4-9.1 Schelkunoff's Unit-Circle Method Cases

The attached program UCSYO generates unit-circle cases including the Orchard Method, Section 4-14. The program can be run by using an input file or manually by entering inputs. It generates an output file UCSYO.OUT which needs to renamed to prevent it being overwritten by the next run. Below is a screen capture of the manual run for a 10-element array.

Command Prompt - ucsyo

```
C:\Analyses\Schelkunoff_Unit_Circle>ucsyo
Enter input 0 keyboard, 1 file 0
Schelkunoff Unit Circle Array Synthesis
Enter the Number of Elements 10
ucsyo: ??

UCSYN Directives
 1. (??,<pr>). . . . List Directives
 2. (ze,st, ). . . . Zeros, Standard,<UN,BI,CH,VI,TA,BA>
 3. (ge,pl). . . . . Generate, Plot
 4. (ge,re). . . . . Generate, Rectangular plot
 5. (ge,ov). . . . . Generate, Overlay
 6. (ge,di). . . . . Generate, Diagram
 7. (ch,pl). . . . . Change, Plotter
 8. (li,ze, ). . . . List, Zero,<#,ALL>
 9. (li,co,(pr,fi).  List Coefficients (printer,file)
10. (el,sp,  ,re). . Element, Spacing,<Value>,<Retain Nulls>
11. (el,an,  ) . . . Element, Angle, <Value>
12. (el,pa). . . . . Element, Pattern
13. (ze,ra, , ). . . Zero Radius <#,All>,<Value>
14. (ze,an,#, ). . . Zero, Angle,<#>,<Value>
15. (st) . . . . . . Status
16. (pa,nu,#, ). . . Pattern, Null, #,<Angle>
17. (li,si). . . . . List, Sidelobes,(printer)
18. (de,si). . . . . Design, Sidelobes
19  (or,sy). . . . . Orchard, Synthesis
20. (ro,ze). . . . . Rotate, zeros
21. (no,fr). . . . . Normalize, Frequency for plots
22. (ex) . . . . . . Exit
ucsyo:
```

After asking for the number of elements, the program responds with its name, ucsyo: and expects typed input commands from a list. Typing ?? produces a list of possible commands, as shown above. For example, 2. (ze,st,) Zeros, Standard, <UN,BI,CH,VI,TA,BA> with shorted names: Uniform, Binomial, Chebyshev, Villeneuve, Taylor, Bayliss distributions. The program only responds to the first two letters of the distribution name, but the full name can be typed for record keeping.

The first command given below is standard zeros for a uniform distribution. The command: ST (status) shows that initially the elements are spaced λ/2 with zero phase shift between elements, that is, unscanned. Command GE,DI generates a plot of diagram similar to Figure 4-11 and asks for a plot label. Command LI,ZE,ALL lists the all zeros as radius and angle and lists the pattern angle of the associated null. The command to draw a polar plot of the pattern uses the previous pattern label and returns with the command / which allows line editing. Type ?? for a list of commands, the one shown exits the line editor.

Command Prompt - ucsyo

```
ucsyo: ze,st,un
ucsyo: st
UCSYN Status
10 Elements
Spacing Between Elements:   0.5000
Phase Shift Between Elements:    0.00
ucsyo: ge,di
New Plot file? y
Enter file name ucsyod10.hpg
Enter label
10 element uniform distribution 0.5 spacings 0 phase shift
ucsyo: li,ze,all

  No   Magnitude   Angle     Null

   1     1.0000    36.00    78.46
   2     1.0000    72.00    66.42
   3     1.0000   108.00    53.13
   4     1.0000   144.00    36.87
   5     1.0000   180.00     0.00
   6     1.0000  -144.00   143.13
   7     1.0000  -108.00   126.87
   8     1.0000   -72.00   113.58
   9     1.0000   -36.00   101.54
ucsyo: ge,pl
Enter Plot File Name ucsyop10.hpg
Enter Plot Pattern 1
Enter pen number 1
Enter label
  10 element uniform distribution 0.5 spacings 0 phase shift
/e
ucsyo: _
```

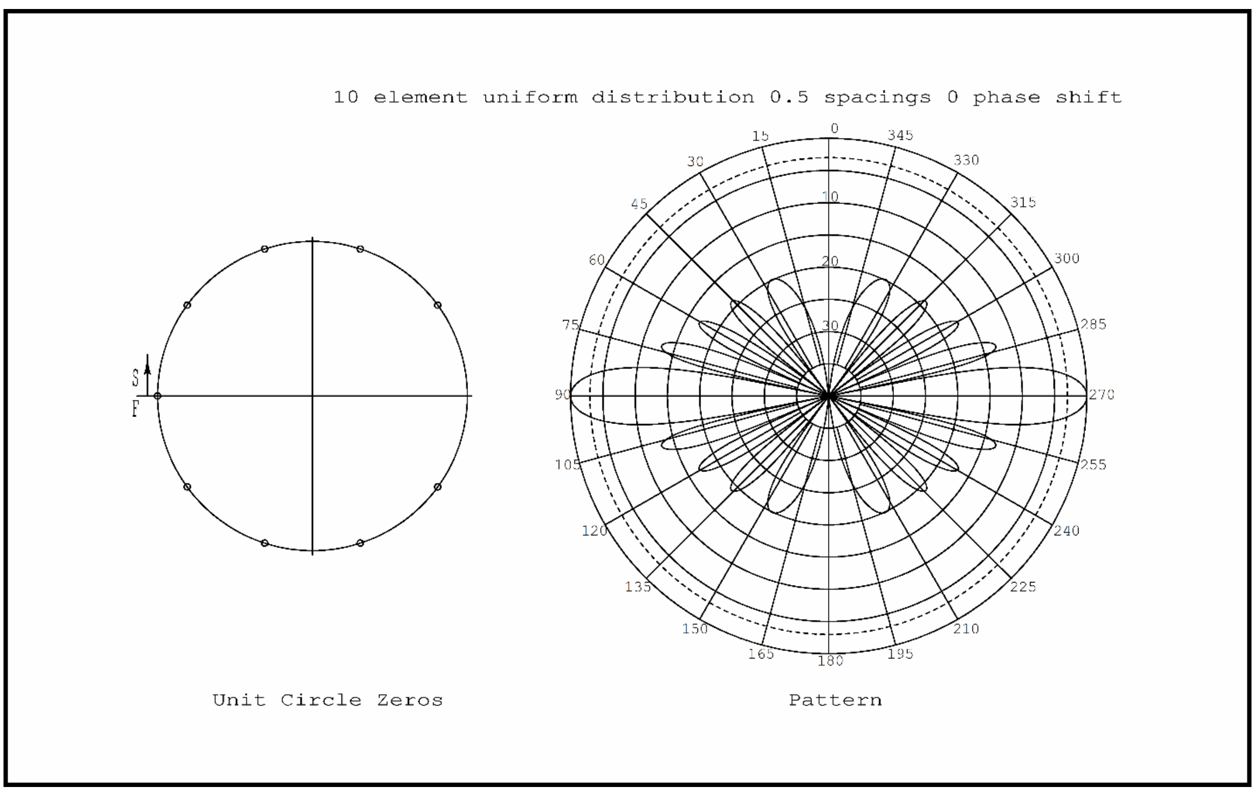


Figure 4-9.1.1 Unit Circle Diagram 10-element uniform distribution

```
UCSYN Status
 10 Elements
 Spacing Between Elements:   0.5000
 Phase Shift Between Elements:    0.00

   No   Magnitude   Angle     Null

    1     1.0000    36.00    78.46
    2     1.0000    72.00    66.42
    3     1.0000   108.00    53.13
    4     1.0000   144.00    36.87
    5     1.0000   180.00     0.00
    6     1.0000  -144.00   143.13
    7     1.0000  -108.00   126.87
    8     1.0000   -72.00   113.58
    9     1.0000   -36.00   101.54

 Array Coefficients

   No   Mag(dB)    Phase   Mag(Volt.)

    1      0.00     0.00      1.0000
    2      0.00     0.00      1.0000
    3      0.00     0.00      1.0000
    4      0.00     0.00      1.0000
    5      0.00     0.00      1.0000
    6      0.00     0.00      1.0000
    7      0.00     0.00      1.0000
    8      0.00     0.00      1.0000
    9      0.00     0.00      1.0000
   10      0.00     0.00      1.0000

 W space sidelobes

   No    Sidelobe dB W angle
    1      -19.89     161.81
    2      -18.99     125.41
    3      -16.95      88.83
    4      -12.97      51.66
    5        0.00       0.00
    6      -12.97     -51.67
    7      -16.95     -88.84
    8      -18.99    -125.41
```

```
    9       -19.89     -161.82
```

UCSYO can generate a file of the excitations which can be used by the array geometry program XADEF (Section 4-27). The example of an Orchard Synthesis below uses XADEF at 1 GHz with cm spacing units.

```
ucsyo: li,co,fi list, coefficients, file
Enter coefficient output file orch8co.out
ucsyo: ge,pl            generate, plot
Enter Plot File Name ucsyoo8p.hpg
Enter Plot Pattern            1
Enter pen number            1
Enter label
-Element Orchard Synthesis, 0.5 Spacings, 0 Element Phase
ucsyo: ex

C:\Analyses\Schelkunoff_Unit_Circle\Orchard_Synthesis\8-element_0.5_spacing>\
Enter input 0 keyboard, 1 file 0
Enter File Name orch8xa.arr
Enter units: 1 in., 2 ft, 3 cm, 4 m 3
New File? y
Enter Frequency (GHz) 1
xadef: ad,re,8
Enter Ampl (dB), Phase 0,0
Enter Number of Elements along X-axis 8
Enter initial spacings in X,Y axes cm  15,15
Array along X-axis
Enter Axis Spacing: 1 Uniform, 2 Bratkovic  3 Geometric, 4 Uneven Taylor 1
Enter 1) Uniform Amplitude Distribution
      2) Area Sampling of Taylor Distribution
      3) Point Sampling of Taylor Distribution
      4) Zero Sampled Taylor Distribution
      5) Point Sampled Bayliss Distribution
      6) Zero Sampled Bayliss Distribution
      7) Chebyshev array
      8) External coefficent input file 8
Enter array coefficient file orch8co.out
Enter Quadratic Phase Factor, S 0
```

```
move: ex
Enter Final New Z axis Rotation of Antennas (array) 0
xadef: li,fi

File:orch8xa.arr

                  Location                     Element
No        X          Y          Z      Ampl(dB)   Phase      Euler Angles
   1    -52.500    0.000     0.000     -8.69     8.70     0.00     0.00     0.00
   2    -37.500    0.000     0.000     -3.90     3.22     0.00     0.00     0.00
   3    -22.500    0.000     0.000     -1.06     1.29     0.00     0.00     0.00
   4     -7.500    0.000     0.000      0.00     4.91     0.00     0.00     0.00
   5      7.500    0.000     0.000      0.00     3.79     0.00     0.00     0.00
   6     22.500    0.000     0.000     -1.06     7.41     0.00     0.00     0.00
   7     37.500    0.000     0.000     -3.90     5.48     0.00     0.00     0.00
   8     52.500    0.000     0.000     -8.69     0.00     0.00     0.00     0.00
xadef:
```

Binomial Distribution

```
Enter input 0 keyboard, 1 file 1
Enter file ucsyob9.txt
Schelkunoff Unit Circle Array Synthesis
Enter the Number of Elements            9
ucsyo: ze,st,bi         zeros, binomial distribution
ucsyo: st                       status
UCSYN Status
 9 Elements
Spacing Between Elements:   0.5000
Phase Shift Between Elements:    0.00
ucsyo: ge,di            generate, diagram
New Plot file? y                        new plot file
Enter file name ucsyod9.hpg
Enter label
-element Binomial Distribution 0.5 Spacings, 0 Element Phase Shift
ucsyo: ge,pl
Enter Plot File Name ucsyop9.hpg
Enter Plot Pattern              1
Enter pen number              1
Enter label
-element Binomial Distribution 0.5 Spacings, 0 Element Phase Shift
ucsyo: st,pr
ucsyo: li,ze,all,pr
ucsyo: li,co,pr
ucsyo: ex
```

The binomial distribution has no sidelobes since all zeros are placed at 180°.

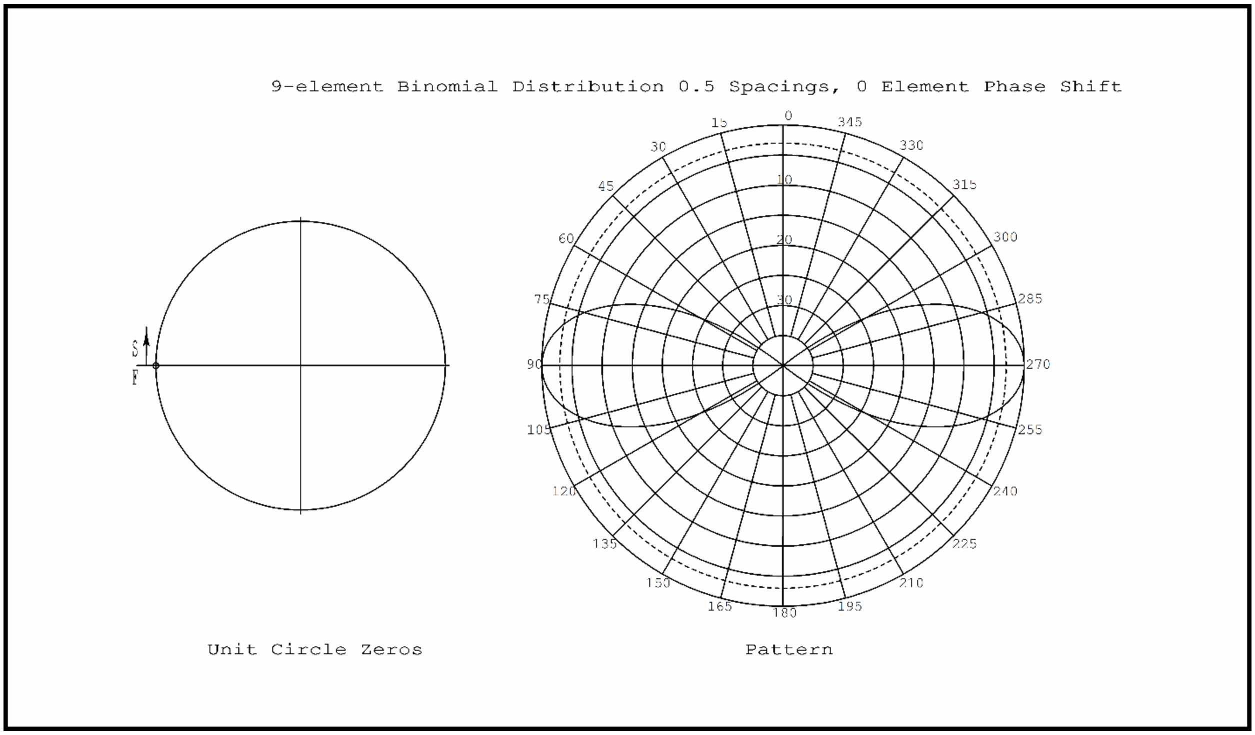


Figure 4-9.1.2 Unit Circle Diagram 9-element binomial distribution

```
UCSYO Status
  9 Elements
 Spacing Between Elements:   0.5000
 Phase Shift Between Elements:    0.00

   No   Magnitude   Angle     Null

    1     1.0000   180.00     0.00
    2     1.0000   180.00     0.00
    3     1.0000   180.00     0.00
    4     1.0000   180.00     0.00
    5     1.0000   180.00     0.00
    6     1.0000   180.00     0.00
    7     1.0000   180.00     0.00
    8     1.0000   180.00     0.00

 Array Coefficients

   No   Mag(dB)    Phase   Mag(Volt.)

    1    -36.90     0.00      0.0143
    2    -18.84     0.00      0.1143
    3     -7.96     0.00      0.4000
```

