Antenna Planning for Small HF Stations (and even larger ones)

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http://k9yc.com/publish.htm

Don't Bother Taking Notes

- This Power Point, and a lot more, are at

  k9yc.com/publish.htm

What This Is About

- This is the third in a series of studies focused on antenna systems for limited space, and/or with limited availability of supports.
  - Part One studied the question, “If I Can Put My Multi-band HF Vertical On My Roof, Should I?”
  - Part Two studied the strengths and weaknesses of the 43 Ft vertical.
  - Both are at k9yc.com/publish.htm

My Method

- **This work is based entirely on modeling, using W7EL's EZNEC**
  - **All use simple antennas – half wave dipoles, ground planes, 3-el Yagi**
- **A model that accurately and completely describes an antenna system will accurately predict its performance**

The Accuracy of a Model

- **A model must include things that interact with the antenna**
  - **The earth – soil conditions, height**
  - **The feedline, if not isolated by a common mode choke**
  - **Other conductors around the antenna (including other antennas and their feedlines)**

What This Presentation Is About

- **The current work:**
  - studies how ground quality affects performance of horizontal and vertical antennas
  - studies how height affects performance of horizontal dipoles and small Yagi antennas
  - compares the performance of ground- and roof-mounted verticals with λ/2 horizontal dipoles at heights in the range of 33 Ft.
  - compares small Yagis at various heights
  - Ignores terrain (assumes “flatland”)
  - Ignores surround objects

What This Presentation Is About

- The current work attempts to help us answer these questions:
  - With my available real estate, skyhooks, budget, and operating interests, will I get better performance from a vertical or a horizontal antenna?
  - How much is additional height worth in dB?
  - Should I spend money on a tower, tree climbers, or a power amp?

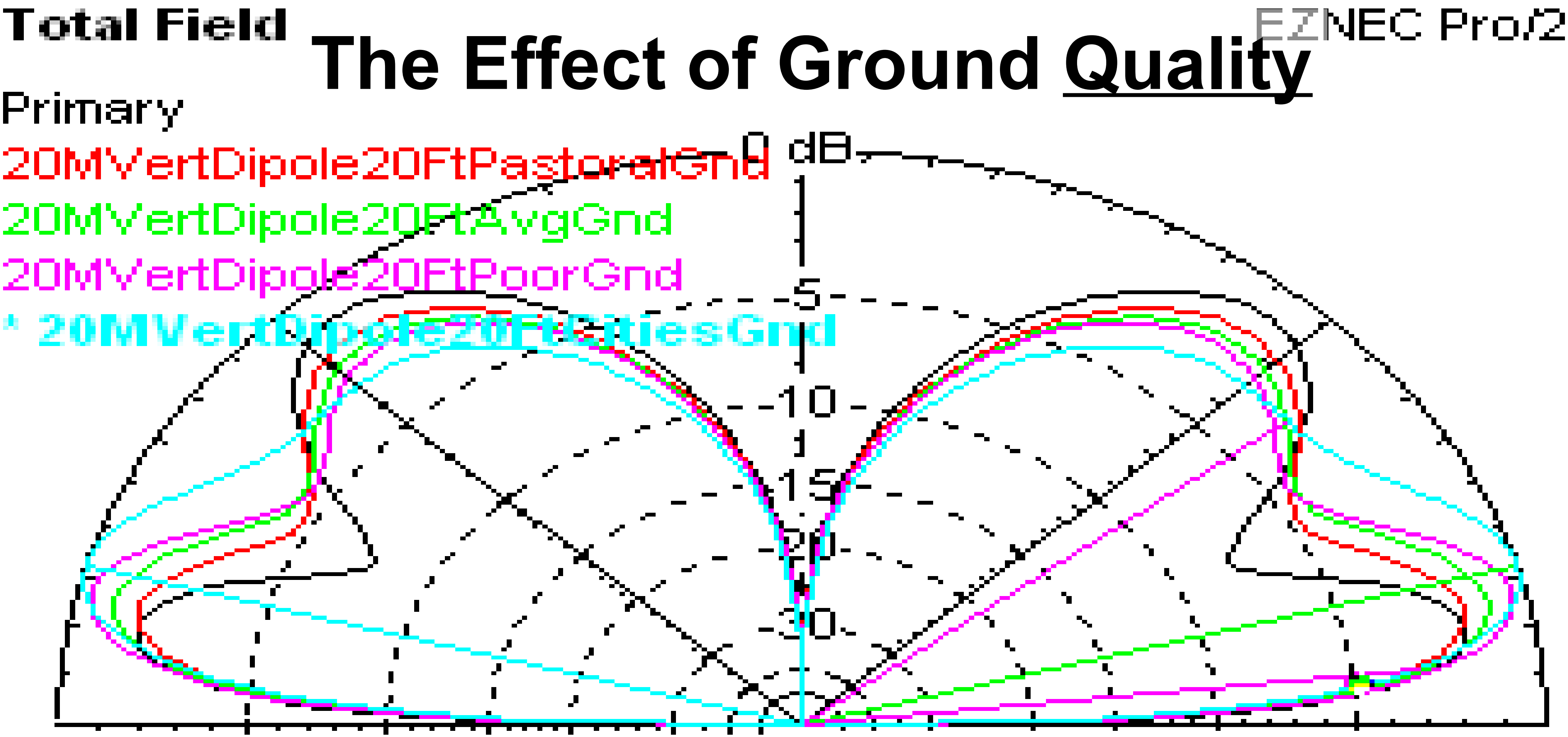
What We've Already Learned

- Vertical antennas work better at 20-40 ft than they do on the ground
  - How much better depends on the quality of your ground
  - Improvement is greatest for poorest soil quality
  - Sandy and rocky soil are very poor
  - City soil conditions are generally worse
  - The best soil around here is in the delta
  - Most of us have poor to average soil

What We've Already Learned

- Measurements by NOAX and K7LXC show that the most effective verticals are dipoles
- Vertical dipoles do <u>not</u> need radials
- Ground planes <u>do</u> need radials
  - Includes most "trap" designs, Butternut
  - Trap designs tend to be less efficient
  - On your roof, two resonant radials per band is pretty good, one per band is OK
  - On the ground, many radials are needed

The Effect of Ground Quality



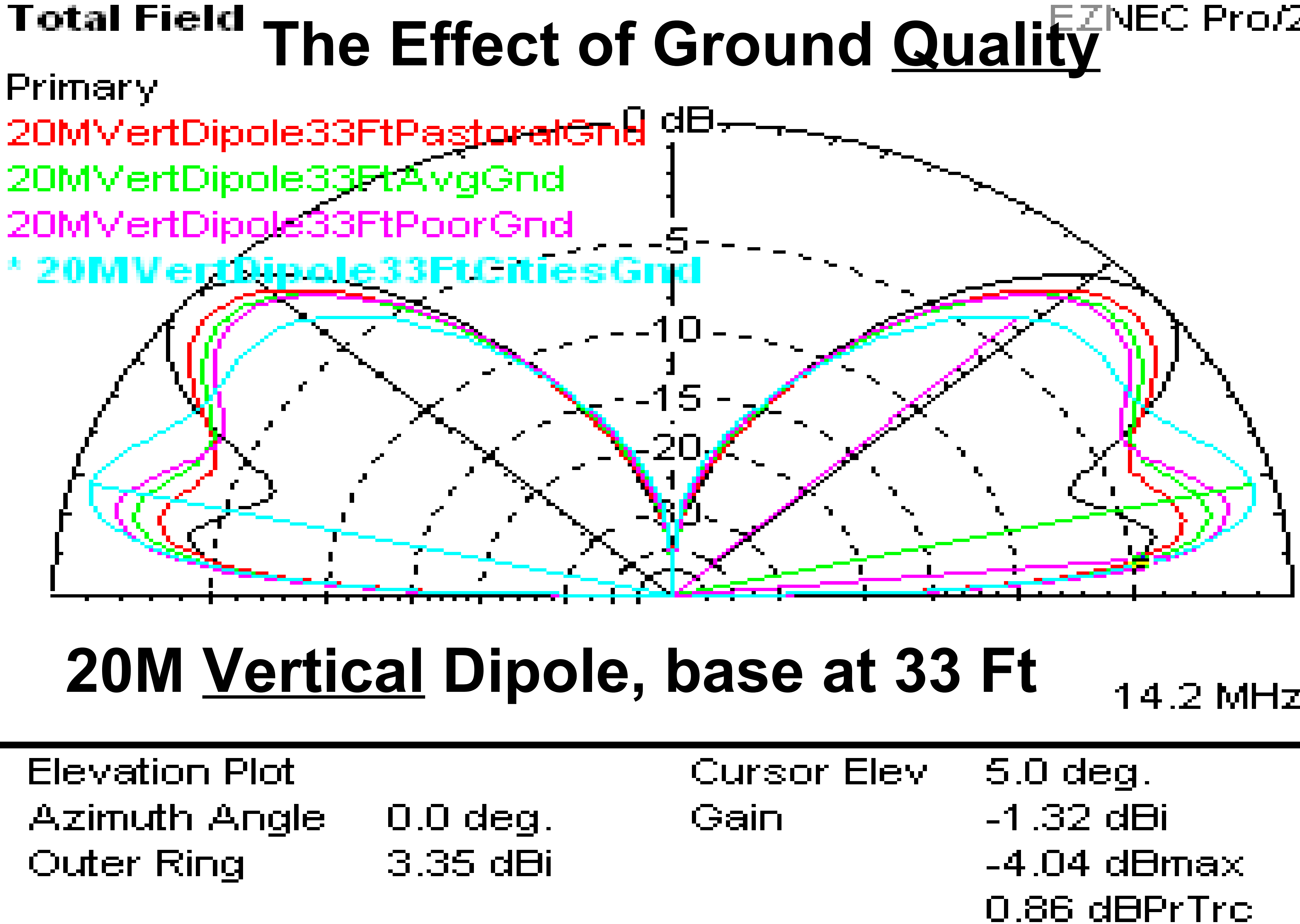
20M Vertical Dipole, base at 20 Ft

14.2 MHz

Elevation Plot		Cursor Elev	5.0 deg.
Azimuth Angle	0.0 deg.	Gain	-2.93 dBi
Outer Ring	1.92 dBi		-4.85 dBmax
			-1.11 dBPrTrc

Black (Reference)Curve is Very Good Ground

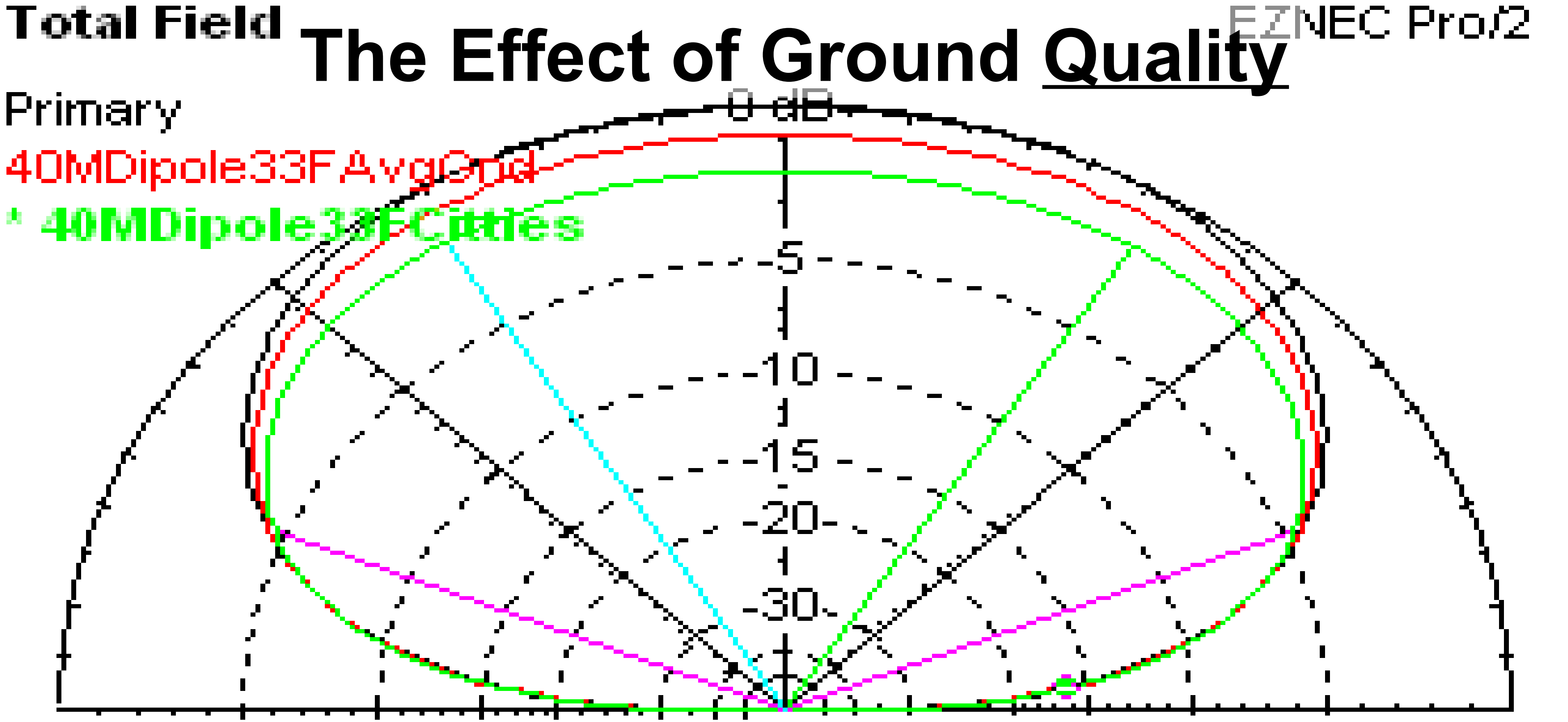
The Effect of Ground Quality



20M Vertical Dipole, base at 33 Ft

Black (Reference)Curve is Very Good Ground

The Effect of Ground Quality



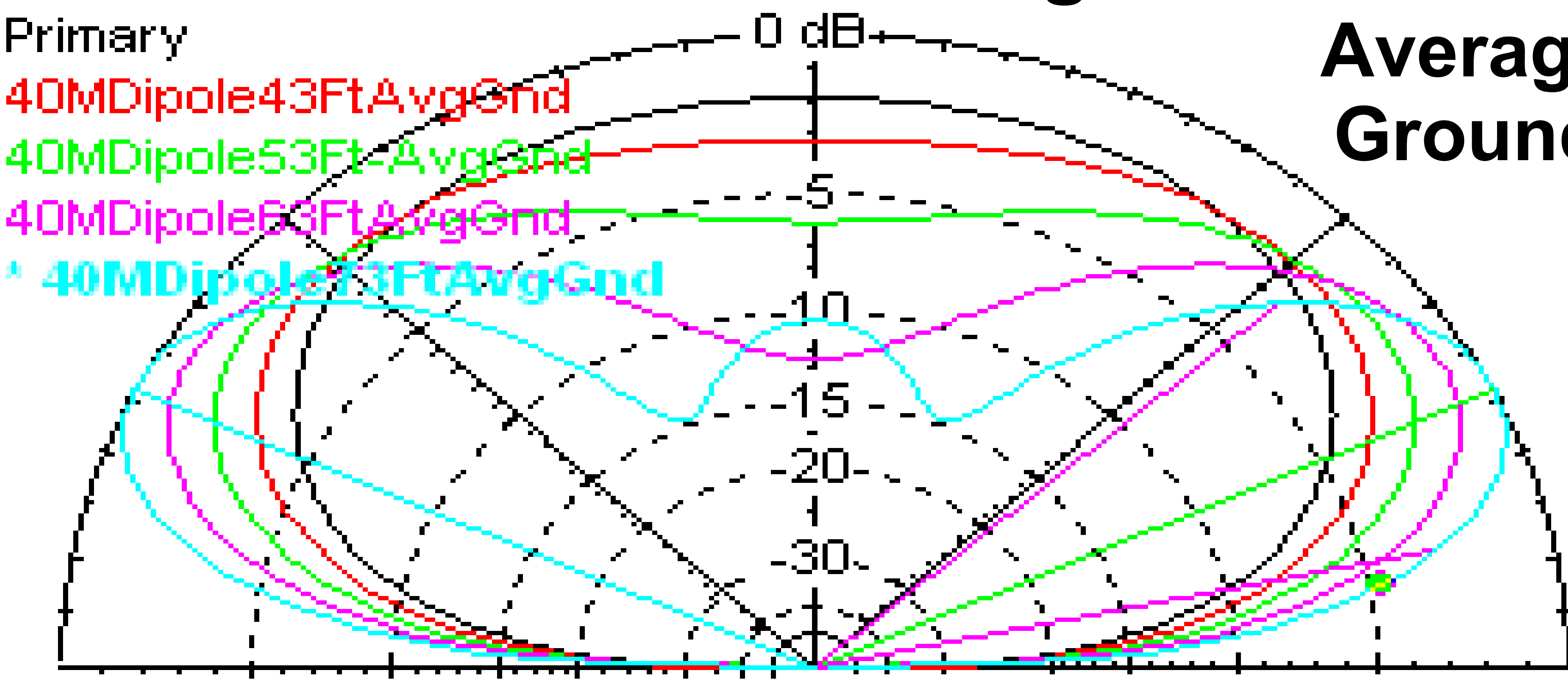
40M Horizontal Dipole, at 33 Ft

7.1 MHz

Elevation Plot		Cursor Elev	5.0 deg.
Azimuth Angle	0.0 deg.	Gain	-9.23 dBi
Outer Ring	6.82 dBi		-14.26 dBmax
			0.6 dBPrTrc

Black (Reference)Curve is Very Good Ground

The Effect of Height



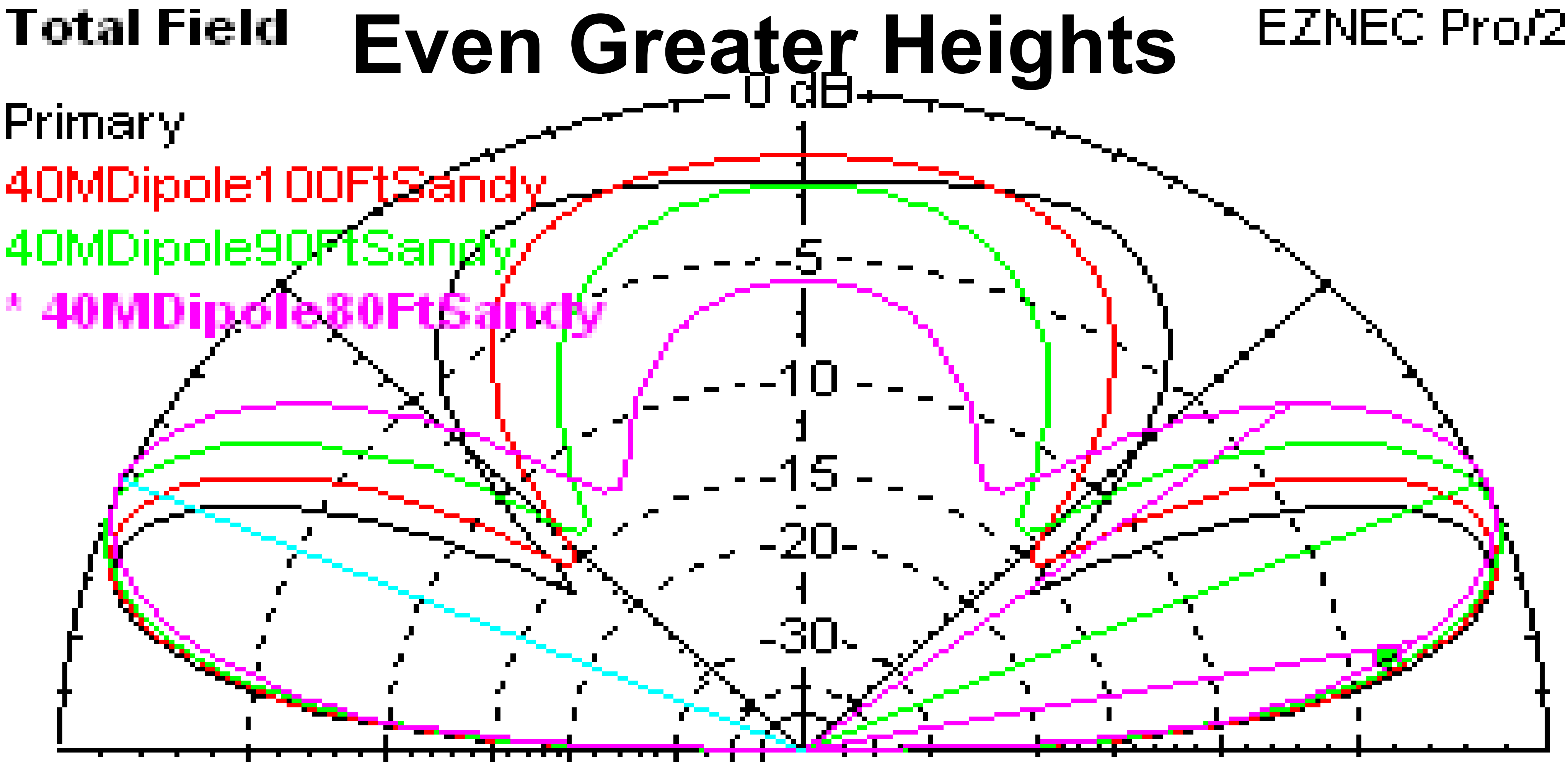
Average Ground

40M Horizontal Dipole @ 33 – 73 Ft 7.1 MHz

Elevation Plot		Cursor Elev	10.0 deg.
Azimuth Angle	0.0 deg.	Gain	3.28 dBi
Outer Ring	7.85 dBi		-4.56 dBmax
			7.17 dBPrTrc

