9-2.2 CHAMP BOR-MoM Analysis of Dielectric Zoned Plate Lenses[1]

Section 9-2.1 discusses various methods of zoning a dielectric lens to reduce thickness and weight. This section considers a variation where the curved sections of the zone lens are replaced by steps. The steps approximately eliminate quadratic phase from a wave spreading from a feed as illustrated in Figure 9-2.2.1 of a plate with λ/6 steps.

Figure 9-2.2.1 Dielectric Zoned Plate Lens with P = 6 (λ/P or λ/6) steps fed by Potter Horn

The figure approximates the continuous surface of the flat radiation side zoned lens of Figure 9-2.2.2. The steps sizes are related to the index of refraction, $n = \sqrt{\varepsilon_R}$. Given the number of step per wavelength, *p*, the step thicknesses are, $t = \lambda / ((n-1)p)$ and the maximum thickness due to steps is $\Delta t_{\max} = t(p-1) = (p-1)\lambda / ((n-1)p)$. The lens thickness is $\Delta t_{\max} + t_{\min}$.

To eliminate the quadratic phase approximately with the zone steps occur at radiuses given by

$$r_k = \sqrt{\frac{2kf\lambda}{p} + \left(\frac{k\lambda}{p}\right)^2} \qquad (1)$$

for a focal length f the distance from feed to center of plate.

[1] Paul F. Goldsmith, *Quasioptical Systems*, IEEE Press, Piscataway, NJ, 1998, pp. 98f.

The approximate number of zones can be found from the lens diameter, *D*

$$k_{\max} = \frac{pD^2}{8f\lambda}$$

However, a narrow search for k_{max} can be found through using Eq. (1) and diameter, since an integer number of steps will not produce a lens with the exact diameter. As the lens diameter grows larger focal lengths will be needed to prevent narrow radial steps which could act as waveguides: $\Delta r_{\min} = 2\lambda f / (Dp)$.

Figure 9-2.2.1 shows the feed side zoned lens for flat radiation side lens which the zone plate lens design is based. Table shows the cross section of the zoned lens with curved sections and the various step approximations of the zone plate lens. A variation on the zone plate lens for $p = 2$ is the optical zone mask which uses opaque rings instead of the grooves. The optical zone mask can be etched on any thin dielectric sheet with good transmission properties. Although the steps are shown on the feed side, they can be placed on the radiation side or a combination of both sides to reduce scatter and the reaction on the feed horn.

CHAMP (TICRA) is used to analyze the zone plate lens by adding the lens to a feed horn analysis. CHAMP uses a BOR-MoM analysis on the combination of the horn exterior and the external dielectric object (lens) to generate the pattern (gain) and horn reflection coefficient. The program *zoplens* designs the lens and generates a file of the lens geometry added to the geometry.tor file.

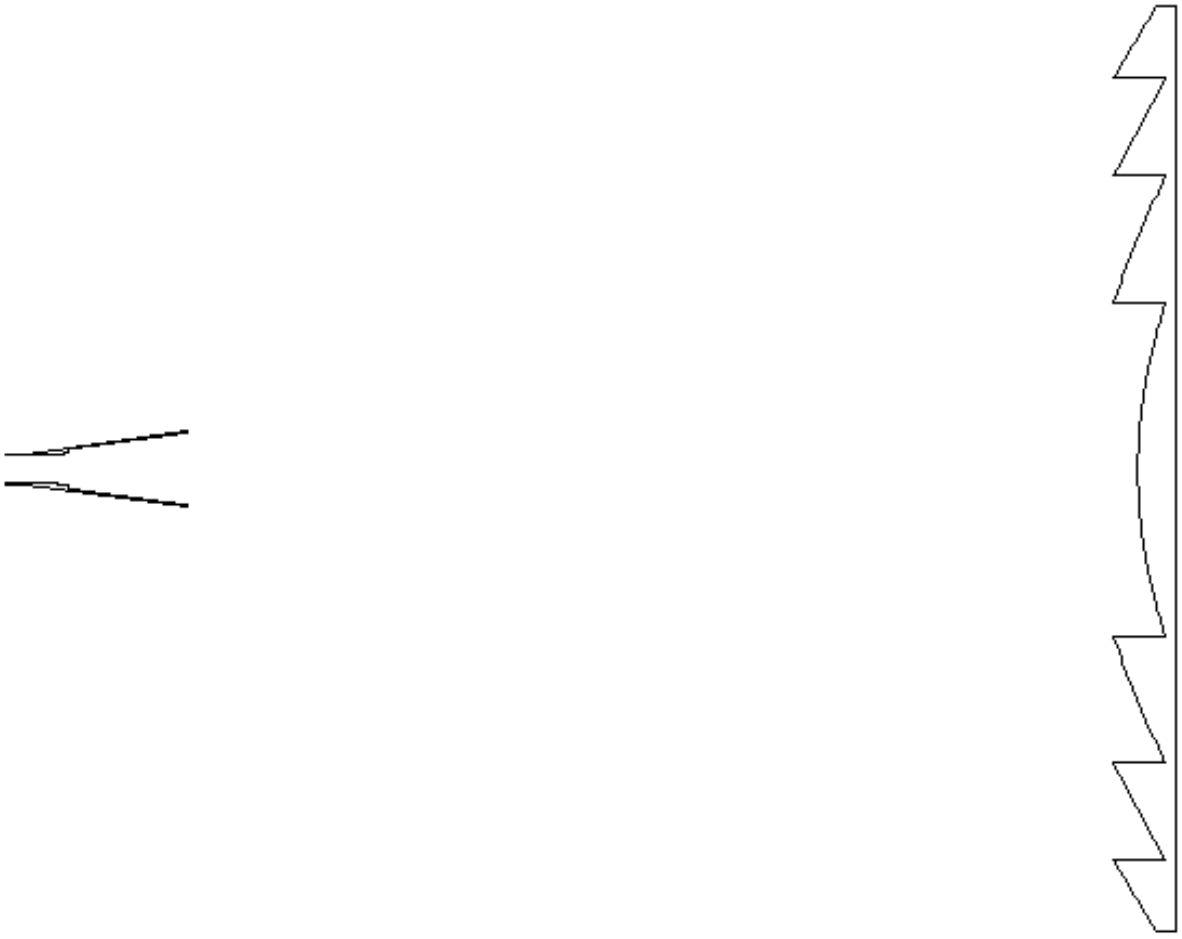


Figure 9-2.2.2 Flat Radiation Side Dielectric Zoned Lens with continuous surfaces fed by Potter Horn

Table 9-2.2.1 Dielectric Zoned Plate Lens

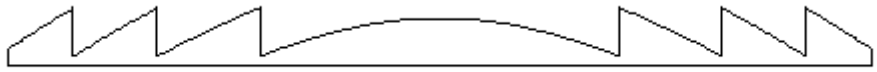
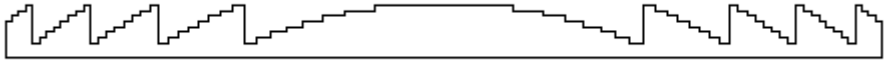
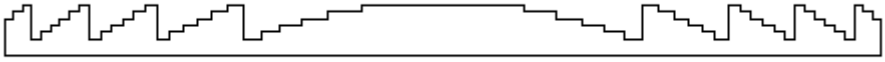
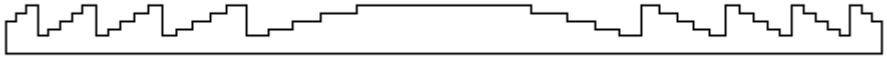
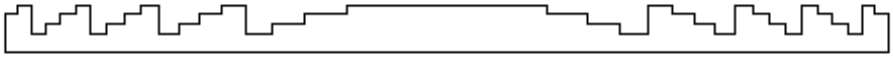
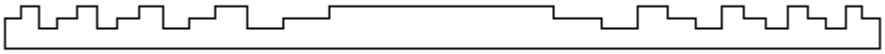
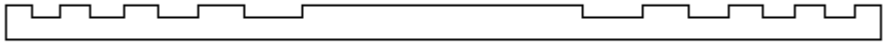
Steps, P	Lens
Continuous	
8	
6	
5	
4	
3	
2	

Table 9-2.2.2 summarizes CHAMP analyses of 30λ diameter lenses fed by Potter horns with 4 different gains to produce a pattern with 10 dB taper in the direction of the lens edge. The principal and diagonal plane patterns are given below.

Table 9-2.2.2 Aperture Efficiencies of Dielectric Zone Plate Lenses for 30λ diameter, $\varepsilon_R = 2.55$

Feed Gain	***f/D***	**Continuous**	**8**	**6**	**5**	**4**	**3**	**2**	**Zone Mask**
14.5	0.767	-3.22 dB	-3.33	-3.30	-3.70	-3.83	-5.76	-8.58	-9.69
16.0	0.937	-2.55	-2.58	-2.61	-2.73	-2.92	-4.84	-8.20	-9.80
18.0	1.25	-1.83	-2.06	-2.39	-2.54	-2.60	-4.52	-8.32	-9.96
20.0	1.653	-2.11	-2.78	-3.03	-3.10	-3.06	-5.76	-8.61	-9.02

Adding ZOLENS output to geometry.tor file of CHAMP feed horn

The program ZOLENS was written to compute dielectric zone plate lens design. 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.

```
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)) Added scatterer
)
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
)
 Added from ZOLENS output
ZLOFF  real_variable
(
  value           :  -3.2000E+00
)

horn_bor_mesh_lens   bor_mesh
(
  regions         : table
    (
       1    2.55000E+00    1.00000E+00    0.00000E+00
     ),
  nodes           : table
    (
       1  "ref(ZLOFF)+  6.9000E+02"     0.0000E+00
       2  "ref(ZLOFF)+  6.9000E+02"     1.0198E+02
             .
             .
             .
      39  "ref(ZLOFF)+  7.3767E+02"     0.0000E+00
  ),
  linear_segments  : table
    (
         1    1    2  0   1   -1.0   0.0
         2    2    3  0   1   -1.0   0.0
             .
             .
             .
        38   38   39  0   1   -1.0   0.0
    ),
  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 11:29:17 on 11.12.2013 by CHAMP ver. 3.0.0 SN=003001
```