4	-1.94	0.00	0.8000
5	0.00	0.00	1.0000
6	-1.94	0.00	0.8000
7	-7.96	0.00	0.4000
8	-18.84	0.00	0.1143
9	-36.90	0.00	0.0143

Chebyshev Array

```
Enter input 0 keyboard, 1 file 1
Enter file ucsyoc9.txt
Schelkunoff Unit Circle Array Synthesis
Enter the Number of Elements          9
ucsyo: ze,st,ch zeros, standard, chebyshev distribution
Chebyshev Array Enter Sidelobe Level       25.000000
ucsyo: st              status
UCSYN Status
 9 Elements
Spacing Between Elements:   0.5000
Phase Shift Between Elements:    0.00
ucsyo: ge,di           generate, diagram
New Plot file? y               new plot file
Enter file name ucsyod9.hpg
Enter label
-element 25-dB Chebyshev Distribution 0.5 Spacings, 0 Element Phase Shift
ucsyo: ge,pl           generate, plot
Enter Plot File Name ucsyop9.hpg
Enter Plot Pattern          1
Enter pen number          1
Enter label
-element 25-dB Chebyshev Distribution 0.5 Spacings, 0 Element Phase Shift
ucsyo: st,pr
ucsyo: li,ze,all,pr
ucsyo: li,co,pr
ucsyo: ex
```

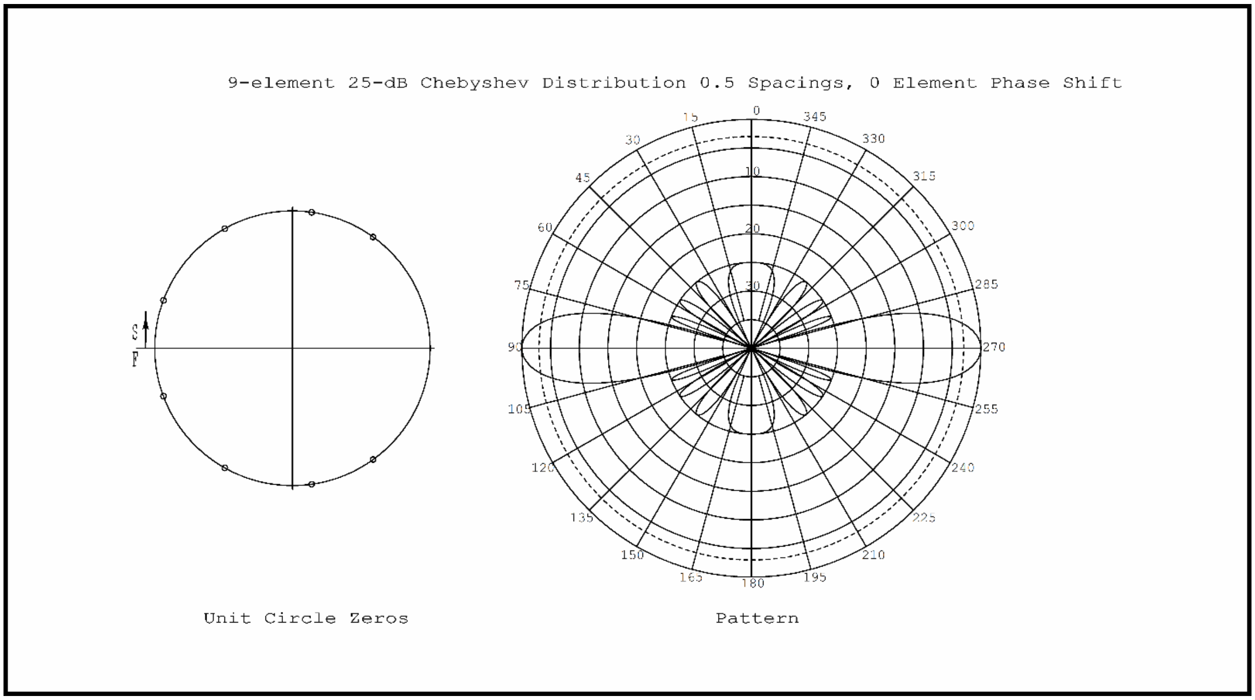


Figure 4-9.1.3 Unit Circle Diagram 9-element 25-dB Chebyshev distribution

```
9 Elements
```

```
Spacing Between Elements:   0.5000
Phase Shift Between Elements:    0.00

  No   Magnitude   Angle     Null

   1     1.0000    54.10    72.51
   2     1.0000   -54.10   107.49
   3     1.0000    81.95    62.92
   4     1.0000   -81.95   117.08
   5     1.0000   119.41    48.44
   6     1.0000  -119.41   131.56
   7     1.0000   159.59    27.55
   8     1.0000  -159.59   152.45

Array Coefficients

  No   Mag(dB)    Phase   Mag(Volt.)

   1     -8.44     0.00      0.3783
   2     -5.50     0.00      0.5310
   3     -2.34     0.00      0.7639
   4     -0.57     0.00      0.9364
   5      0.00     0.00      1.0000
   6     -0.57     0.00      0.9364
   7     -2.34     0.00      0.7639
   8     -5.50     0.00      0.5310
   9     -8.44     0.00      0.3783

W space sidelobes

  No    Sidelobe dB W angle
   1      -25.00     139.33
   2      -25.00     100.10
   3      -25.00      65.95
   4        0.00       0.00
   5      -25.00     -65.95
   6      -25.00    -100.11
   7      -25.00    -139.33
   8      -25.00    -180.00
```

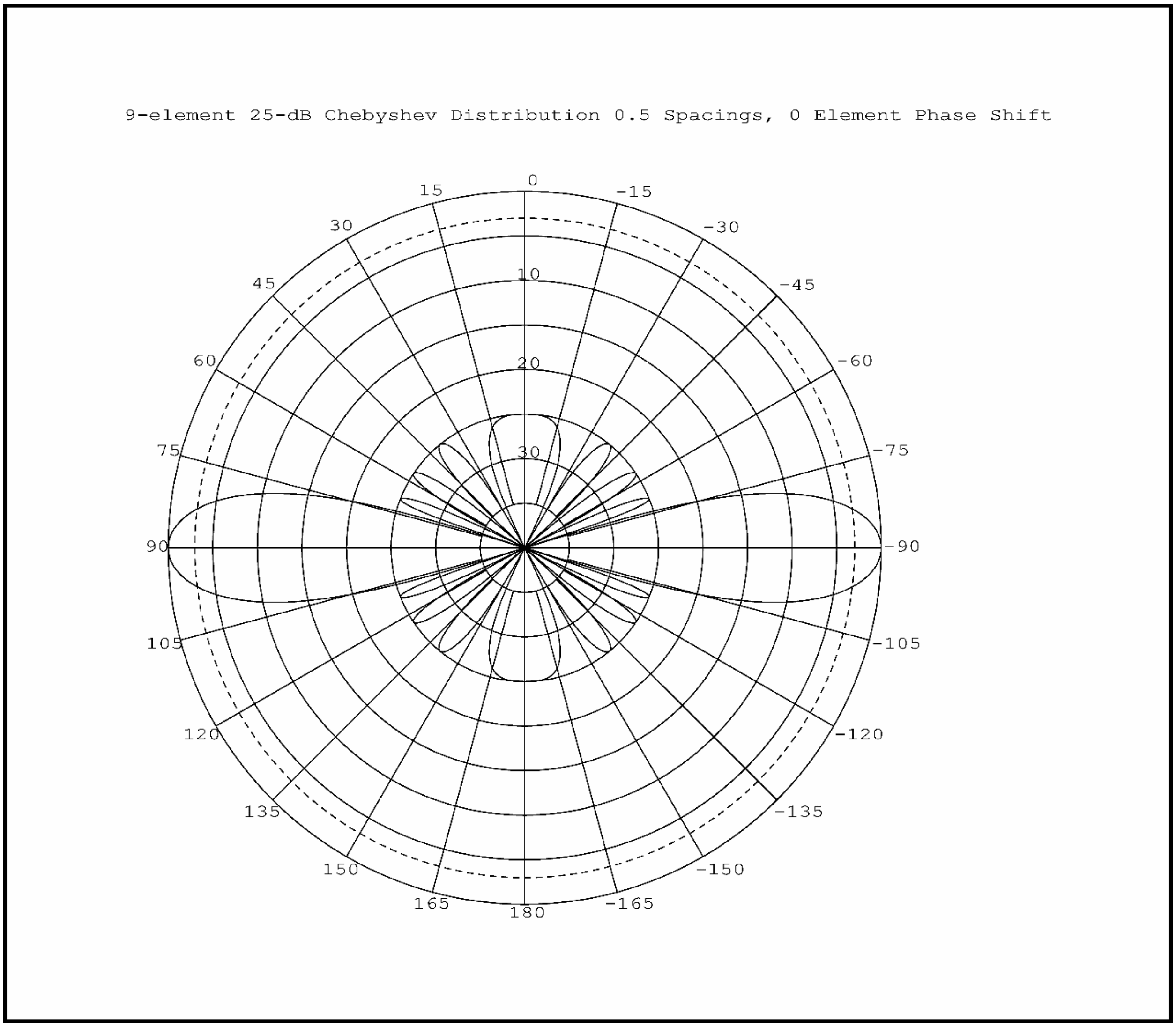


Figure 4-9.1.4 Polar Pattern 9-element 25-dB Chebyshev distribution array along *z*-axis

Taylor Zero Sampled Distribution

The initial design uses a 9-element array to sample a 25-dB Taylor distribution with the 1st unmoved null number 5. The input file for UCSYO is:

```
9             number of array elements
ze,st,ta      zeros, standard, Taylor distribution
1             symmetrical sidelobes
5,25          1st unchanged null, sidelobe level
st            status
ge,di         generate, diagram
y             new plot file
ucsyod9.hpg
9-element 25-dB Taylor Distribution 0.5 Spacings, 0 Element Phase Shift
```

```
ge,pl        generate, plot
ucsyop9.hpg
1            plot pattern
1            pen
9-element 25-dB Taylor Distribution 0.5 Spacings, 0 Element Phase Shift
st,pr
li,ze,all,pr
li,co,pr
li,si,pr
ex
```

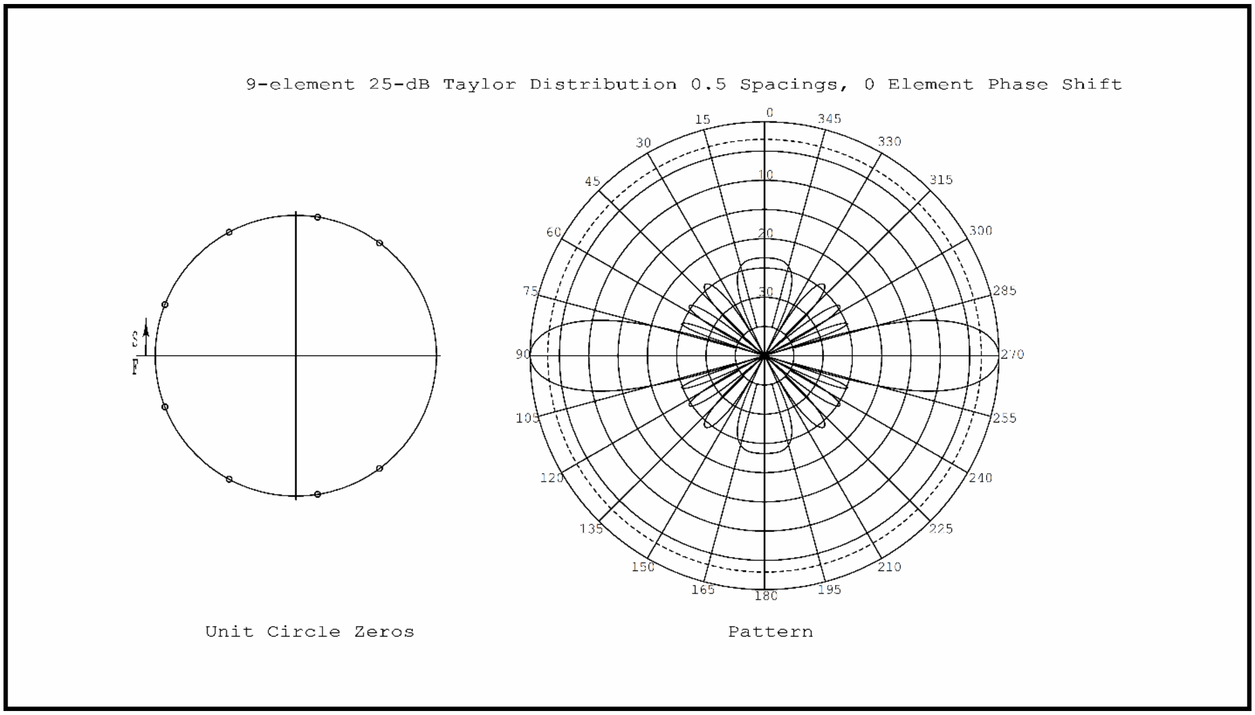


Figure 4-9.1.5 Unit Circle Diagram 9-element 25-dB, $\bar{n} = 5$ Taylor distribution

The sidelobes of this pattern rise above 25-dB because with only 4 independent nulls of the symmetrical array, it cannot include the 5th null of the distribution.

```
UCSYO Status
  9 Elements
 Spacing Between Elements:   0.5000
 Phase Shift Between Elements:    0.00

   No   Magnitude   Angle     Null

    1     1.0000   158.57    28.24
    2     1.0000   118.34    48.90
    3     1.0000    81.10    63.22
    4     1.0000    53.51    72.71
```

5	1.0000	-53.51	107.29
6	1.0000	-81.10	116.78
7	1.0000	-118.34	131.10
8	1.0000	-158.57	151.76

Array Coefficients

No	Mag(dB)	Phase	Mag(Volt.)
1	-7.94	0.00	0.4009
2	-5.58	0.00	0.5260
3	-2.26	0.00	0.7705
4	-0.62	0.00	0.9309
5	0.00	0.00	1.0000
6	-0.62	0.00	0.9309
7	-2.26	0.00	0.7705
8	-5.58	0.00	0.5260
9	-7.94	0.00	0.4009

W space sidelobes

No	Sidelobe dB	W angle
1	-24.13	138.50
2	-24.57	99.27
3	-24.82	65.29
4	0.00	0.00
5	-24.82	-65.29
6	-24.57	-99.27
7	-24.13	-138.50
8	-23.28	-180.00

It is necessary to limit the first unmoved null of the Taylor distribution to 4.

