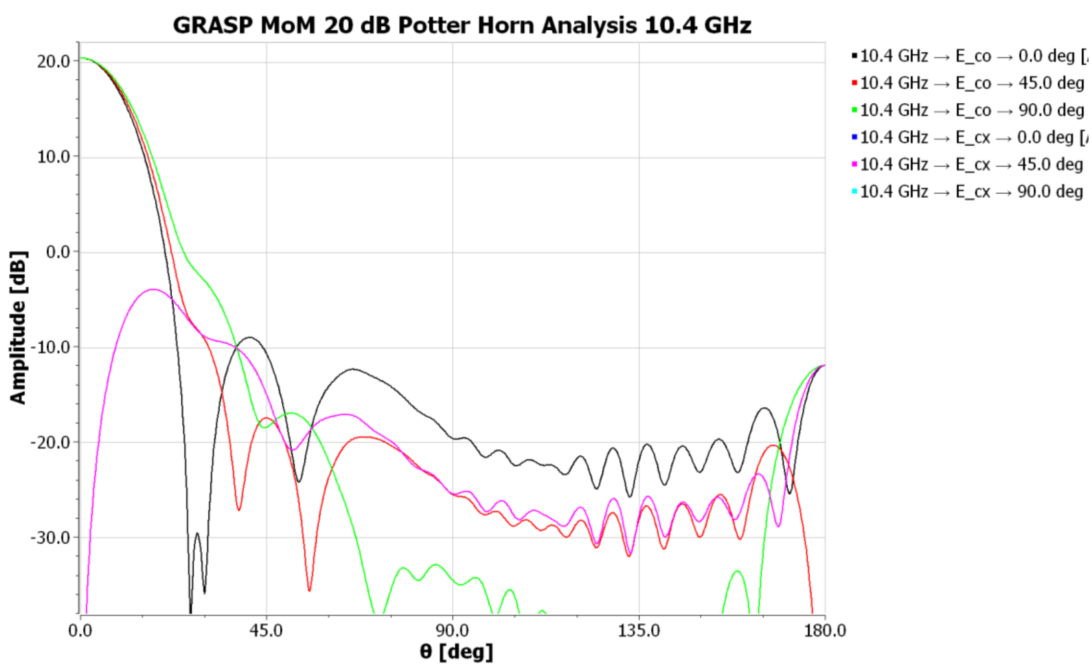

Figure 7-11.22 Radiation pattern of Potter horn designed for 20 dB gain at 10 GHz @ 10.4 GHz

16 dB Gain Potter Horn

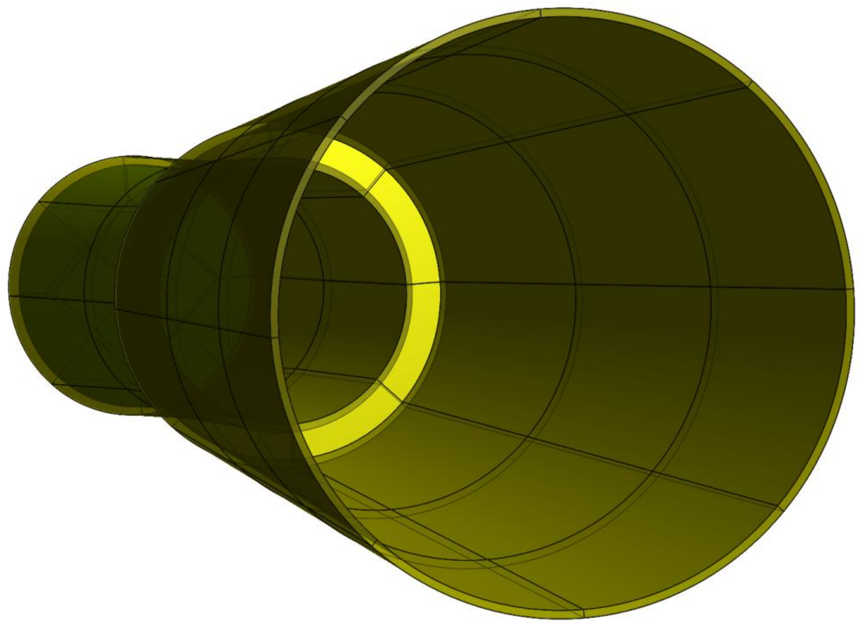

Figure 7-11.23 Potter horn designed for 16 dB gain at 10 GHz

By modifying the input file to POTHGRA we can generate a new GRASP project by using the “save as” command on the 20-dB GRASP project and a text editor to change the upper portion of the TOR file located in the new “working” subdirectory. Figure 7-11.23 shows the reduced aperture and length of this horn.

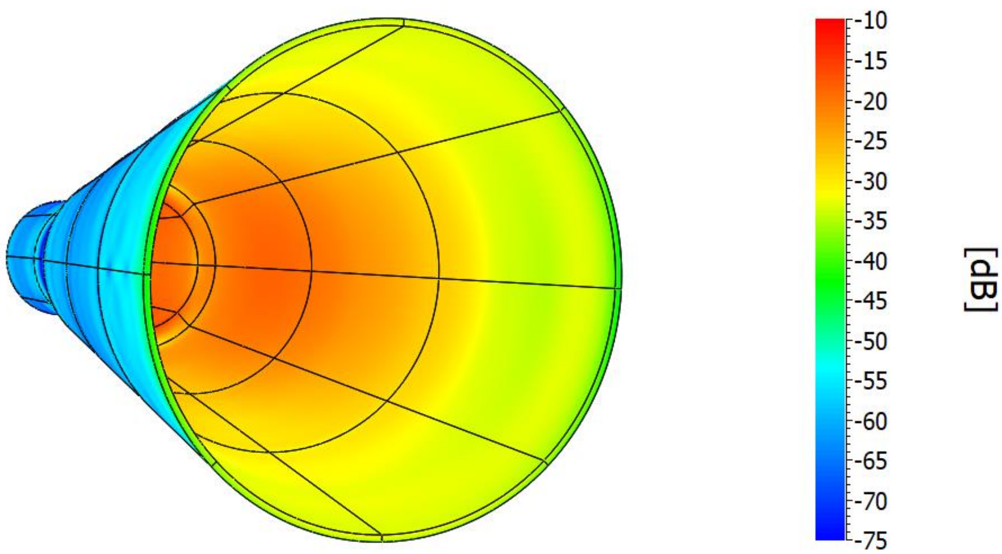

Figure 7-11.24 Wall currents of Potter horn designed for 16 dB gain at 10 GHz

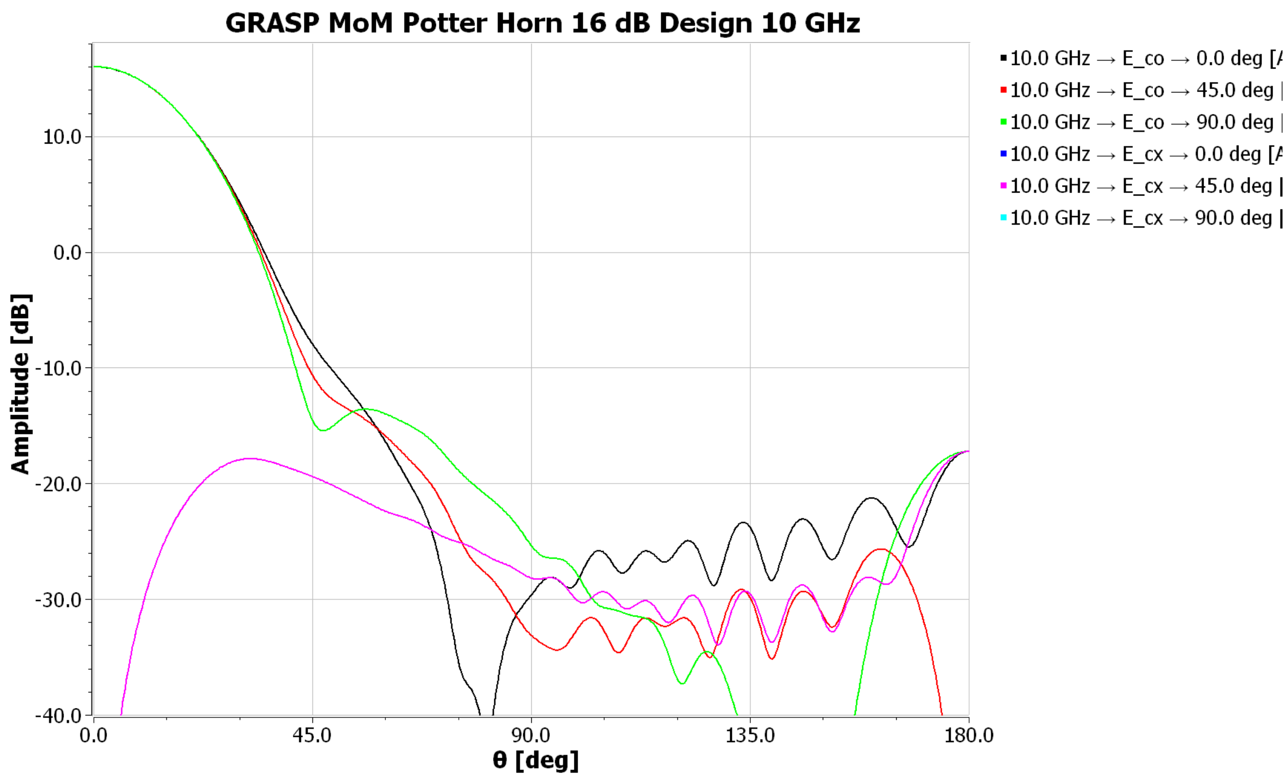

Figure 7-11.25 Radiation pattern of Potter horn designed for 16 dB gain at 10 GHz

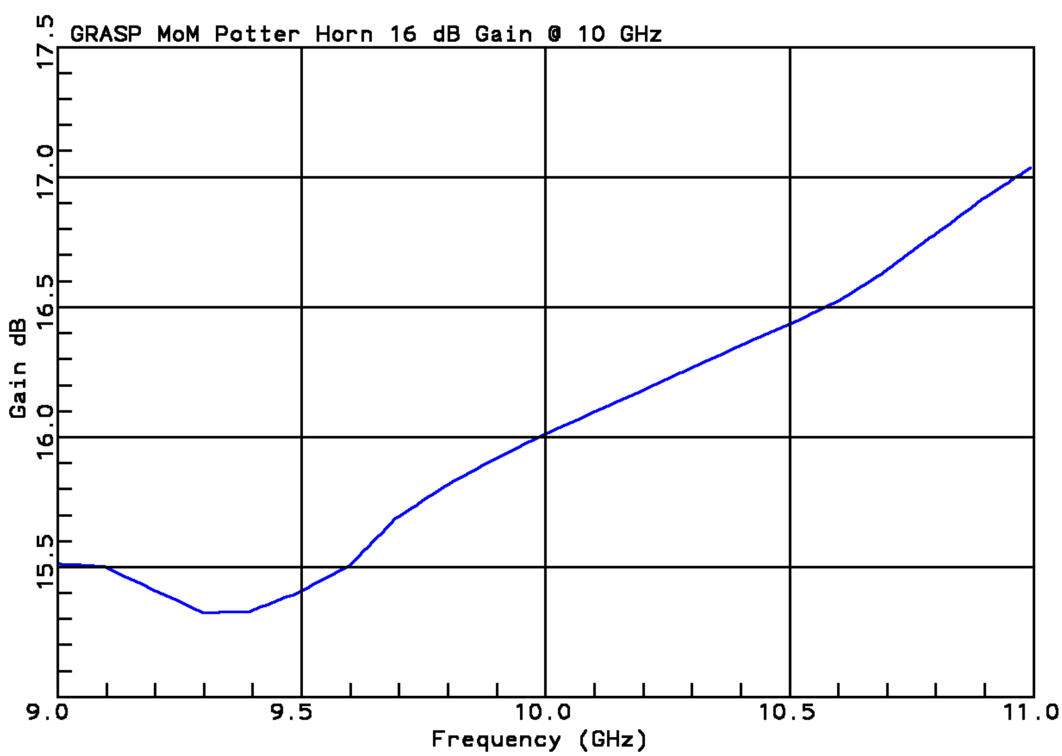

Figure 7-11.26 Gain response of Potter horn designed for 16 dB gain at 10 GHz

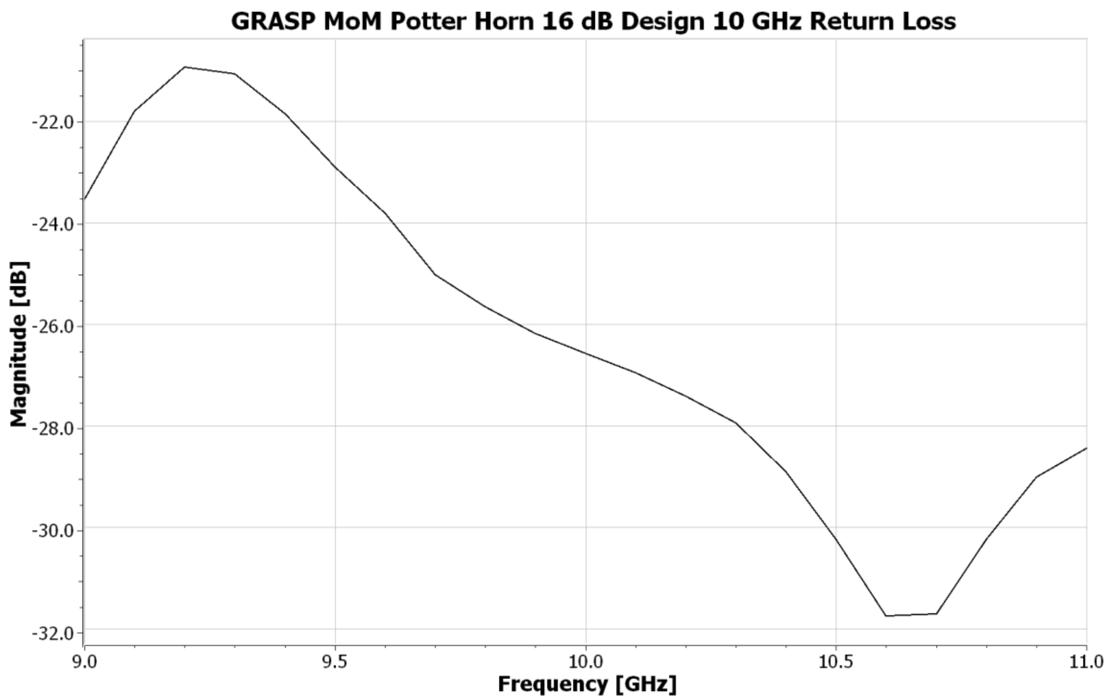

Figure 7-11.27 Reurn Loss response of Potter horn designed for 16 dB gain at 10 GHz

GRASP MoM computes the input impedance at the waveguide input and can plot return loss, Figure 7-11.27. This Potter horn has a similar 8% 25-dB cross polarization bandwidth as the 20 dB horn.

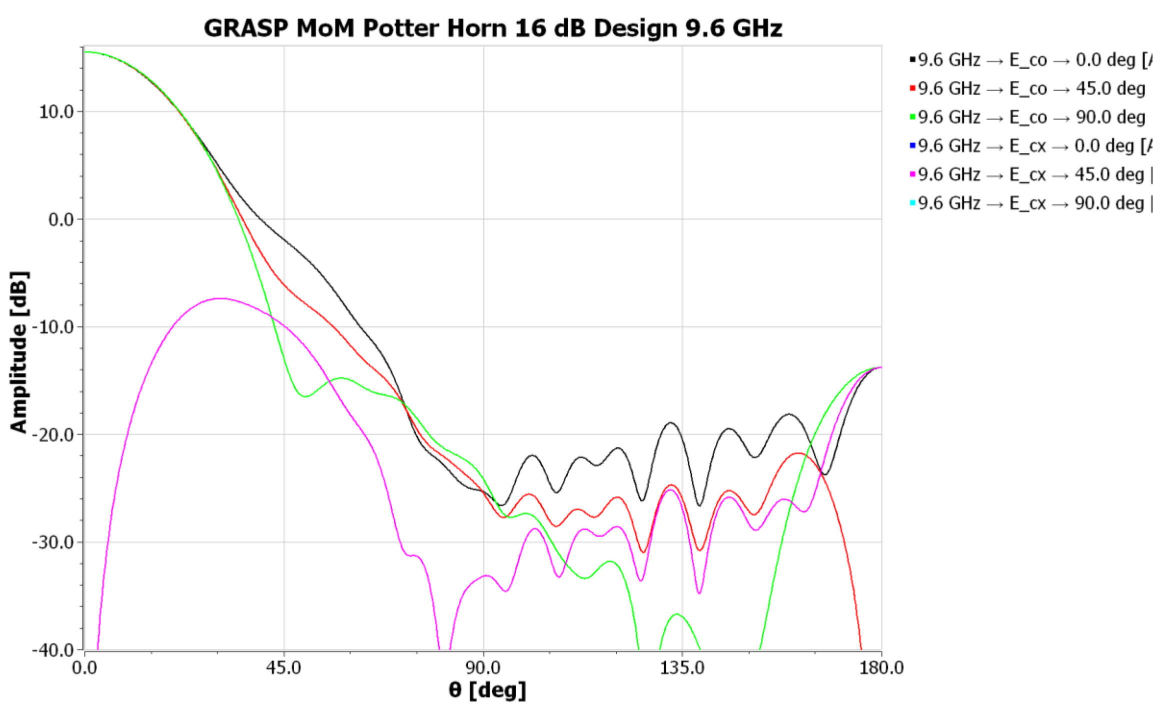

Figure 7-11.28 Radiation pattern of Potter horn designed for 16 dB gain at 10 GHz @ 9.6 GHz

7-11.2.3 Corrugated Circular Horn

Corrugated can be made using corrugations (slots) machined radial to the horn axis or machined slanted so that the ridges are normal to the bell surface. Of course, the edges of the ridges lie along a cone where the inner diameter of the ridge at the aperture is the aperture radius. Ridges in the throat transition from the waveguide to the flared bell usually have a depth approximately a little less than λ/2 while those near the aperture are a little greater than λ/4. Because the horn needs to cover a frequency band, these are loose rules. The program CORHGRAT writes an edit file for the new project TOR geometry file located in the "working" subdirectory. Similar to the circular horns above, the CORHGRAT output TOR edit file contains the geometry of the horn as a "piecewise_linear_bor" object.

```
C:\milligan\ANTENNA\HORN>corhgrat
File input? n
Corrugated Horn GRASP BOR-MoM geometry
Enter input waveguide radius, length 14.134,30
Enter length units: 1 in., 2 ft., 3 mm, 4 cm, 5 m 3
Enter design frequency (GHz) 10
Enter backwall distance of waveguide port (~3 mm) 3
Enter outer wall thickness (none) 1.5
Enter input: 1 aperture (wavelengths), 2 Gain dB 2
Enter design frequency gain (dB) 16
Enter quadratic factor S .2
Aperture radius (wavelengths) =   1.2583
Enter GRASP BOR-MoM TOR edit output file corhgrat1t.txt
Enter output type: 1 GRASP, 2 CHAMP exterior 1
Enter corrugation type: 1 vertical, 2 slant 2
Length along bell =    74.212
Enter number of corrugations, wall thickness 13,.8
Enter corrugation depth: 1 file list, 2 Initial linear taper 2
Enter initial, final corrugation depths 12.4,7.5
Enter number of corrugations in taper 4
Enter length along slant to first corrugation 5
Enter frequency range (GHz) start,stop,number 8,12,11
Enter waveguide mode: (1 TE, 2 TM), Mode (Az), (rad) 1,1,1
Enter Circular waveguiude modal expansion settings
Az mode min, radial max, Az mode max 1,1,1
```

CORHGRAT can also generate an exterior file for CHAMP especially useful for slanted corrugations. Even with vertical corrugations which CHAMP normally handles using mode-matching, the program can apply BOR-MoM for a solution. GRASP is using a MoM solution which cannot use the BOR geometry because of the waveguide excitation. CHAMP runs much faster than GRASP because of its use of the BOR-MoM computation. Our goal is to compare results from CHAMP and GRASP beyond runtime to see how well MoM works compared to mode-matching. While the output file: corhgrat1t.txt contains the GRASP TOR file that replaces every line above: (//DO NOT MODIFY OBJECTS BELOW THIS LINE.), the CHAMP output only replaces the exterior of the geometry.tor file. For a CHAMP analysis start a blank project and enter the input waveguide. Add an "exterior" to the input waveguide by using a couple points. Close the CHAMP file and edit the geometry.tor file located in the project directory. Replace the two points of the "exterior" with the output of CORHGRAT with CHAMP output. Complete the edit and reopen the project

(*.champ). The corrugations will be included as a BOR-MoM exterior which closes with a bell exterior traced to the waveguide input. The GRASP output geometry closes behind the circular waveguide port.