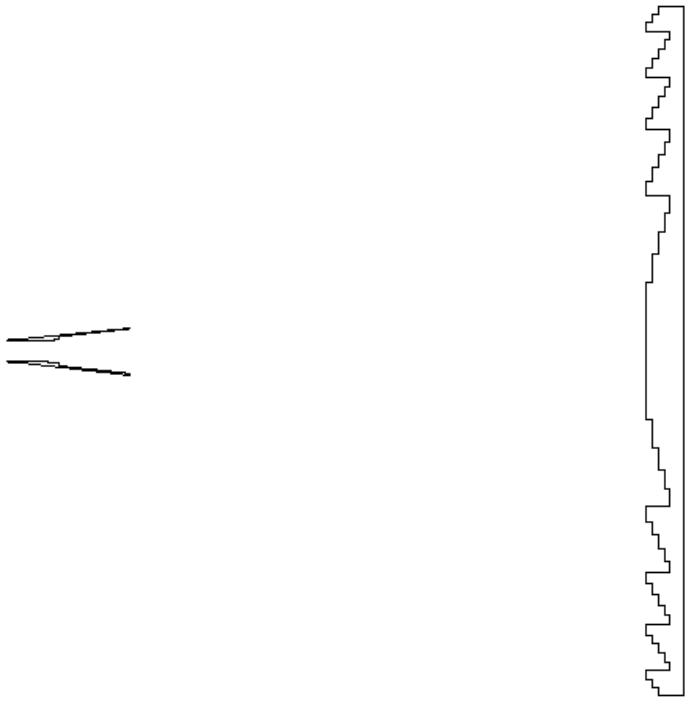
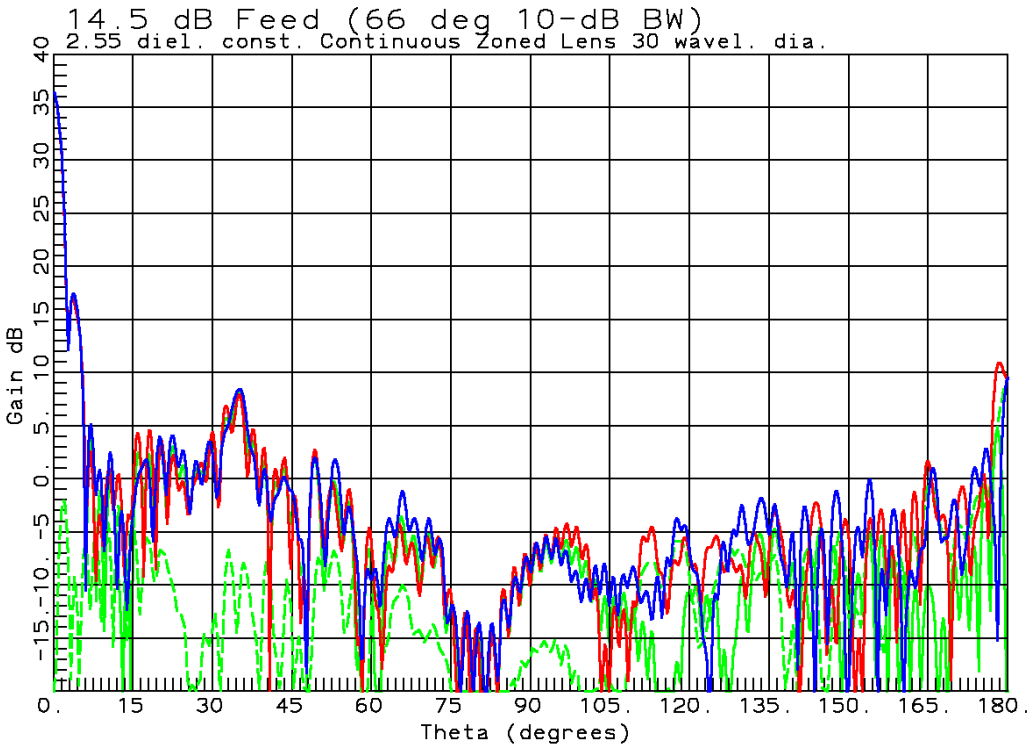
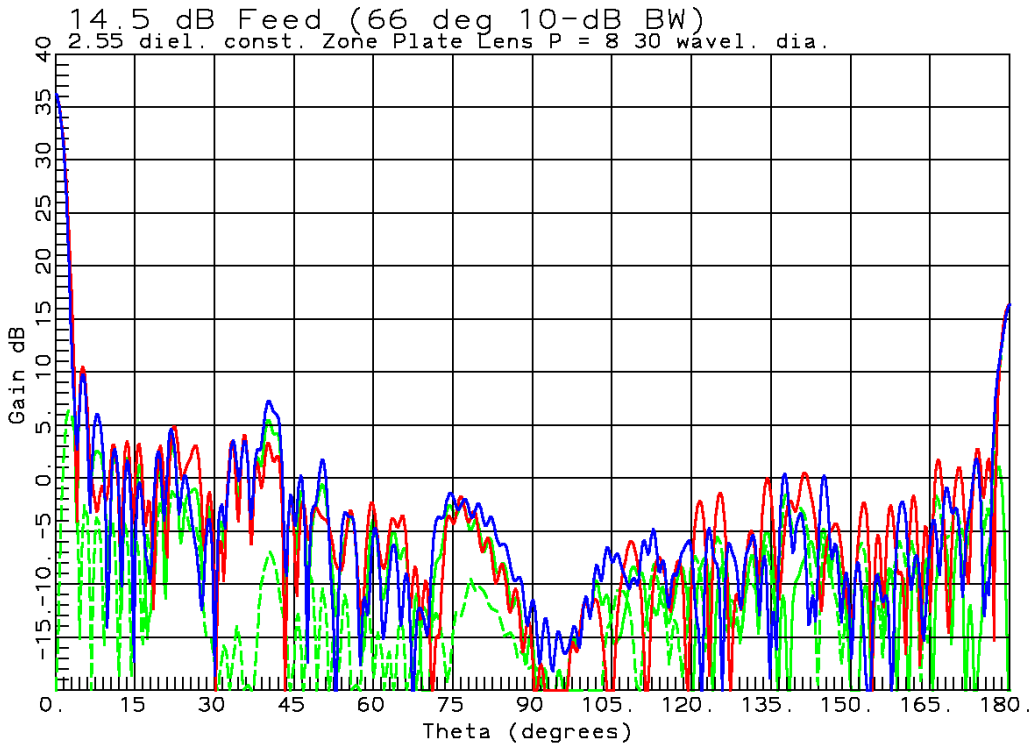


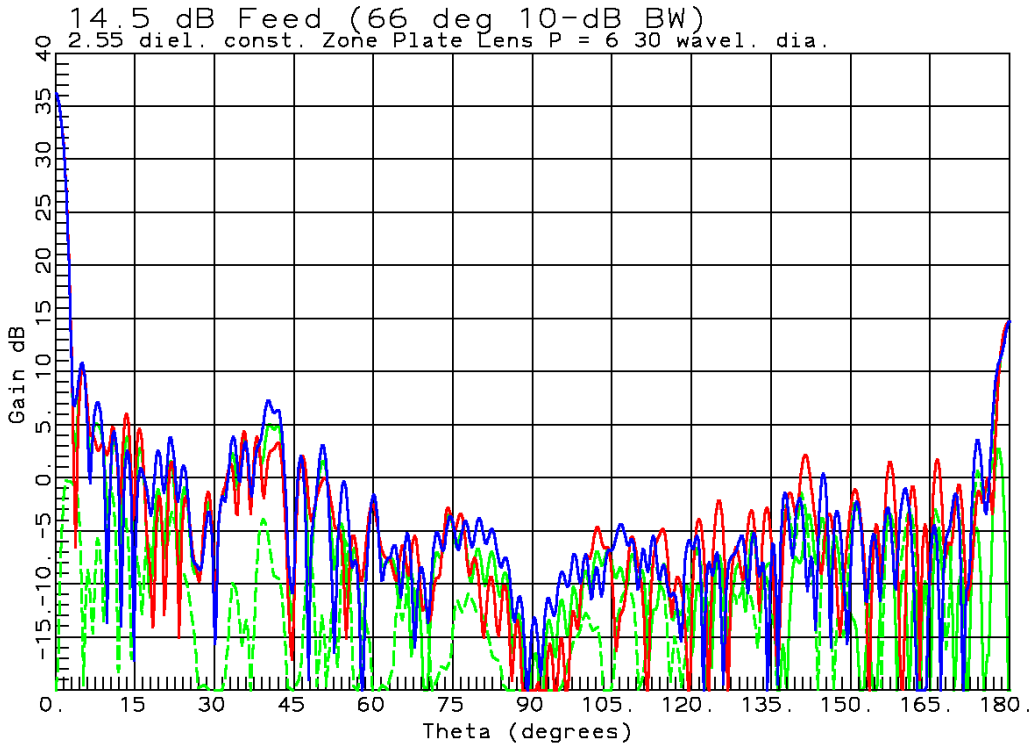
Figure 9-2.2.3 *f/D* = 0.767 Dielectric Zoned Plate Lens with P = 5 (λ/P or λ/5) steps fed by 14.5 dB Potter Horn



