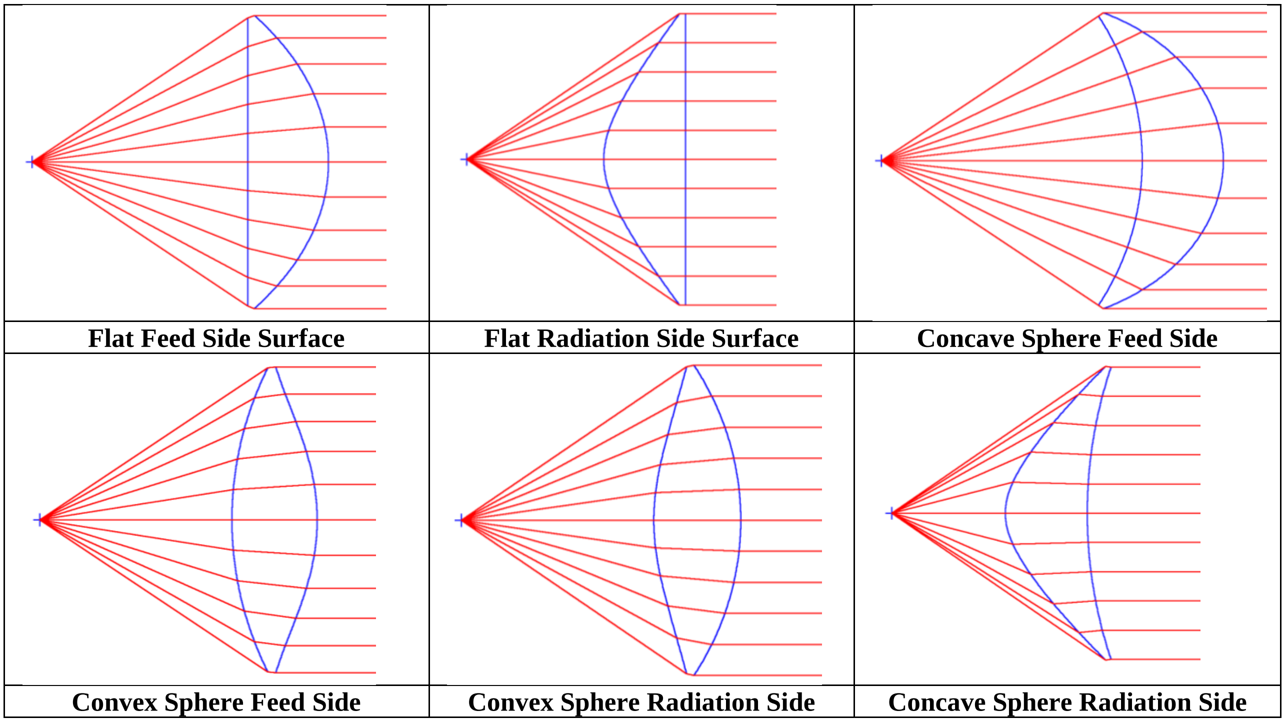
CHAMP BOR-MoM Analyses of Dielectric Lenses

A dielectric lens can be added to a feed analysis in CHAMP (TICRA) and the pattern of the combination computed using the BOR-MoM of a dielectric object external to the horn. The various general two-surface lenses have been considered.

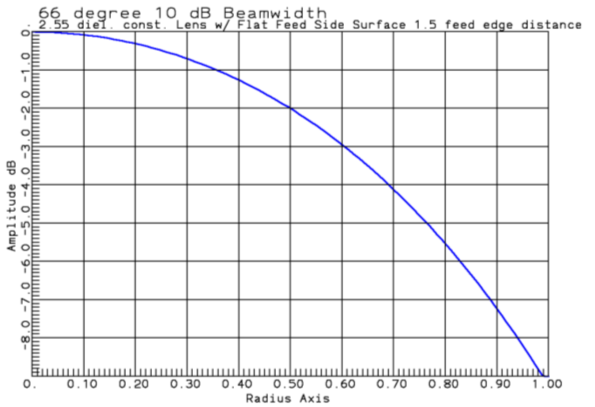


General Two-Surface Lenses

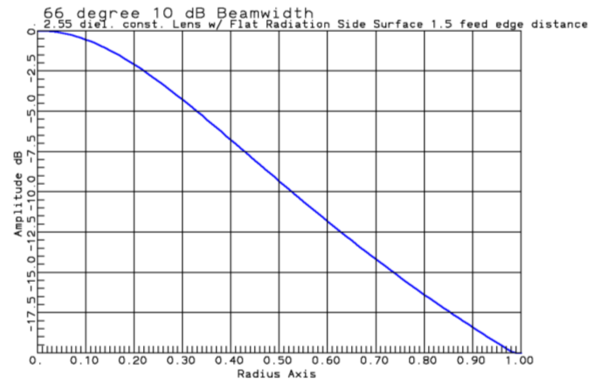
The "Flat Radiation Side" and "Concave Sphere Feed Side" lenses are the single refracting surface lens where the rays pass through one surface without refracting and all refraction takes place on the other surface. The other four lenses refract the rays at both surfaces. The lenses above use either flat or spherical surfaces on one surface and in general we could specify other types of surfaces and solve for the second surface through ray tracing. Notice that these lenses do not have spherical surfaces (including the flat surface as a sphere of infinite radius) on both sides as used in the lens maker's equation. This approach to lenses is normally discussed in college physics but it is a paraxial ray approximation that produces spherical aberration in the focus for these wide angle lenses.

The lenses will be fed using a 14.5 dB gain Pickett-Potter horn with its single discontinuity near the horn throat where the conical taper radius is 0.51λ and jumps to a radius of 0.65λ and then the cone continues at the same angle to the aperture. This 14.5 dB gain horn has a 10-dB beamwidth of about 66°. The combinations of taper due to the ray trace through the lens and the feed taper are plotted below over a normalized lens radius.

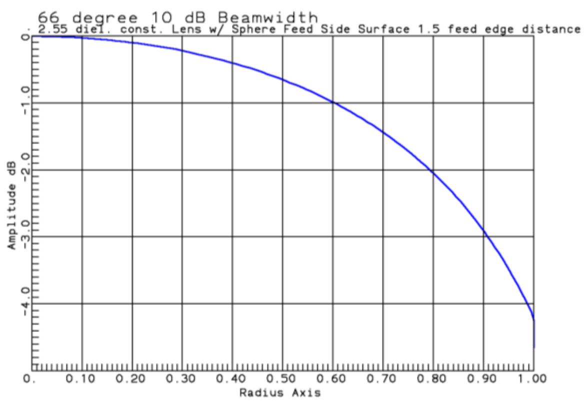
Ray tracing through the lenses produces the amplitude distribution using Eq. (9-12) by using a cubic spline between the aperture radius and the feed angle to compute the derivative in the equation. This operation produced the series of amplitude taper plots given below for the six lenses above.



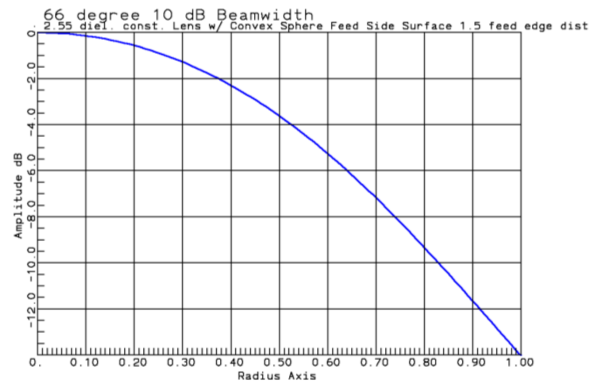
Flat Feed Side Surface



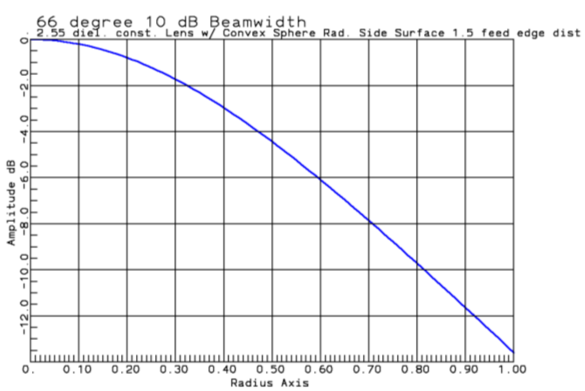
Flat Radiation Side Surface



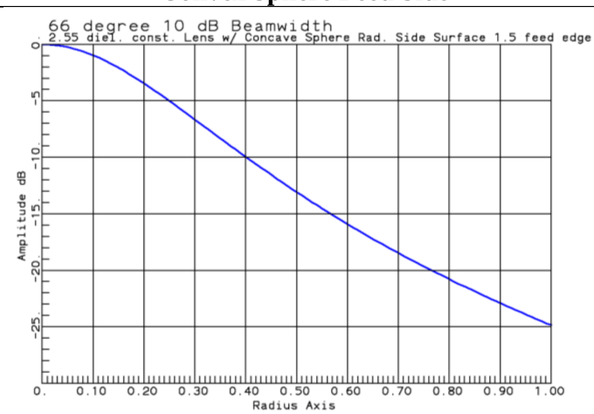
Concave Sphere Feed Side



Convex Sphere Feed Side



Convex Sphere Radiation Side



Concave Sphere Radiation Side

Aperture distribution of Lenses fed by 14.5 dB Gain Pickett-Potter Horn

Table 1 Amplitude Taper Loss using 66° 10-dB Beamwidth Feed using Ray Tracing Analysis

Flat Feed Side Surface	-0.43 dB
Flat Radiation Side Surface	-1.89
Concave Sphere Feed Side	-0.10
Convex Sphere Feed Side	-0.90
Convex Sphere Radiation Side	-0.84
Concave Sphere Radiation Side	-2.78

The program SPSLENS was written to compute the two lens surfaces with one specified as either a flat or sphere. The program also generates the additions to the geometry.tor CHAMP file to add the lens to the analysis of the feed-lens combination. The file includes a ZLOFF parameter to allow arbitrary positioning of the lens. Cases below have the lens focus moved inside the horn aperture to its phase center. Since the lens could be in the near-field of the feed horn, this parameter could be used as an optimization variable to maximize gain.

