

Design of an 8X8 Printed Circuit Board Dipole Phased Array using HFSS

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Outline

- Introduction
- Antenna Specifications
- Designing the isolated dipole
- Designing the arrayed dipole
- Results

Antenna Design Goals

- Objective: build a low cost, high performance, broad band multi-beam with large scan angles print circuit board dipole phased array antenna
- Challenges
 - Difficult to analyze the dielectric loading effects on the active impedance and radiation pattern using expansion of ordinary space modes
 - Difficult to design the phased array with large scan angles
 - Difficult to predict antenna blindness due to surface wave

Antenna Specifications

- Frequency: 1.71 – 1.99 GHz
- Number of Beams: 7 simultaneous multi-beam
- Beam Directions: $-53^\circ, -32^\circ, -15^\circ, 0^\circ, 15^\circ, 32^\circ, 53^\circ$
- Antenna Gain:
 - 1.71 GHz: 18 dB center beam, 16 dB edge beam
 - 1.8 GHz: 18.4 dB center beam, 16.4 dB edge beam
 - 1.9 GHz: 18.8 dB center beam, 16.8 dB edge beam
 - 1.99 GHz: 19.1 dB center beam, 17.1 dB edge beam
- Azimuth Beamwidth:
 - 1.71 GHz: 14.5° center beam, 23.4° edge beam
 - 1.8 GHz: 13.8° center beam, 22.3° edge beam
 - 1.9 GHz: 13.1° center beam, 21.1° edge beam
 - 1.99 GHz: 12.5° center beam, 20.1° edge beam
- Elevation Beamwidth: 9°
- Polarization: Linear, vertical

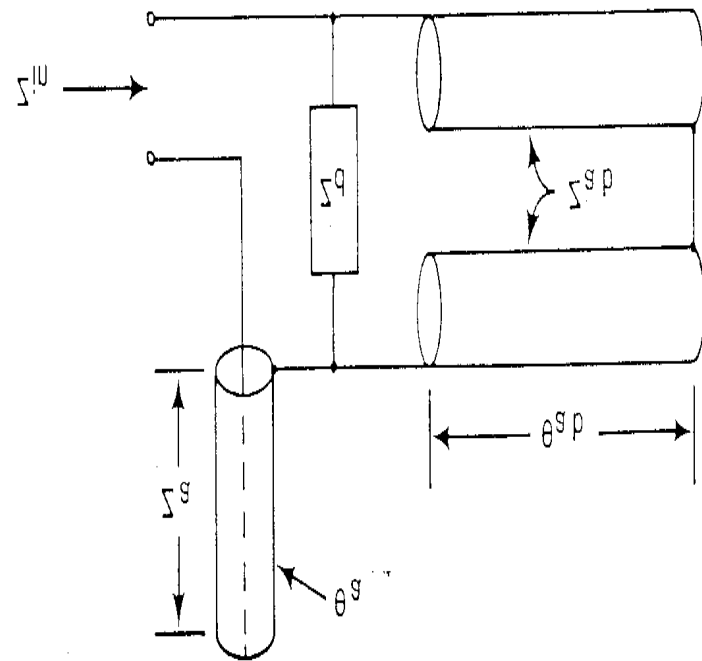
Antenna Description

- Substrate: FR-408 ($\epsilon_r = 3.7$, loss tangent = 0.01)
- Substrate thickness: 0.03"
- 8X8 array
- Element separation: 0.7λ in elevation, 0.5λ in azimuth

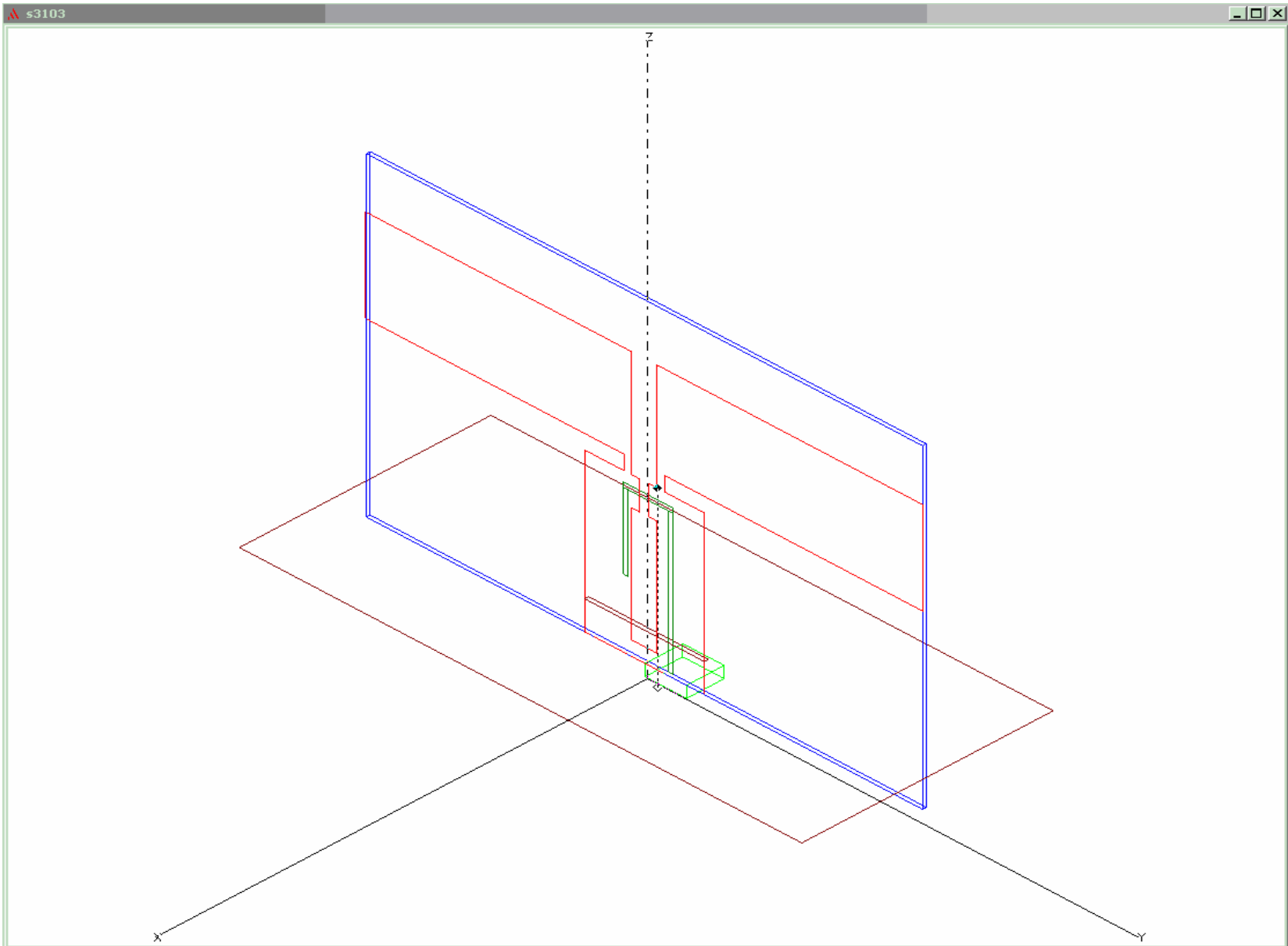
Equivalent Circuit of Isolated Dipole Balun