16 dB Corrugated Horn with Slant Corrugations (input above)

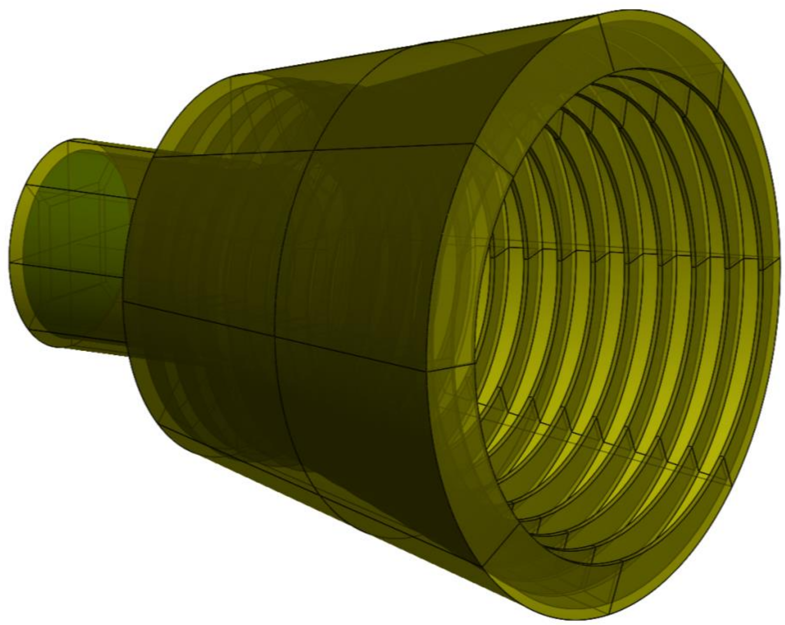

Figure 7-11.29 16 dB Gain Slant Corrugated Horn designed for 10 GHz

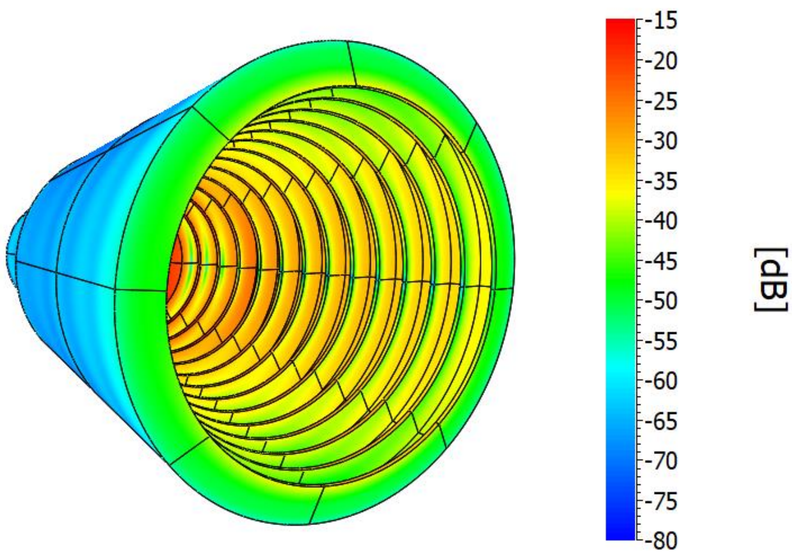

Figure 7-11.30 Wall currents of 16 dB Gain Slant Corrugated Horn designed for 10 GHz

The MoM solution replaces the metal walls with the surface currents to calculate radiation pattern. Both the inner and outer wall currents are included.

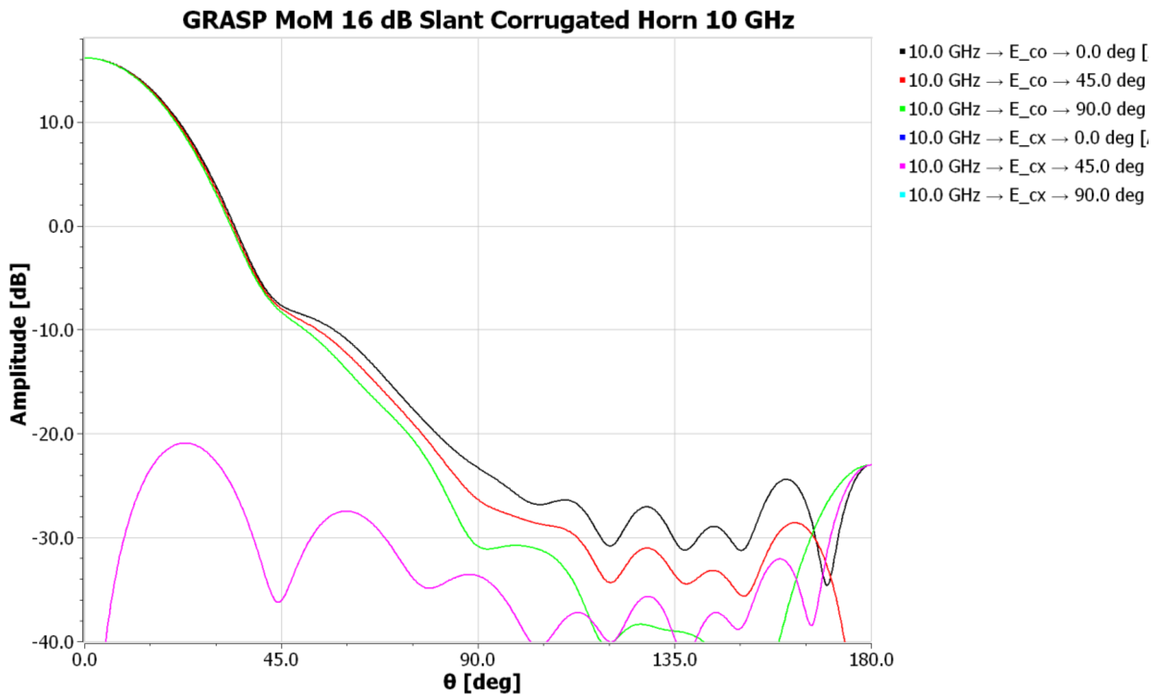

Figure 7-11.31 16 dB Gain Slant Corrugated Horn designed for 10 GHz

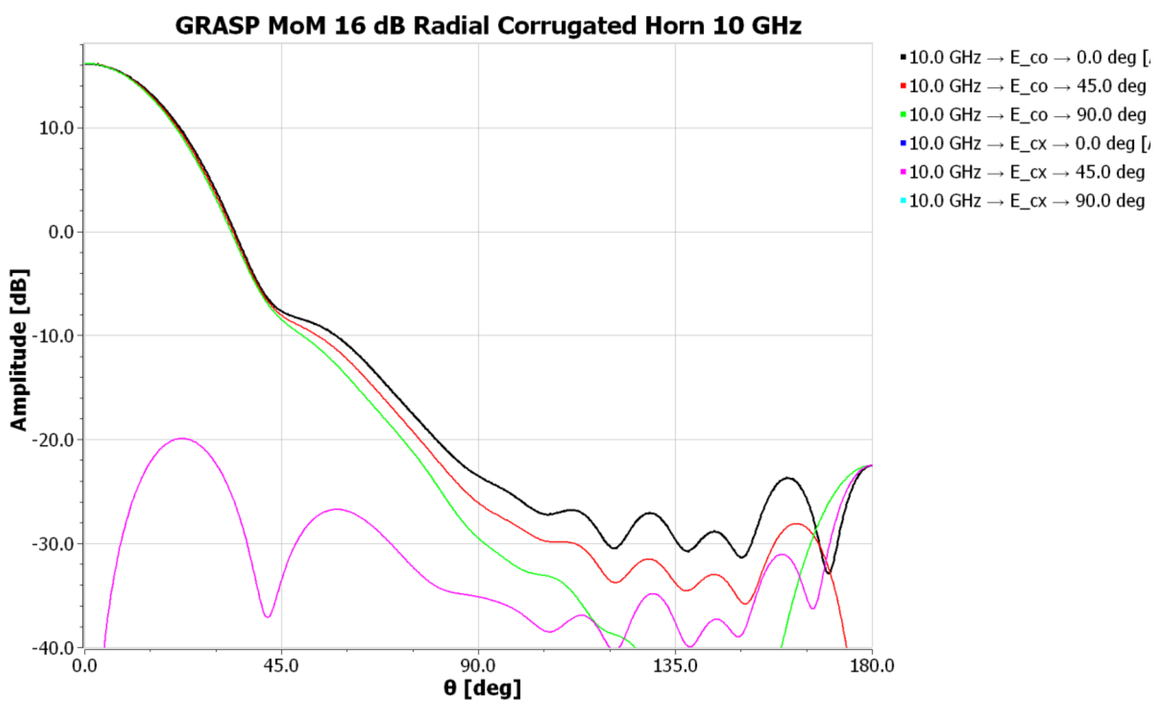

Figure 7-11.32 16 dB Gain Vertical or Radial Corrugated Horn designed for 10 GHz

Figures 7-11.31 and 7-11.32 show the center frequency (10 GHz) patterns of a 16 dB corrugated horn with slant and vertical (radial) corrugations. The direction of the corrugations causes no practical pattern change in. The center frequency gain of the slanted corrugated horn is 16.16 dB and the radially corrugated horn gain is 16.17 dB.

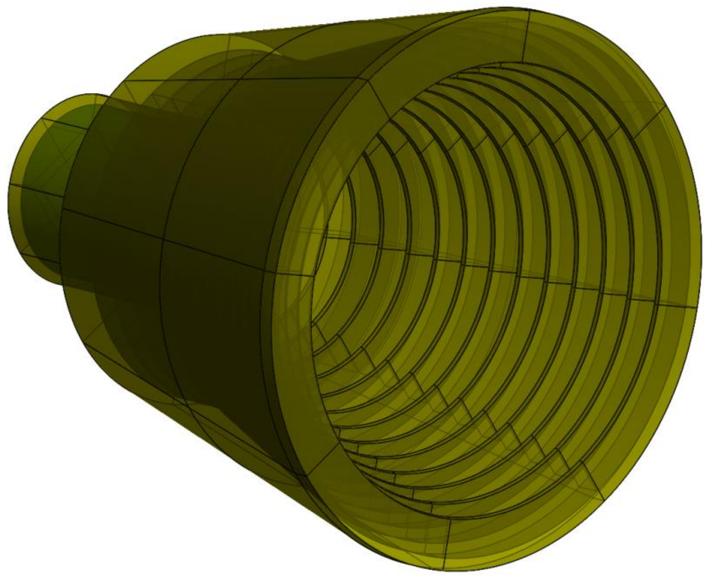

Figure 7-11.33 16 dB Gain Vertical or Radial Corrugated Horn designed for 10 GHz

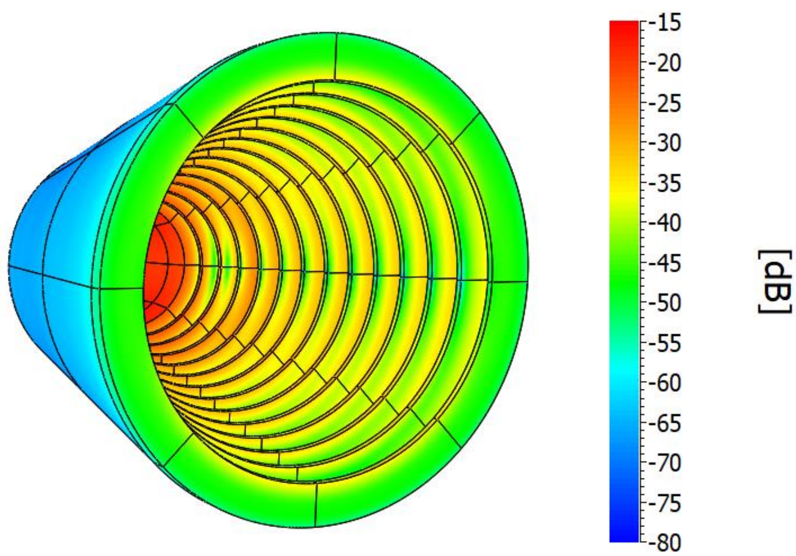

Figure 7-11.34 Wall currents of 16 dB Gain Vertical or Radial Corrugated Horn designed for 10 GHz

CHAMP was used to analyze the slanted corrugated horn at 4 times the number of frequencies using BOR-MoM. The CHAMP runtime was about 100 times faster than the GRASP MoM analysis on the same computer. The CHAMP center frequency pattern Figure 7-11.35 matches those above. CHAMP readily plots frequency responses of beam parameters. Both analysis methods match.

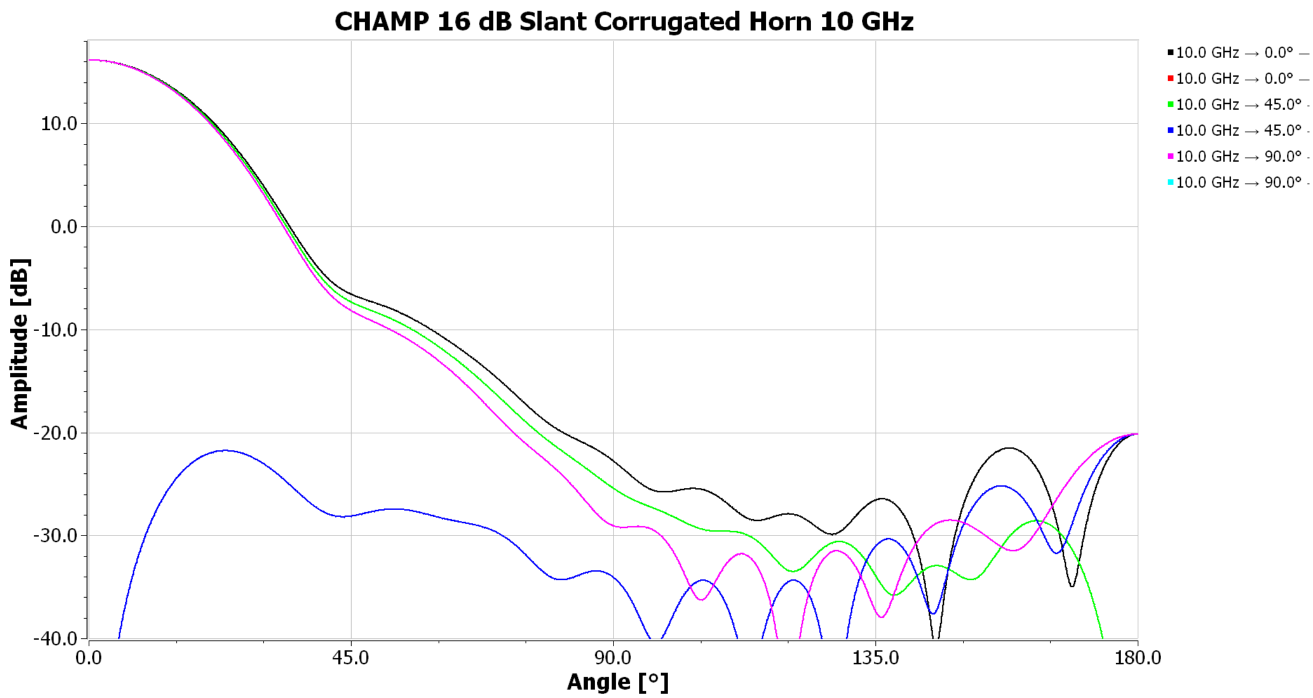

Figure 7-11.35 CHAMP analysis 16 dB Gain Slant Corrugated Horn designed for 10 GHz

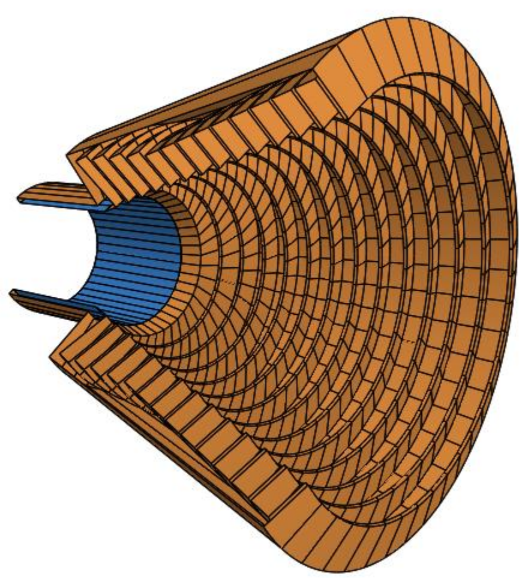

Figure 7-11.36 CHAMP model of 16 dB Gain Slant Corrugated Horn designed for 10 GHz