After the feed horn is designed, the project files can be copied into another project before altering the geometry.tor file located in the top directory of feed subdirectory. Below is a listing of the 14.5 dB gain Pickett-Potter horn geometry.tor file with the lens added using a text editor. The additions are printed in blue with some of the repetitive lines removed. This lens was grooved to reduce surface reflections with the grooves cut into material added to the lens surfaces to form a "coating". If we use the Lichtenecker logarithmic dielectric mixing equation for the coating to produce a layer with the square root of the lens material, the width of the gaps should equal the groove width. The groove depth should be $\lambda/4$ computed in the coating dielectric constant. The coating alters the effective focal length of the lens so SPSLENS allows adjustments to allow the groove to penetrate the design surfaces for hand optimization of groove layers.

Table 2 Gain of 10λ diameter Lens with 14.5 dB Gain Potter Horn Feed

Lens	Grooved Surface Lens	Smooth Surface Lens
Flat Feed Side Surface	29.58 input 5	29.19 input 6
Flat Radiation Side Surface	27.82 input 7	27.68 input 8
Concave Sphere Feed Side	29.78 input 9	29.64 input 10
Convex Sphere Feed Side	29.02 input 11	28.61 input 12
Convex Sphere Radiation Side	29.03 input 13	28.69 input 14
Concave Sphere Radiation Side	26.74 input 15	26.48 input 16

Additions to CHAMP geometry.tor file for 14.5 dB Gain Pickett-Porter Horn

```
horn  combined_horn_section
(
  horn_sections    : sequence(ref(circular_waveguide_section),ref(smooth_horn_section),
ref(smooth_horn_section_0001),ref(smooth_horn_section_0002)),
  scatterers       : sequence(ref(horn_bor_mesh),ref(horn_bor_mesh_lens))  Add lens to scatterers list
)
wavel  real_variable
(
  value          : 29.97925
)
length  real_variable
(
  value          : 92.86019175
)
rout  real_variable
(
  value          : 29.61470627
)
WR  real_variable
(
  value          : 13.0
)
rstep  real_variable
(
  value          : "0.65*ref(wavel)"
```

```
)
istep  real_variable
(
  value           : "0.51*ref(wavel)"
)
WL  real_variable
(
  value           : "ref(wavel)"
)
lenc  real_variable
(
  value           : "ref(length)*(ref(rstep)-ref(istep))/(ref(rout)-ref(rstep))"
)
leno  real_variable
(
  value           : "ref(length)*(ref(rout)-ref(WR)+ref(WT))/(ref(WT)+ref(rout)-ref(rstep))"
)
WT  real_variable
(
  value           : 2.0
)
circular_waveguide_section  circular_waveguide_section
(
  radius          : "ref(WR)" mm,
  length          : "ref(WL)" mm,
  conductivity    : 33000000.0 S/m
)
smooth_horn_section  smooth_walled_section
(
  profile         : ref(smooth_horn_section_profile),
  conductivity    : 33000000.0 S/m
)
smooth_horn_section_profile  linear_profile
(
  input_radius    : "ref(WR)" mm,
  output_radius   : "ref(istep)" mm,
  length          : "ref(lenc)" mm
)
smooth_horn_section_0001  smooth_walled_section
(
  profile         : ref(smooth_horn_section_profile_0001),
  conductivity    : 33000000.0 S/m
)
smooth_horn_section_profile_0001  linear_profile
(
  input_radius    : "ref(istep)" mm,
  output_radius   : "ref(rstep)" mm,
  length          : 0.1E+00 mm
)
smooth_horn_section_0002  smooth_walled_section
(
  profile         : ref(smooth_horn_section_profile_0002),
  conductivity    : 33000000.0 S/m
)
smooth_horn_section_profile_0002  linear_profile
(
```

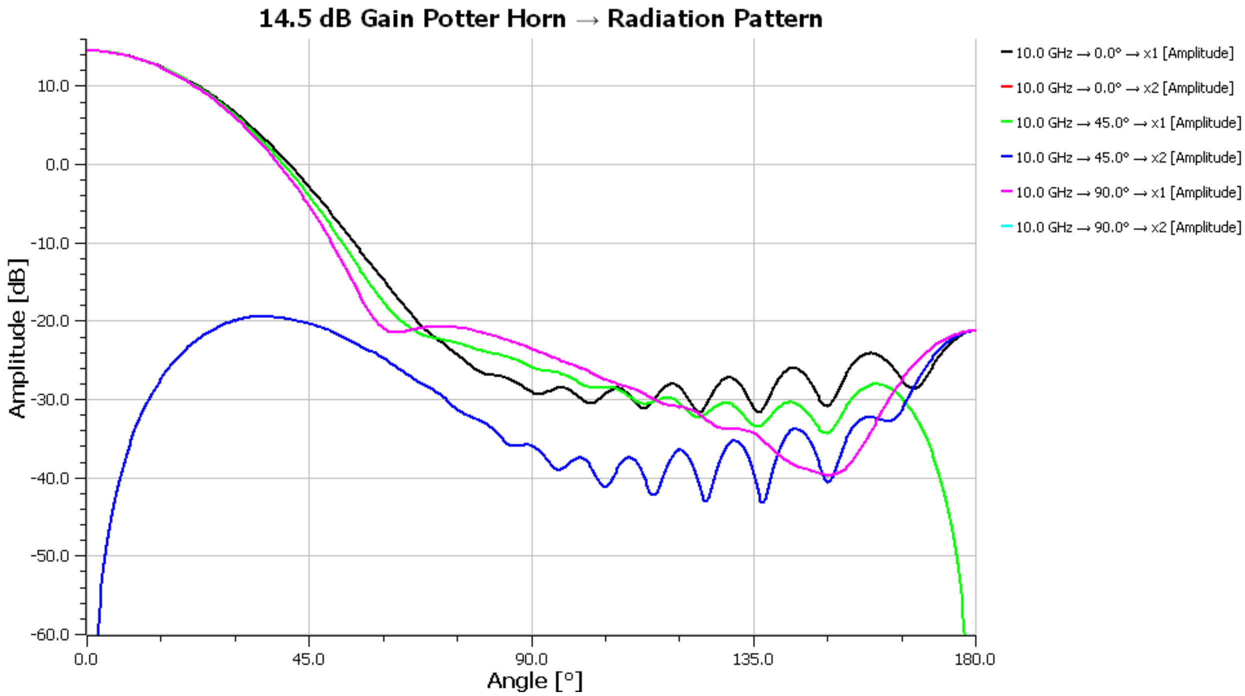
```
  input_radius     : "ref(rstep)" mm,
  output_radius    : "ref(rout)" mm,
  length           : "ref(length)" mm
)

horn_bor_mesh  bor_mesh
(
  regions          : table
    (
    ),
  nodes            : table
    (
      1   0.00000E+00  "ref(rout)"
      2   0.00000E+00  "ref(rout)+ref(WT)"
      3  "-ref(leno)"  "ref(WR)+ref(WT)"
      4  "-ref(WL)-ref(length)-ref(lenc)"  "ref(WR)+ref(WT)"
      5  "-ref(WL)-ref(length)-ref(lenc)"  "ref(WR)"
    ),
  linear_segments  : table
    (
      1    1    2    0    0    0.00000E+00    0.00000E+00
      2    2    3    0    0    0.00000E+00    0.00000E+00
      3    3    4    0    0    0.00000E+00    0.00000E+00
      4    4    5    0    0    0.00000E+00    0.00000E+00
    ),
  cubic_segments   : table
    (
    ),
  length_unit      : mm
)

ZLOFF  real_variable
(
  value            : -3.2
)

horn_bor_mesh_lens  bor_mesh
(
  regions          : table
    (
      1   2.55000E+00    1.00000E+00    0.00000E+00
    ),
  nodes            : table
    (
      1  "ref(ZLOFF)+2.1907e+02"    0.00000E+00
      2  "ref(ZLOFF)+2.1907e+02"    4.68750E+00
          .
          .
          .
    192  "ref(ZLOFF)+2.3183e+02"    1.52530E+02
    ),
  linear_segments  : table
    (
      1    1    2    0    1   -1.00000E+00    0.00000E+00
      2    2    3    0    1   -1.00000E+00    0.00000E+00
          .
```

```
          .
          .
     95    64    192     0     1   -1.00000E+00    0.00000E+00
   ),
  cubic_segments   : table
   (
      1    65    66    67    68     0     1   -1.00000E+00    0.00000E+00
      2    69    70    71    72     0     1   -1.00000E+00    0.00000E+00
          .
          .
          .
     32   189   190   191   192     0     1   -1.00000E+00    0.00000E+00
   ),
  length_unit      : mm
)

TX_wide  corrugated_horn_mode_matching
(
  frequency        : ref(TX_wide_freq),
  horn             : ref(horn),
  output_file_name : TX_wide/reflections.edx,
  coef_file_name   : TX_wide/reflections.dat
)

TX_wide_freq  frequency_range
(
  frequency_range  : struct(start_frequency: 9.0 GHz, end_frequency: 11.0 GHz, number_of_frequencies: 41)
)

TX_cent  corrugated_horn_mode_matching
(
  frequency        : ref(TX_cent_freq),
  horn             : ref(horn),
  output_file_name : " ",
  coef_file_name   : " "
)

TX_cent_freq  frequency_range
(
  frequency_range  : struct(start_frequency: 10.0 GHz, end_frequency: 10.0 GHz, number_of_frequencies: 1)
)

optimiser  optimisation_manager
(
  variables        : ref(optimiser_0001),
  goals            : sequence(ref(optimisation_goals_radiation_pattern)),
  max_iterations   : 30
)

optimiser_0001  optimisation_variables
(
  real_variables   : sequence
    (    struct(variable_object: ref(length), min: 80.0, max: 500.0),
    struct(variable_object: ref(rout), min: 20.0, max: 150.0)
    )
)
```