- Double-tuning capability of the balun
- Input impedance is a combination of a series open stub and a shunt short circuit

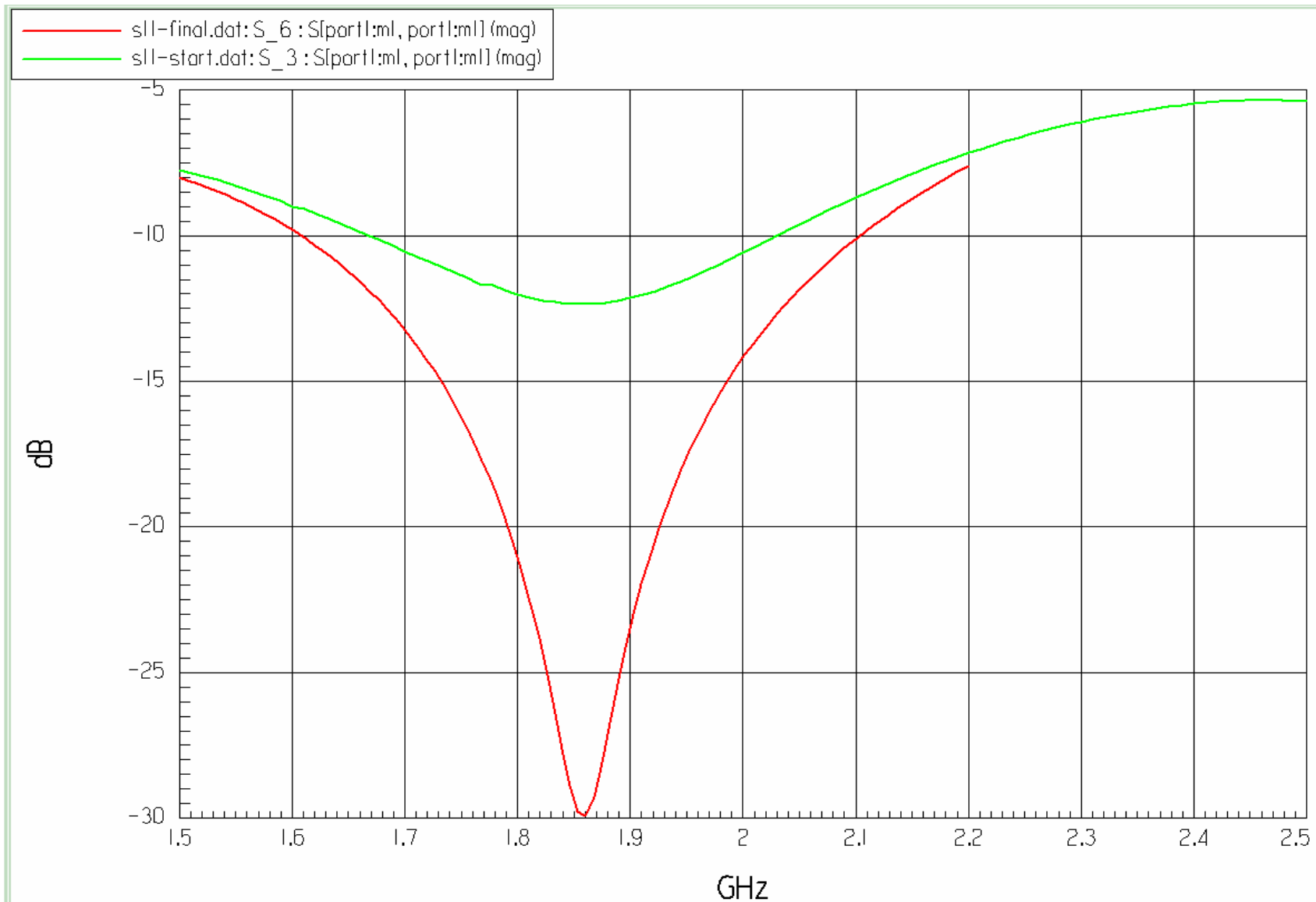
$$Z_{in} = -jZ_a \cot \mathbf{q}_a + \frac{jZ_d Z_{ab} \tan \mathbf{q}_{ab}}{Z_d + jZ_{ab} \tan \mathbf{q}_{ab}}$$



Model of Broad Band Printed Circuit Board Dipole in HFSS



Comparison of Reflection Coefficient before and after Optimization Design



Set-up Parameters in HFSS Macro

The screenshot displays the Ansoft Macro Editor interface. The main window contains a macro script with the following code:

```

62 NewObjColor 0 0 255
63 Box [-0.015, -2.5, -1.875] 0.03 5 2.75 "substrate"
64 FitAllViews
65 NewObjColor 255 0 0
66 Rectangle Pos3 0.015 arm5BaseY arm5BaseZ
67 NewObjColor 255 0 0
68 Rectangle Pos3 0.015 arm4BaseY arm4BaseZ
69 NewObjColor 255 0 0
70 Rectangle Pos3 0.015 arm3BaseY arm3BaseZ
71 NewObjColor 255 0 0
72 Rectangle Pos3 0.015 arm2BaseY arm2BaseZ
73 NewObjColor 255 0 0
74 Rectangle Pos3 0.015 arm1BaseY arm1BaseZ
75 Unite { "rect1" "rect2" "rect3" "rect4"
76 Select { "+rect1" }
77 DupMirror [0, 0, 0] [0, -1, 0]
78 Unite { "rect1" "rect2" }
79 NewObjColor 0 128 0
80 ReName "rect1" "arm"
81 NewObjColor 0 255 255
82 Box [-4, -4, -4] 8 8 8 "air"
83 FitAllViews
84 NewObjColor 128 0 0
85 FitAll
86 Select { "-air" }
87 SelClear
88 NewObjColor 128 0 0
89 Rectangle [1, -4, -1.625] 2 -2 8 "rect11
90 NewObjColor 128 0 0
91 Rectangle [0.015, -0.475, -1.625] 2 -0.0
92 Subtract { "rect11" } { "rect13" }
93 FitAll
94 ReName "rect11" "ground1"
95 NewObjColor 0 255 0
96 Box [0.015, 0.0045, -1.875] -0.3 0.33 -0
97 Select { "+box1" }
98 ReName "box1" "cap1"
99 FitAll
100 NewObjColor 0 128 0
101 Rectangle Pos3 -0.015 trace1BaseY trace1
102 NewObjColor 0 128 0
103 Rectangle Pos3 -0.015 trace2BaseY trace2
104 NewObjColor 0 128 0
105 Rectangle Pos3 -0.015 trace3BaseY trace3
  
