Why We Stack 'Em!

Covering All the Angles

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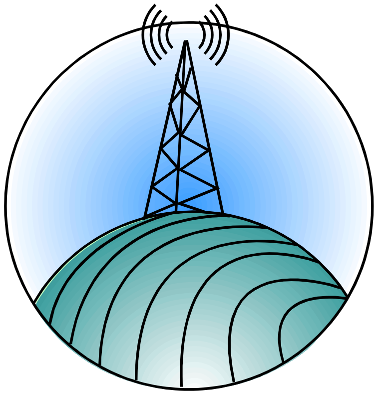
Scientifically Planning a Station

There are three elements needed to plan an HF station *scientifically*:

- The range of elevation angles needed.
- Antenna performance parameters.
- The effects of local terrain.

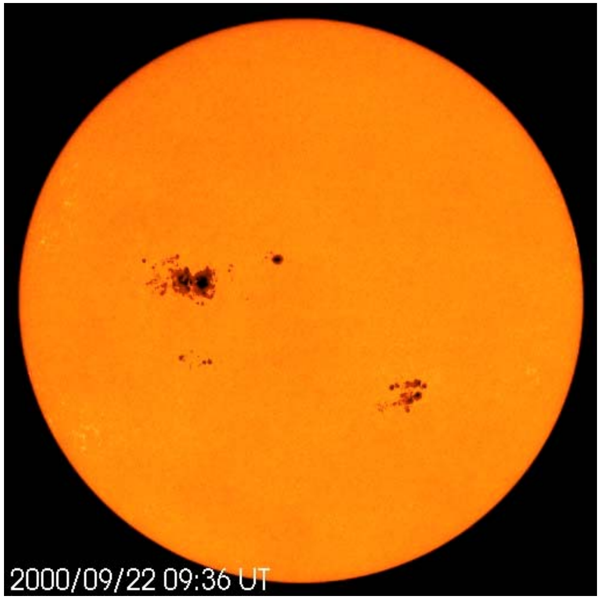


Elevation Angles

- About ten years ago I started a detailed study at ARRL HQ on the range of elevation angles needed for communication between various QTHs around the world.
- I used the *IONCAP* program (now upgraded to the *VOACAP* program), along with proprietary software I wrote.

What Angles Do You Need?

The elevation-angle files from *The ARRL Antenna Book* contain statistical averages over the entire 11-year solar cycle -- for all months of the year and for all hours of the day.