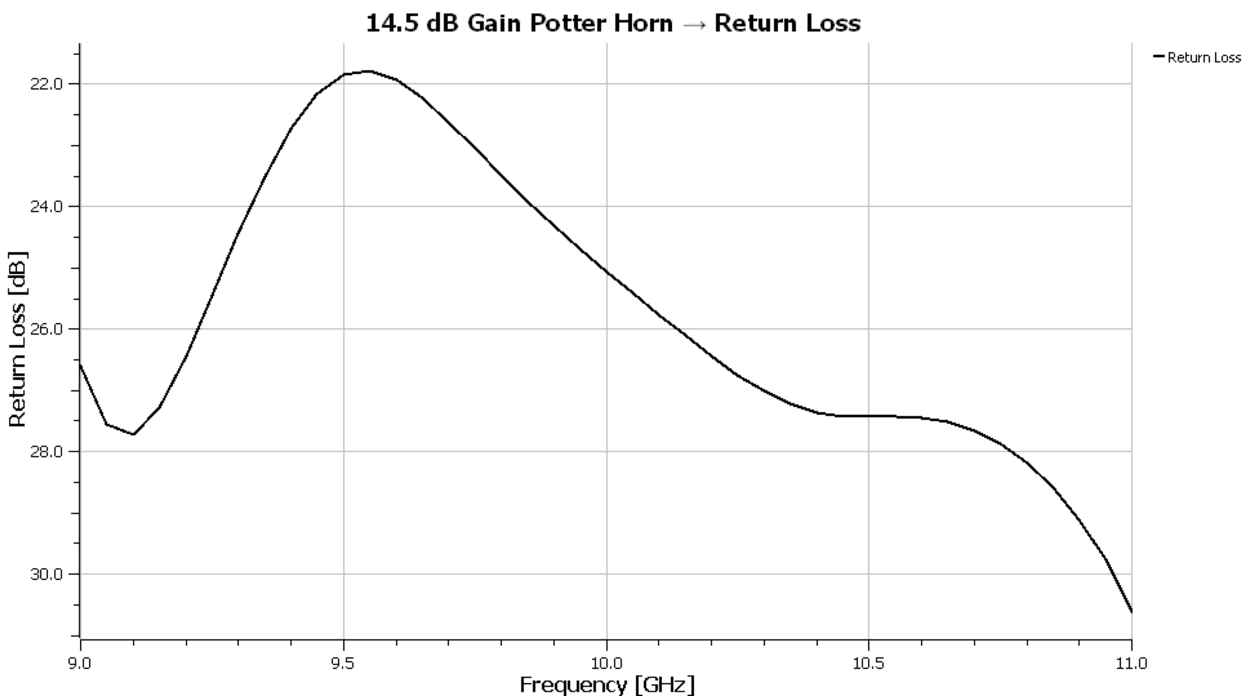
```
optimisation_goals_radiation_pattern  optimisation_goals_radiation_pattern
(
  source          : ref(TX_cent),
  goals_on_axis_directivity : sequence
    (    struct(frequency_index: -1.0, goal: 14.5, weight: 1.0, action: target)
    ),
  goals_cross_polar : sequence
    (    struct(frequency_index: -1.0, theta_min: 0.0, theta_max: 60.0, goal: -30.0, weight: 1.0, action:
minimise)
    )
)

//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  view
(
  objects         : sequence(ref(view_horn_section_plot)),
  dimension       : 2D
)

view_horn_section_plot  horn_section_plot
(
)

 //$$ Saved at 18:23:01 on 02.12.2013 by CHAMP ver. 3.0.0 SN=003001
```

Potter Horn Feed Characteristics

The Pickett-Potter horn is a mechanically simple horn with its single waveguide step and tuned bell length to produce approximately corrugated horn performance. By using this horn some of the effects of the lens reflections into a real feed horn can be modeled. Its pattern has less than perfect cross polarization in the diagonal plane and we will see that the lens reflections affect the balance of modes in the horn which show in the diagonal plane pattern response of the lens-horn combination. The lens reflected wave interacts with the horn’s internal reflections and we see in the return loss response the combined response.

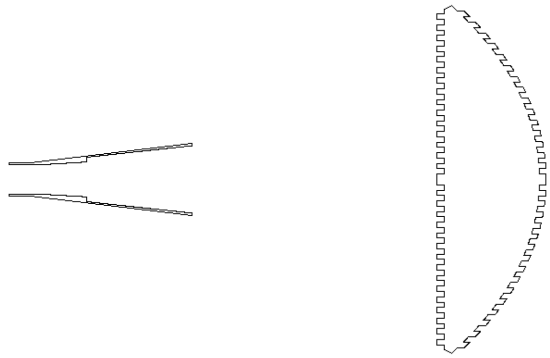


Potter Feed Horn Pattern Response at Center Frequency from CHAMP analysis

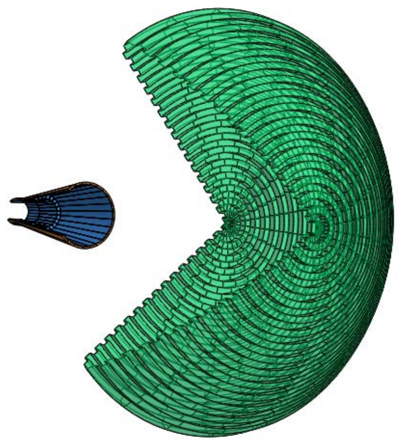


Potter Feed Horn Return Loss radiating into Free Space from CHAMP analysis

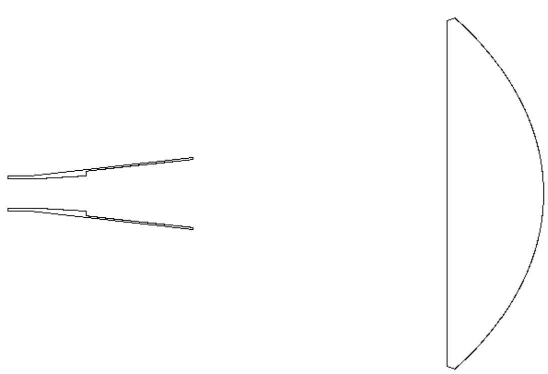
Flat Feed Side Surface Lens (Plano-Convex Lens)



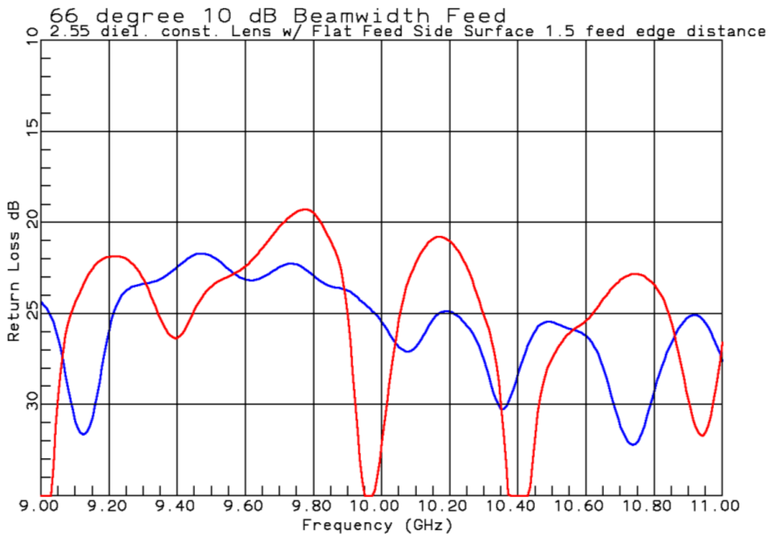
Lens containing surface reflection matching grooves and feed horn



Lens containing surface reflection matching grooves and feed horn

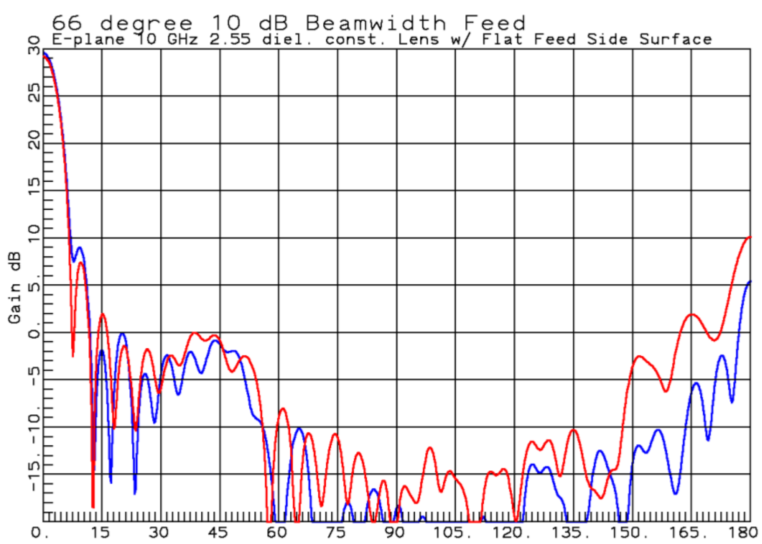


Lens and feed horn



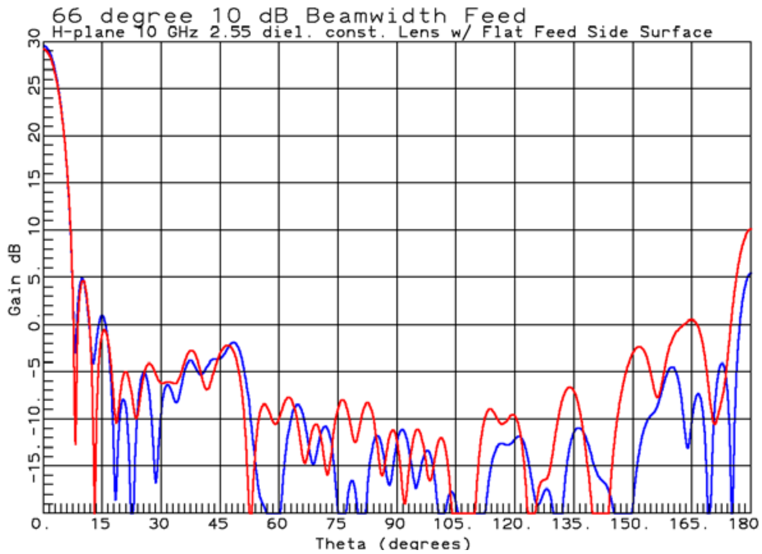
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves

The figure above illustrates that grooving the surface of the lens has little effect on the scattering of the lens into the feed horn. The grooved lens return loss response in both shape and level is very similar to the horn response radiating into free space. The 390 MHz frequency difference between the ripple peaks corresponds to distance to the equivalent reflection from the lens surface which is a half wavelength of this difference. The 380 mm distance is somewhat just inside the 300 mm distance from the horn aperture to the free side of the lens in this model. If we include the distance from the horn aperture to the feed flare step, it is close to the 380 mm distance. The response has a single frequency uniform ripple that show there is not a multiple response from the two surfaces of the lens.