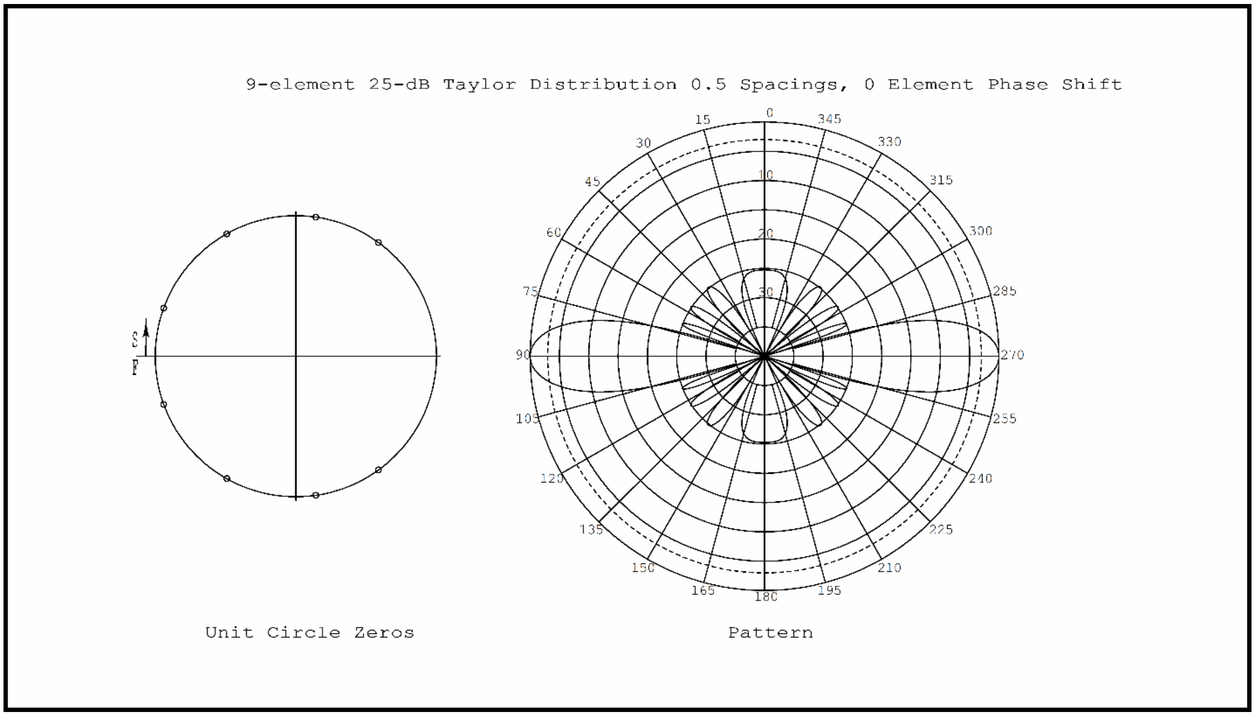


Figure 4-9.1.6 Unit Circle Diagram 9-element 25-dB, $\bar{n} = 4$ Taylor distribution

```
UCSYO Status
  9 Elements
 Spacing Between Elements:   0.5000
 Phase Shift Between Elements:    0.00

   No   Magnitude   Angle     Null

    1     1.0000   160.00    27.27
    2     1.0000   119.40    48.44
    3     1.0000    81.83    62.96
    4     1.0000    53.99    72.55
    5     1.0000   -53.99   107.45
    6     1.0000   -81.83   117.04
    7     1.0000  -119.40   131.56
    8     1.0000  -160.00   152.73

 Array Coefficients

   No   Mag(dB)    Phase   Mag(Volt.)

    1     -8.37     0.00      0.3817
    2     -5.44     0.00      0.5347
```

3	-2.34	0.00	0.7639
4	-0.53	0.00	0.9408
5	0.00	0.00	1.0000
6	-0.53	0.00	0.9408
7	-2.34	0.00	0.7639
8	-5.44	0.00	0.5347
9	-8.37	0.00	0.3817

W space sidelobes

No	Sidelobe dB	W angle
1	-24.80	139.47
2	-24.85	100.05
3	-24.93	65.84
4	0.00	-0.01
5	-24.93	-65.84
6	-24.85	-100.06
7	-24.80	-139.47
8	-25.28	-180.00

When we increase the number of elements in the array to zero sample Taylor distribution, the beam narrows and the sidelobes fall off.

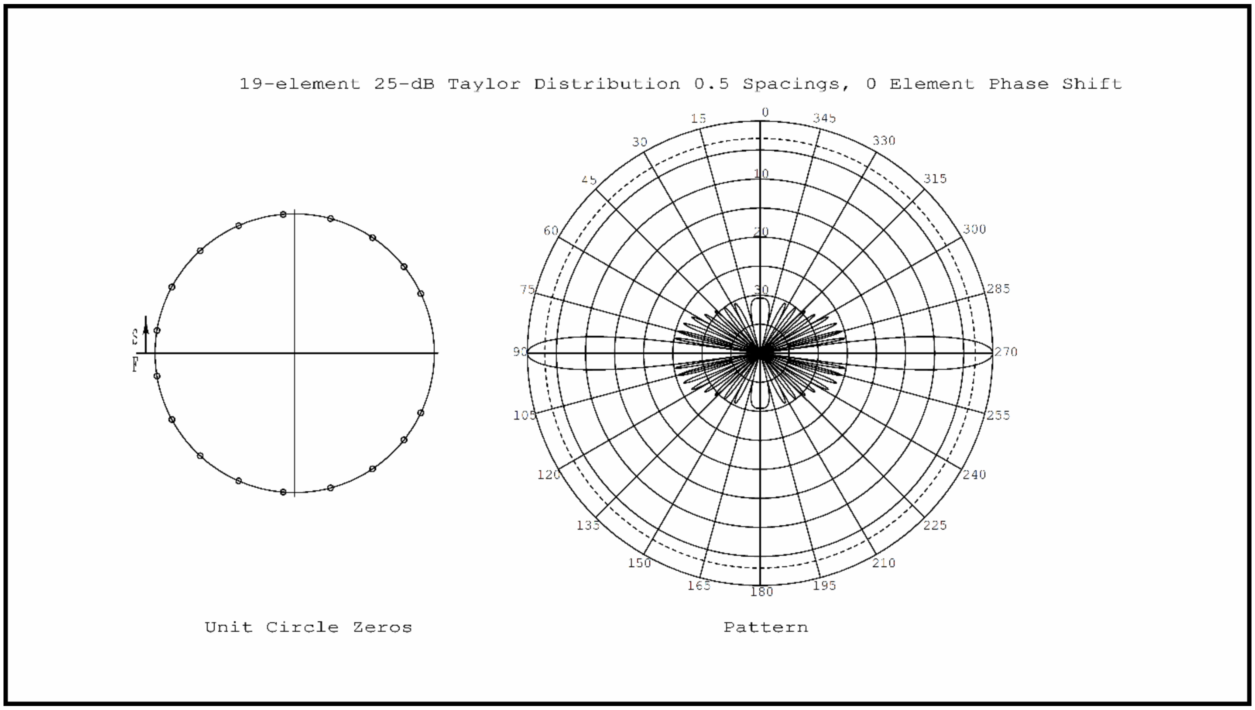


Figure 4-9.1.7 Unit Circle Diagram 9-element 25-dB, $\overline{n} = 5$ Taylor distribution

```
W space sidelobes of 19-element zero sampled Taylor distribution

   No    Sidelobe dB W angle
    9        0.00       0.00
   10      -25.19     -30.88
   11      -25.44     -46.88
   12      -25.91     -65.35
   13      -26.71     -84.64
   14      -28.41    -103.95
   15      -29.39    -122.98
   16      -30.03    -142.00
   17      -30.39    -161.00
   18      -30.51    -180.00
```

Villeneuve Array Synthesis (4-11)

Input file to UCSYO:

```
9           number of array elements
ze,st,vi    zeros, standard, Villeneuve distribution
4,25        1st unchanged null, sidelobe level
st          status
ge,di       generate, diagramtion
y           new plot file
ucsyod9.hpg
9-element 25-dB Villeneuve Distribution 0.5 Spacings, 0 Element Phase
Shift
ge,pl       generate, plot
ucsyop9.hpg
1           plot pattern
1           pen
9-element 25-dB Villeneuve Distribution 0.5 Spacings, 0 Element Phase
Shift
st,pr
li,ze,all,pr
li,co,pr
li,si,pr
ex
```

The Villeneuve array modifies the inner nulls of a uniform distribution similar to Taylor to achieve specified sidelobes.

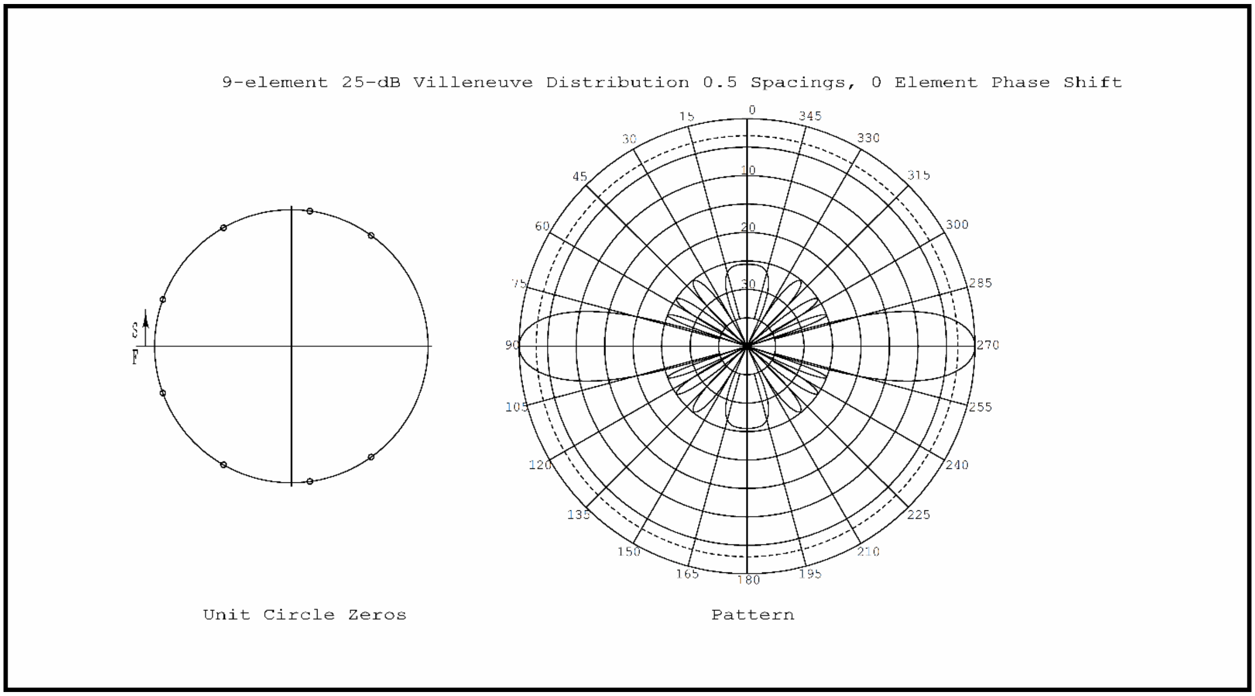


Figure 4-9.1.8 Unit Circle Diagram 9-element 25-dB, $\bar{n} = 4$ Villeneuve distribution

```
Villeneuve array n-bar =  4 Sidelobe =   25.00 Alpha =  1.00255
 UCSYO Status
  9 Elements
 Spacing Between Elements:   0.5000
 Phase Shift Between Elements:    0.00

   No   Magnitude   Angle     Null

    1     1.0000    54.24    72.46
    2     1.0000   -54.24   107.54
    3     1.0000    82.16    62.84
    4     1.0000   -82.16   117.16
    5     1.0000   119.71    48.31
    6     1.0000  -119.71   131.69
    7     1.0000   160.00    27.27
    8     1.0000  -160.00   152.73

 Array Coefficients

   No   Mag(dB)     Phase   Mag(Volt.)
```

```
    1     -8.57     0.00      0.3730
    2     -5.47     0.00      0.5330
    3     -2.36     0.00      0.7622
    4     -0.55     0.00      0.9387
    5      0.00     0.00      1.0000
    6     -0.55     0.00      0.9387
    7     -2.36     0.00      0.7622
    8     -5.47     0.00      0.5330
    9     -8.57     0.00      0.3730

 W space sidelobes

   No    Sidelobe dB W angle
    1      -25.19     139.61
    2      -25.08     100.33
    3      -25.03      66.10
    4        0.00      -0.01
    5      -25.03     -66.11
    6      -25.08    -100.33
    7      -25.19    -139.61
    8      -25.58    -180.00
```

The sidelobes drop-off faster than the equivalent Taylor distribution design.

Bayliss Distribution Array Synthesis

The array that samples this distribution should have even number of elements to form the null at zero. An input UCSYO file is:

```
12          number of array elements
ze,st,ba    zeros, standard, Bayliss distribution
4,25        1st unchanged null, sidelobe level
st          status
ge,di       generate, diagramtion
y           new plot file
ucsyod12.hpg
12-element 25-dB Bayliss Distribution 0.5 Spacings, 0 Element Phase Shift
ge,pl       generate, plot
ucsyop12.hpg
1           plot pattern
1           pen
12-element 25-dB Bayliss Distribution 0.5 Spacings, 0 Element Phase Shift
st,pr
li,ze,all,pr
```

```
li,co,pr
li,si,pr
ex
```