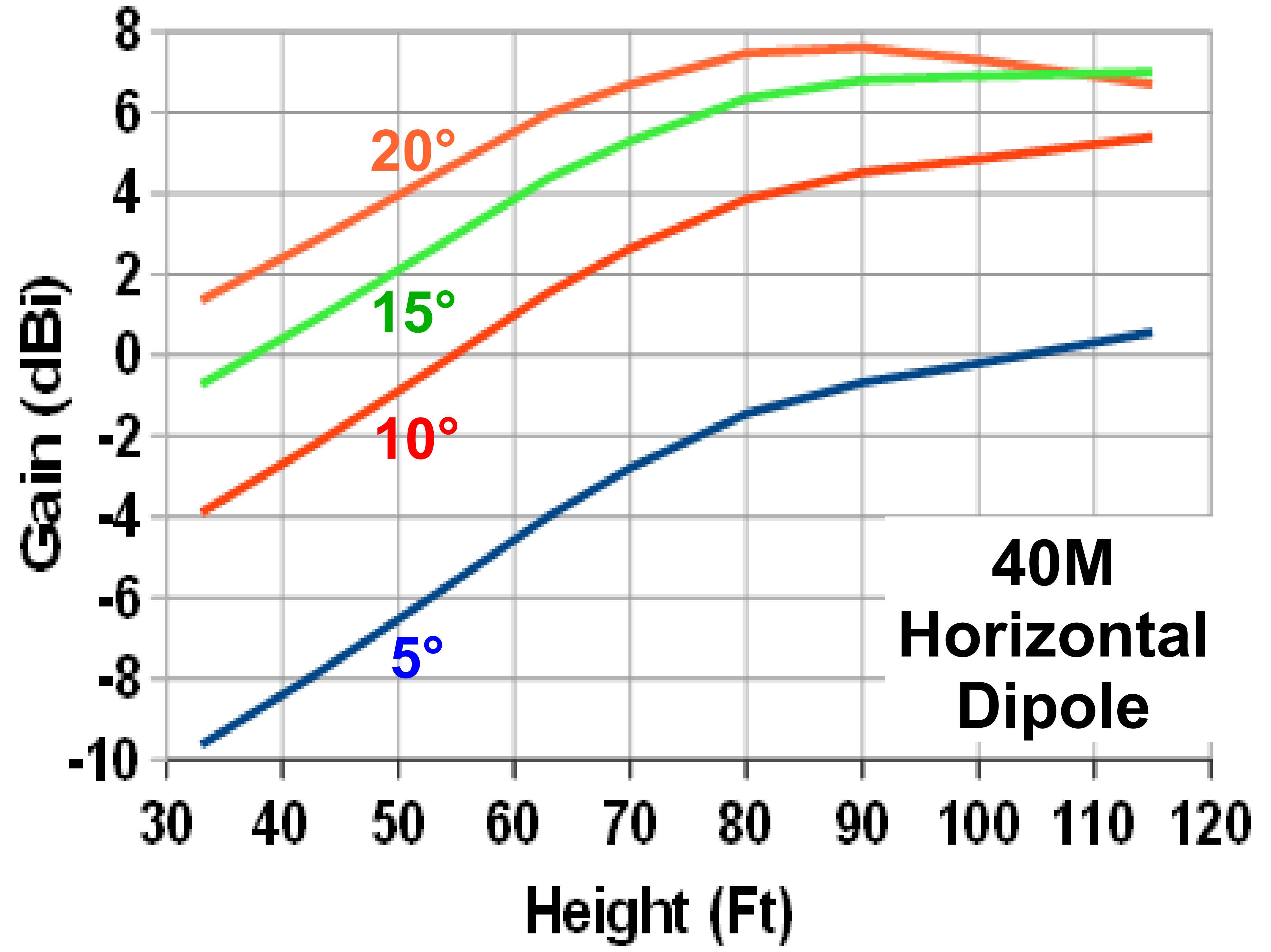
Black (Reference) Curve is 33 Ft

Even Greater Heights



40M Horizontal Dipole @ 80 – 110 Ft

Black (Reference) Curve is 110 Ft



8
6
4
2
0
-2
-4
-6
-8
-10
Gain (dBi)
20°
15°
10°
5°
40M
Horizontal
Dipole
30
40
50
60
70
80
90
100
110
120
Height (Ft)

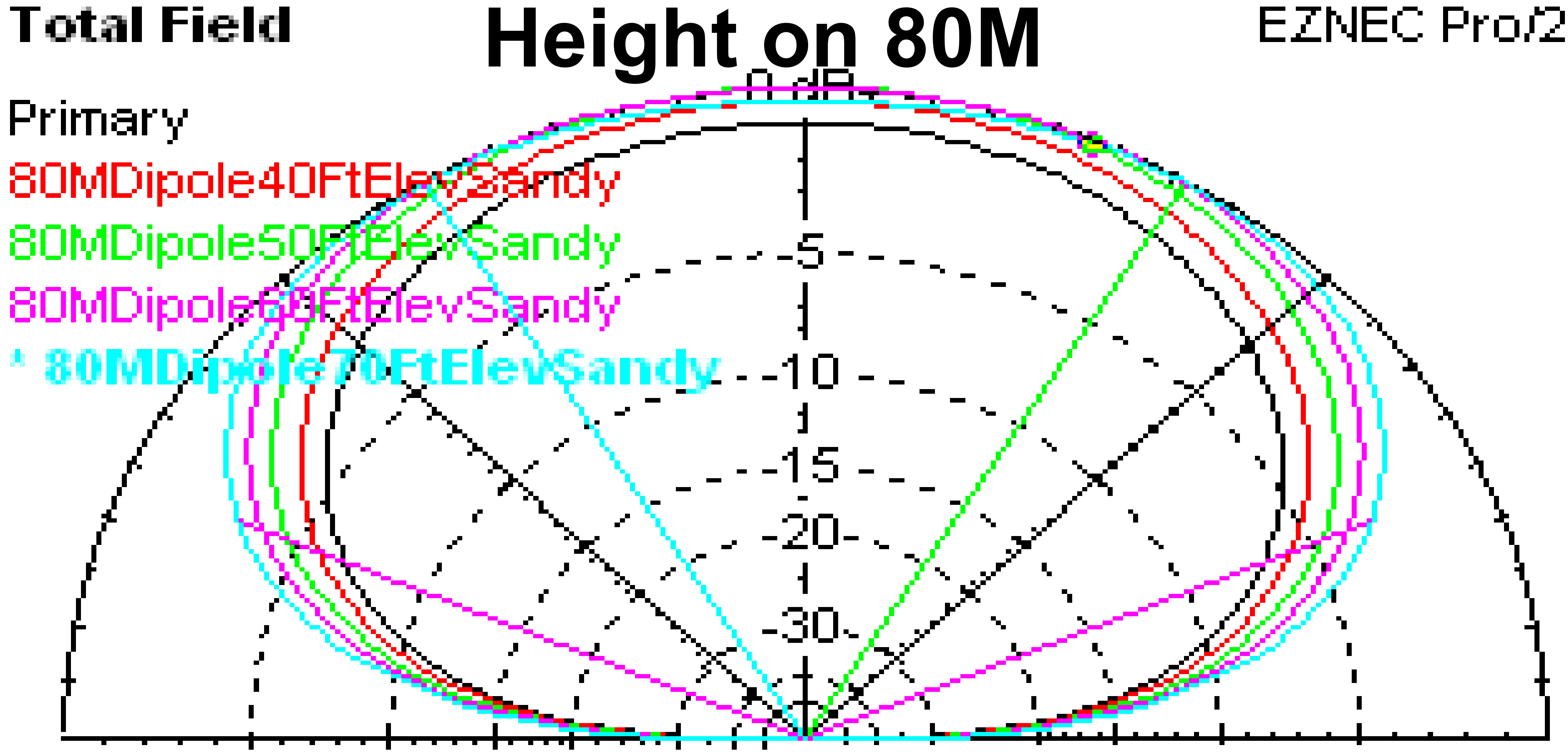
How Much is Height Worth?

- For a 40M horizontal dipole (or Yagi)
  - 0.9 dB for 5 ft between 30 Ft and 70 Ft below 15°
  - 6 dB for λ/4 (33 Ft) to λ/2 (67 Ft)
  - 2.5 dB for λ/2 (67 Ft) to λ (133 Ft)

How Much is a <u>Tower</u> Worth?

- For a 40M horizontal dipole (or Yagi)
  - 0.9 dB for 5 ft between 30 Ft and 70 Ft below 15°
  - 6 dB for λ/4 (33 Ft) to λ/2 (67 Ft)
  - 2.5 dB for λ/2 (67 Ft) to λ (133 Ft)

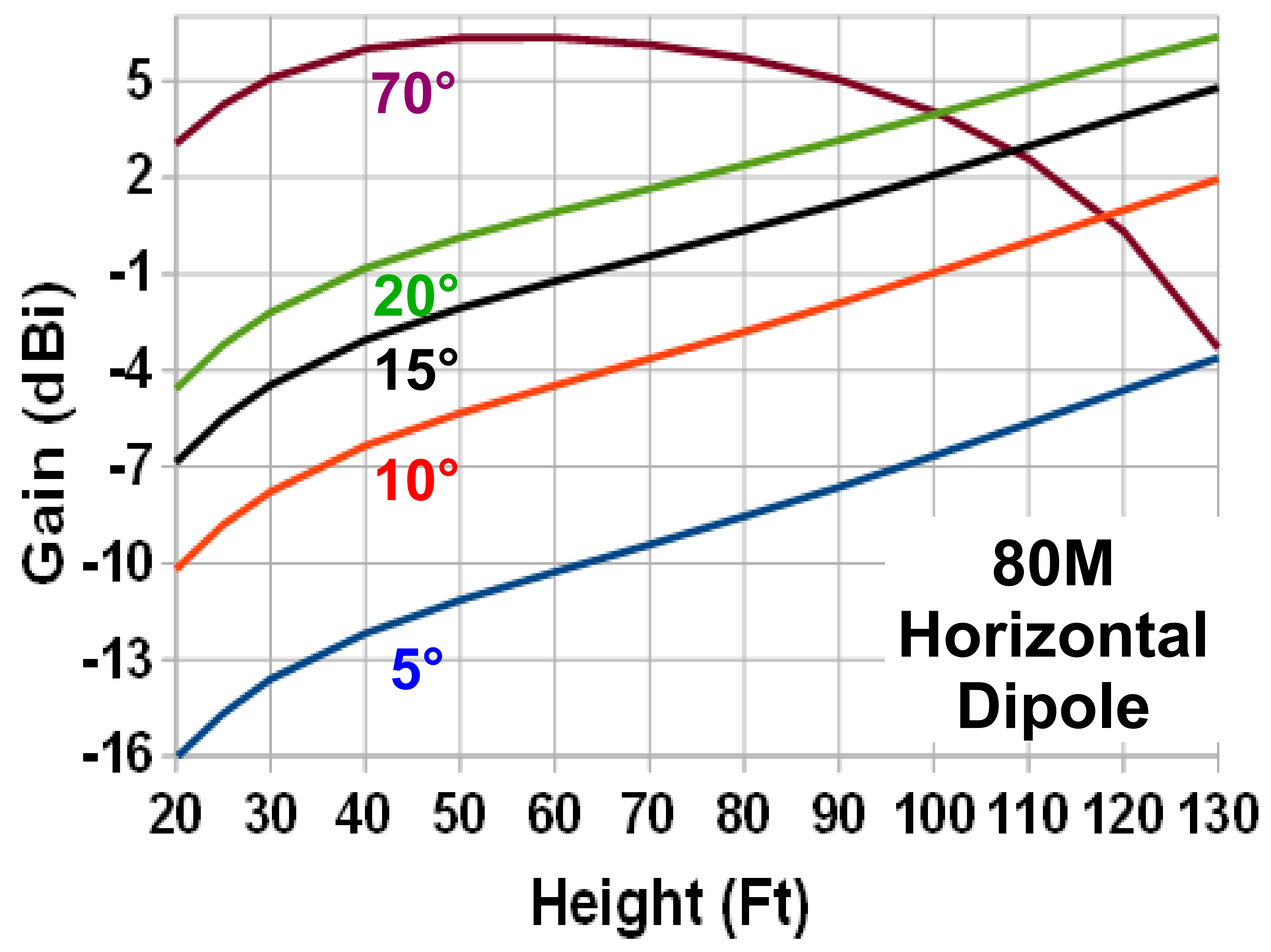
Height on 80M



80M Horizontal Dipole @ 33 – 70 Ft

Elevation Plot		Cursor Elev	67.0 deg.
Azimuth Angle	5.0 deg.	Gain	5.7 dBi
Outer Ring	5.87 dBi		-0.05 dBmax
			1.21 dBPrTrc

Black (Reference) Curve is 33 Ft



Gain (dBi)
5
2
-1
-4
-7
-10
-13
-16
70°
20°
15°
10°
5°
80M
Horizontal
Dipole
20
30
40
50
60
70
80
90
100
110
120
130
Height (Ft)

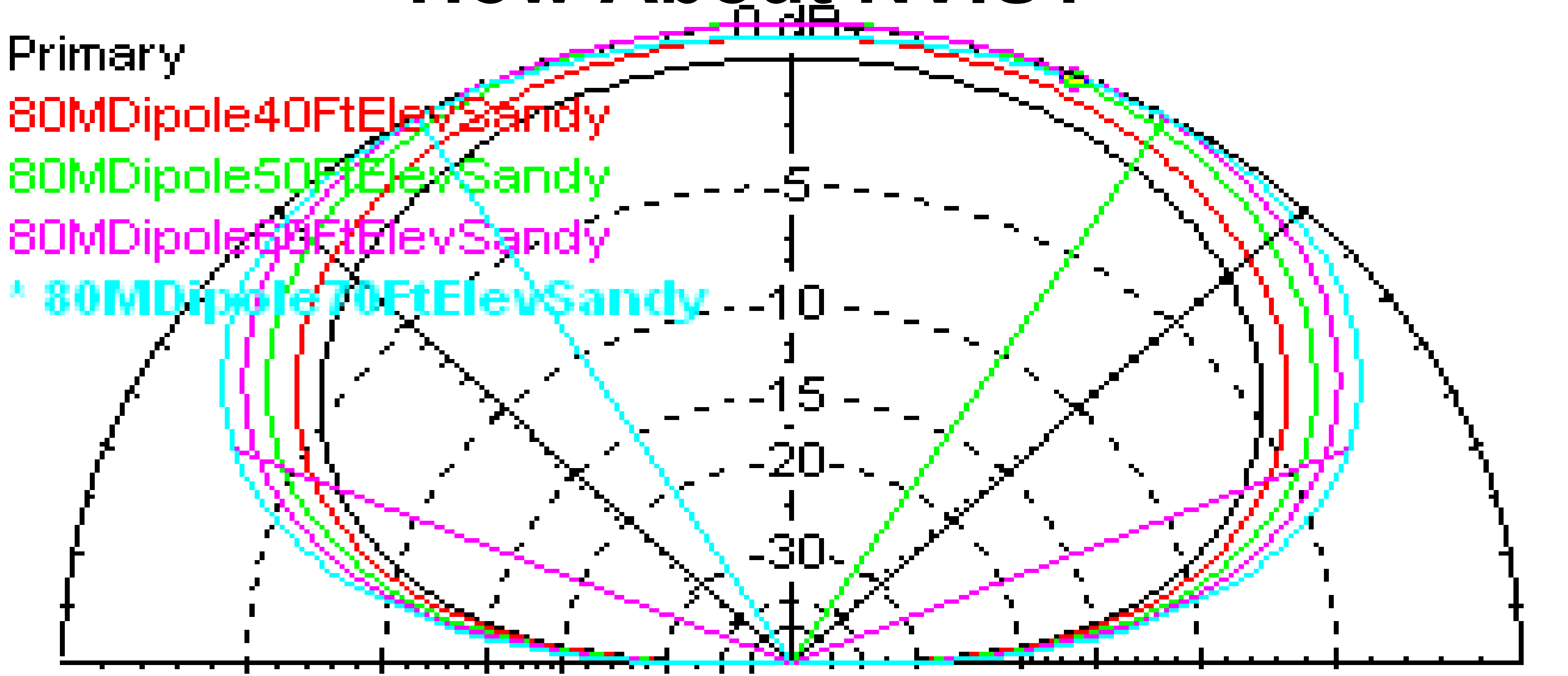
How Much is Height Worth?

- For an 80M horizontal dipole (or Yagi) at 15° and below
  - 0.9 dB for 10 ft between 40 Ft and 130 Ft
  - 3.5 dB for λ/8 (33 Ft) to λ/4 (67 Ft)
  - 6 dB for λ/4 (67 Ft) to λ/2 (133 Ft)
- On the lower bands, we need less signal to work short distances than long distances
- An antenna cannot be "too high" for 80M

Total Field

How About NVIS?

EZNEC Pro/2



80M Horizontal Dipole @ 33 – 70 Ft

3.55 MHz

Elevation Plot		Cursor Elev	67.0 deg.
Azimuth Angle	5.0 deg.	Gain	5.7 dBi
Outer Ring	5.87 dBi		-0.05 dBmax
			1.21 dBPrTrc

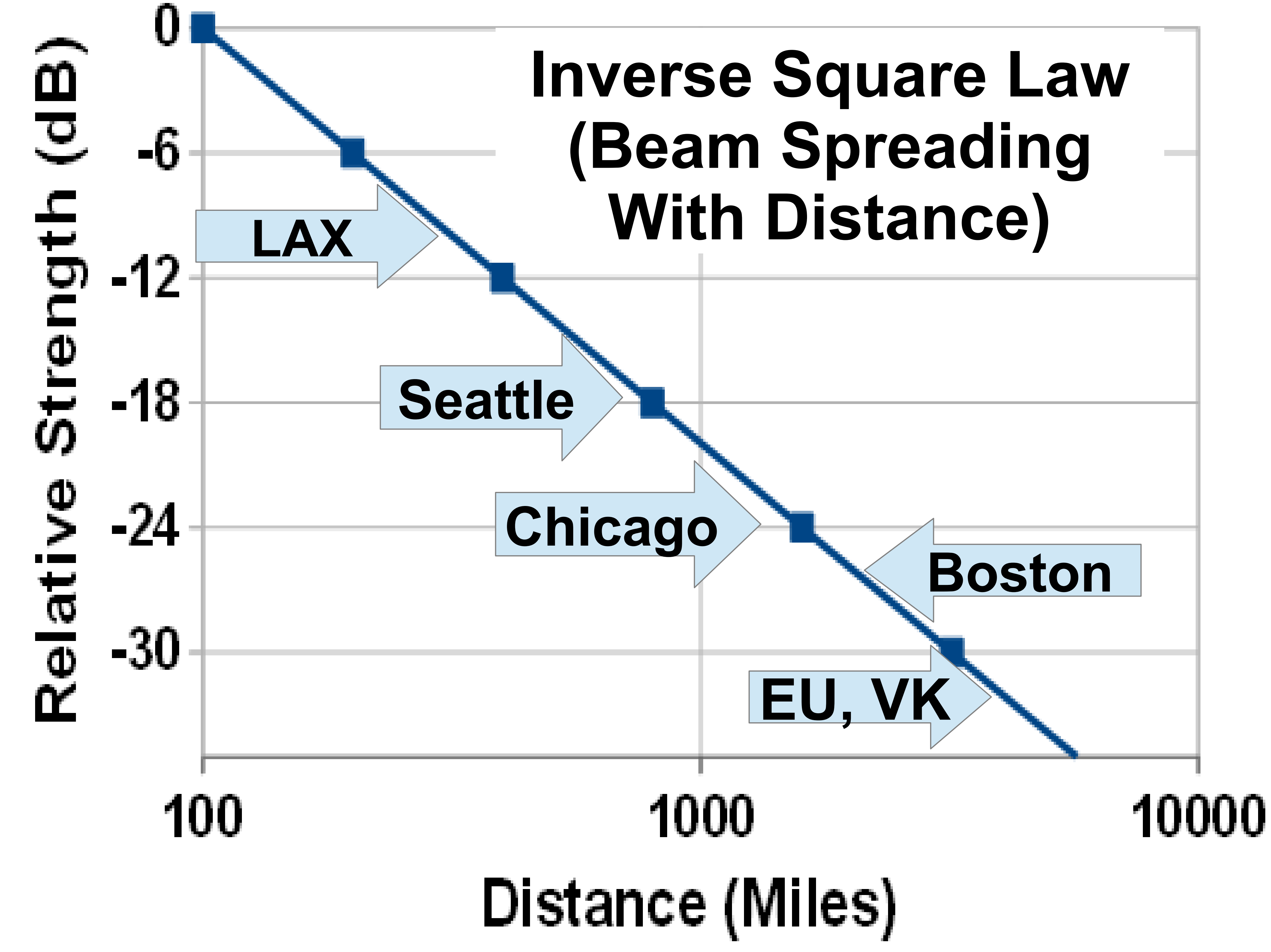
Black (Reference) Curve is 33 Ft

How About NVIS?