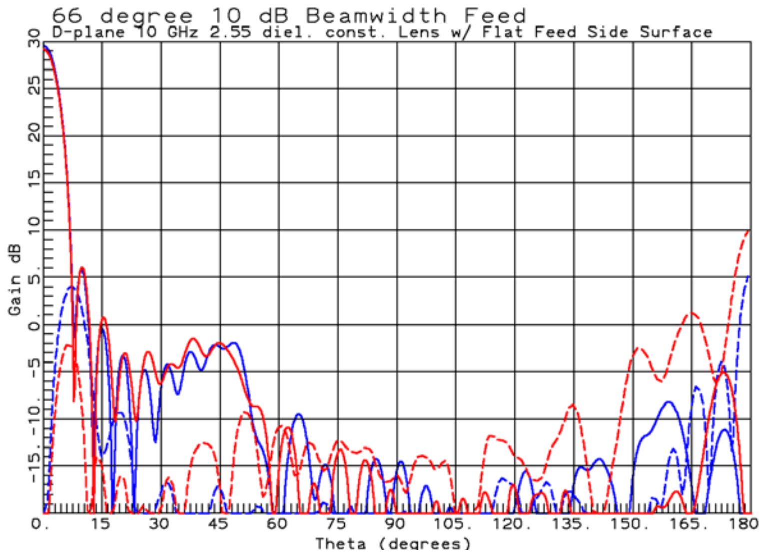
Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves

The responses of the lens are similar with or without the grooves. We can see that the grooves have changed the effective focal length by considering the fill-in of the first null and rise in the first sidelobe. The lens backlobe has caused by the reflection from the feed side reflection which we see reduced by the groove surface matching.



Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves

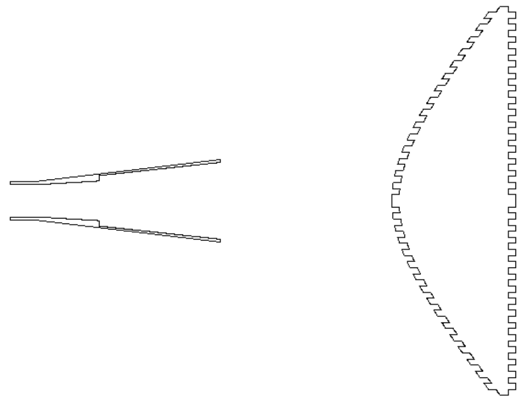
The H-plane pattern shows less effect of defocusing due to the grooves because the first null is filled-in less and the peak has little change. The backlobe has increased by 5 dB just like the E-plane pattern. In both the E- and H-plane patterns we can see the spillover lobe that occurs around 33°, the edge of the lens.



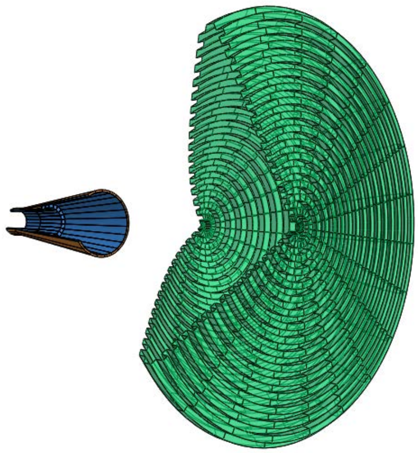
Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed

The grooves increase the cross-polarization lobe in the diagonal plane by 6 dB, but the levels of -25 dB (grooved) and -31 dB (smooth surface) are similar to the feed horn level of -34 dB. The grooves cause more interaction with the modes in the horn aperture than the smooth surface but the effect is small.

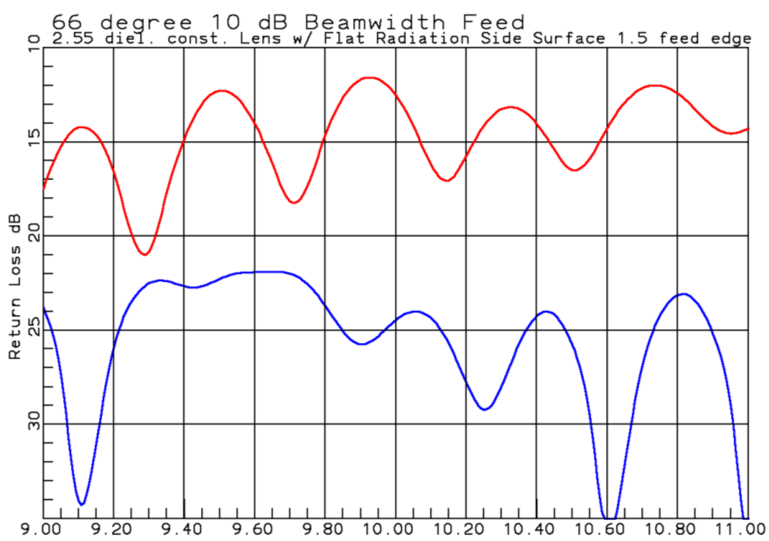
Flat Radiation Side Surface Lens



Lens containing surface reflection matching grooves and feed horn

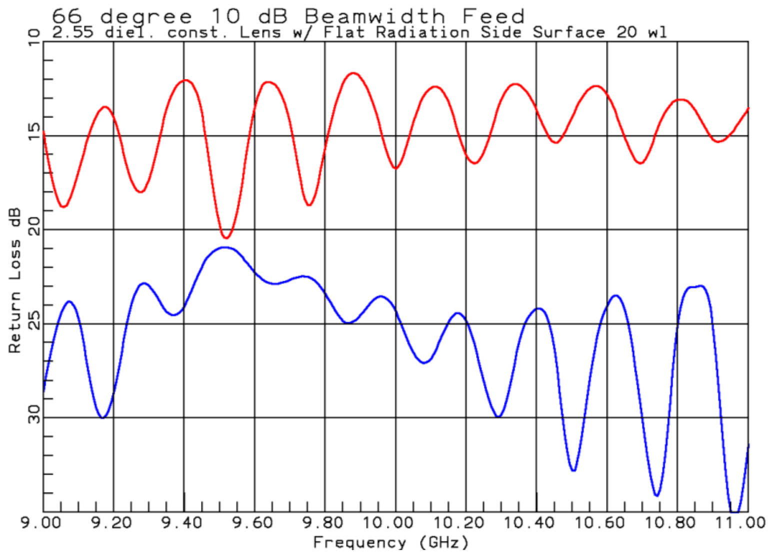


Lens containing surface reflection matching grooves and feed horn



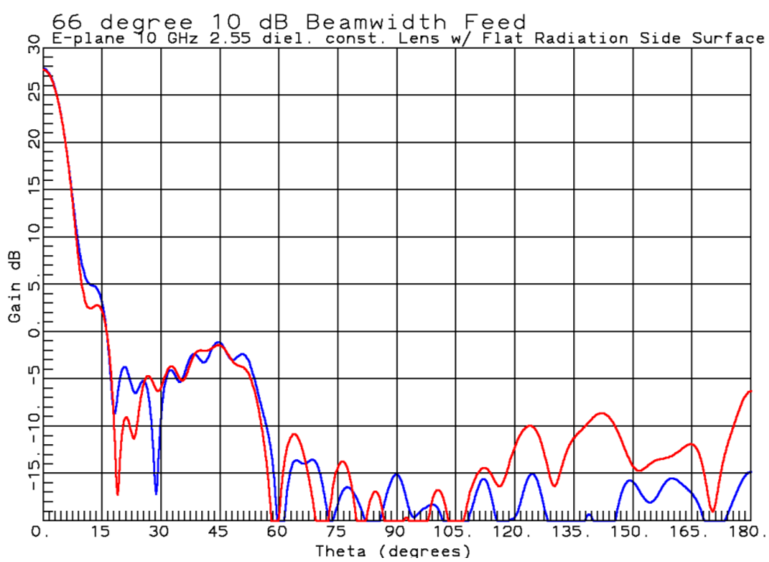
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves for 10λ diameter lens

This single refraction surface lens has significant reflection into the feed horn which is due to the radiation side flat surface since the reflections from all portions of its surface add in phase at the feed when traced back along the feed rays. Adding the grooves greatly reduces this reflection because the response with them has a level about that of the feed alone.



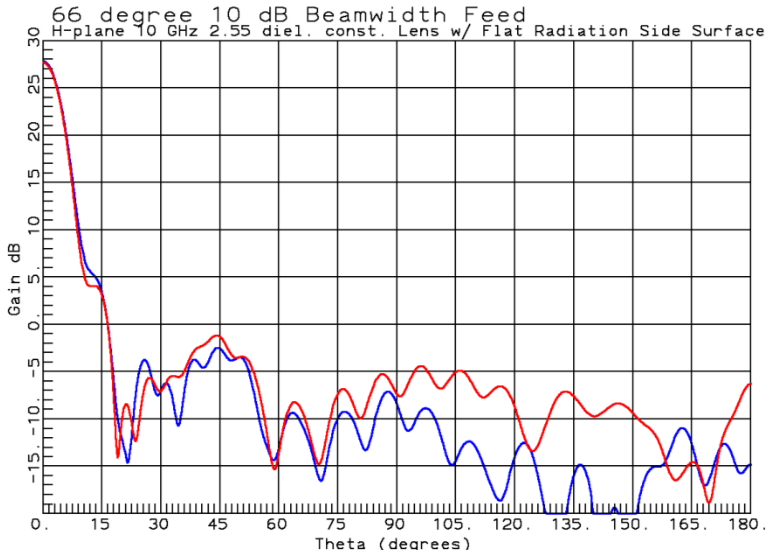
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves for 20λ diameter lens

The plot above for the return loss of the lens twice the diameter of the previous one shows that the response levels are the same. When we double the diameter of a reflector, the reflection into the feed is reduced by 6 dB, but it is not true for a lens. Of course, the larger lens has half the frequency ripple rate of the half sized lens, since the distance from the feed to the lens surface is two times.