```

An "Edit Parameters" dialog box is open, displaying a table of parameters:

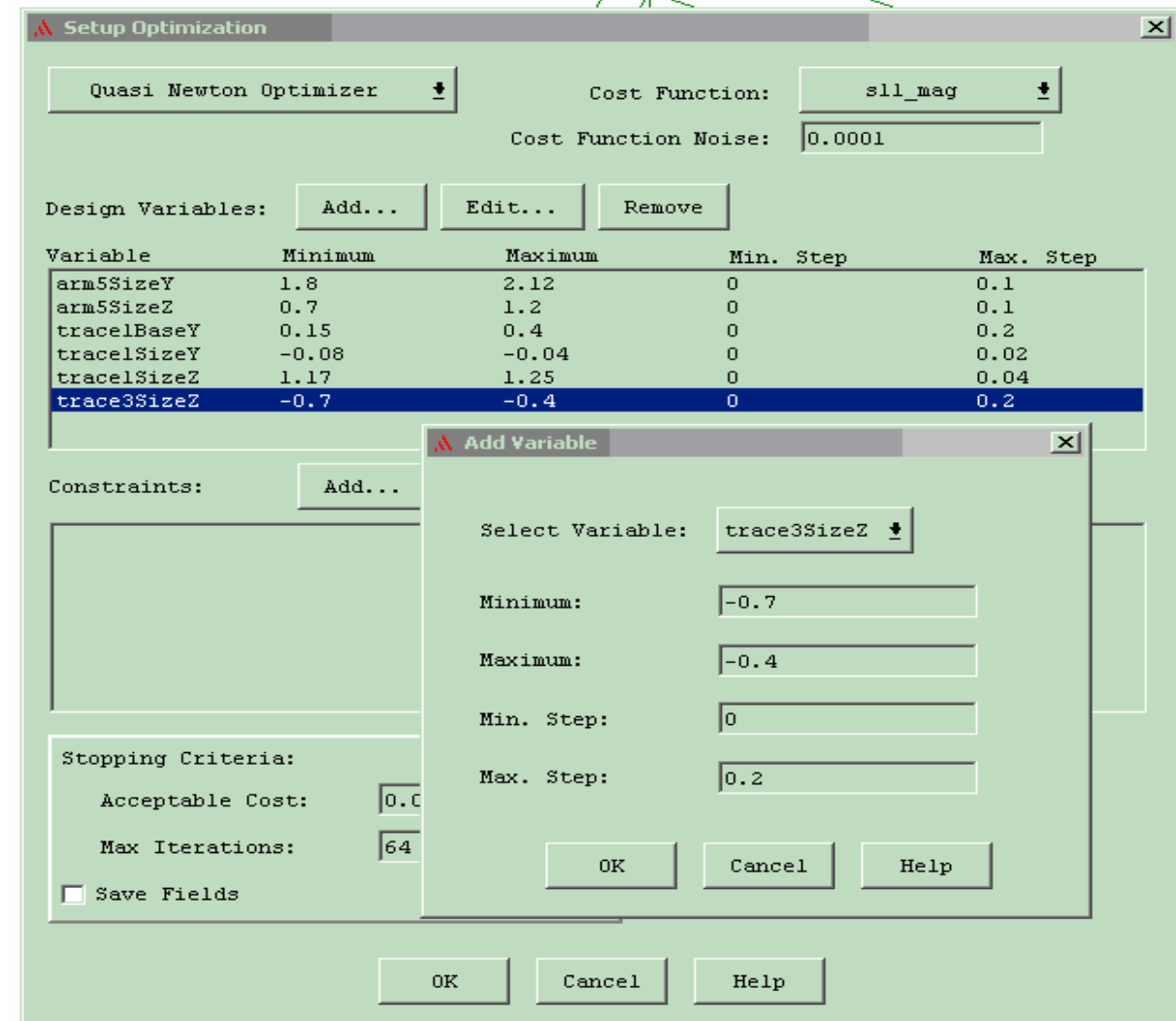
Name	Value	Expression
arm1BaseY	0.475	0.475
arm1BaseZ	-1.875	-1.875
arm1SizeY	-0.475	-0.475
arm1SizeZ	0.125	0.125
arm2BaseY	0.475	arm1BaseY
arm2BaseZ	-1.75	arm1BaseZ+arm1SizeZ
arm2SizeY	-0.375	-0.375
arm2SizeZ	1	1
arm3BaseY	0.475	arm1BaseY
arm3BaseZ	-0.75	arm2BaseZ+arm2SizeZ
arm3SizeY	-0.4375	-0.4375
arm3SizeZ	0.25	0.25
arm4BaseY	0.1	0.1
arm4BaseZ	-0.5	arm3BaseZ+arm3SizeZ
arm4SizeY	0.0625	0.0625
arm4SizeZ	0.125	0.125
arm5BaseY	0.1	arm4BaseY
arm5BaseZ	-0.375	arm4BaseZ+arm4SizeZ
arm5SizeY	2.3	2.3
arm5SizeZ	0.98281	0.98281
trace1BaseY	0.2205	0.2205
trace1BaseZ	-1.875	-1.875
trace1SizeY	-0.066	-0.066

Below the table, the parameter "arm1BaseY" is set to "0.475". Buttons for "Update", "Add", "Delete", "Help...", "Dataset", and "Done" are visible.

An "Object type: Rectangle" dialog box is also open, showing the object name "rect4" and various coordinate and size parameters.

At the bottom of the Macro Editor, there are radio buttons for "Single" and "Multiple" (selected), and buttons for "Accept", "Preview", and "Cancel".