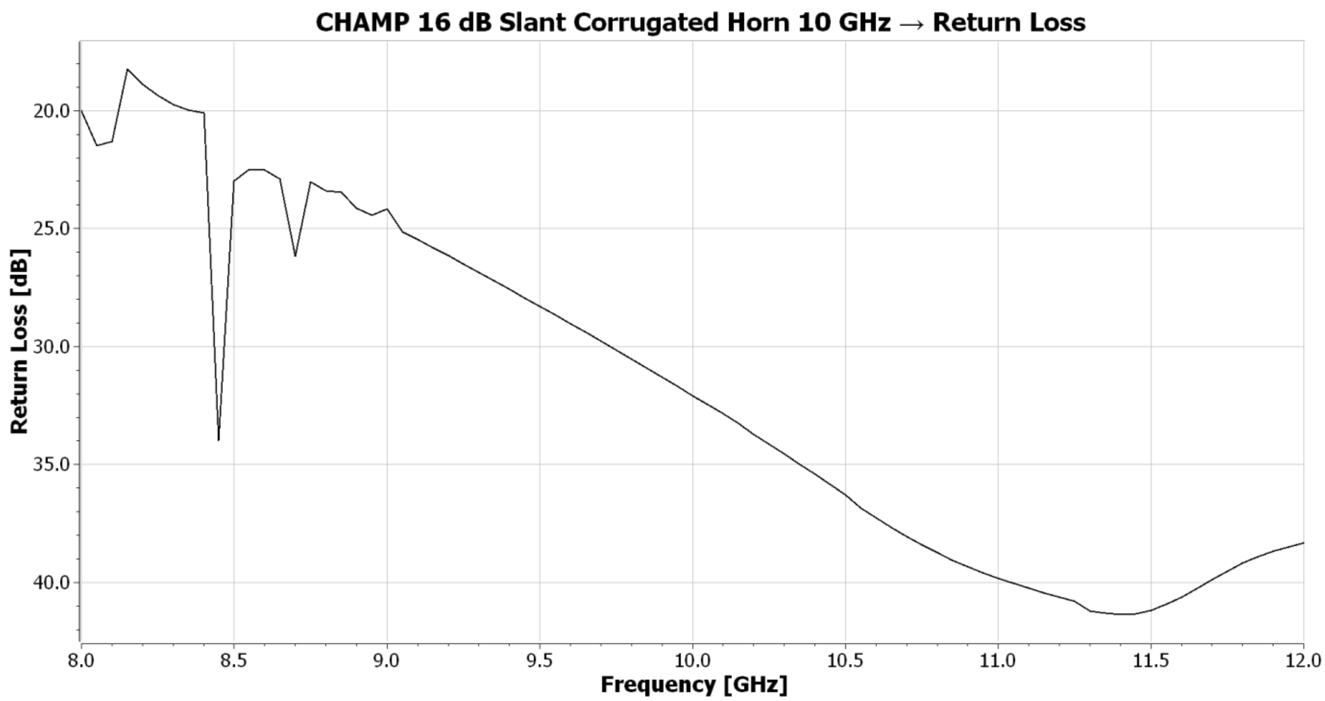

Figure 7-11.37 CHAMP 16 dB Gain Slant Corrugated Horn designed for 10 GHz Return Loss

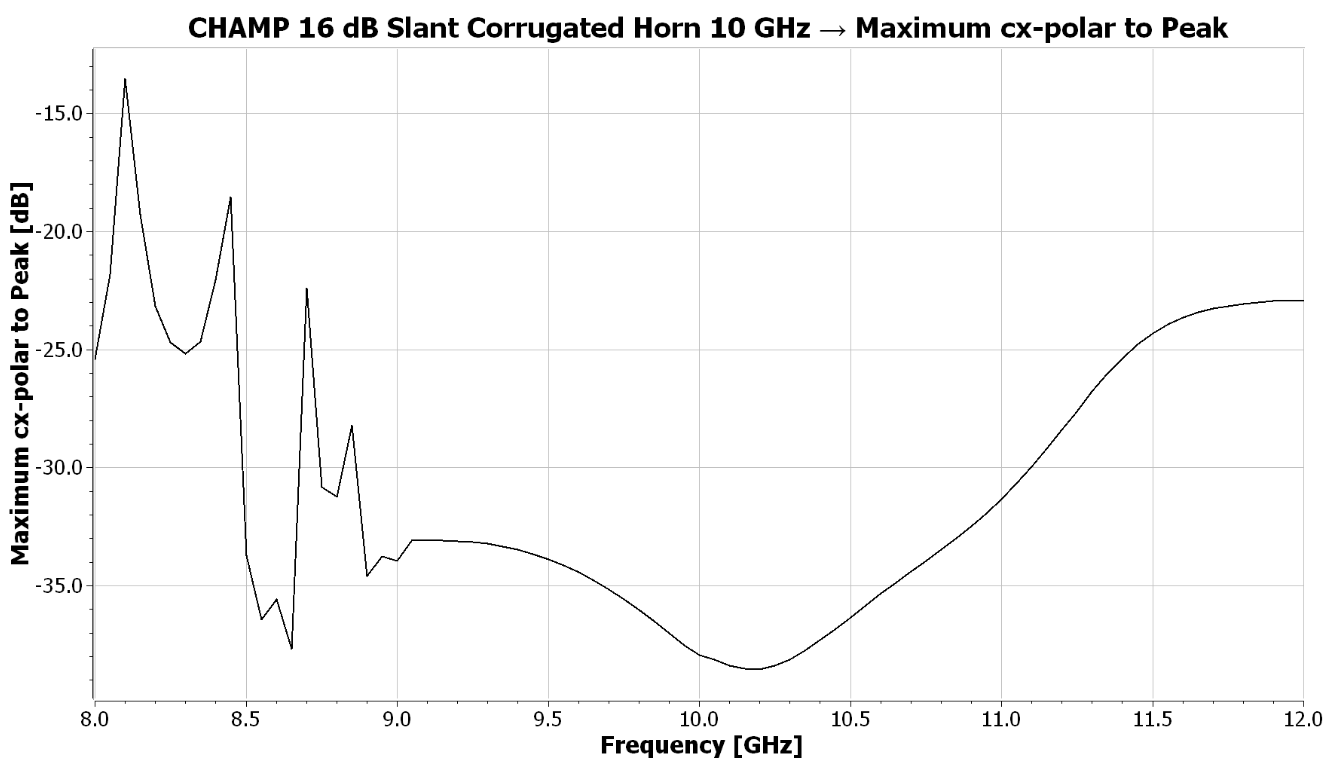

Figure 7-11.38 CHAMP 16 dB Gain Slant Corrugated Horn designed for 10 GHz Max X-pol.

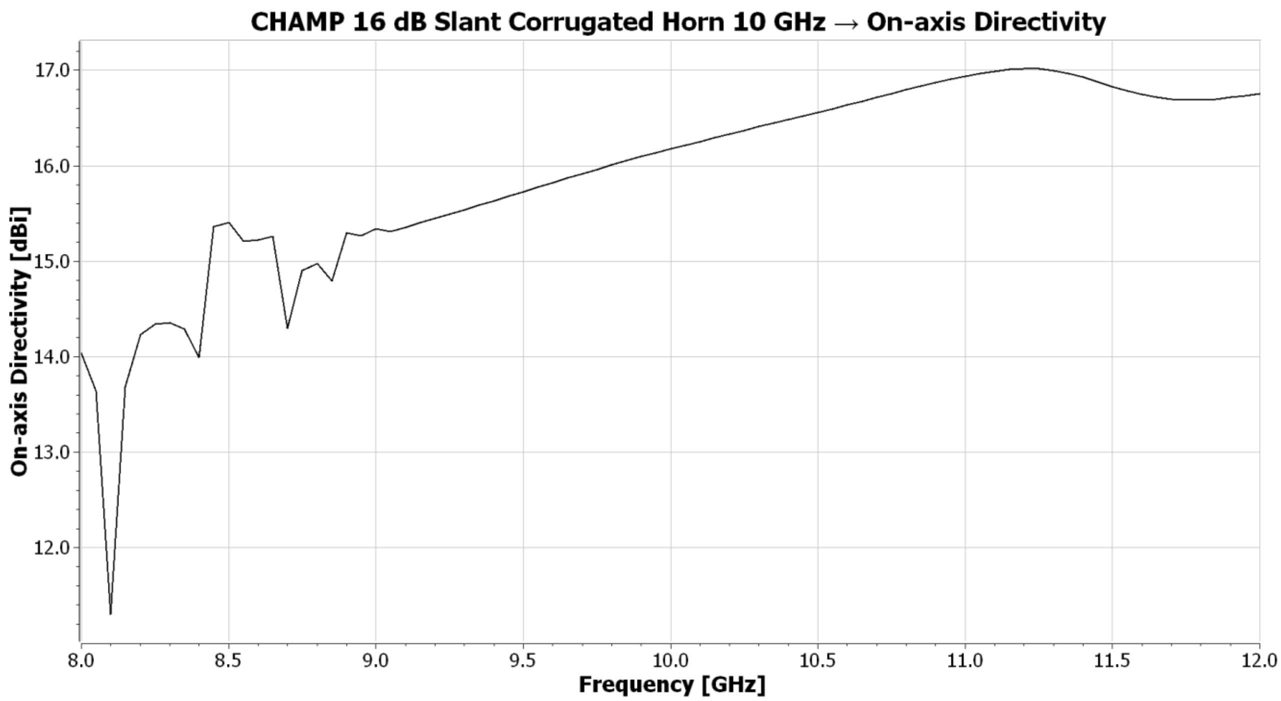

Figure 7-11.39 CHAMP 16 dB Gain Slant Corrugated Horn designed for 10 GHz Directivity

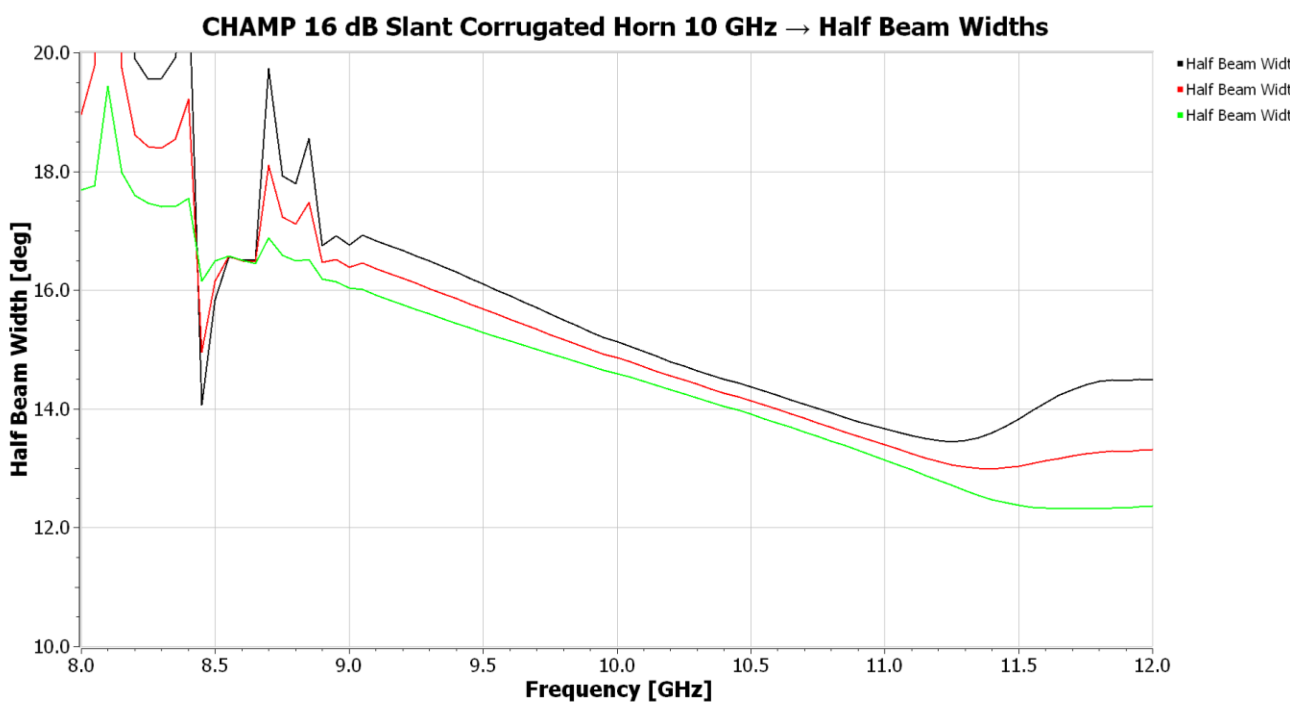

Figure 7-11.40 CHAMP 16 dB Gain Slant Corrugated Horn designed for 10 GHz Half Beamwidth

The corrugated horn has reasonable performance from 8.8 GHz to 11.2 GHz, about 24% bandwidth. One way to improve the performance is to increase the number of slots in the taper. When all 13 slots are in the initial taper, only the aperture slot is near λ/4.

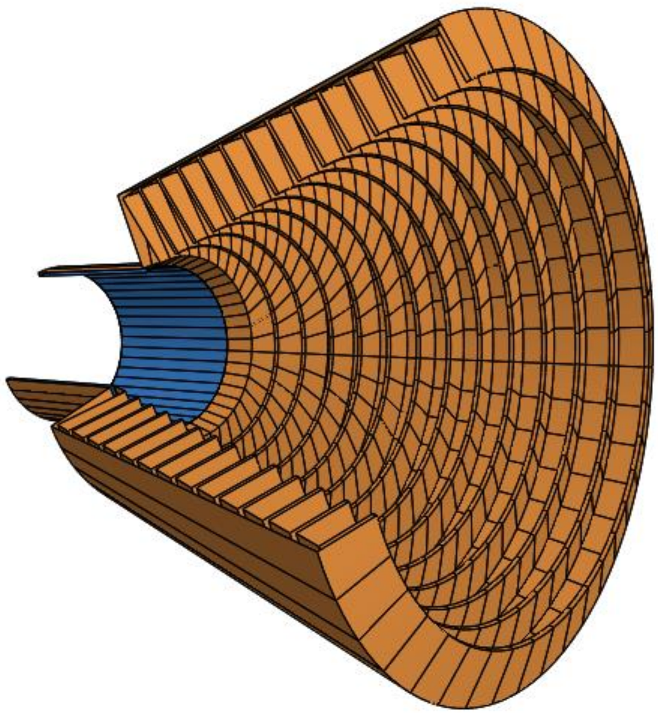

Figure 7-11.41 16 dB Gain Slant Corrugated Horn designed for 10 GHz with depth taper over all 13 slots

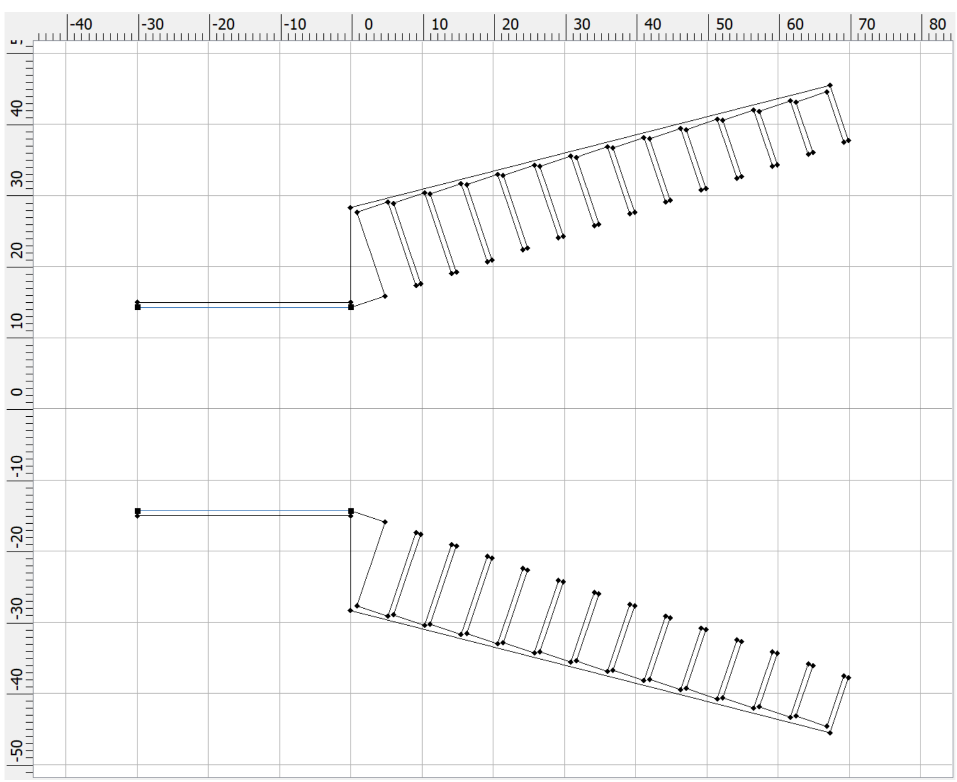

Figure 7-11.42 16 dB Gain Slant Corrugated Horn designed for 10 GHz with depth taper over all 13 slots

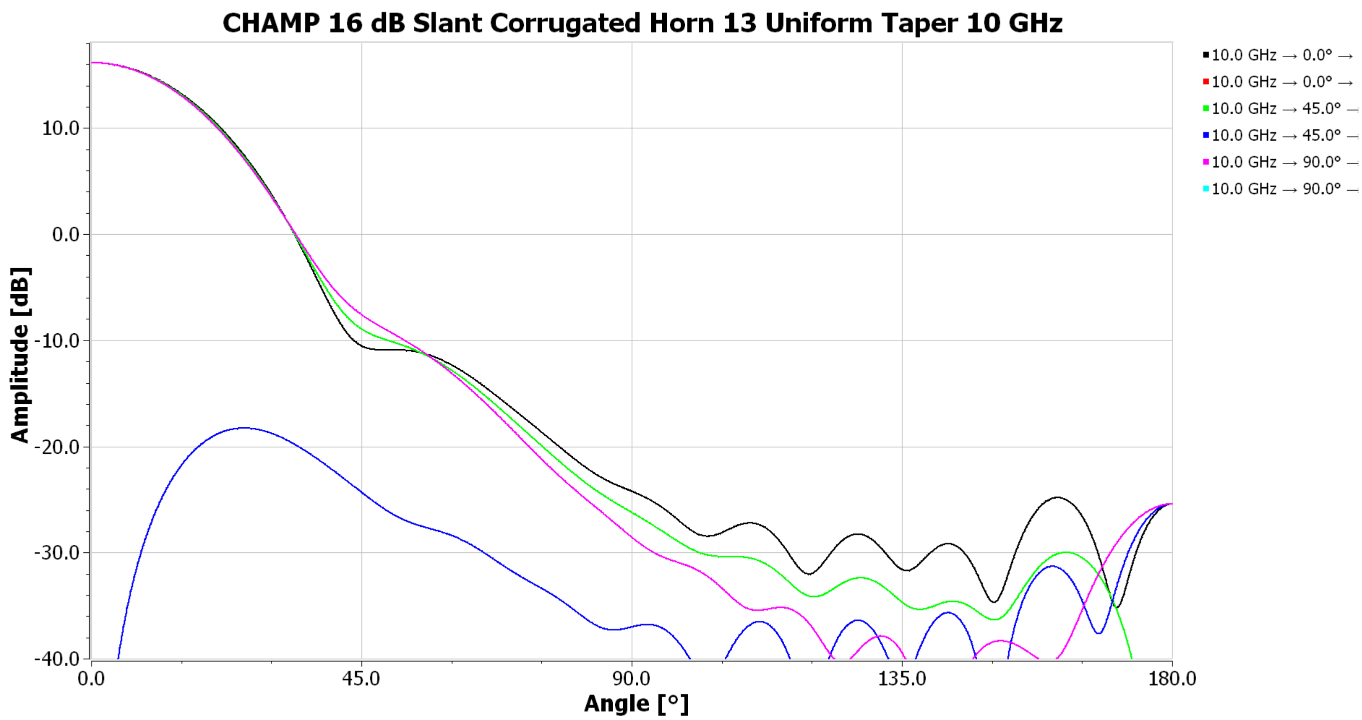

Figure 7-11.43 16 dB Gain Slant Corrugated Horn designed for 10 GHz with depth taper over all 13 slots

Figure 7-11.43 matches Figures 7-11.32 and 7-11.33 except the maximum X-pol. is higher. The boresight gain 16.17 dB matches the other designs.