- For a horizontal dipole, λ/4 high is near optimum
  - 133 ft on 160M
  - 67 ft on 80M
  - 33 ft on 40M
- The only reason to rig a horizontal antenna lower than λ/4 is that's the best you can do

Can An Antenna Be Too High?

- I want to work locals for nets and during contests. Does a high antenna give away too much high angle performance?


Inverse Square Law
(Beam Spreading
With Distance)
Relative Strength (dB)
0
-6
-12
-18
-24
-30
LAX
Seattle
Chicago
Boston
EU, VK
100
1000
10000
Distance (Miles)

Inverse Square Law

- **Seattle is 6 dB closer than Chicago, 8 dB closer than Boston**
- **An antenna that favors Chicago (70° azimuth) will work Seattle (5°) as easily as it works Chicago**
- **On the lower bands, we need less signal to work short distances than long distances**

How About NVIS?

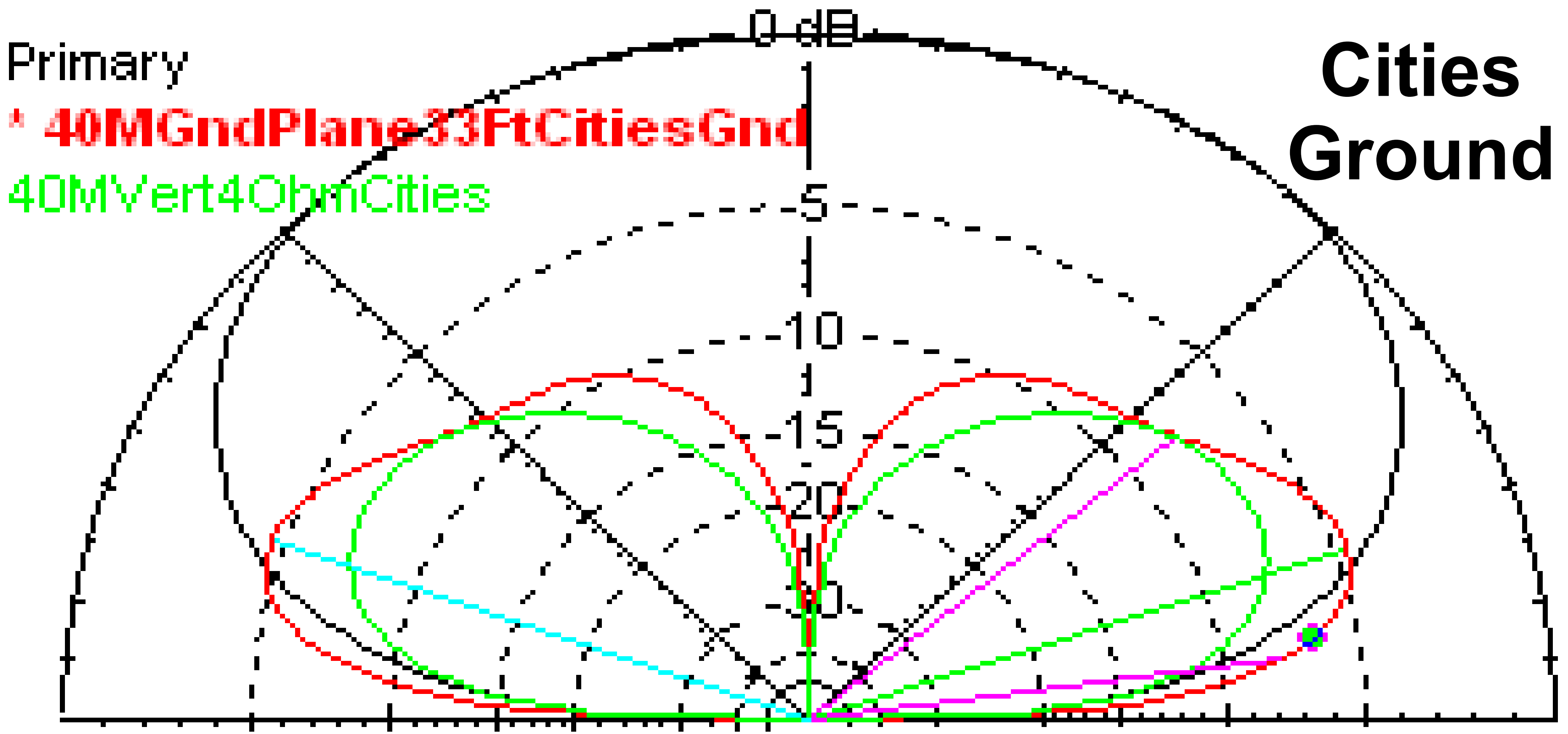
- For a horizontal dipole, λ/4 high is near optimum
  - 133 ft on 160M
  - 67 ft on 80M
  - 33 ft on 40M
- At λ/2 high, an antenna is -10 dB from λ/4 high, but Inverse Square Law makes up the difference
- The only reason to rig a horizontal antenna lower than λ/4 is that it's the highest you can get it

Let's Study Some Modeling Results

First Series

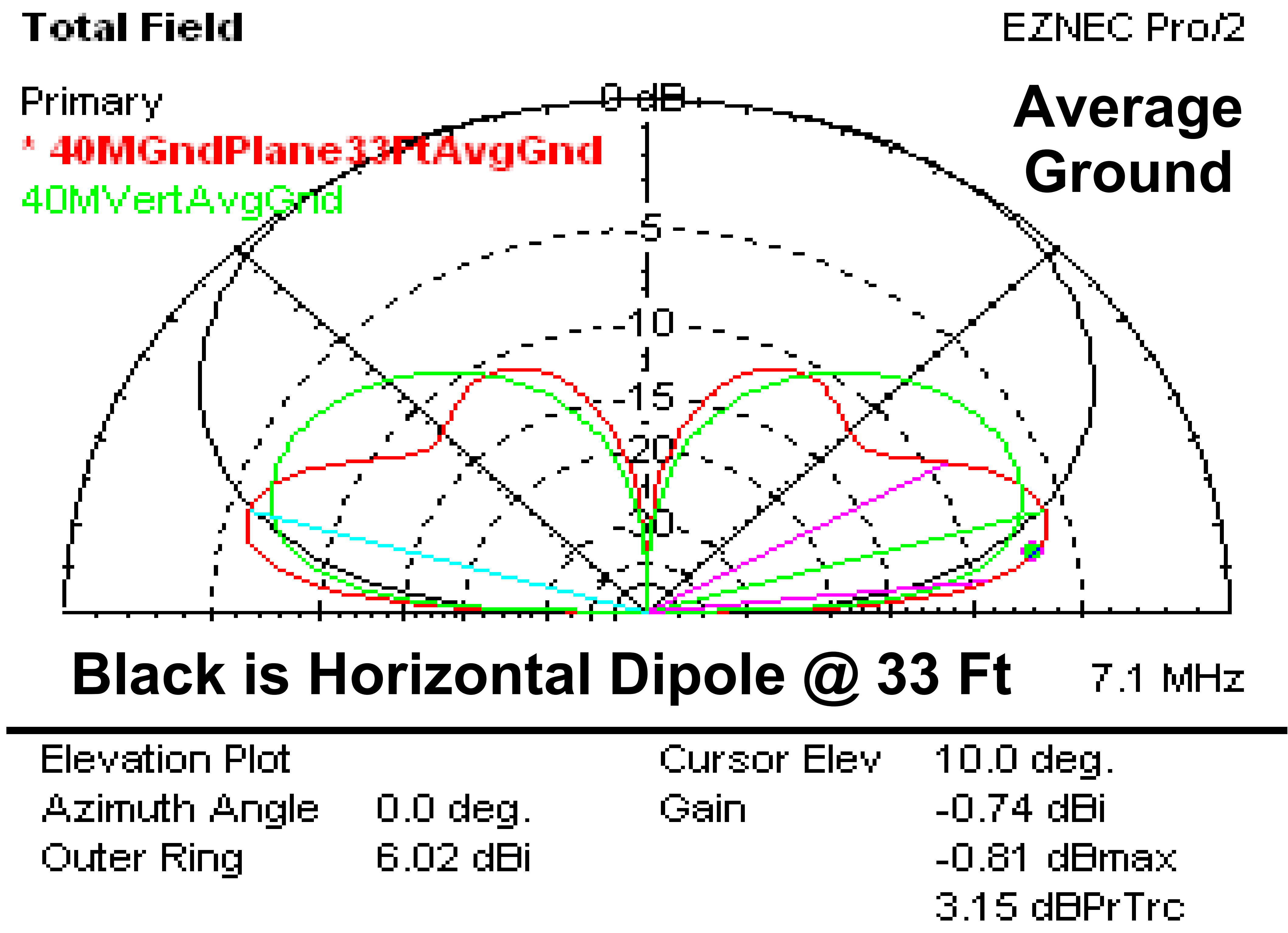
40M Horizontal Dipole @33 Ft (Black curve)
compared to:
40M Ground-mounted quarter wave with 4 Ohm Radial System (Green curve), and
40M Ground Plane @ 33 Ft (Red Curve)
Vertical Pattern, Cursor at 10°

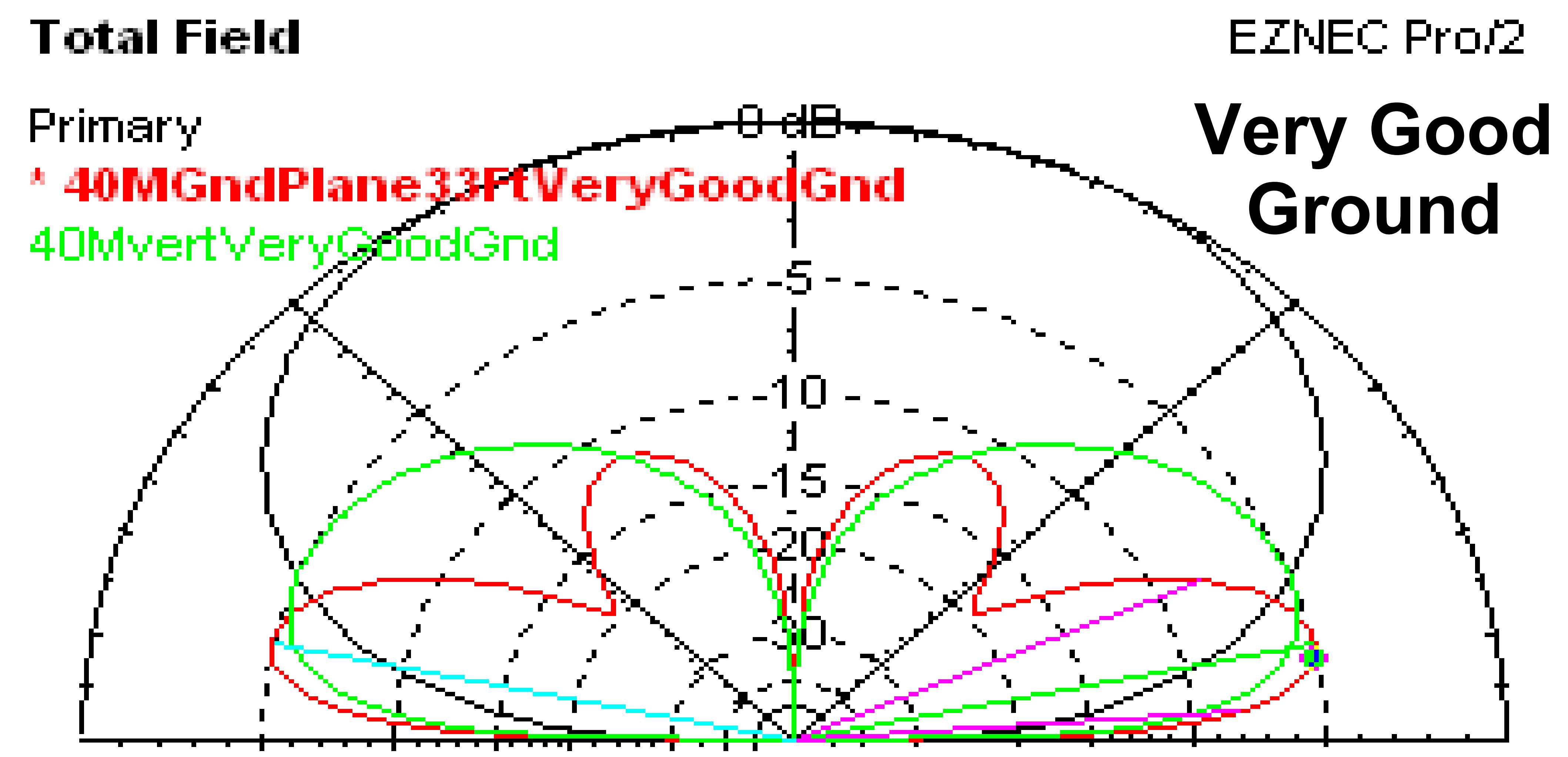
Total Field EZNEC Pro/2



Black is Horizontal Dipole @ 33 Ft

Elevation Plot		Cursor Elev	10.0 deg.
Azimuth Angle	0.0 deg.	Gain	-1.43 dBi
Outer Ring	5.03 dBi		-1.79 dBmax
			2.23 dBPrTrc


Total Field
EZNEC Pro/2
Primary
* 40MGndPlane33FtAvgGnd
40MVertAvgGnd
0 dB
-5
-10
-15
-20
Average Ground
Black is Horizontal Dipole @ 33 Ft
7.1 MHz
Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 6.02 dBi
Cursor Elev 10.0 deg.
Gain -0.74 dBi
-0.81 dBmax
3.15 dBPrTrc

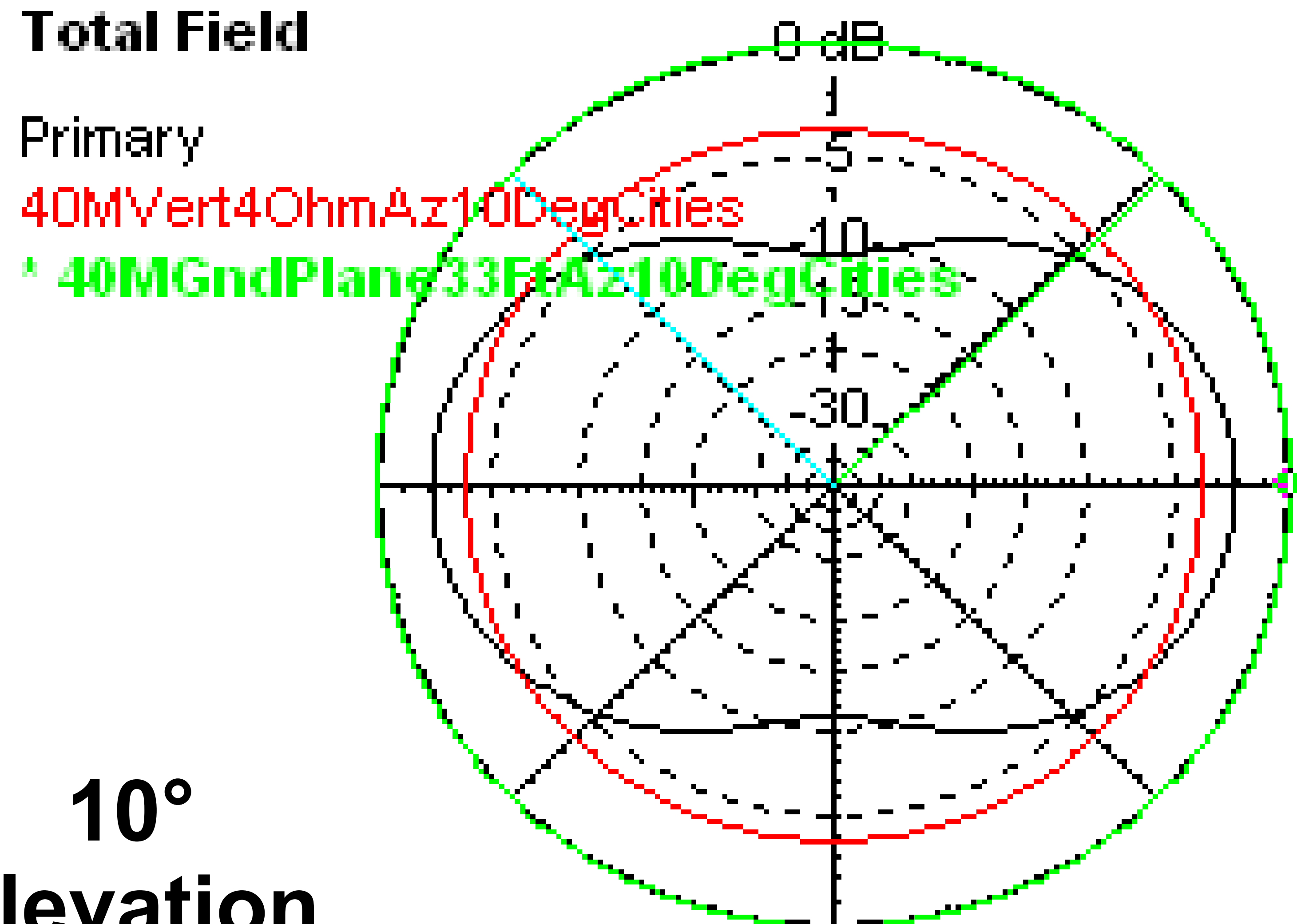


Black is Horizontal Dipole @ 33 Ft 7.1 MHz

Elevation Plot		Cursor Elev	10.0 deg.
Azimuth Angle	0.0 deg.	Gain	1.66 dBi
Outer Ring	6.82 dBi		-0.15 dBmax
			5.65 dBPrTrc

First Series – Azimuth Plots

40M Vertical on Ground (Red curve)
40M Ground Plane at 33 Ft (Green curve)
40M Horizontal Dipole @ 33 Ft
Azimuth Plot @ 10° Elevation