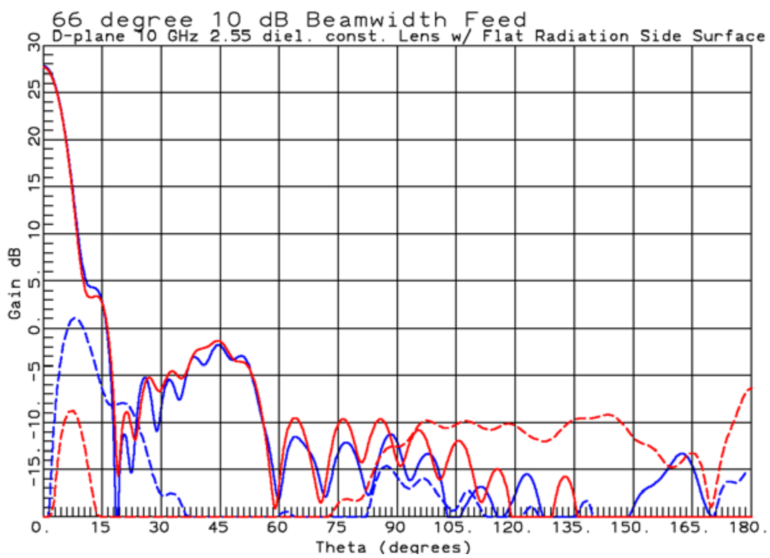
Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves

The E-plane pattern above has a vestigial first sidelobe which has a lower level than the plano-convex lens discussed previously. The defocusing effect of the grooves increases its peak but both cases lack a distinct null that can also be seen in the phase response (not given) which lacks a rapid change through the null. The spillover lobe around 40° is similar for both lenses. The curved surface pointed toward the feed greatly reduces the back lobe compared to the previously discussed lens. The grooves also reduce the back lobe.



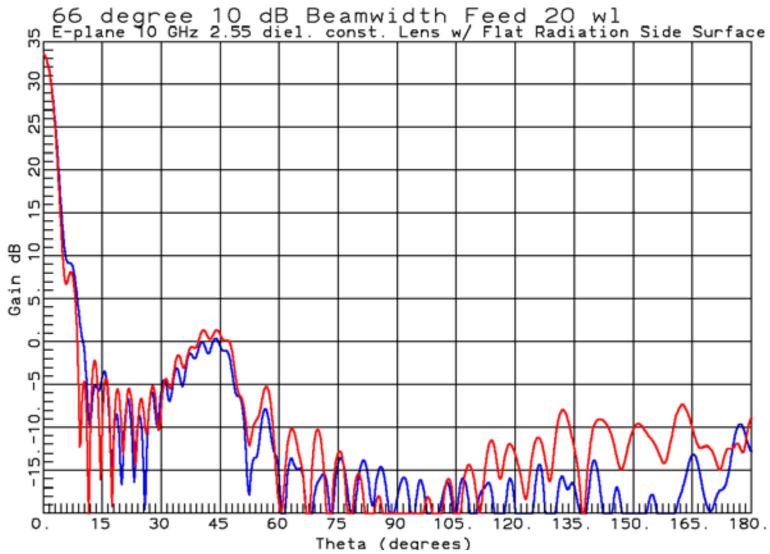
Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves

The H-plane pattern of this single refracting surface lens is similar to the E-plane with its vestigial first sidelobe, spillover lobe, and back lobes. Turning around the flat surface of the lens has decreased gain by about 1.5 dB which we saw in the table of gain for the various lens. Although the simple lens maker's formula would predict the same pattern and gain for the two previous lenses since turning around the lens would have no effect, we see a significant effect for the properly designed short focal length lenses.



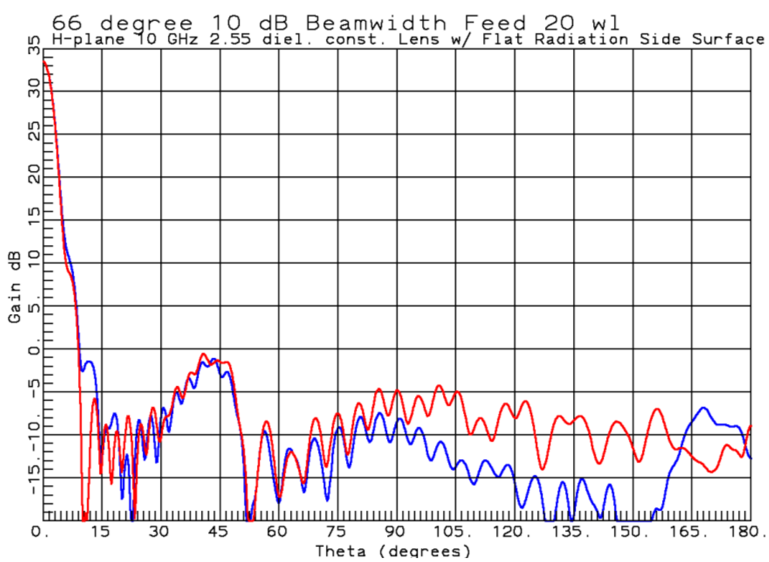
Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed

The grooves increase the near boresight cross polarization lobe by about 10-dB, while the further-out cross polarization is increased in the directions behind the feed.



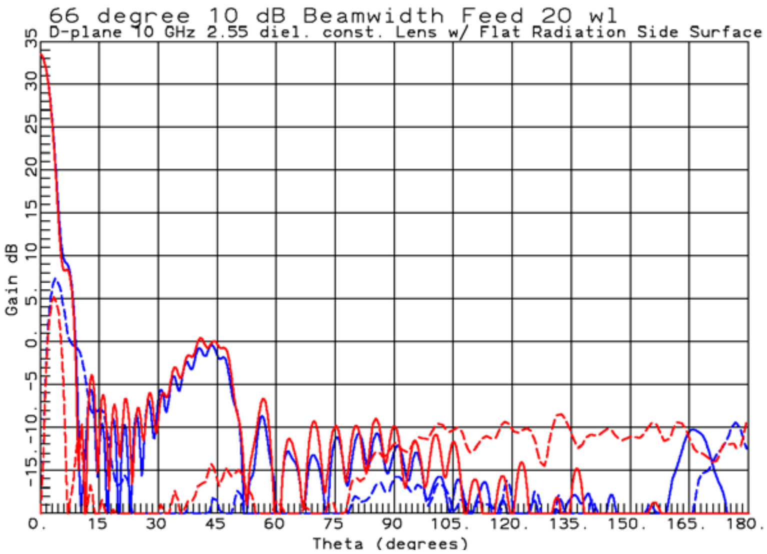
Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves for 20λ diameter lens

Doubling the lens diameter places the nearest surface of the lens about 6λ from the horn aperture. The $2D^2/\lambda$ far-field is about 8λ for the 2λ diameter horn aperture. This greater distance compared to the 10λ diameter lens generates a better first sidelobe which shows in the pattern of the lens without grooves; the phase response also contains a rapid phase change when sweep across angles which indicates a true sidelobe instead of a vestigial one. The defocusing of the grooves reduces this effect as shown in the plot above. Of course, doubling the lens diameter increases gain by 6 dB. Although the return loss of the 20λ diameter lens has the same level as the 10λ, the back lobe in absolute gain of the lens without grooves is lower for 20λ diameter.



Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves for 20λ diameter lens

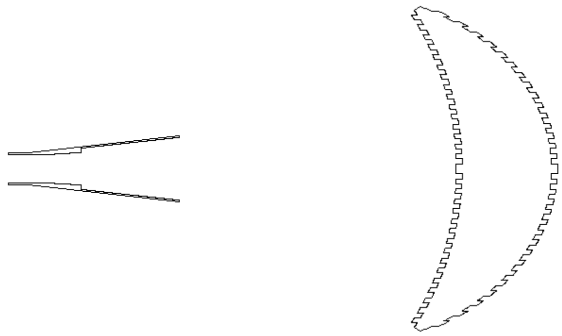
The H-plane pattern still includes a vestigial first sidelobe, but to a lesser extent. Increasing the lens diameter further will decrease this lobe.



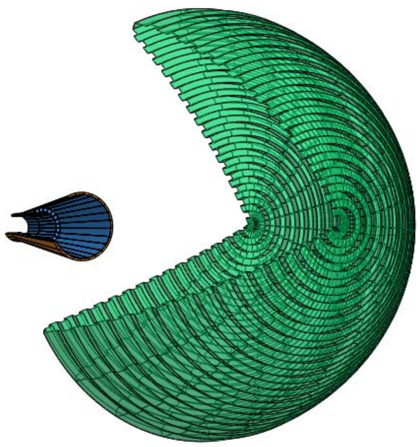
Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed for 20λ dia.

There is less difference in cross polarization between the grooved and smooth surface lens for this larger lens and shows there is less reaction from the lens on the horn. The cross-polarization in the diagonal plane is near the level of the horn alone.

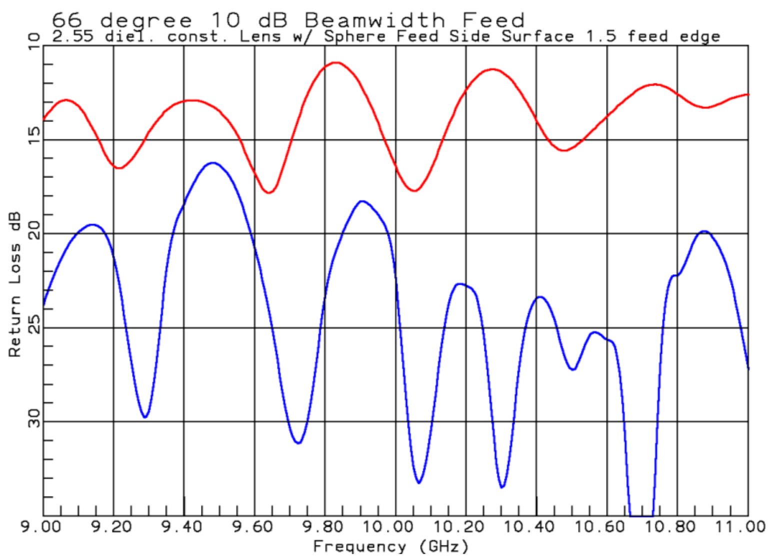
Concave Sphere Feed Side Lens



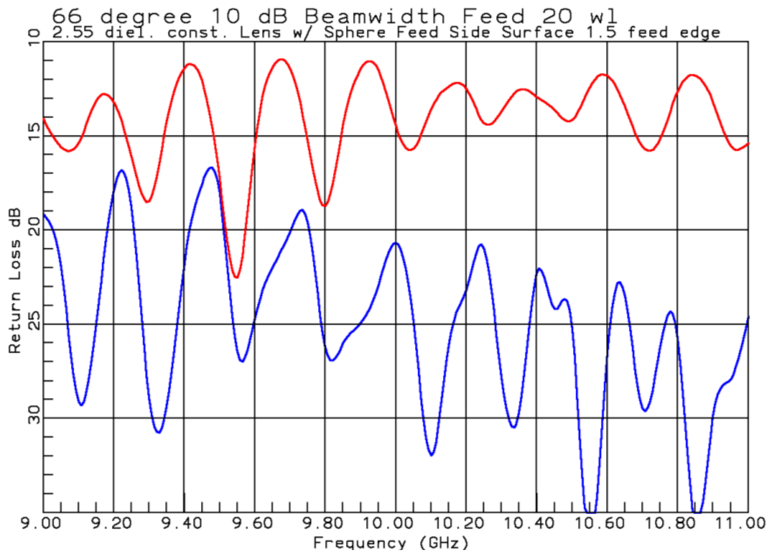
Lens containing surface reflection matching grooves and feed horn