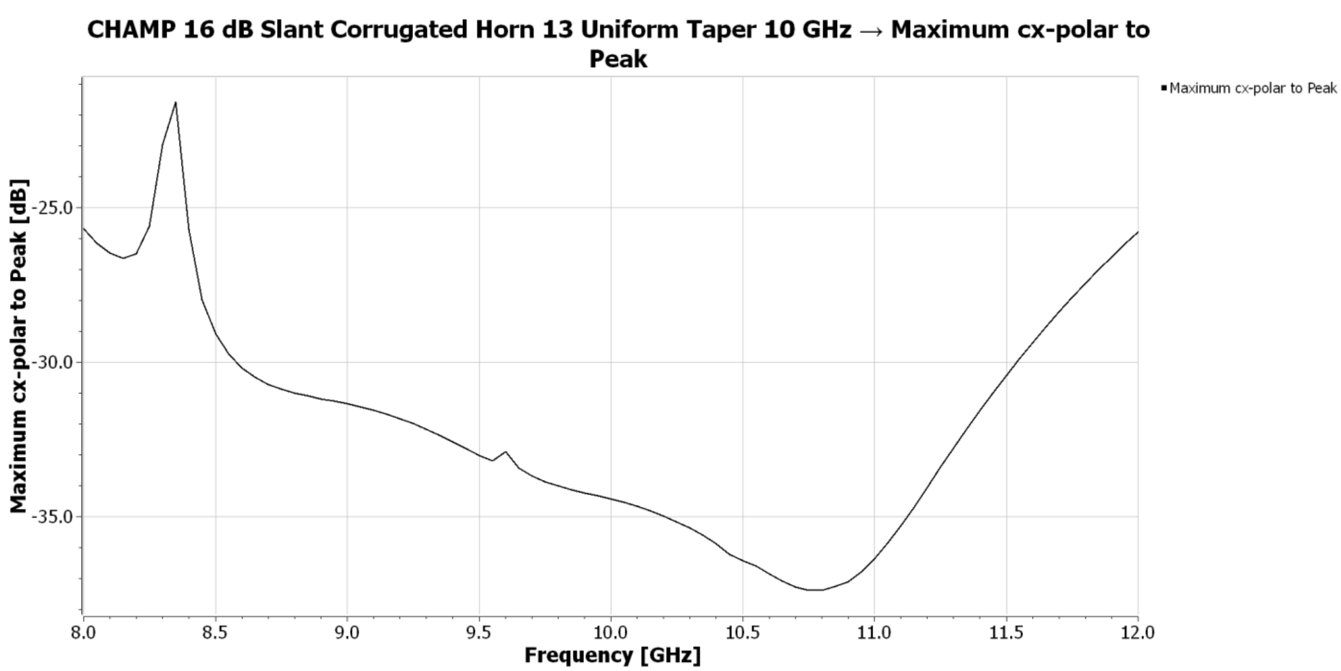

Figure 7-11.44 16 dB Gain Slant Corrugated Horn designed for 10 GHz with depth taper over all 13 slots – max X-pol.

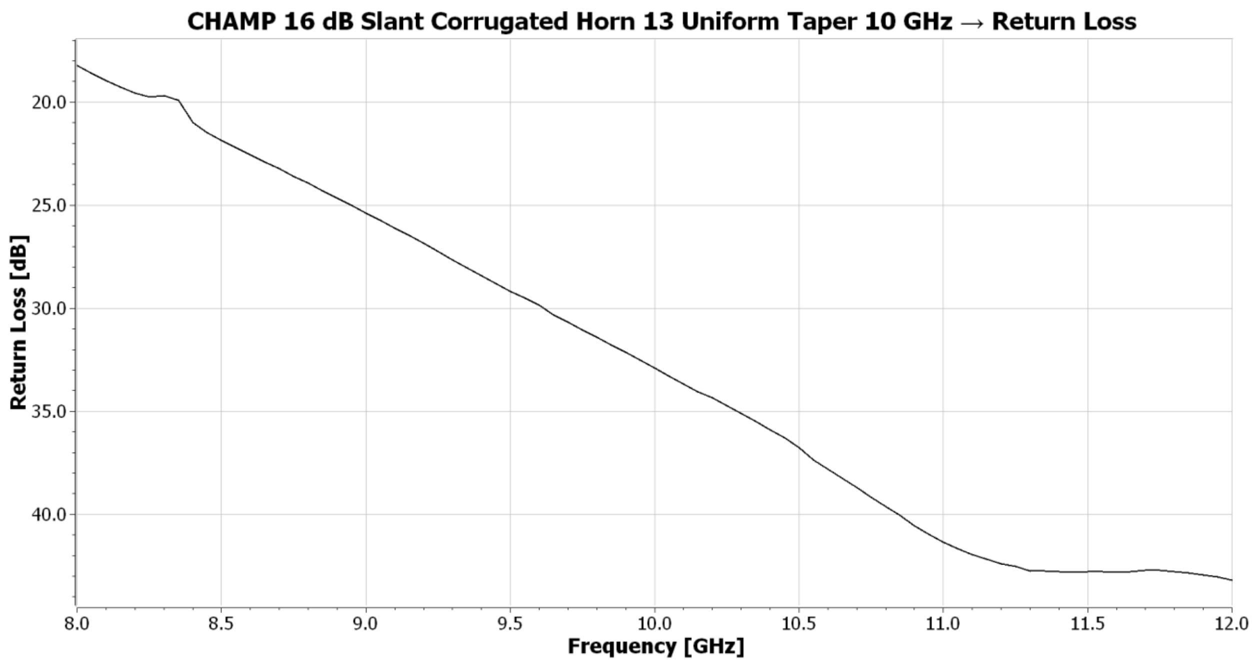

Figure 7-11.45 16 dB Gain Slant Corrugated Horn designed for 10 GHz with depth taper over all 13 slots – Return Loss

The uniform taper across all slots produces a broader bandwidth design, but the basic corrugated horn structure has its limits. The outer cone of the horn has nearly a uniform thickness which means for low frequency designs the antenna can be built using sheet metal. The conical shape of the corrugation ridges means first than they can be cut-out flat and rolled into cones. When they are attached to the outer cone of the bell, the whole structure becomes very rigid and light-weight.

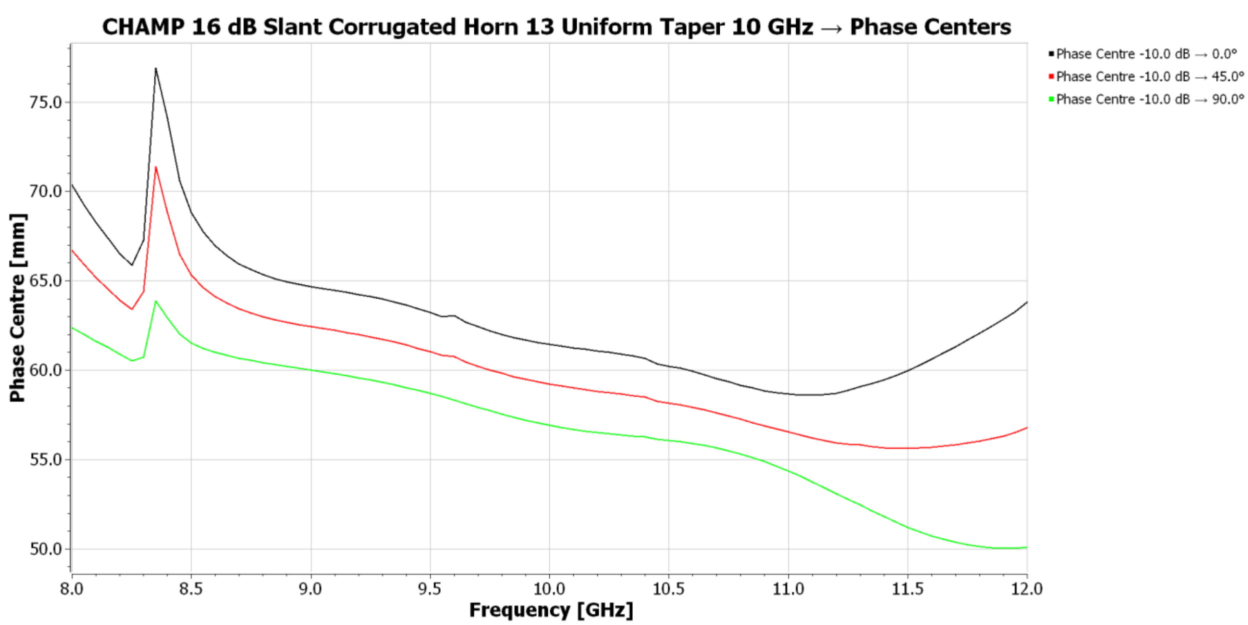

Figure 7-11.46 Phase Center of 16 dB Slant Corrugated Horn designed at 10 GHz

A 1.3 m. diameter aperture corrugated horn feed was built using sheet metal instead of machining a billet and could be easily carried with one hand. Figure 7-11.46 plots positive *z*-axis values of phase center because the corrugations are exterior BOR-MoM elements in the model. The phase reference is the end of the input waveguide and not the aperture.

16 dB Slant Corrugated Horn without Outer Walls

CORHGRAT has the option of generating a corrugated horn model without the outer walls. We repeat the slanted wall 16 dB corrugated horn. The GRASP run is about 3.8 times faster producing 0.04 dB difference.

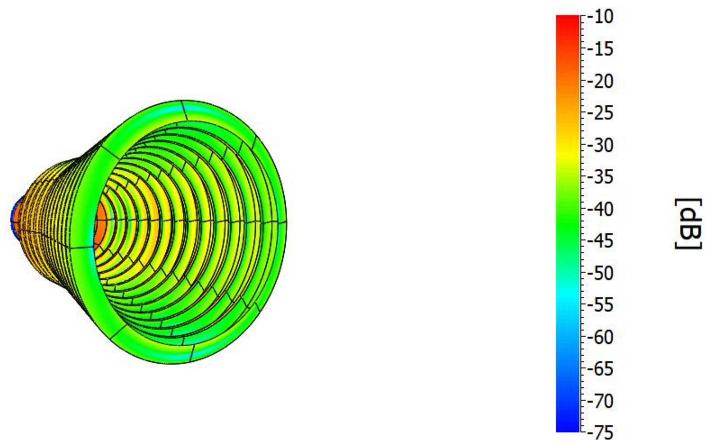

Figure 7-11.47 Wall Currents of GRASP MoM 16 dB Slanted Corrugated Horn w/o Walls at 10 GHz

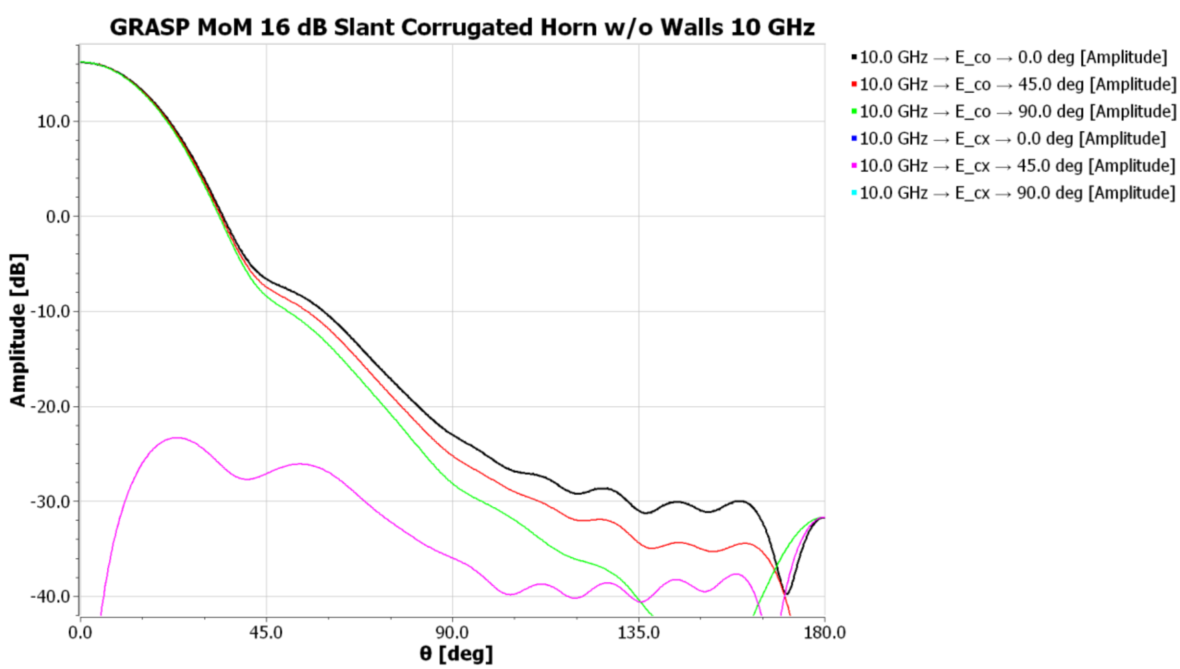

Figure 7-11.48 GRASP MoM 16 dB Slanted Corrugated Horn w/o walls at 10 GHz

7-11.2.4 Scalar Horn

Section 7-3.1 discusses the scalar horn a wide flare angle corrugated horn with slant corrugations. Earlier studies suggest this horn radiates nearly constant beamwidth (gain) patterns over a band. CORHGRA can generate the GRASP MoM or CHAMP exterior BOR-MoM models for the scalar horn. An optimum scalar horn with a 35° half flare angle and a 4.5 λ diameter aperture is selected from Table 7-8.

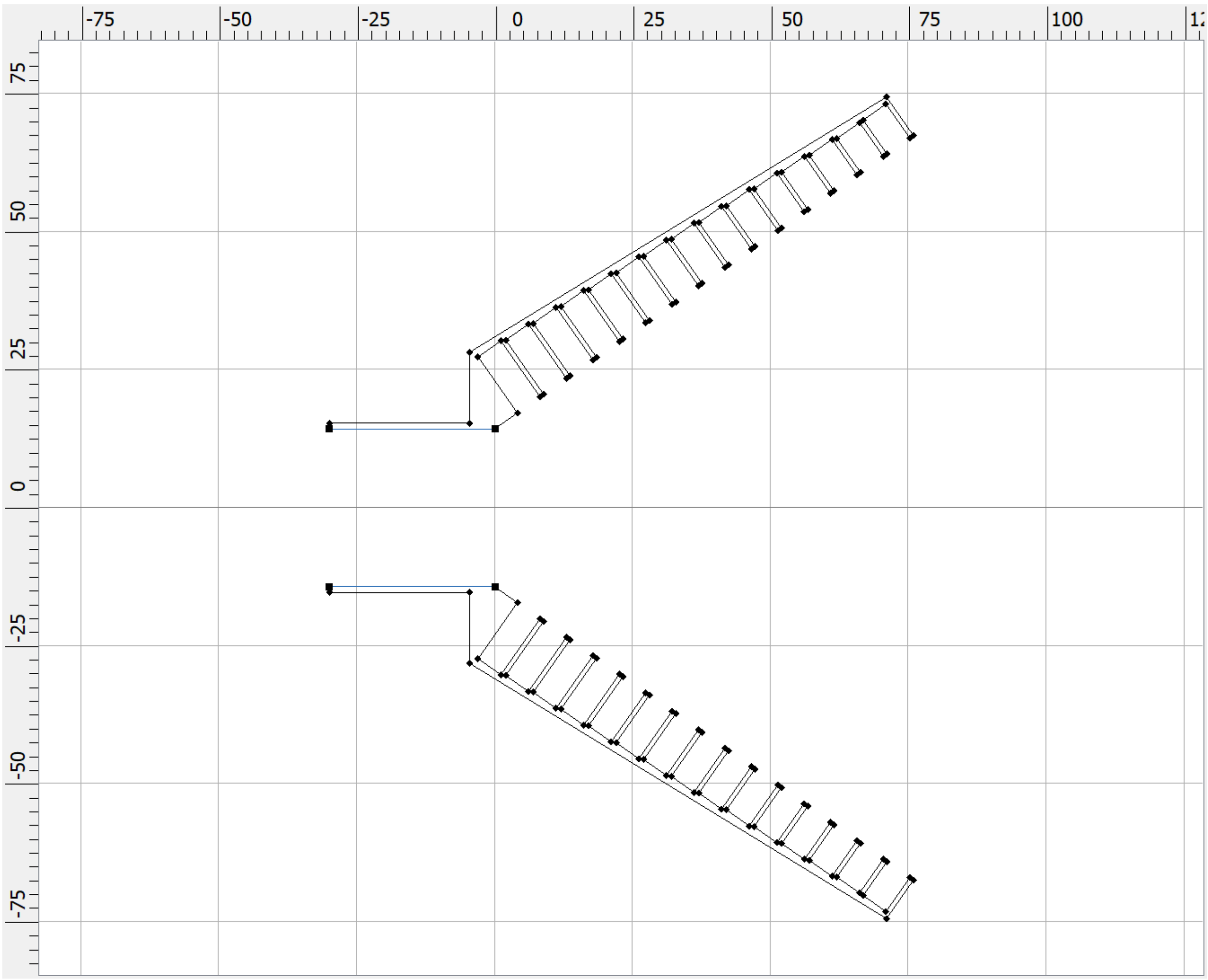

Figure 7-11.49 CHAMP geometry of 35° flare angle 4.5λ diameter scalar horn

In Figure 7-11.49 the bell of the horn connects to the output of the waveguide the phase reference point and modeled as an exterior BOR-MoM object. The GRASP model is also a BOR-MoM structure, but the waveguide port excitation does not allow a BOR solution and a full MoM model is used and runtimes greatly exceed those of CHAMP.