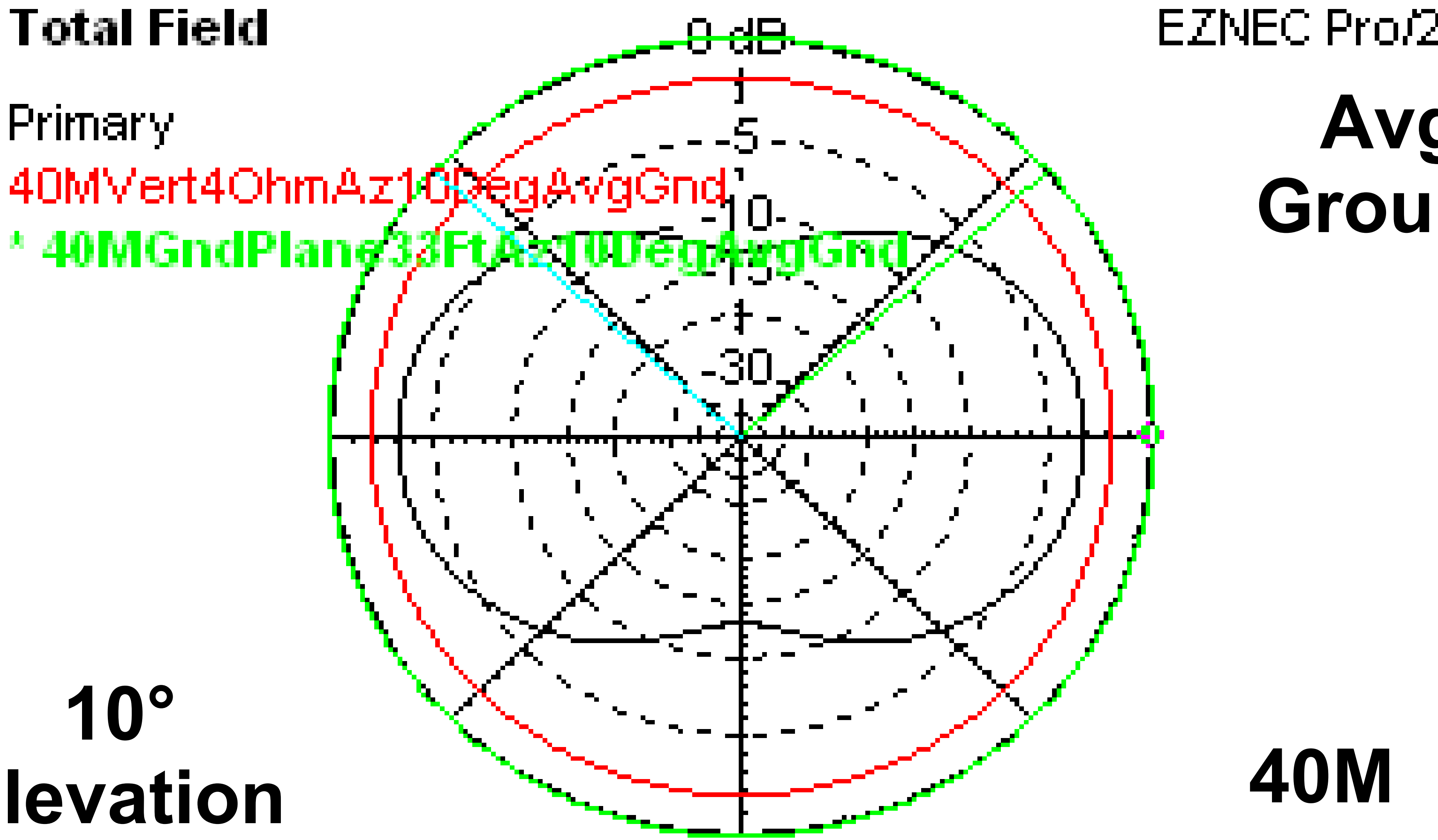
Cities Ground

10° Elevation

40M

Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	-1.46 dBi
Outer Ring	-1.43 dBi		-0.03 dBmax
			2.2 dBPrTrc

Black (Reference) Curve is Dipole @ 33 Ft



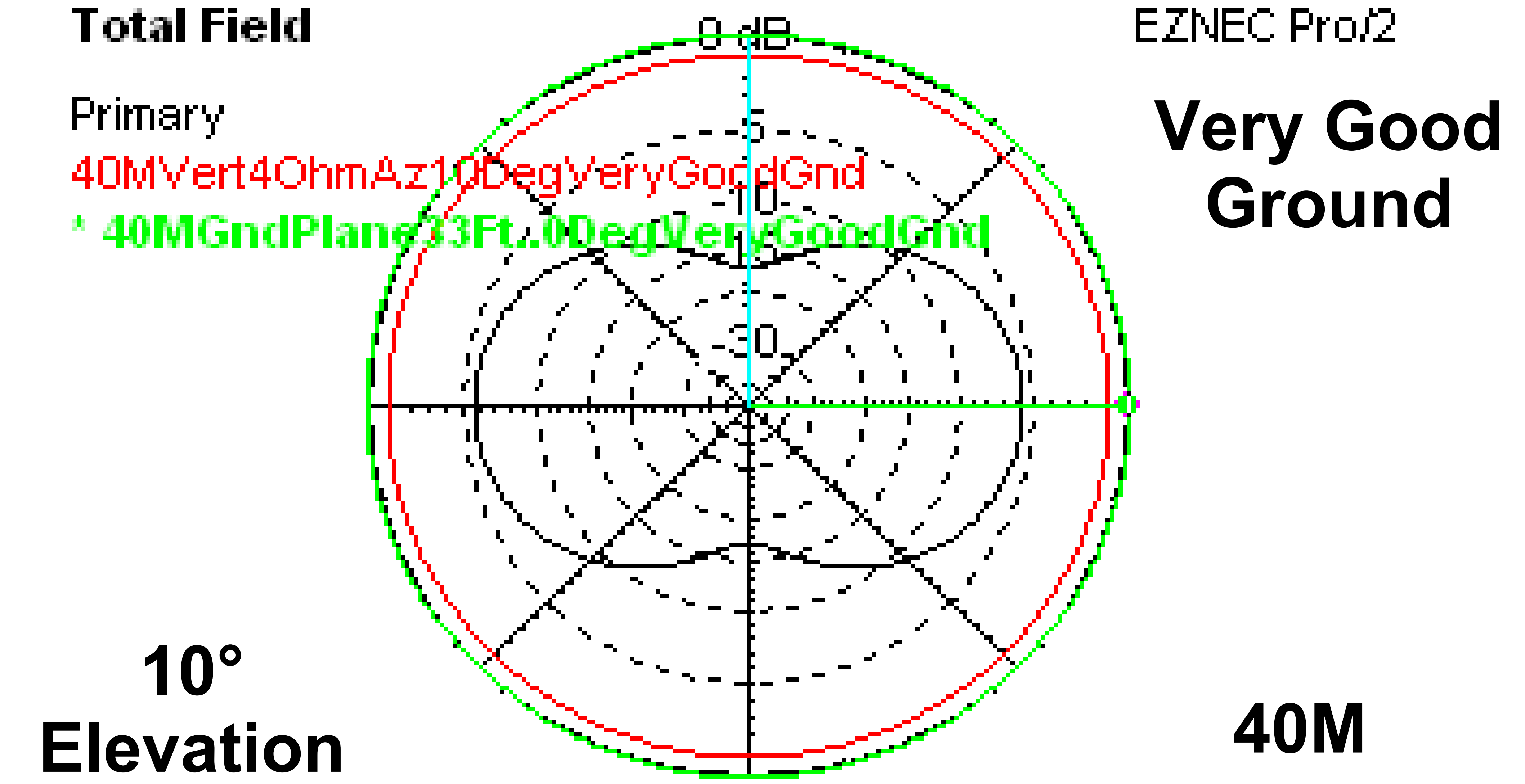
Avg Ground

10° Elevation

40M

Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	-0.74 dBi
Outer Ring	-0.73 dBi		0.0 dBmax
			3.15 dBPrTrc

Black (Reference) Curve is Dipole @ 33 Ft

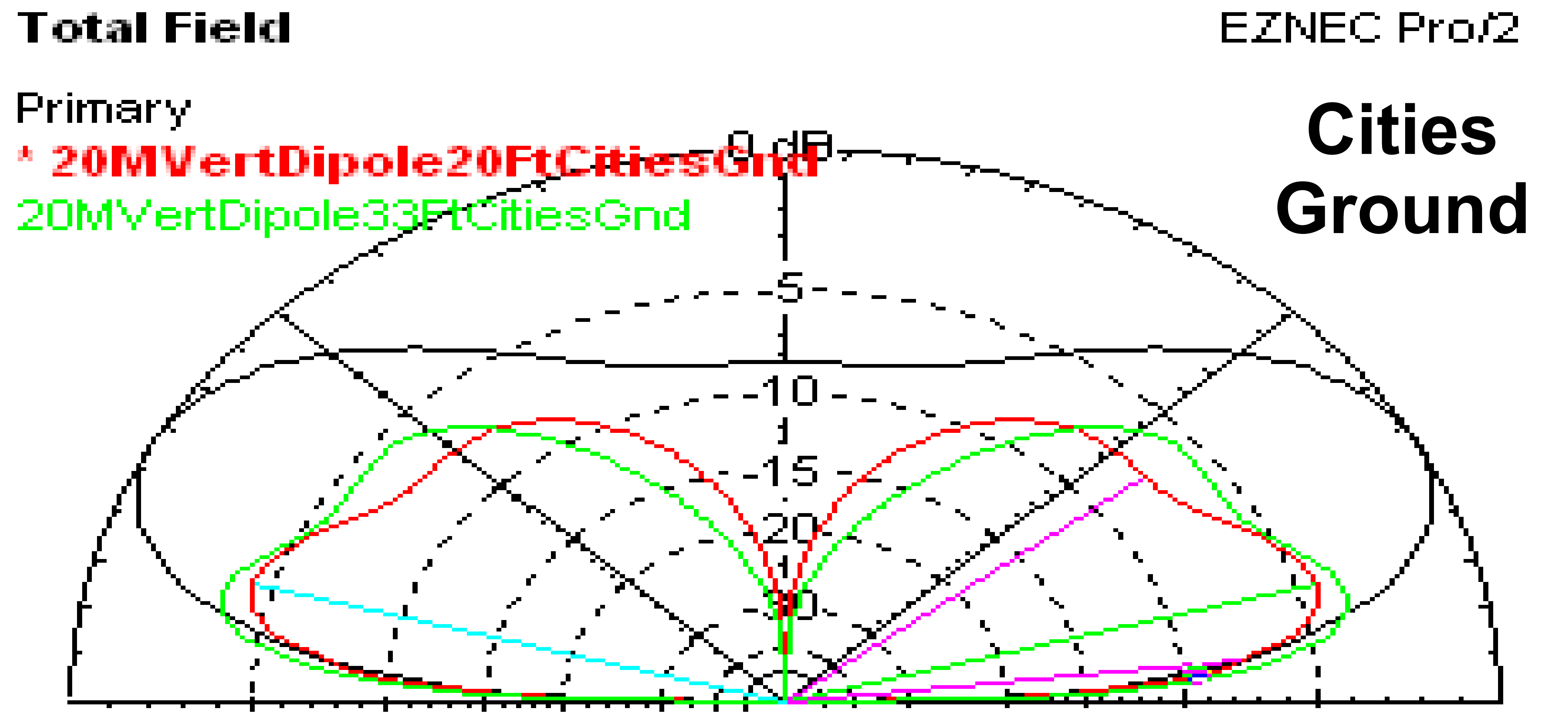


Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	1.66 dBi
Outer Ring	1.66 dBi		0.0 dBmax
			5.65 dBPrTrc

Black (Reference) Curve is Dipole @ 33 Ft

Second Series

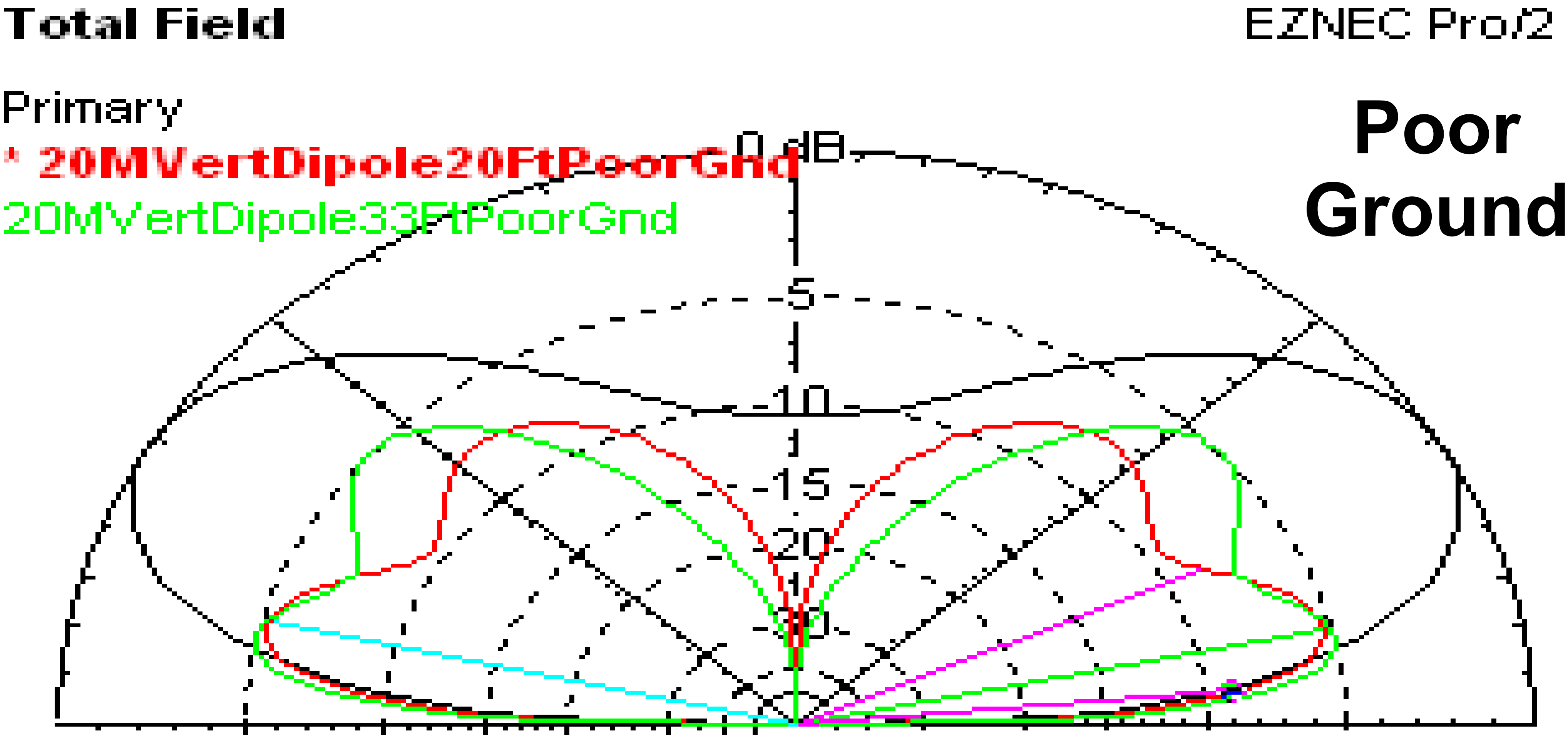
20M Vertical Dipole at 20 Ft (Red curve)
20M Vertical Dipole at 33 Ft (Green curve)
20M Horizontal Dipole @ 33 Ft (Black curve)
Cursor at 5 degrees



20M Horizontal Dipole @ 33 Ft

14.1 MHz

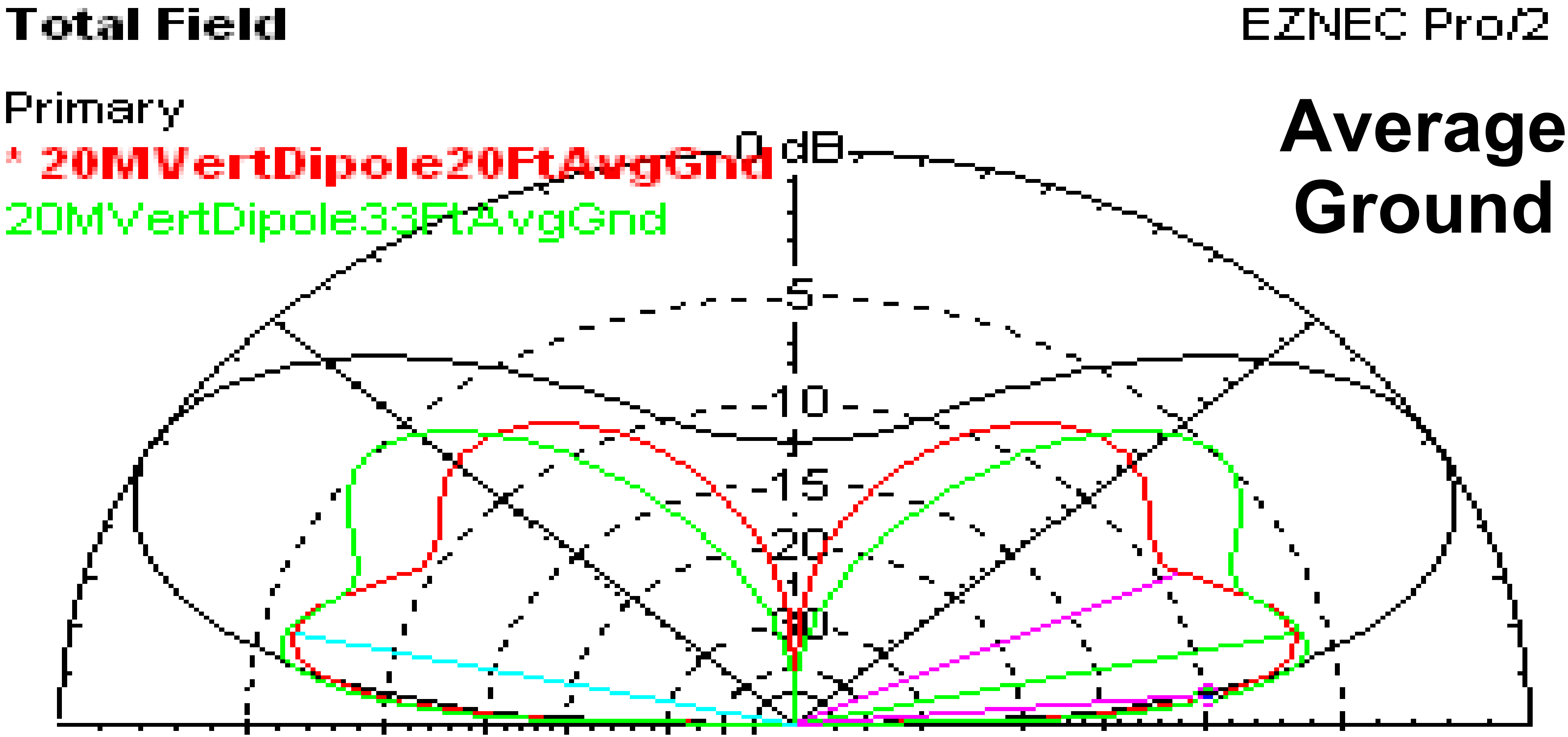
Elevation Plot		Cursor Elev	5.0 deg.
Azimuth Angle	0.0 deg.	Gain	-2.93 dBi
Outer Ring	6.37 dBi		-4.85 dBmax
			0.75 dBPrTrc



20M Horizontal Dipole @ 33 Ft

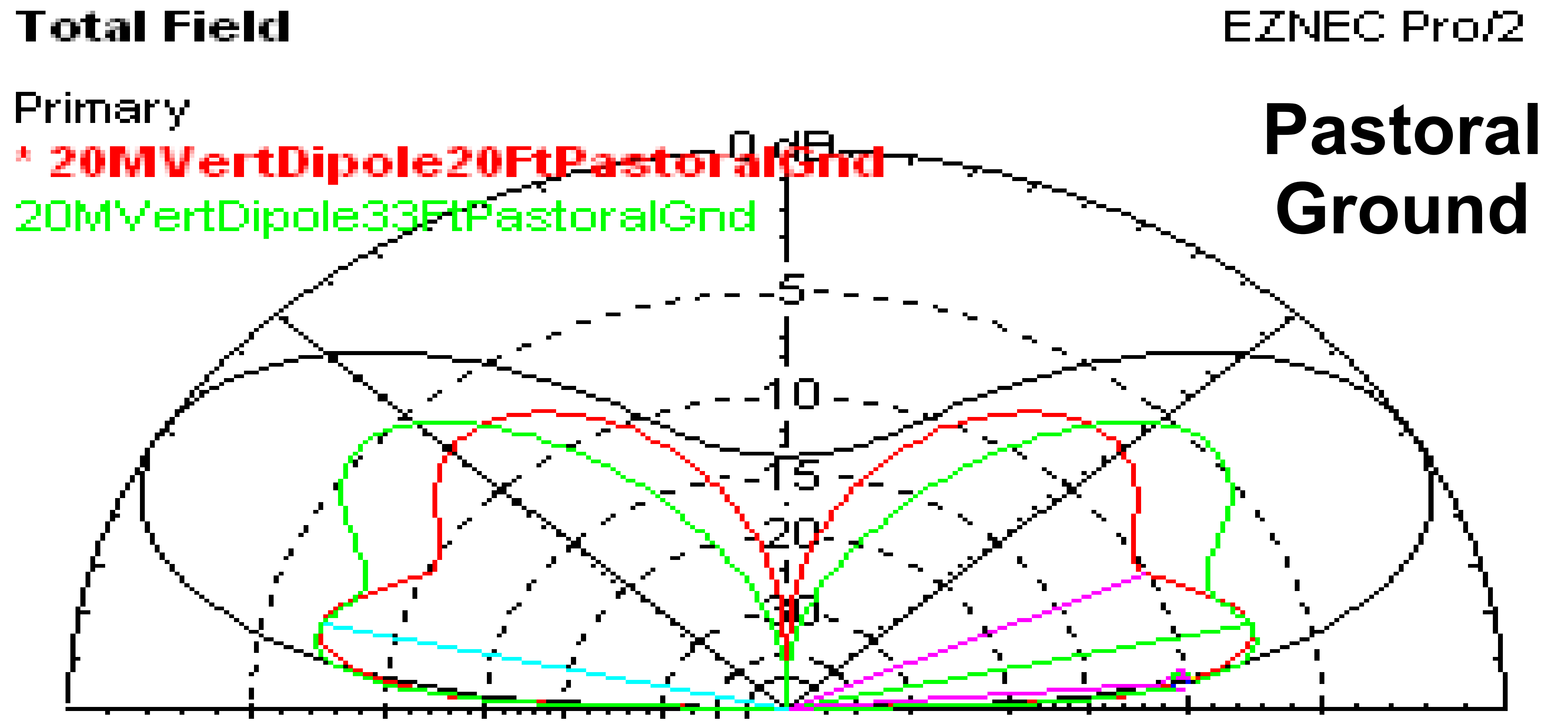
14.1 MHz

Elevation Plot		Cursor Elev	5.0 deg.
Azimuth Angle	0.0 deg.	Gain	-2.03 dBi
Outer Ring	6.86 dBi		-3.58 dBmax
			1.7 dBPrTrc



