7-3.3 Axially Corrugated Horns [17b]

Low gain horns can be designed using a wide bell flare angle and circular choke corrugations coaxial with its axis. Figure 7-ab gives the geometry of these corrugations. The 30° flare horn has a range from 10.5- to 18.4-dB gain. The gain ranges from 10.5 dB to 14.5 dB for $\theta = 45°$ and 10.3 dB to 12.4 dB for $\theta = 60°$ for realizable designs. The antenna has good patterns over an entire waveguide band without applying optimization. The horn aperture radius is given in wavelengths in the scales below.

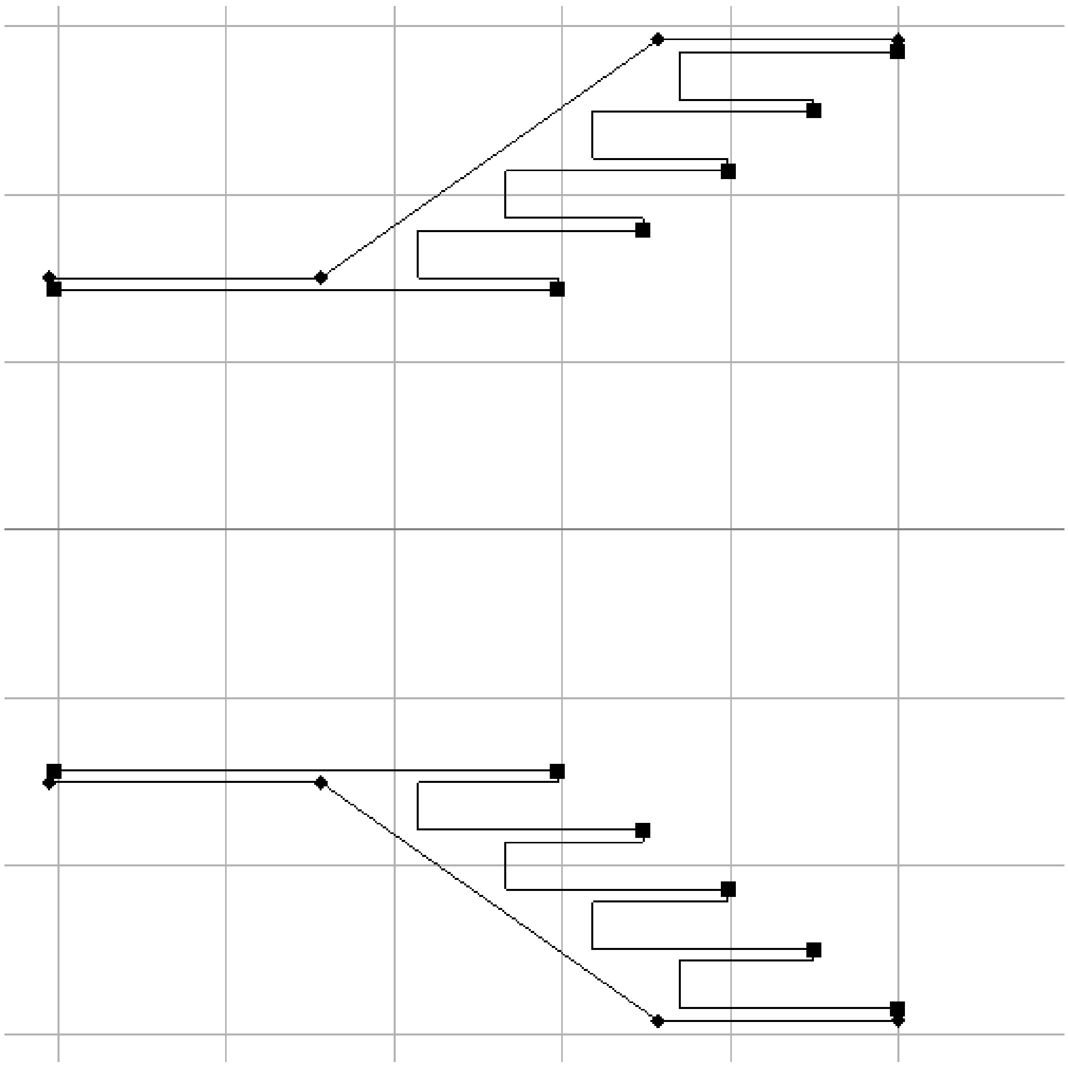
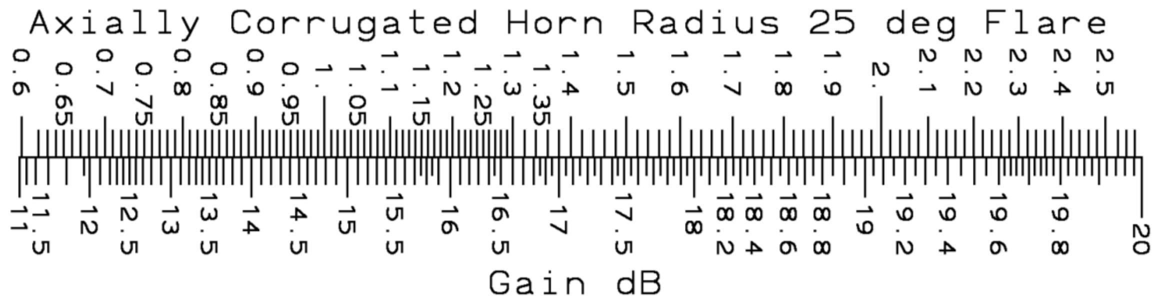
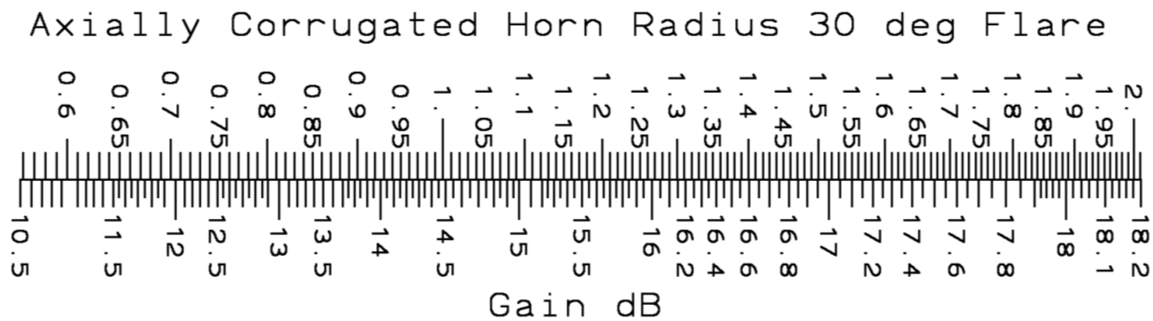


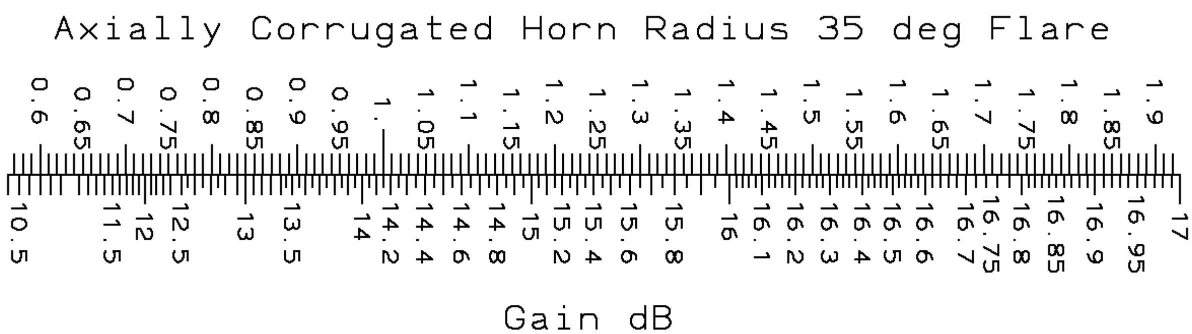
Figure 7-ab Axially Corrugated Horn Geometry

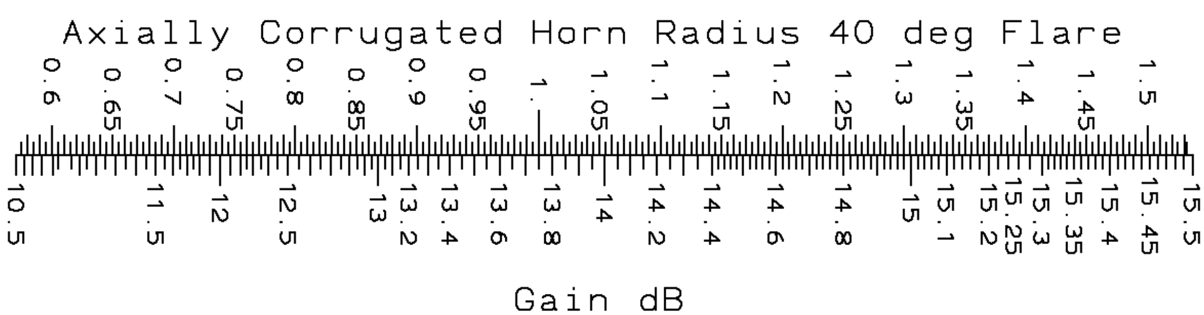
The aperture radius determines the antenna gain for a given half-flare angle of the horn. Greater flare angles produce higher quadratic phase error in the aperture, reduce gain, and limit the range of gain available. The scales below illustrate the limits of gain given half-flare angle.

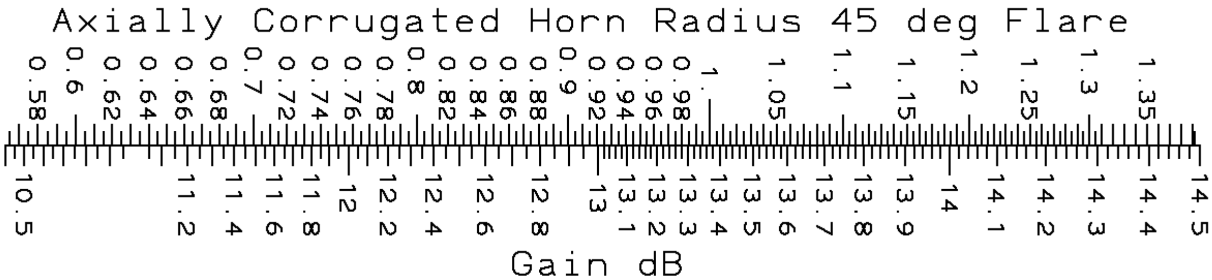
17b. Christophe Granet, et al, Chapter 3 Aperture Antennas: Waveguides and Horns, *Modern Antenna Handbook*, Wiley, 2008, p. 127f.

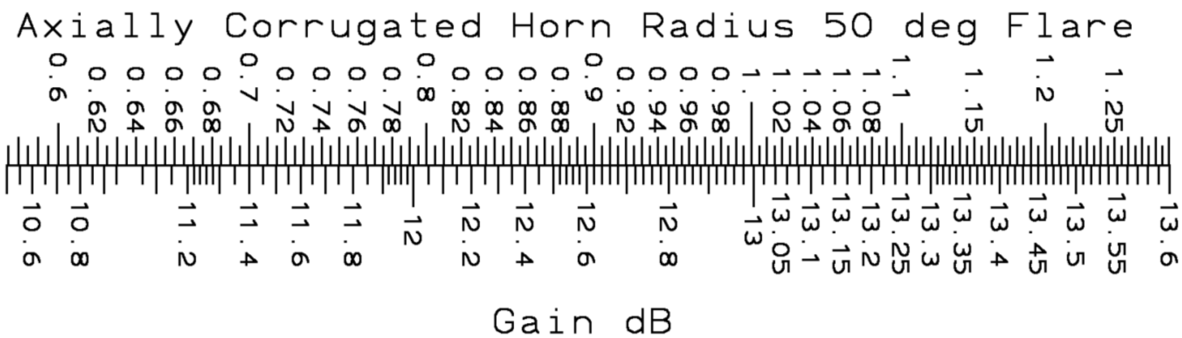


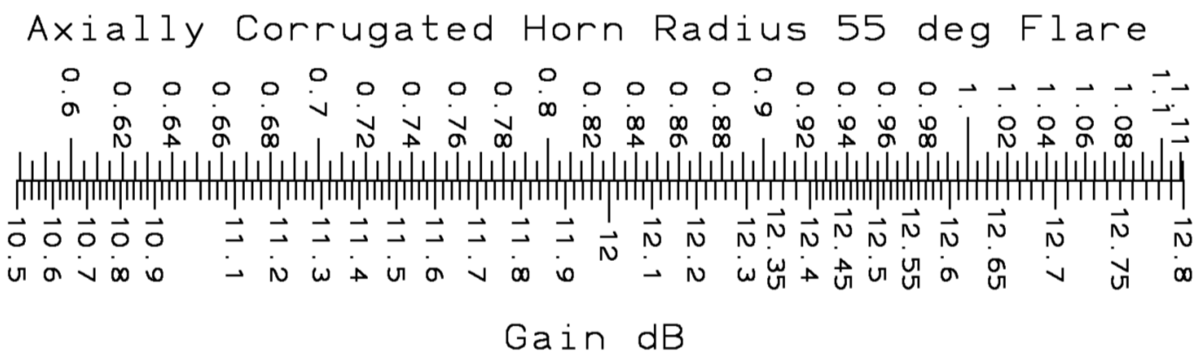


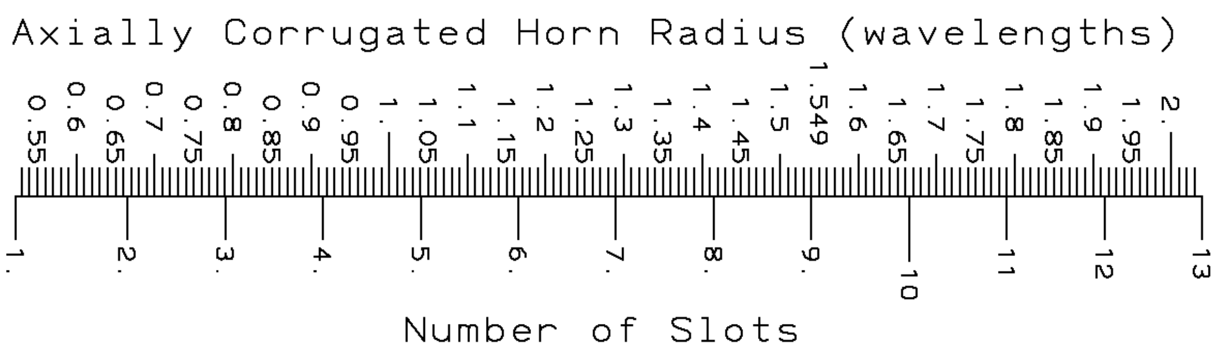


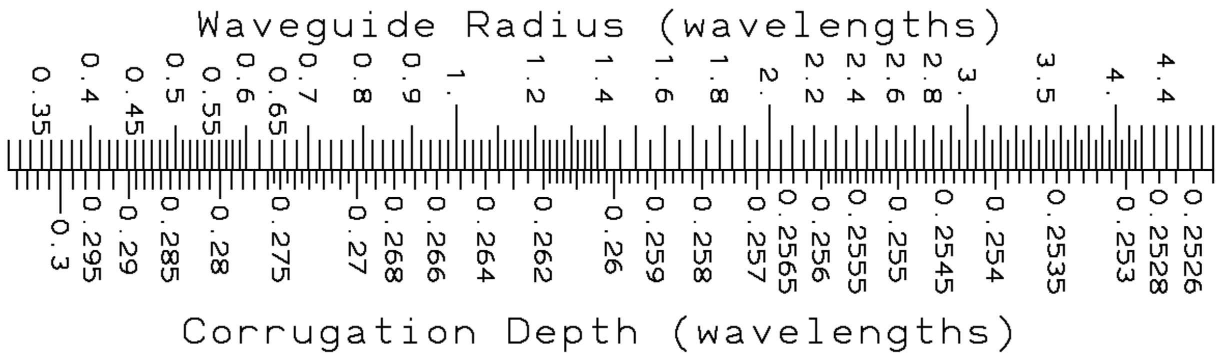



Axially Corrugated Horn Radius 45 deg Flare
Gain dB


Axially Corrugated Horn Radius 50 deg Flare
Gain dB


Axially Corrugated Horn Radius 55 deg Flare
Gain dB


Axially Corrugated Horn Radius (wavelengths)
Number of Slots



By using the mode matching analysis and design program CHAMP (TICRA) over a range of the output radius, lists of gain versus of the output radius versus gain can be interpolated for design when the input radius is given by $a_i = 3\lambda_c / (2\pi)$, pitch-to-width ratio is 0.8, and the approximate pitch is $\lambda/8$. In CHAMP it is necessary to include the analysis of the horn exterior using a BOR-MoM analysis since currents are excited on the exterior. Without exterior analysis incorrect results are obtained.

$$N_{slots} = (a_o - a_i)/(0.125\lambda_c) + 0.5 \text{ where } N_{slots} \text{ is an integer}$$
$$p = (a_o - a_i)/N_{slots},\ L = N_{slots}p,\ a_j = a_i + jp$$

Equation 7-23 determines the slot depths given radius of the slots, a_j.