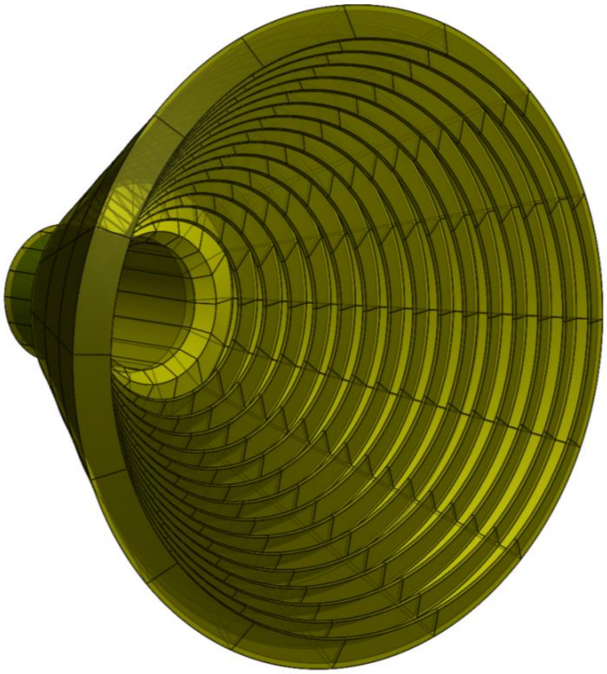

Figure 7-11.50 GRASP model of 35° flare angle 4.5λ diameter scalar horn

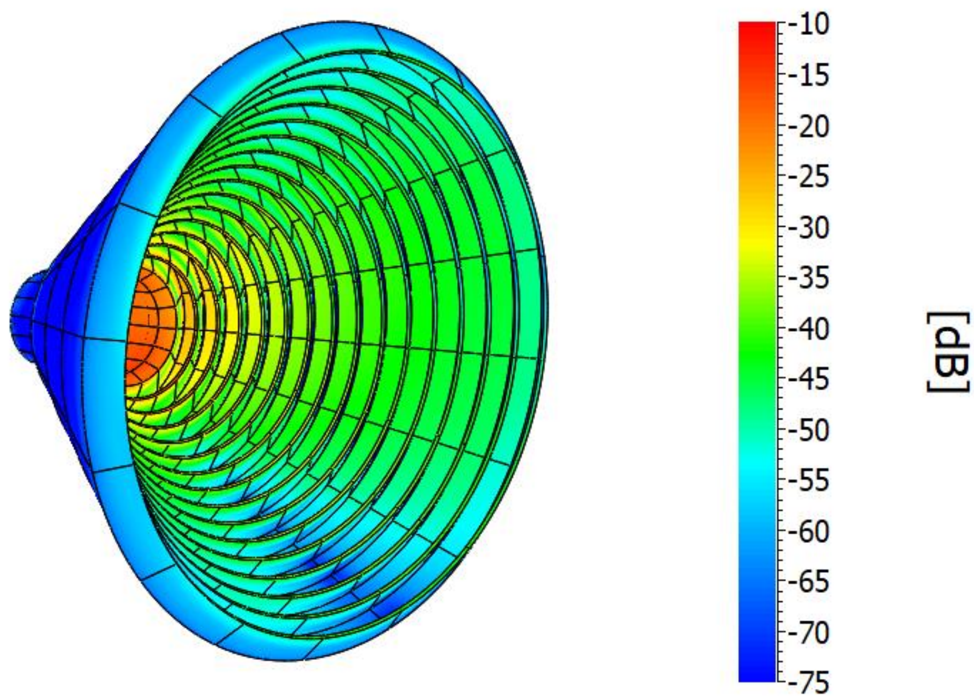

Figure 7-11.51 Wall Currents GRASP model of 35° flare angle 4.5λ diameter scalar horn @ 10 GHz

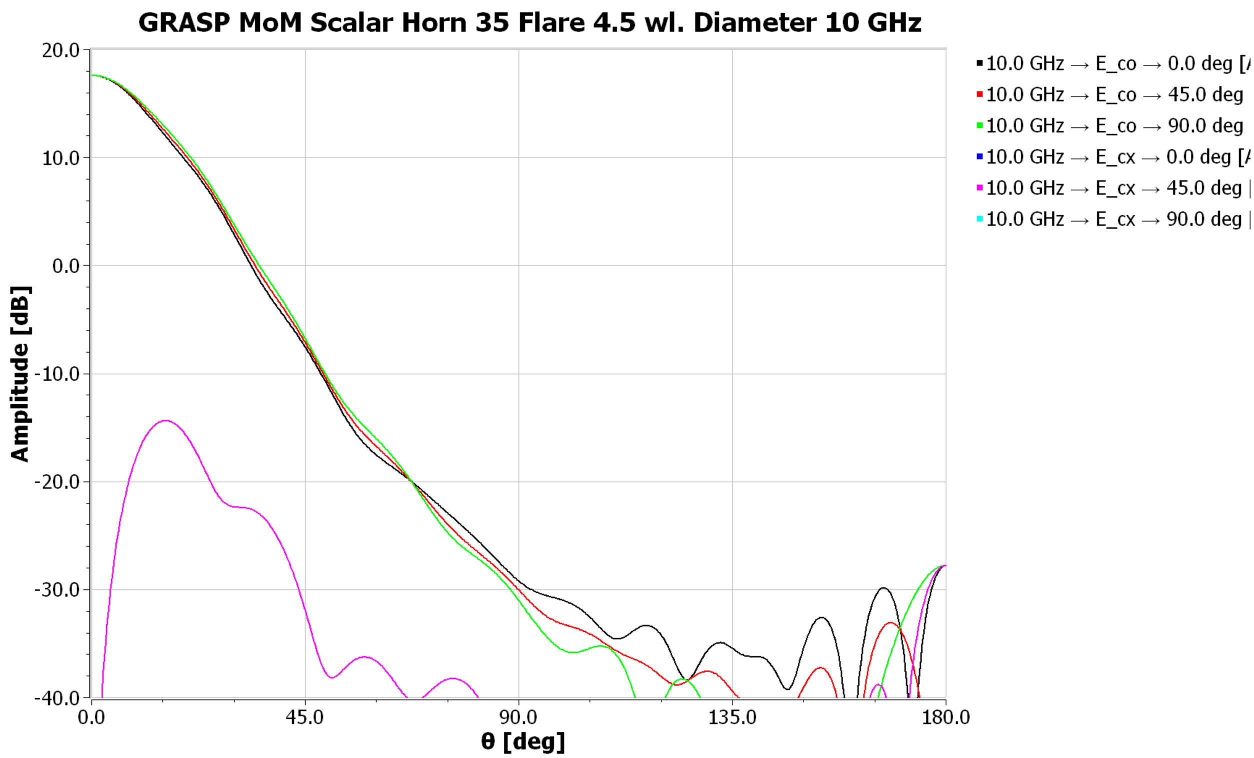

Figure 7-11.52 GRASP Pattern of 35° flare angle 4.5λ diameter scalar horn @ 10 GHz

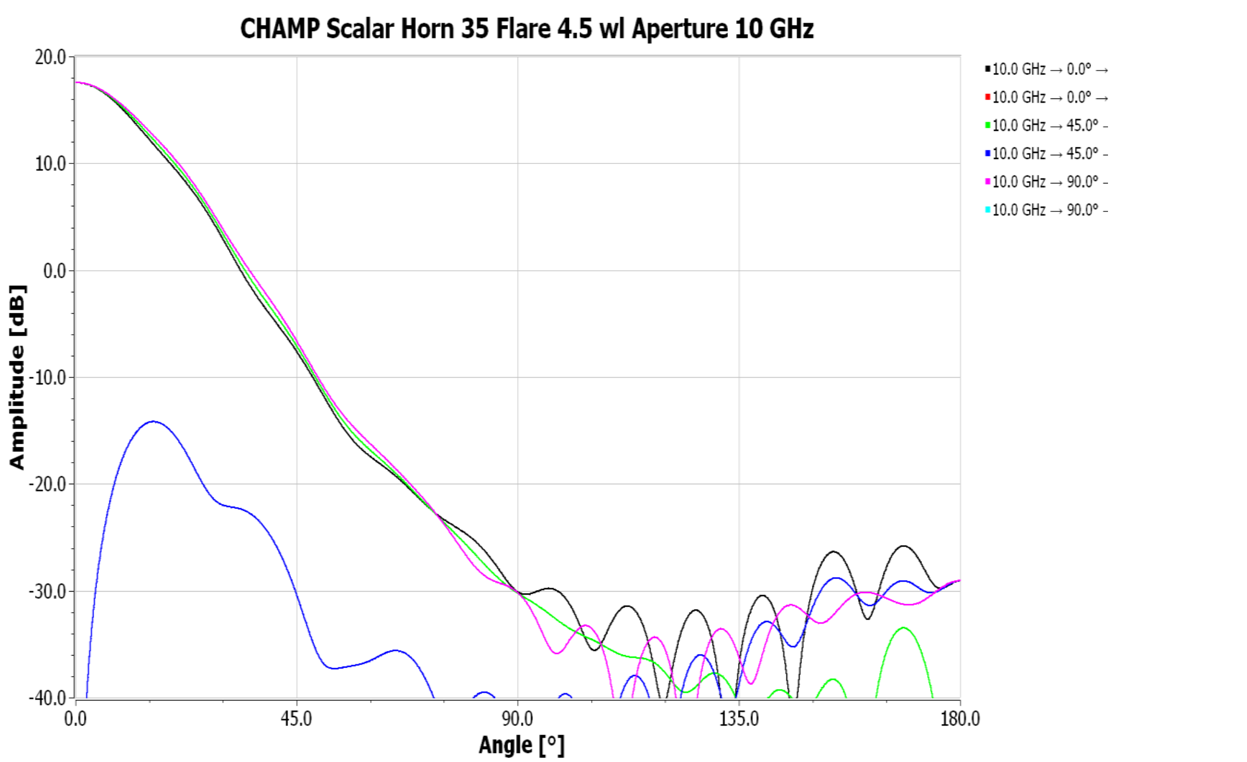

Figure 7-11.53 CHAMP Pattern of 35° flare angle 4.5λ diameter scalar horn @ 10 GHz

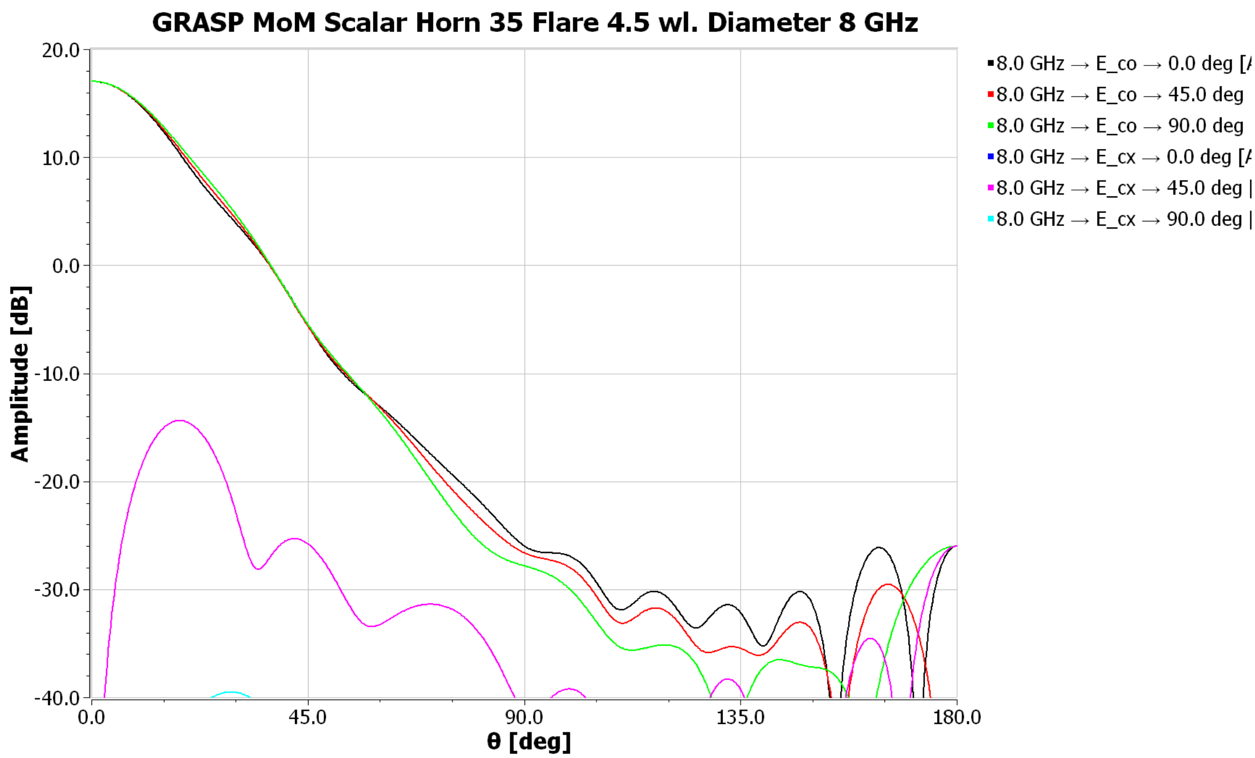

Figure 7-11.54 GRASP Pattern of 35° flare angle 4.5λ diameter scalar horn @ 8 GHz

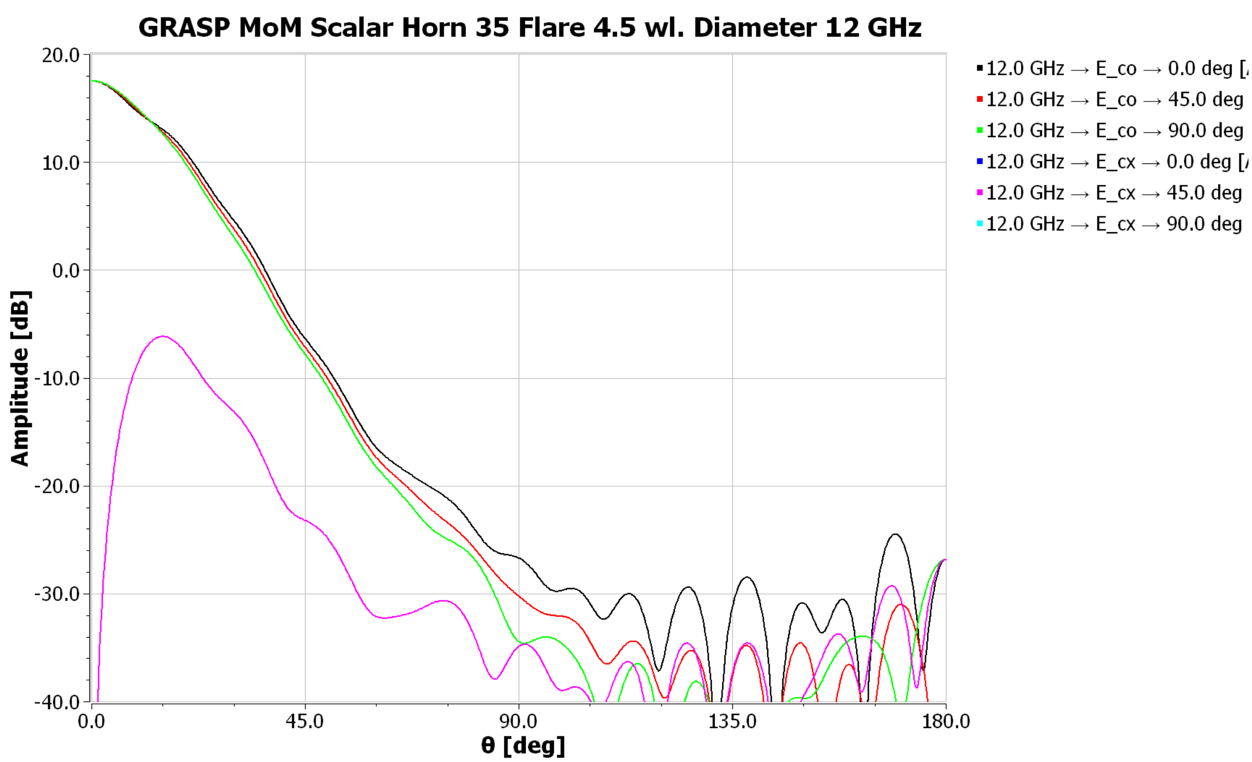

Figure 7-11.55 GRASP Pattern of 35° flare angle 4.5λ diameter scalar horn @ 12 GHz