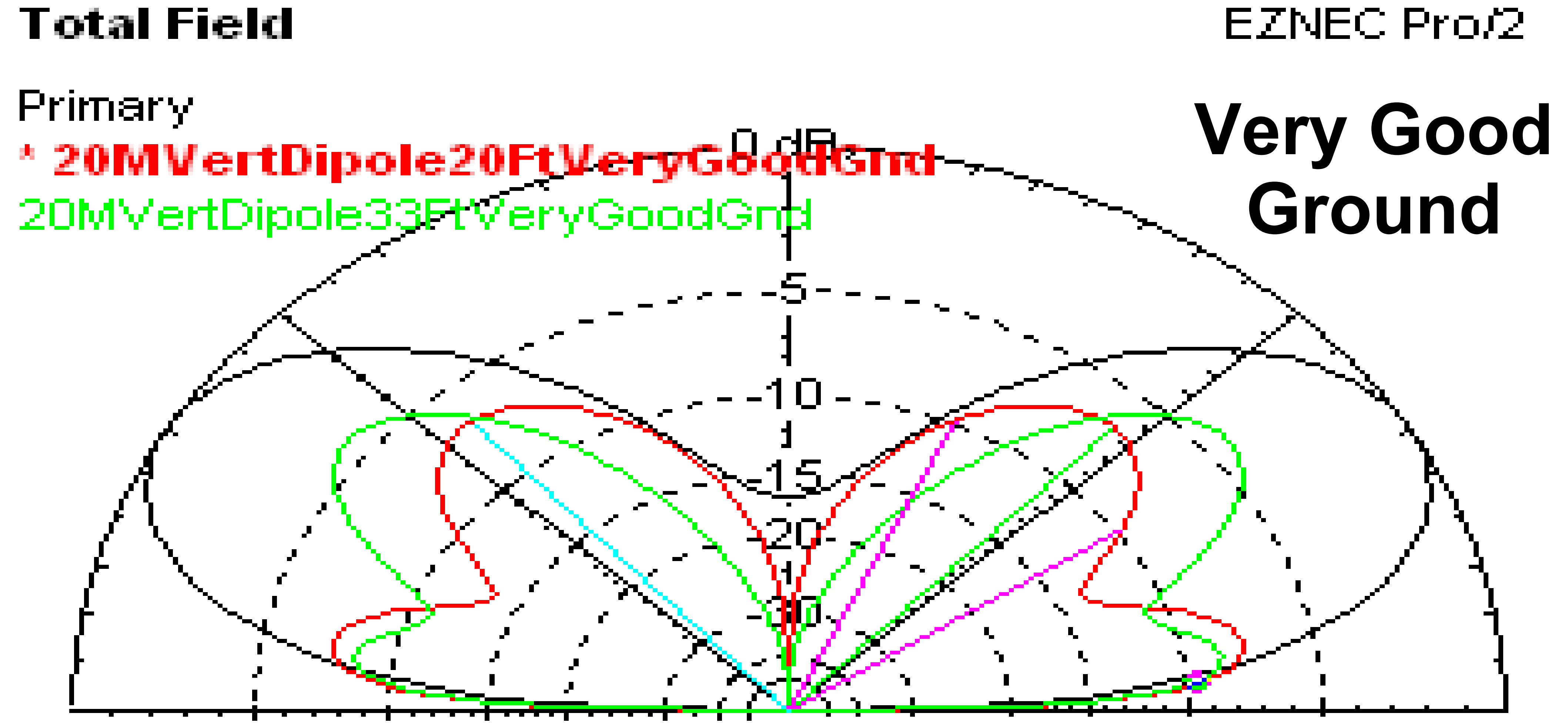
20M Horizontal Dipole @ 33 Ft 14.1 MHz

Elevation Plot		Cursor Elev	5.0 deg.
Azimuth Angle	0.0 deg.	Gain	-2.51 dBi
Outer Ring	7.11 dBi		-3.48 dBmax
			1.12 dBPrTrc



20M Horizontal Dipole @ 33 Ft 14.1 MHz

Elevation Plot		Cursor Elev	5.0 deg.
Azimuth Angle	0.0 deg.	Gain	-2.81 dBi
Outer Ring	7.33 dBi		-3.11 dBmax
			0.69 dBPrTrc

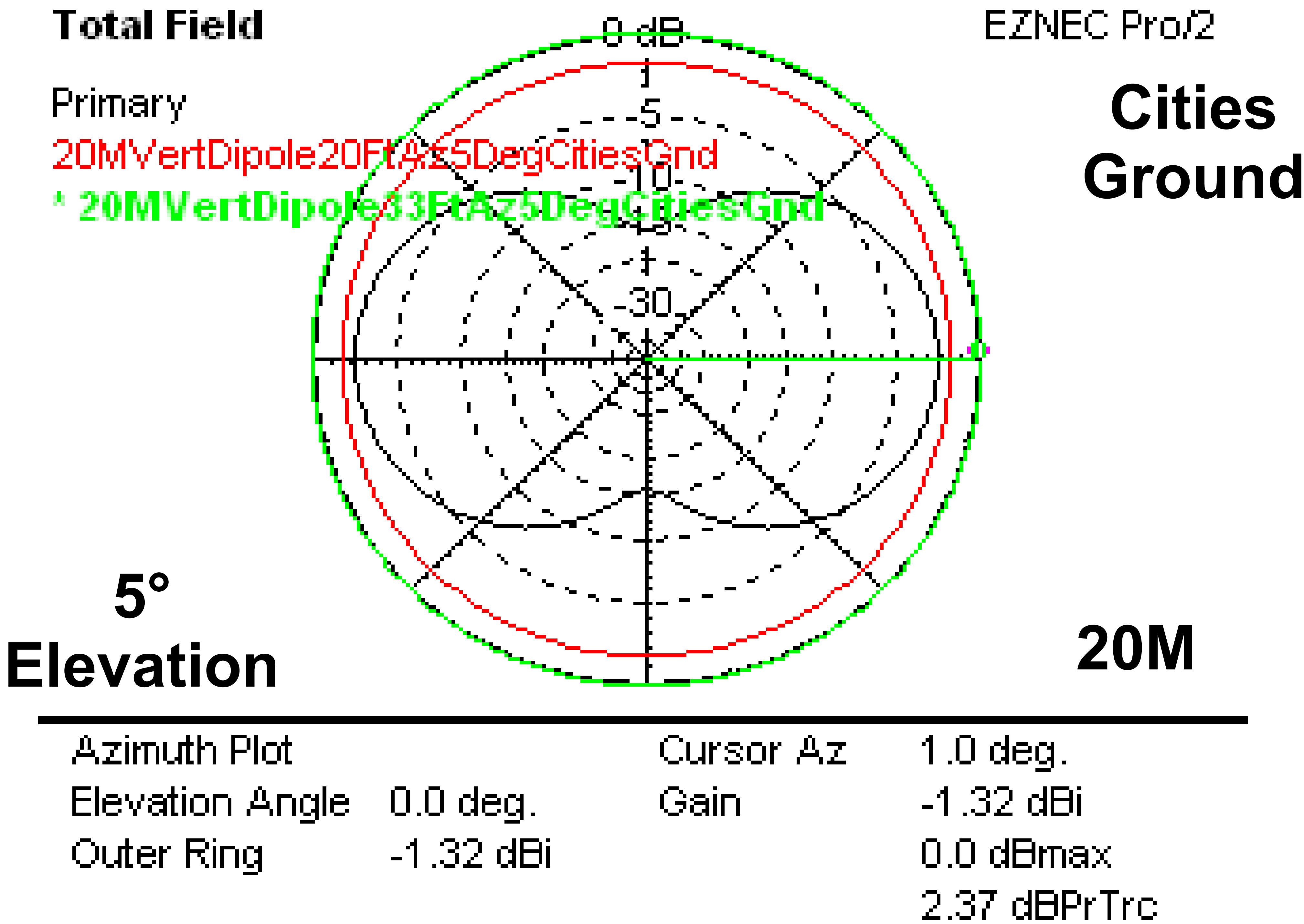


20M Horizontal Dipole @ 33 Ft 14.1 MHz

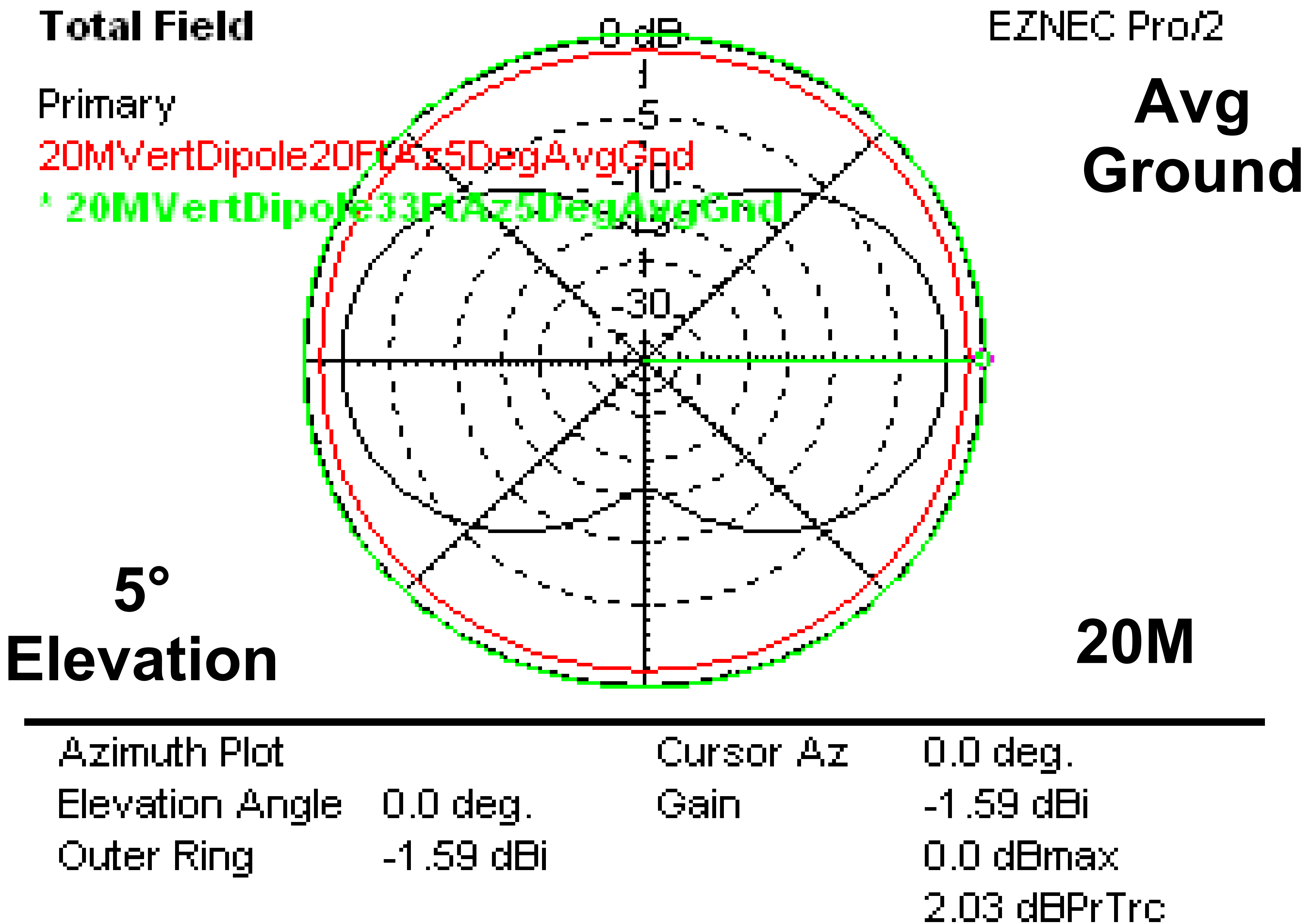
Elevation Plot		Cursor Elev	5.0 deg.
Azimuth Angle	0.0 deg.	Gain	-1.82 dBi
Outer Ring	7.67 dBi		-2.75 dBmax
			1.65 dBPrTrc

Second Series – Azimuth Plot

20M Vertical Dipole at 20 Ft (Red curve)
20M Vertical Dipole at 33 Ft (Green curve)
20M Horizontal Dipole @ 33 Ft (Black curve)
Azimuth Plot @ 5° Elevation



Black (Reference) Curve is Dipole @ 33 Ft



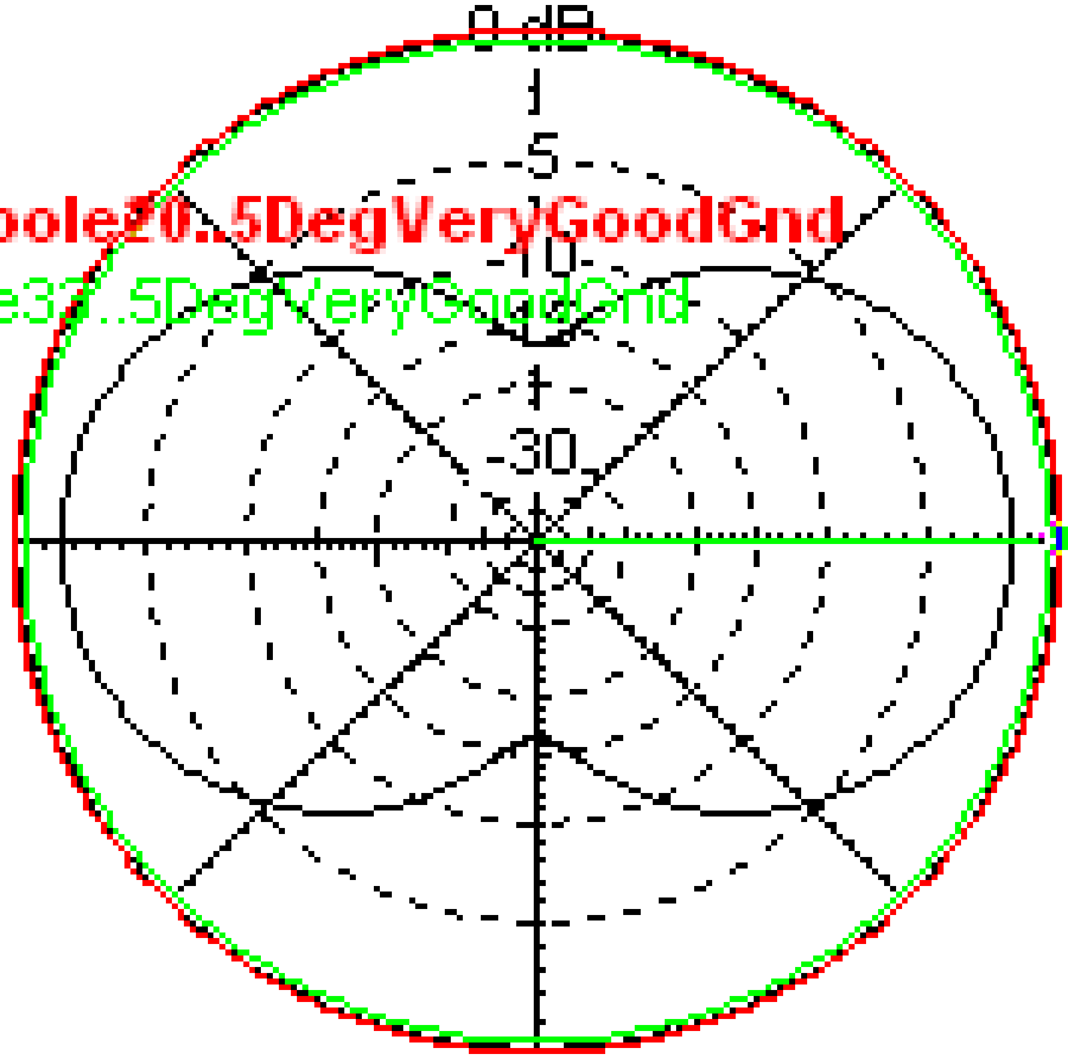
Black (Reference) Curve is Dipole @ 33 Ft

Total Field EZNEC Pro/2

Primary

* 20MVertDipole20.5DegVeryGoodGnd

20MVertDipole37.5DegVeryGoodGnd



Very Good Ground

5° Elevation

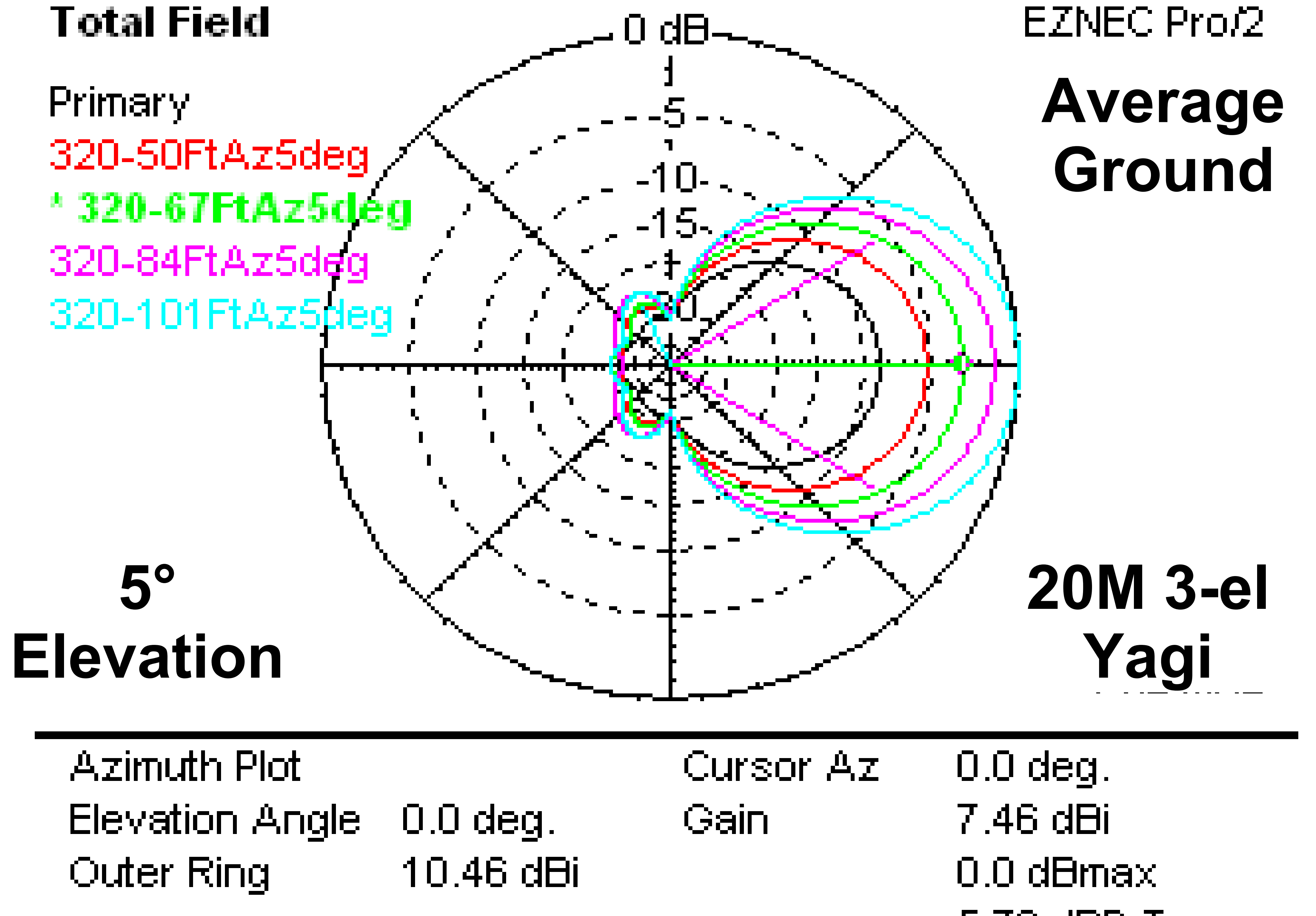
20M

Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	-1.82 dBi
Outer Ring	-1.82 dBi		0.0 dBmax
			1.65 dBPrTrc

