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

Shu Li Ansoft

Hsueh-Yuan Pao Lawrence Livermore National Lab, University of California

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: -53º, -32º, -15º, 0º, 15º, 32º, 53º
- 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: 14.5º center beam, 23.4º edge beam
  - 1.8 GHz: 13.8º center beam, 22.3º edge beam
  - 1.9 GHz: 13.1º center beam, 21.1º edge beam
  - 1.99 GHz: 12.5º center beam, 20.1º edge beam
- Elevation Beamwidth: 9º
- Polarization: Linear, vertical

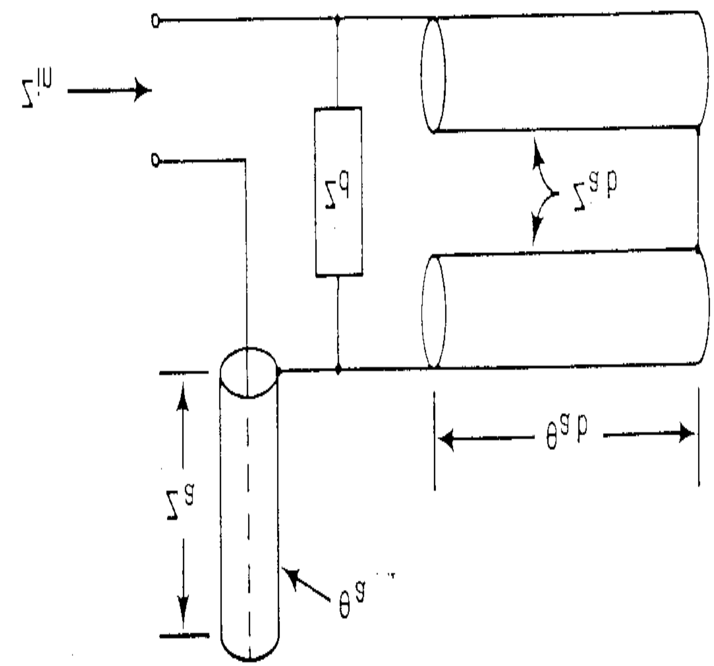
Antenna Description

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

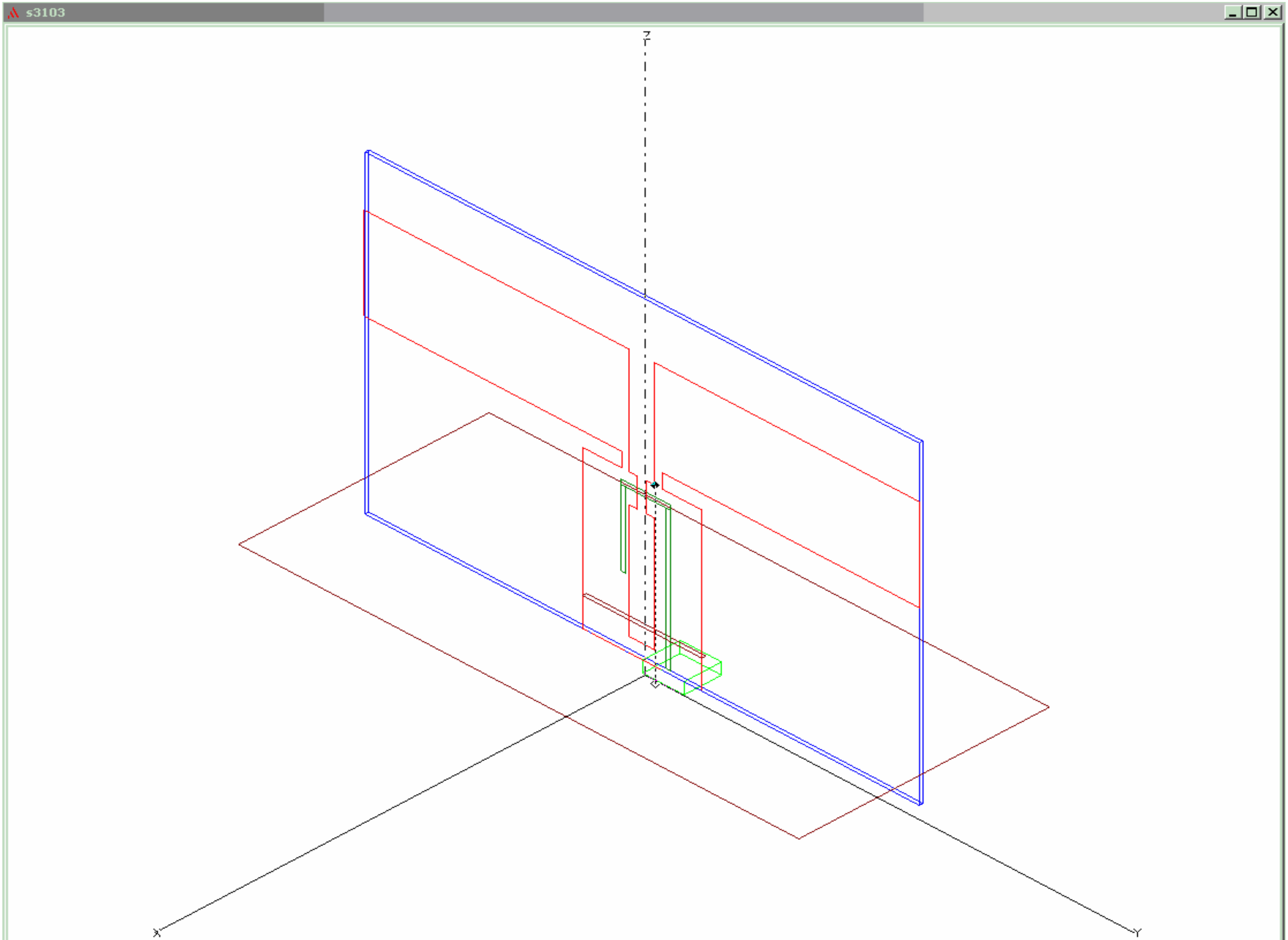
Equivalent Circuit of Isolated Dipole Balun