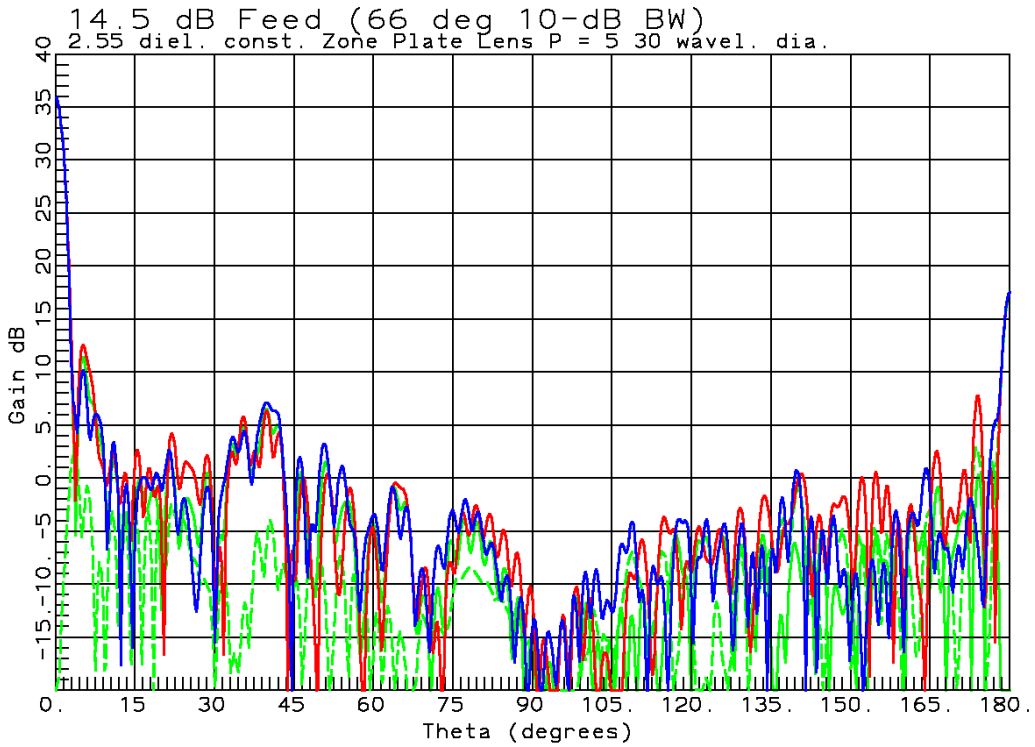
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



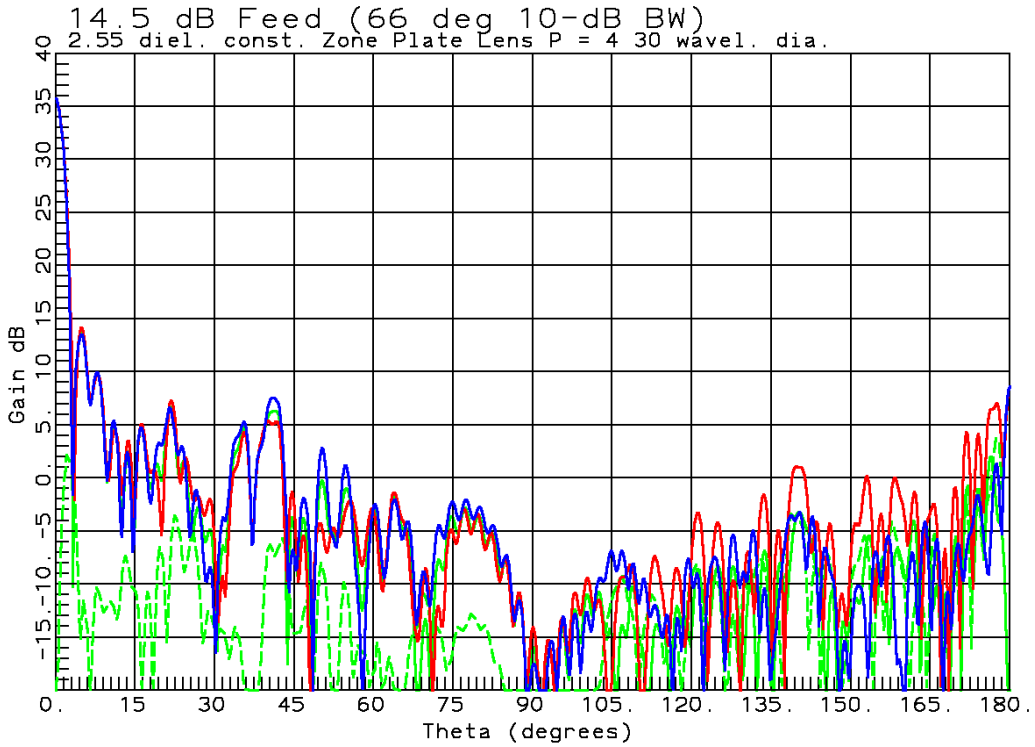
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



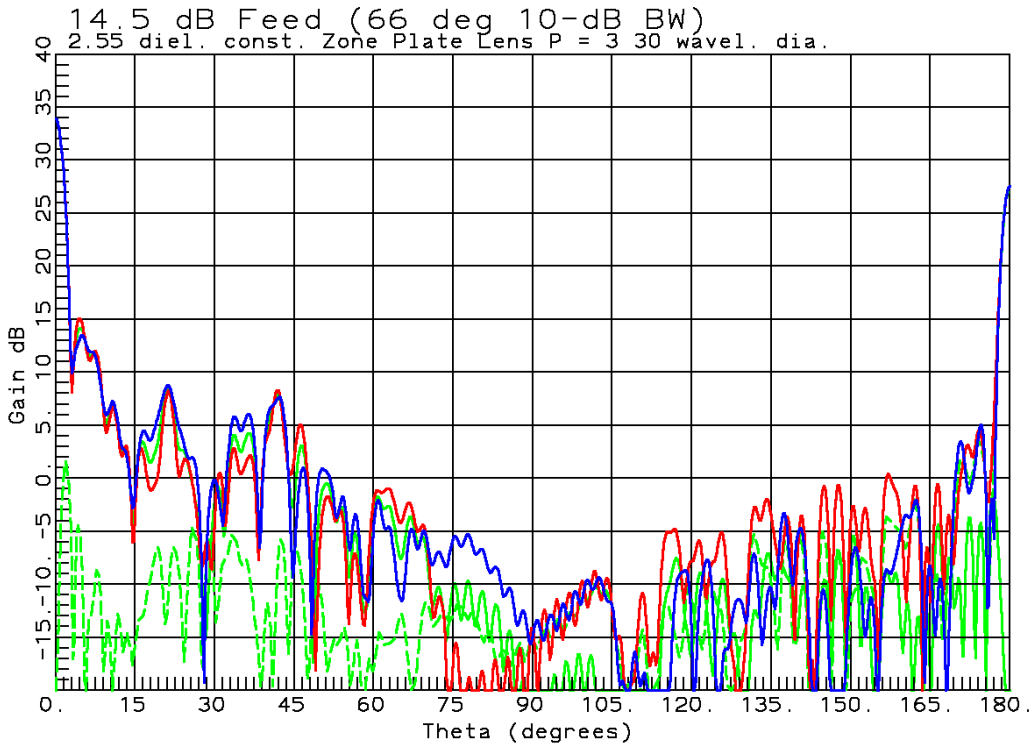
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



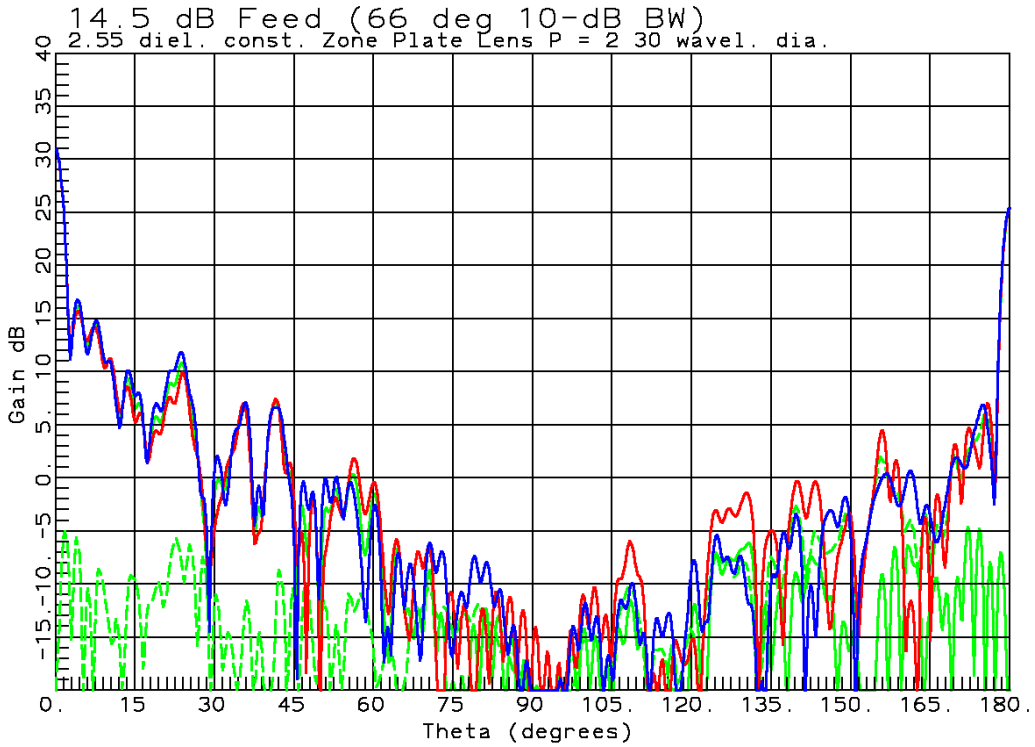
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