An empirical formula for the depth is given by [17a]

$$d = \frac{\lambda_c}{4}\exp\frac{1}{2.114(k_c a)^{1.134}} \qquad k_c a > 2 \tag{7-23}$$

The value $k_c = 2\pi/\lambda_c$ depends on the desired bandwidth.

The output radius of horns with a 45° flare range from $0.55\lambda_c$ with one slot at 10 dB gain to $1.45\lambda_c$ with eight slots at 14.5 dB gain. Lower half-flare angle designs produce antennas with higher possible gain.

The executable AXHCHA interpolates the lists of gain versus aperture radius for the 7 half-flare angles: 25°, 30°, 35°, 40°, 45°, 50°, and 55° to generate designs to a given gain. The output of AXHCHA generates a text file of CHAMP geometry.tor additions given flare angle, aperture radius or gain. AXHCHA can interpolate between the 7 half-flare angles to generate designs at half-flare angles between the 7 angles. For a given half-flare angle the possible gain saturates because increases in aperture radius fails to produce higher gain. The quadratic phase error in the aperture grows faster than aperture gain. The scales above illustrate this effect.

AXHCHA can be run using an input text file. Below is an example designing to a given aperture size in wavelengths and any half-flare angle.

```
14.314,30               waveguide radius, length
3                       units: mm
10                      design frequency
0.7                     ridge thickness
30                      horn bell flare angle
1                       input aperture size
1.0                     aperture (wavelengths)
8                       number of corrugations per wavelength
ax_corr10.txt
y                       add exterior
```

A second type of AXHCHA input is to design to a given gain (dB) including interpolation between the lists of the 7 half-flare angles to 32°.

```
14.314,30               waveguide radius, length
3                       units: mm
10                      design frequency
0.7                     ridge thickness
32                      horn bell flare angle
2                       input gain
15                      gain
8                       number of corrugations per wavelength
ax_corr15.txt
y                       add exterior
```

The output of AXHCHA generates additions to a CHAMP geometry.tor file. Start with a CHAMP project containing only the input waveguide. It is a good idea to generate a new project with a name that indicates the key design parameter. The first line of AXHCHA input asks for the radius of the input waveguide and its length. Next the units are requested: 1 in, 2 ft, 3 mm, 4 cm, or 5 m. The design frequency is in GHz. If the output of AXHCHA is to be used for an axially corrugated horn the exterior should be added. The exterior uses the length of the input waveguide. In the example above ax_corr10.txt (ax_corr15.txt) is the output text file.

The project directory contains the geometry.tor file. Open this file in a text editor (Notepad). Open the output of AXHCHA in another text editor window; for example:

```
ref(axial_corrugation_1),ref(axial_corrugation_2),
ref(axial_corrugation_3),ref(axial_corrugation_4),
ref(axial_corrugation_5),ref(axial_corrugation_6),
ref(axial_corrugation_7),ref(axial_corrugation_8)),
  scatterers       : sequence(ref(axial_horn_exterior))
rad_out  real_variable
(
  value            :   4.49689E+01
)
.
.
.
```

This example has 8 axial corrugations listed in the first four lines. The next line specifies a horn exterior scatterer. Below these specifications are the variables and generation of axial corrugated structures, etc. In this example the first five lines need to be moved into the initial structures listing at the top of the geometry.tor file.

The geometry.tor with only the input waveguide starts:

```
horn  combined_horn_section
(
  horn_sections    : sequence(ref(circular_waveguide_section))
)

circular_waveguide_section  circular_waveguide_section
(
  radius           : 14.314 mm,
  length           : 30.0 mm,
  conductivity     : 33000000.0 S/m
)

TX_01  corrugated_horn_mode_matching
(
  frequency        : ref(TX_01_freq),
  horn             : ref(horn),
  output_file_name : "",
  coef_file_name   : "",
  coor_sys         : ref(TX_01_output_coor_sys)
)

TX_01_freq  frequency_range
(
  frequency_range  : struct(start_frequency: 8.0 GHz, end_frequency: 12.0
GHz, number_of_frequencies: 41)
)

TX_01_output_coor_sys  coor_sys
(
)
```

Copy the entire output of AXHCHA (Control A, Control C) and insert it just below the input waveguide; just above the lines in red in the geometry.tor file. It looks like this.

```
horn  combined_horn_section
(
  horn_sections    : sequence(ref(circular_waveguide_section))
)

circular_waveguide_section  circular_waveguide_section
(
  radius           : 14.314 mm,
  length           : 30.0 mm,
  conductivity     : 33000000.0 S/m
)
ref(axial_corrugation_1),ref(axial_corrugation_2),
ref(axial_corrugation_3),ref(axial_corrugation_4),
```

```
ref(axial_corrugation_5),ref(axial_corrugation_6),
ref(axial_corrugation_7),ref(axial_corrugation_8)),
  scatterers        : sequence(ref(axial_horn_exterior))
rad_out  real_variable
(
  value             :   4.49689E+01
)

design_wl  real_variable
(
  value             :   2.99792E+01
)
. . .
```

Highlight the lines as shown (blue) with the cursor at the end of the "scatterers" line. Cut this portion (Control X).

On the horn_sections line backspace the final ")" and replace it with "," and then paste (Control V) the axial corrugations and horn exterior scatterer, as shown in red below.

```
horn  combined_horn_section
(
  horn_sections     : sequence(ref(circular_waveguide_section),
)

circular_waveguide_section  circular_waveguide_section
(
  radius            : 14.314 mm,
  length            : 30.0 mm,
  conductivity      : 33000000.0 S/m
)

rad_out  real_variable
(
  value             :   4.49689E+01
)

design_wl  real_variable
(
  value             :   2.99792E+01
)
```

The top of geometry.tor file now looks like this:

```
horn  combined_horn_section
(
  horn_sections     :
sequence(ref(circular_waveguide_section),ref(axial_corrugation_1),ref(axial_c
orrugation_2),
ref(axial_corrugation_3),ref(axial_corrugation_4),
ref(axial_corrugation_5),ref(axial_corrugation_6),
ref(axial_corrugation_7),ref(axial_corrugation_8)),
  scatterers        : sequence(ref(axial_horn_exterior))
)

circular_waveguide_section  circular_waveguide_section
```

```
(
  radius            : 14.314 mm,
  length            : 30.0 mm,
  conductivity      : 33000000.0 S/m
)

rad_out  real_variable
(
  value             :   4.49689E+01
)
```

Save the geometry.tor file which now contains the axial corrugations and the horn exterior. Open the project in CHAMP and it is ready for analysis. Note the real variable shown in the listing above is the output aperture radius "rad_out" can be used in the CHAMP optimization to adjust gain if necessary. Changing the output aperture radius adjusts the slot widths while adjusting the output slot length to maintain the half-flare angle as specified.

Design Examples with Axial Corrugations

Half Flare Angle = 35°

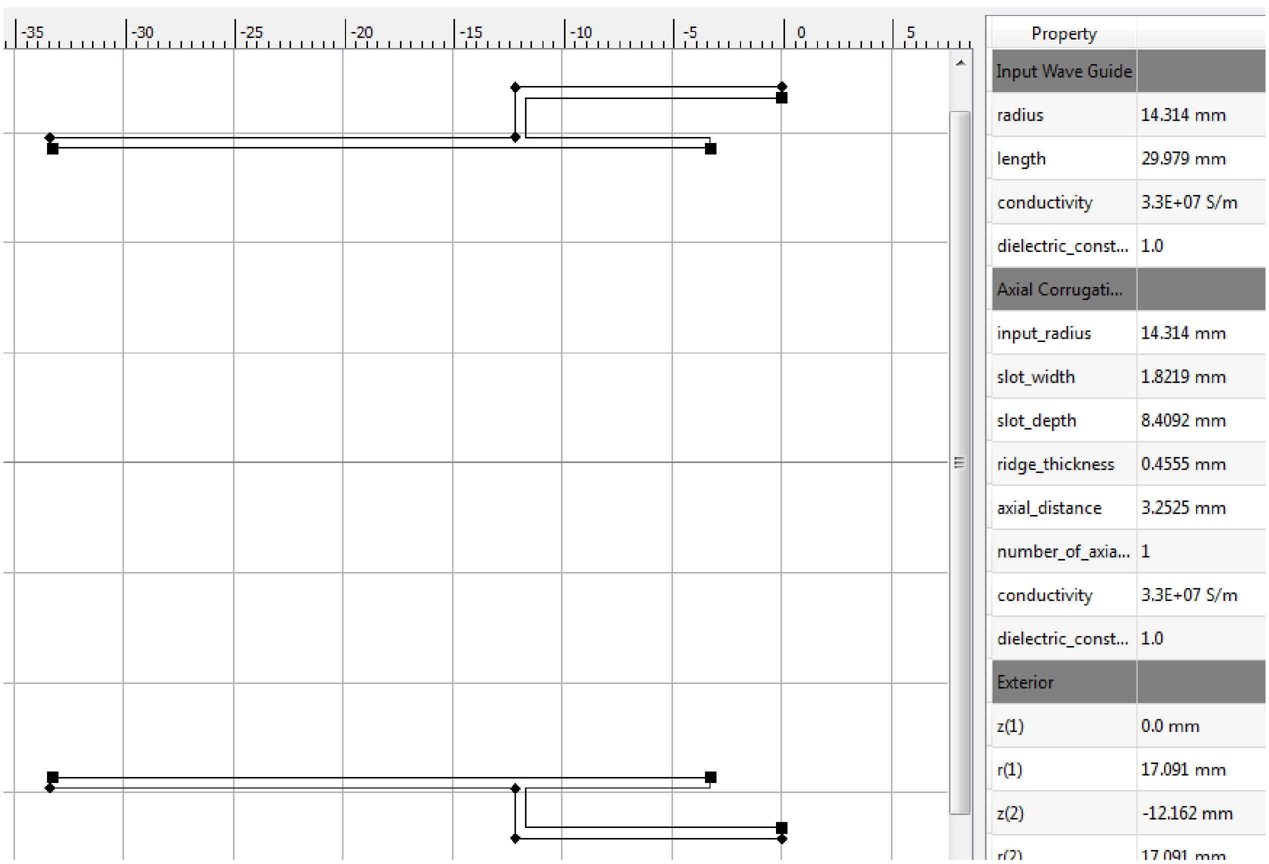


Figure 1 CHAMP geometry for 10.3 dB Gain Design at 10 GHz

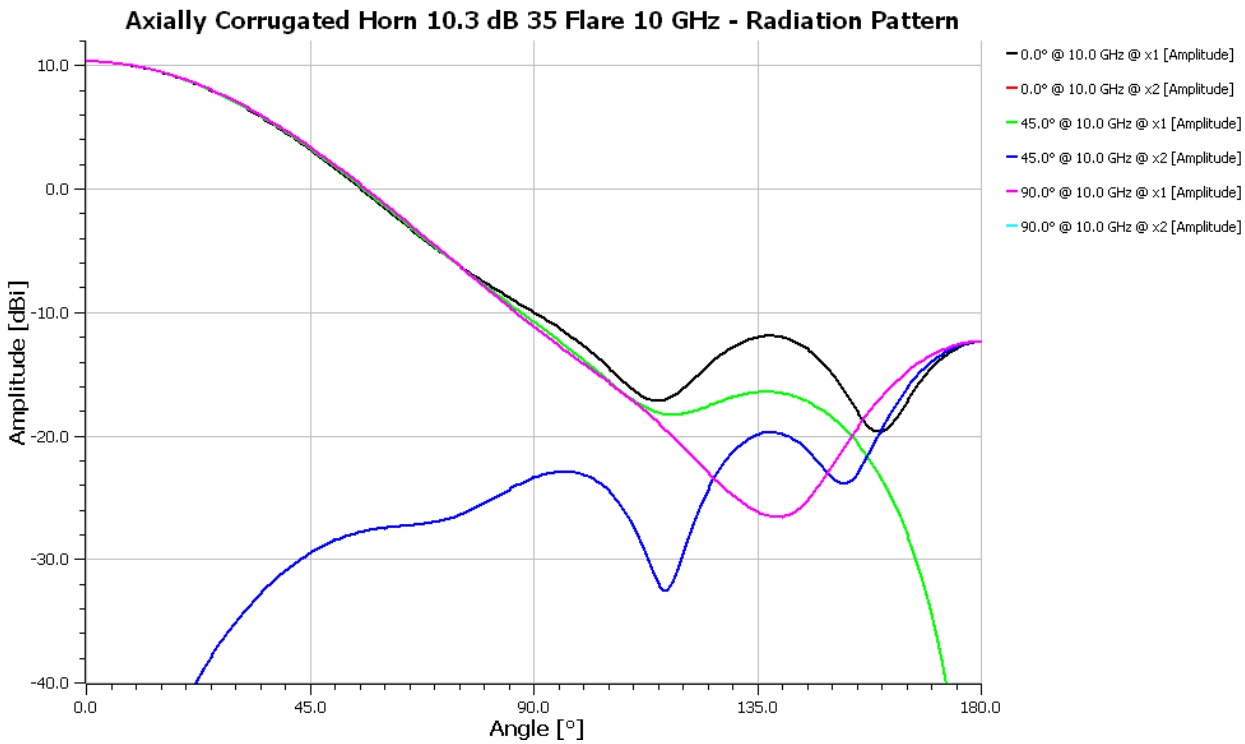


Figure 2 10.3 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz)