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

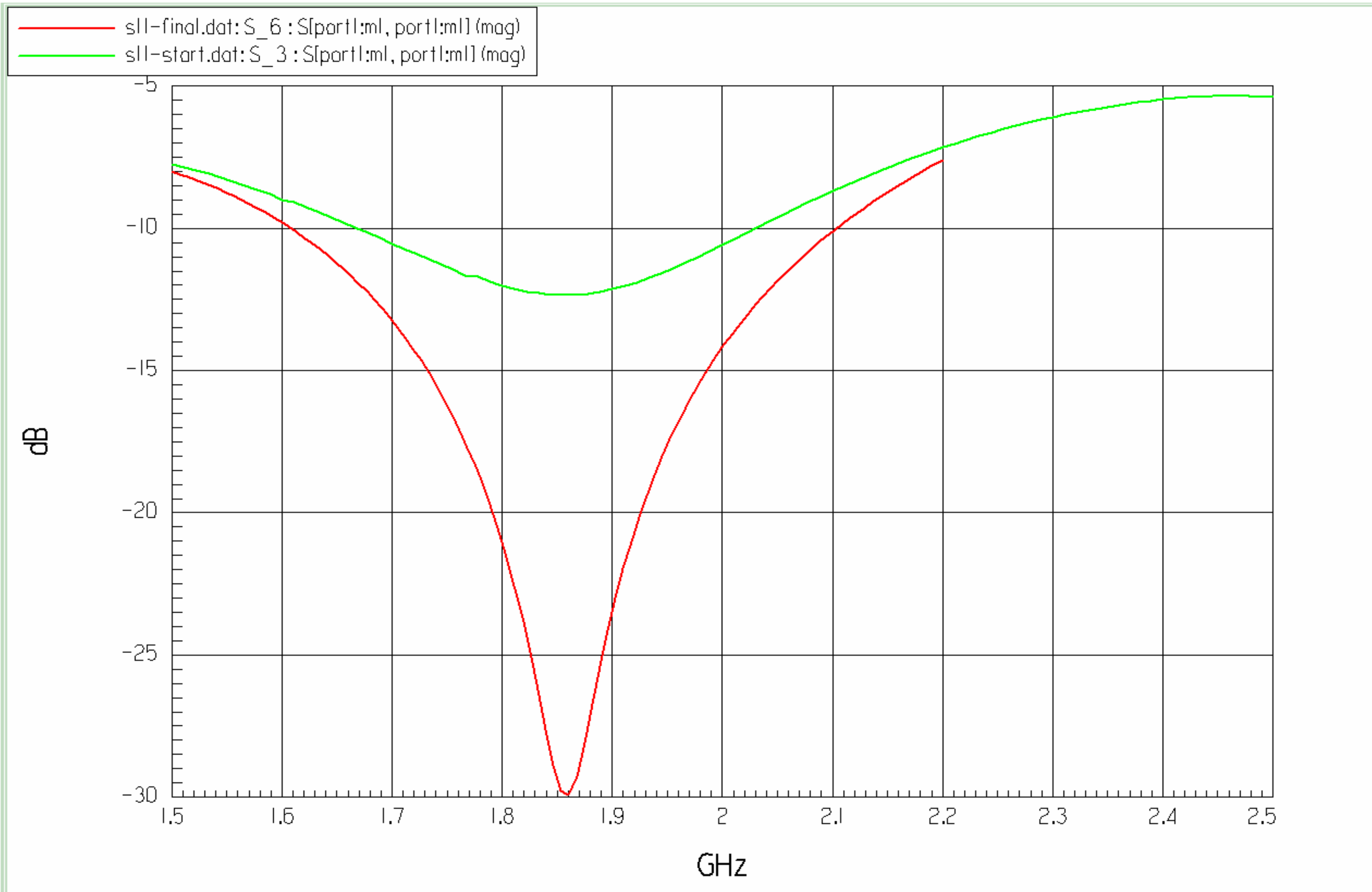
$$Z_{in} = -jZ_a \cot \mathbf{q}_a + \frac{jZ_d Z_{ab} \tan \mathbf{q}_{ab}}{Z_d + jZ_{ab} \tan \mathbf{q}_{ab}}$$



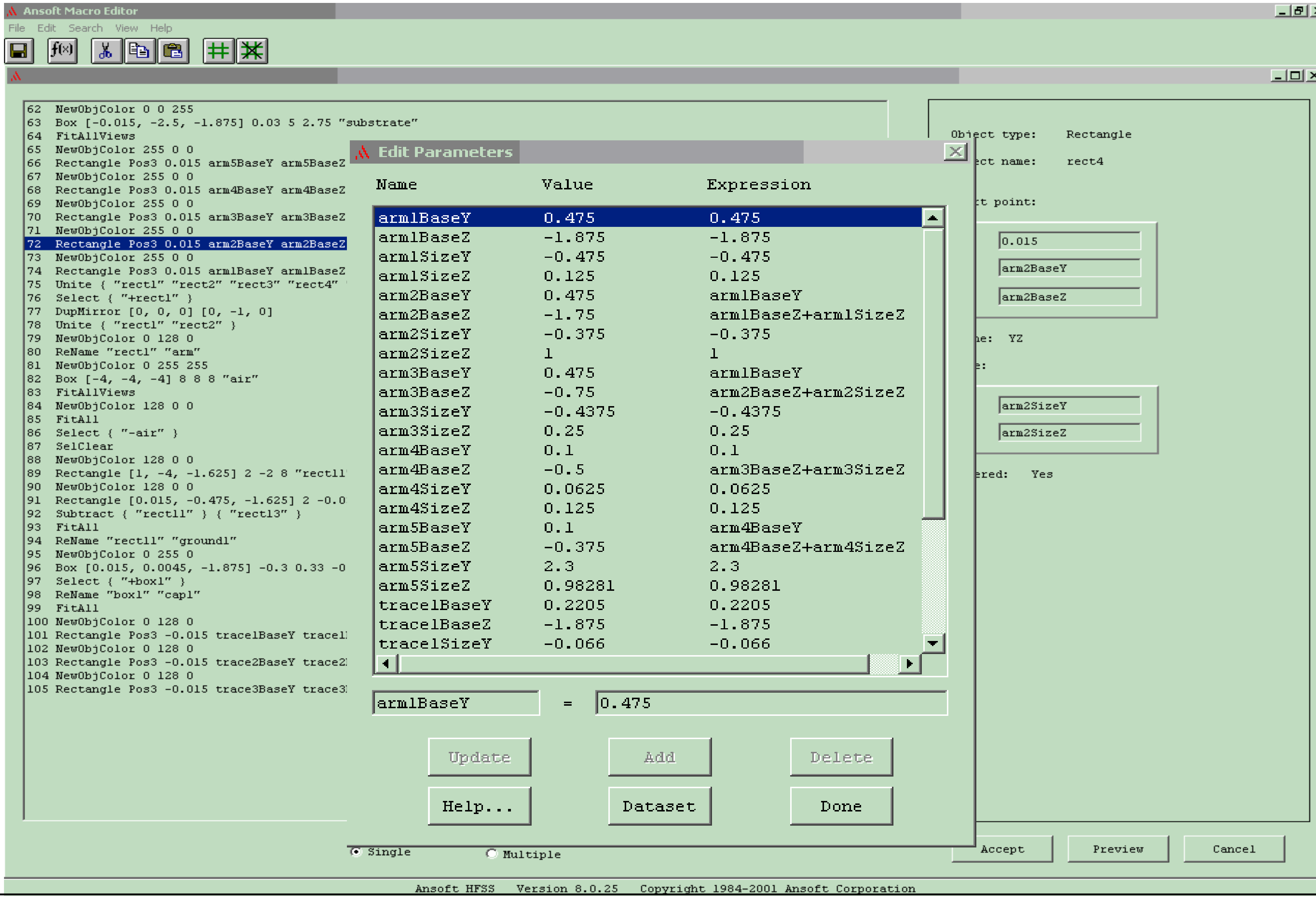
Model of Broad Band Printed Circuit Board Dipole in HFSS