Set-up Variables in Optimetrics



Optimization Output Table

Setup	arm5SizeY	arm5SizeZ	tracelBaseY	tracelSizeY	tracelSizeZ	trace3SizeZ	Solved	Sensitivity Done	Save Fields	Solve	cost	sll_mag
setup1	1.875	0.75	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0713968	0.267202
setup2	1.89598	0.75	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0753092	0.274425
setup3	1.875	0.784973	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0703962	0.265323
setup4	1.85402	0.75	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0802195	0.283231
setup5	1.875	0.715027	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0791836	0.281396
setup6	1.87897	0.772822	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0569096	0.238557
setup7	1.88295	0.795645	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0693318	0.263309
setup8	1.88032	0.780556	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0673117	0.259445
setup9	1.89263	0.772822	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0680803	0.260922
setup10	1.87897	0.804097	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0659079	0.256725
setup11	1.86532	0.772822	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0723127	0.26891
setup12	1.87897	0.741548	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0673682	0.259554
setup13	1.88076	0.776523	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0611184	0.247221
setup14	1.87915	0.773193	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0560023	0.236648
setup15	1.88012	0.775188	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0797446	0.282391
setup16	1.88504	0.773193	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0674096	0.259634
setup17	1.87915	0.788844	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0667098	0.258282
setup18	1.87326	0.773193	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0712704	0.266965
setup19	1.87915	0.757541	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0700394	0.26465
setup20	1.88	0.775466	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0692426	0.26314
setup21	1.87924	0.77342	0.2205	-0.066	1.217	-0.617	Y	N	N	N	0.0700132	0.2646
setup22	1.87915	0.773193	0.236978	-0.066	1.217	-0.617	Y	N	N	N	0.0683719	0.26148
setup23	1.87915	0.773193	0.2205	-0.0633636	1.217	-0.617	Y	N	N	N	0.0474847	0.21791
setup24	1.87915	0.773193	0.2205	-0.066	1.22227	-0.617	Y	N	N	N	0.0667595	0.258379
setup25	1.87915	0.773193	0.2205	-0.066	1.217	-0.597227	Y	N	N	N	0.0627792	0.250558
setup26	1.87915	0.773193	0.204022	-0.066	1.217	-0.617	Y	N	N	N	0.0621574	0.249314
setup27	1.87915	0.773193	0.2205	-0.0686364	1.217	-0.617	Y	N	N	N	0.0744954	0.272939
setup28	1.87915	0.773193	0.2205	-0.066	1.21173	-0.617	Y	N	N	N	0.0681452	0.261046
setup29	1.87915	0.773193	0.2205	-0.066	1.217	-0.636773	Y	N	N	N	0.0684168	0.261566
setup30	1.87956	0.774196	0.217827	-0.0618672	1.21715	-0.614197	Y	N	N	N	0.0570866	0.238928
setup31	1.87934	0.77367	0.219227	-0.0640324	1.21707	-0.615665	Y	N	N	N	0.06736	0.259538
setup32	1.88163	0.773193	0.2205	-0.0633636	1.217	-0.617	Y	N	N	N	0.0657145	0.256348
setup33	1.87915	0.780009	0.2205	-0.0633636	1.217	-0.617	Y	N	N	N	0.064299	0.253572
setup34	1.87915	0.773193	0.228757	-0.0633636	1.217	-0.617	Y	N	N	N	0.0998145	0.315934
setup35	1.87915	0.773193	0.2205	-0.0633636	1.21938	-0.617	Y	N	N	N	0.0632597	0.251515
setup36	1.89871	0.773193	0.2205	-0.0633636	1.217	-0.617	Y	N	N	N	0.0619039	0.248805

Set-up Scan-angle Parameter

Abs. [inches] ▾

X

Y

Z

Rad

Ang

Snap To: Vertex

Grid Other...

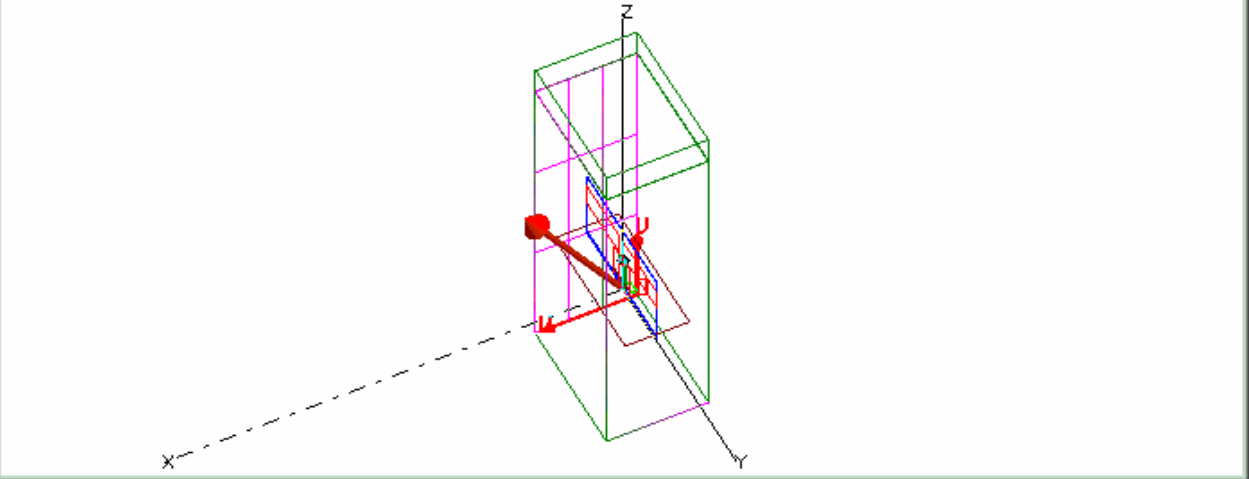
Graphical Pick

Object

Face

Boundary

Name	Assigned
impedance	impedance
metal	perfect_e
radABC	radiation
masterX	master
slaveX	slave
masterY	master
slaveY	slave
masterX_pml	master
slaveX_pml	slave
masterY_pml	master
slaveY_pml	slave
port1	port



Name:

Source Boundary

Slave ▾

Boundary/Source:

Master:

Scan Angles Field Relation

Phi (deg):

Theta (deg):

(applies to entire model)

Scan direction:

Axis definition:

Origin :

U point :

V point :