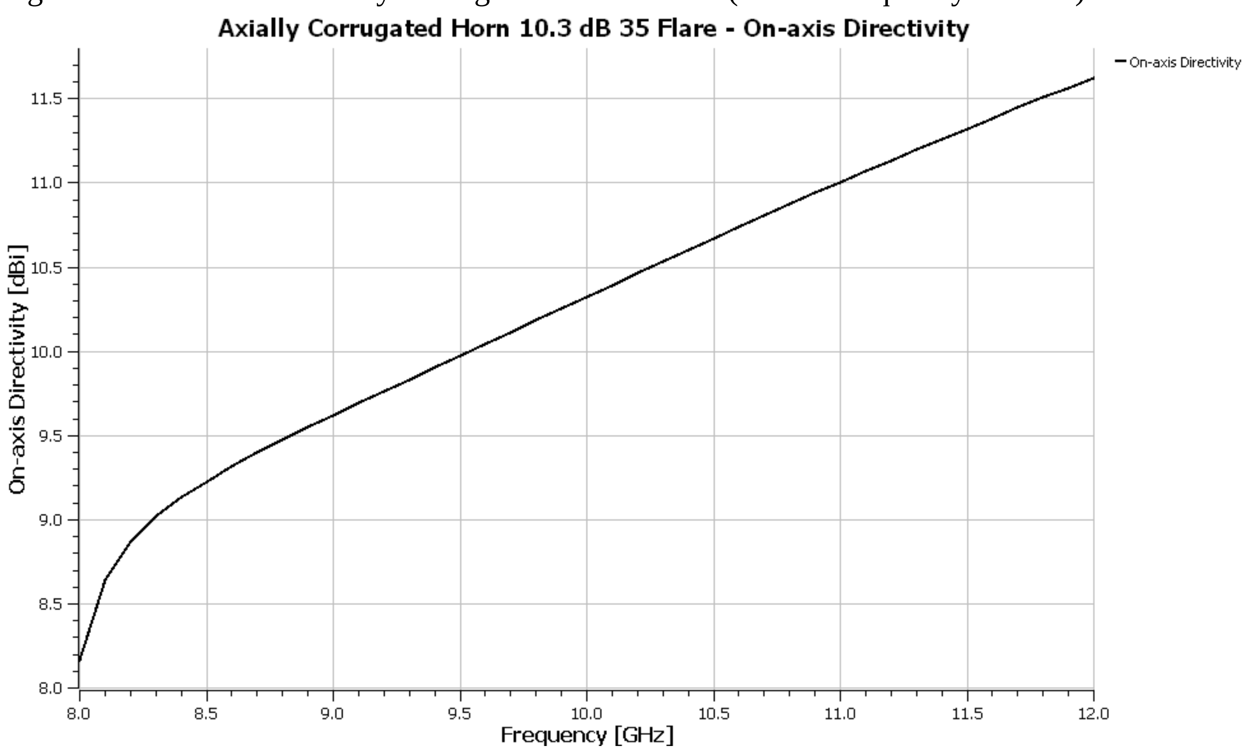


Figure 3 10.3 dB Gain Axially Corrugated Horn θ = 35° on-axis Directivity

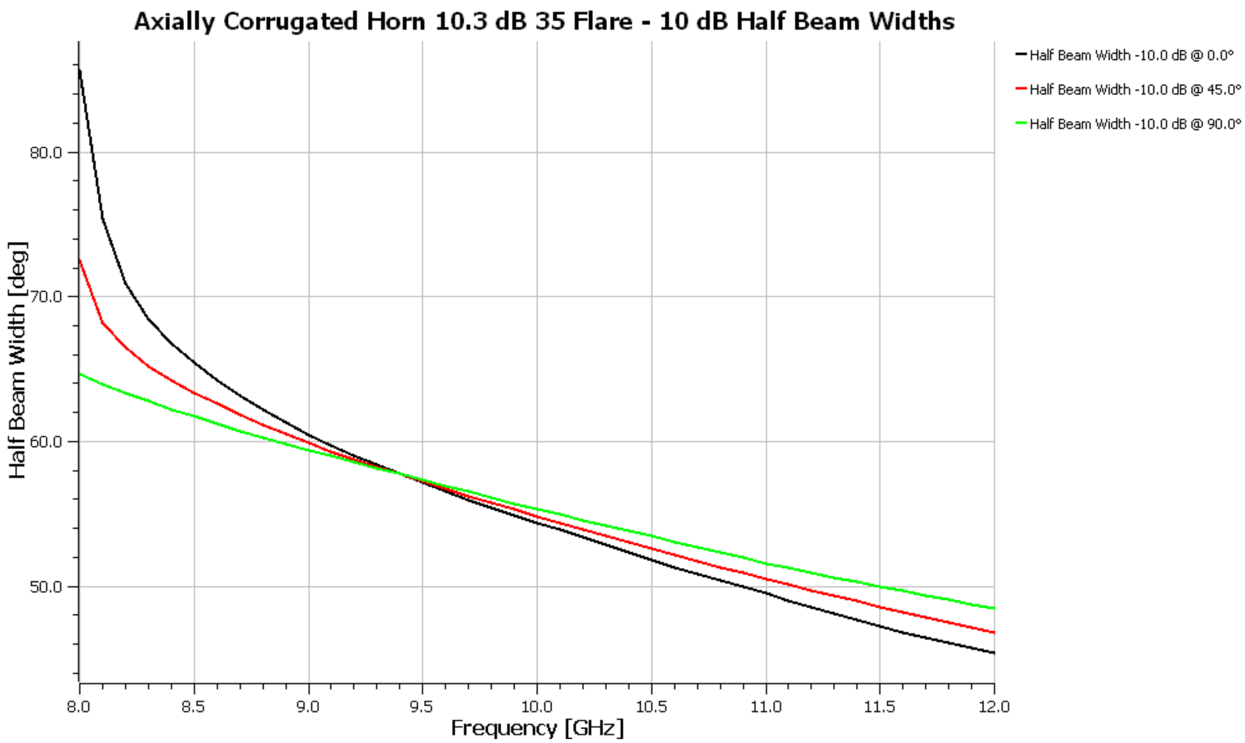


Figure 4 10.3 dB Gain Axially Corrugated Horn θ = 35° 10 dB Half Beam Width

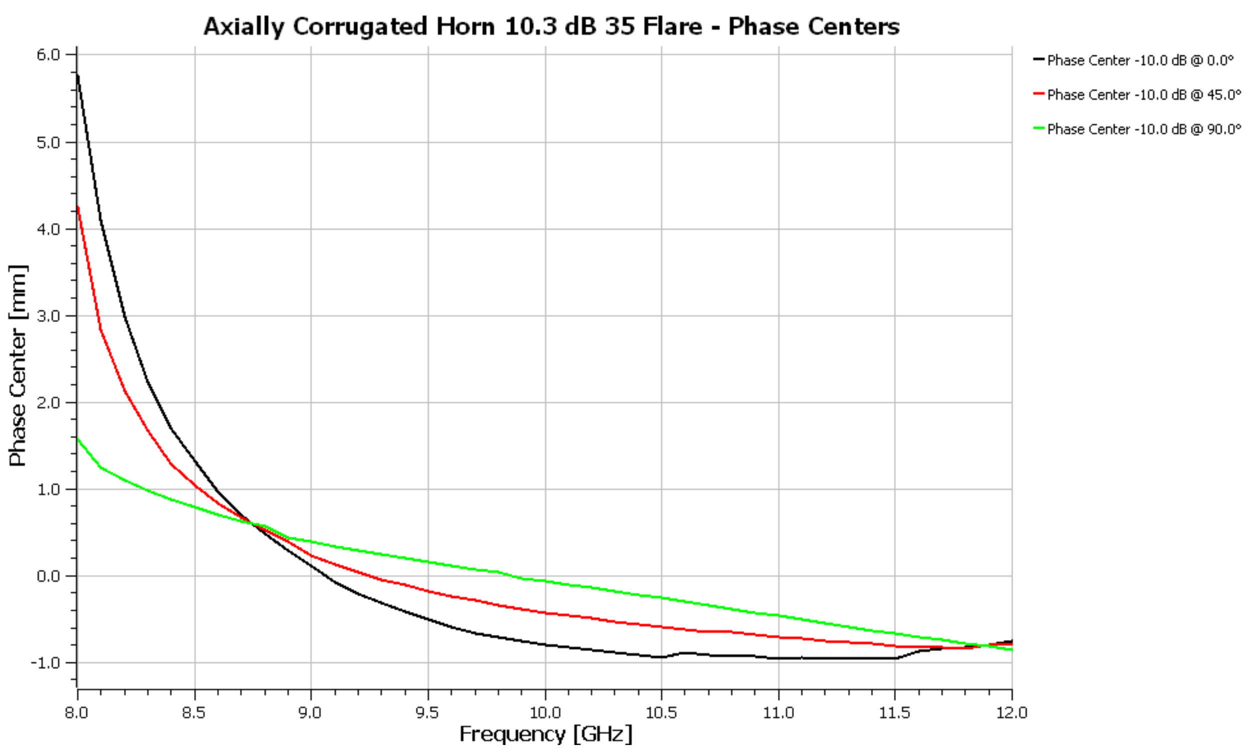


Figure 5 10.3 dB Gain Axially Corrugated Horn θ = 35° Phase Center from Aperture

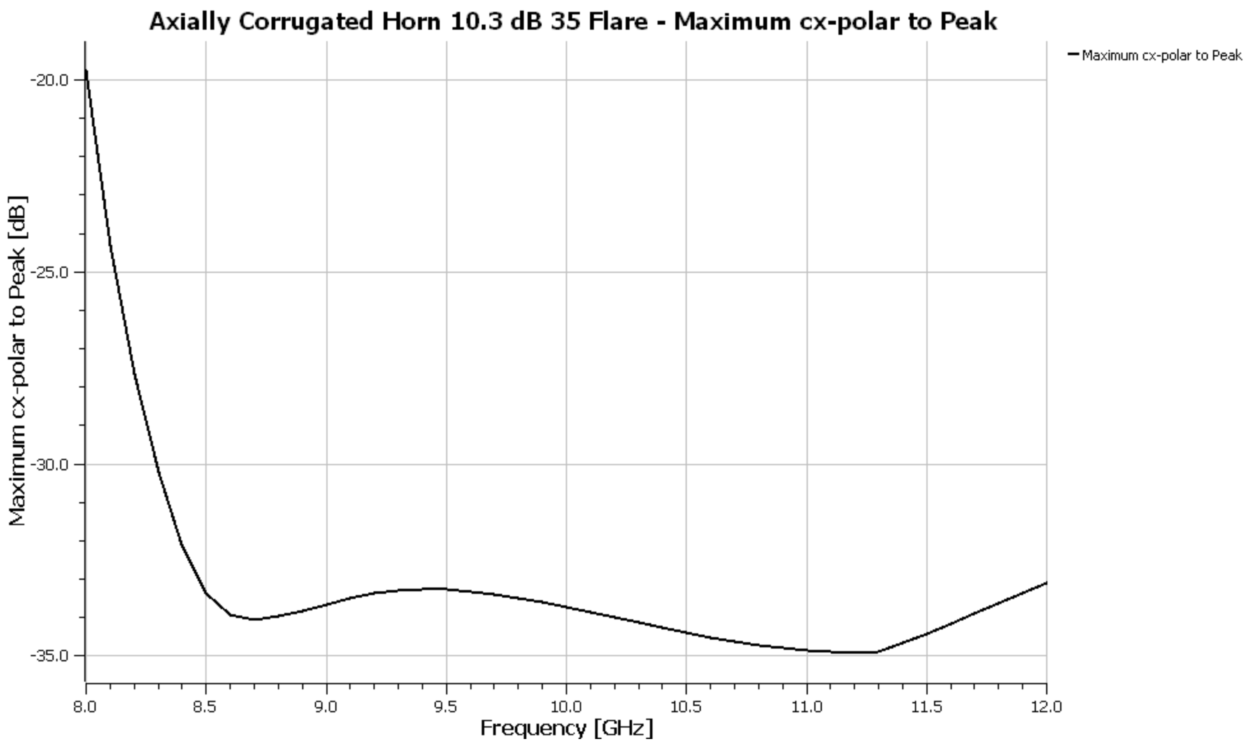


Figure 6 10.3 dB Gain Axially Corrugated Horn θ = 35° Cross Polarization relative Co-Pol.