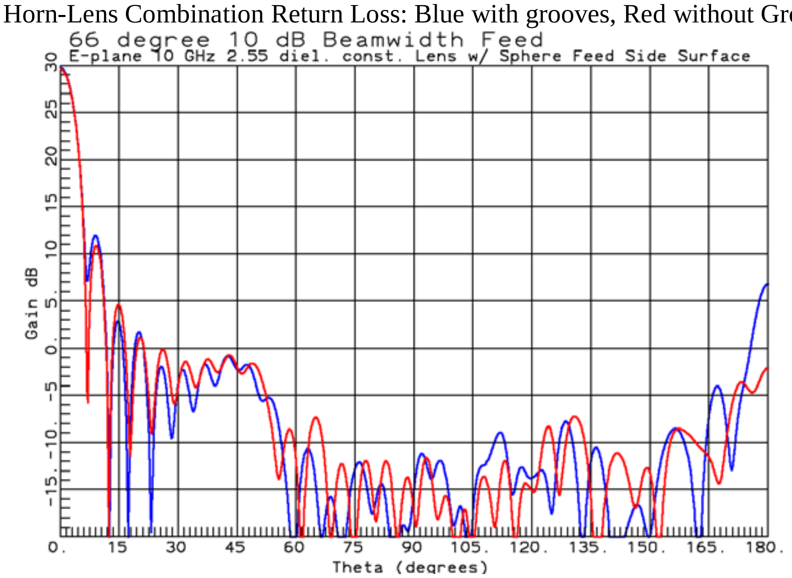
Lens containing surface reflection matching grooves and feed horn



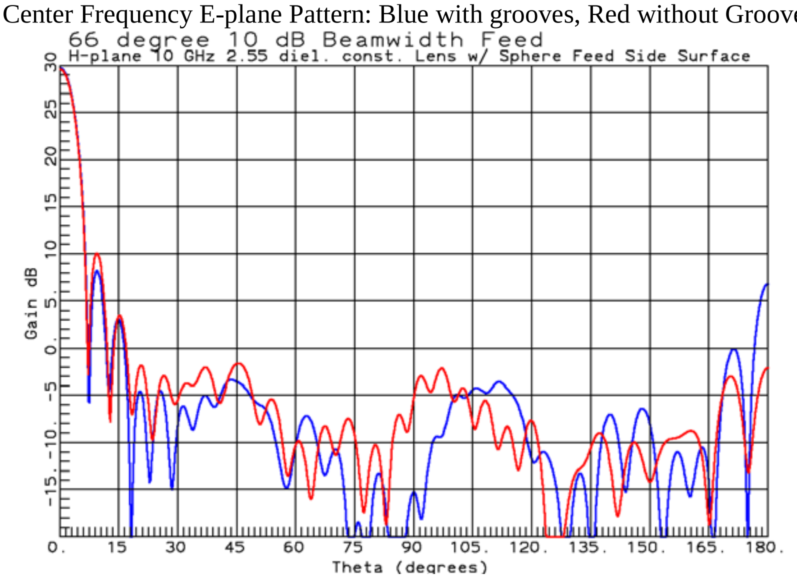
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves for 10λ diameter lens



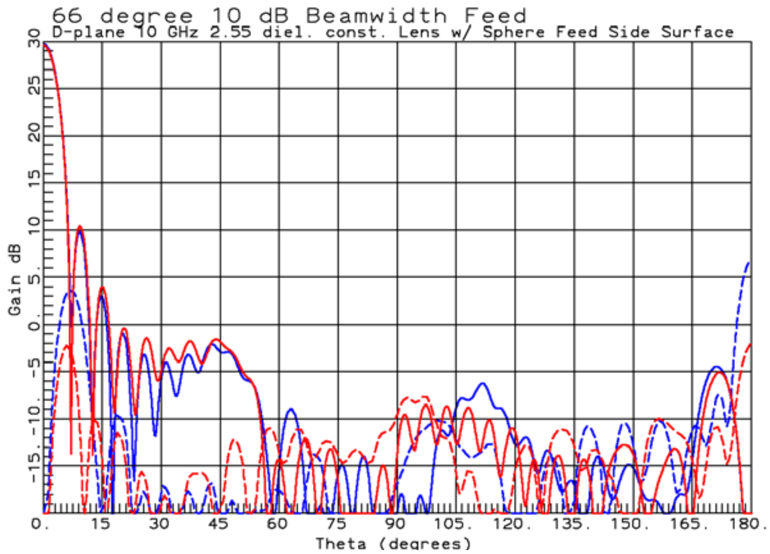
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves for 20λ diameter lens



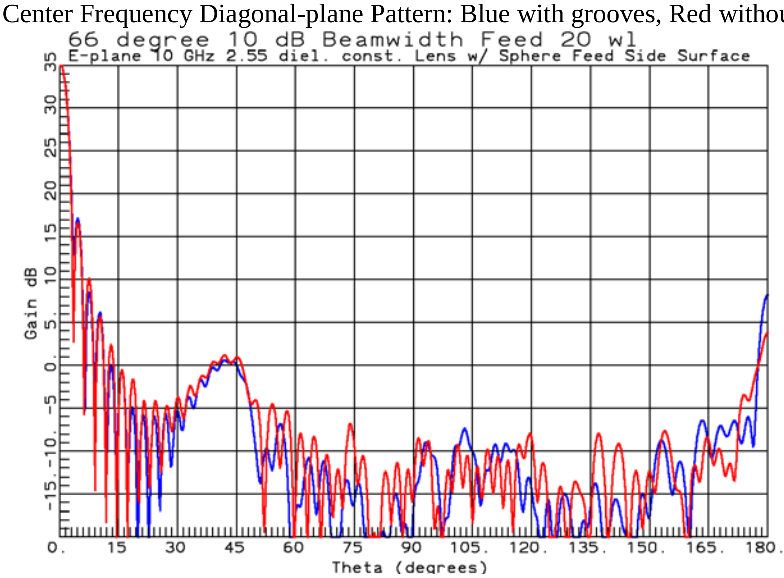
Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves



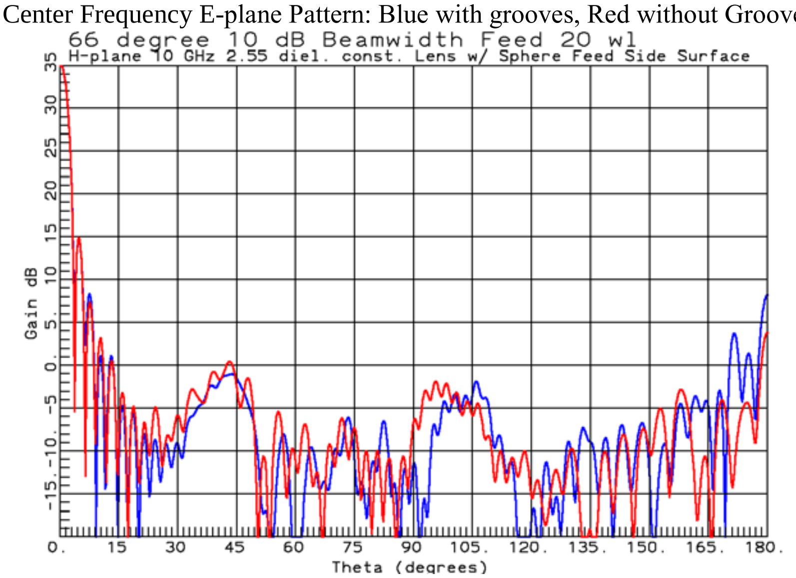
Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves



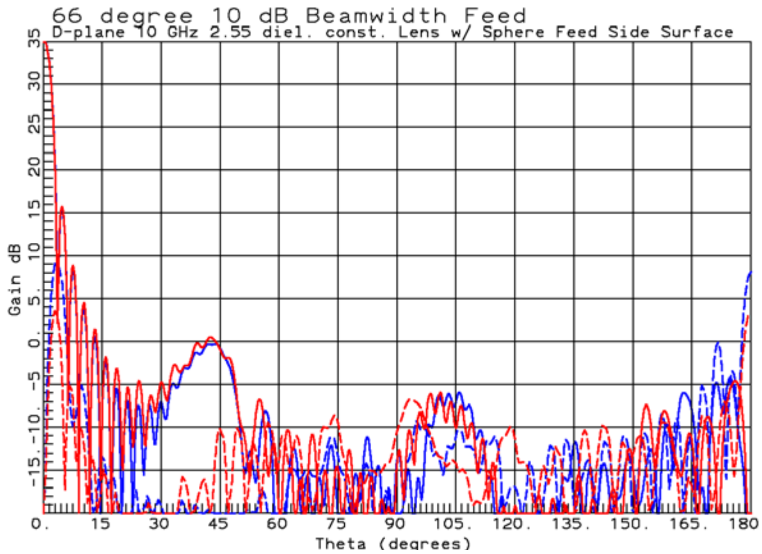
Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed



Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves 20λ diameter



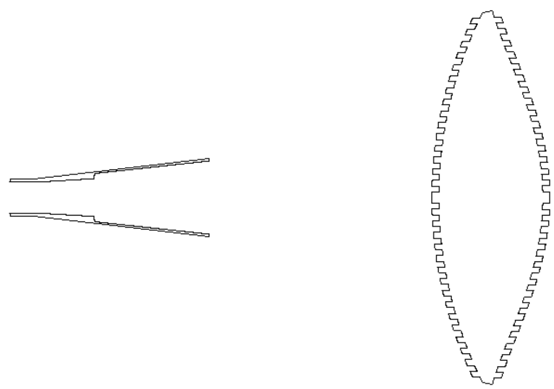
Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves 20λ diameter



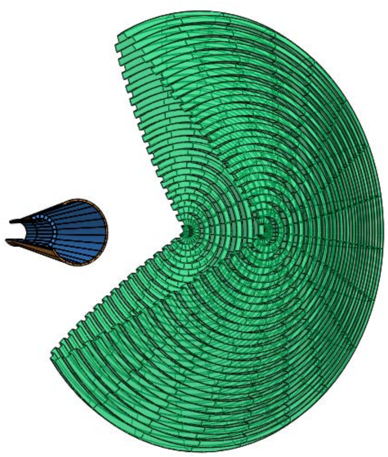
Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed, 20λ dia.