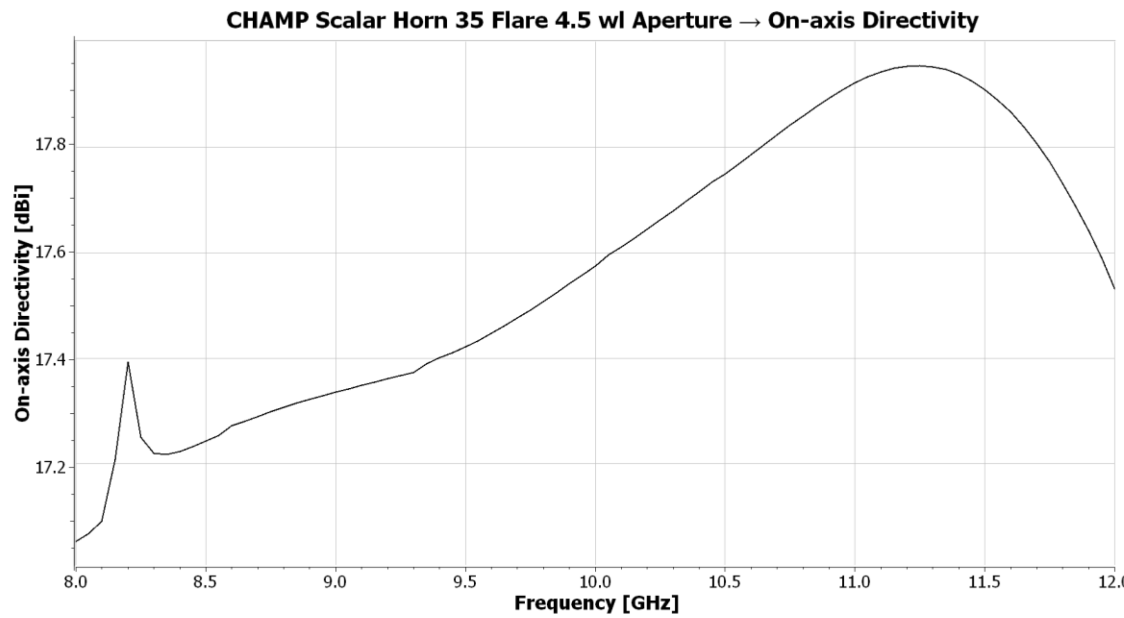

Figure 7-11.56 CHAMP Gain of 35° flare angle 4.5λ diameter scalar horn

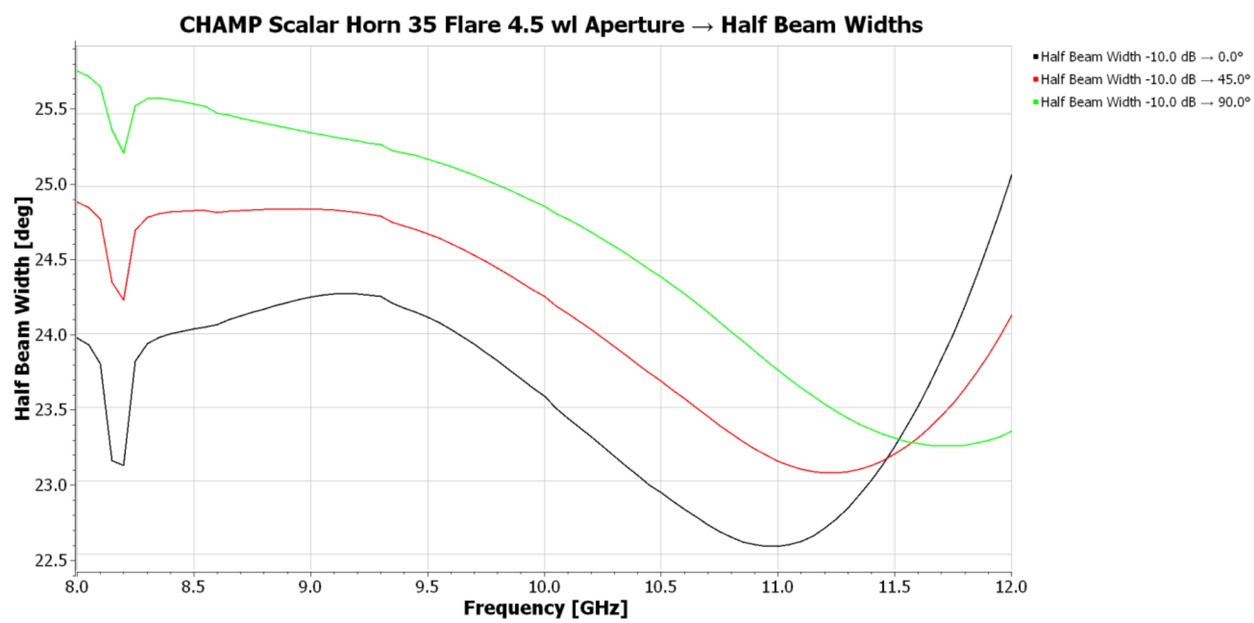

Figure 7-11.57 CHAMP Half 10-dB Beamwidth of 35° flare angle 4.5λ diameter scalar horn

The pattern changes little over the band from 8- to 12-GHz as illustrated by Figures 7-11.52, 7-11.54, and 7-11.55. GRASP and CHAMP predict the same pattern Figures 7-11.52 and 7-11.53, but use either a complete 3-d MoM or a BOR-MoM solution. Figure 7-11.56 uses gain while Figure 7-11.57 uses the 10-dB half beamwidth to show the nearly constant pattern of the horn over the 8- to 12-GHz band.

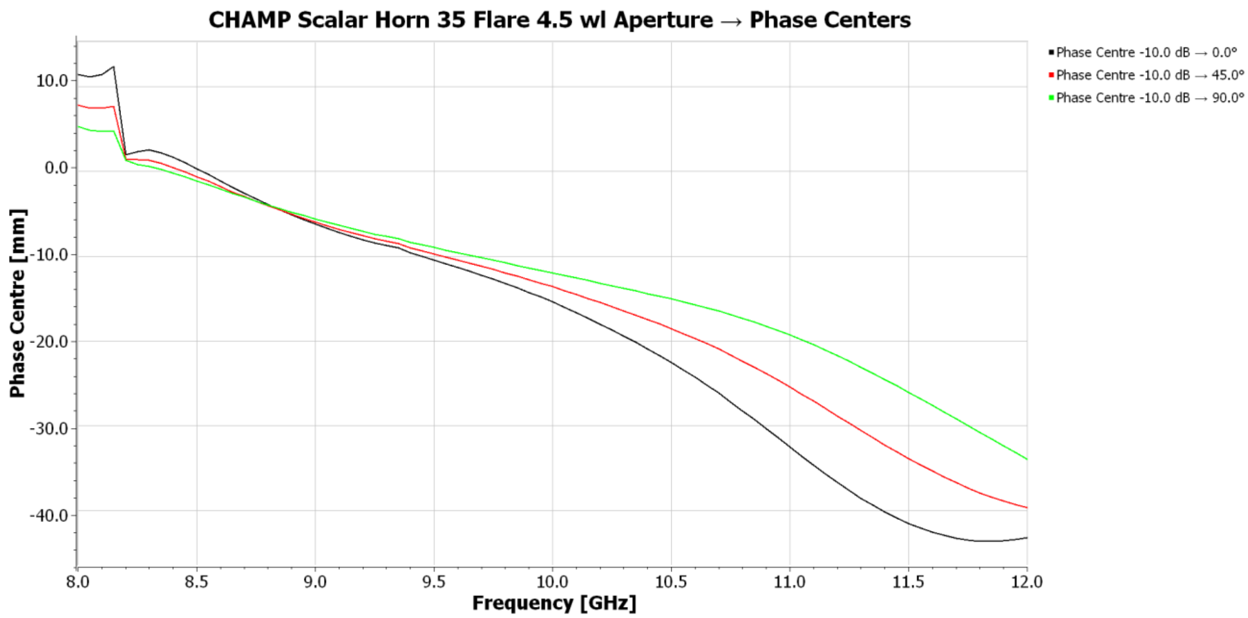

Figure 7-11.58 CHAMP Phase Center of 35° flare angle 4.5λ diameter scalar horn

The phase reference point of the analytical model is located at the juncture between the waveguide and the bell (Figure 7-11.49). Figure 7-11.58 gives the phase center at center frequency (10 GHz) as the projection of the bell cone vertex into the feeding waveguide. The optimum reflector *f*/*D* for this feed is 1.15. By using Scale 8-3 with a defocusing of about λ (~30 mm) (Figure 7-11.58) we compute an S = 0.09. Table 4-43 of quadratic phase error loss lists a loss of 0.13 dB at the band edges for an equivalent circular Gaussian distribution.

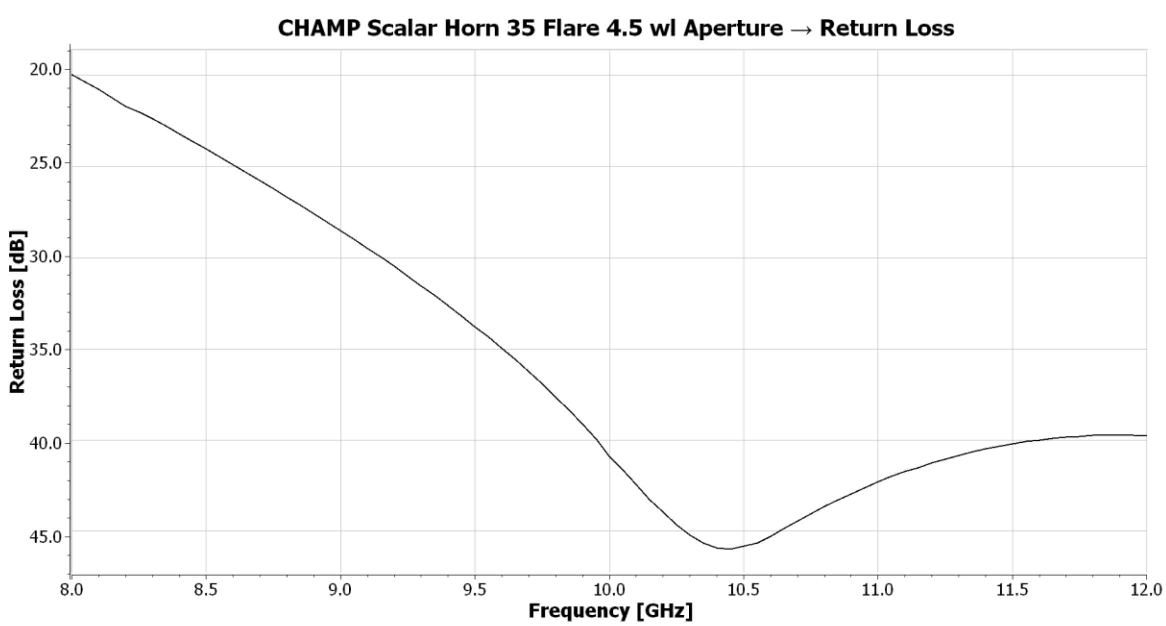

Figure 7-11.59 CHAMP Return Loss of 35° flare angle 4.5λ diameter scalar horn

7-11.2.5 Axially Corrugated Horn

This low gain horn with its good axial pattern symmetry is a good test between a full MoM solution in GRASP and the mode-matching analysis technique of CHAMP. Section 7-3.3 discusses the design and response of the horn by using CHAMP for analysis. The program AXHGRA generates the GRASP TOR file edits for an existing TOR file to enter the geometry and analysis parameters. The program designs the horn with inputs of bell flare angle and either aperture radius (λ) or gain dB. We run the program in a command line window and input parameters either on the keyboard or from an input file.

```
C:\milligan\ANTENNA\HORN>axhgra
File input? n
Axial Corrugated Horn GRASP BOR-MoM geometry
Enter input waveguide radius, length 14.314,30
Enter length units: 1 in., 2 ft., 3 mm, 4 cm, 5 m 3
Enter design frequency (GHz) 10
Enter ridge thickness .8
Enter horn bell flare angle 35
Enter input: 1 aperture (wavelengths), 2 Gain dB 2
Enter design frequency gain (dB) 16
Aperture radius (wavelengths) =  1.4068
Enter number of corrugations per wavelength 8
Enter GRASP BOR-MoM TOR edit output file axhgra1t.txt
Enter frequency range (GHz) start,stop,number 8,12,21
Enter waveguide mode: (1 TE, 2 TM), Mode (Az), (rad) 1,1,1
Enter Circular waveguiude modal expansion settings
Az mode min, radial max, Az mode max 1,1,1
```

AXHGRA1.TXT:

14.314,30	waveguide radius, length
3	units: mm
10	design frequency GHz
.8	ridge thickness
35	horn bell flare angle
2	specify gain
16	gain dB
8	corrugations per wavelength
axhgra1t.txt	
8,12,21	frequency start,stop,number
1,1,1	TE - 11 mode
1,1,1	circular waveguide modal expansion settings

The first example uses a 16 dB gain horn with a 35° bell flare angle. We start with an existing GRASP project and save it as a new project. Look in the "working" directory of the new project and open the TOR (*.tor) file with a text editor and erase all lines above the line: //DO NOT MODIFY OBJECTS BELOW THIS LINE and replace them with the output of AXHGRA: AXHGRA1T.TXT from the example output above. Complete the edit and re-start the GRASP project.

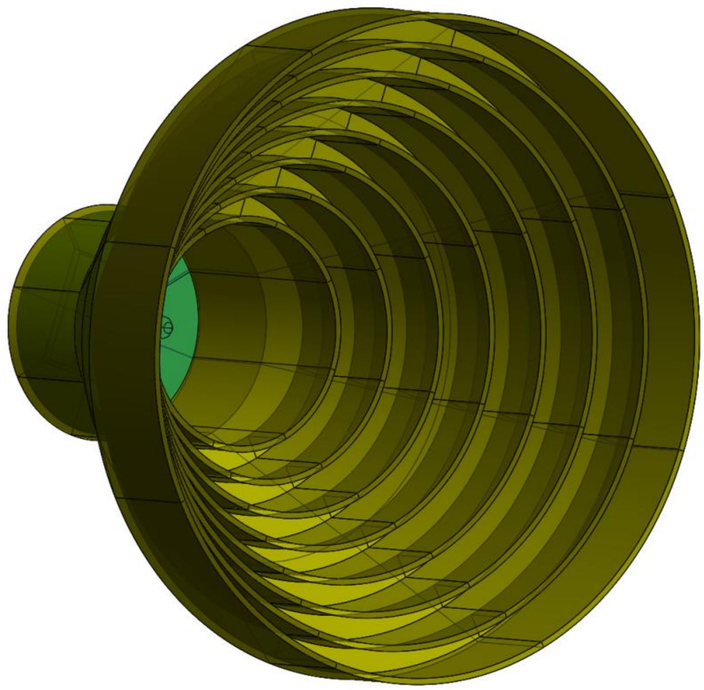

Figure 7-11.60 GRASP MoM model of 16 dB gain Axially Corrugated Horn for 10 GHz

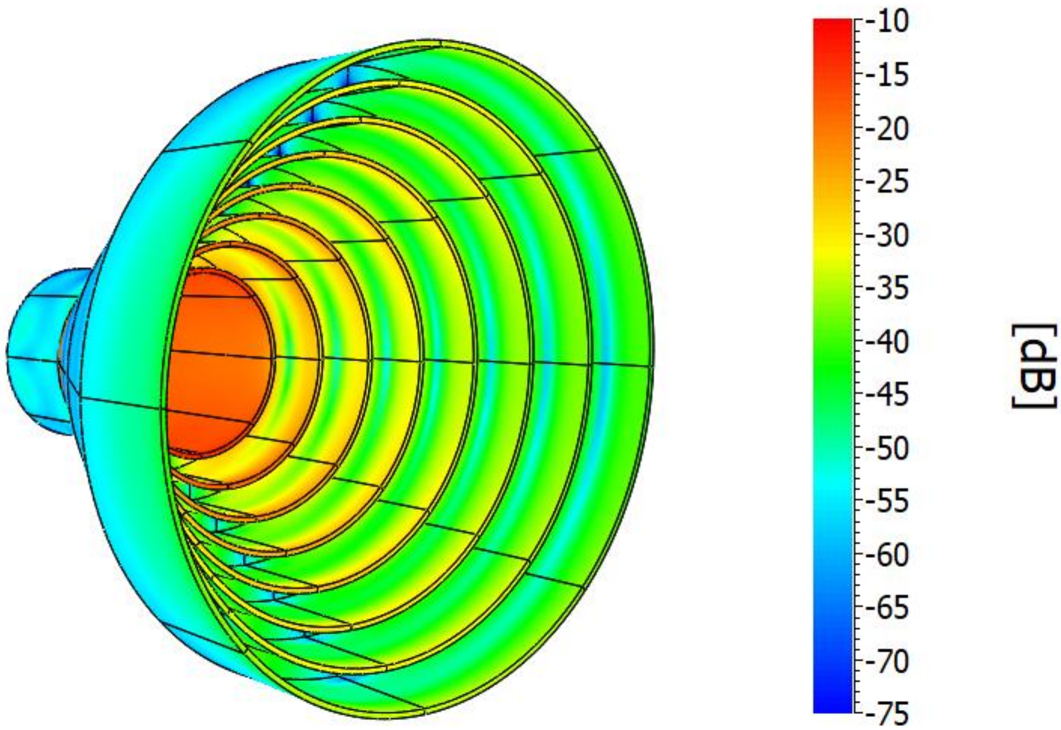

Figure 7-11.61 Wall currents in GRASP MoM model of 16 dB gain Axially Corrugated Horn for 10 GHz

The MoM analysis replaces the metal parts with the currents induced on the interior and exterior walls of the bell including both sides of each corrugation to compute the radiated pattern.

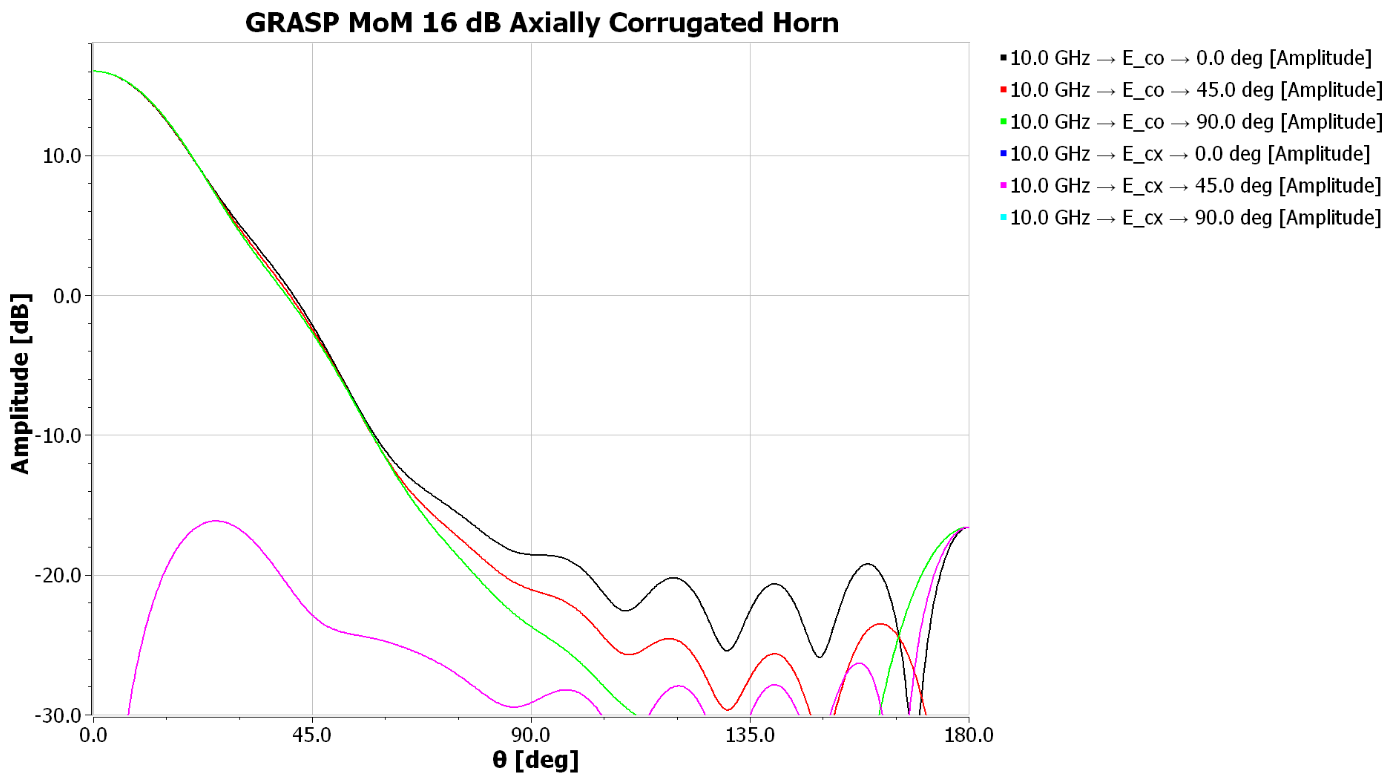

Figure 7-11.62 GRASP MoM of 16 dB gain Axially Corrugated Horn for 10 GHz Pattern