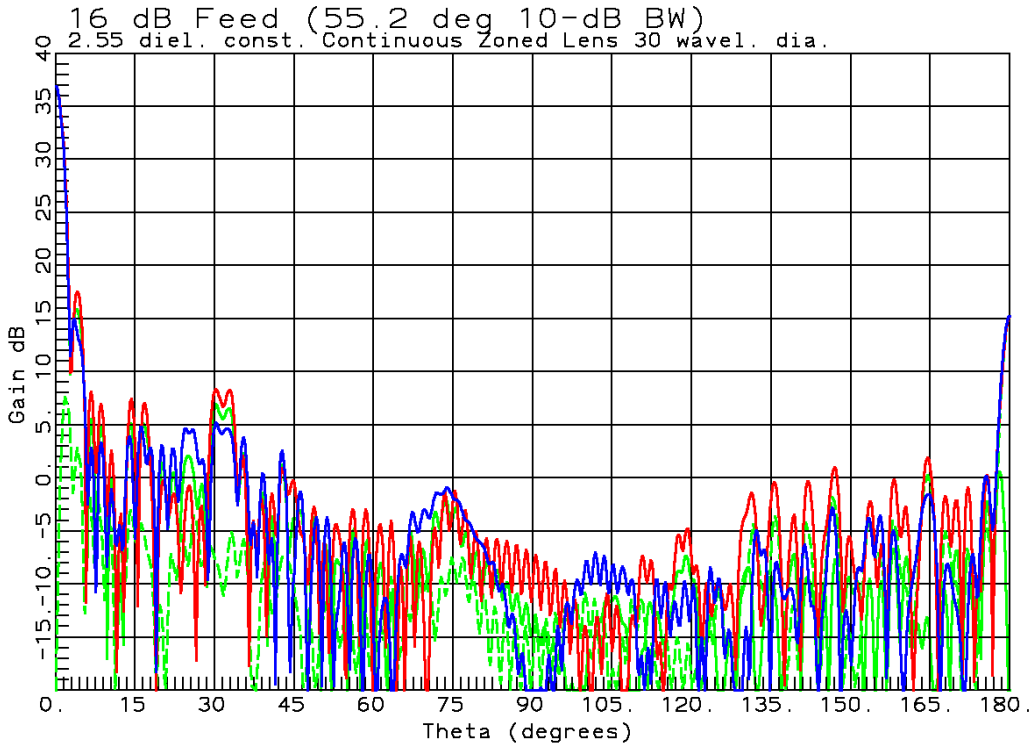


30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

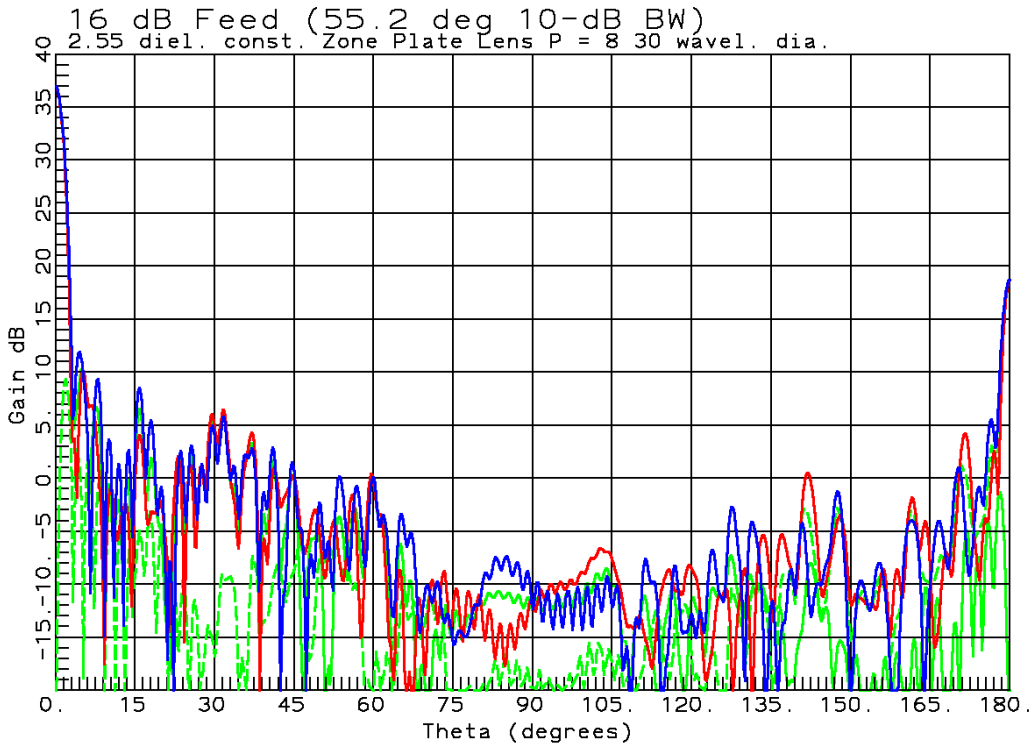


30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

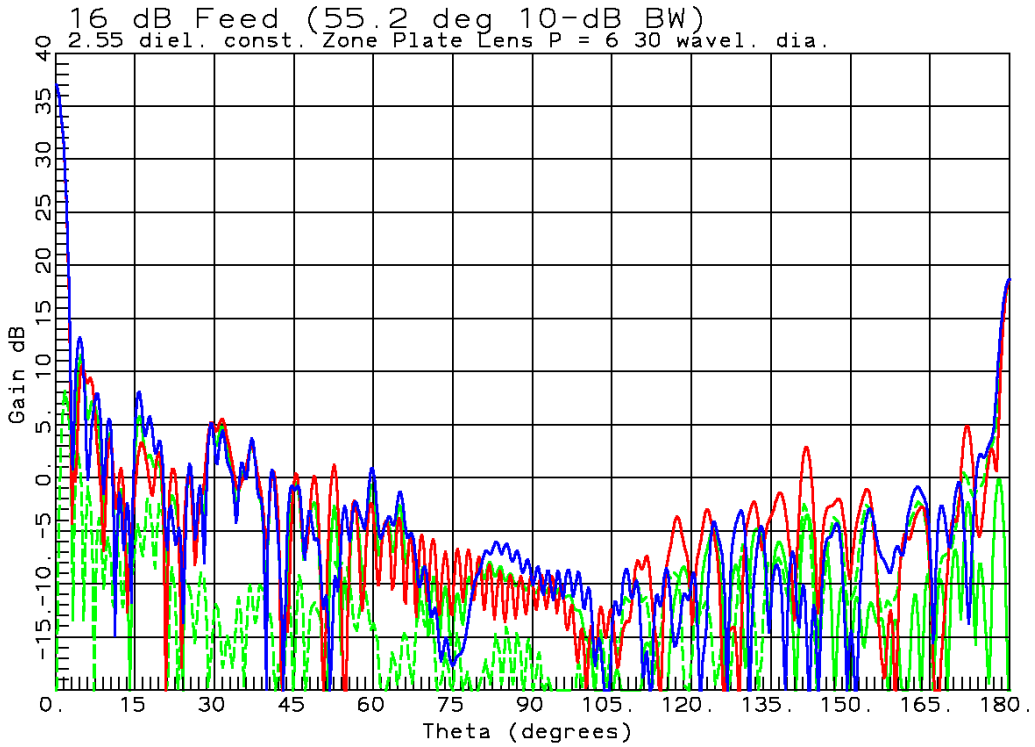
Figure 9-2.2.4 *f/D* = 0.937 Dielectric Zoned Plate Lens with P = 5 (λ/P or λ/5) steps fed by 16 dB Potter Horn



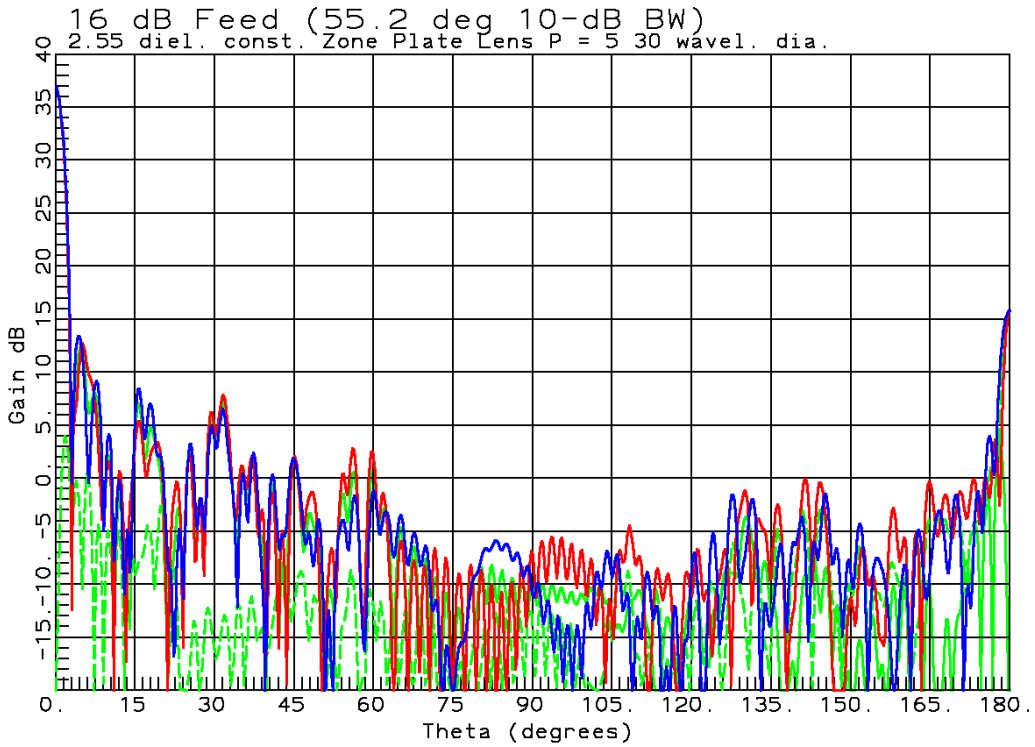
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



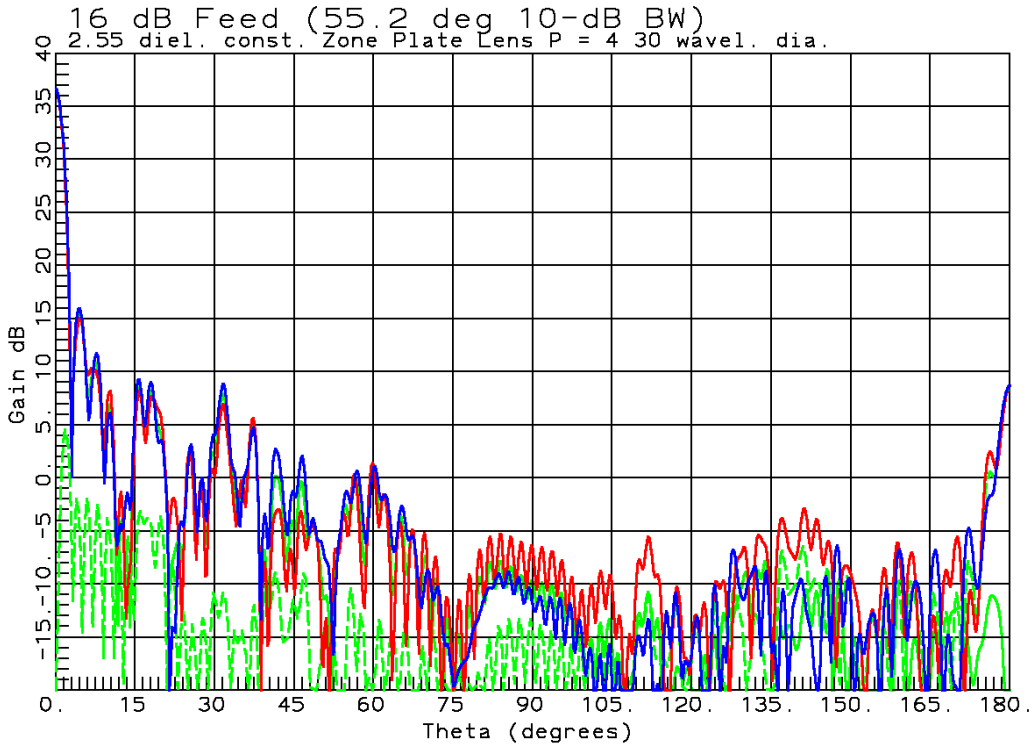
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