Convex Sphere Feed Side Lens

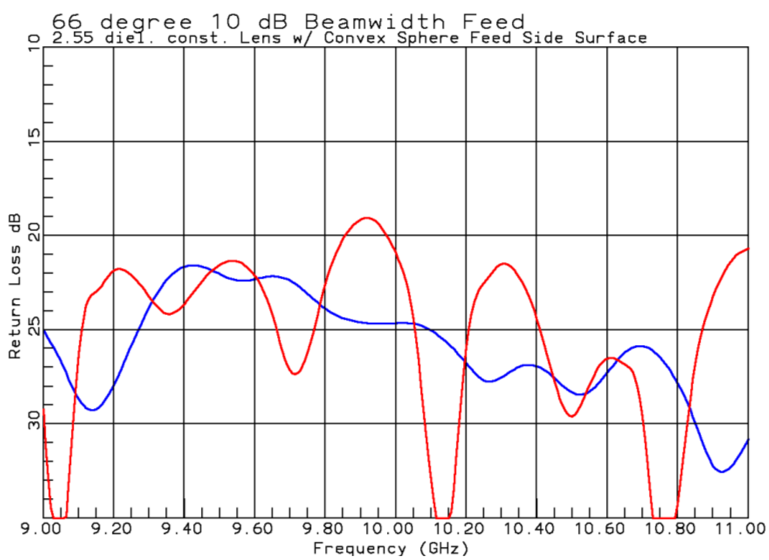
Lens containing surface reflection matching grooves and feed horn



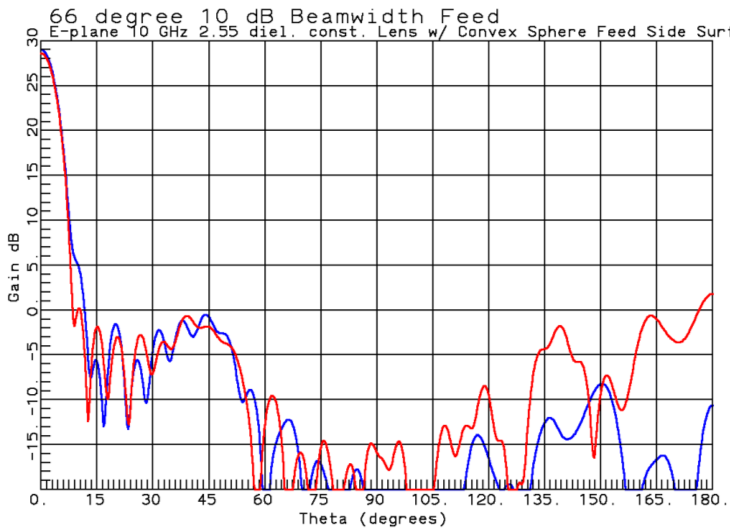
Lens containing surface reflection matching grooves and feed horn



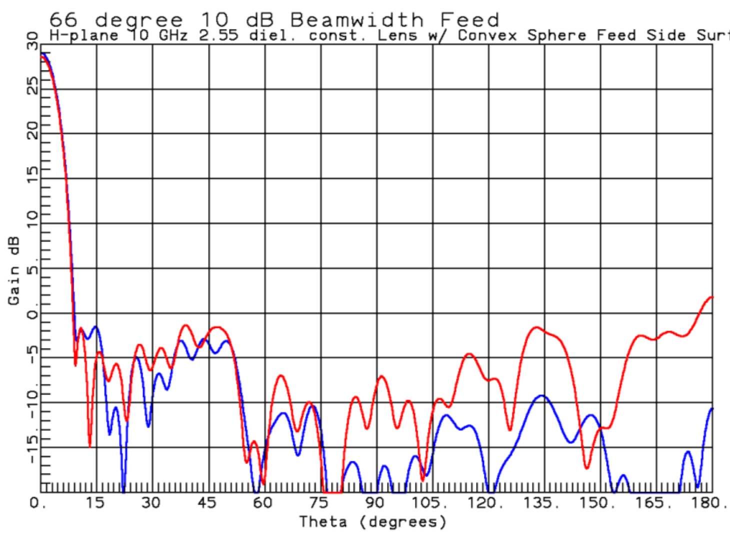
Lens containing surface reflection matching grooves and feed horn



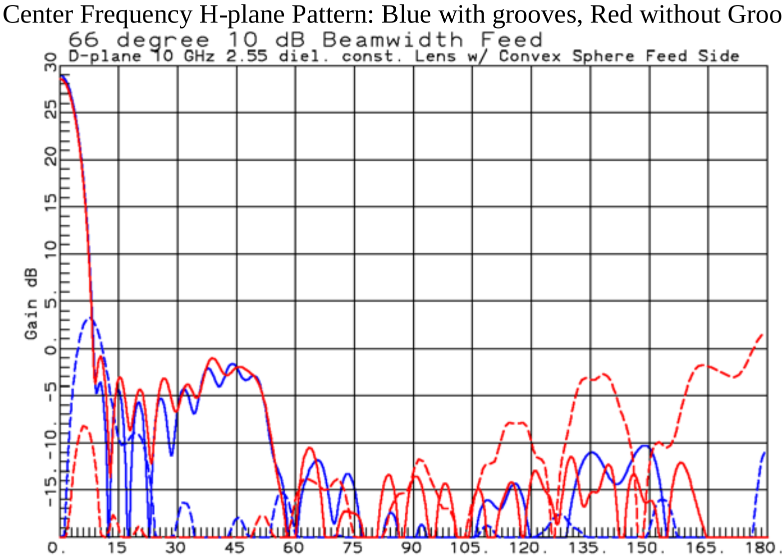
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves for 10λ diameter lens



Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves

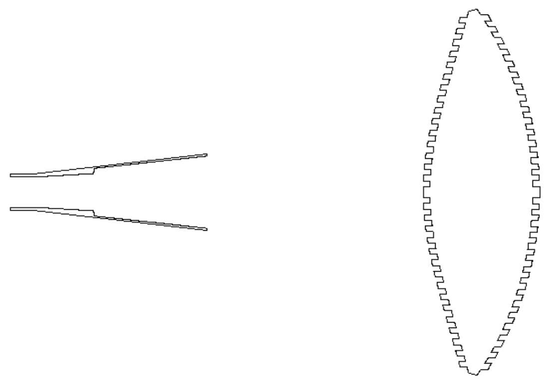


Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves

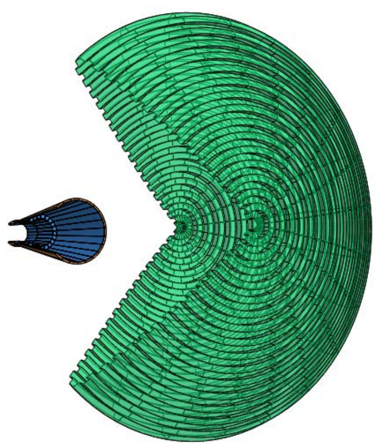


Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed

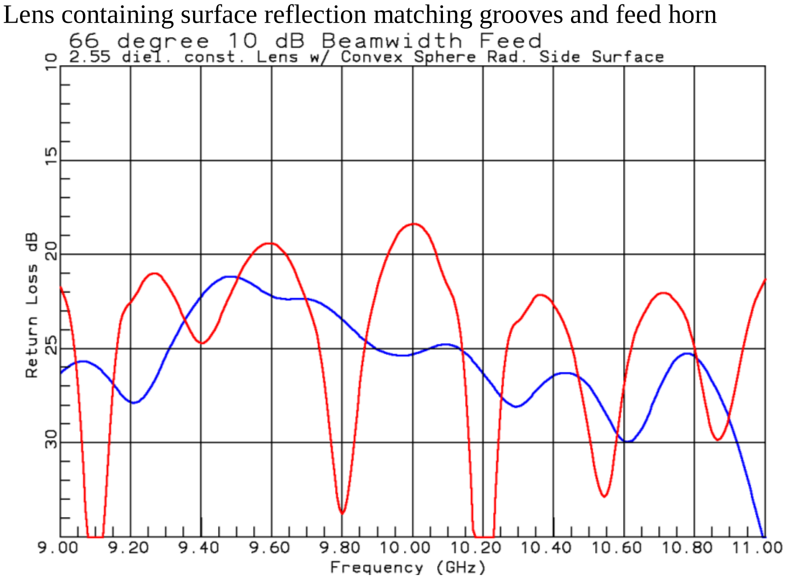
Convex Sphere Radiation Side Lens



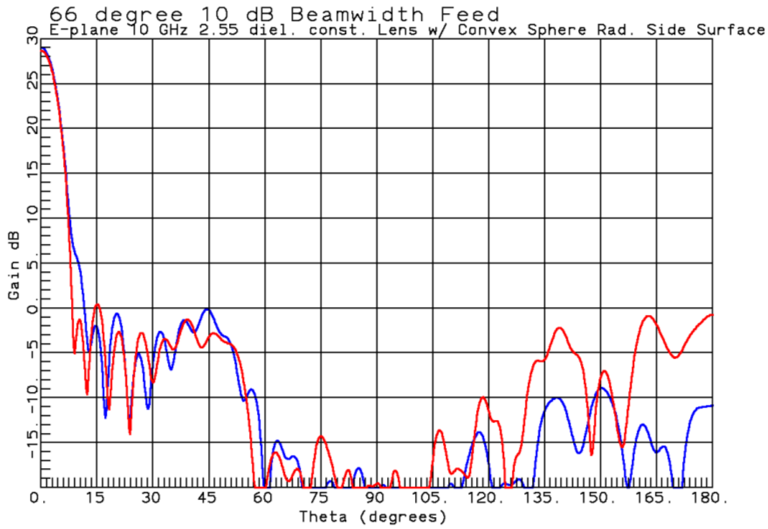
Lens containing surface reflection matching grooves and feed horn