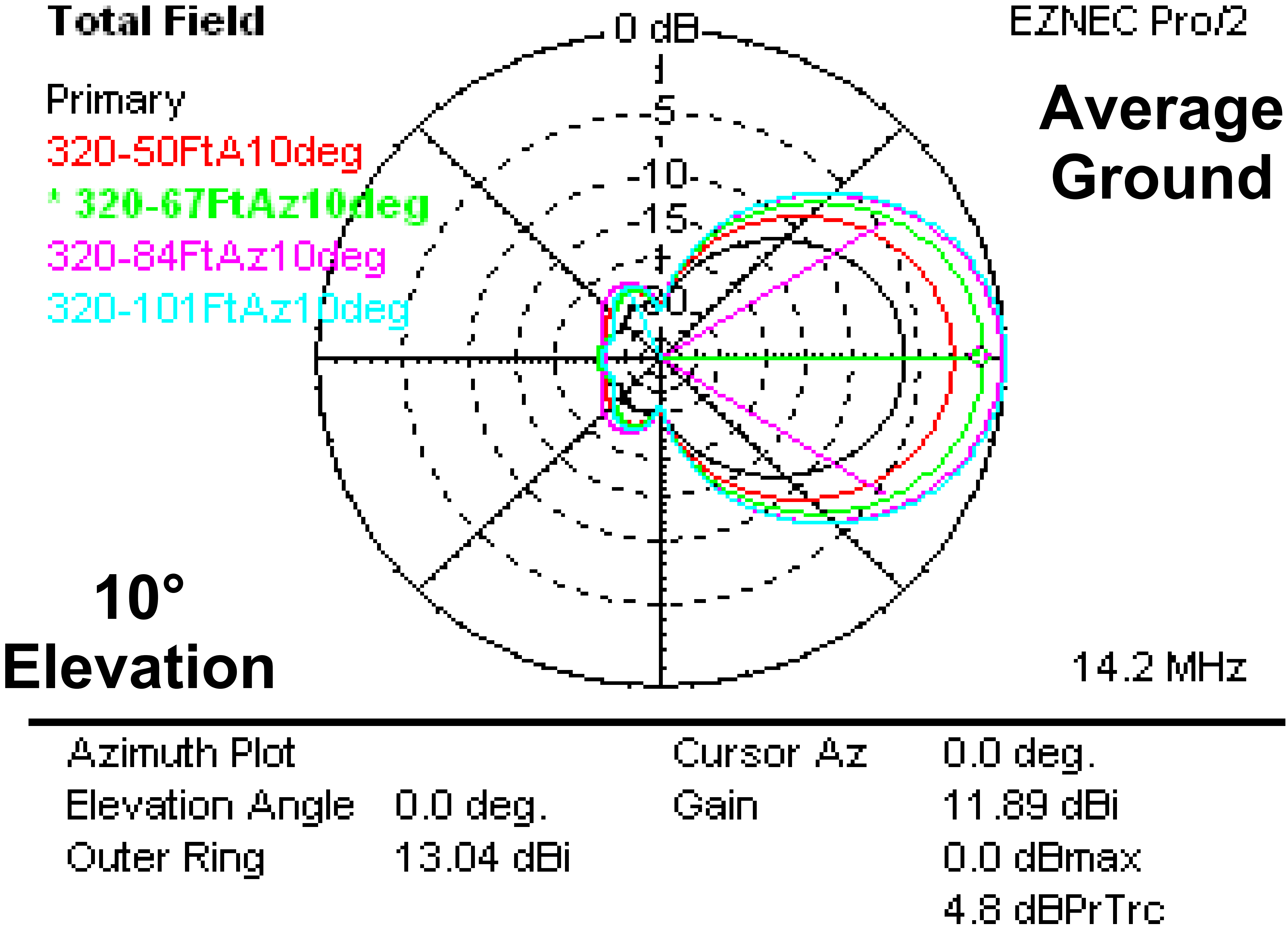
Black (Reference) Curve is Dipole @ 33 Ft

Third Series

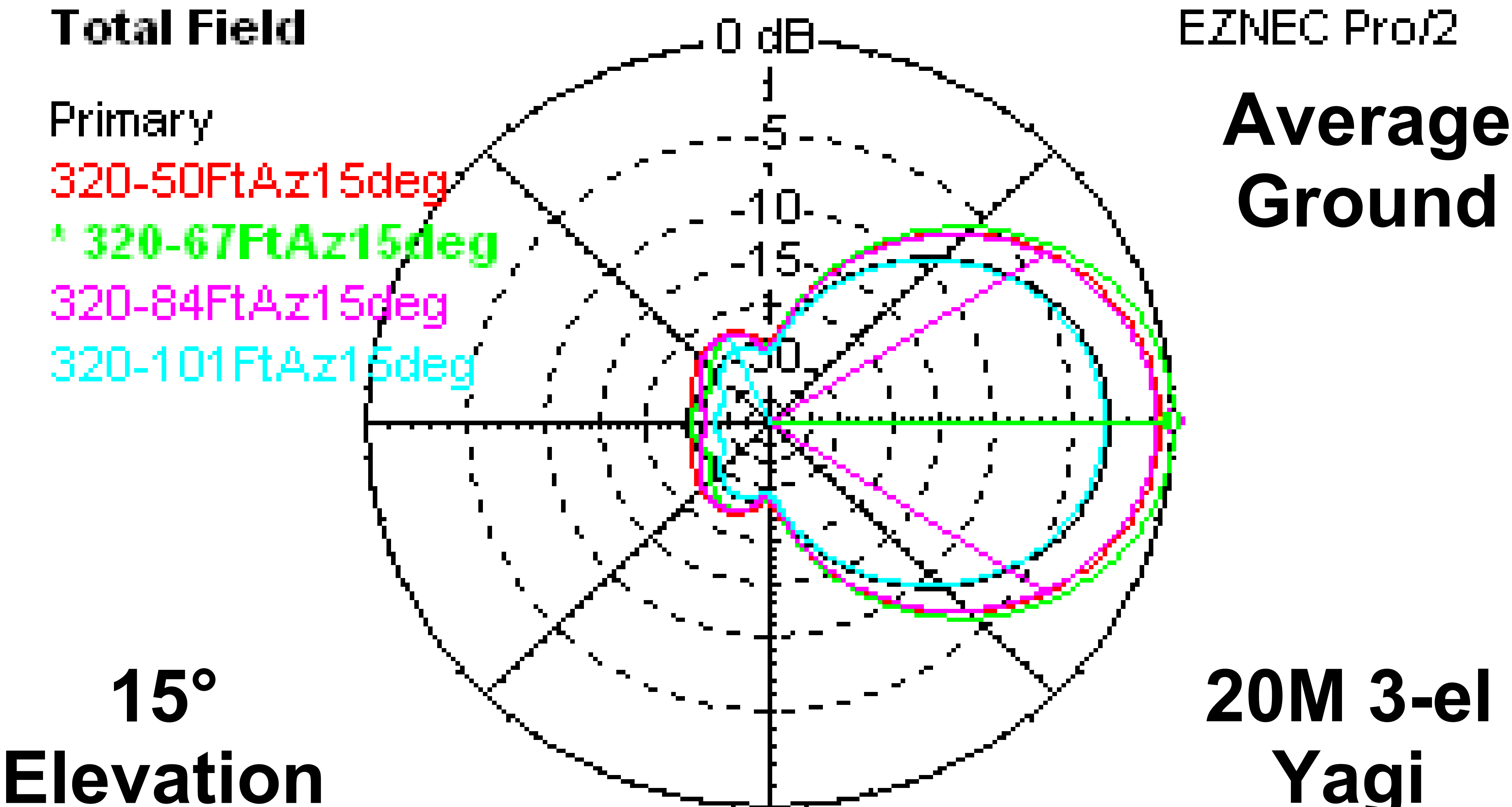
Varying height of 20M 3-el Yagi
@ 33 Ft, 50 Ft, 67 Ft, 84 Ft, 101 Ft
(λ/2, 3λ/4, λ, 5λ/4, 3λ/2)
Azimuth Plot @ 5° Elevation



33 Ft, 50 Ft, 67 Ft, 84 Ft, 101 Ft

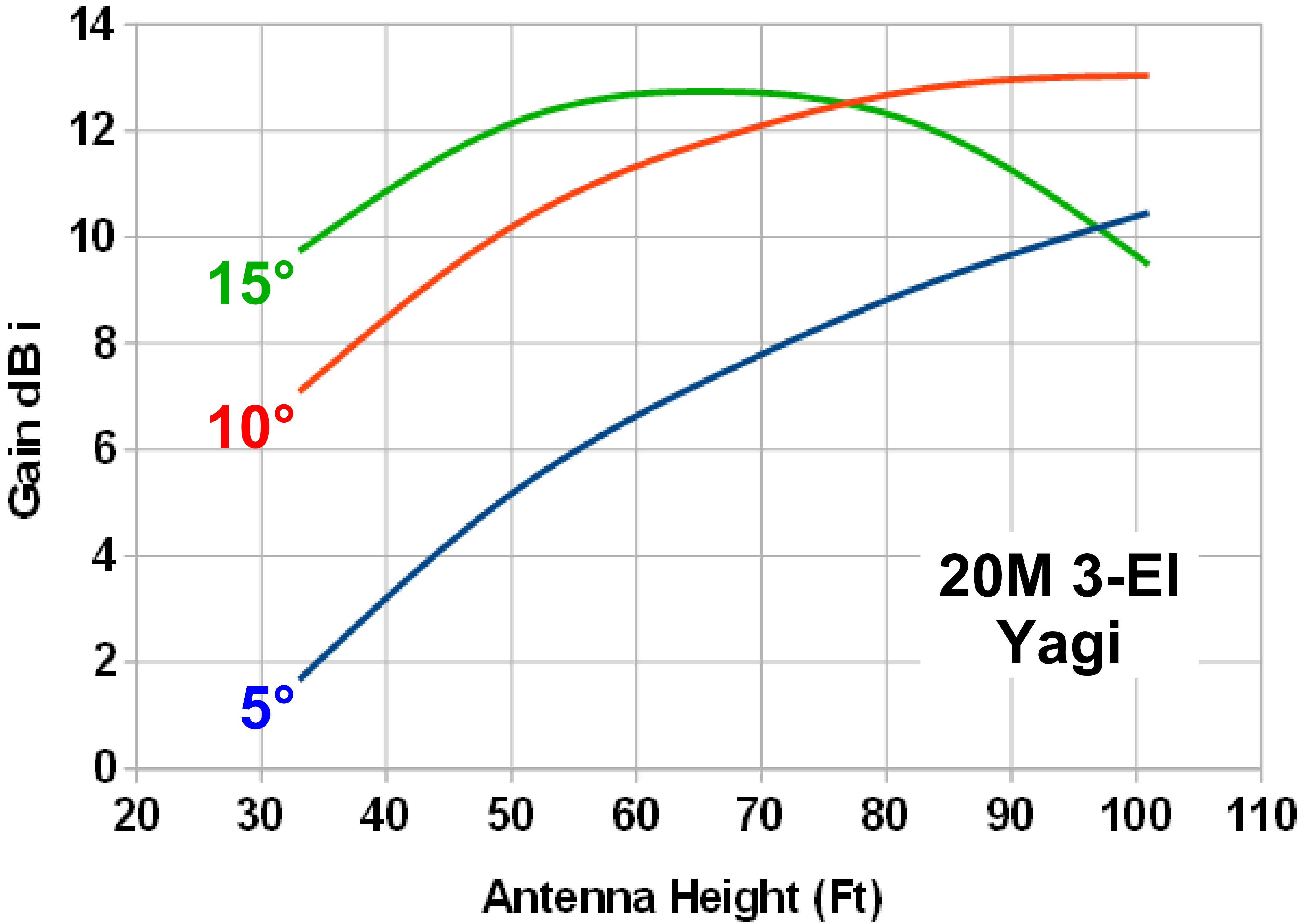


33 Ft, 50 Ft, 67 Ft, 84 Ft, 101 Ft



Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	12.74 dBi
Outer Ring	12.74 dBi		0.0 dBmax
			3.01 dBPrTrc

33 Ft, 50 Ft, 67 Ft, 84 Ft, 101 Ft

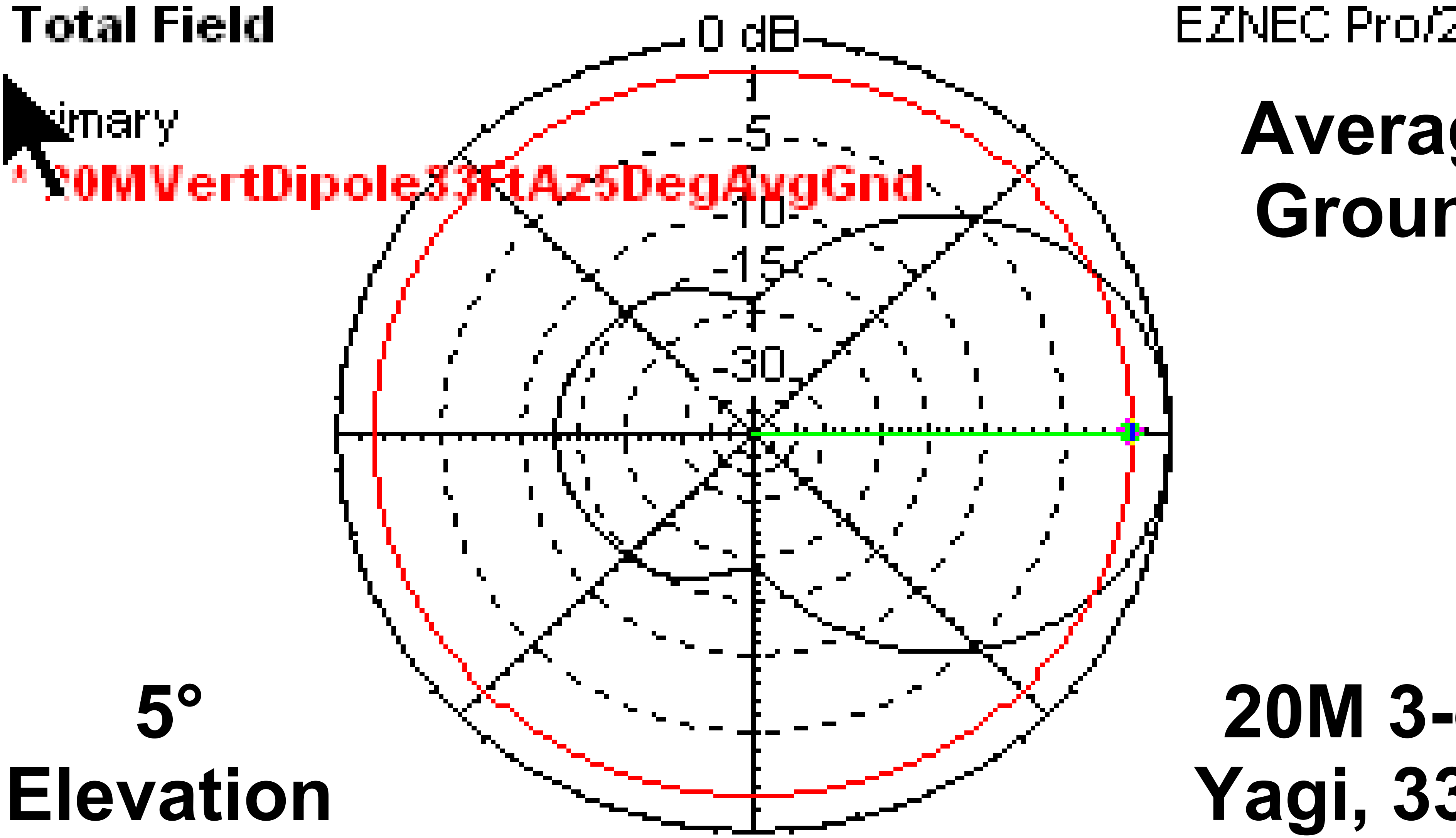

14
12
10
8
6
4
2
0
Gain dBi
15°
10°
5°
20M 3-El
Yagi
20
30
40
50
60
70
80
90
100
110
Antenna Height (Ft)

How Much is Height Worth on 20M?

- For a 20M Yagi (or horizontal dipole) at low angles
  - 1 dB for 5 ft between 30 Ft and 60 Ft
  - 6 dB for λ/2 (33 Ft) to λ (67 Ft)
  - 2 dB at 5° for 67 Ft to 100 Ft

Fourth Series

Height of 20M 3-el Yagi (Black curves)
@ 33 Ft, 50 Ft, 67 Ft (λ/2, 3λ/4, λ)
λ/2 Vertical dipole at 33 Ft (Red curves)
Azimuth Plot @ 5° Elevation



Average Ground

5° Elevation

20M 3-el Yagi, 33Ft

Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	-1.59 dBi
Outer Ring	0.06 dBi		0.0 dBmax
			-1.65 dBPrTrc

Vertical Dipole @ 33 Ft

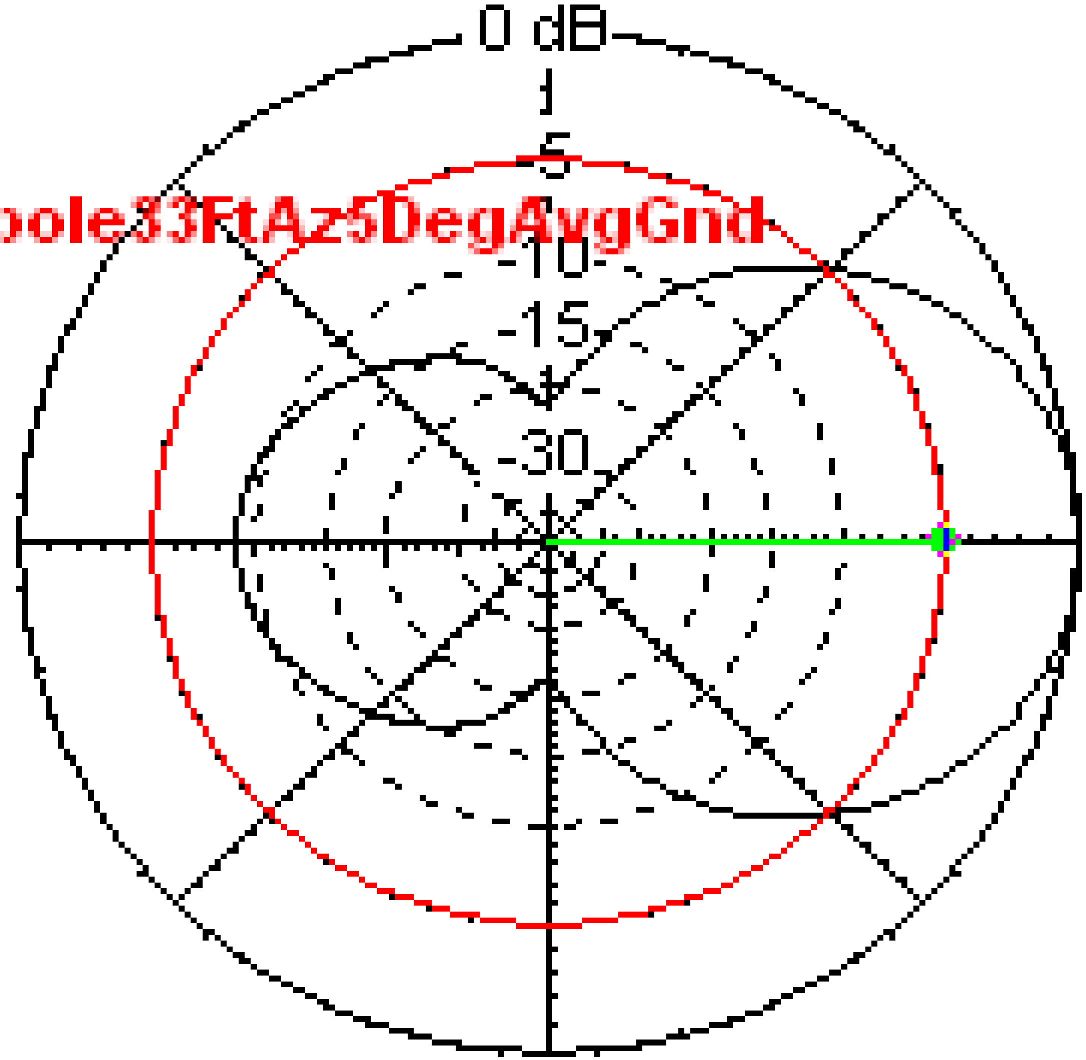
Total Field

EZNEC Pro/2

Primary

*** 20MVertDipole33FtAz5DegAvgGnd**

Average Ground



5° Elevation

20M 3-el Yagi, 50 Ft

Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	-1.59 dBi
Outer Ring	3.46 dBi		0.0 dBmax
			-5.05 dBPrTrc