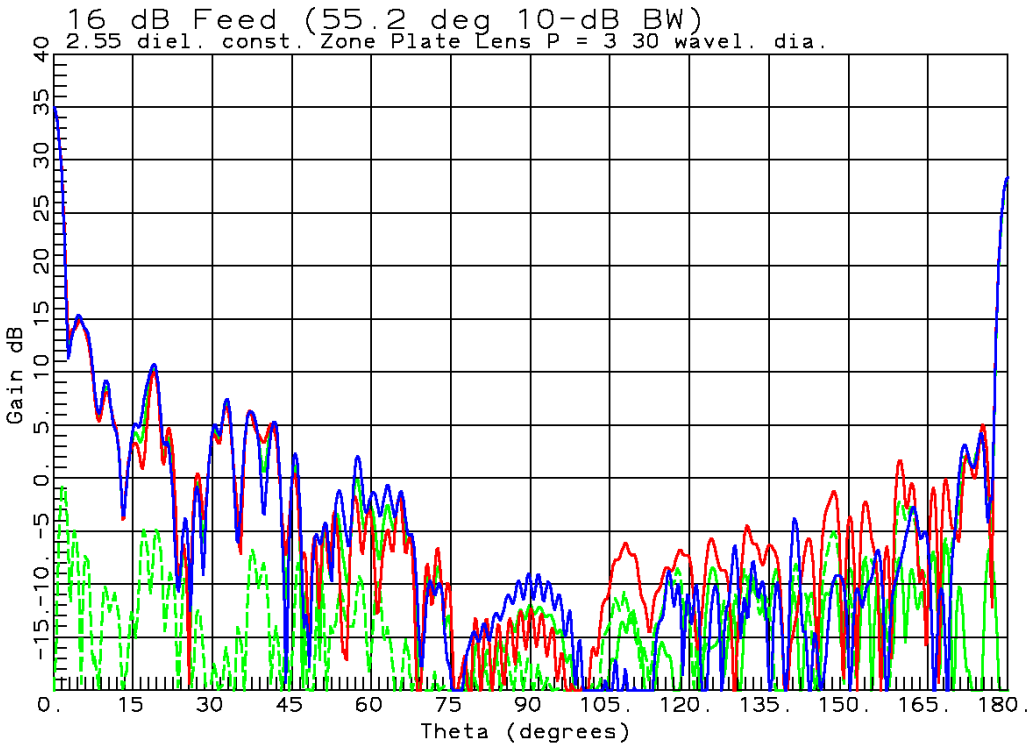
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



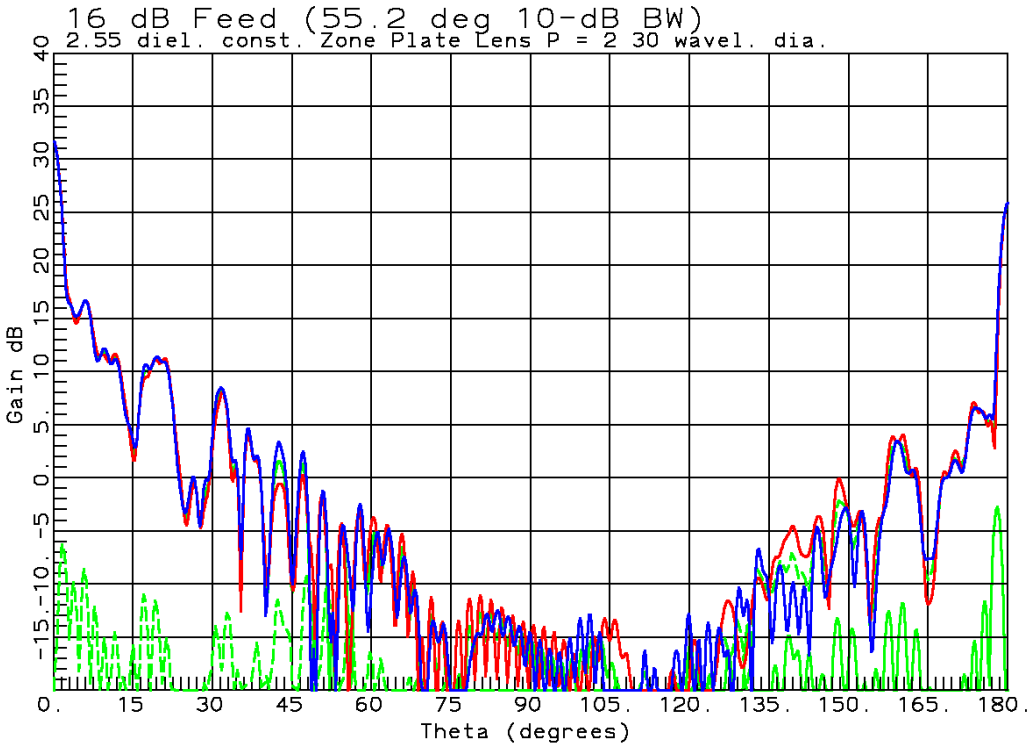
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