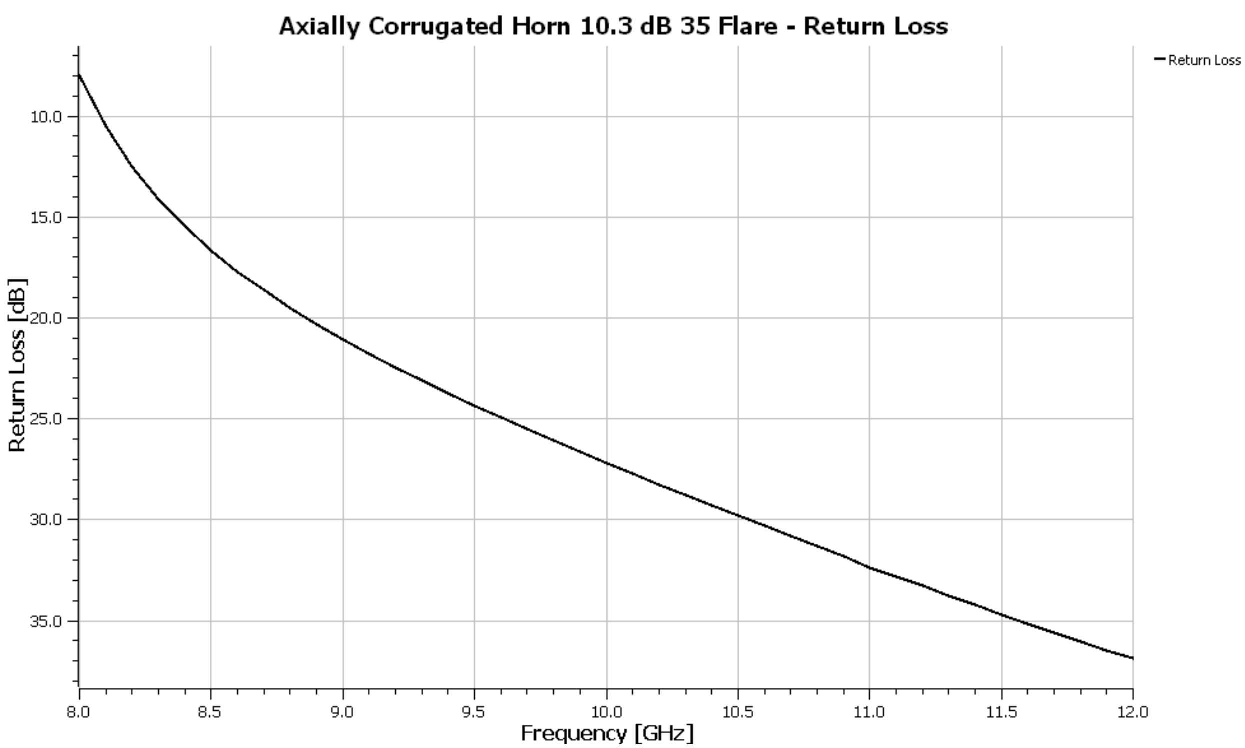


Figure 7 10.3 dB Gain Axially Corrugated Horn θ = 35° Return Loss

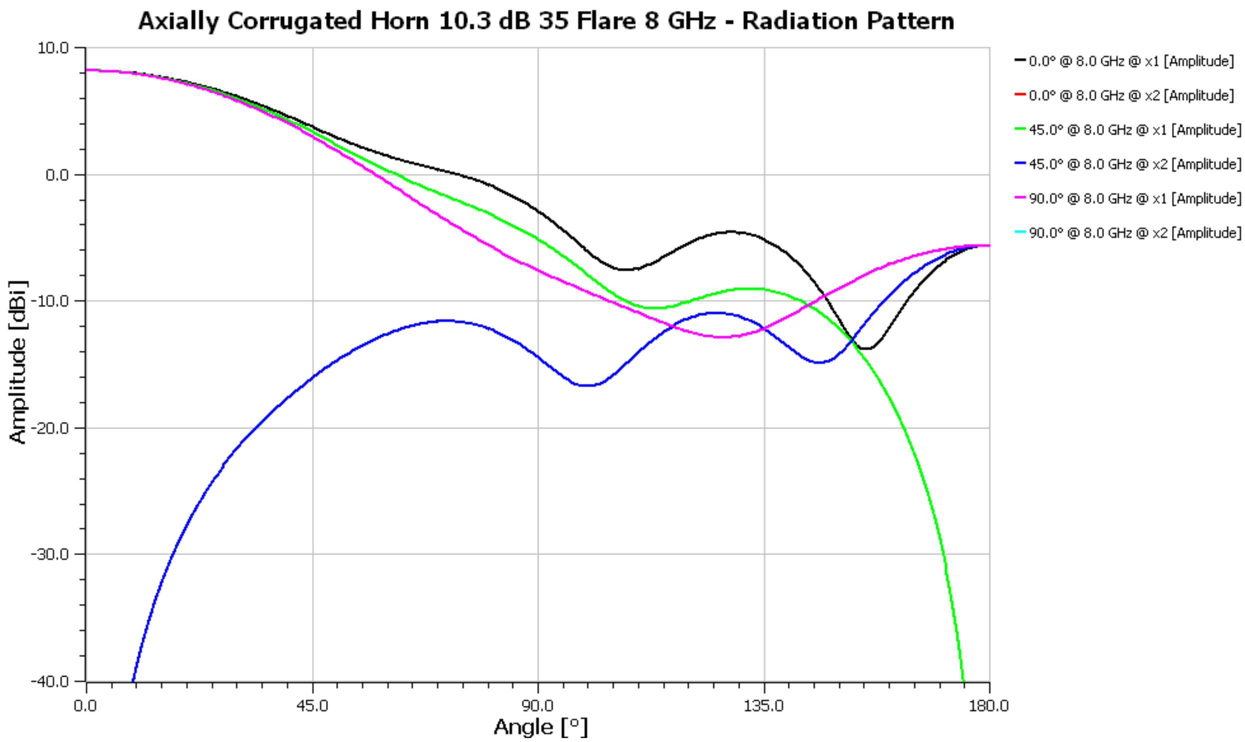


Figure 8 10.3 dB Gain Axially Corrugated Horn $\theta = 35°$ (Center Frequency 10 GHz) 8 GHz

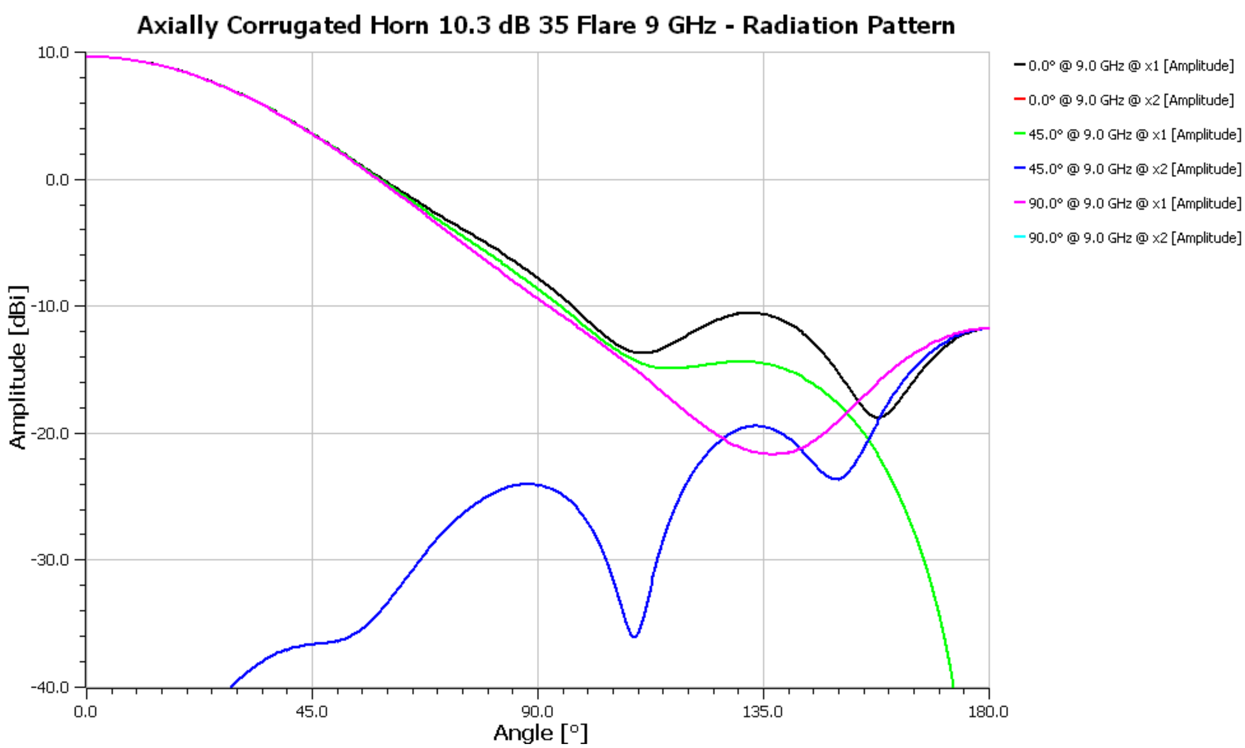


Figure 9 10.3 dB Gain Axially Corrugated Horn $\theta = 35°$ (Center Frequency 10 GHz) 9 GHz