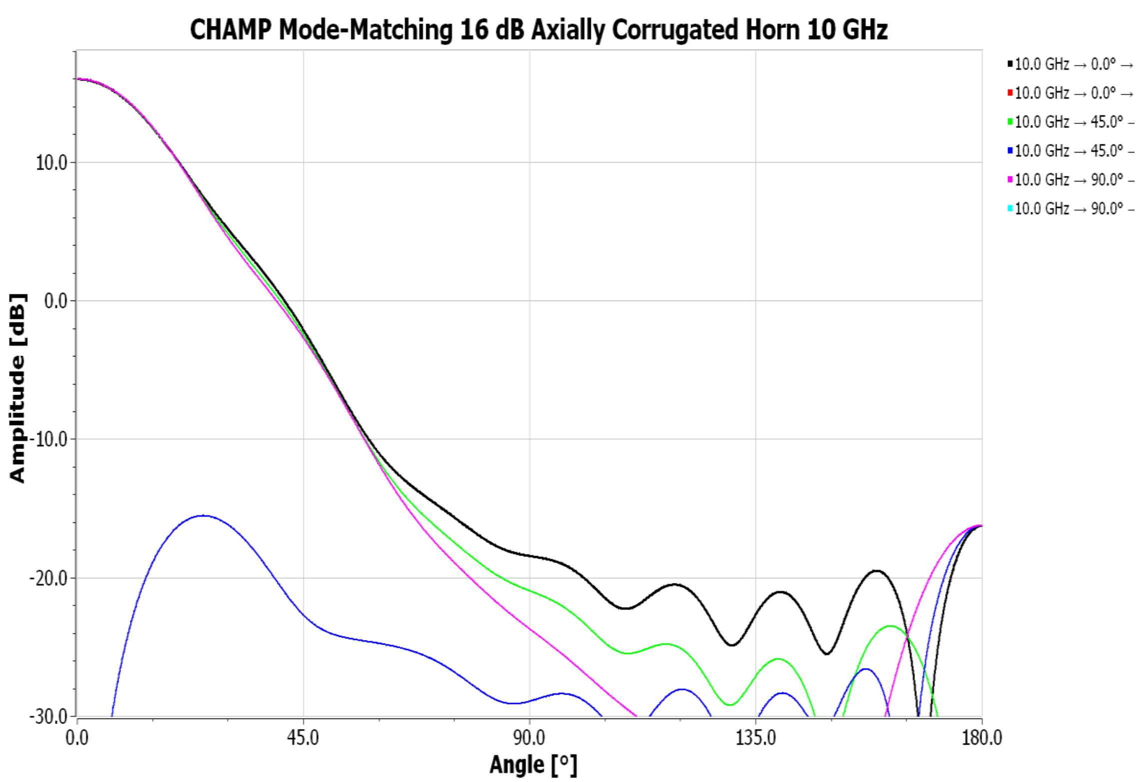

Figure 7-11.63 CHAMP Mode-Matching of 16 dB gain Axially Corrugated Horn for 10 GHz Pattern

GRASP MoM predicts 0.012 dB higher boresight gain and the two methods predict very closely the same patterns at all angles.

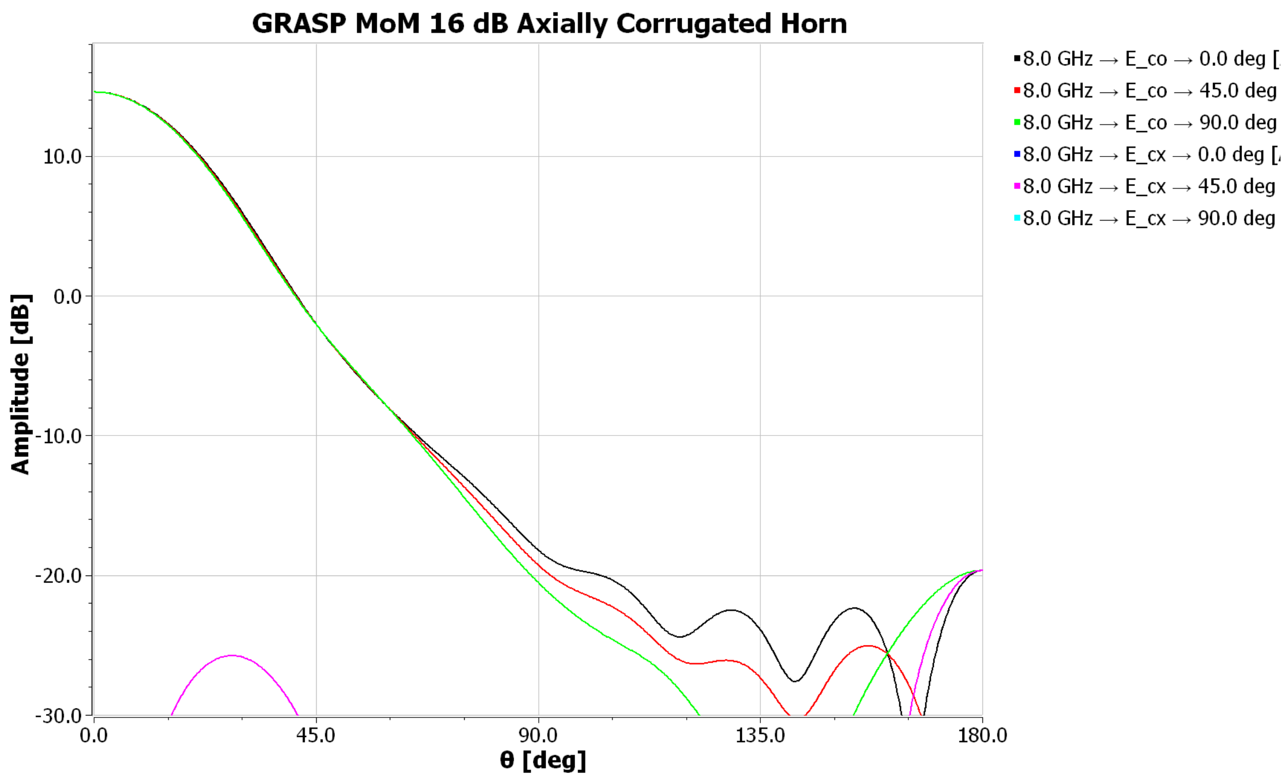

Figure 7-11.64 GRASP MoM of 16 dB gain Axially Corrugated Horn for 10 GHz Pattern @ 8 GHz

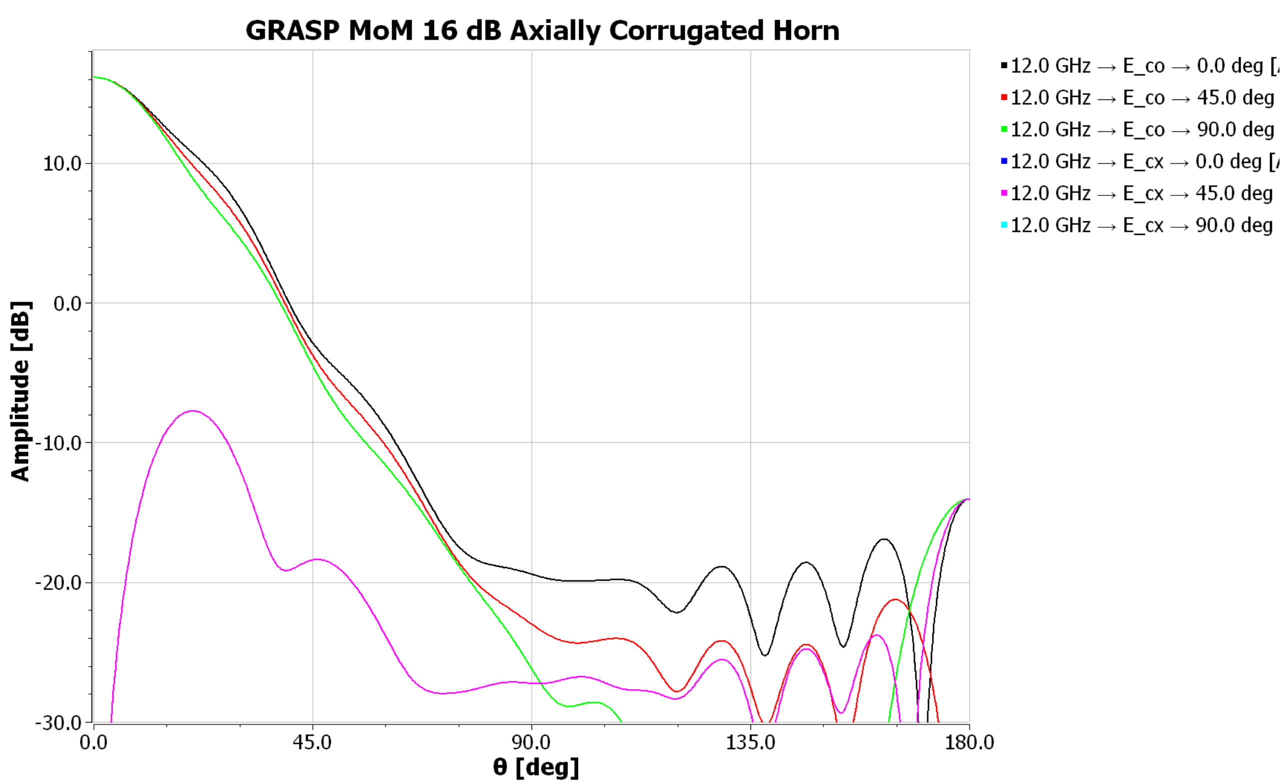

Figure 7-11.65 GRASP MoM of 16 dB gain Axially Corrugated Horn for 10 GHz Pattern @ 12 GHz

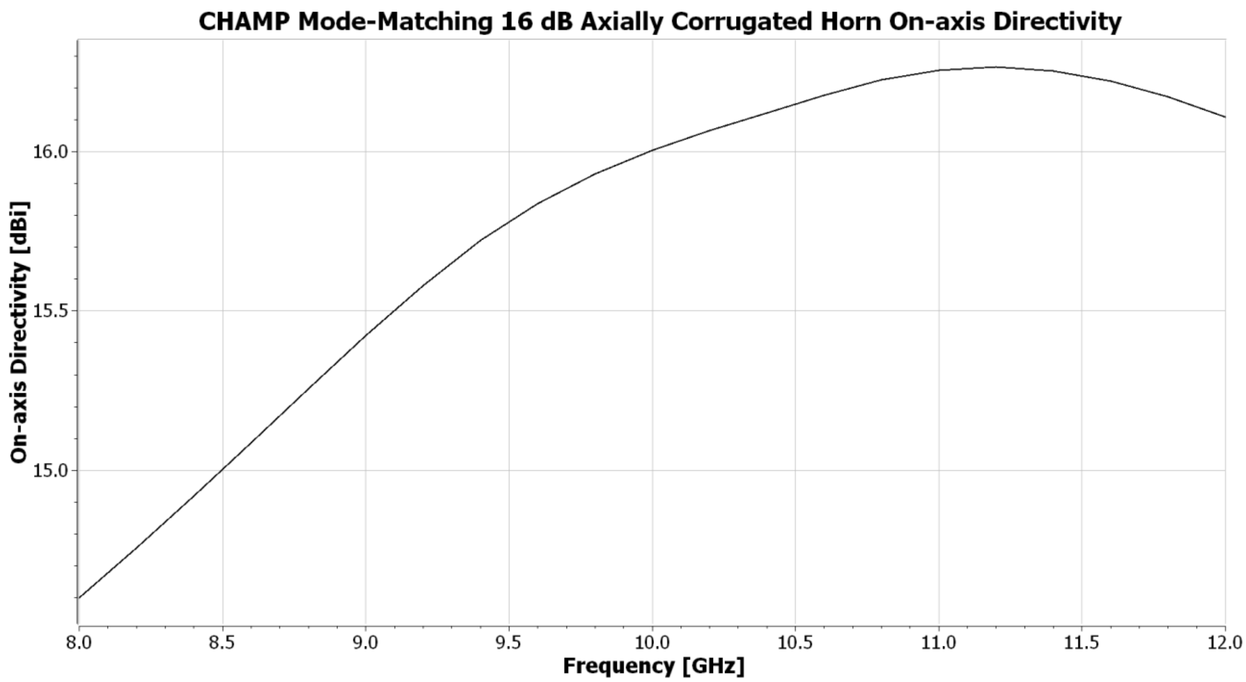

Figure 7-11.66 CHAMP Mode-Matching of 16 dB gain Axially Corrugated Horn for 10 GHz Directivity

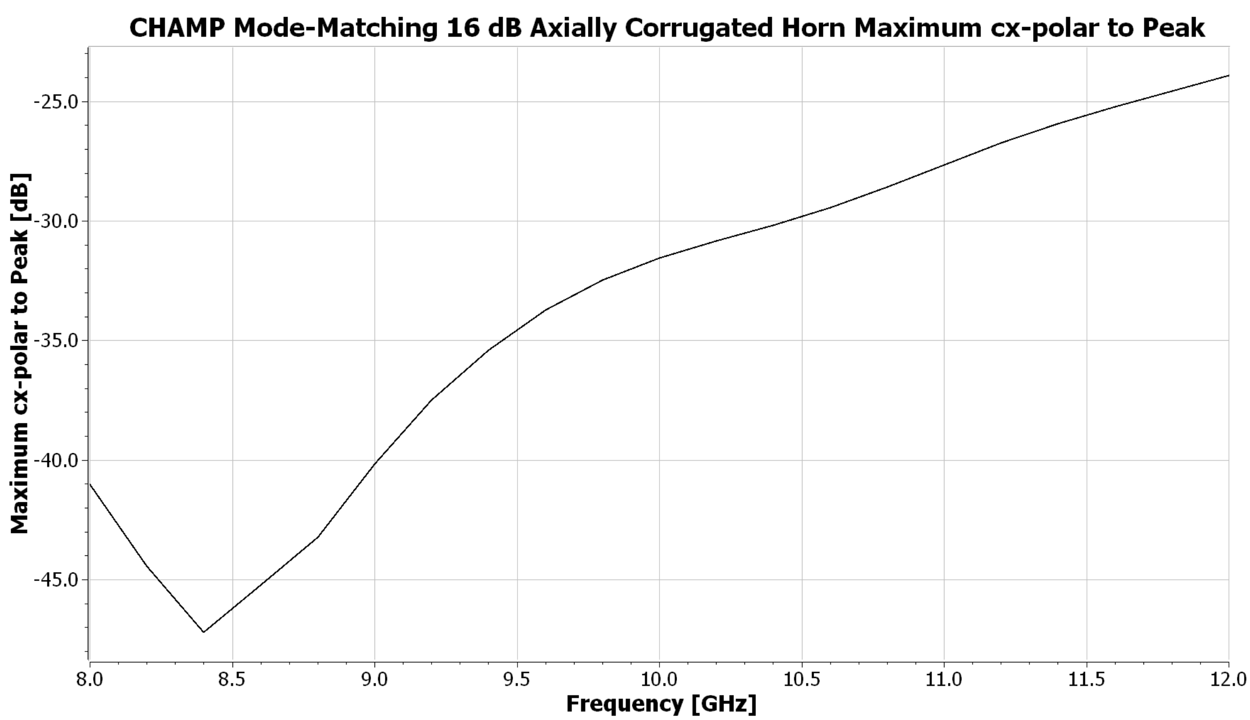

Figure 7-11.67 CHAMP Mode-Matching of 16 dB gain Axially Corrugated Horn for 10 GHz Max X-pol

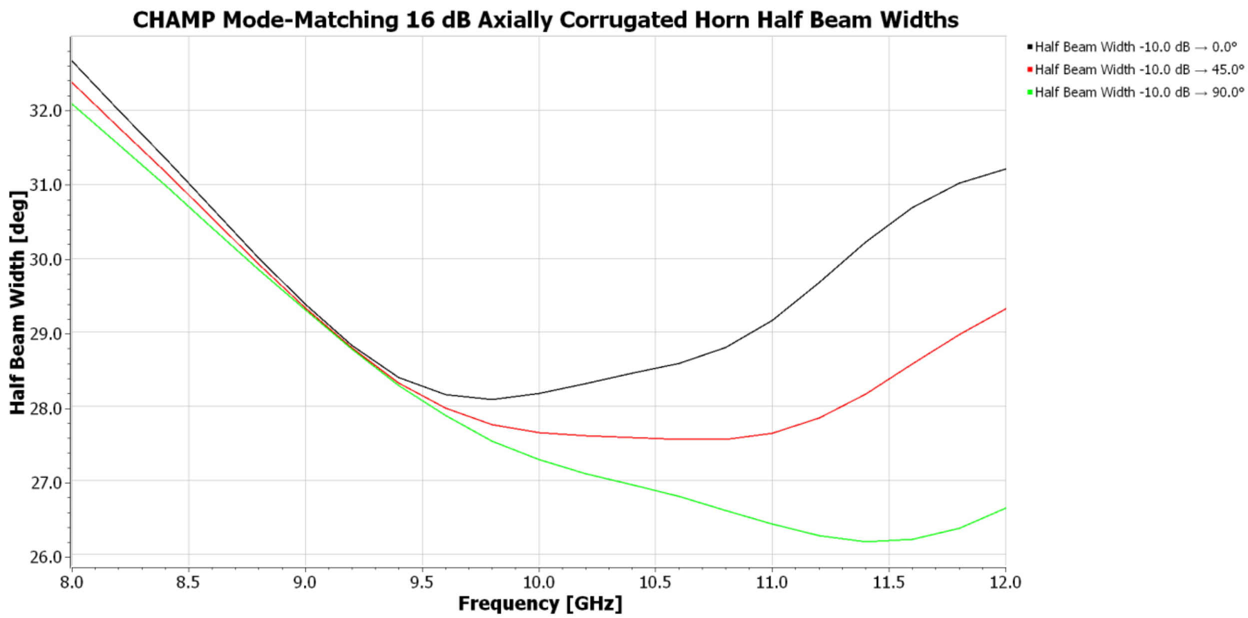

Figure 7-11.68 CHAMP Mode-Matching of 16 dB gain Axially Corrugated Horn for 10 GHz Half 10-dB Beamwidths