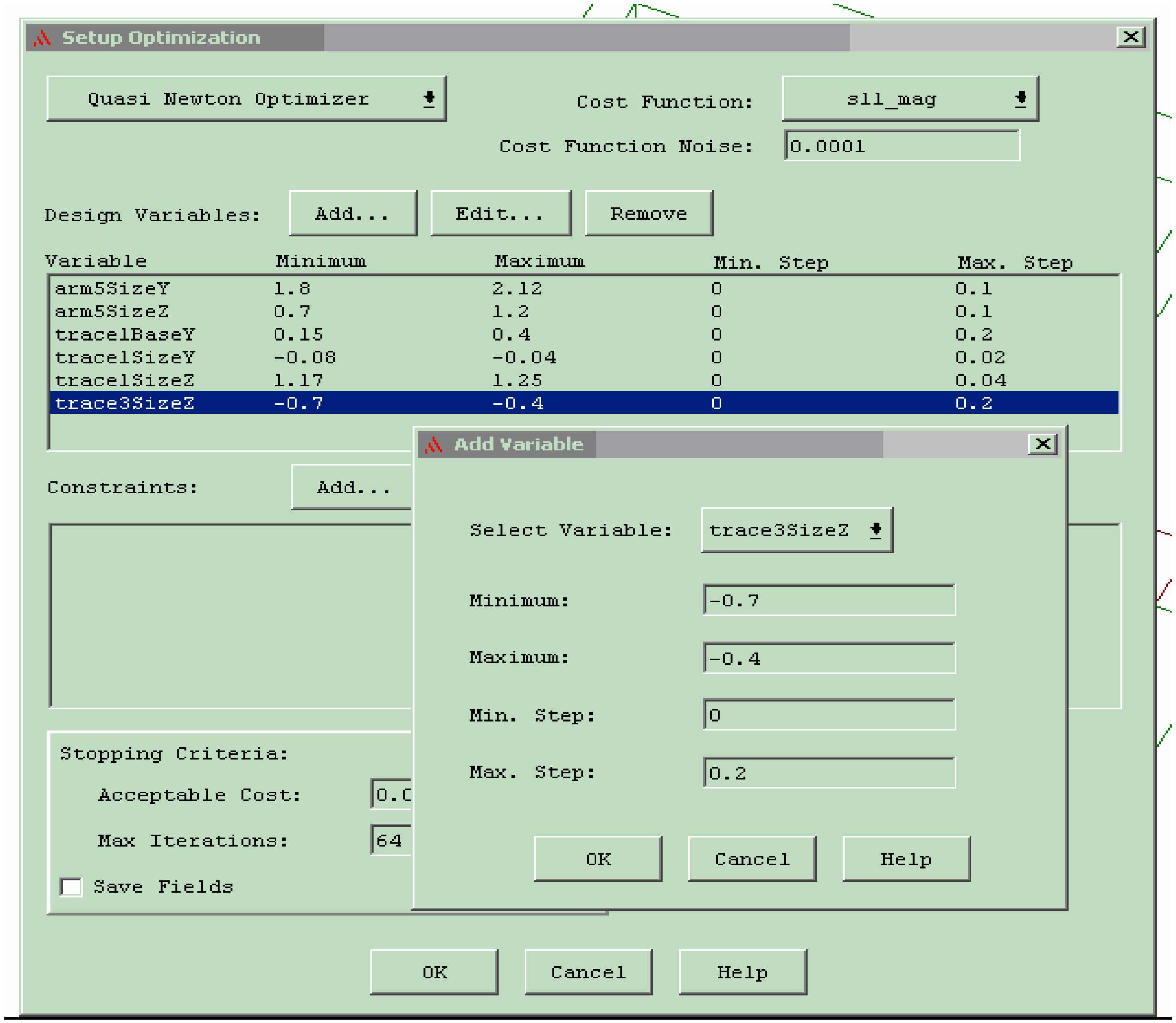
Comparison of Reflection Coefficient before and after Optimization Design