Ansoft HFSS Version 8.0.25 Copyright 1984-2001 Ansoft Corporation

Edit Variables in Optimetrics

Solve fields on 4 frequencies and 7 scan-angles using Optimetrics

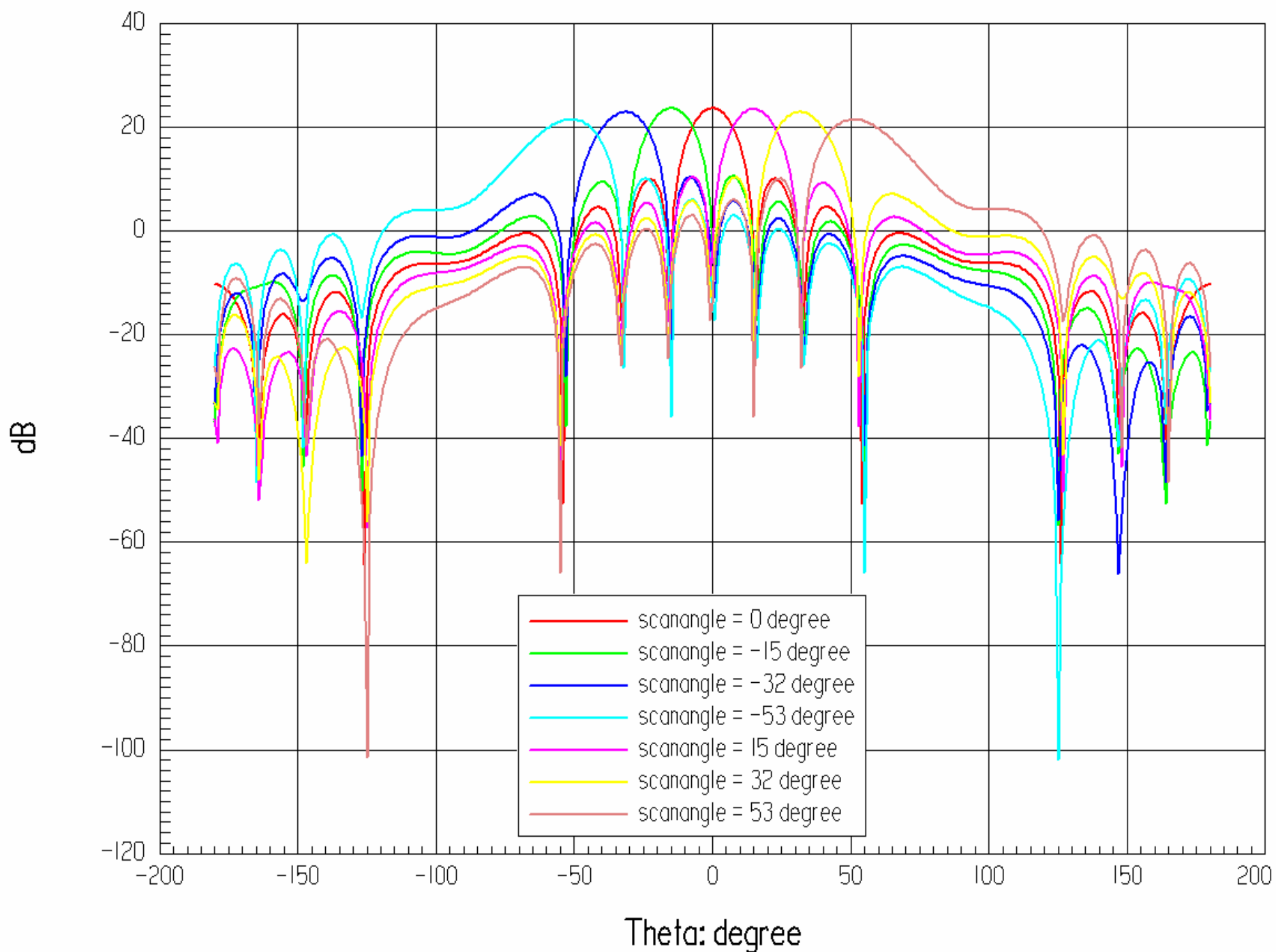
7 hours and 30 minutes to run the 4X7=28 simulations

The screenshot shows the 'opt-workshop-final' application window. It contains a table with 7 columns: Setup, frequency, scanangle, Solved, Sensitivity Done, Save Fields, and Solve. The table lists 26 simulation setups (setup1 to setup26). A 'View Variables' dialog box is open over the table, showing a list of project variables and their nominal values.