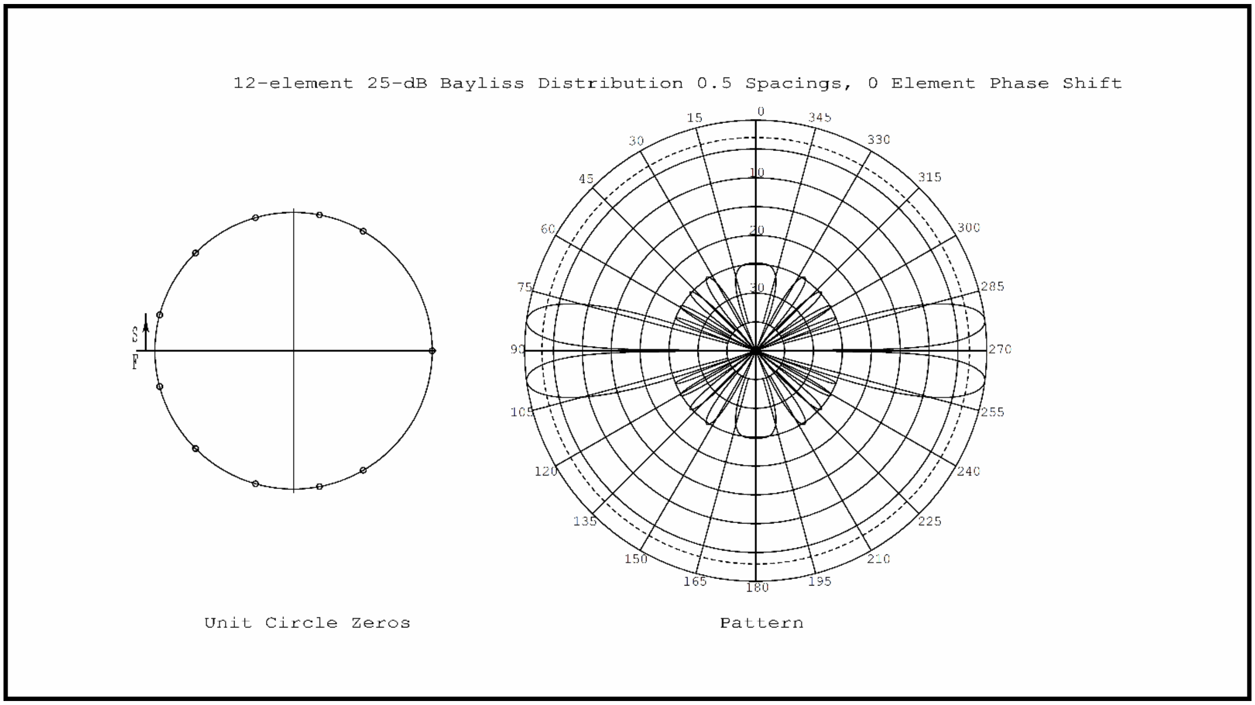


Figure 4-9.1.9 Unit Circle Diagram 12-element 25-dB, $\overline{n}$ = 4 Bayliss distribution

```
Array Coefficients

   No   Mag(dB)    Phase   Mag(Volt.)

    1     -6.66   180.00      0.4647
    2     -3.04   180.00      0.7046
    3     -0.39   180.00      0.9558
    4      0.00   180.00      1.0000
    5     -2.36   180.00      0.7623
    6    -10.87   180.00      0.2863
    7    -10.87     0.00      0.2863
    8     -2.36     0.00      0.7623
    9      0.00     0.00      1.0000
   10     -0.39     0.00      0.9558
   11     -3.04     0.00      0.7046
   12     -6.66     0.00      0.4647

 W space sidelobes

   No    Sidelobe dB W angle
```

```
    1      -24.70     149.94
    2      -24.76     120.32
    3      -24.83      92.15
    4      -24.96      68.04
    5        0.00      23.97
    6        0.00     -23.96
    7      -24.96     -68.04
    8      -24.83     -92.16
    9      -24.76    -120.33
   10      -24.70    -149.94
   11      -24.81    -180.00
```

Endfire Array Synthesis (4-9)

Elements spaced less than λ/2 are required with a matching phase shift to scan the main beam to zero. The design requirements in Section 4-9 are pattern nulls at 90° and 135°. A design using λ/4 element spacing with 3 elements can meet minimum requirements while a second design using four-elements spaced 0.35λ adds a null at 180° which improves the pattern.

```
UCSYO input file:
3                 number of array elements
el,sp,.25         element, spacing, wavelengths
el,an,-90.        element, angle
pa,nu,1,90.       pattern, null, #, angle
pa,nu,2,135.            pattern, null, #, angle
st                status
ge,di       generate, diagram
y                 new plot file
ucsyod3.hpg
3-element Endfire Distribution 0.25 Spacings
```

Or a 2nd input:

```
4                 number of array elements
el,sp,.35         element, spacing, wavelengths
el,an,-126
pa,nu,1,90.       pattern, null, #, angle
pa,nu,2,135.            pattern, null, #, angle
pa,nu,3,180.            pattern, null, #, angle
st                status
ge,di       generate, diagram
y                 new plot file
ucsyod4.hpg
4-element Endfire Distribution 0.35 Spacings
```

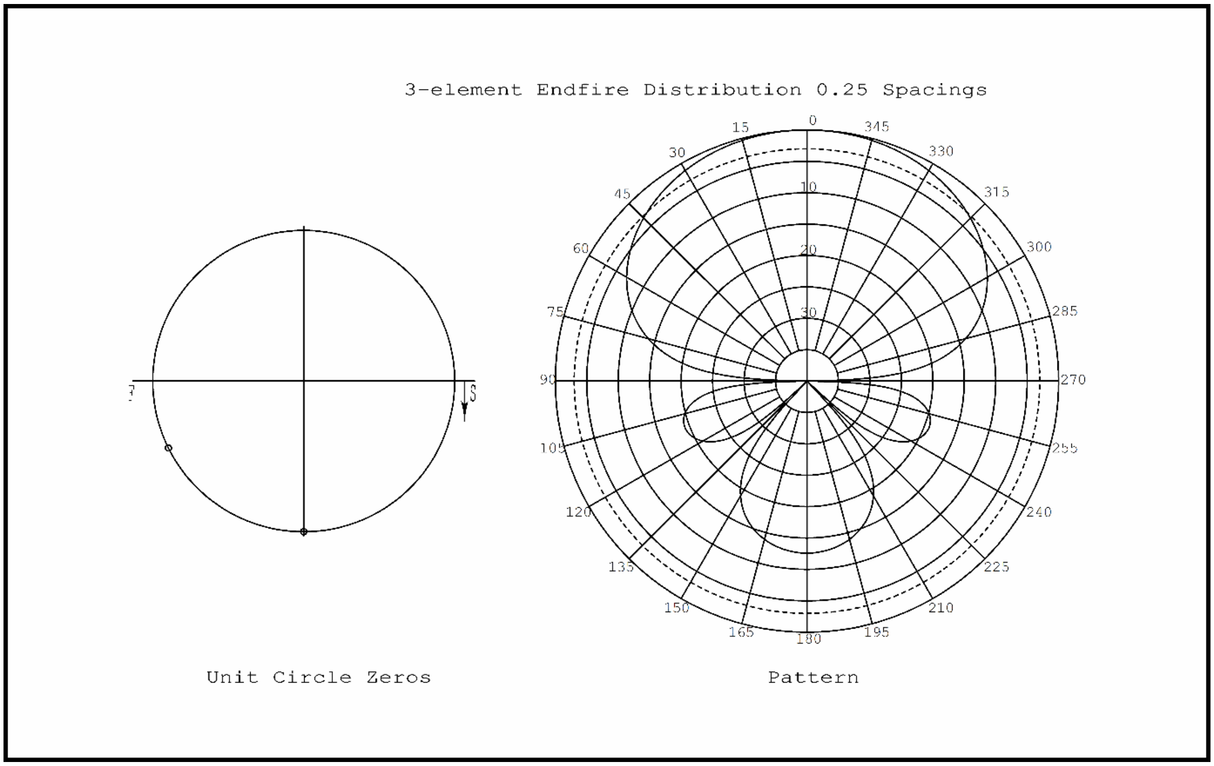
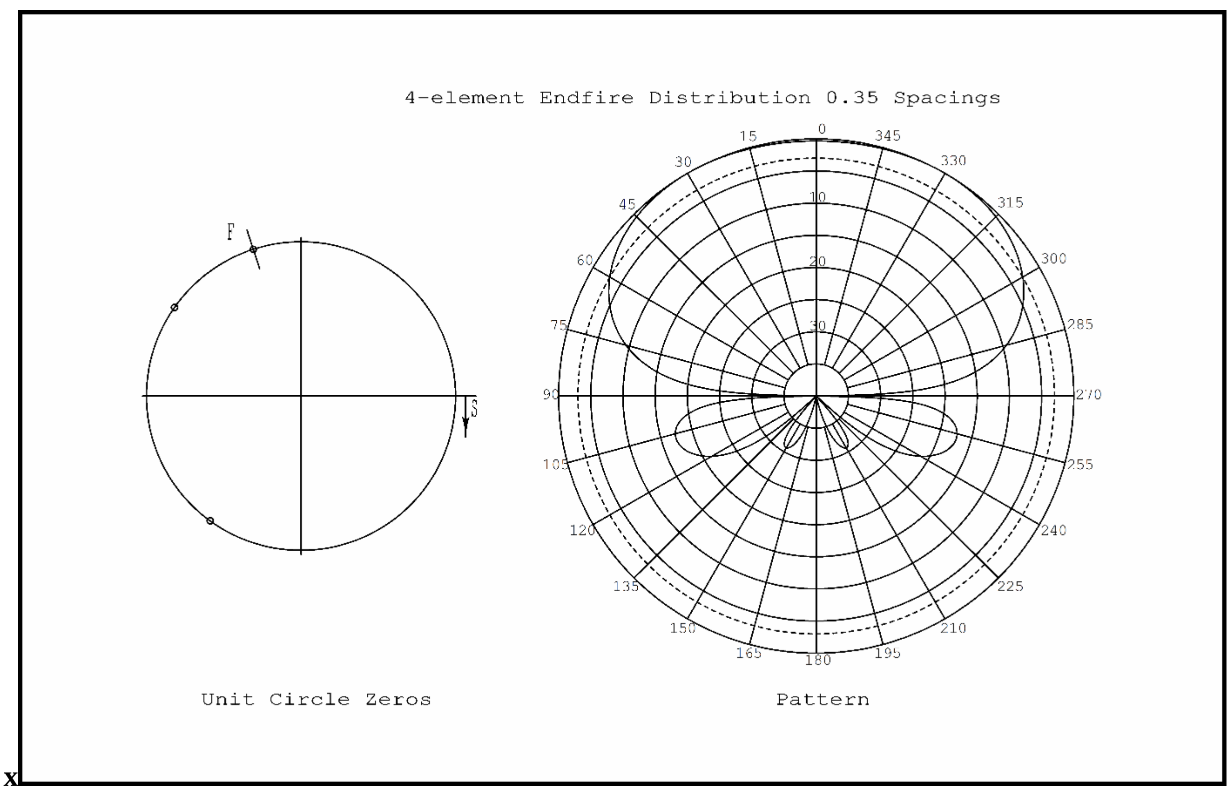


Figure 4-9.1.10 Unit Circle Diagram 3-element Endfire Array with Nulls: 90° and 135°



x

Figure 4-9.1.11 Unit Circle Diagram 4-element Endfire Array with Nulls: 90°, 135°, 180°

Pattern nulls form from cancellation of element radiation across array. Small changes in frequency will reduce the depth of nulls and increase sidelobes. UCSYO can compute the pattern at a shifted frequency. In input file UCSYO4F.TXT adds the command: NO,FR to alter the normalized frequency of pattern calculation and to add new traces on the initial polar plot.

```
4           number of array elements
el,sp,.35         element, spacing, wavelengths
el,an,-126        element, angle (inter-element)
pa,nu,1,90. pattern, null, #, angle
pa,nu,2,135.      pattern, null, #, angle
pa,nu,3,180.      pattern, null, #, angle
st          status
ge,pl       generate, pattern (polar)
ucsyop4f.hpg
1           plot pattern
1           pen
4-element Endfire 0.35 Spacings, Norm Freq 1, 1.1, 1.2
st,pr       status, printer
li,ze,all,pr      list, zeros, all, printer
li,co,pr    list, coefficients, printer
li,si,pr    list, sidelobes, printer
no,fr       normalized, frequency
1.1         frequency
ge,pl       generate, pattern (polar)
y           Same coord. (overlay trace)
2,2         plot pattern, pen
4-element Endfire 0.35 Spacings, Norm Freq 1, 1.1, 1.2
no,fr       normalized, frequency
1.2         frequency
ge,pl       generate, pattern (polar)
y           same coord. (overlay trace)
3,3         plot pattern, pen
4-element Endfire 0.35 Spacings, Norm Freq 1, 1.1, 1.2
ex
```

This short array can operate with its frequency 20% higher and have a similar main beam but increased sidelobes and a little null filling, especially at 180°.

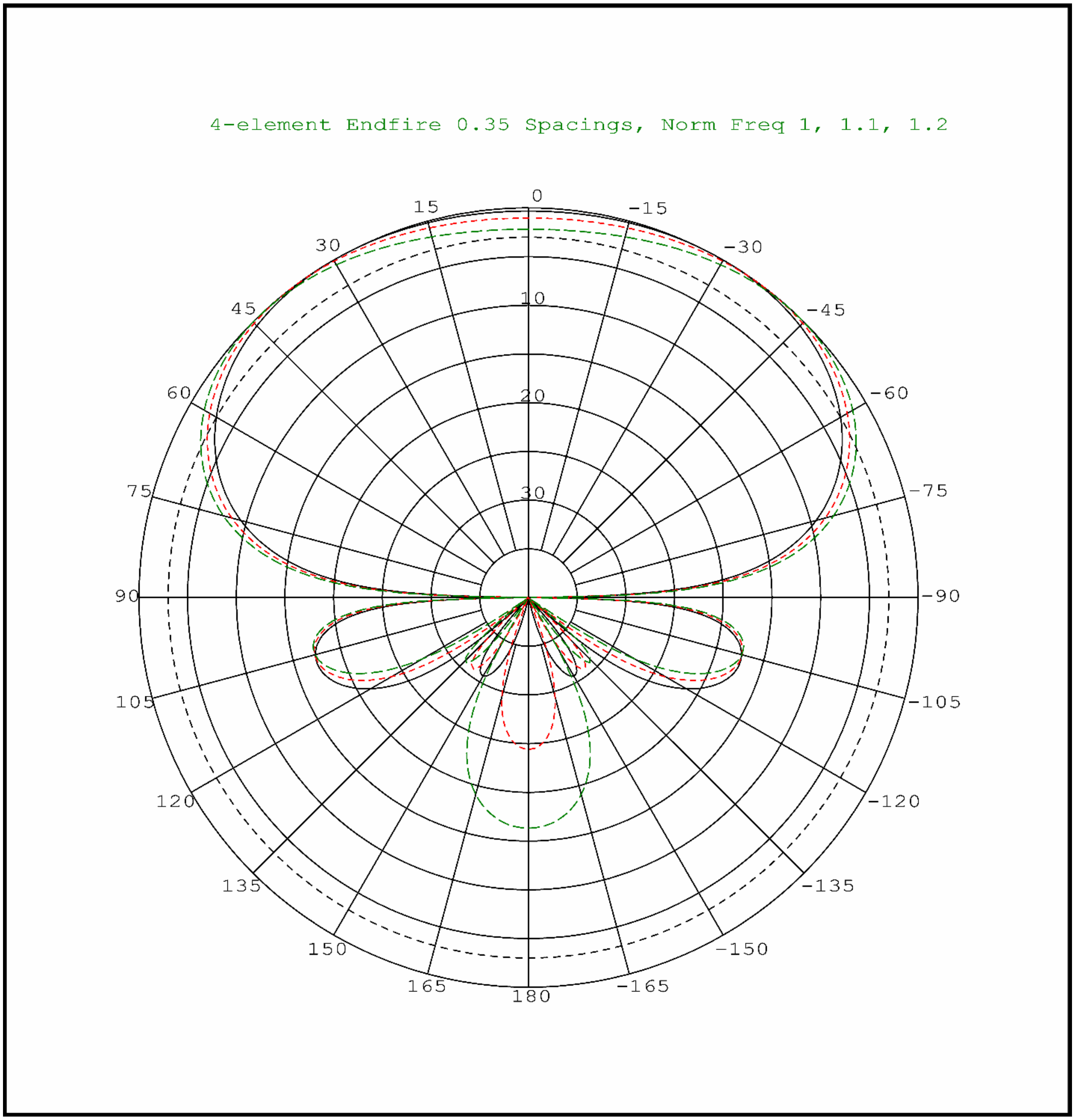


Figure 4-9.1.12 Polar Pattern 4-element Endfire Array with Nulls: 90°, 135°, 180°, Normalized Frequencies: 1, 1.1, and 1.2

Orchard Synthesis (Section 4-14)

Orchard synthesis involves iteration of pattern nulls to form a specified pattern which can involve adding extra pattern specifications including sidelobes and inter-angle values.