Set-up Parameters in HFSS Macro



Set-up Variables in Optimetrics

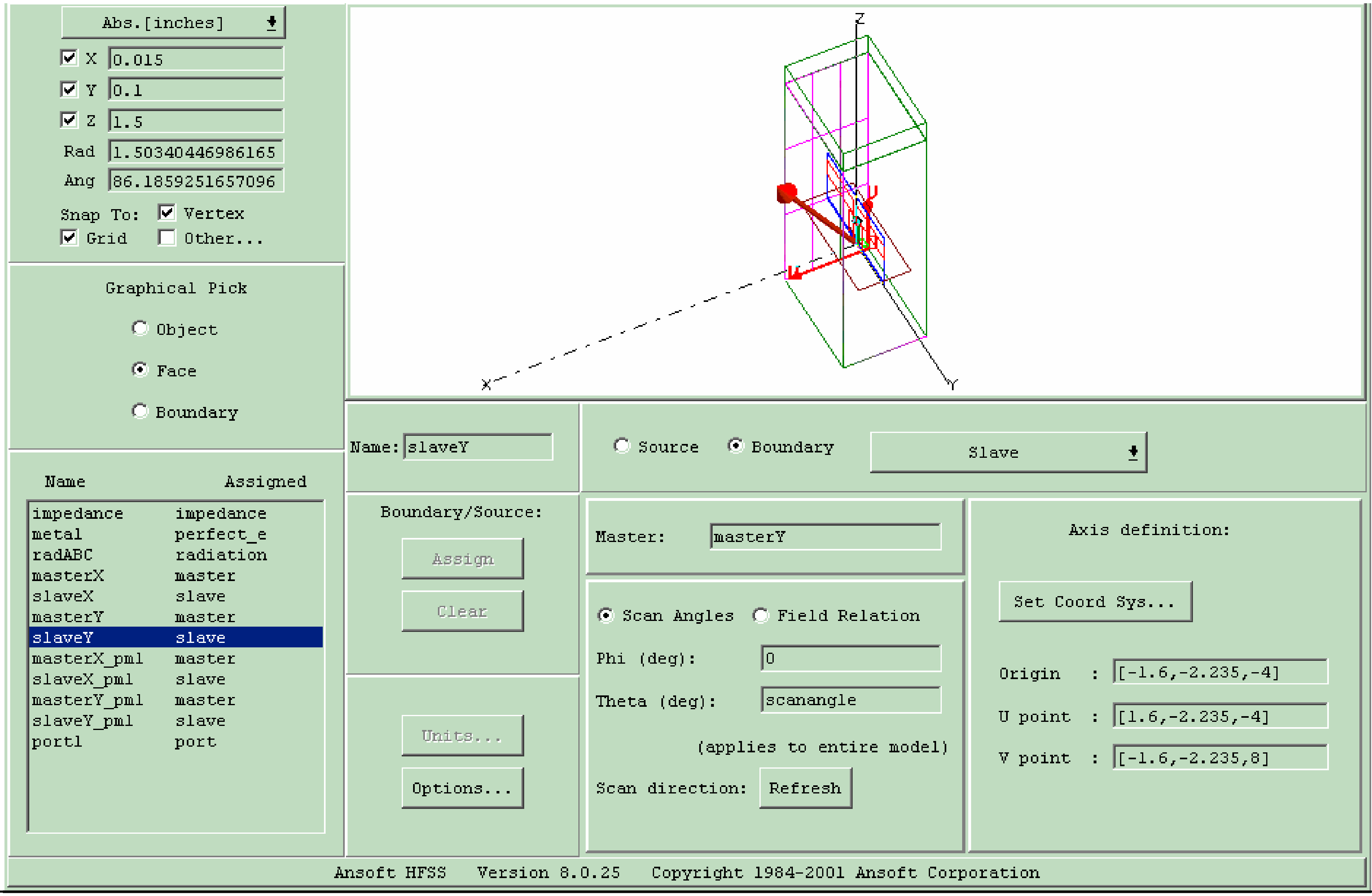


Optimization Output Table

optim-workshop-1 [read-only]

Setup	arm5SizeY	arm5SizeZ	trace1BaseY	trace1SizeY	trace1SizeZ	trace3SizeZ	Solved	Sensitivity Done	Save Fields	Solve	cost	s11_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