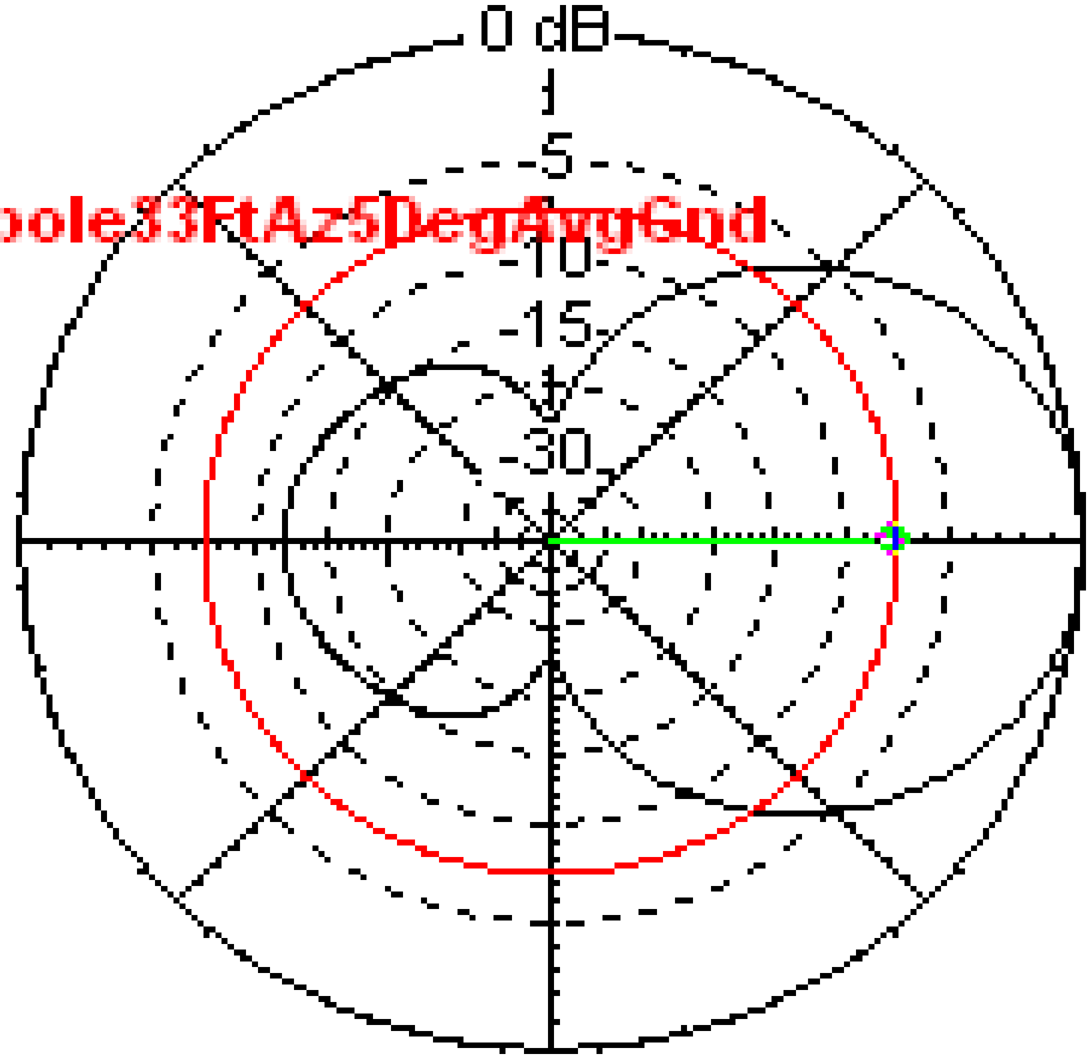
Vertical Dipole @ 33 Ft

Total Field

EZNEC Pro/2

Primary

* 20MVertDipole33FtAz5DegAvgGnd



Average Ground

5° Elevation

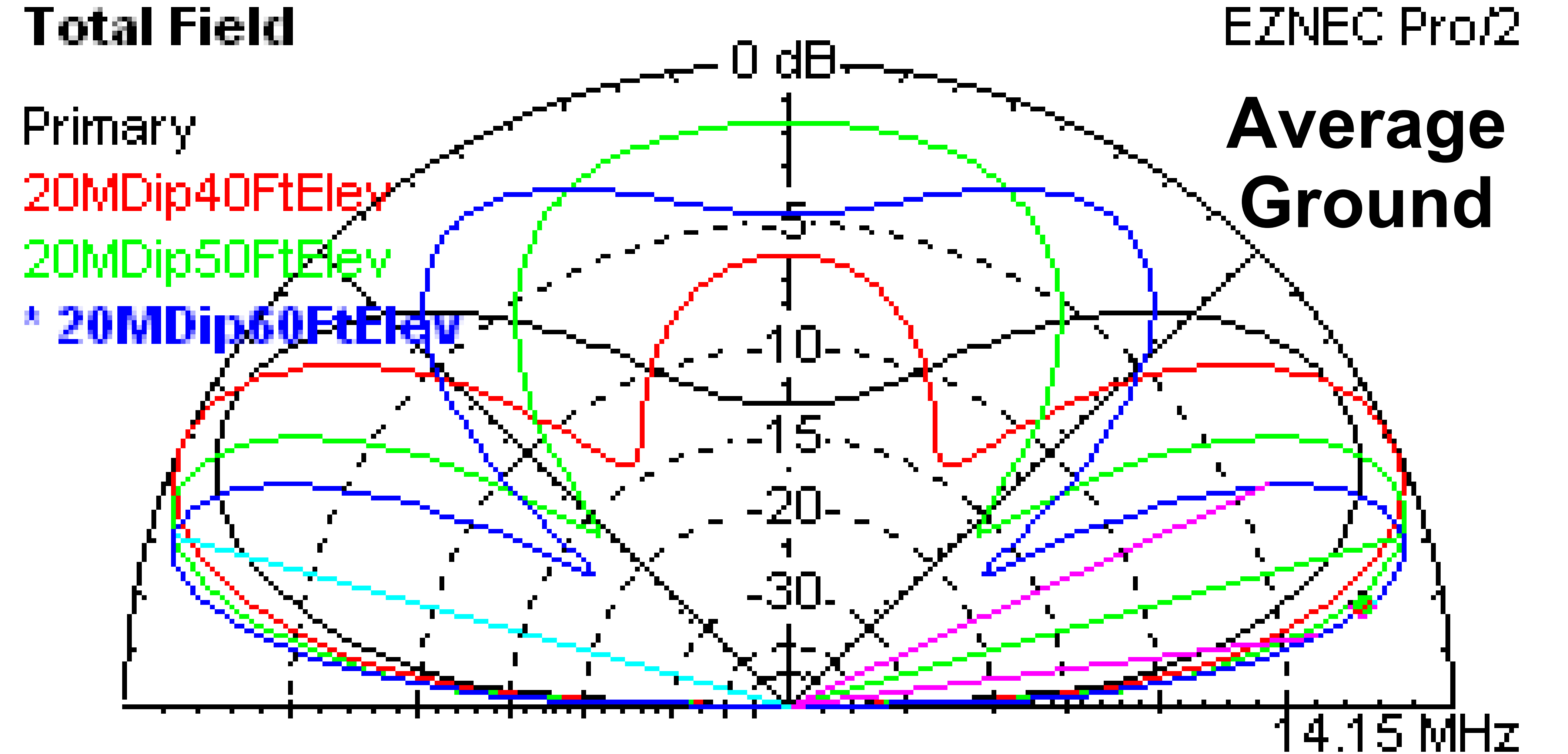
20M 3-el Yagi, 67 Ft

Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	-1.59 dBi
Outer Ring	5.78 dBi		0.0 dBmax
			-7.38 dBPrTrc

Vertical Dipole @ 33 Ft

Fifth Series

Height of 20M Dipole
@ 33 Ft, 40 Ft, 50 Ft, 60 Ft

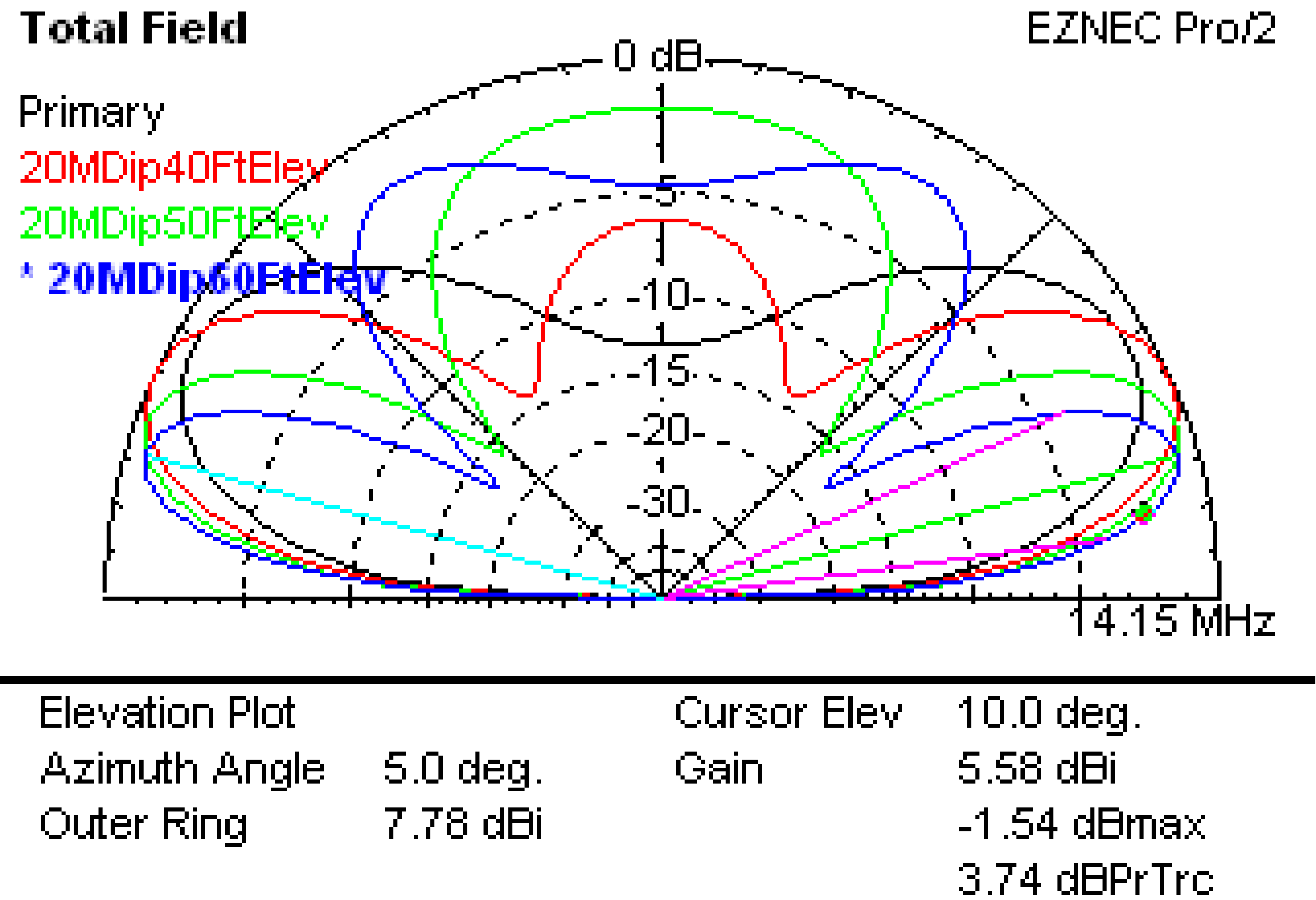


Elevation Plot		Cursor Elev	10.0 deg.
Azimuth Angle	5.0 deg.	Gain	5.58 dBi
Outer Ring	7.78 dBi		-1.54 dBmax
			3.74 dBPrTrc

Effect of Height on a Horizontal 20M Dipole

Higher Antennas Have Nulls

- **Nulls in vertical pattern begin for height > λ/2**
  - **67 Ft on 40M**
  - **33 Ft on 20M**
  - **22 Ft on 15M**
  - **17 Ft on 10M**
- **The Null starts high, move down as antenna is raised**
- **Above λ, a second null develops**
- **Height does the same thing to a Yagi**



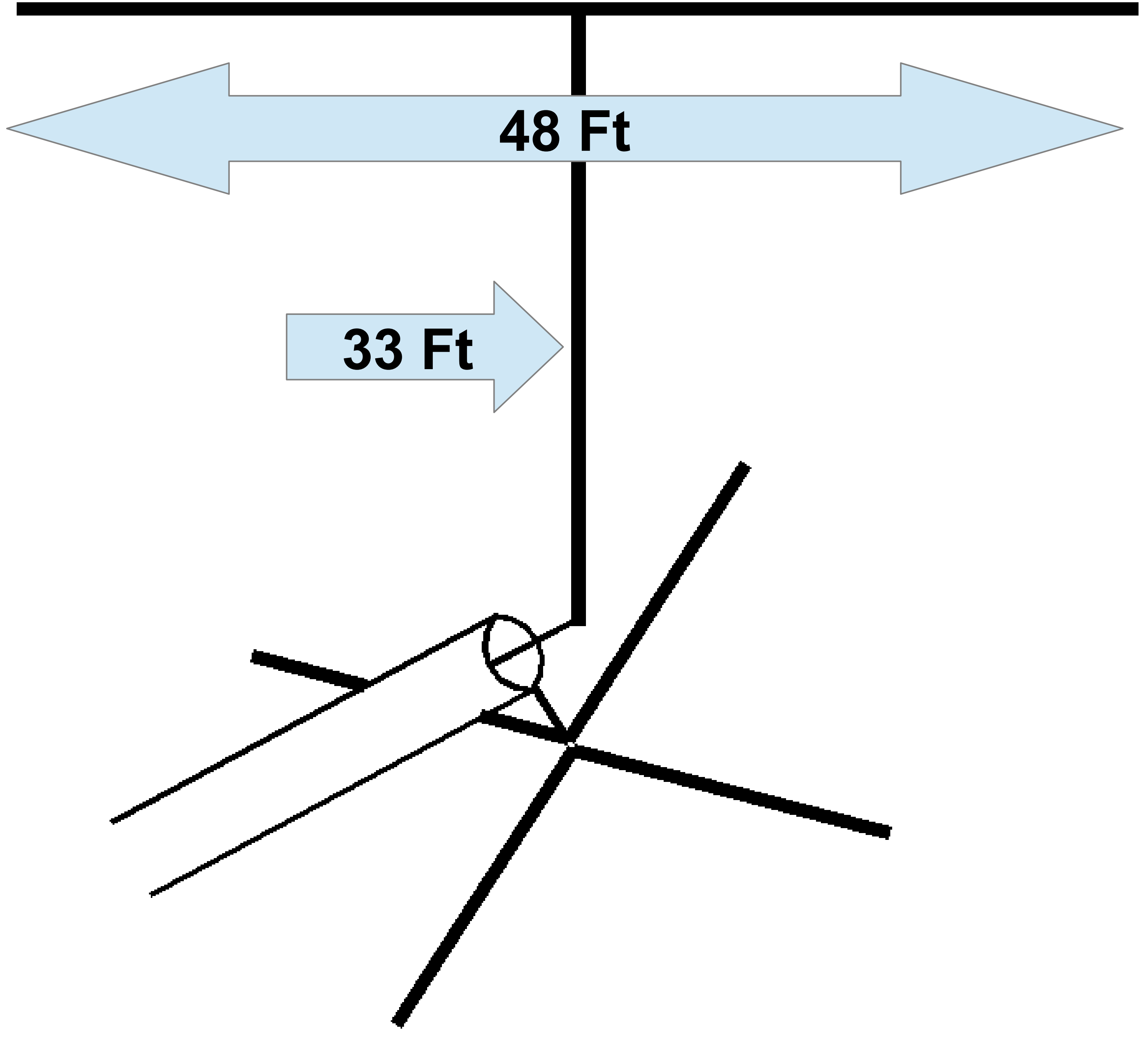
Effect of Height on a Horizontal 20M Dipole

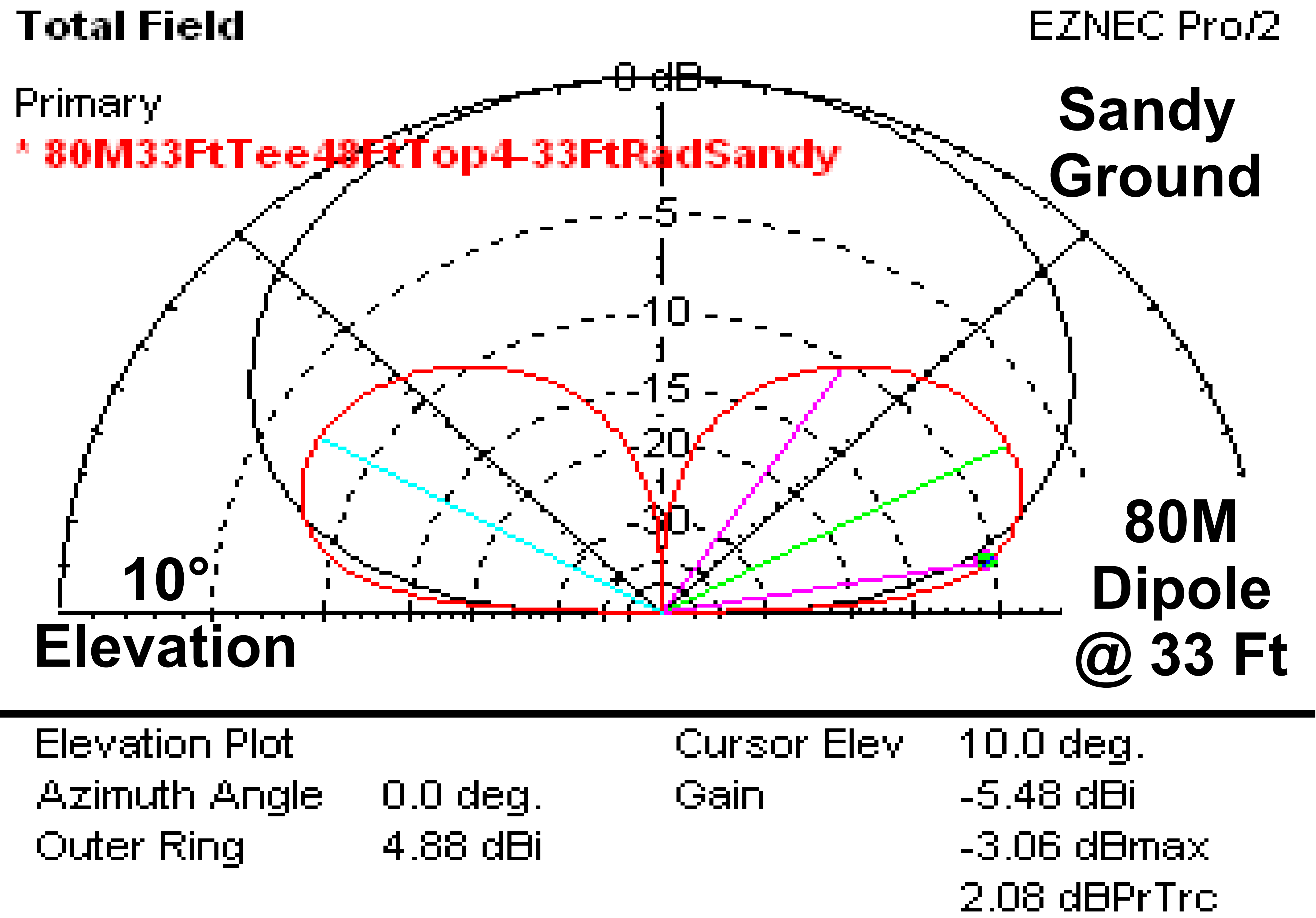
Sixth Series

Vertical or Low Dipole for 80M?
80M λ/2 (133 ft long) Dipole at 33 ft (Black curve)
33 Ft Tall Tee Vertical w/48 Ft Top (Red curve)