8-element Orchard Synthesis Specified Sidelobes λ/2 spacing Broadside Beam

The example plotted in Figure 4-17 uses a list of specified sidelobes easily seen in the figure. UCSYO input starts by specifying Orchard Synthesis: OR,SY and the file with list of sidelobes: ORCHS07.IN.

```
8           number of elements (orchard synthesis)
or,sy       orchard, synthesis
1           beam type: constant
90          main beam direction
85,95       flat-top range
ORCHS07.IN
0           roots off unit circle
n           generate root pairs
y           pick this iteration
ge,di generate, diagram
y           new pattern
ucsyoo8d.hpg
8-Element Orchard Synthesis, 0.5 Spacings, 0 Element Phase
```

ORCHS07.IN file:

```
1,-20.
2,-25.
3,-30.
4,-25.
5,-30.
6,-25.
7,0.
0,0
C  Sum pattern for 8 elements
C
C  Array C specifies sidelobes - N sidelobe levels relative to
C  absolute maximum in unshaped region and ripple maximum (first)
C  then minimum relative to shaping function beginning at -Pi
C  and progressing to +Pi
C
```

UCSYO output file

```
 Orchard Method for Linear Array
 Number of elements:               8
 Flat top beam
 Main beam w.r.t. axis:        90.00
 Beam start:                   85.00
 Beam stop:                    95.00
 Sidelobe file: ORCHS07.IN
  Number  Sidelobe
     1   -20.00
```

```
    2   -25.00
    3   -30.00
    4   -25.00
    5   -30.00
    6   -25.00
    7     0.00
Number of roots off unit circle =   0
Generate root pairs?  Roots of moveable roots on unit circle =   6
                     Convergence data
Iteration =   0 Maximum error =   3.16340E+01  2.35619E+00 C1    0.00
Iteration =   1 Maximum error =   1.71089E+00  2.13722E+00 C1 -248.14
Iteration =   2 Maximum error =   1.26736E-02  2.12907E+00 C1 -239.28
Iteration =   3 Maximum error =   1.63605E-03  2.12909E+00 C1 -239.24
Iteration =   4 Maximum error =   9.65791E-08  2.12913E+00 C1 -239.24
Unrotated roots
Root:  1 An:  0.0000 Bn: -2.4216
Root:  2 An:  0.0000 Bn: -1.6631
Root:  3 An:  0.0000 Bn: -1.0450
Root:  4 An:  0.0000 Bn: -0.1462
Root:  5 An:  0.0000 Bn:  0.4381
Root:  6 An:  0.0000 Bn:  1.0440
Root:  7 An:  0.0000 Bn:  3.1416

Rotated roots and associated currents

Current case:   1
Current rotation code An exponents


Number     W plane Zero       Element Excitation
           Real   Imaginary   Ampl(dB)   Phase
    1  -0.160906   0.986970       0.00    8.70
    2  -0.795715   0.605671       4.79    3.22
    3  -0.999471   0.032517       7.63    1.29
    4  -0.647664  -0.761926       8.69    4.91
    5  -0.119944  -0.992781       8.69    3.79
    6   0.466767  -0.884380       7.63    7.41
    7   0.529775   0.848138       4.79    5.48
    8                             0.00    0.00
Max:    8.69 Min:    0.00 Extent:    8.69
UCSYO Status
 8 Elements
Spacing Between Elements:   0.5000
```

```
 Phase Shift Between Elements:    0.00


W space sidelobes

   No    Sidelobe dB W angle
    1      -30.00     160.26
    2      -25.00     118.82
    3      -20.00      74.99
    4        0.00      -0.01
    5      -25.00     -76.25
    6      -30.00    -113.19
    7      -25.00    -155.95

   No   Magnitude   Angle     Null

    1     1.0000    99.26    56.53
    2     1.0000   142.72    37.54
    3     1.0000   178.14     8.25
    4     1.0000  -130.37   136.41
    5     1.0000   -96.89   122.57
    6     1.0000   -62.18   110.21
    7     1.0000    58.01    71.20

 Array Coefficients

   No   Mag(dB)    Phase   Mag(Volt.)

    1     -8.69     8.70      0.3676
    2     -3.90     3.22      0.6379
    3     -1.06     1.29      0.8851
    4      0.00     4.91      1.0000
    5      0.00     3.79      1.0000
    6     -1.06     7.41      0.8851
    7     -3.90     5.48      0.6379
    8     -8.69     0.00      0.3676
```

The output file shows the convergence with the W-space nulls, computed sidelobes from the pattern analysis, the angles of the W-space nulls and corresponding pattern nulls, and the final array coefficients.

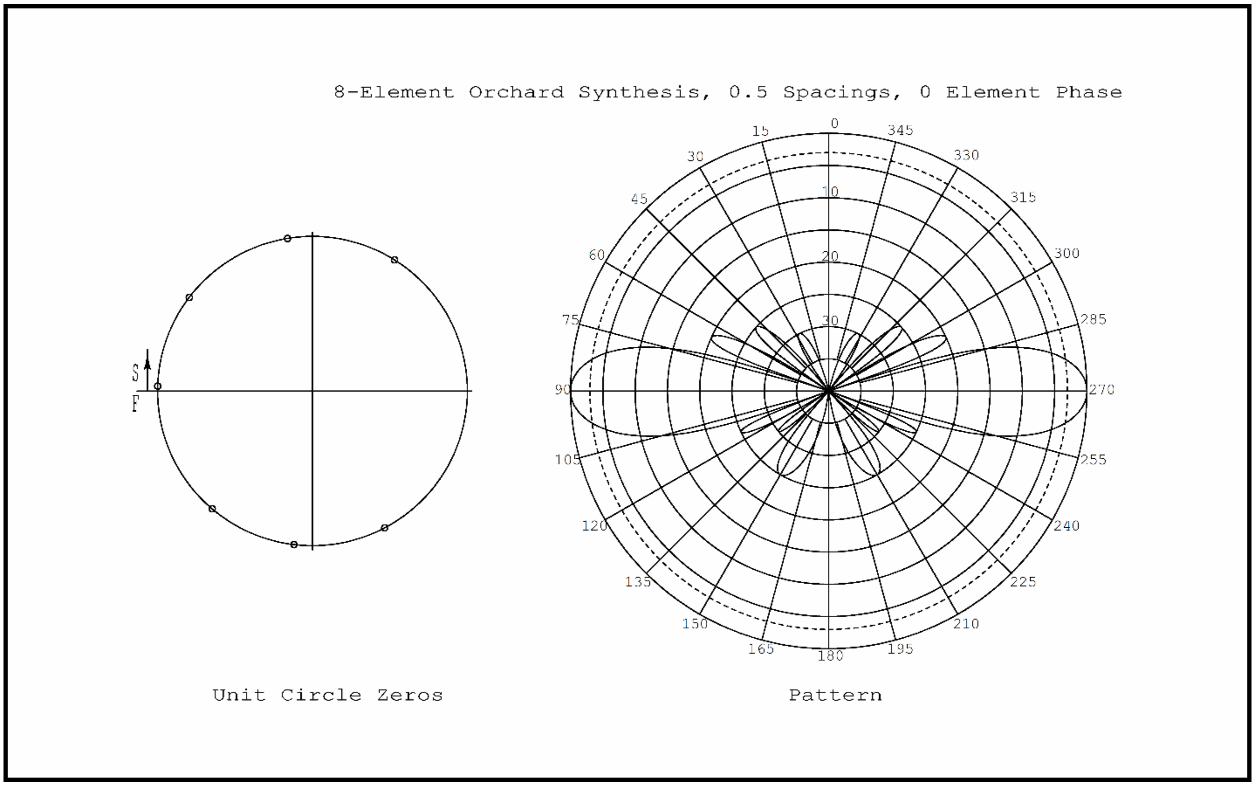


Figure 4-9.1.13 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, λ/2

8-element Orchard Synthesis Specified Sidelobes 0.7λ spacings Broadside Beam

This uses the same sidelobe file, ORCHS07.IN, as the first case with inputs:

```
8           number of elements (orchard synthesis)
or,sy       orchard, synthesis
1           beam type: constant
90          main beam direction
85,95       flat-top range
ORCHS07.IN
0           roots off unit circle
n           generate root pairs
y           pick this iteration
el,sp,0.7   element, spacing,     (only element spacing changes)
ge,di       generate, diagram
y           new pattern
ucsyoo8d.hpg
8-Element Orchard Synthesis, 0.7 Spacings, 0 Element Phase
```

The Orchard synthesis computes the same array coefficients as the λ/2 spacings.

```
Array Coefficients
```

No	Mag(dB)	Phase	Mag(Volt.)
1	-8.69	8.70	0.3676
2	-3.90	3.22	0.6379
3	-1.06	1.29	0.8851
4	0.00	4.91	1.0000
5	0.00	3.79	1.0000
6	-1.06	7.41	0.8851
7	-3.90	5.48	0.6379
8	-8.69	0.00	0.3676

The Schelkunoff Unit-Circle Diagram shows that the unique sidelobes are used multiple times since the W-space nulls have not moved. Orchard synthesis uses λ/2 spaced elements.

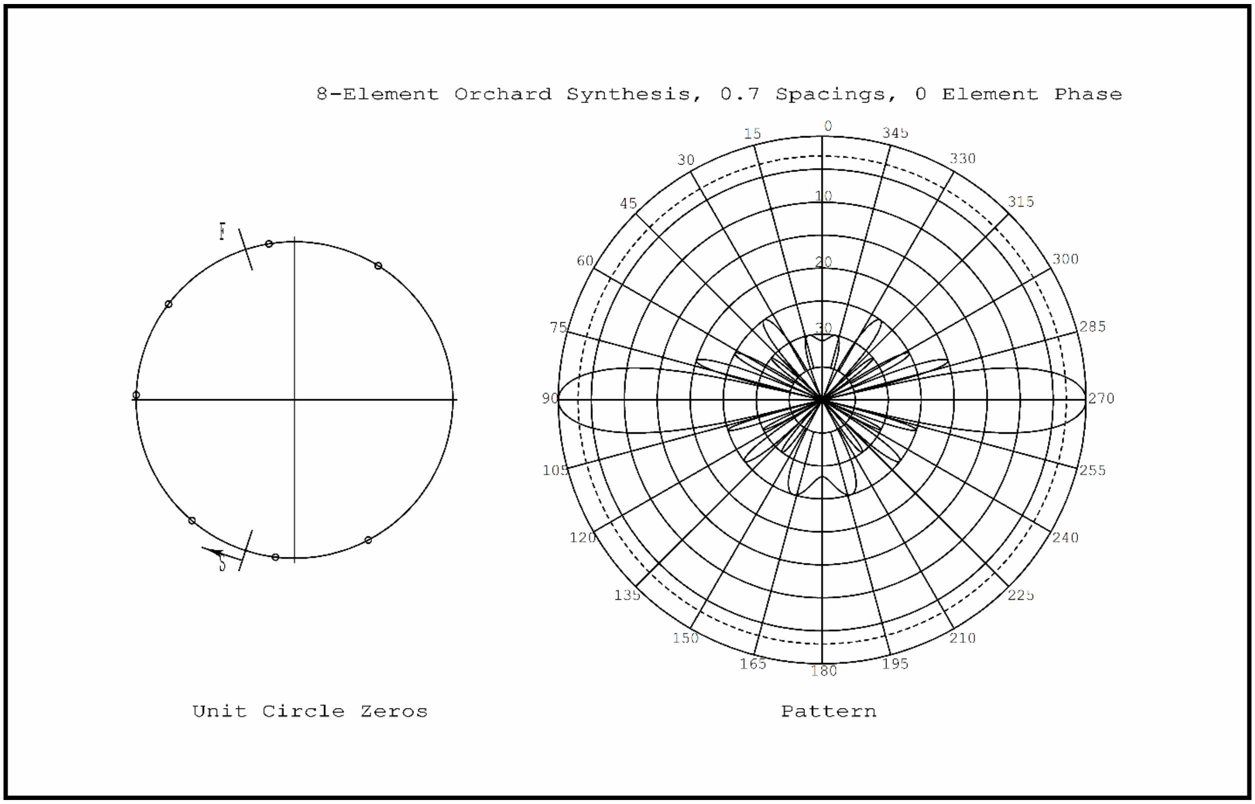


Figure 4-9.1.14 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, 0.7λ

8-element Orchard Synthesis Specified Sidelobes λ/4 spacings End-fire Beam

The Orchard synthesis uses the 8-specified sidelobes (ORCHS07.IN) in the synthesis but the λ/4 spacings limit the pattern region to use only the last three-sidelobes: -25, -30, and -25 and half the W-space angular range.

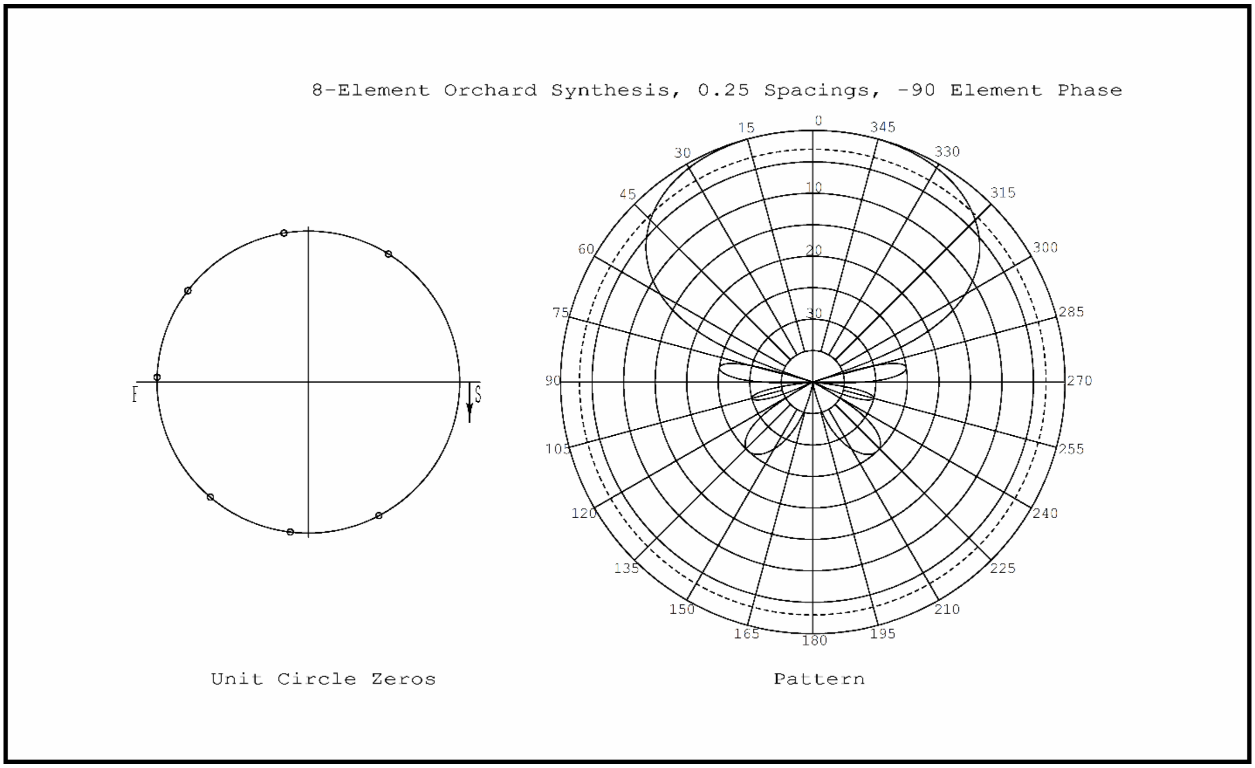


Figure 4-9.1.15 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, λ/4 spacings limit pattern to 3 sidelobes and 5 elements from 4 nulls

The output file UCSYO.OUT lists the array excitation including the -90° phase progression between elements.

```
Array Coefficients

   No   Mag(dB)    Phase   Mag(Volt.)

    1     -8.69     8.70      0.3676
    2     -3.90   -86.78      0.6379
    3     -1.06  -178.71      0.8851
    4      0.00    94.91      1.0000
    5      0.00     3.79      1.0000
    6     -1.06   -82.59      0.8851
    7     -3.90  -174.52      0.6379
    8     -8.69    90.00      0.3676
```

The array uses the last four excitations: 5 – 8, and 1 of the listing above.