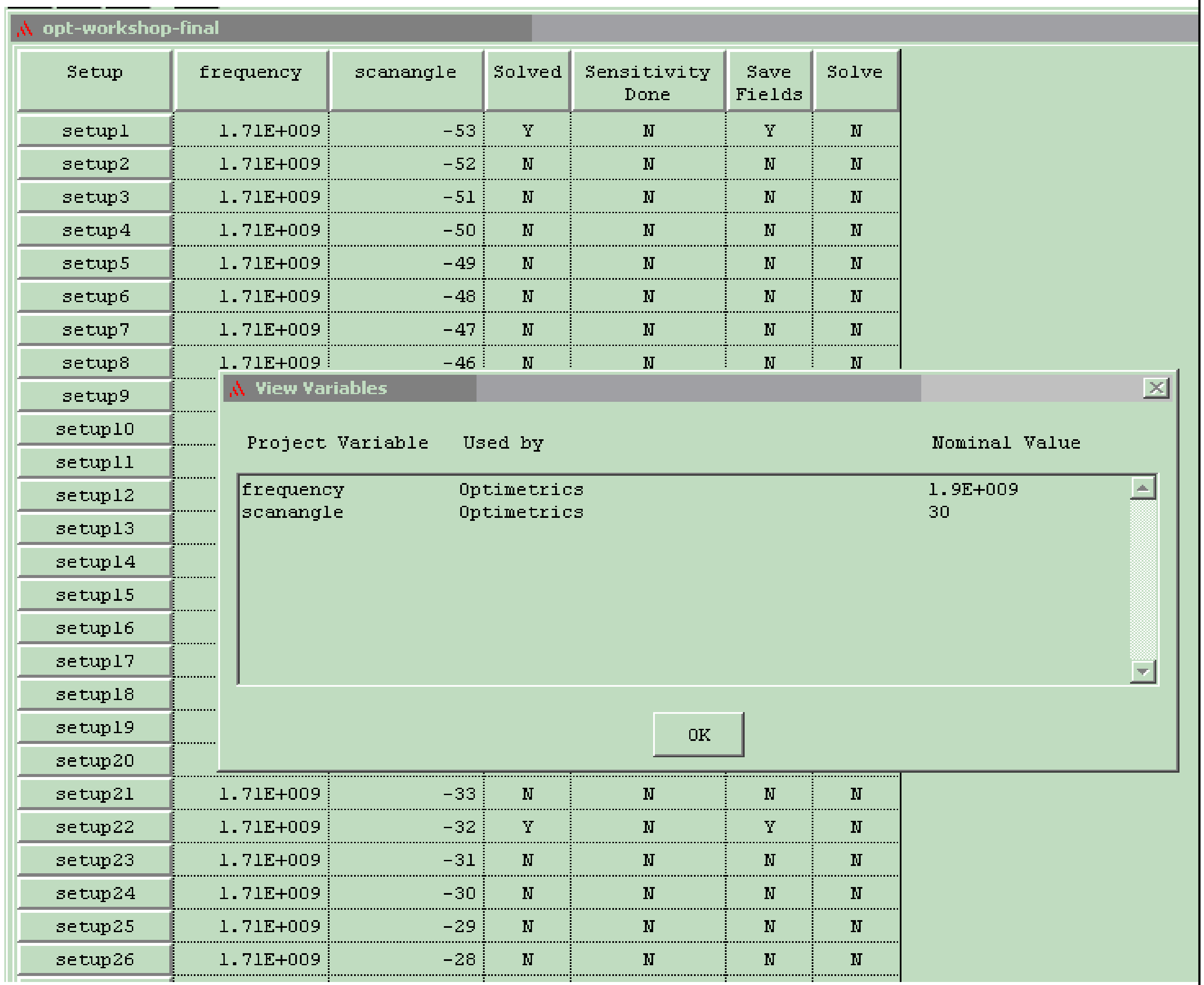
Set-up Scan-angle Parameter

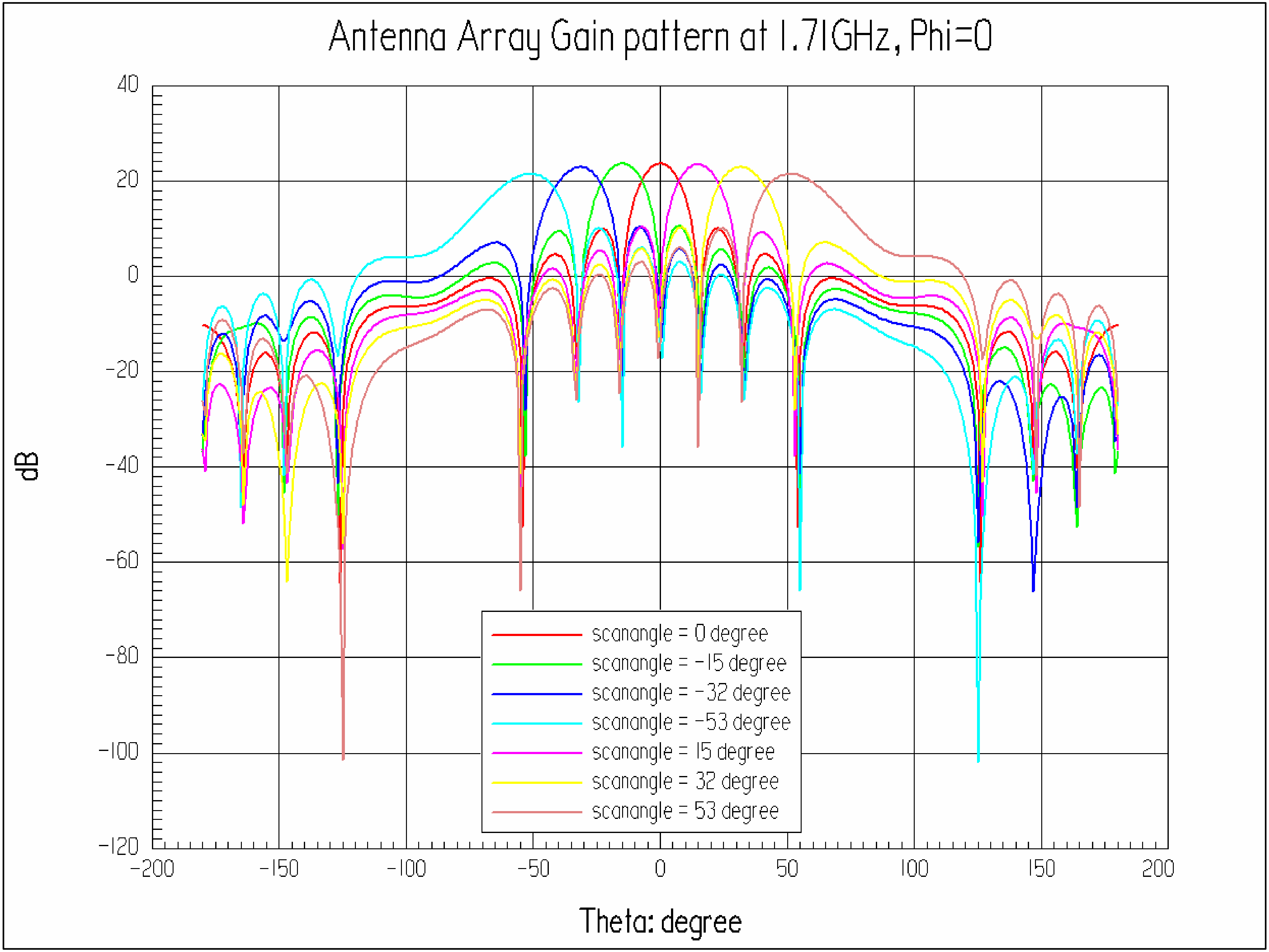


Edit Variables in Optimetrics

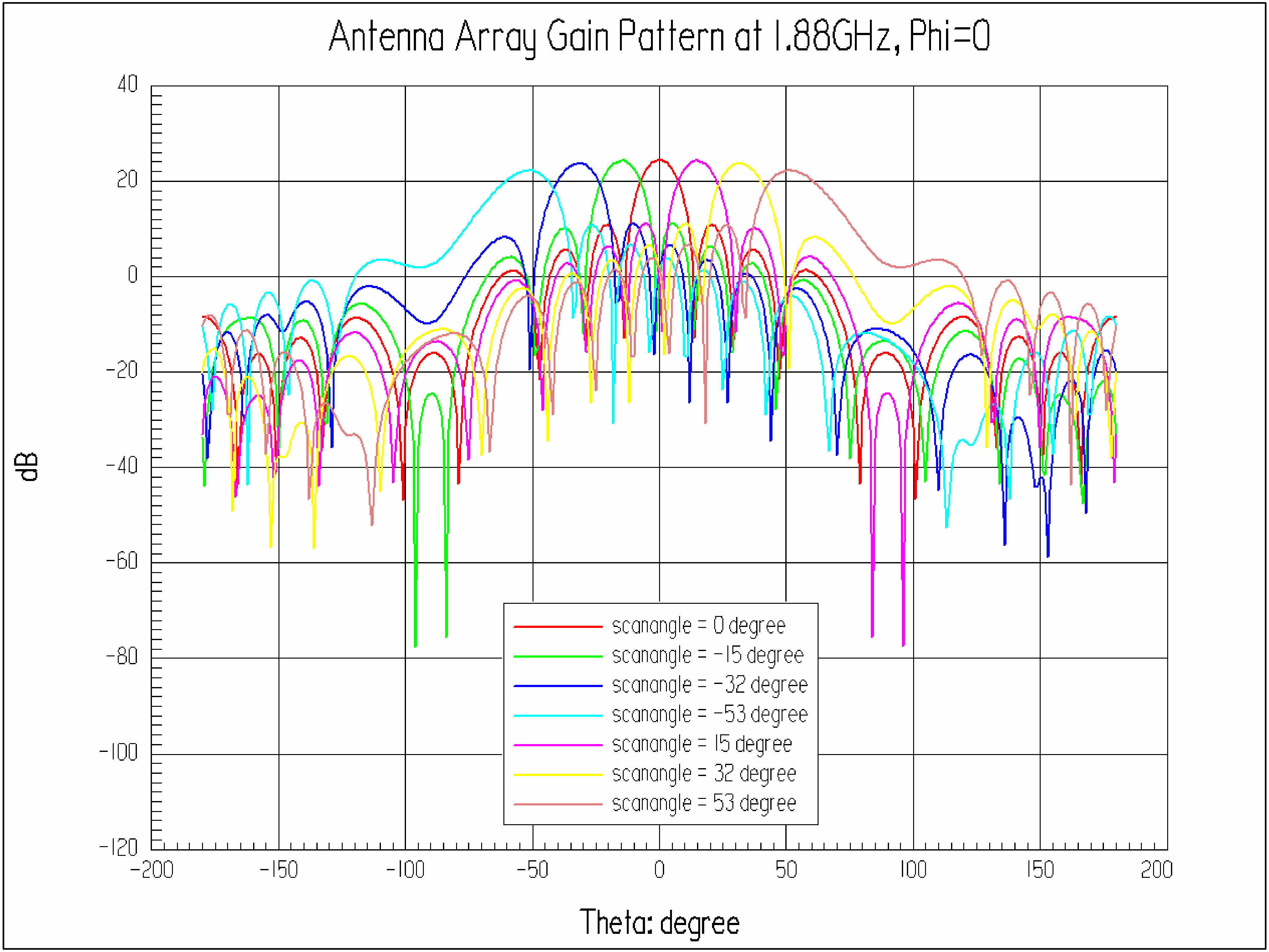
Solve fields on 4 frequencies and 7 scan-angles using Optimetrics