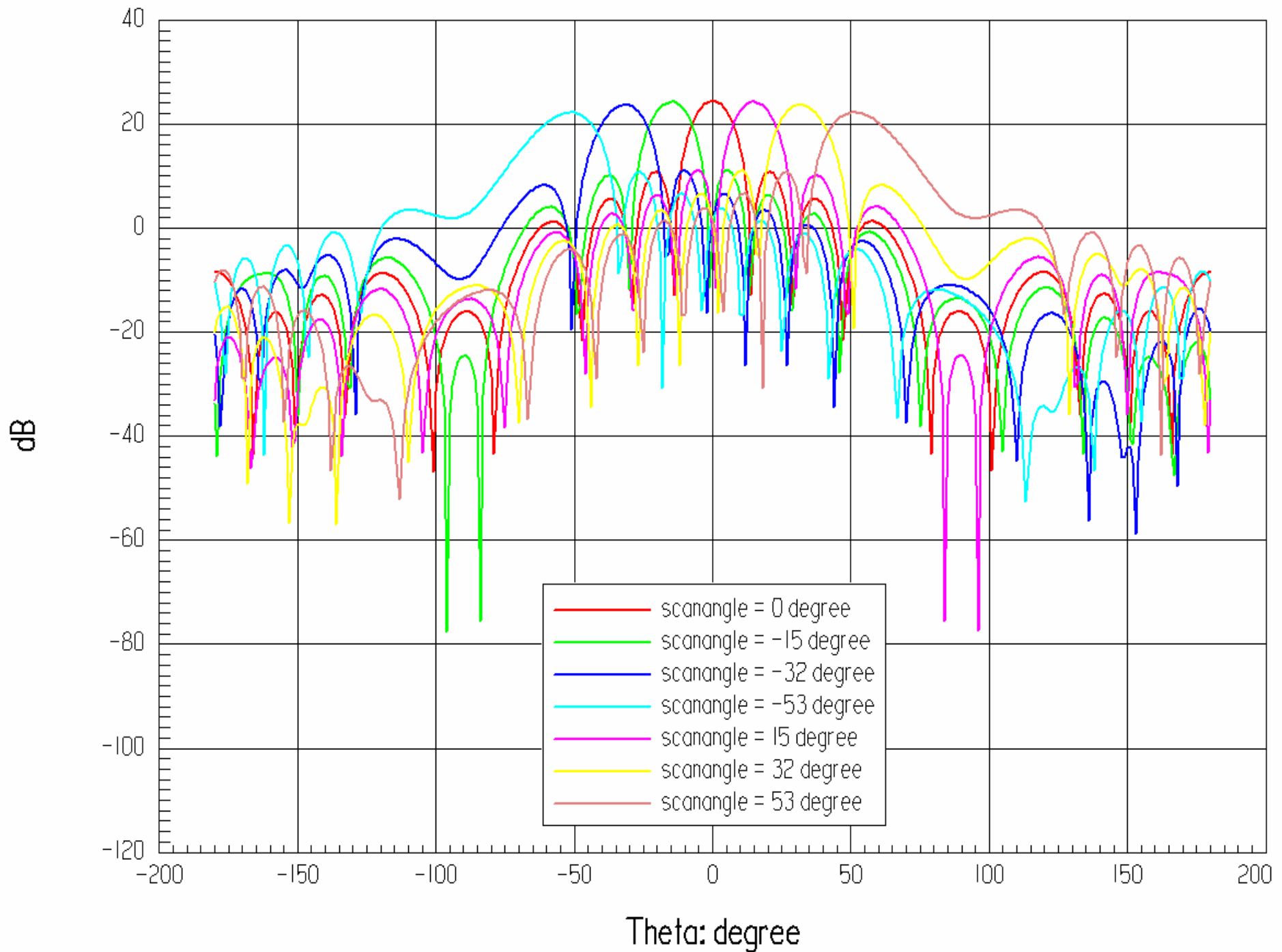
Setup	frequency	scanangle	Solved	Sensitivity Done	Save Fields	Solve
setup1	1.71E+009	-53	Y	N	Y	N
setup2	1.71E+009	-52	N	N	N	N
setup3	1.71E+009	-51	N	N	N	N
setup4	1.71E+009	-50	N	N	N	N
setup5	1.71E+009	-49	N	N	N	N
setup6	1.71E+009	-48	N	N	N	N
setup7	1.71E+009	-47	N	N	N	N
setup8	1.71E+009	-46	N	N	N	N
setup9						
setup10						
setup11						
setup12						
setup13						
setup14						
setup15						
setup16						
setup17						
setup18						
setup19						
setup20						
setup21	1.71E+009	-33	N	N	N	N
setup22	1.71E+009	-32	Y	N	Y	N
setup23	1.71E+009	-31	N	N	N	N
setup24	1.71E+009	-30	N	N	N	N
setup25	1.71E+009	-29	N	N	N	N
setup26	1.71E+009	-28	N	N	N	N

Project Variable	Used by	Nominal Value
frequency	Optimetrics	1.9E+009
scanangle	Optimetrics	30

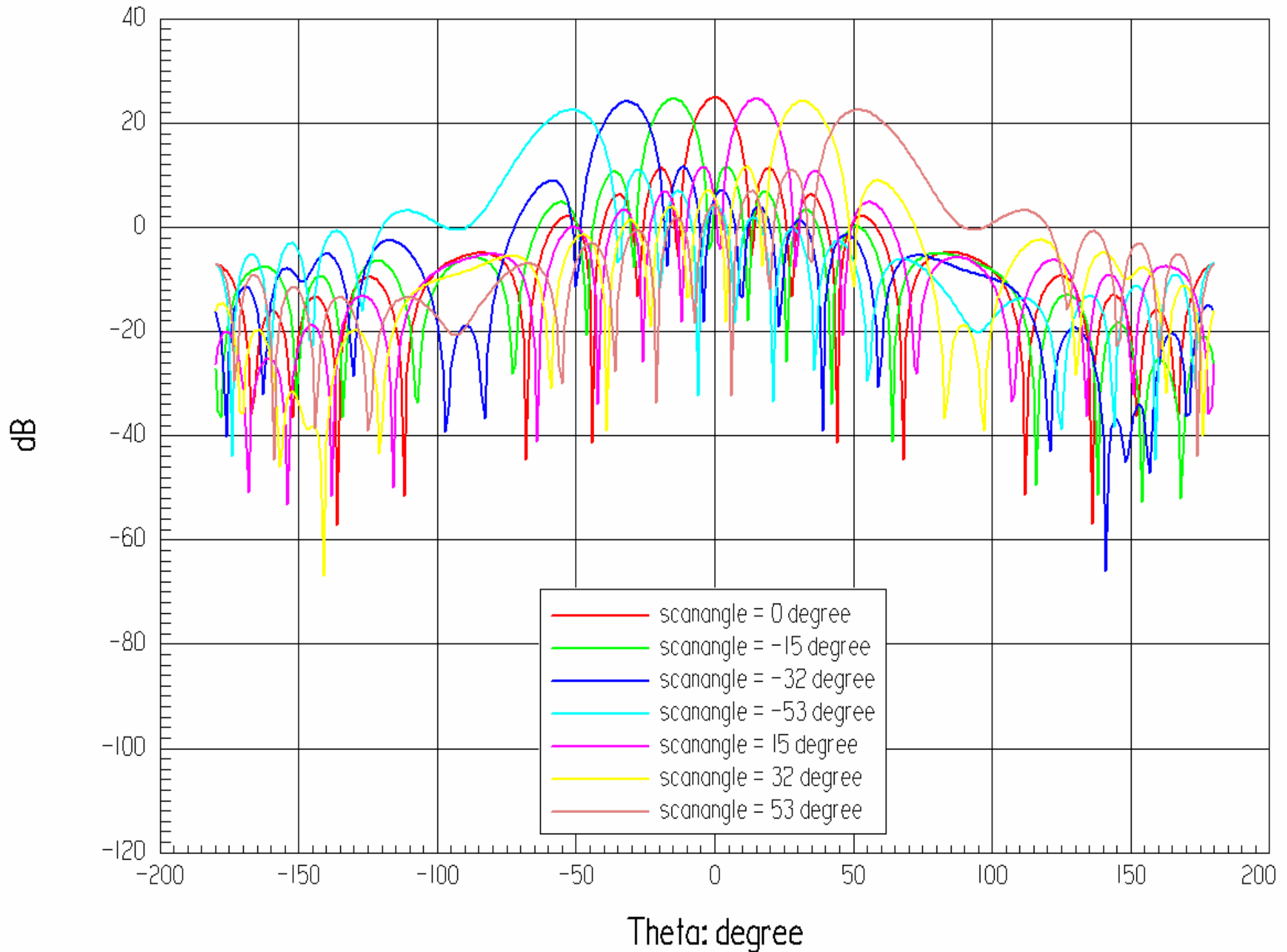
Antenna Array Gain pattern at 1.71GHz, Phi=0