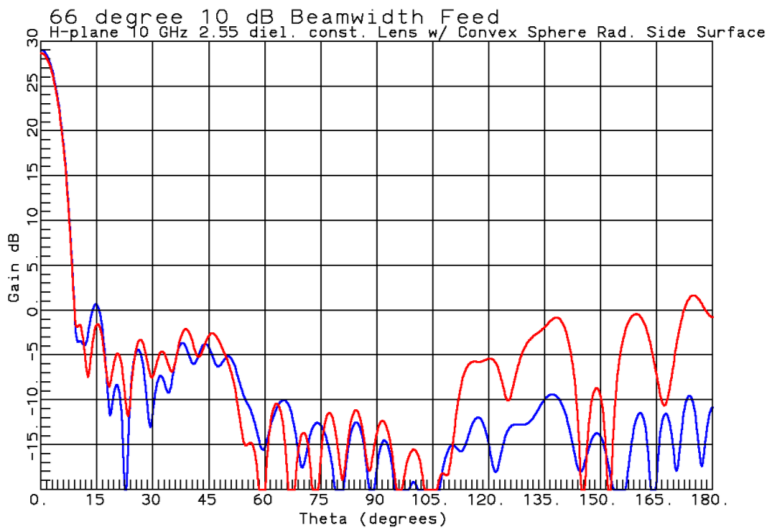
Lens containing surface reflection matching grooves and feed horn



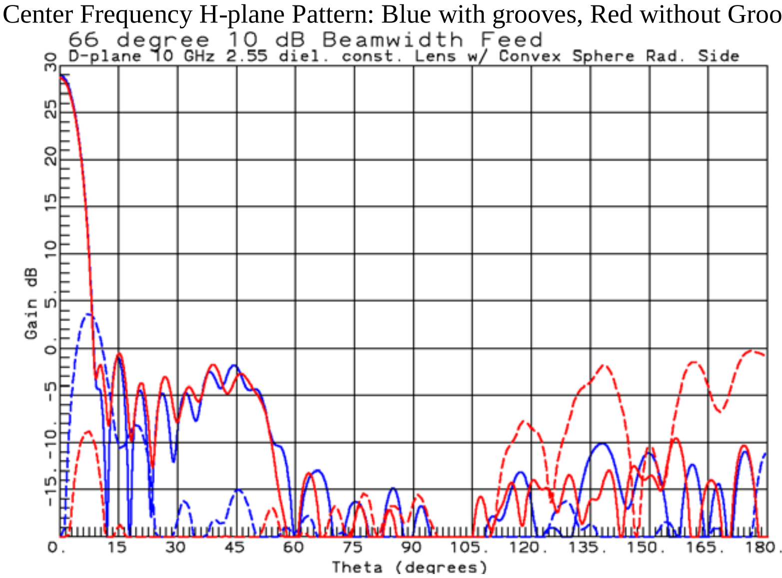
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves for 10λ diameter lens



Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves

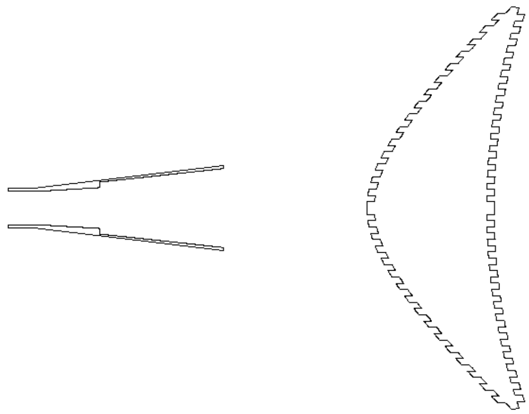


Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves

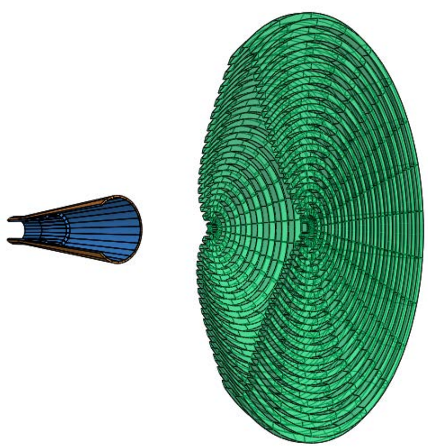


Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed

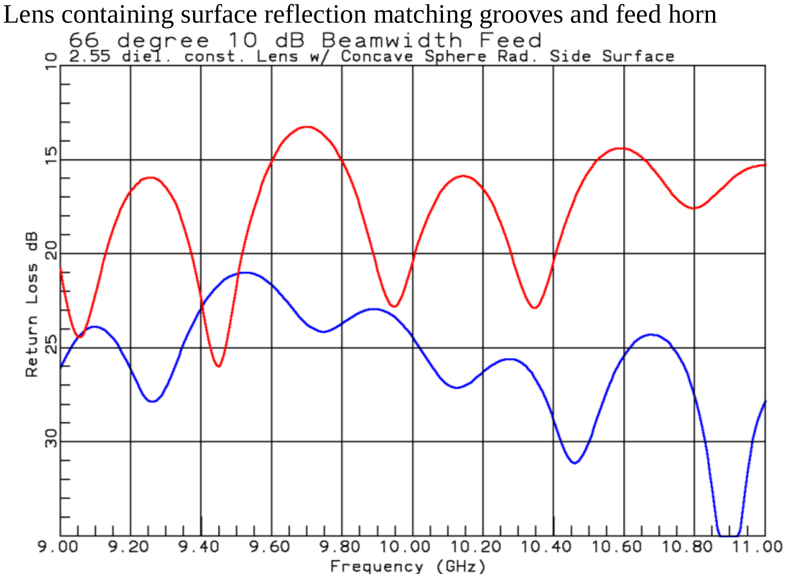
Concave Sphere Radiation Side Lens



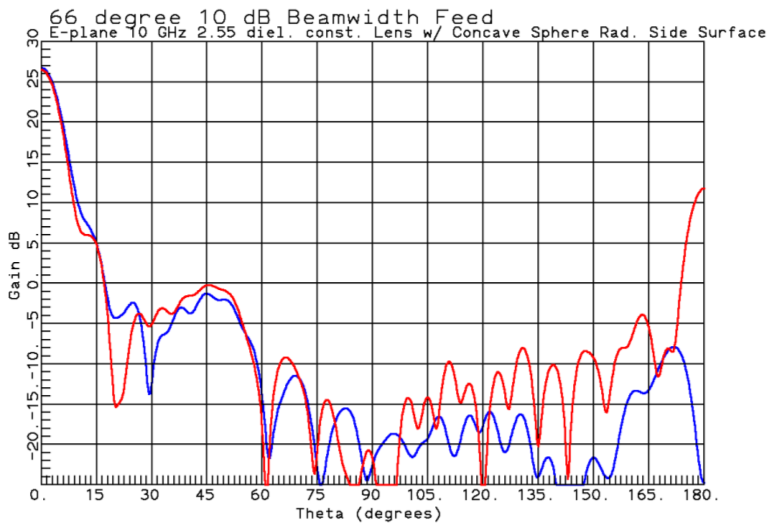
Lens containing surface reflection matching grooves and feed horn



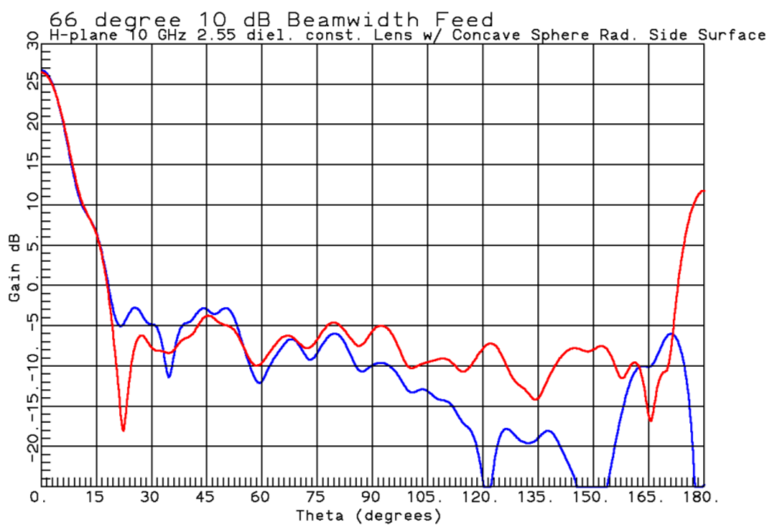
Lens containing surface reflection matching grooves and feed horn



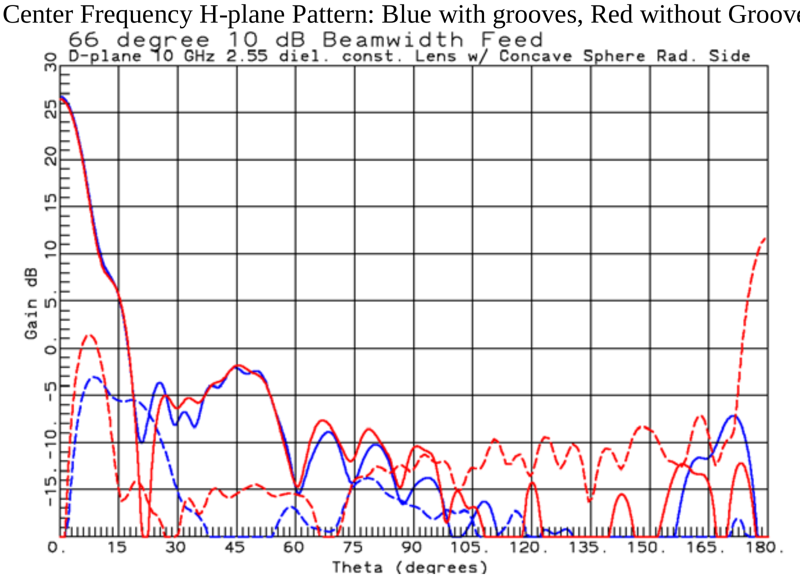
Horn-Lens Combination Return Loss: Blue with grooves, Red without Grooves for 10λ diameter lens



Center Frequency E-plane Pattern: Blue with grooves, Red without Grooves



Center Frequency H-plane Pattern: Blue with grooves, Red without Grooves



Center Frequency Diagonal-plane Pattern: Blue with grooves, Red without Grooves, Cross-Pol. Dashed