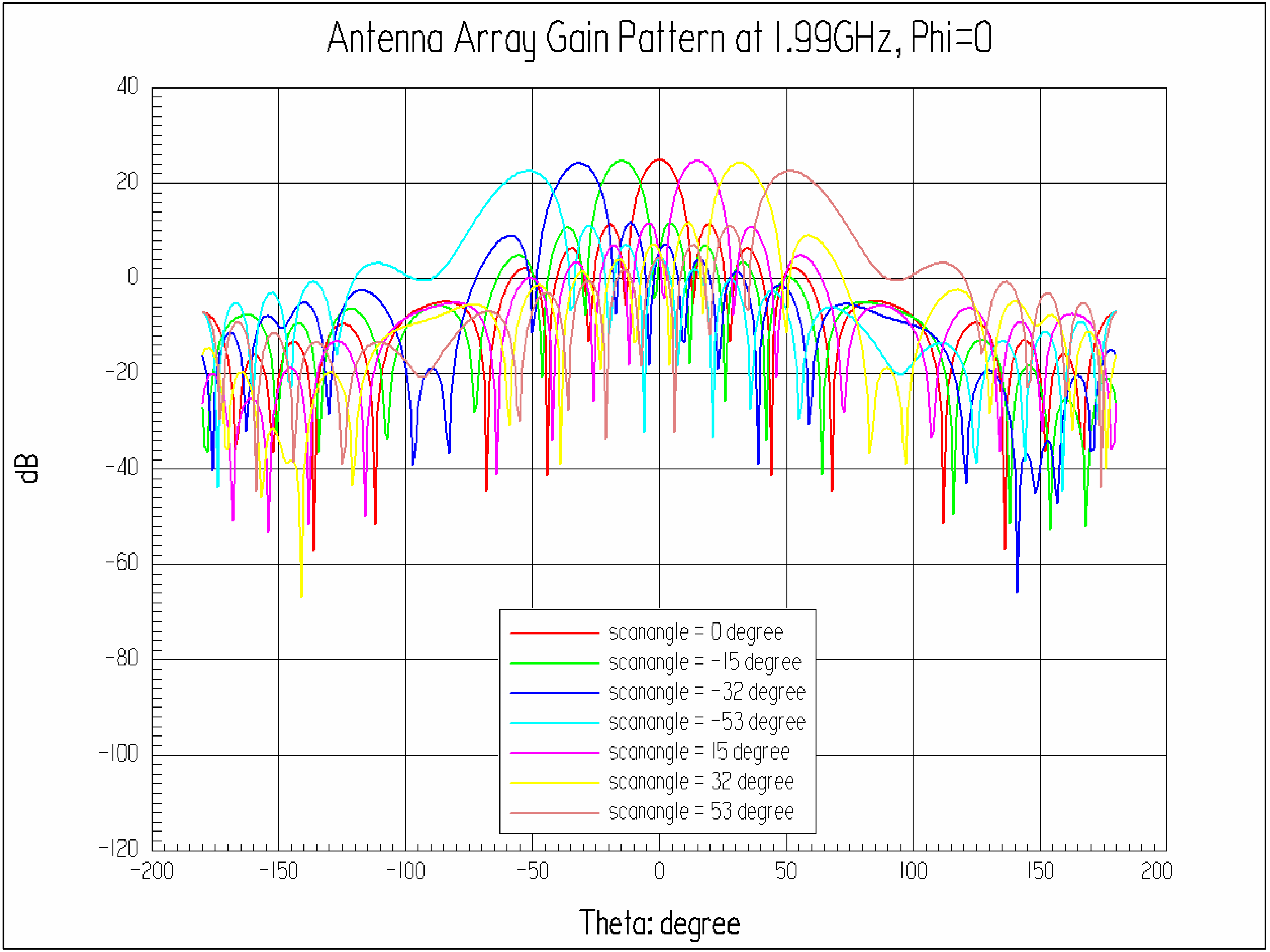
7 hours and 30 minutes to run the 4X7=28 simulations