8-element Orchard Synthesis Specified Sidelobes 0.42λ spacings End-fire Beam

The Orchard synthesis uses the 8-specified sidelobes (ORCHS07.IN) in the synthesis but the 0.42λ spacings limit the pattern region uses all the sidelobes: -25, -30, -25, -30, -25, and -20 by using 0.84 the W-space angular range and six-elements.

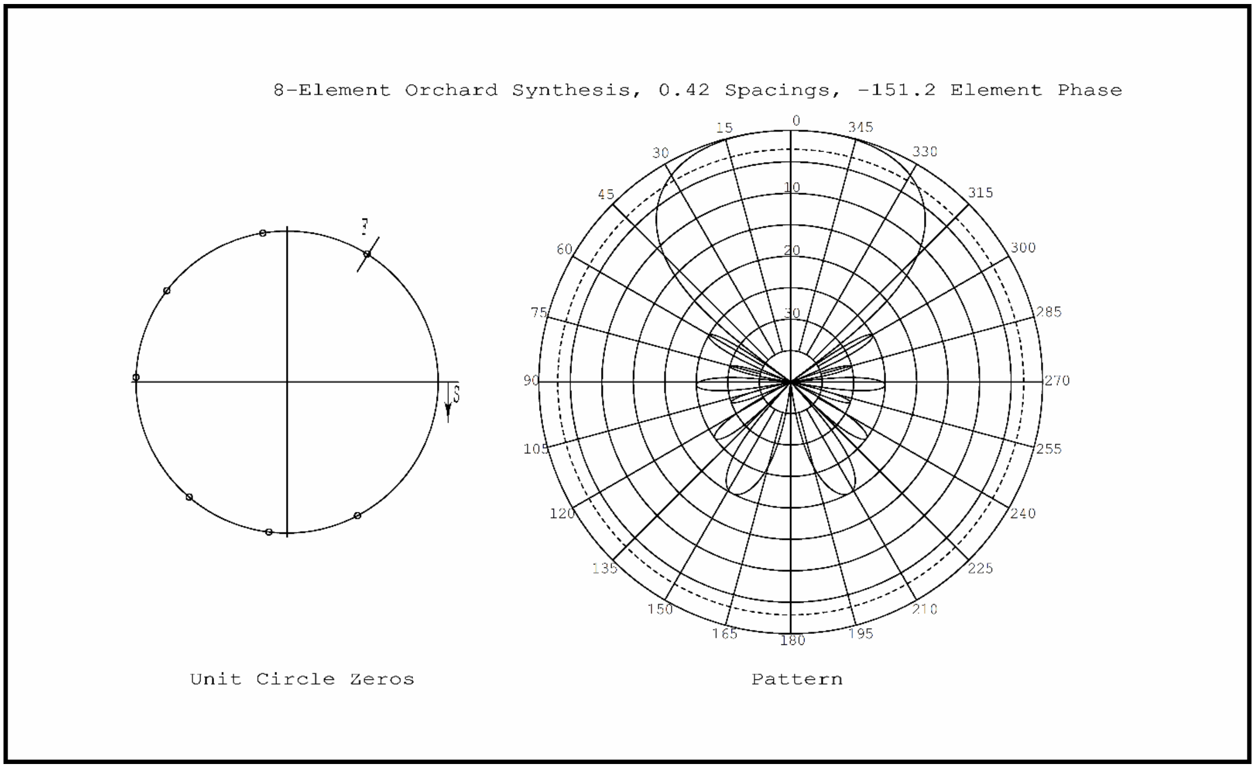


Figure 4-9.1.16 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, 0.42λ spacings limit pattern to 6 sidelobes and 7 elements from 7 nulls

```
UCSYO Status
  8 Elements
 Spacing Between Elements:   0.4200
 Phase Shift Between Elements: -151.20

 W space sidelobes

   No    Sidelobe dB W angle
    1      -30.00     160.26
    2      -25.00     118.82
    3      -20.00      74.99
    4        0.00      -0.01
    5      -25.00     -76.25
```

```
    6      -30.00    -113.19
    7      -25.00    -155.95
```

Scanned to endfire, the array uses sidelobes in order: 5, 6, 7, 1, 2, 3 of the listing above.

```
Array Coefficients

   No   Mag(dB)    Phase   Mag(Volt.)

    1     -8.69     8.70      0.3676
    2     -3.90  -147.98      0.6379
    3     -1.06    58.89      0.8851
    4      0.00   -88.69      1.0000
    5      0.00   118.99      1.0000
    6     -1.06   -28.59      0.8851
    7     -3.90   178.28      0.6379
    8     -8.69    21.60      0.3676
```

The array uses the last four excitations: 5 – 8, and 1, 2, 3 of the listing above.

8-element Orchard Synthesis Specified Sidelobes λ/2 spacing Difference Beam

The list of sidelobes removes the last sidelobe before the main beam and adds another beam: -20, -25, -30, -25, -30, 0., and 0

Running Orchard Synthesis on this list of sidelobes and two main beams produces the Schelkunoff Unit-Circle diagram.

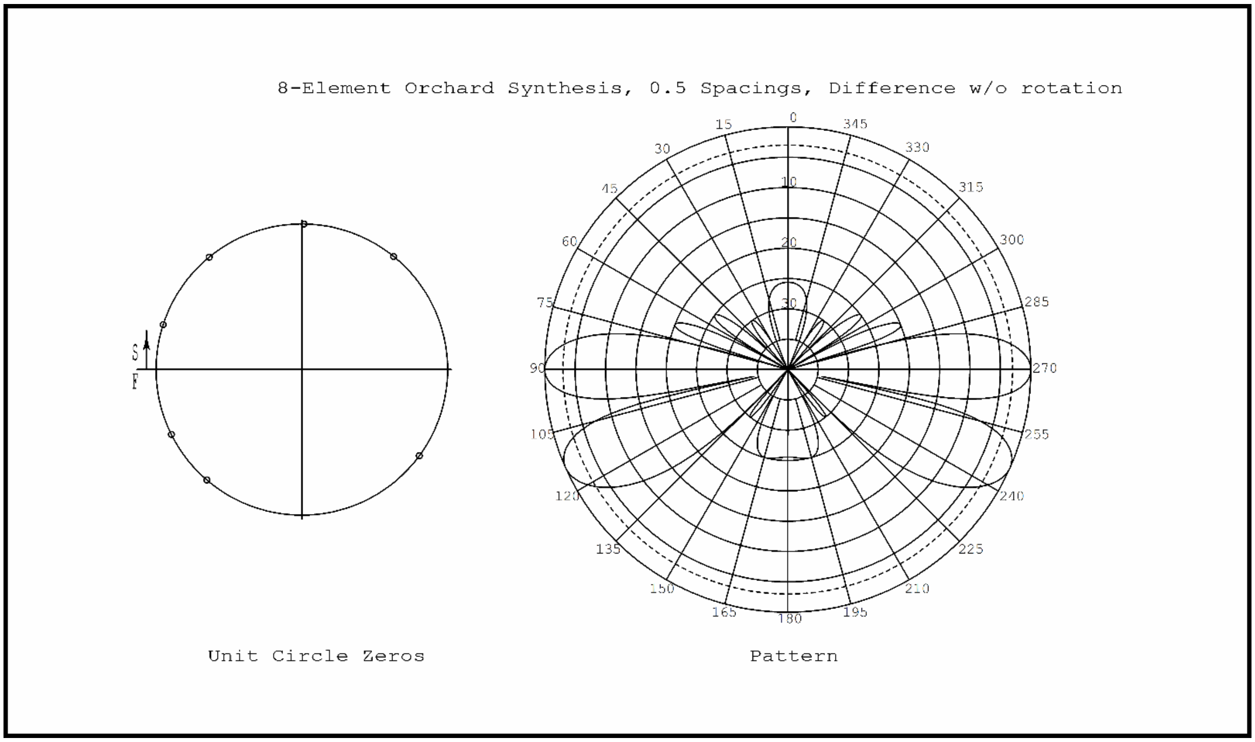


Figure 4-9.1.17 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, λ/2

To move the null between the two main beams to 90°, it is necessary to rotate all the zeros in the W-space until the null in the 4th quadrant is at zero. The output file UCSYO1.OUT lists the W-space nulls.

Number	W plane Zero Real	Imaginary	Element Excitation Ampl(dB)	Phase
1	0.015720	0.999876	0.00	-68.87
2	-0.636163	0.771554	5.97	-36.67
3	-0.951099	0.308886	6.32	-0.82
4	-0.894805	-0.446458	-0.59	41.75
5	-0.651497	-0.758651	-0.59	-110.62
6	0.805685	-0.592344	6.32	-68.05
7	0.629637	0.776889	5.97	-32.21
8			0.00	0.00

Null #6 is located in the 4th quadrant and located at -32.3235°. After the Orchard synthesis, all zeros need to be rotated by the commands:

```
ro,ze       rotate, zeros
1           give angle
36.3235     angle
0           scan angle from axis
```

This locates a null at zero in W-plane.

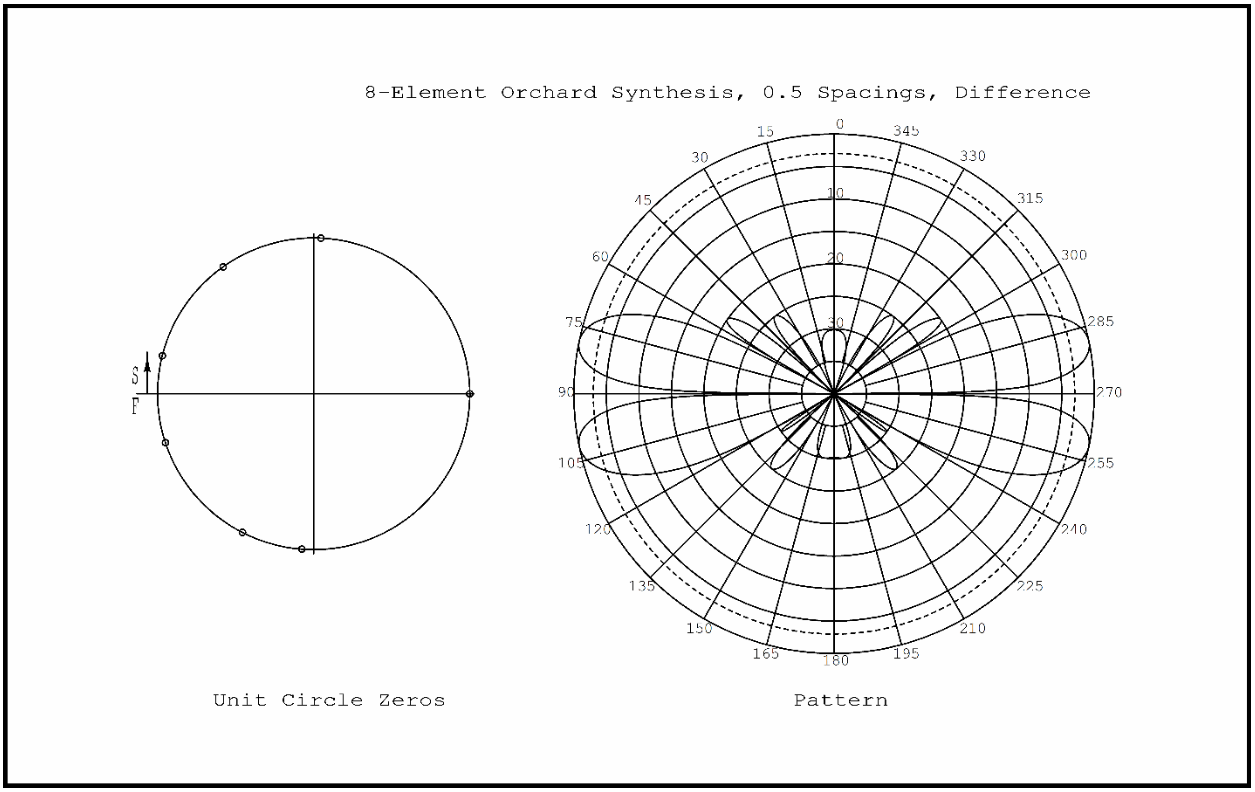


Figure 4-9.1.18 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, λ/2 for difference pattern

8-element Orchard Synthesis Specified Sidelobes λ/2 spacing 22° Flat Top Beam

A flat top beam centered on 90° can be synthesized by using the Orchard method. If the beam is specified from 79° to 101°, the synthesis computation will fail. The beam needs to be specified either over the range 68° to 90° or 90° to 112°, synthesized and have its W-spaced zeros rotated until the beam

-20 -25 -30 -25 -30 0 0 -1

The initial design for a beam from 90° to 112° with beam peak 90° produces the following Schelkunoff unit circle diagram.