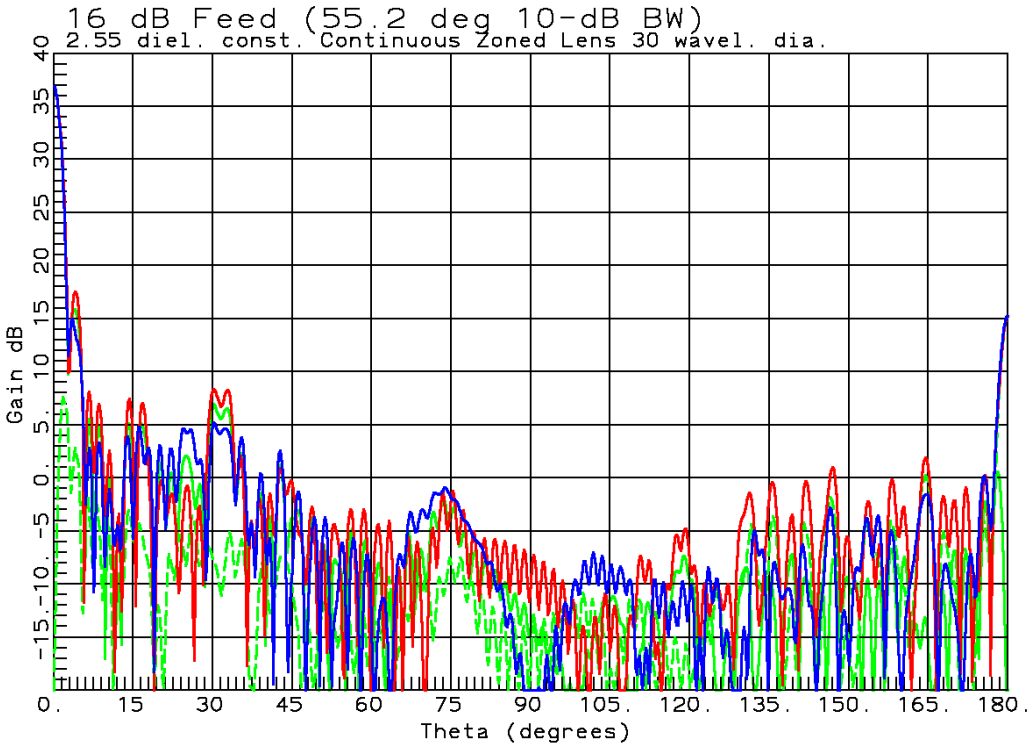


30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

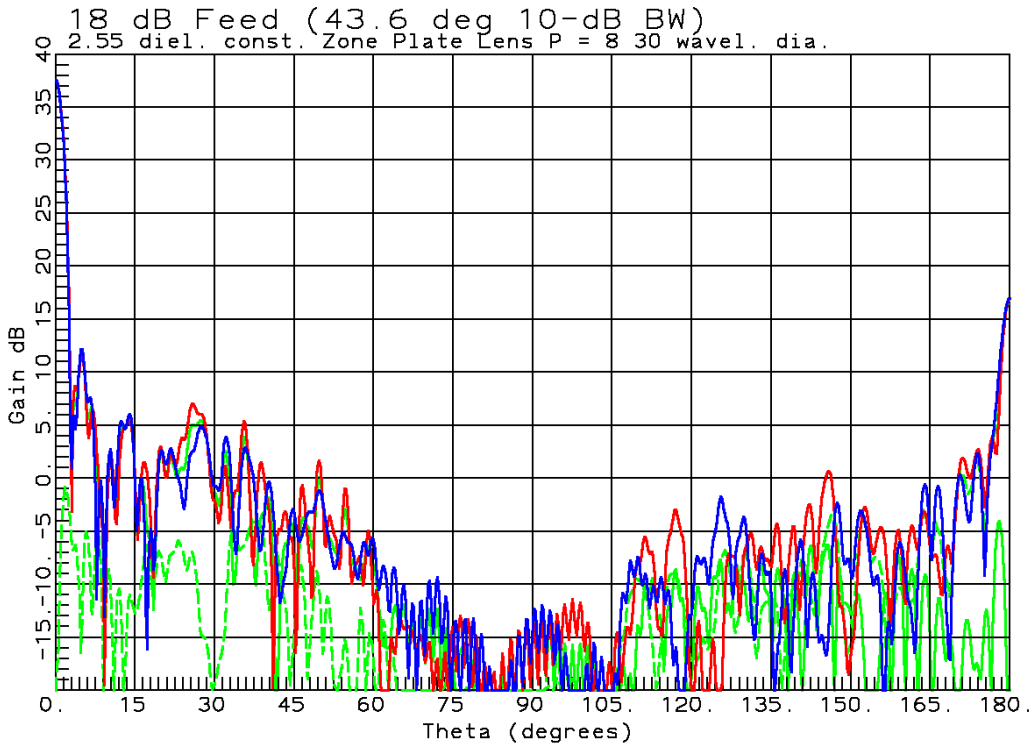


30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

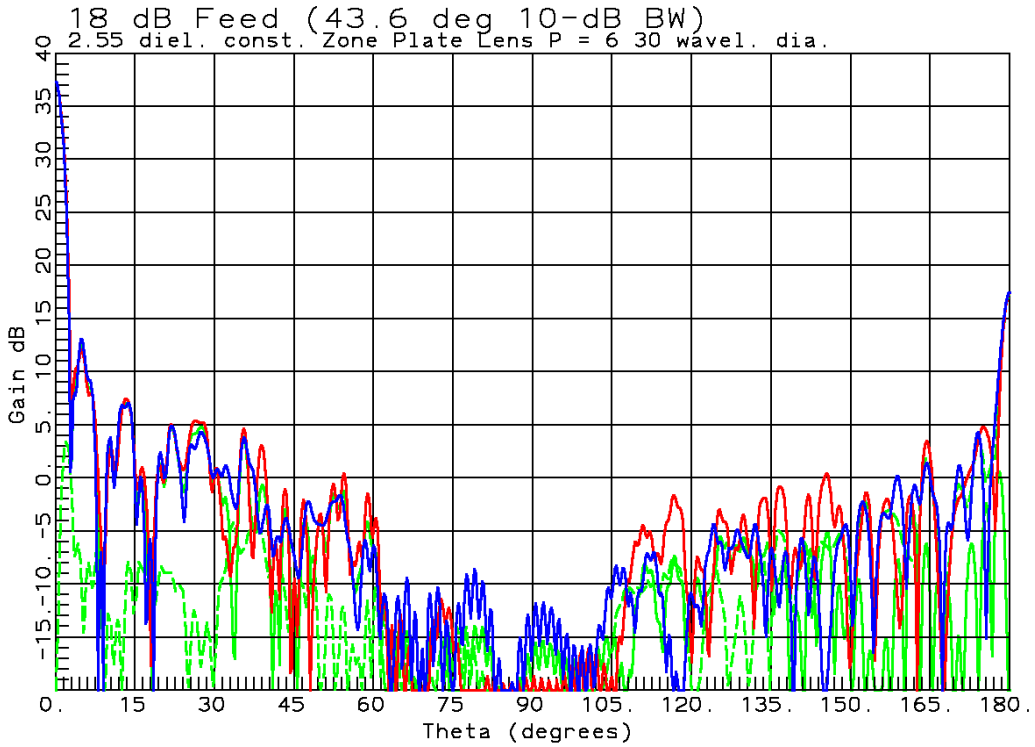
Figure 9-2.2.5 *f/D* = 1.25 Dielectric Zoned Plate Lens with P = 5 (λ/P or λ/5) steps fed by 18 dB Potter Horn



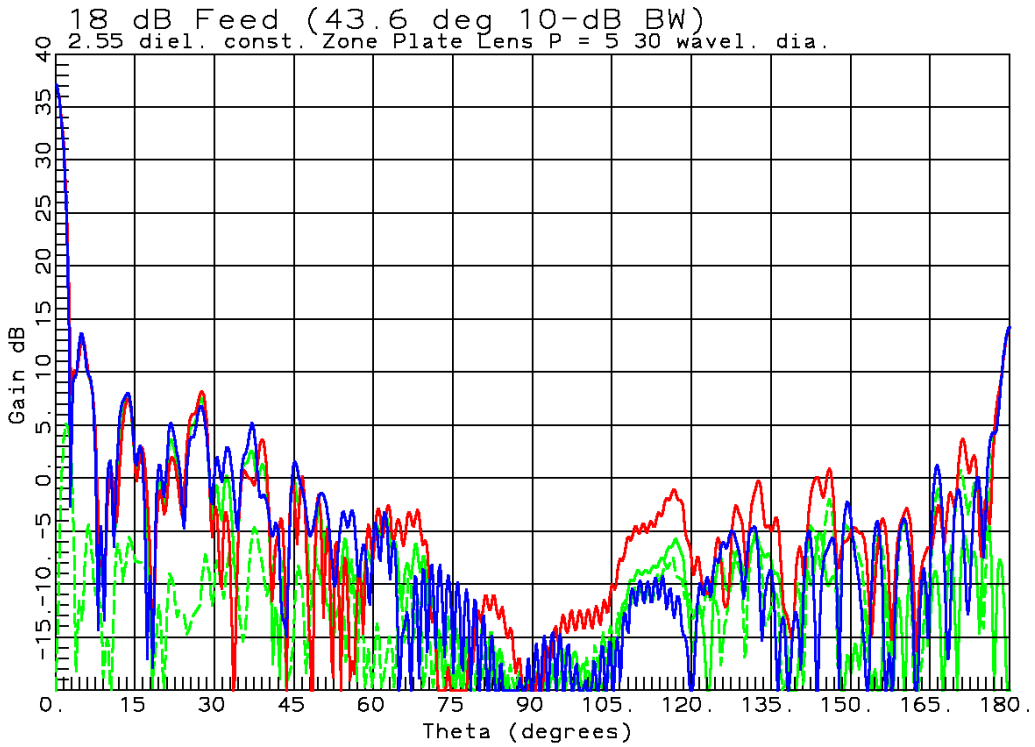
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



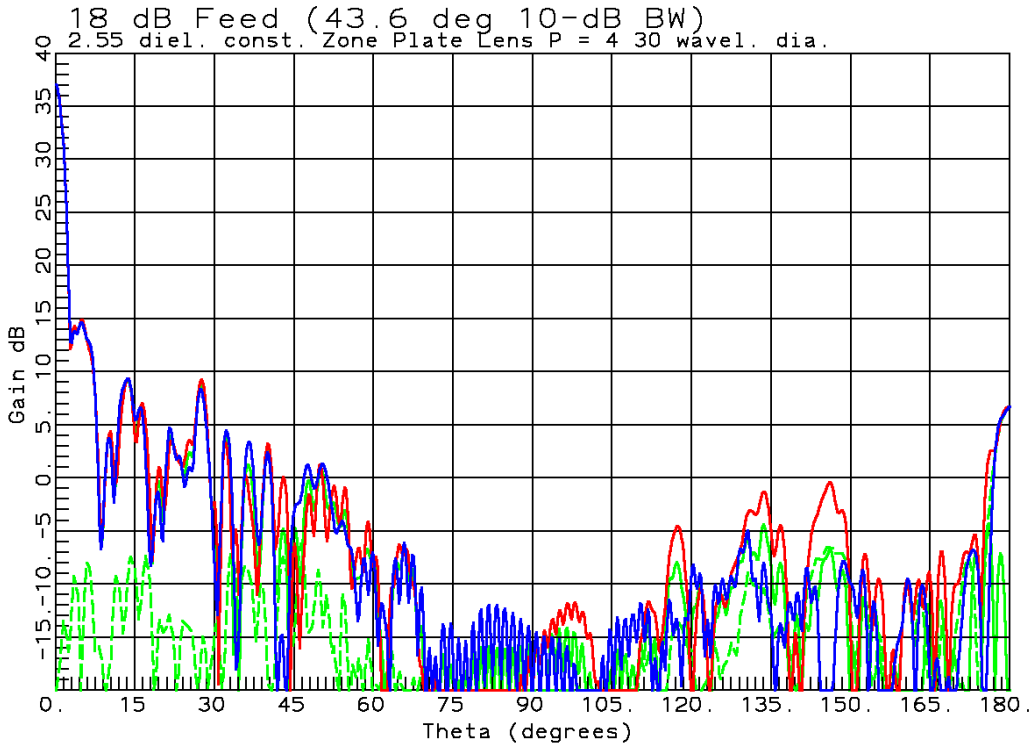
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



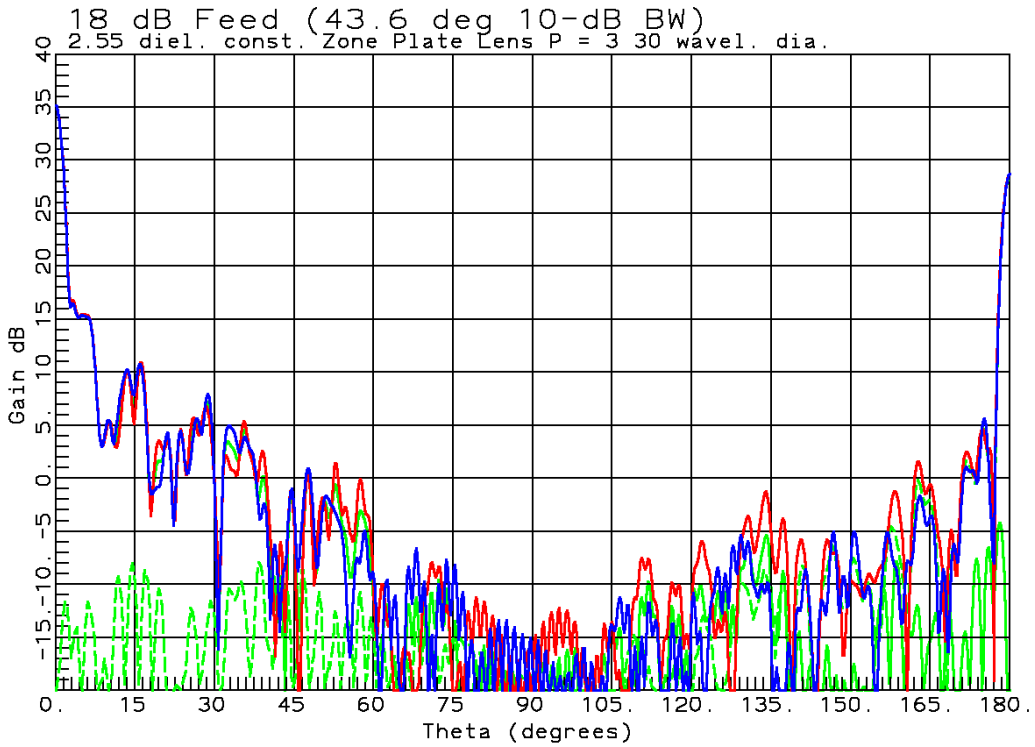
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