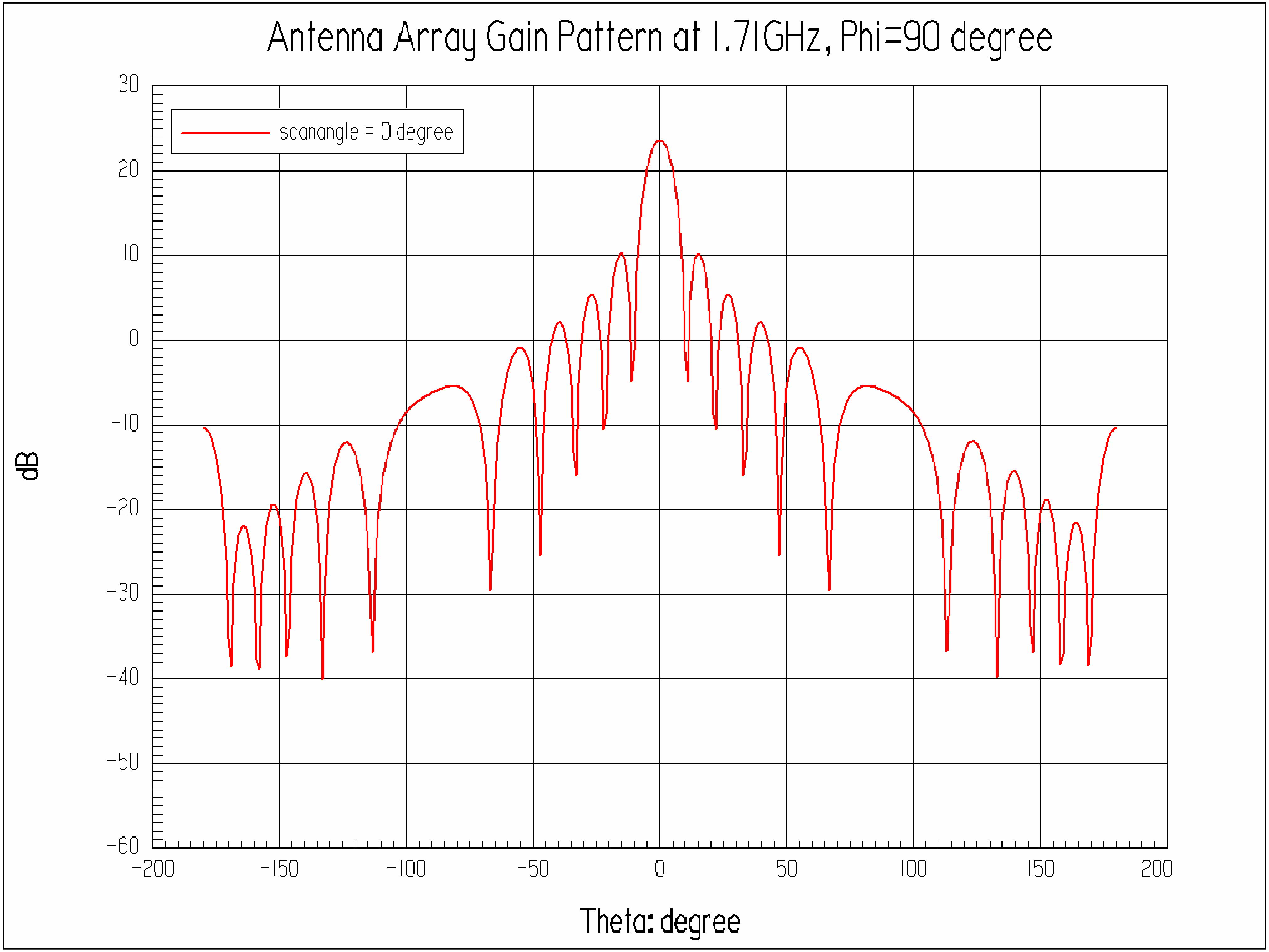


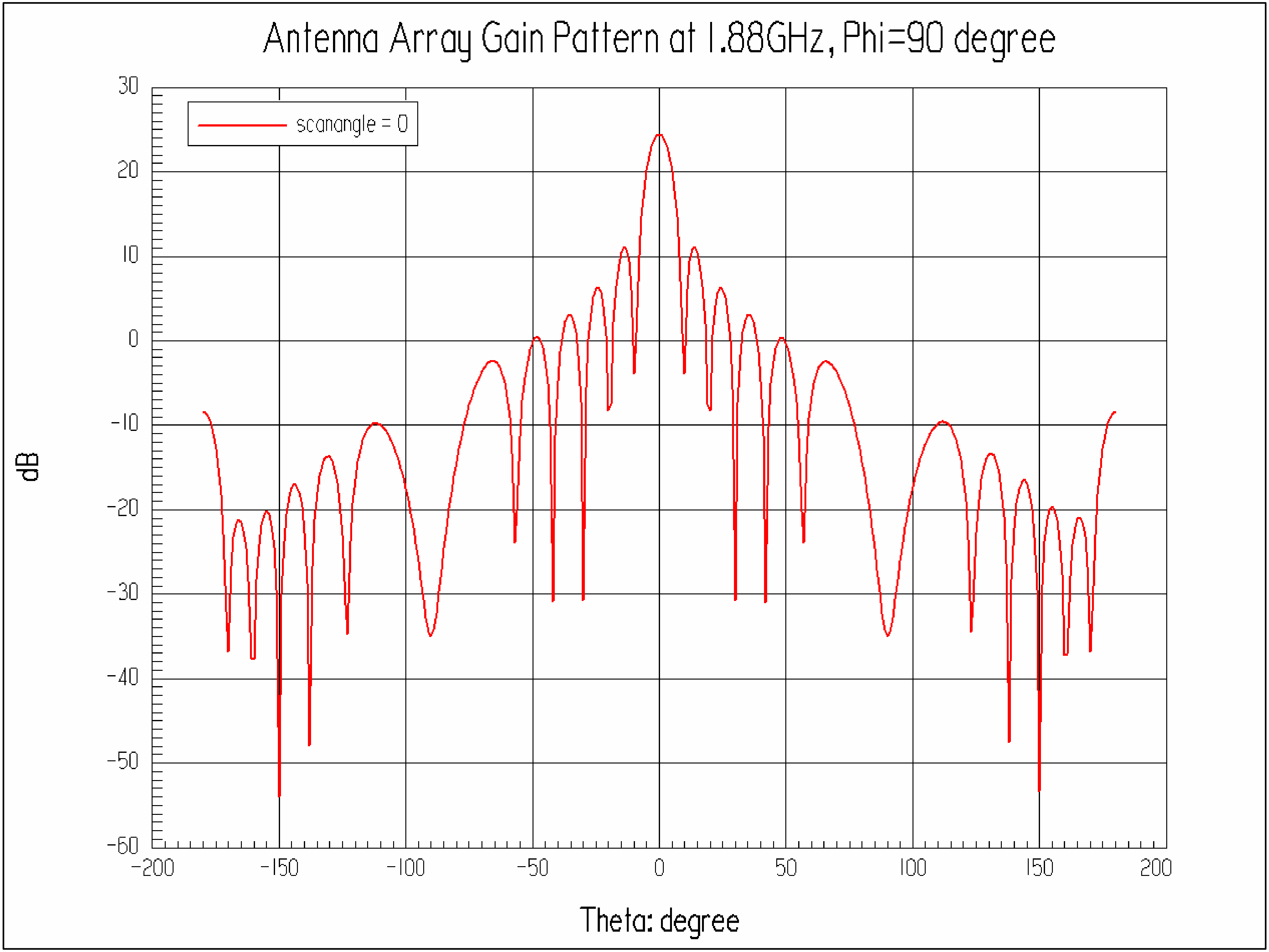
Antenna Array Gain pattern at 1.71GHz, Phi=0
dB
Theta: degree
40
20
0
-20
-40
-60
-80
-100
-120
-200
-150
-100
-50
0
50
100
150
200
scanangle = 0 degree
scanangle = -15 degree
scanangle = -32 degree
scanangle = -53 degree
scanangle = 15 degree
scanangle = 32 degree
scanangle = 53 degree