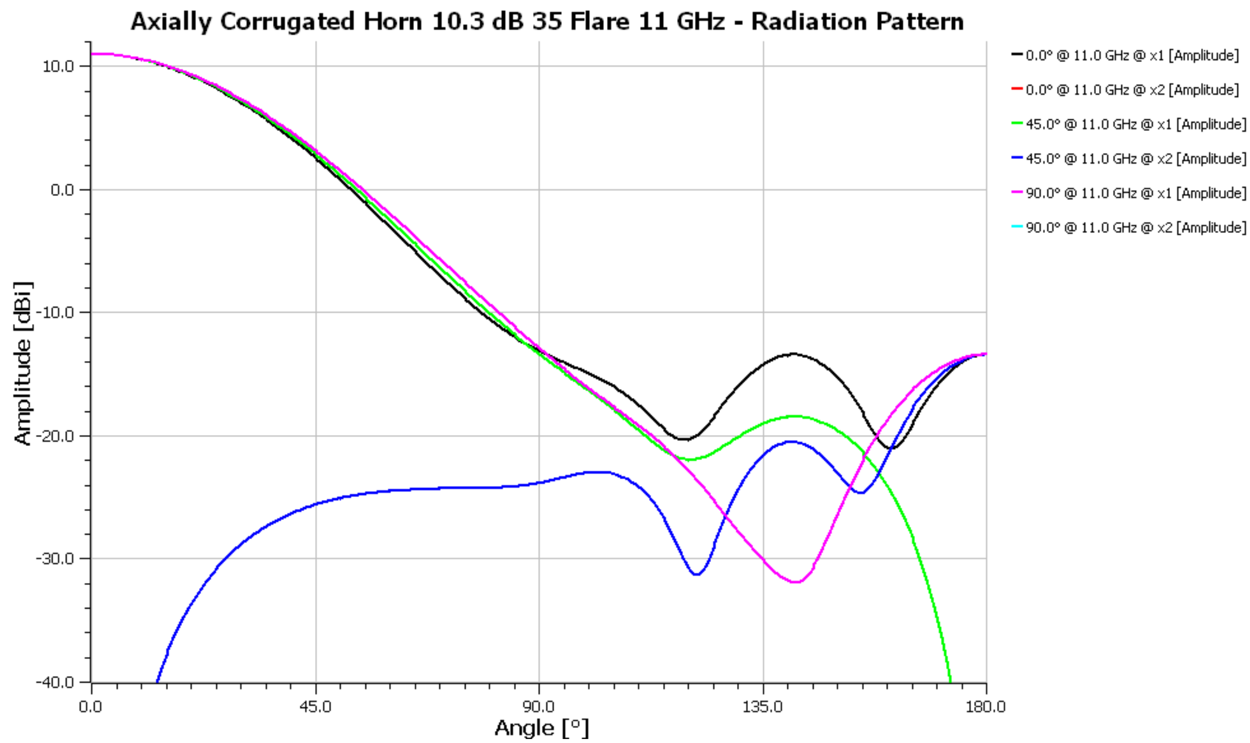


Figure 10 10.3 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz) 11 GHz

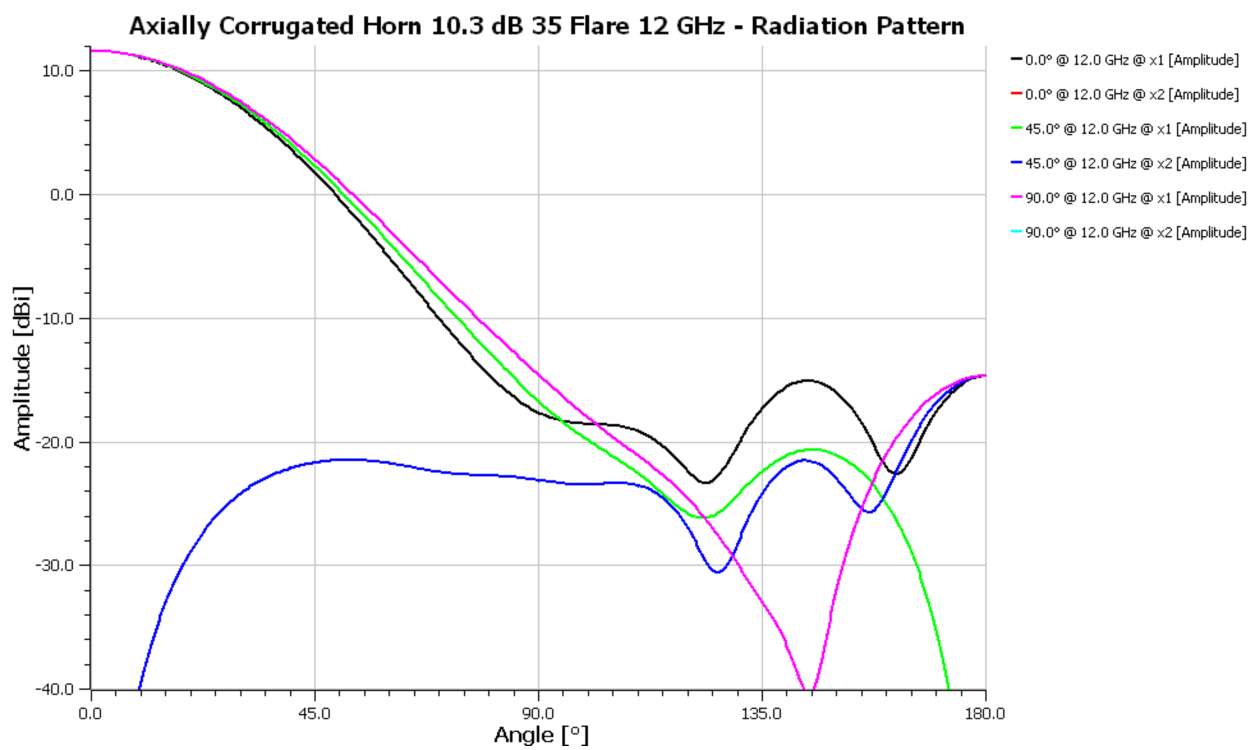


Figure 11 10.3 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz) 12 GHz

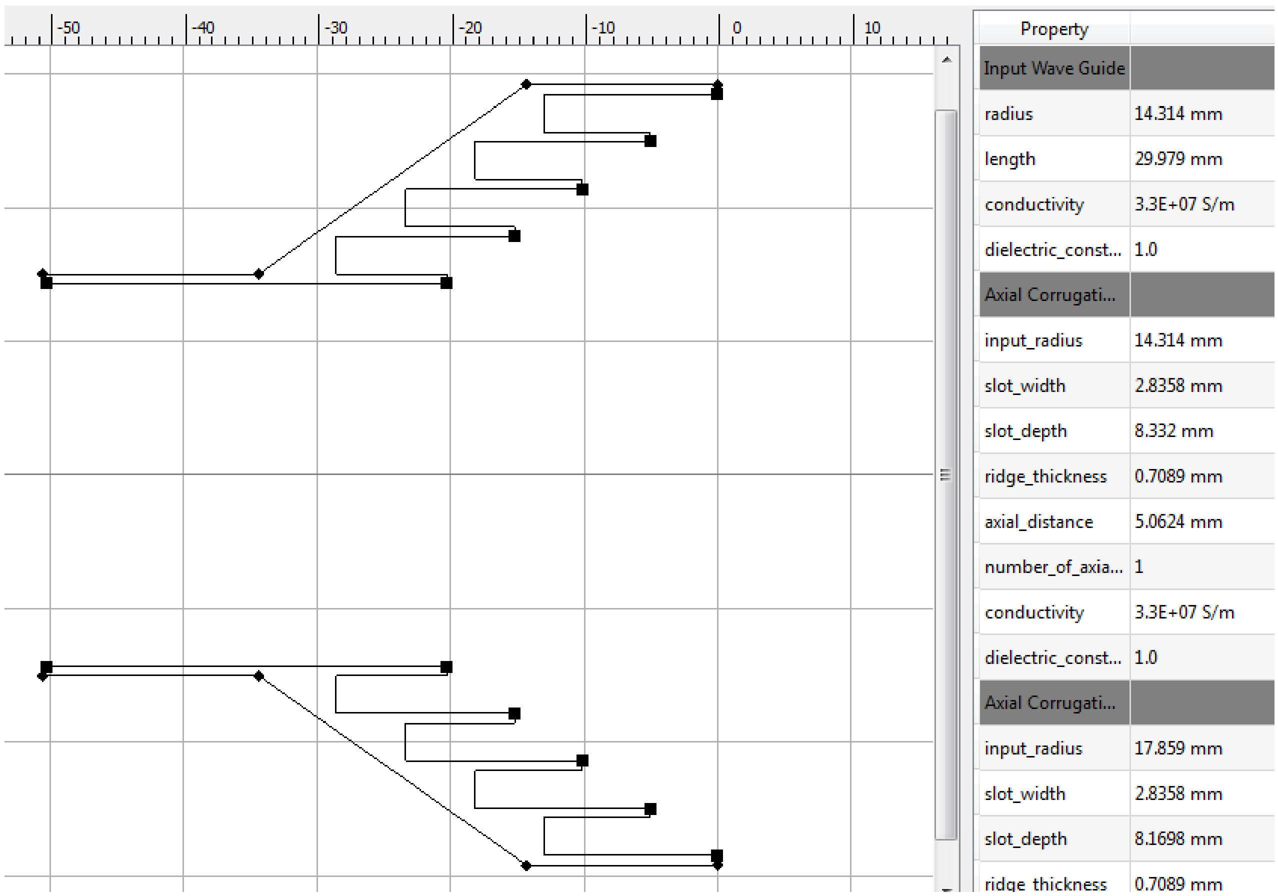


Figure 12 CHAMP geometry for 13.8 dB Gain Design at 10 GHz

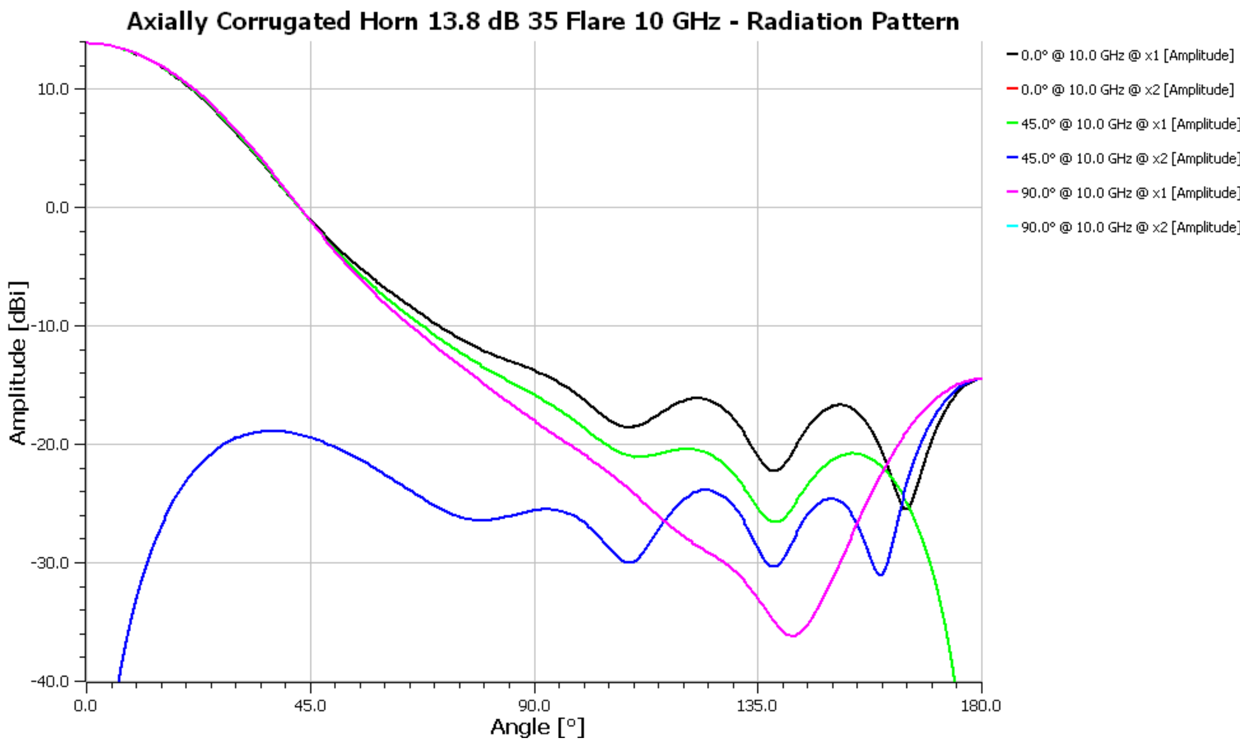


Figure 13 13.8 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz)

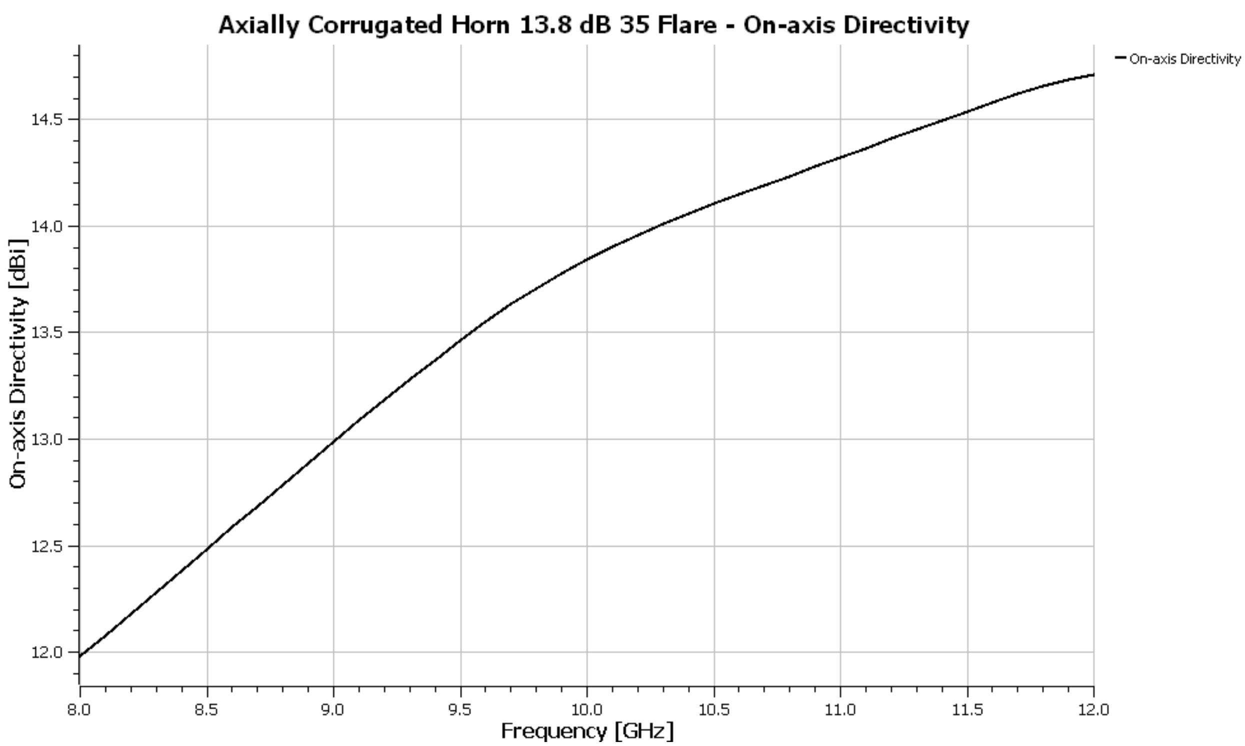


Figure 14 13.8 dB Gain Axially Corrugated Horn θ = 35° on-axis Directivity

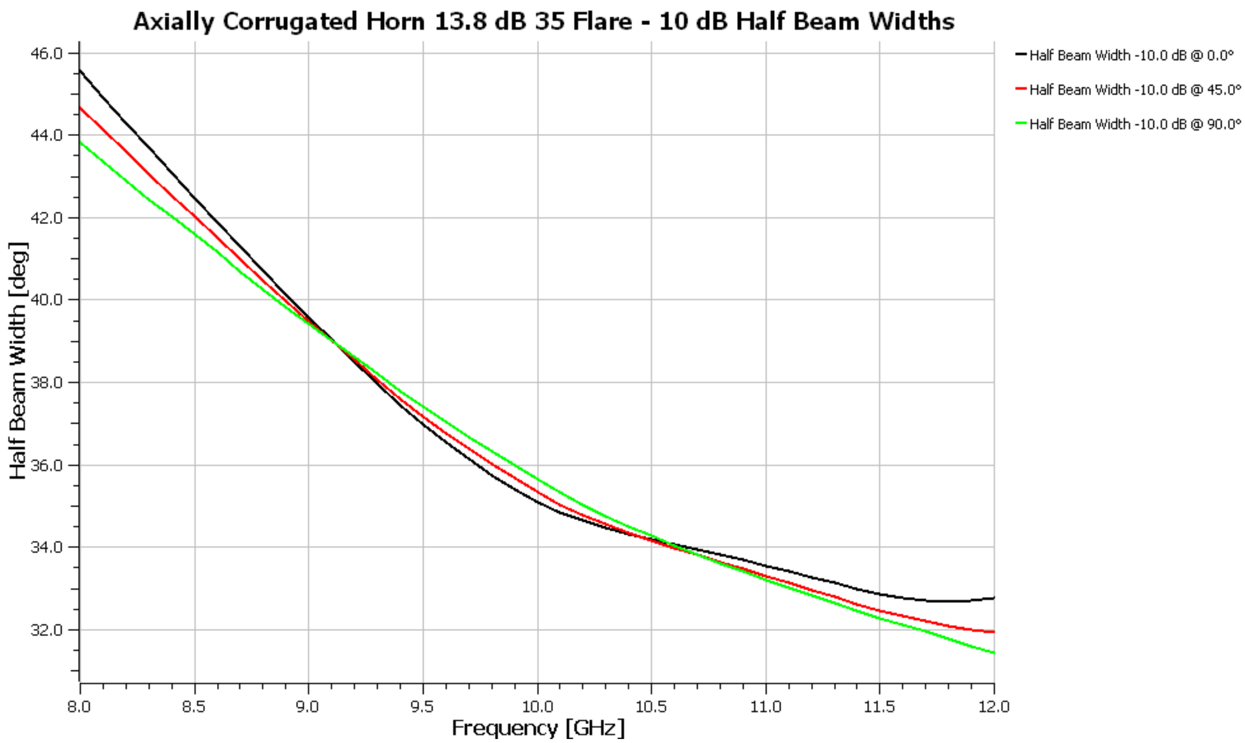


Figure 15 13.8 dB Gain Axially Corrugated Horn θ = 35° 10 dB Half Beam Width

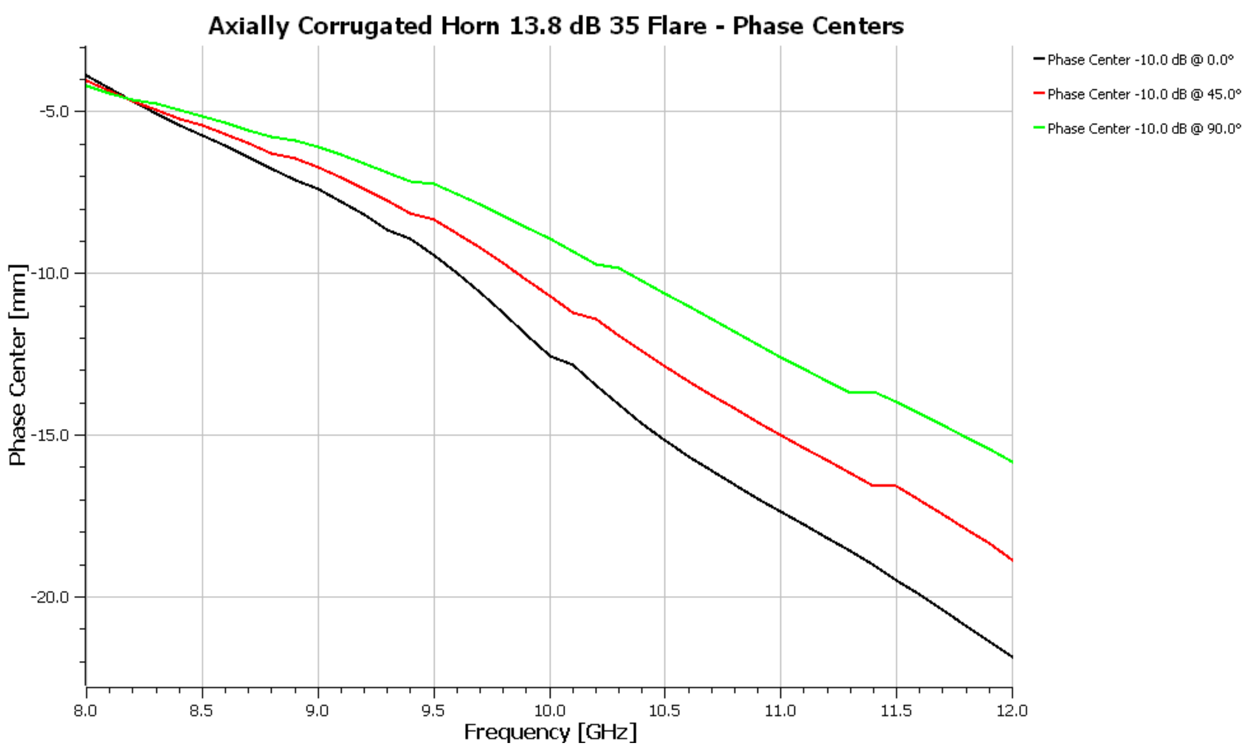


Figure 16 13.8 dB Gain Axially Corrugated Horn θ = 35° Phase Center relative Aperture

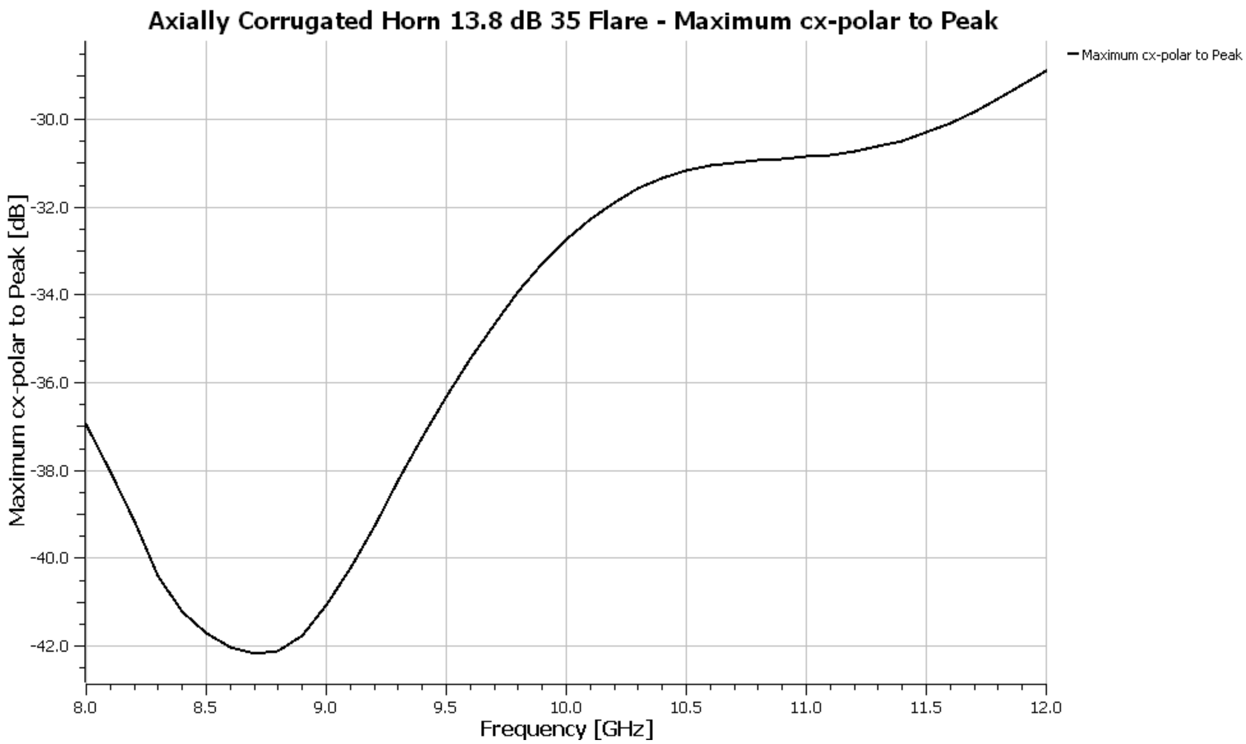


Figure 17 13.8 dB Gain Axially Corrugated Horn θ = 35° Cross Polarization relative Co-Pol.