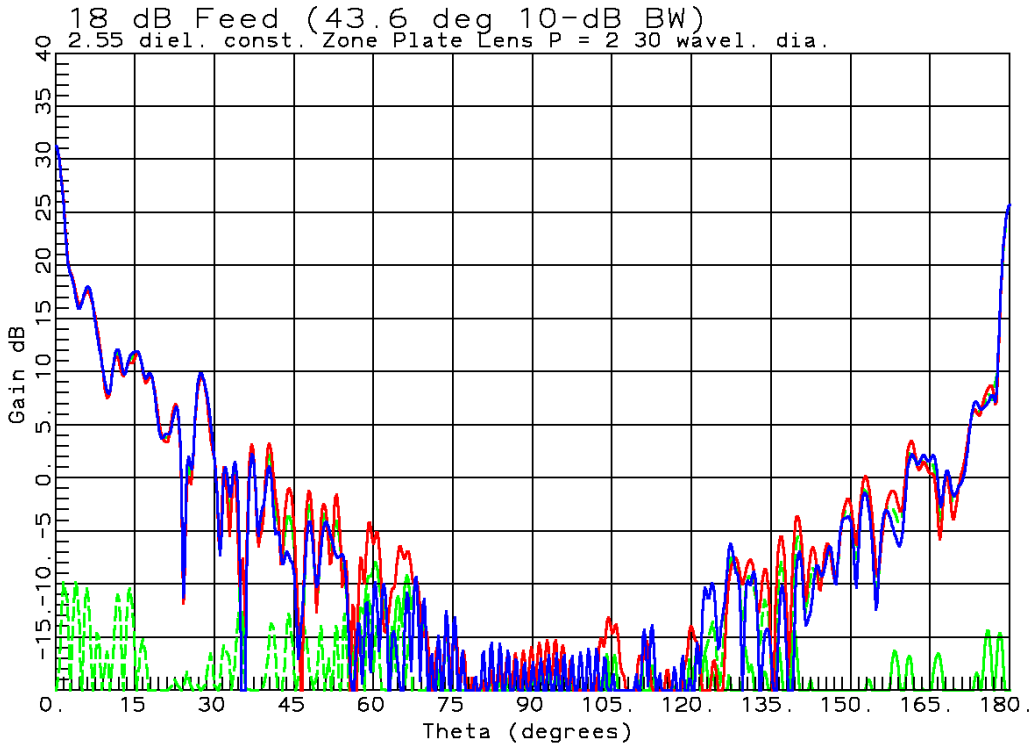
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

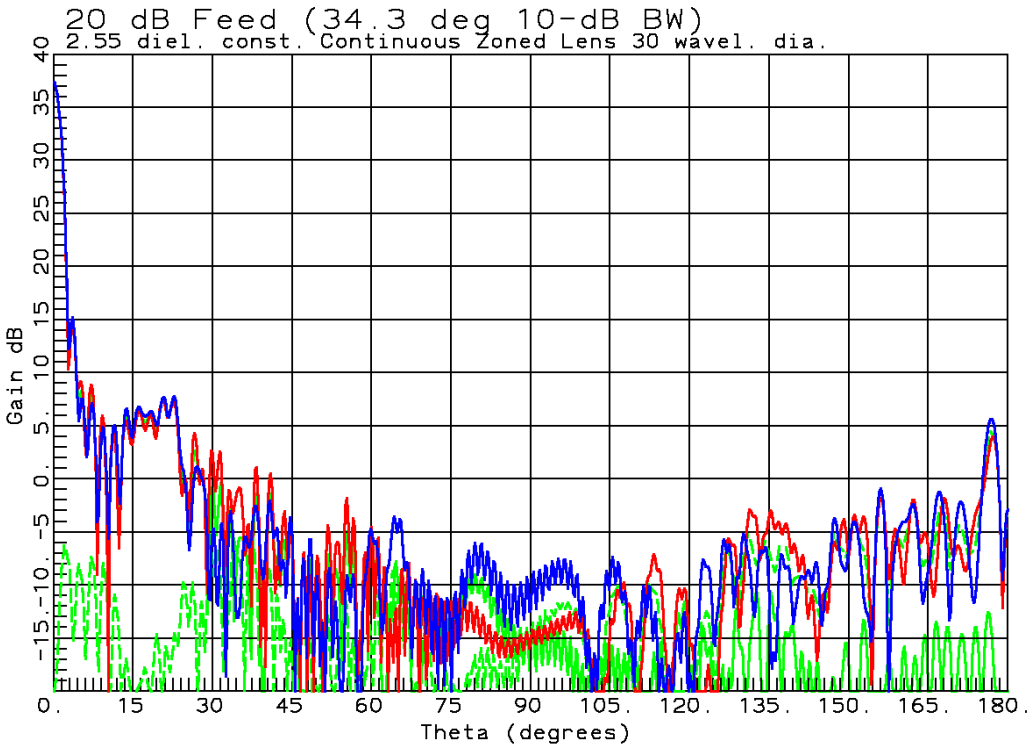


30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

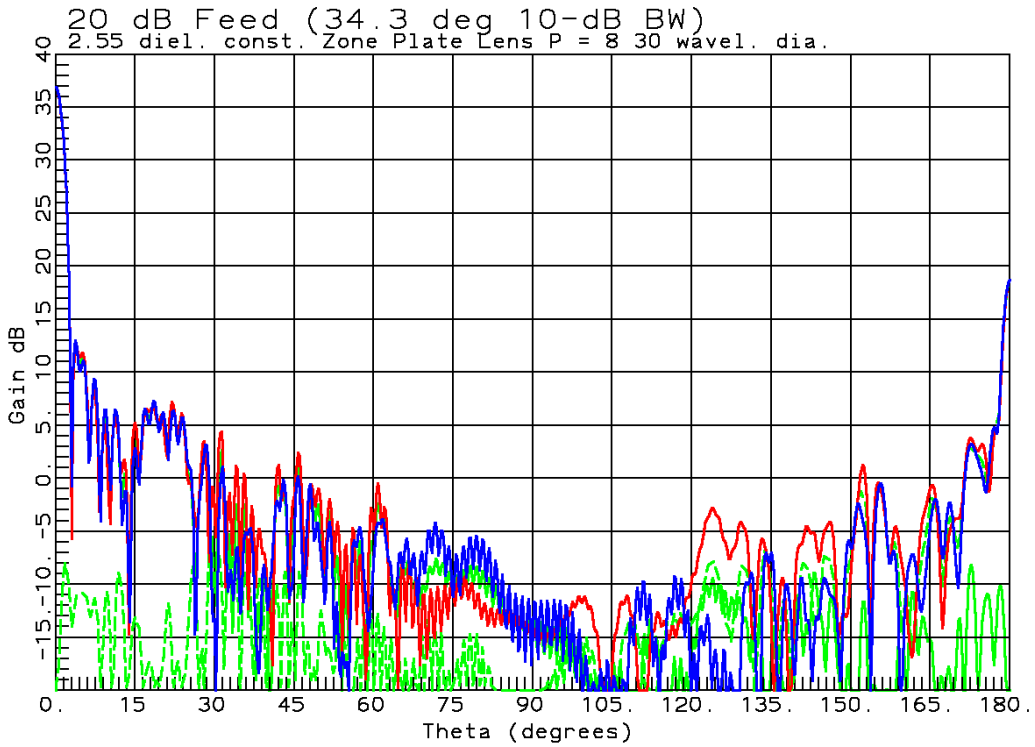


30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane

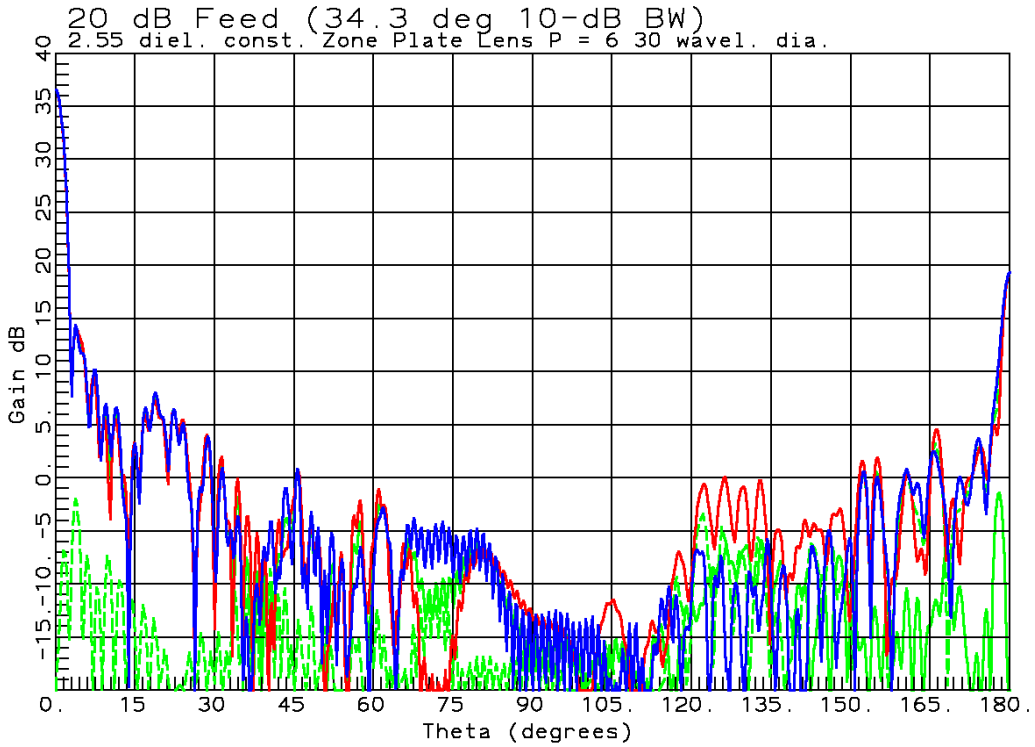
Figure 9-2.2.6 *f/D* = 1.653Dielectric Zoned Plate Lens with P = 5 (λ/P or λ/5) steps fed by 20 dB Potter Horn