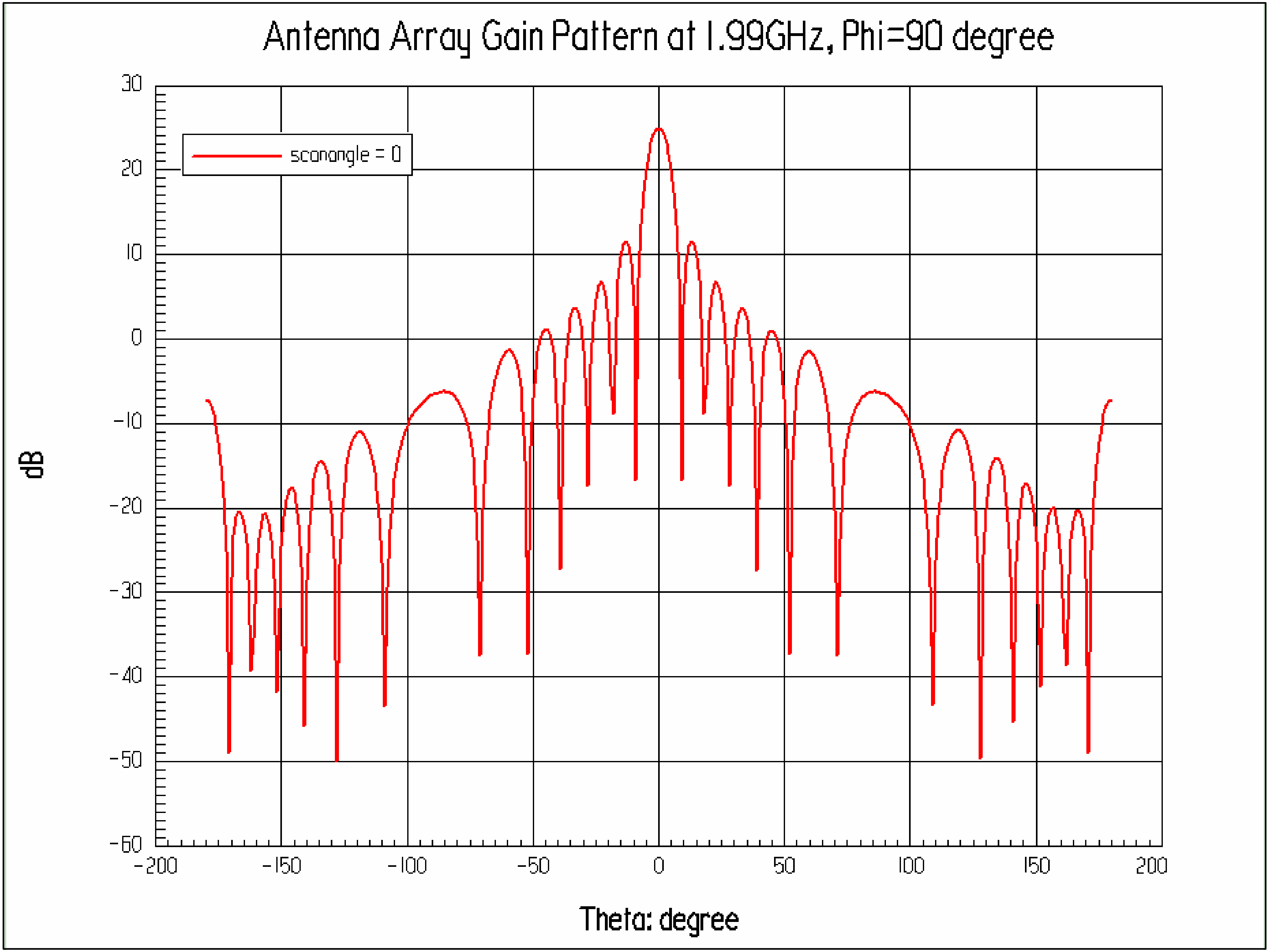

Antenna Array Gain Pattern at 1.88GHz, Phi=0
dB
Theta: degree
40
20
0
-20
-40
-60
-80
-100
-120
-200
-150
-100
-50
0
50
100
150
200
scanangle = 0 degree
scanangle = -15 degree
scanangle = -32 degree
scanangle = -53 degree
scanangle = 15 degree
scanangle = 32 degree
scanangle = 53 degree



Antenna Array Gain Pattern at 1.99GHz, Phi=0
40
20
0
-20
-40
-60
-80
-100
-120
dB
-200
-150
-100
-50
0
50
100
150
200
Theta: degree
scanangle = 0 degree
scanangle = -15 degree
scanangle = -32 degree
scanangle = -53 degree
scanangle = 15 degree
scanangle = 32 degree
scanangle = 53 degree


Antenna Array Gain Pattern at 1.71GHz, Phi=90 degree
scanangle = 0 degree
dB
30
20
10
0
-10
-20
-30
-40
-50
-60
-200
-150
-100
-50
0
50
100
150
200
Theta: degree


Antenna Array Gain Pattern at 1.88GHz, Phi=90 degree
scanangle = 0
dB
30
20
10
0
-10
-20
-30
-40
-50
-60
-200
-150
-100
-50
0
50
100
150
200
Theta: degree



Antenna Array Gain Pattern at 1.99GHz, Phi=90 degree
scanangle = 0
dB
Theta: degree
30
20
10
0
-10
-20
-30
-40
-50
-60
-200
-150
-100
-50
0
50
100
150
200

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	21.35º
1.88GHz	24.44 dB	12.34º	22.24 dB	19.62º
1.99GHz	24.92 dB	11.7º	22.6 dB	18.86º

Conclusion

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

  best design performance