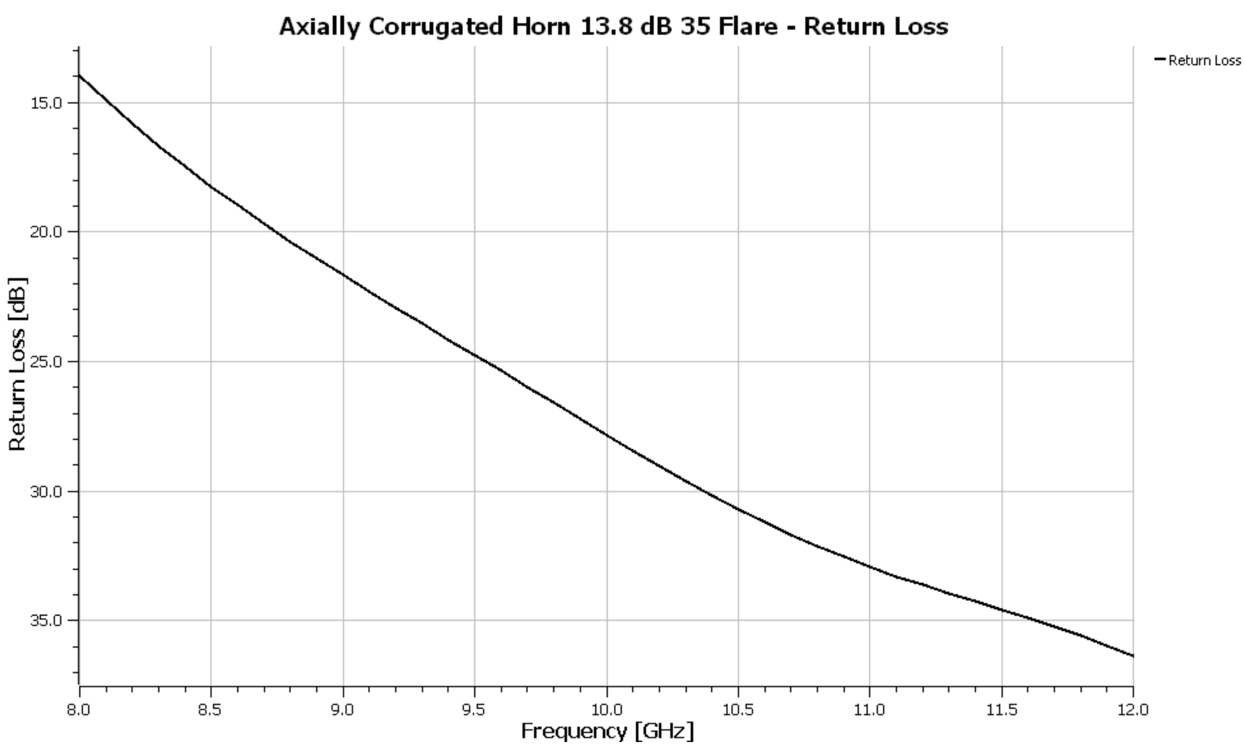


Figure 18 13.8 dB Gain Axially Corrugated Horn θ = 35° Return Loss

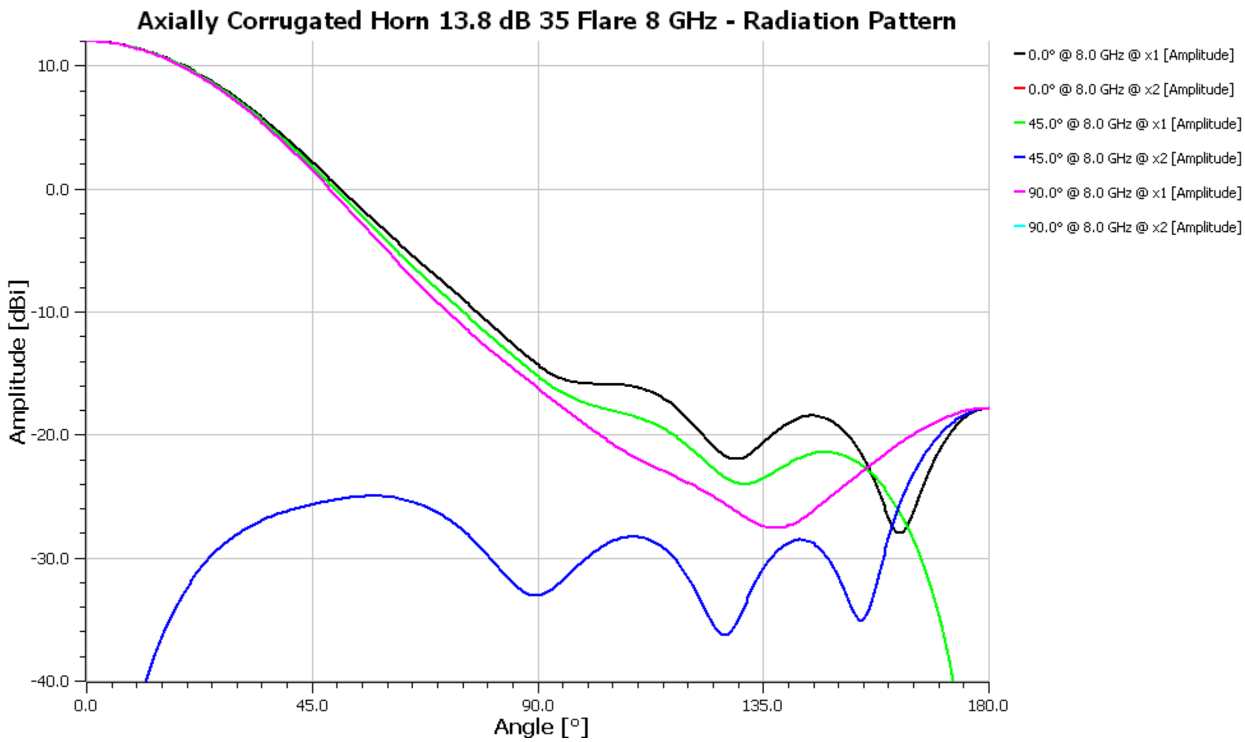


Figure 19 13.8 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz) 8 GHz

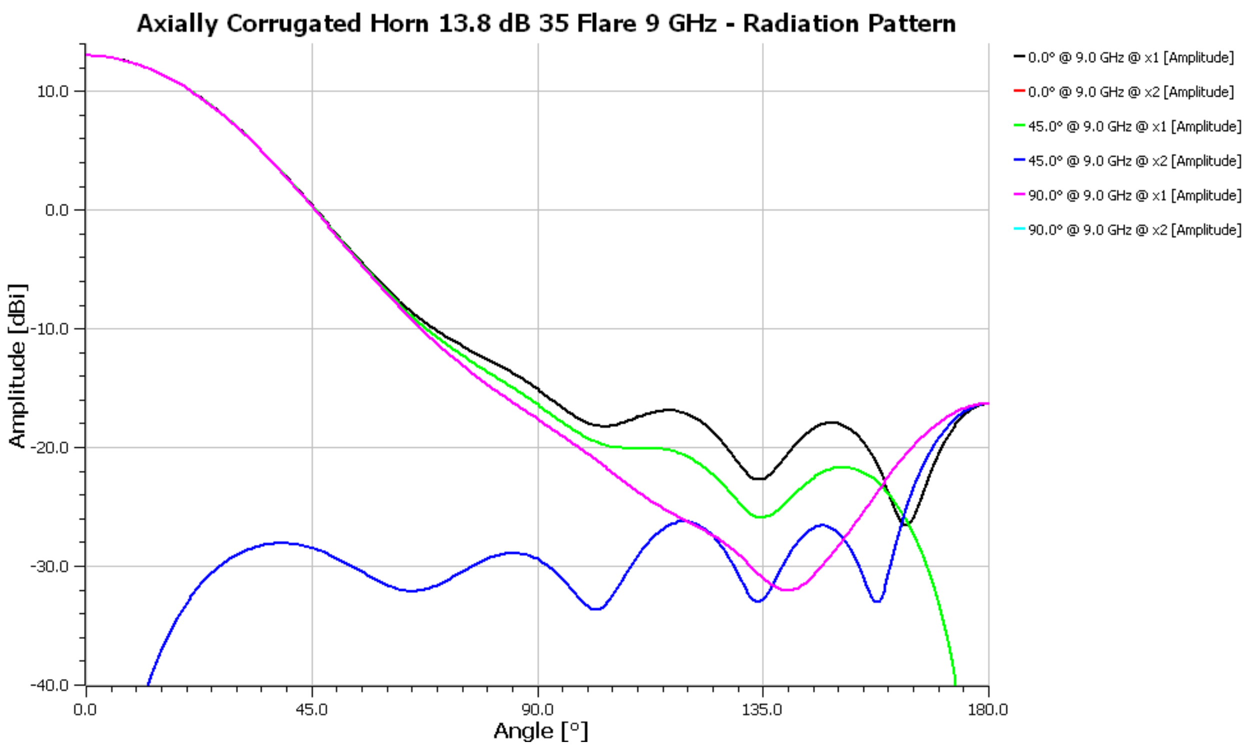


Figure 20 13.8 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz) 9 GHz

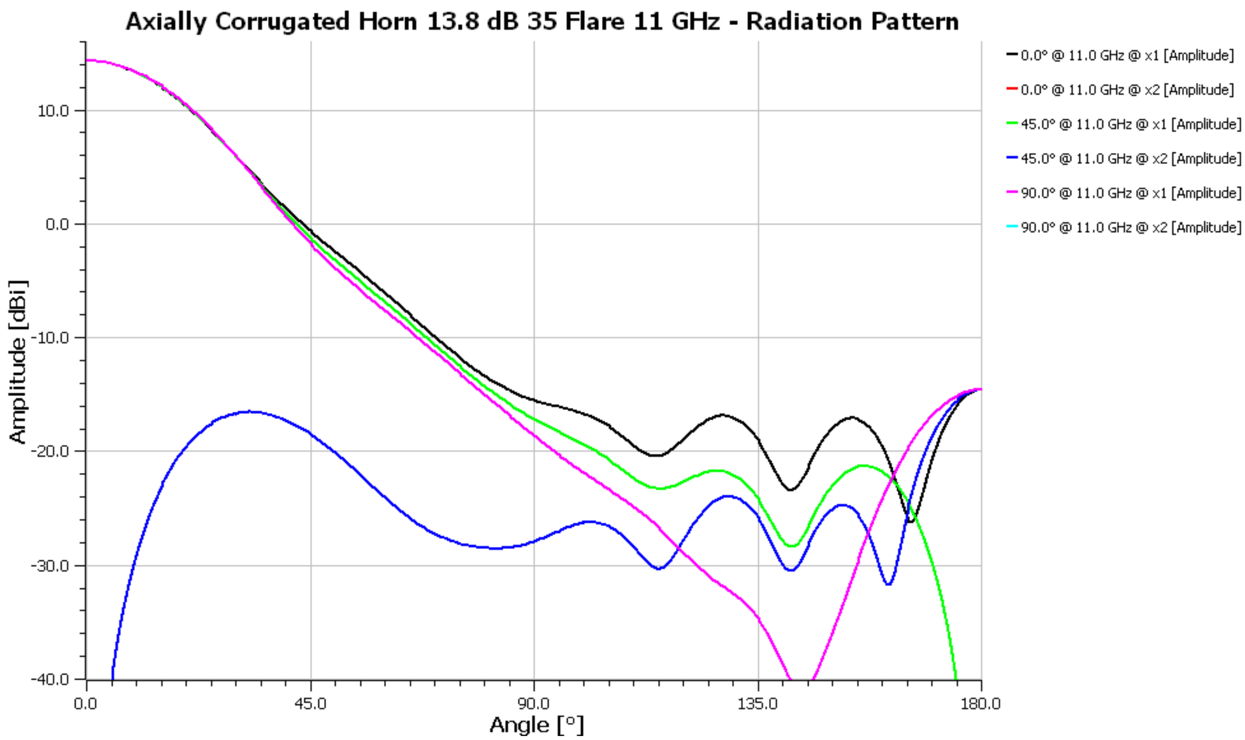


Figure 21 13.8 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz) 11 GHz

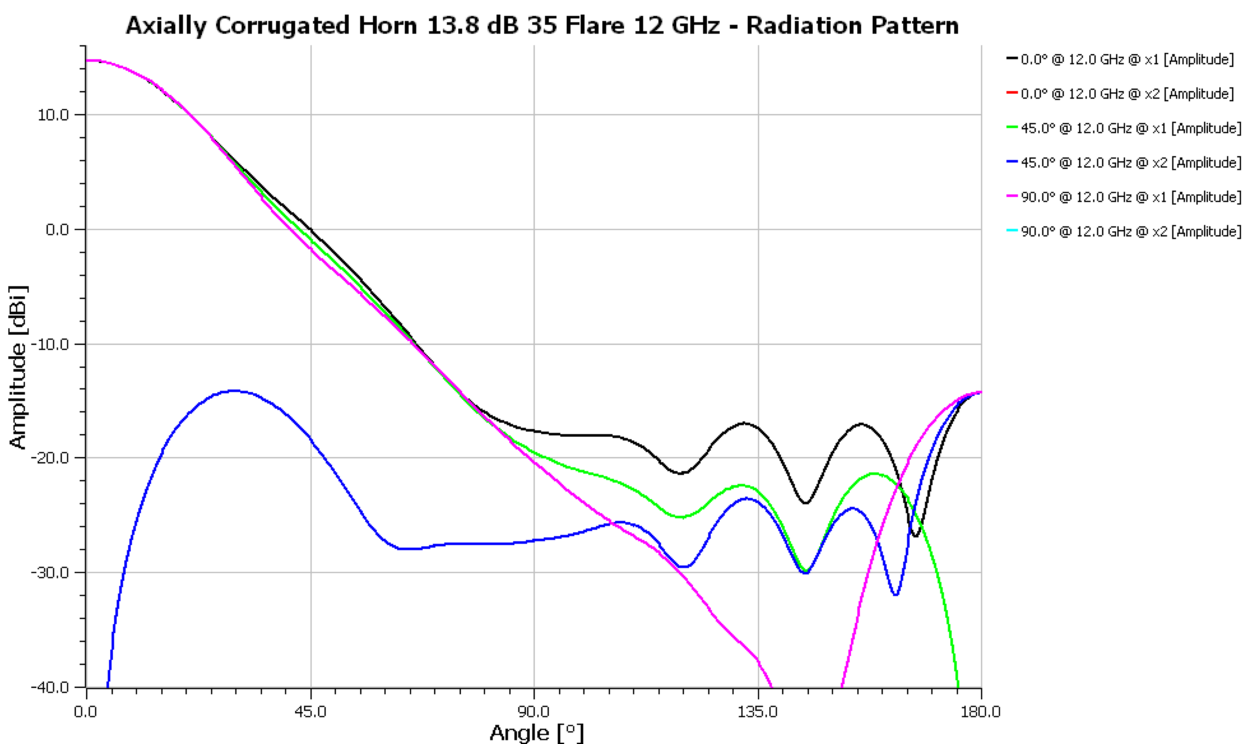


Figure 22 13.8 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz) 12 GHz

The cross polarization in the diagonal plane can be improved by applying the optimization on the four slot depths in CHAMP.