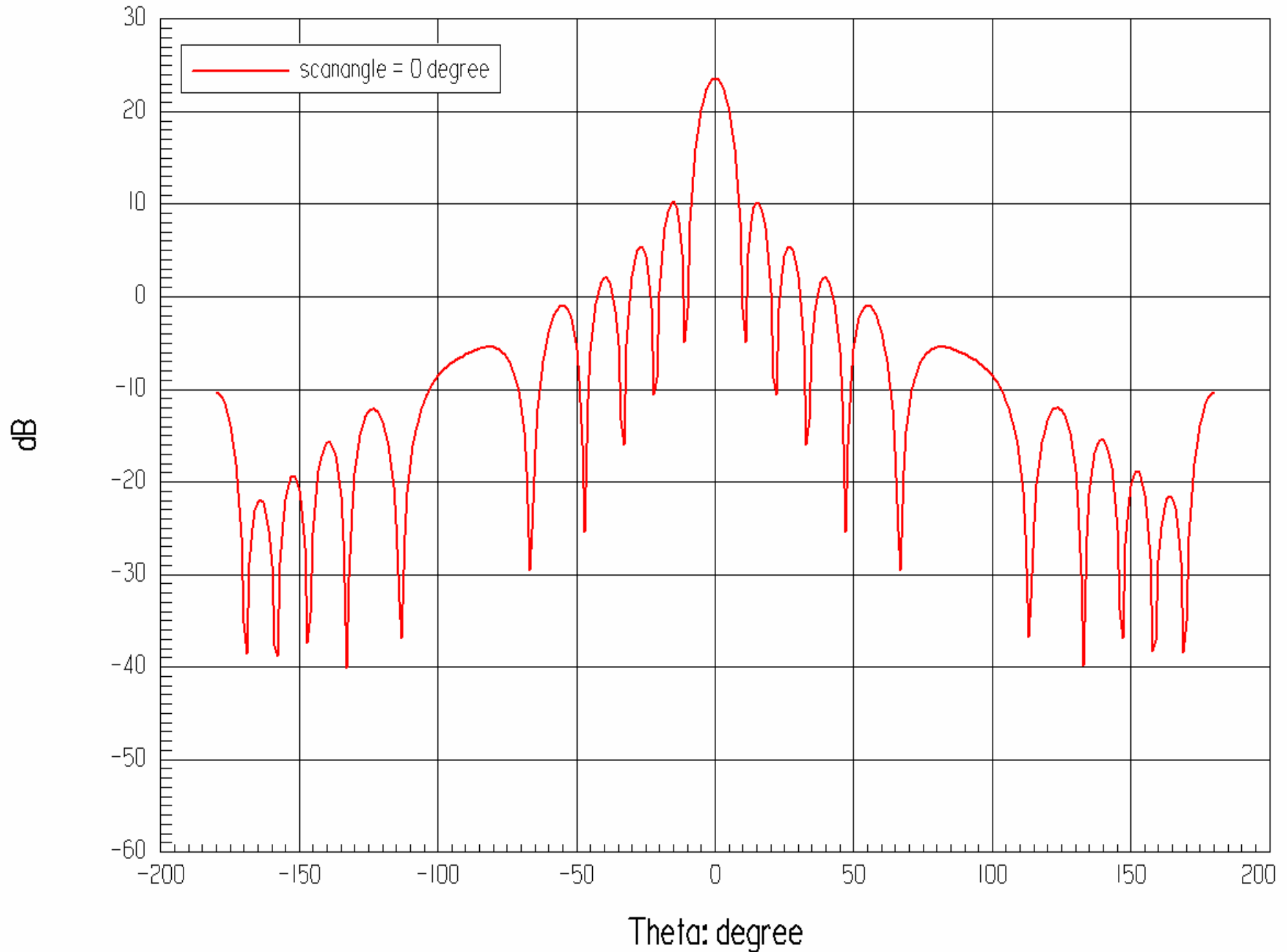
Antenna Array Gain Pattern at 1.88GHz, Phi=0



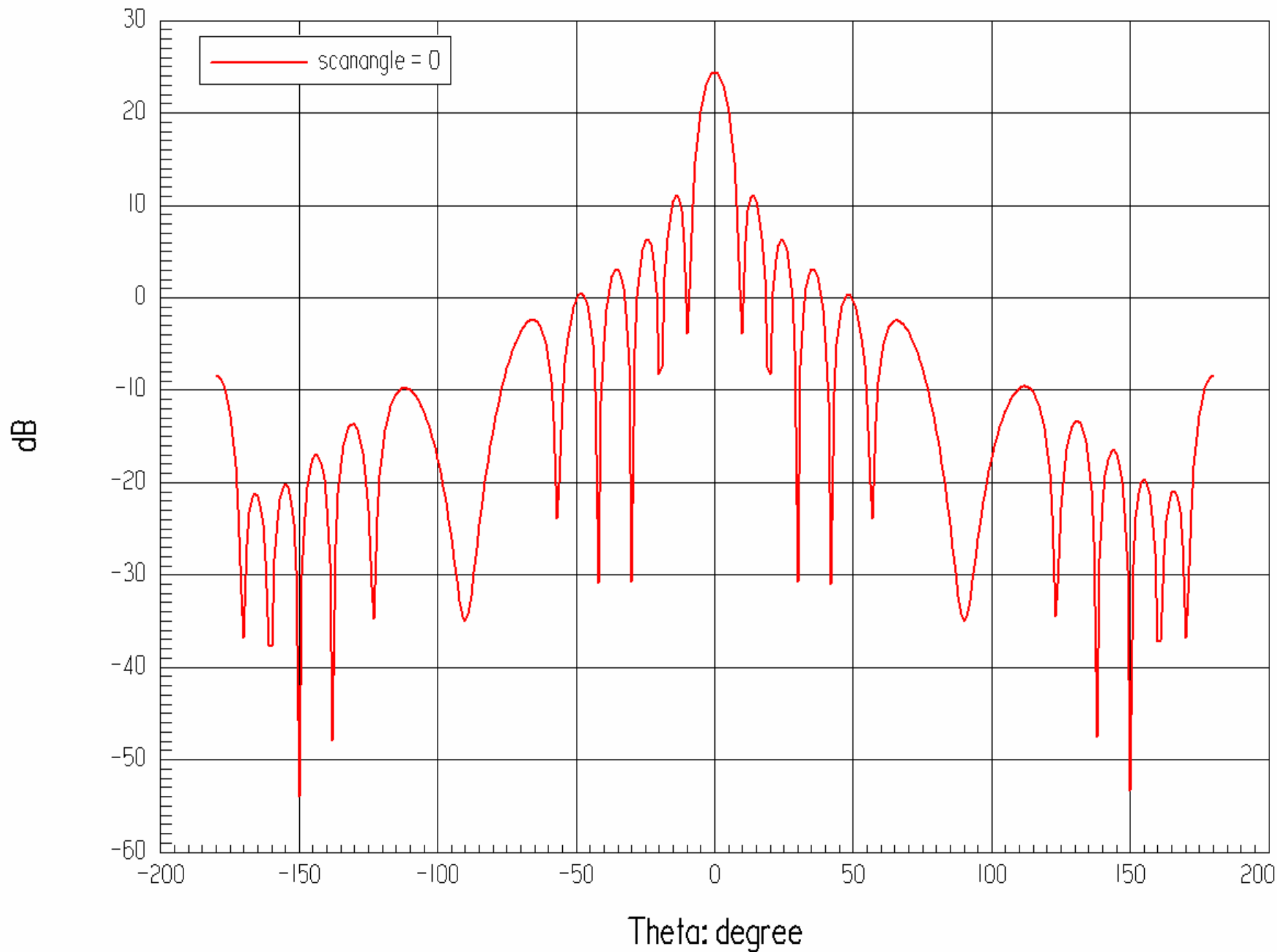
Antenna Array Gain Pattern at 1.99GHz, Phi=0