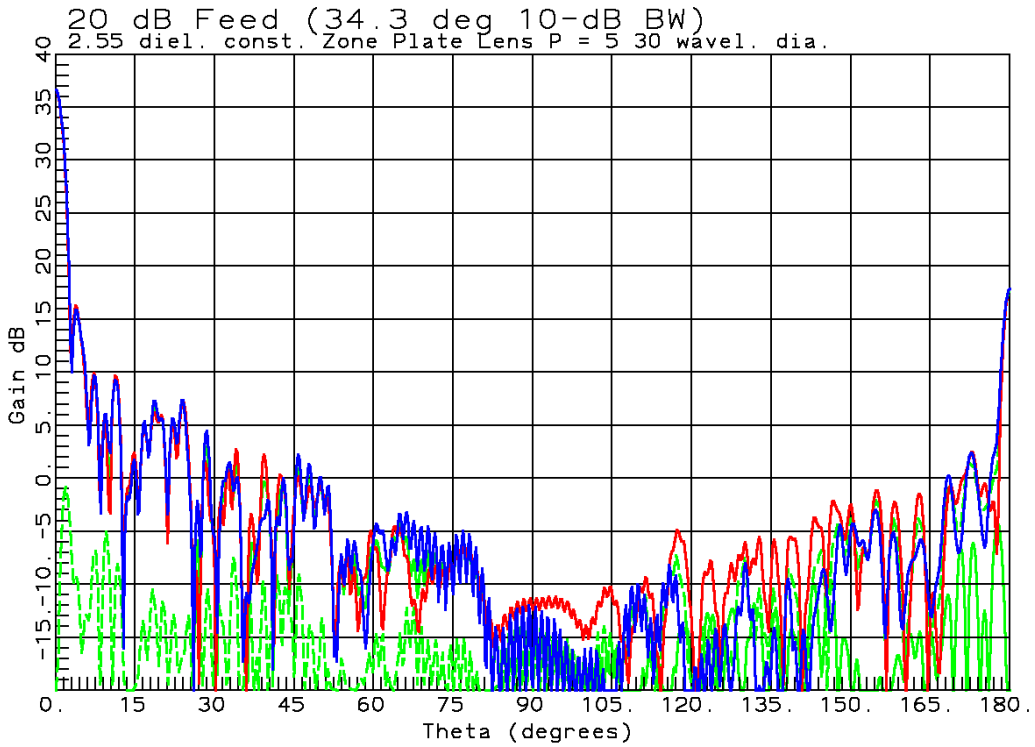
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



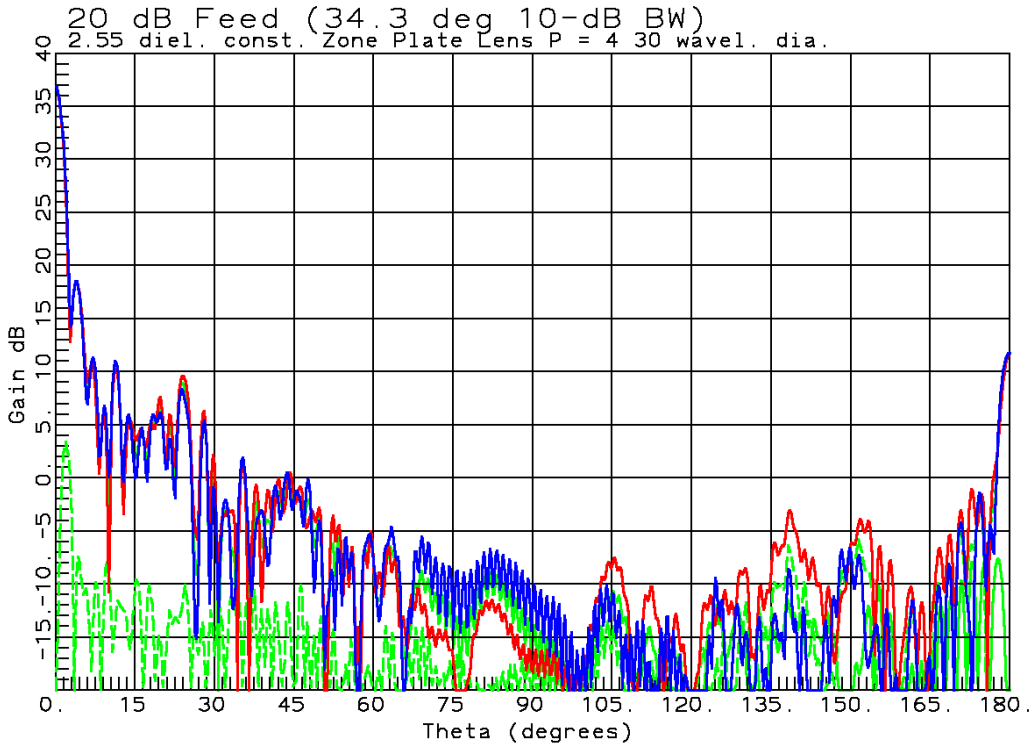
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



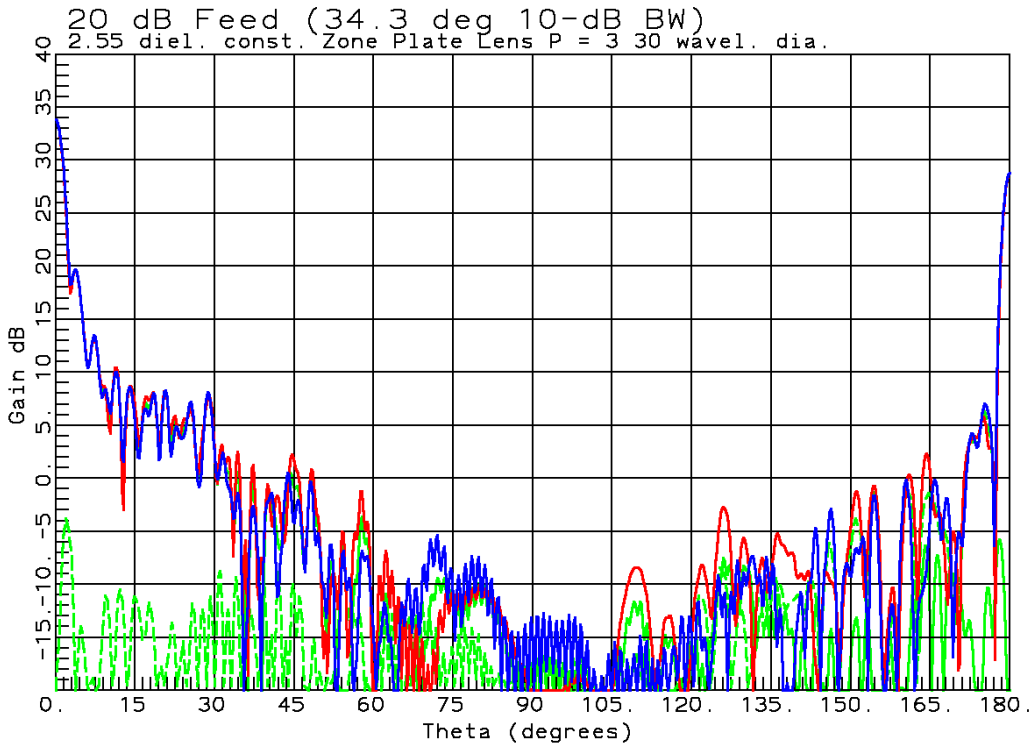
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



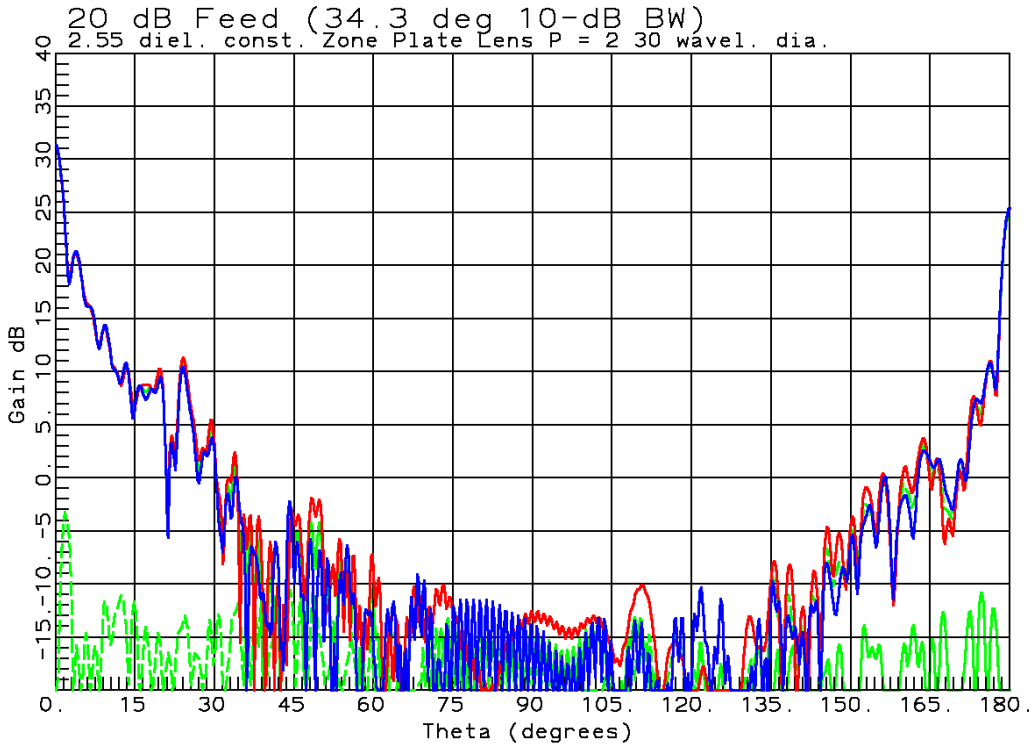
30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane



30λ diameter Blue: *E*-plane, Red: *H*-plane, Green: Diagonal plane