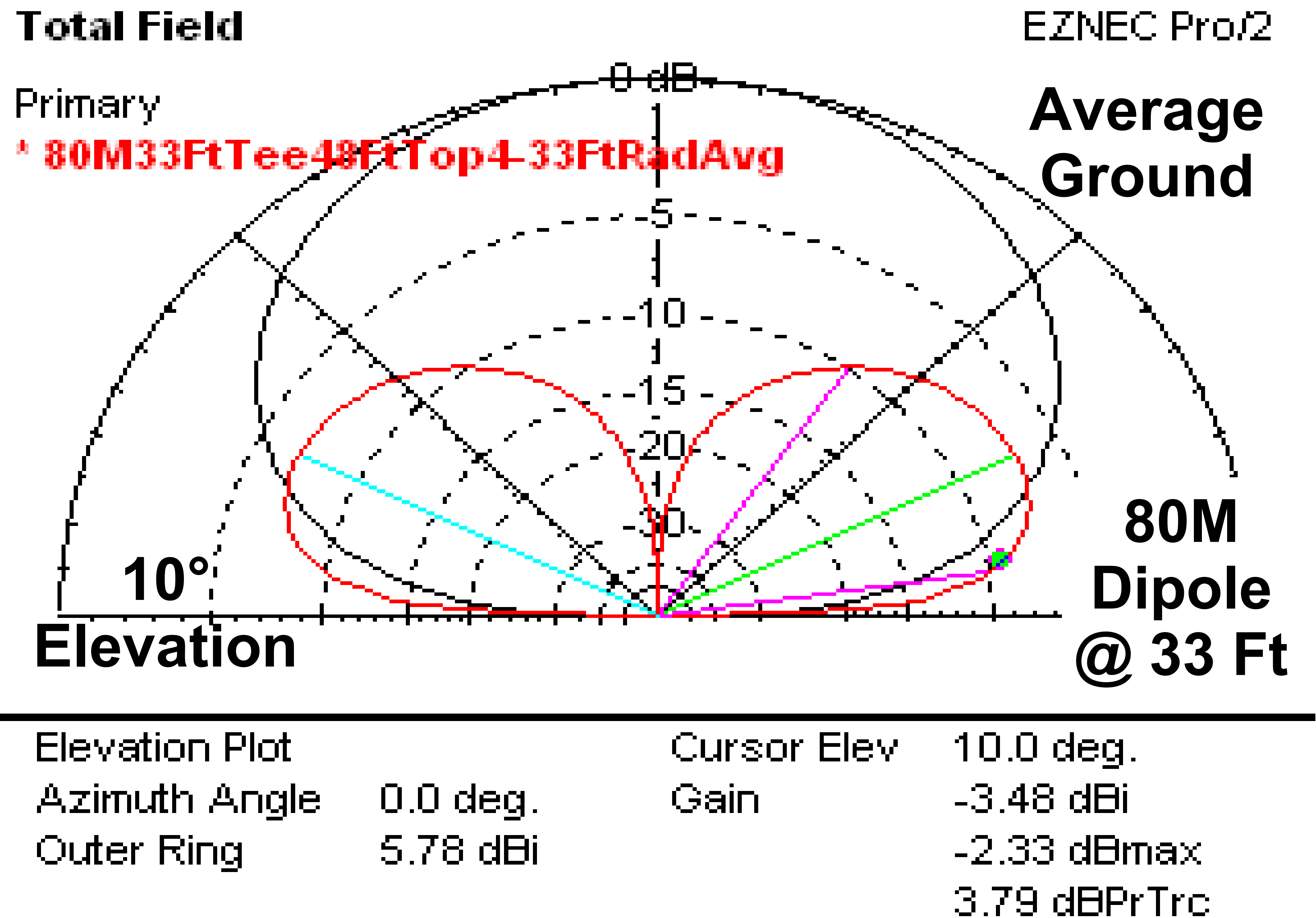
Poor to Average Grounds

Simple Tee Vertical

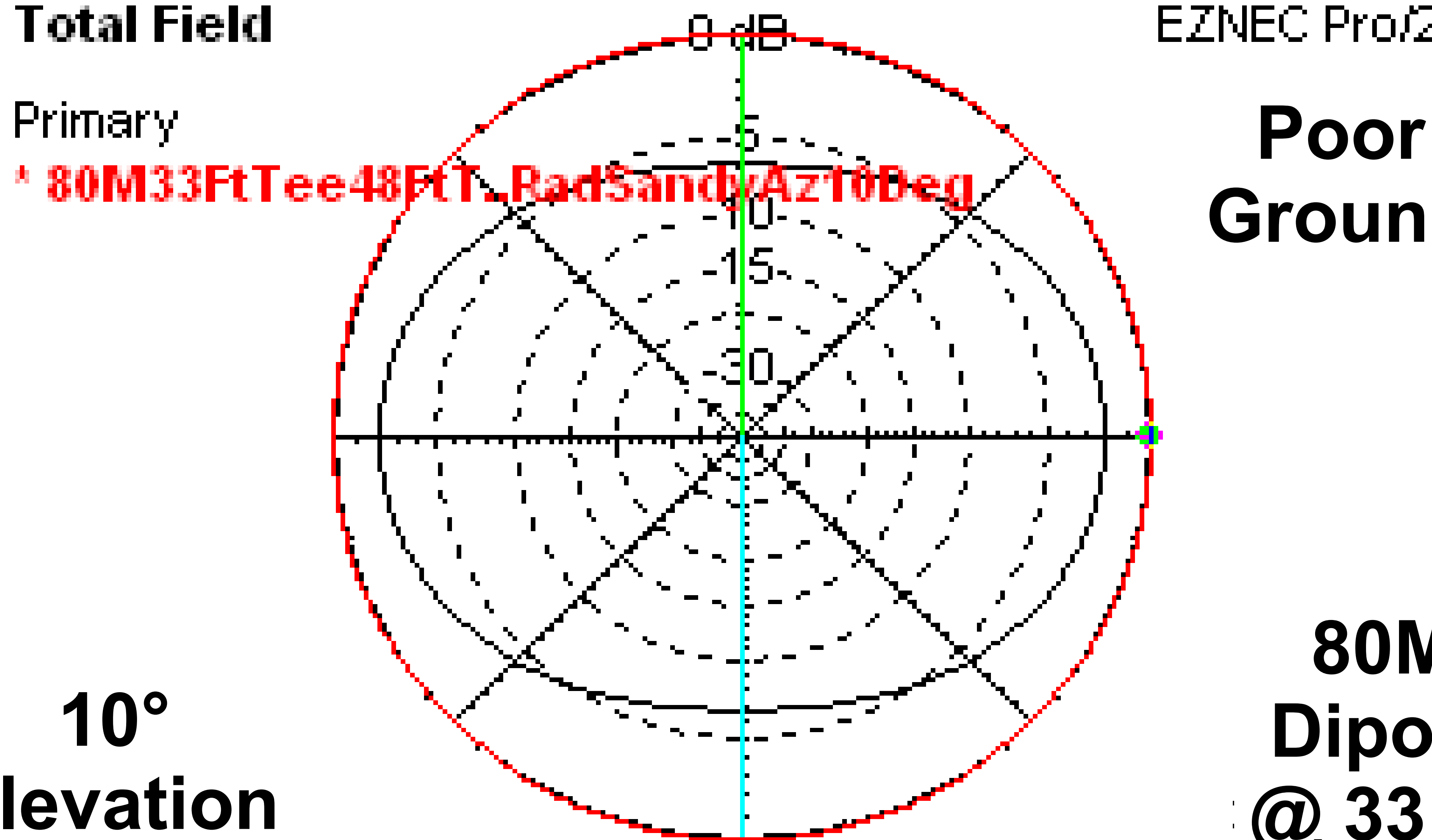




Tee Vertical 33 Ft Tall, 48 Ft Top



Tee Vertical 33 Ft Tall, 48 Ft Top



Poor Ground

10° Elevation

80M Dipole @ 33 Ft

Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	-5.53 dBi
Outer Ring	-5.48 dBi		-0.05 dBmax
			2.04 dBPrTrc

Tee Vertical 33 Ft Tall, 48 Ft Top

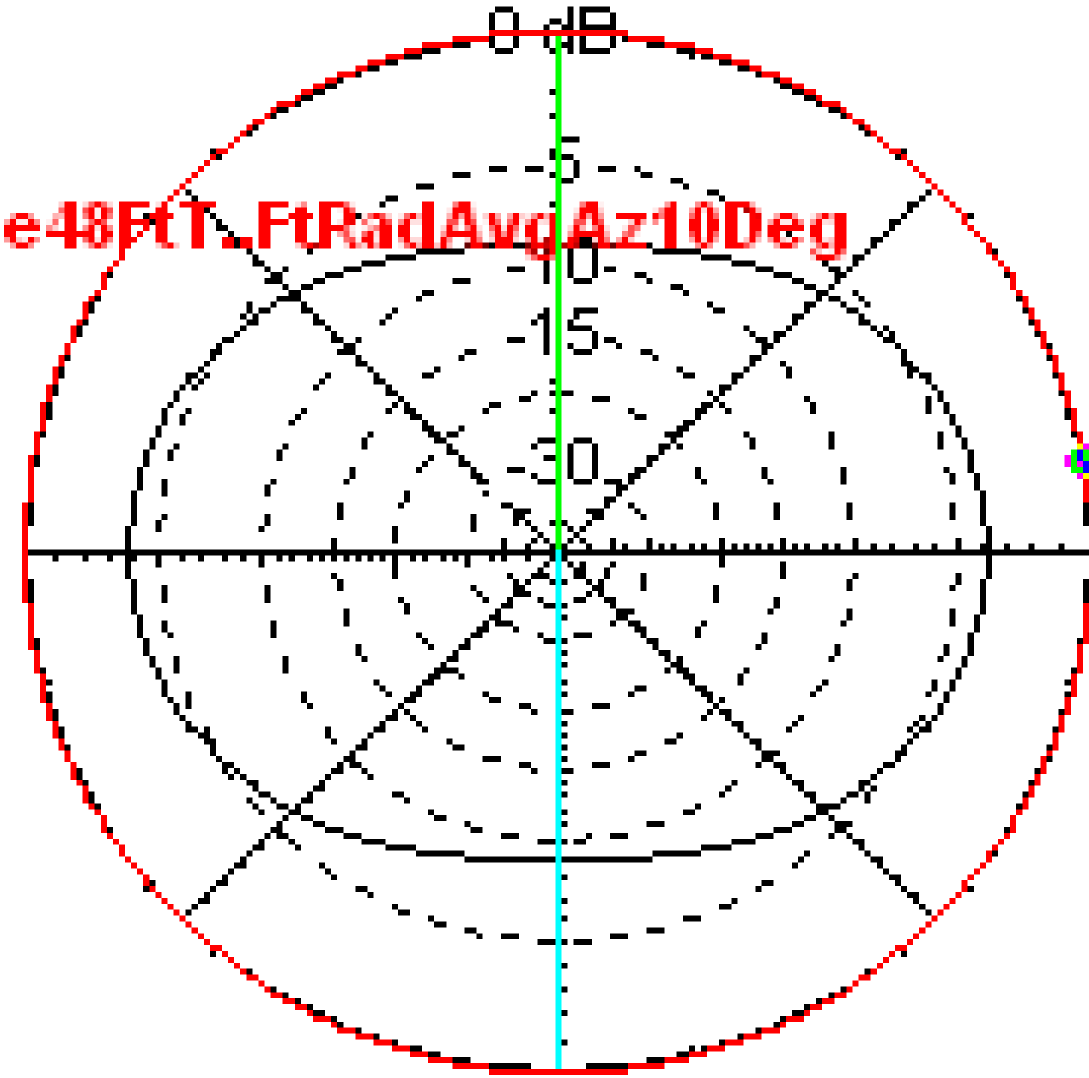
Total Field

Primary

* 80M33FtTee48FtT..FtRadAvgAz10Deg

EZNEC Pro/2

Average Ground



10° Elevation

80M Dipole @ 33 Ft

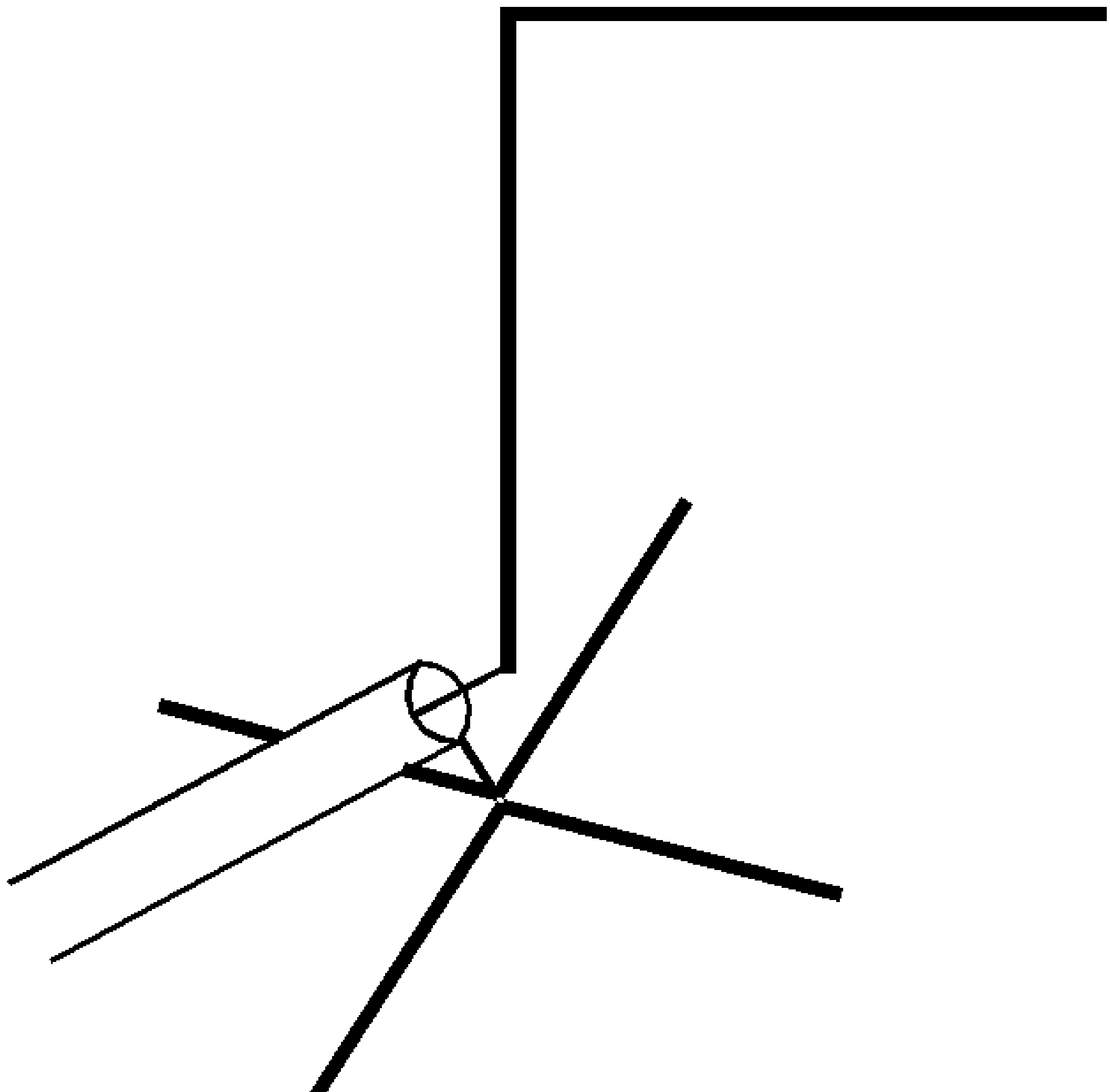
Azimuth Plot		Cursor Az	10.0 deg.
Elevation Angle	0.0 deg.	Gain	-3.54 dBi
Outer Ring	-3.48 dBi		-0.06 dBmax
			3.86 dBPrTrc

Tee Vertical 33 Ft Tall, 48 Ft Top

Conclusions – What We've Learned

- Higher/taller is nearly always better
  - All verticals work better up in the air
  - High horizontal antennas work better
- Inverted L or Tee vertical with radials beats a low dipole
  - 40 ft is low for 80M
  - 125 ft is low for 160M

Inverted L



How Much is Height Worth?

- For a 40M horizontal dipole (or Yagi)
  - 0.9 dB for 5 ft between 30 Ft and 70 Ft below 15°
  - 6 dB for λ/4 (33 Ft) to λ/2 (67 Ft)
  - 2.5 dB for λ/2 (67 Ft) to λ (133 Ft)
- For a 20M Yagi (or horizontal dipole)
  - 1 dB for 5 ft between 30 Ft and 60 Ft
  - 6 dB for λ/2 (33 Ft) to λ (67 Ft)
  - 2 dB at 5° for 67 Ft to 100 Ft

How Much is a Tower Worth?

- For a 40M horizontal dipole (or Yagi)
  - 0.9 dB for 5 ft between 30 Ft and 70 Ft below 15°
  - 6 dB for λ/4 (33 Ft) to λ/2 (67 Ft)
  - 2.5 dB for λ/2 (67 Ft) to λ (133 Ft)
- For a 20M Yagi (or horizontal dipole)
  - 1 dB for 5 ft between 30 Ft and 60 Ft
  - 6 dB for λ/2 (33 Ft) to λ (67 Ft)
  - 2 dB at 5° for 67 Ft to 100 Ft

How Much is Height Worth?

- For an 80M horizontal dipole (or Yagi) at 15° and below
  - 0.9 dB for 10 ft between 40 Ft and 130 Ft
  - 3.5 dB for λ/8 (33 Ft) to λ/4 (67 Ft)
  - 6 dB for λ/4 (67 Ft) to λ/2 (133 Ft)
- On the lower bands, we need less signal to work short distances than long distances
- Antennas cannot be “too high” or too tall for 80M or 160M, and few of us can get an antenna too high for 40M

Most Rules Have Exceptions

- Terrain affects an antenna's vertical pattern
  - Use HFTA to study your non-flat QTH
  - ARRL Antenna Book CD
- Verticals are usually best for all distances on 160M

Most Rules Have Exceptions

- **Most DX is at low angles – <u>but not always</u>!**
  - **If DX is at high angles, a lower antenna may work better**
- **We may want to work short distances (a few hundred miles) on 80M and 40M**
  - **Verticals don't work well at high angles (which is why verticals are thought of as weak by ragchewers on 75 and 40M)**
  - **Horizontal antennas will work better**

For NVIS

- For a horizontal dipole, λ/4 high is near optimum
  - 133 ft on 160M
  - 67 ft on 80M
  - 33 ft on 40M
- Horizontal antenna lower than λ/4 are both cloud-warmers and worm warmers
- The only reason to rig a horizontal antenna lower than λ/4 is that's the highest you can rig it

Using What We've Learned

- Study your QTH for a while
- Explore all possible skyhooks, their cost
- Try to rig dipoles broadside to 70° - 90° Az
  - Nulls matter more than peaks
  - Nulls should avoid population centers
- Avoid crossing over a power line
- Be safe – get help from other hams when you need it

Using What We've Learned

- **Don't let the "great" be the enemy of the good**
- **Use this presentation to help you learn what works best for what you <u>can</u> do**
- **Put something up and get on the air**
- **Any antenna that's in the air works better than an antenna that's in your basement!**
- **Think about ways to do it better**
- **Use my results to predict the relative results of antennas that <u>you</u> can rig**

2-El Yagi 40M or Higher Dipoles?

- **If I had a choice between 2 elements at 70 feet on a tower, or two dipoles at right angles at 120 ft, which gives me the best bang for the buck?**
  - **120 ft is 2dB better on 40M than 70 ft**
  - **40M Yagi is about 3.5 dB better than a dipole at the same height (assuming compact version)**
  - **The Yagi at 70 ft is 1.5dB better than dipoles at 120 ft for same feedline length**

Cost of the Two Options

- Cost of two high dipoles
  - About $1,800 if you have the trees ($1,400 for climbers, $400 for antennas, coax, chokes)
- Cost of Optibeam Moxon on 70 ft tower
  - About $7,500 ($2,500 for antenna, coax, choke, $2,000 for the tower, $1,000 for rotor & cable, $2,000 for climber)
- Cost of Yagi 1.5dB advantage about $5,500
- Cheaper for what you can do yourself

References and More Ideas

- **On k9yc.com/publish.htm**
  - ***If I Can Put My HF Vertical on my Roof, Should I?***
  - ***Antennas For Limited Space (Power Point)***
  - ***Getting On 160M From a Small Lot (and Larger Ones Too)***
- **ARRL Antenna Book**

Antenna Planning for Small HF Stations (and even larger ones)

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