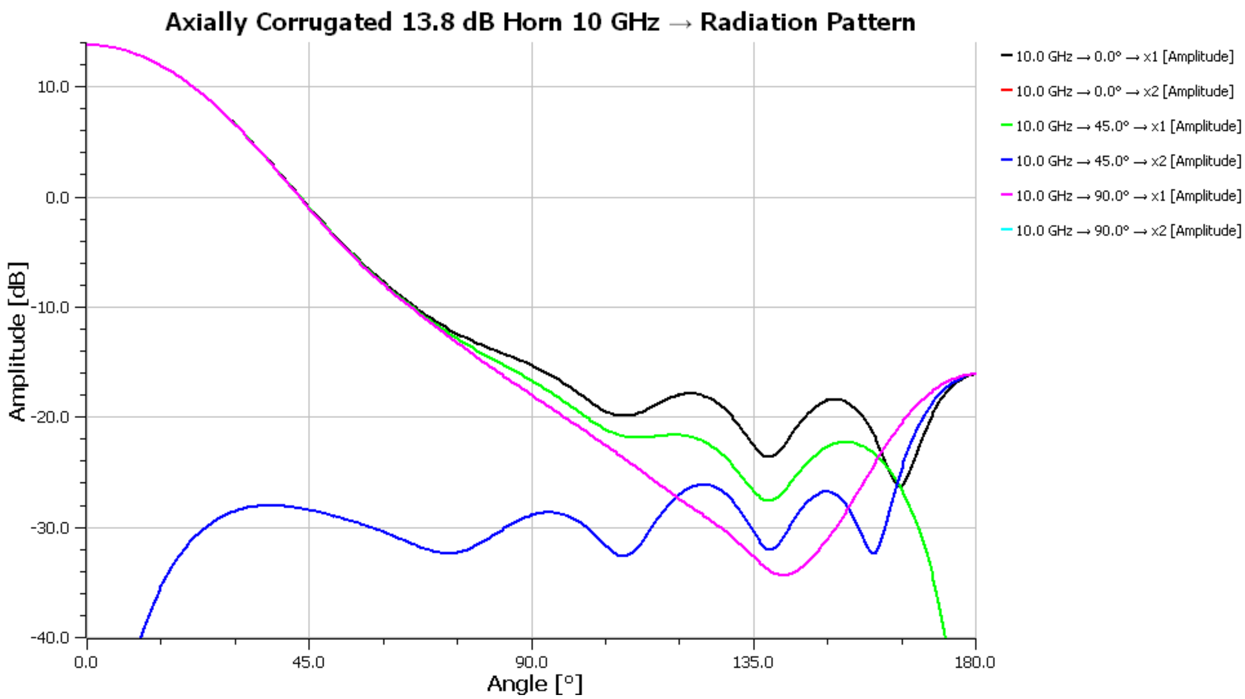


Figure 23 Optimized 13.8 dB Gain Axially Corrugated Horn θ = 35° (Center Frequency 10 GHz)

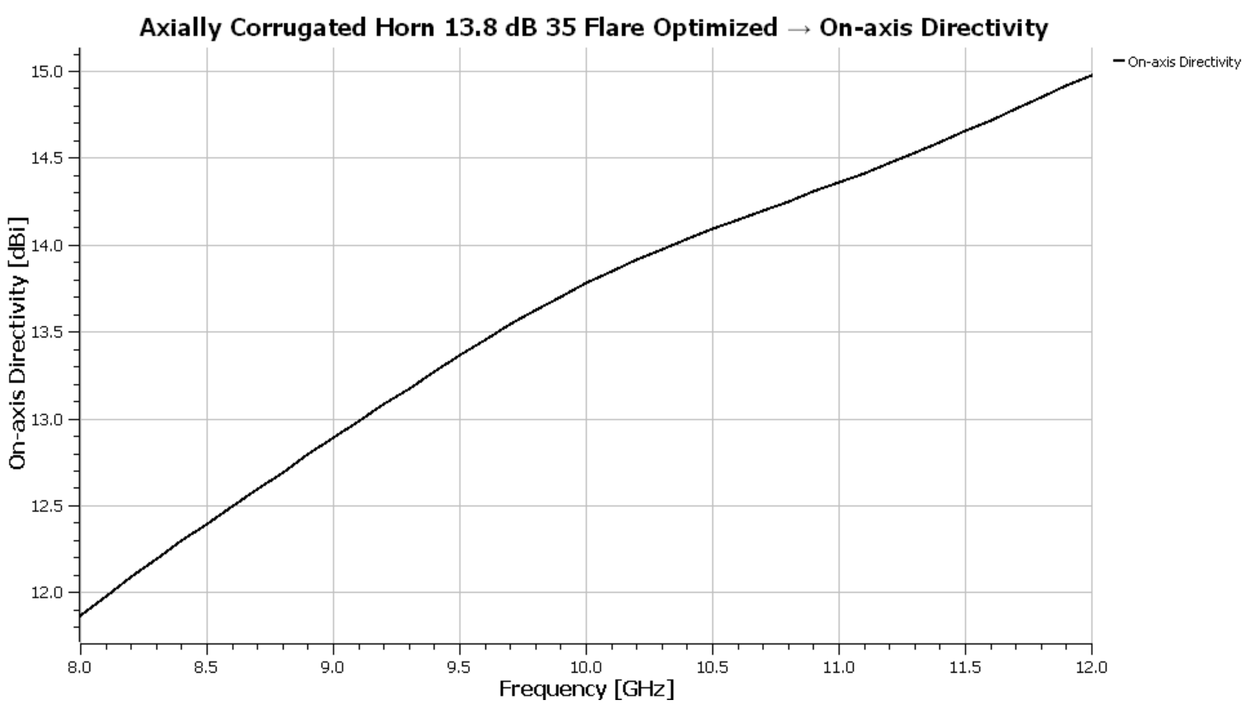


Figure 24 Optimized 13.8 dB Gain Axially Corrugated Horn θ = 35° Directivity

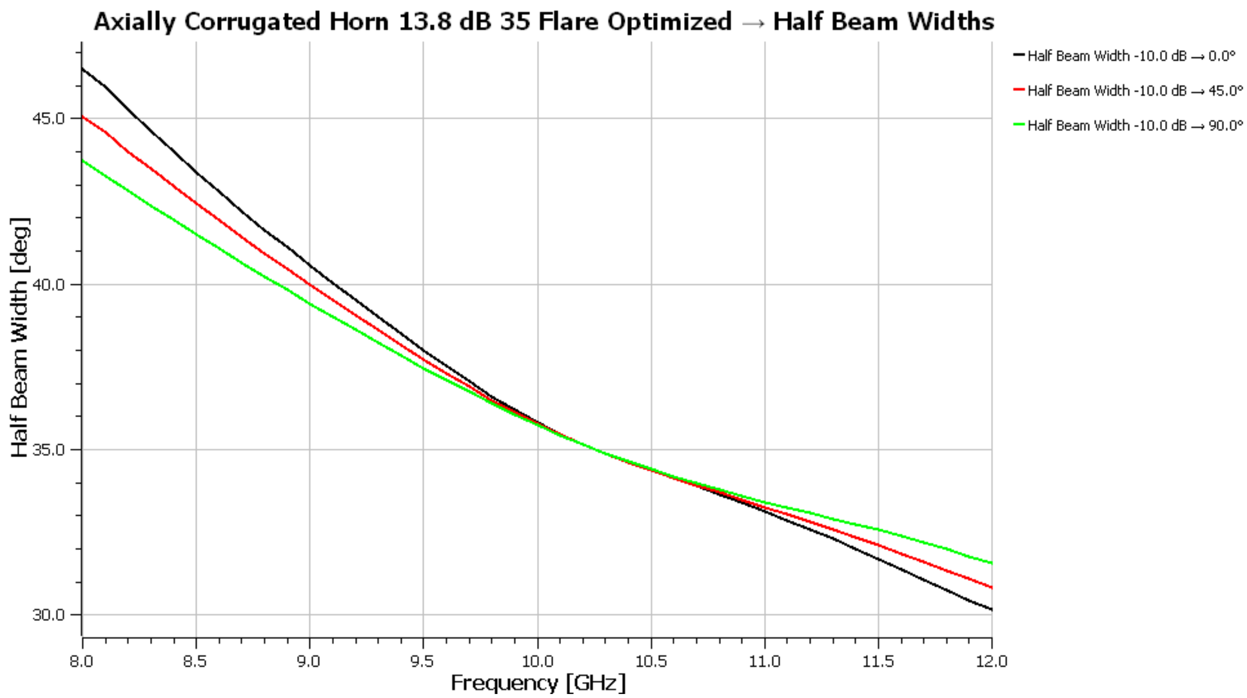


Figure 25 Optimized 13.8 dB Gain Axially Corrugated Horn θ = 35° 10 dB Half Beam Width

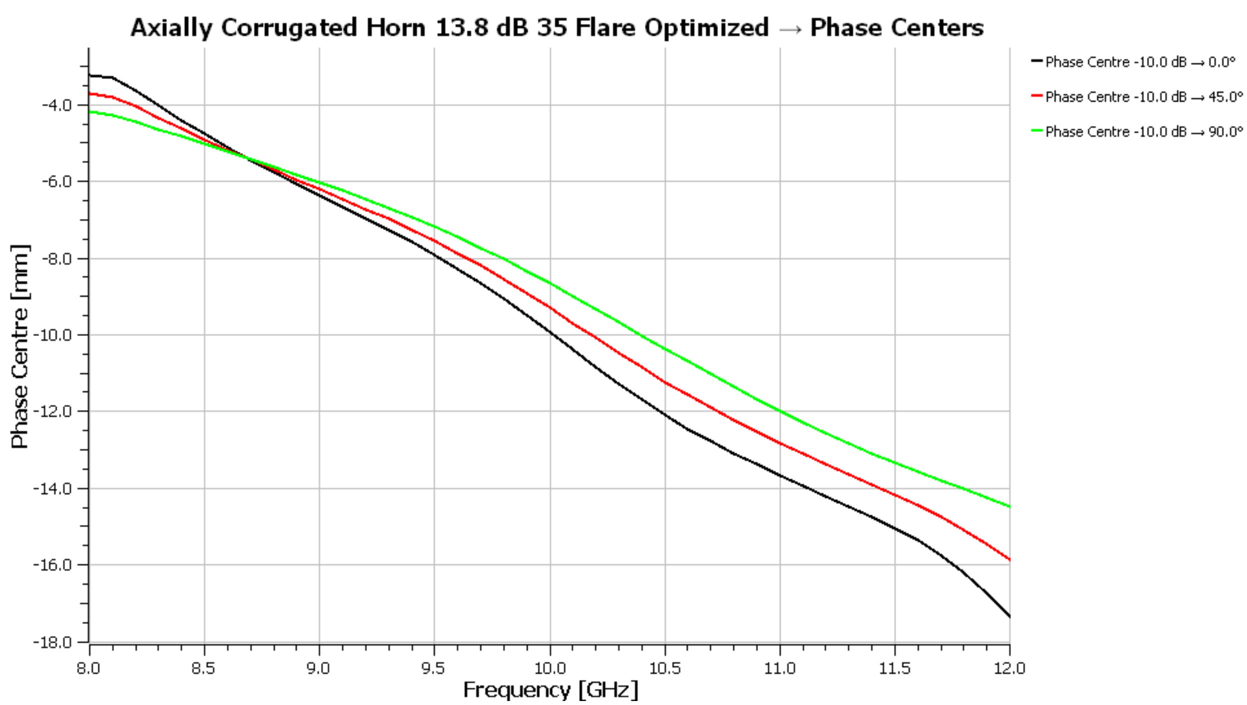


Figure 26 Optimized 13.8 dB Gain Axially Corrugated Horn θ = 35° Phase Center

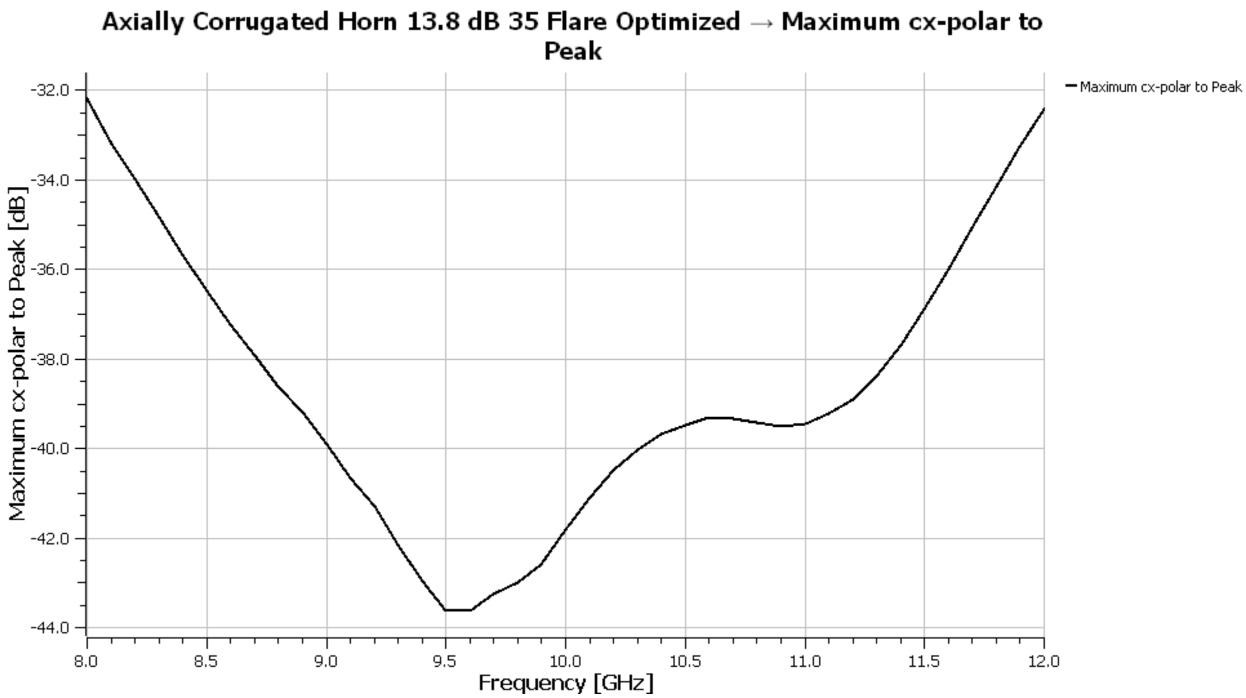


Figure 27 Optimized 13.8 dB Gain Axially Corrugated Horn θ = 35° Cross Polarization