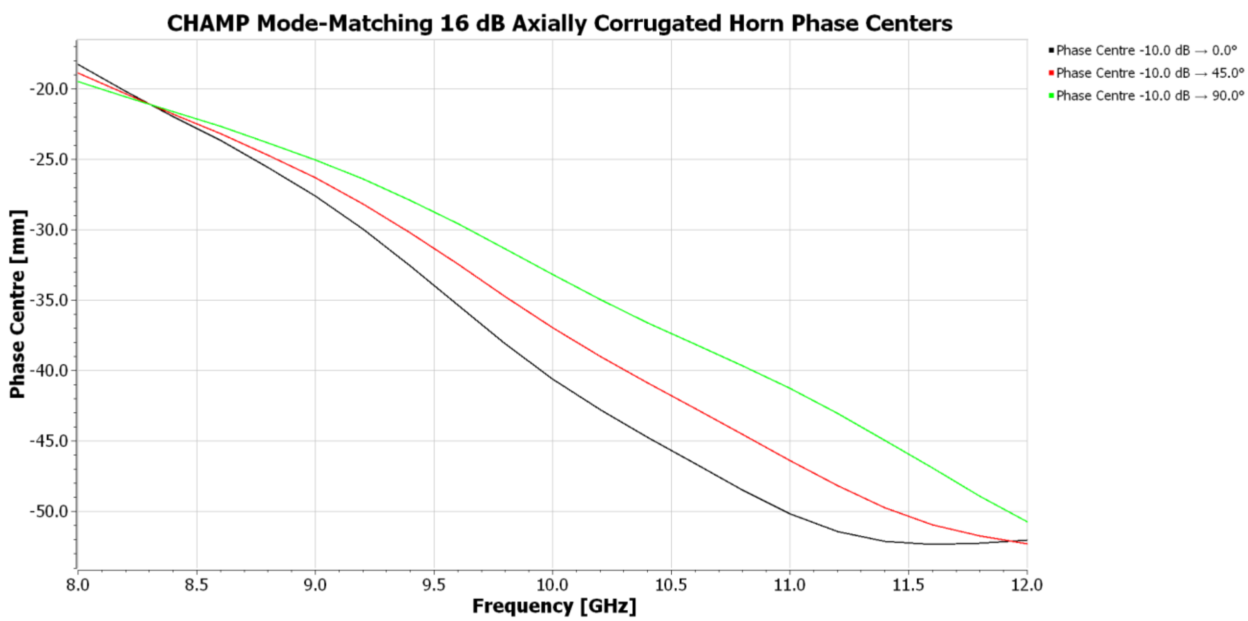

Figure 7-11.69 CHAMP Mode-Matching of 16 dB gain Axially Corrugated Horn for 10 GHz 10-dB Phase Centers

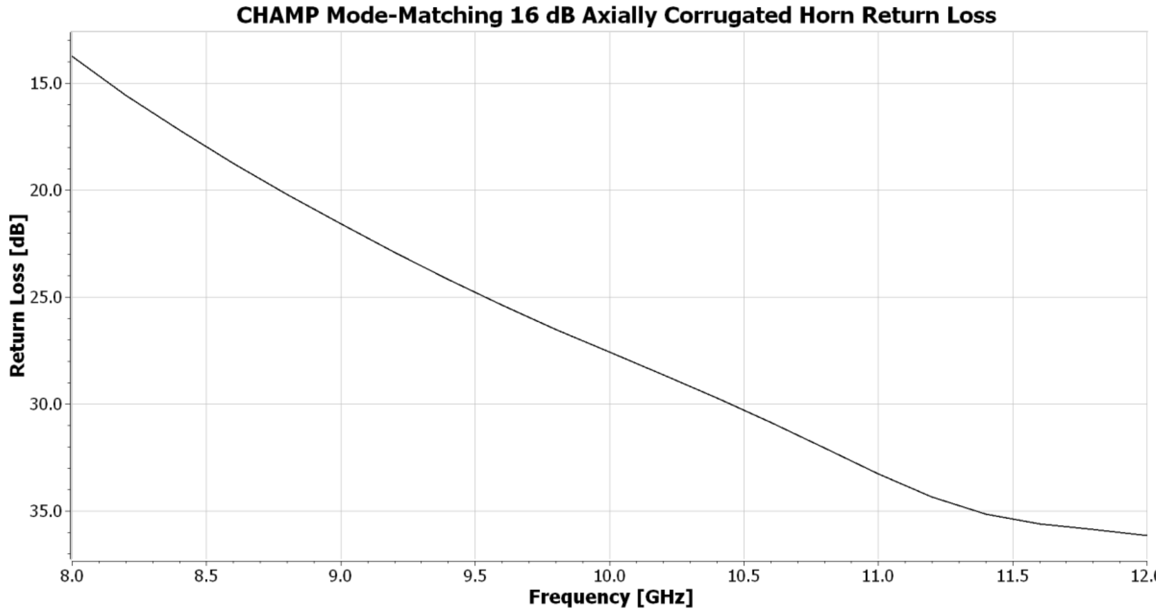

Figure 7-11.70 CHAMP Mode-Matching of 16 dB gain Axially Corrugated Horn for 10 GHz Return Loss

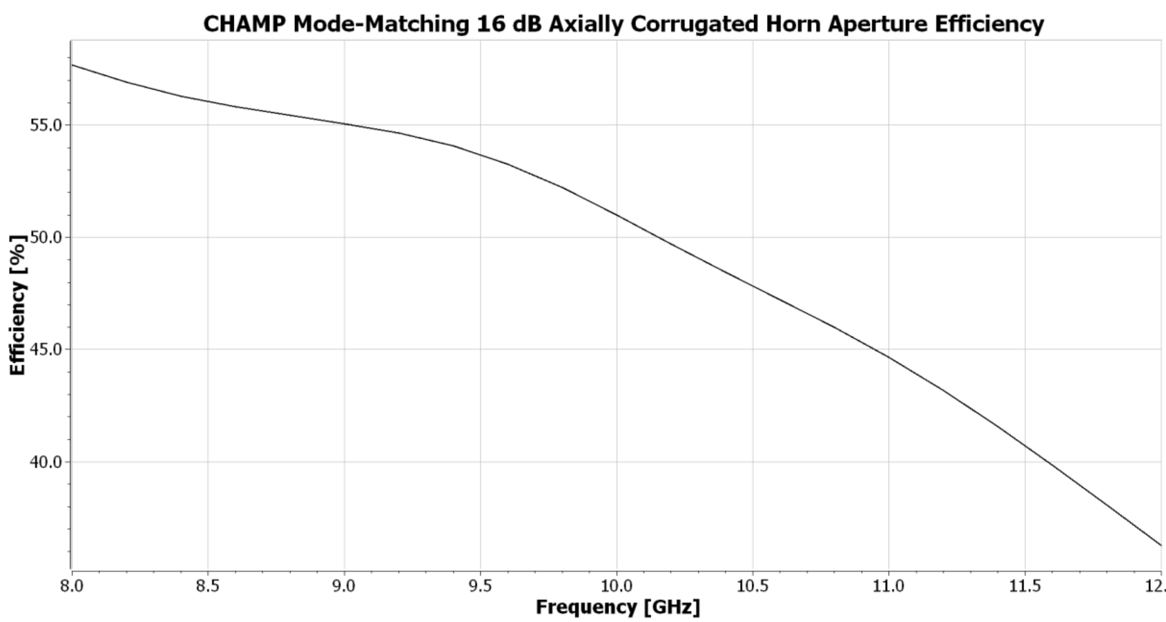

Figure 7-11.71 CHAMP Mode-Matching of 16 dB gain Axially Corrugated Horn for 10 GHz Efficiency

10.3 dB Gain Axially Corrugated Horn using 35° Bell Flare Angle

This design is at the lower gain limit of an axially corrugated horn and has only one corrugation. By using AXHGRA to write the TOR file edit file, creating a new GRASP project, and editing the TOR file in the "working" directory, we generate a new design analysis.

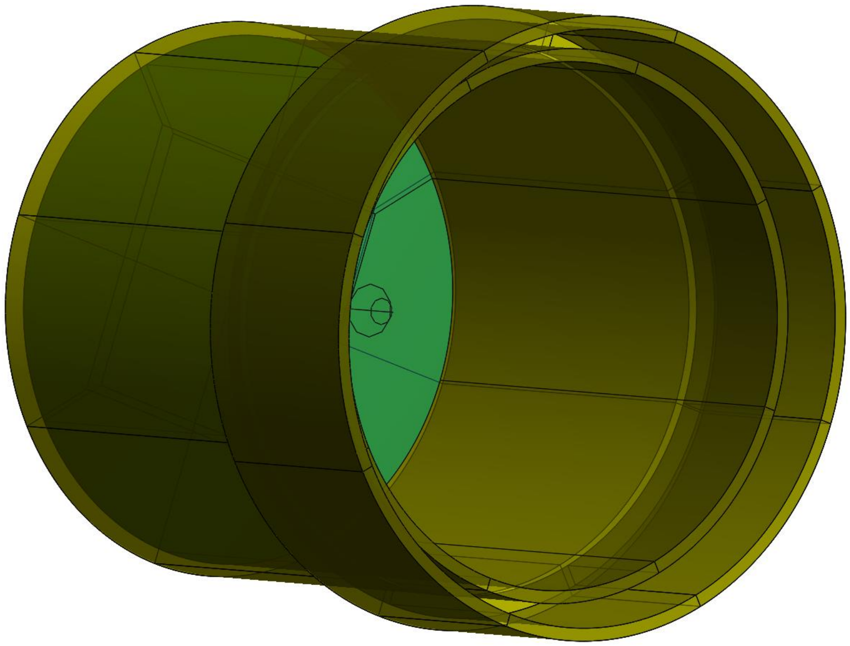

Figure 7-11.72 GRASP MoM Model of 10.3 dB Gain 35° Flare Axially Corrugated Horn for 10 GHz

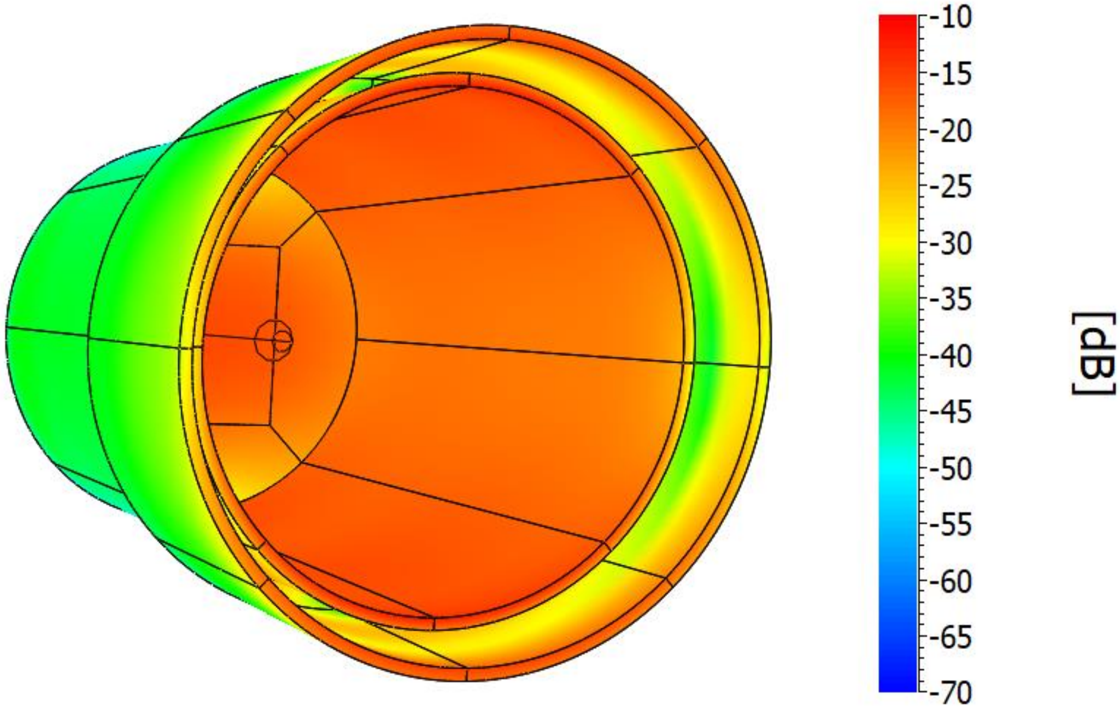

Figure 7-11.73 Wall currents in GRASP MoM Model of 10.3 dB Gain 35° Flare Axially Corrugated Horn for 10 GHz

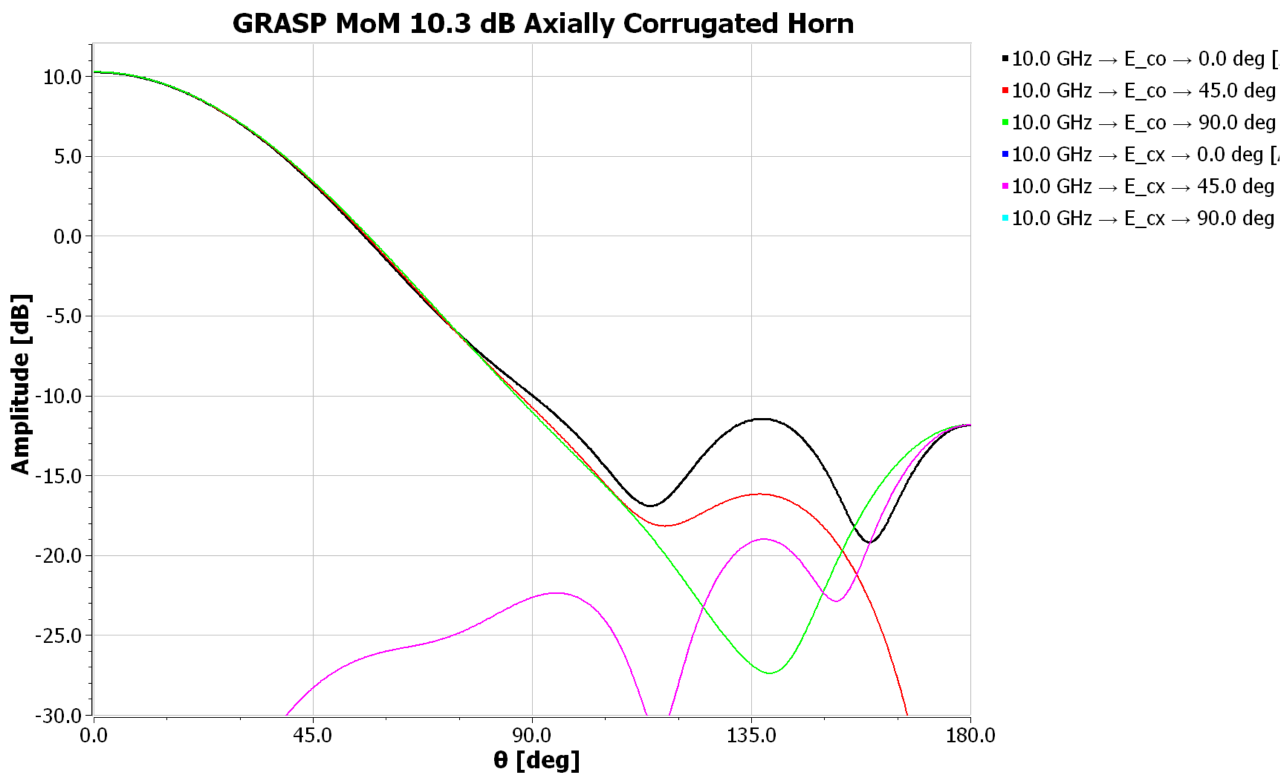

Figure 7-11.74 GRASP MoM Pattern of 10.3 dB Gain 35° Flare Axially Corrugated Horn for 10 GHz

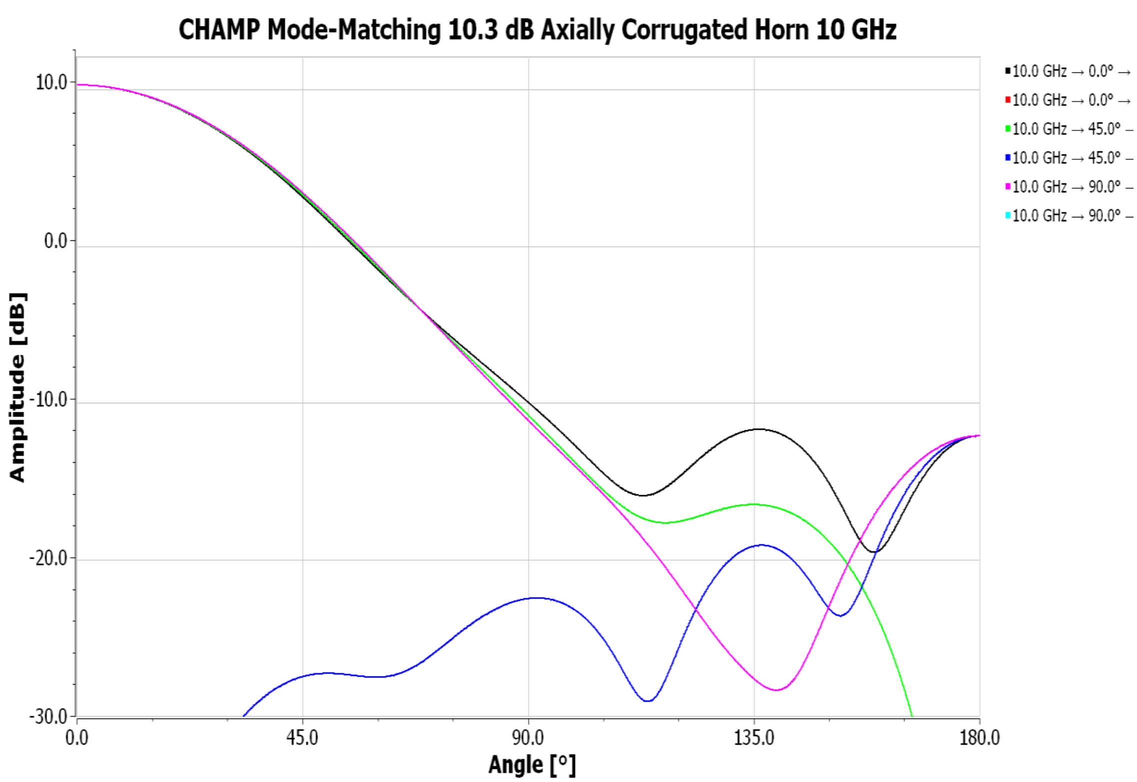

Figure 7-11.75 CHAMP Mode-Matching Pattern of 10.3 dB Gain 35° Flare Axially Corrugated Horn for 10 GHz

The CHAMP model predicts 10.30 dB gain while the GRASP model predicts 10.26 dB, a 0.9% difference.