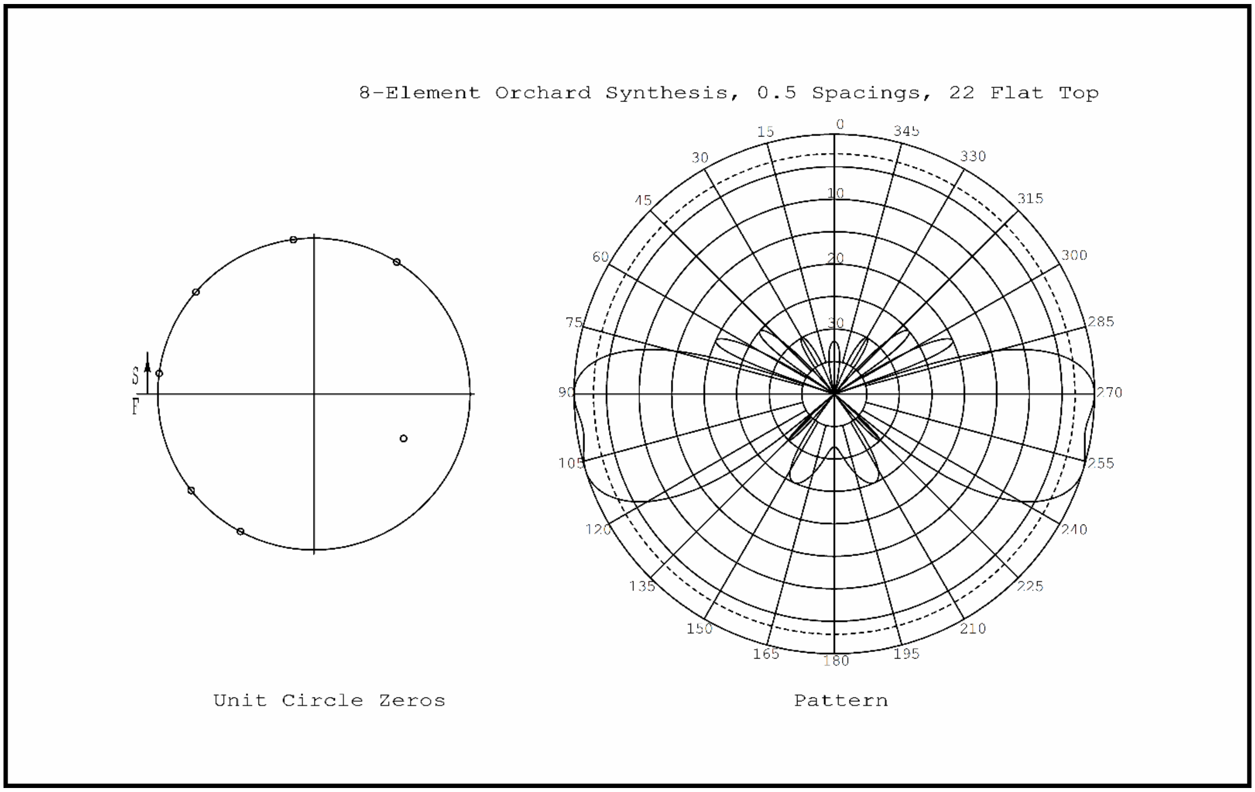


Figure 4-9.1.19 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, λ/2 for 22° flat-top pattern for beam peak at 90°

The diagram occurs for the second case design where the W-space zero for the pattern dip is inside the unit circle, the first case has this zero outside the unit circle. We need to rotate all the W-space zeros to center the pattern. The output file of this case lists the W-space zeros.

Number	W plane Zero		Element Excitation	
	Real	Imaginary	Ampl(dB)	Phase
1	-0.131693	0.991291	-3.85	0.64
2	-0.755701	0.654917	-1.69	20.30
3	-0.991207	0.132318	-15.60	35.80
4	-0.786017	-0.618204	1.19	-107.17
5	-0.470556	-0.882370	7.95	-77.73
6	0.574761	-0.285614	9.10	-48.48
7	0.531355	0.847149	6.83	-22.48

The 6th zero is located inside the unit circle. We compute the rotation to place this zero on the axis as 26.242°. By adding the zeros rotation command:

ro,ze	rotate, zero
1	enter angle
26.424	angle
0	scan angle

The pattern is centered at 90° for the W-space zero on axis.

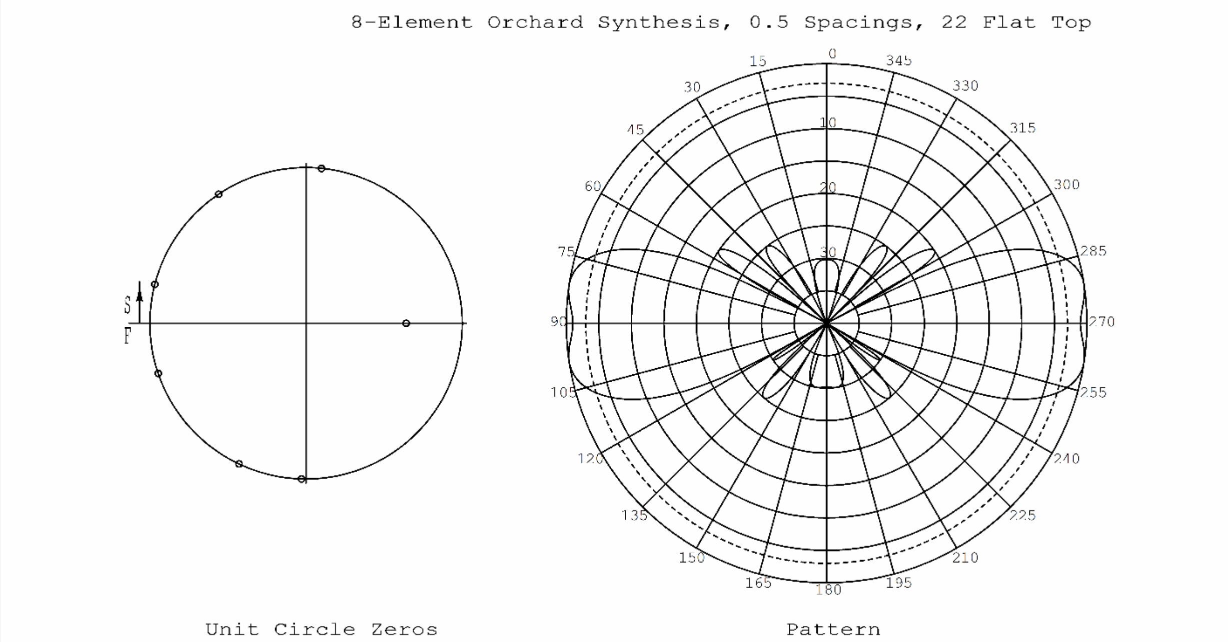


Figure 4-9.1.20 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, λ/2 for 22° flat-top pattern centered at 90°

Array Coefficients

No	Mag(dB)	Phase	Mag(Volt.)
1	-12.95	-174.39	0.2252
2	-10.78	178.85	0.2890
3	-24.69	167.92	0.0583
4	-7.90	-1.47	0.4026
5	-1.15	1.54	0.8759
6	0.00	4.37	1.0000
7	-2.26	3.95	0.7705
8	-9.10	0.00	0.3509

The other option uses a beam peak at 68° for a constant beam from 68° to 90° whose synthesis produces the Schelkunoff unit circle diagram.

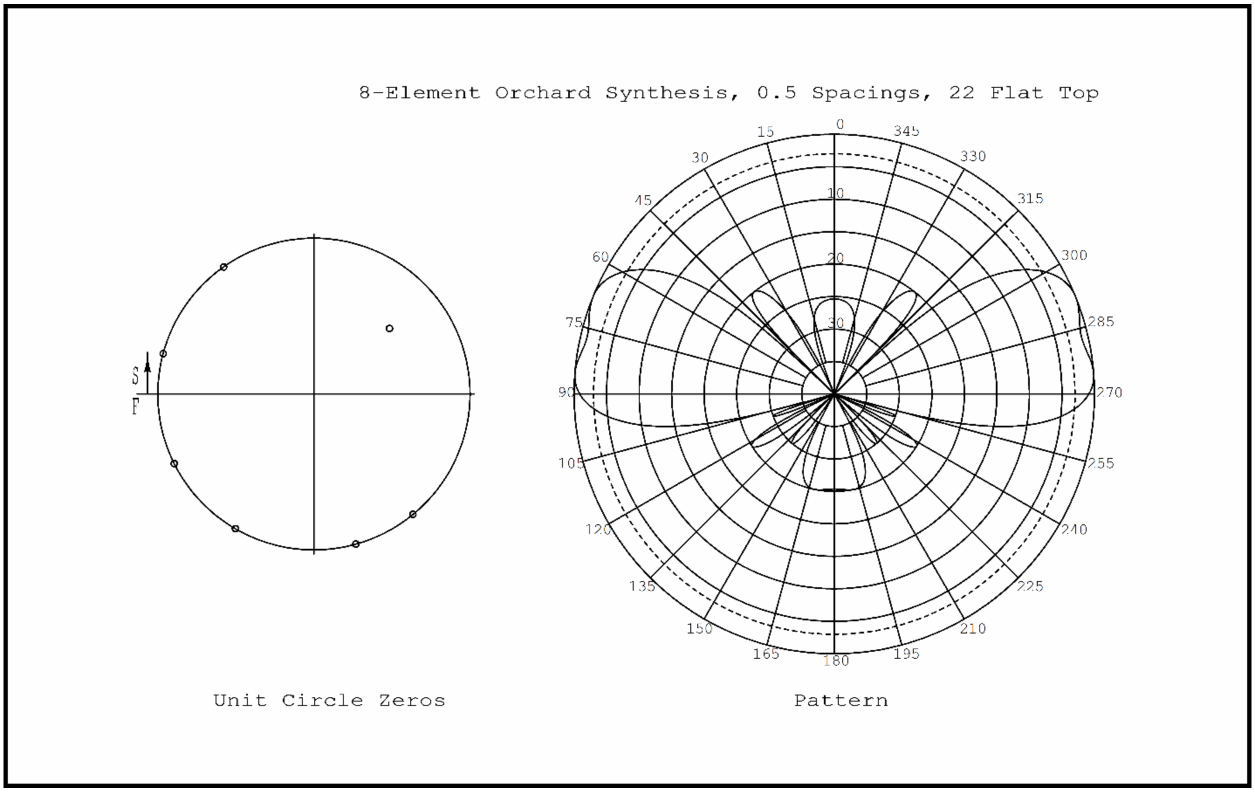


Figure 4-9.1.21 Unit Circle Diagram 8-element Orchard Synthesis for Specified Sidelobes, λ/2 for 22° flat-top pattern for beam peak at 68°

The W-space rotation of -41.005° places the zero of the dip zero on axis and produces the same diagram as of Figure 4-9.1.20 and generates the same array coefficients.

Figure 4-9.1.22 plots the polar pattern of the array when normalized frequency is shifted upward to 1.1 and 1.2. Increasing frequency narrows the flat-top beam and shifts sidelobes with an increase at 0° and 180°.

21-element Orchard Synthesis Specified Sidelobes λ/2 spacing Constant Beam Centered 60° with a 45° beamwidth (Figure 4-23)

```
21          number of elements (orchard synthesis)
or,sy       orchard, synthesis
1           beam type: constant
45.         main beam direction
45.,77.           flat-top range
ORCHS04.IN
5           roots off unit circle
```

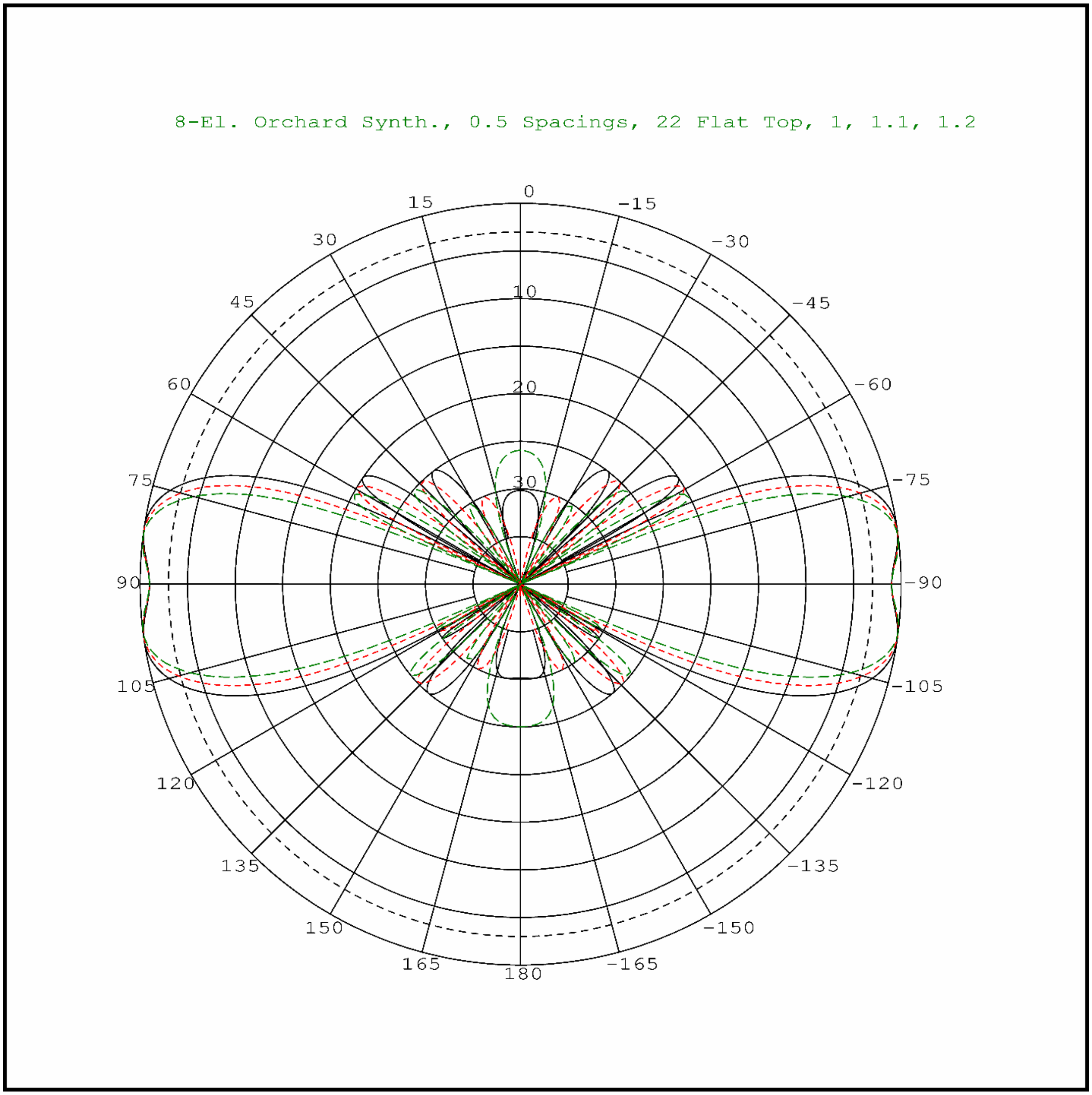


Figure 4-9.1.22 8-element Orchard Synthesis for Specified Sidelobes, λ/2 for 22° flat-top pattern centered at 90° Frequency Response

The synthesis suggests 5 zeros be displaced from the unit circle. Trying other cases usually fails to converge. Section 4-14 states that 32 cases place the dip zeros in different combinations of inside and outside the unit circle. When running these cases, we find only 16 different array coefficients cases occur. Generally, we chose the case with the minimum amplitude range of element excitations. Case 7 produces the Schelkunoff unit circle diagram shown in Figure 4-23. All cases produce the same pattern response.