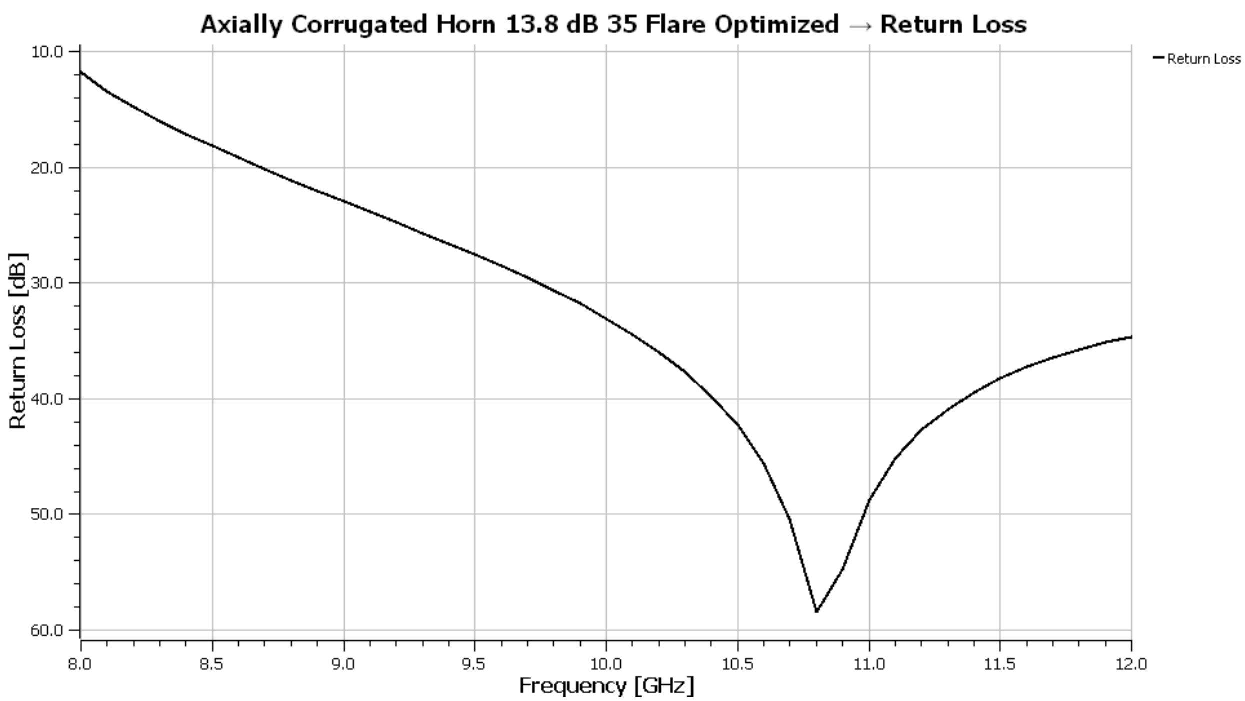


Figure 28 Optimized 13.8 dB Gain Axially Corrugated Horn θ = 35° Return Loss

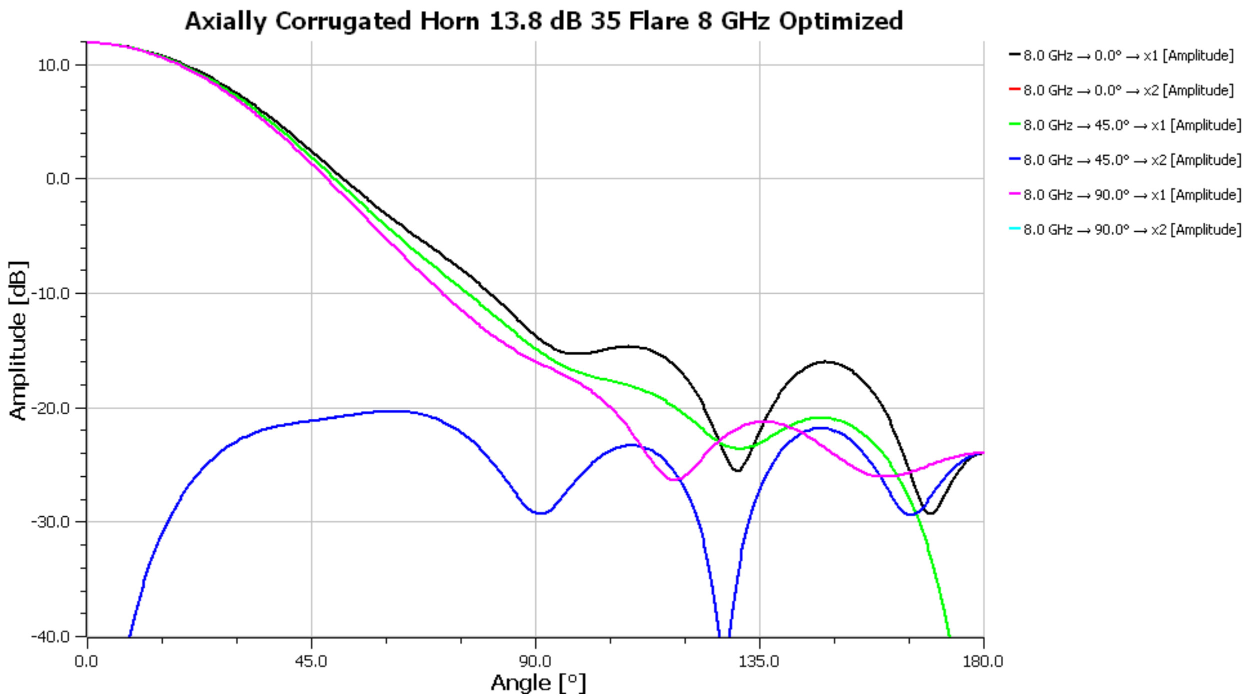


Figure 29 Optimized 13.8 dB Gain Axially Corrugated Horn $\theta = 35°$ (Center Frequency 10 GHz) 8 GHz

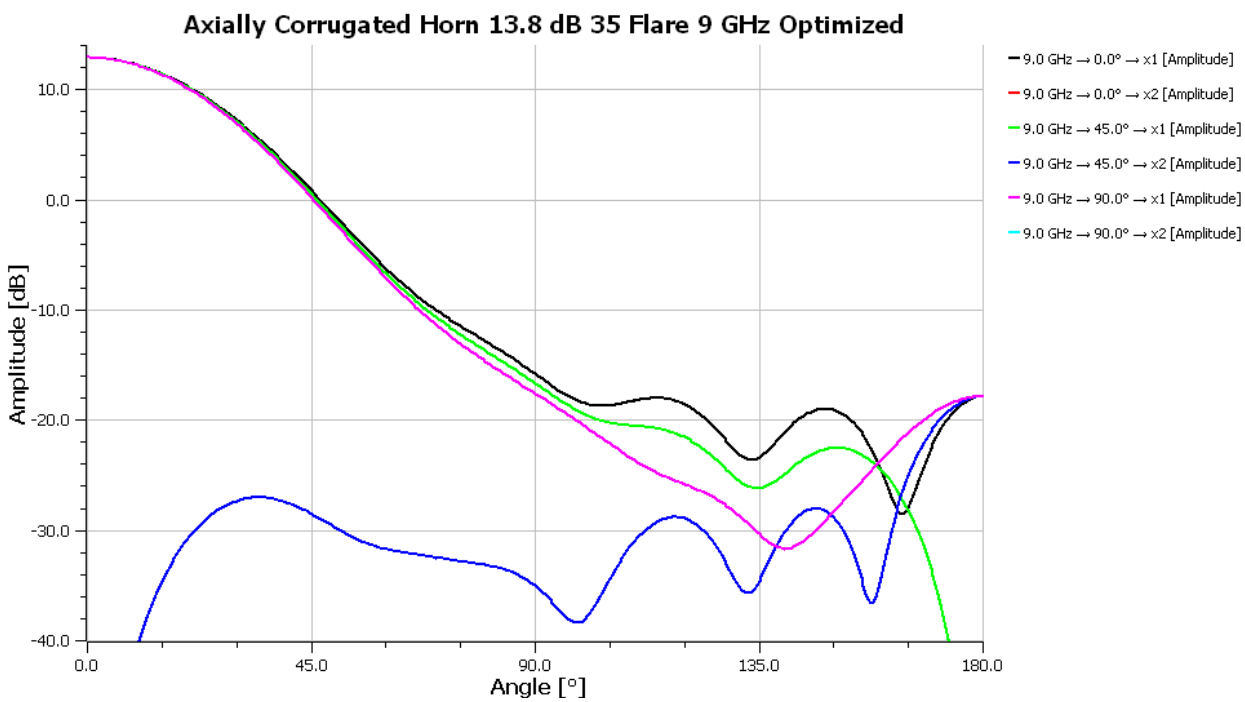


Figure 30 Optimized 13.8 dB Gain Axially Corrugated Horn $\theta = 35°$ (Center Frequency 10 GHz) 9 GHz

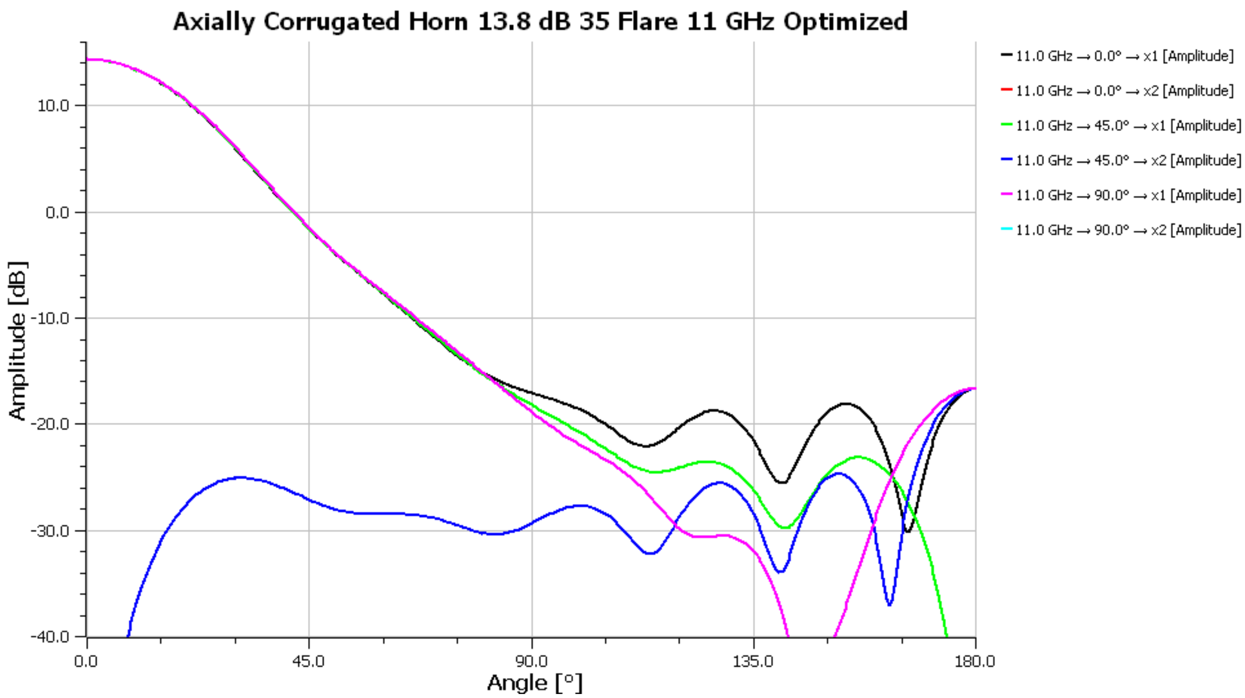


Figure 31 Optimized 13.8 dB Gain Axially Corrugated Horn $\theta = 35°$ (Center Frequency 10 GHz) 11 GHz

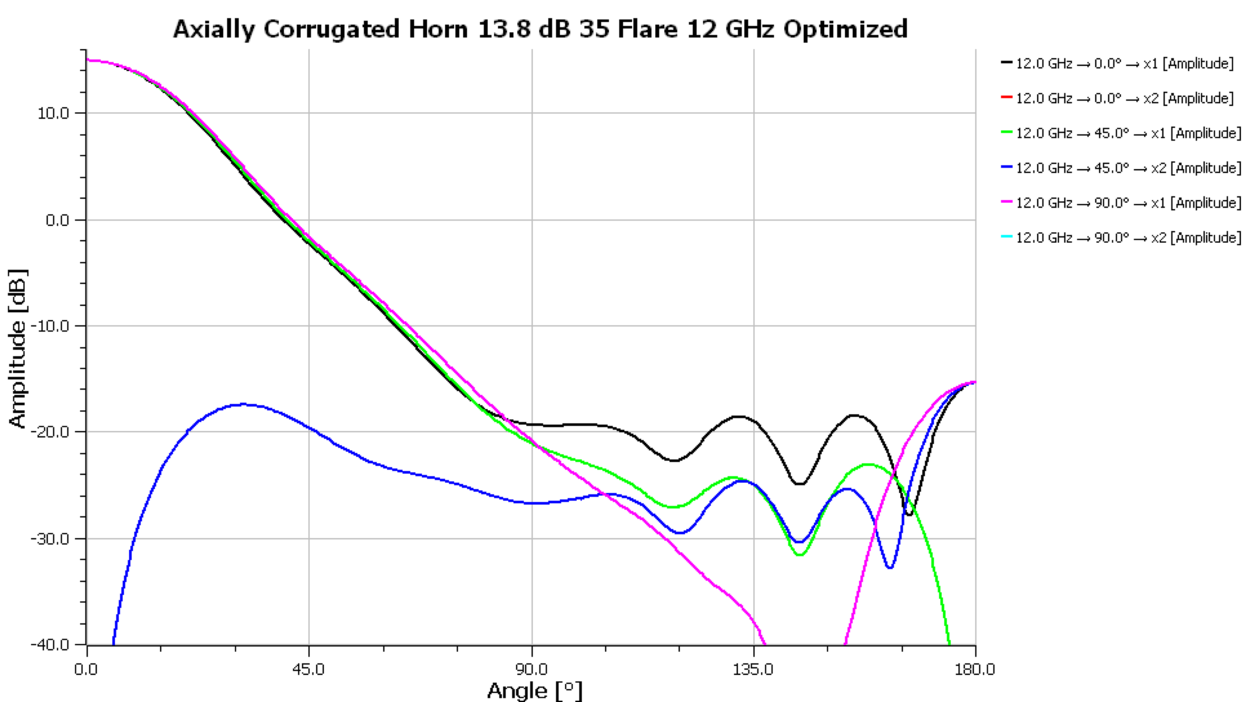


Figure 32 Optimized 13.8 dB Gain Axially Corrugated Horn $\theta = 35°$ (Center Frequency 10 GHz) 12 GHz