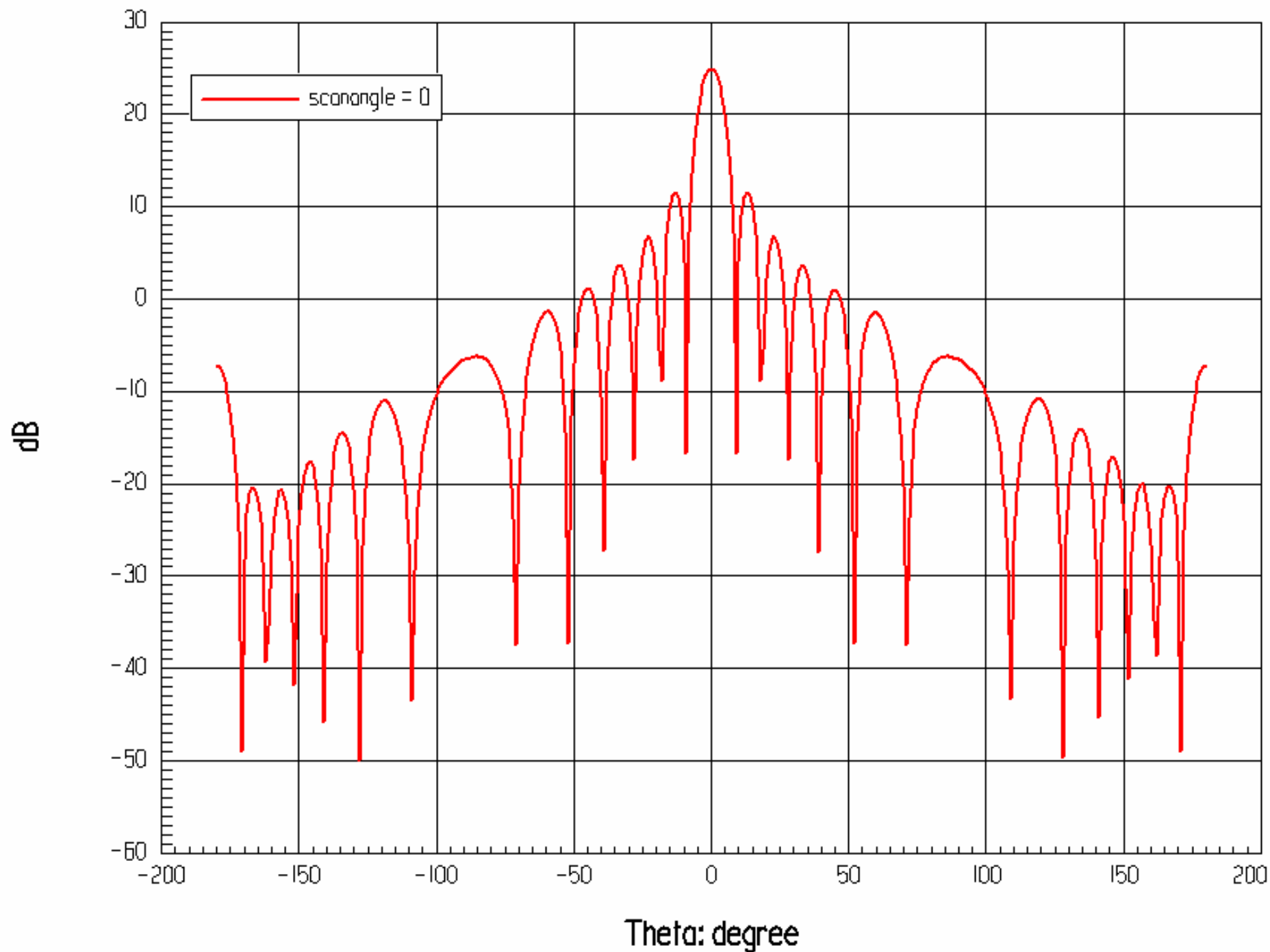
Antenna Array Gain Pattern at 1.71GHz, Phi=90 degree



Antenna Array Gain Pattern at 1.88GHz, Phi=90 degree



Antenna Array Gain Pattern at 1.99GHz, Phi=90 degree



Final Antenna Array Design Results

Frequency	Antenna Gain – center beam	Azimuth Beamwidth – center beam	Antenna Gain – edge beam	Azimuth Beamwidth – edge beam
1.71GHz	23.65 dB	13.7°	21.5 dB	21.35°
1.88GHz	24.44 dB	12.34°	22.24 dB	19.62°
1.99GHz	24.92 dB	11.7°	22.6 dB	18.86°

Conclusion

- Printed Circuit Board Dipole Phased Array —
Broad band
- HFSS – accuracy
- Optimetics – saving time
best design performance