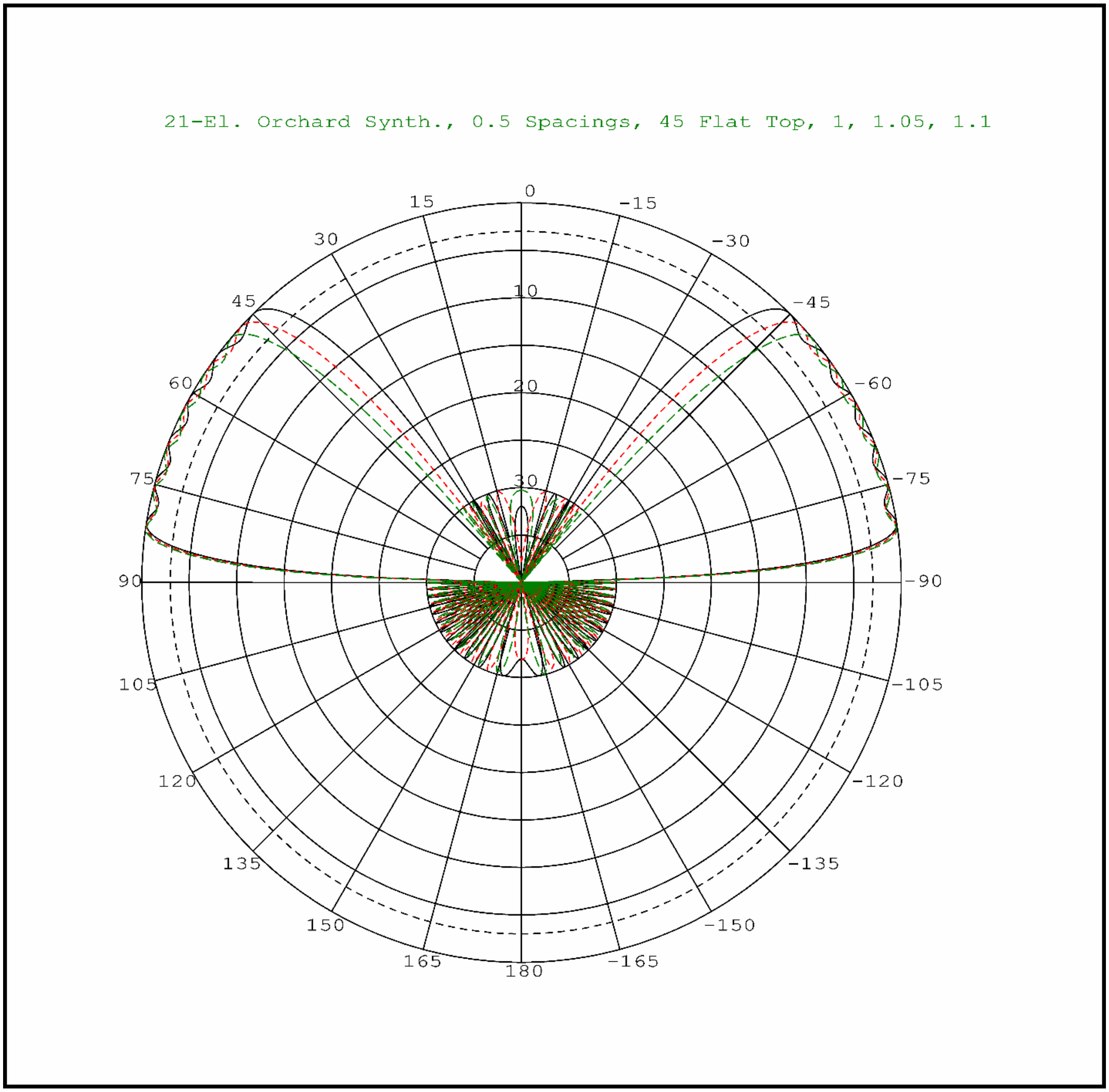


Figure 4-9.1.23 21-element Orchard Synthesis for Specified Sidelobes, λ/2 for flat-top pattern centered at 60° with 45° beamwidth Frequency Response

As frequency increases the upper beam edge remains constant while the total beamwidth decreases as frequency increases. A second case with a wider beamwidth produces a beam closer to specifications.

21	number of elements (orchard synthesis)
or,sy	orchard, synthesis
1	beam type: constant
40	main beam direction
40,78.5	flat-top range

ORCHS05.IN

5 roots off unit circle

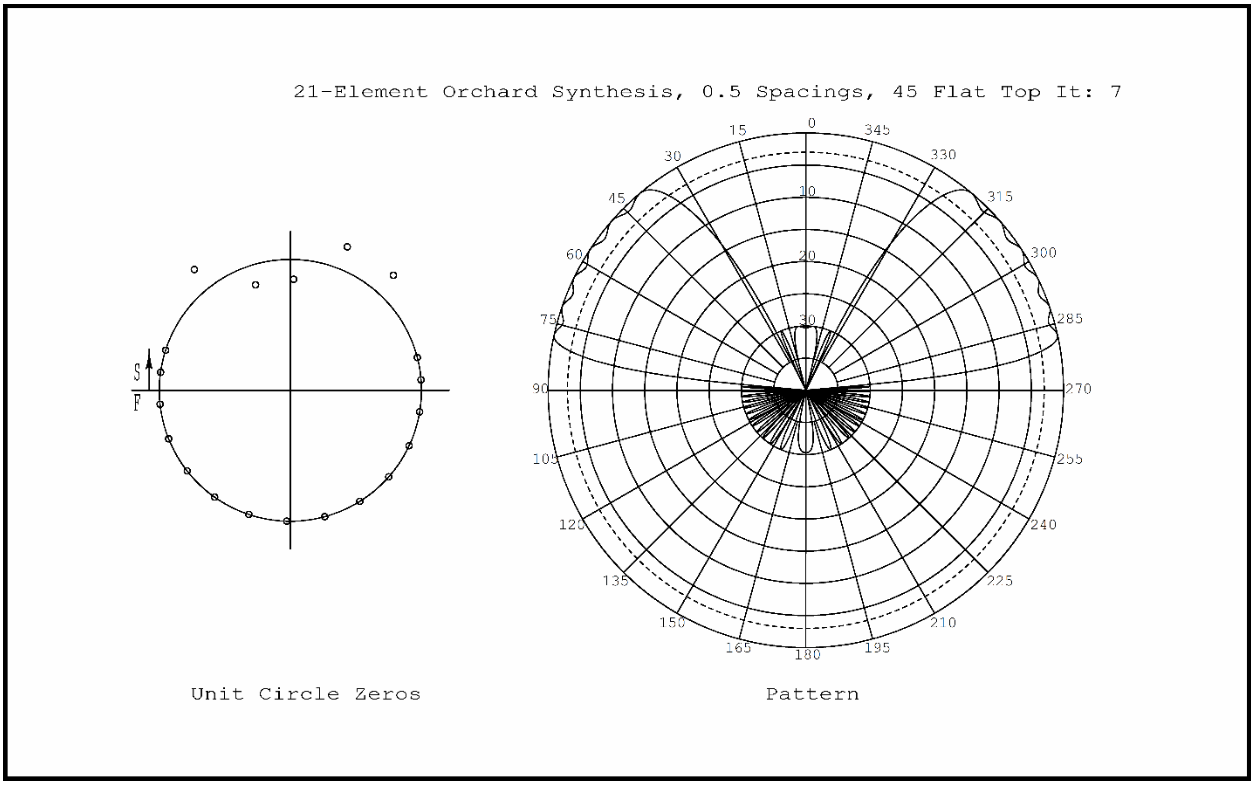


Figure 4-9.1.24 Unit Circle Diagram 21-element Orchard Synthesis for Specified Sidelobes, λ/2 for 45° flat-top pattern centered at 60° for beam peak at 40° (40° to 78.5°)

Cosec$^2\vartheta$ cos ϑ Patterns

Input files for these patterns have no surprises and are given in the folders. Below are the frequency responses.

16	number of elements (orchard synthesis)
or,sy	orchard, synthesis
2	beam type: csc-cos
100.	main beam direction
100.,133.	beam extent
ORCHS10.IN	
4	roots off unit circle
n	generate root pairs

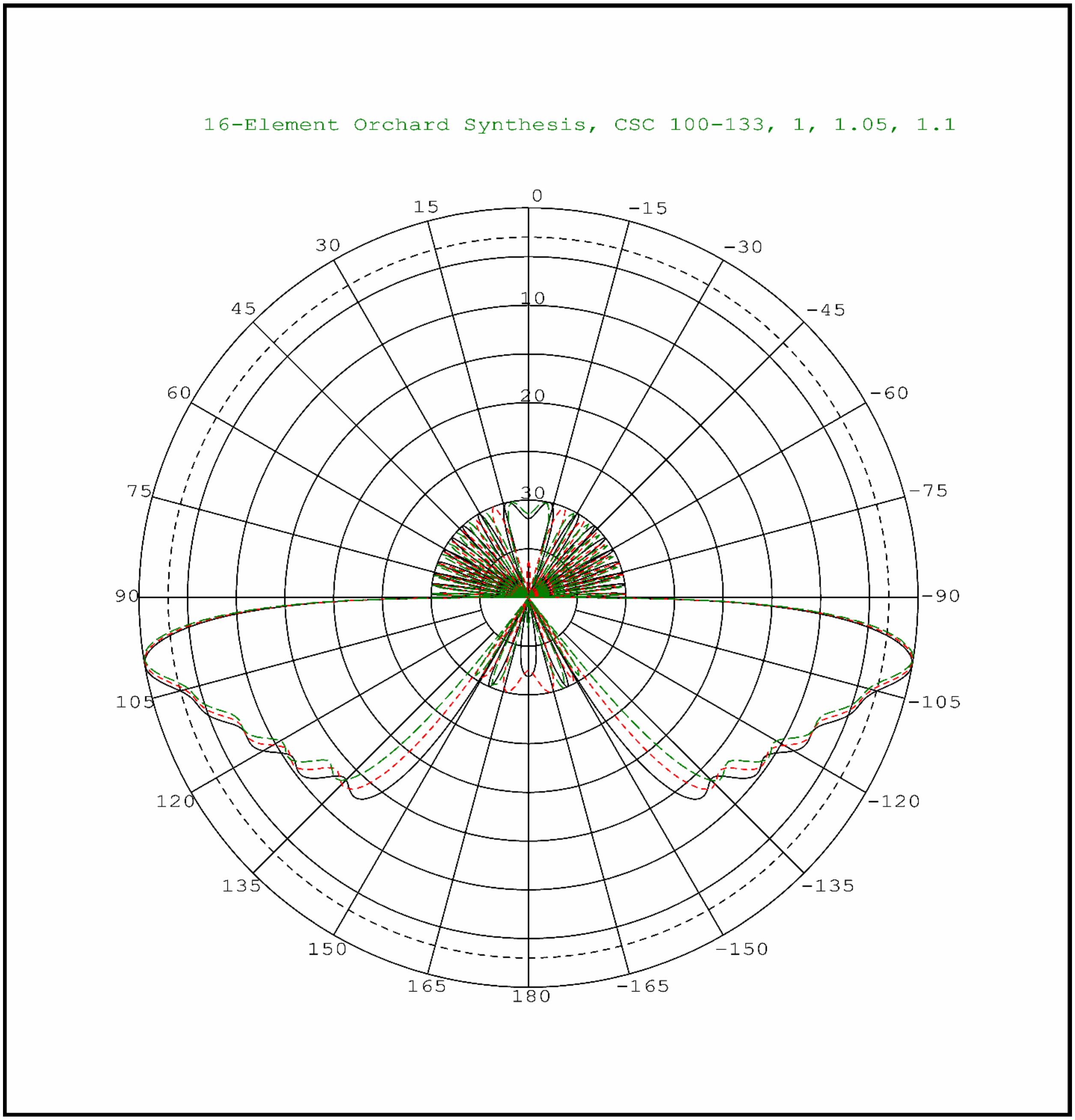


Figure 4-9.1.25 16-element Orchard Synthesis for Specified Sidelobes, λ/2 Spacings for Csc^2 *θ Cos θ* pattern Frequency Response

8	number of elements (orchard synthesis)
or,sy	orchard, synthesis
2	beam type: csc-cos
100.	main beam direction
100.,140.	beam extent
ORCHS05.IN	

2 roots off unit circle

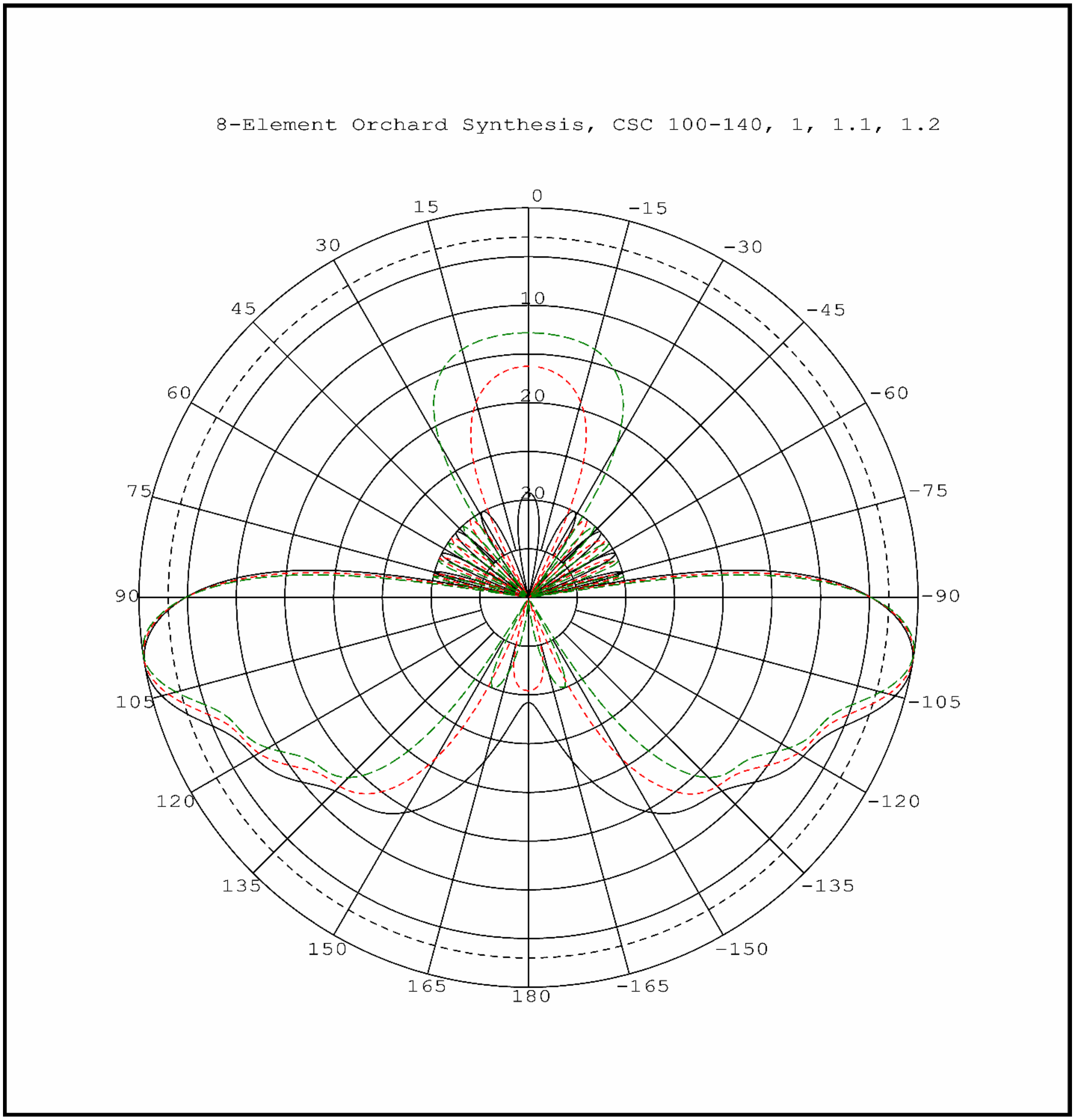


Figure 4-9.1.26 8-element Orchard Synthesis for Specified Sidelobes, λ/2 Spacings for Csc^2 *θ Cos θ* pattern Frequency Response