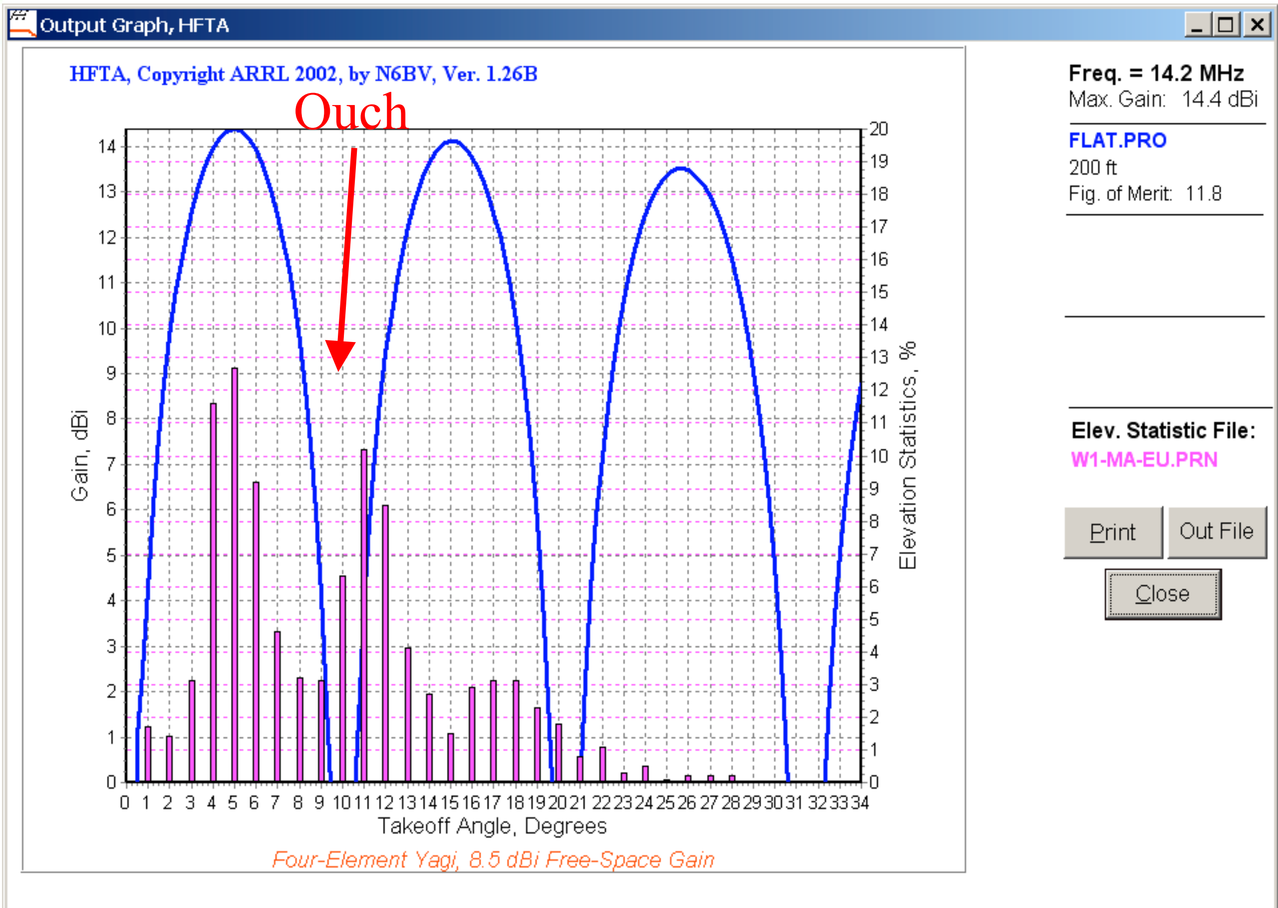


Sample Table, Boston to Europe

Boston, Massachusetts to Europe

Elev	80m	40m	30m	20m	17m	15m	12m	10m
1	4.1	9.6	4.6	1.7	2.1	4.4	5.5	7.2
2	0.8	2.3	7.2	1.4	2.8	2.8	3.7	5.3
3	0.3	0.7	4.3	3.1	2.4	2.2	4.4	7.9
4	0.5	4.1	8.7	11.6	12.2	9.4	8.1	3.9
5	4.6	4.8	7.5	12.7	14.3	13.1	9.2	11.2
6	7.1	8.9	5.5	9.2	9.6	12.2	9.2	7.2
7	8.5	6.9	7.2	4.6	7.9	7.4	10.0	5.9
8	5.1	7.0	5.4	3.2	5.9	7.4	4.8	6.6
9	3.3	5.6	3.2	3.1	2.1	3.9	8.1	9.2
10	1.0	4.0	7.9	6.3	5.1	3.7	11.1	6.6
11	1.9	3.8	9.7	10.2	7.2	5.4	3.7	7.9
12	5.6	3.4	4.8	8.5	6.9	7.4	4.8	6.6
13	11.0	3.0	2.4	4.1	5.9	4.6	3.3	2.6
14	7.6	4.8	2.0	2.7	3.8	3.9	6.3	5.9
15	5.3	7.9	2.0	1.5	2.4	1.7	1.5	2.0
16	2.8	6.4	3.8	2.9	1.5	1.3	2.6	2.6
17	5.0	3.4	4.5	3.1	1.0	1.5	0.0	0.0
18	4.2	2.0	3.1	3.1	2.0	2.2	1.8	1.3
19	5.7	1.4	1.4	2.3	1.3	0.7	0.0	0.0
20	6.6	1.4	1.2	1.8	1.1	1.3	0.7	0.0
21	4.4	1.4	0.5	0.8	0.7	0.7	0.4	0.0
22	2.3	2.4	1.0	1.1	0.6	1.3	0.7	0.0
23	1.3	1.8	0.1	0.3	0.1	0.0	0.0	0.0
24	0.6	1.0	0.5	0.5	0.4	0.7	0.0	0.0
25	0.3	0.8	0.3	0.1	0.4	0.0	0.0	0.0
26	0.0	0.5	0.7	0.2	0.1	0.4	0.0	0.0
27	0.1	0.1	0.1	0.2	0.1	0.2	0.0	0.0
28	0.0	0.3	0.1	0.2	0.0	0.2	0.0	0.0
29	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0
30	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

One Picture is Worth a Thousand Tables!



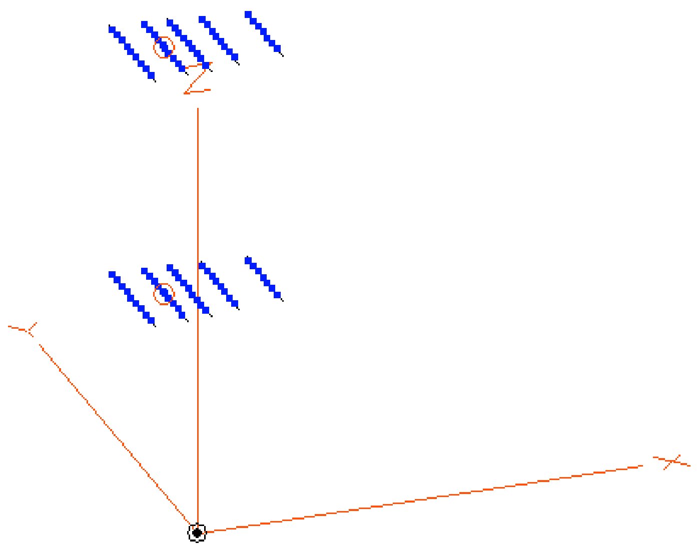
The gain is nice but the null is a disaster.

Clearly, 200' is too high for Europe on 20 meters from New England.

Why Do We Stack Yagis?

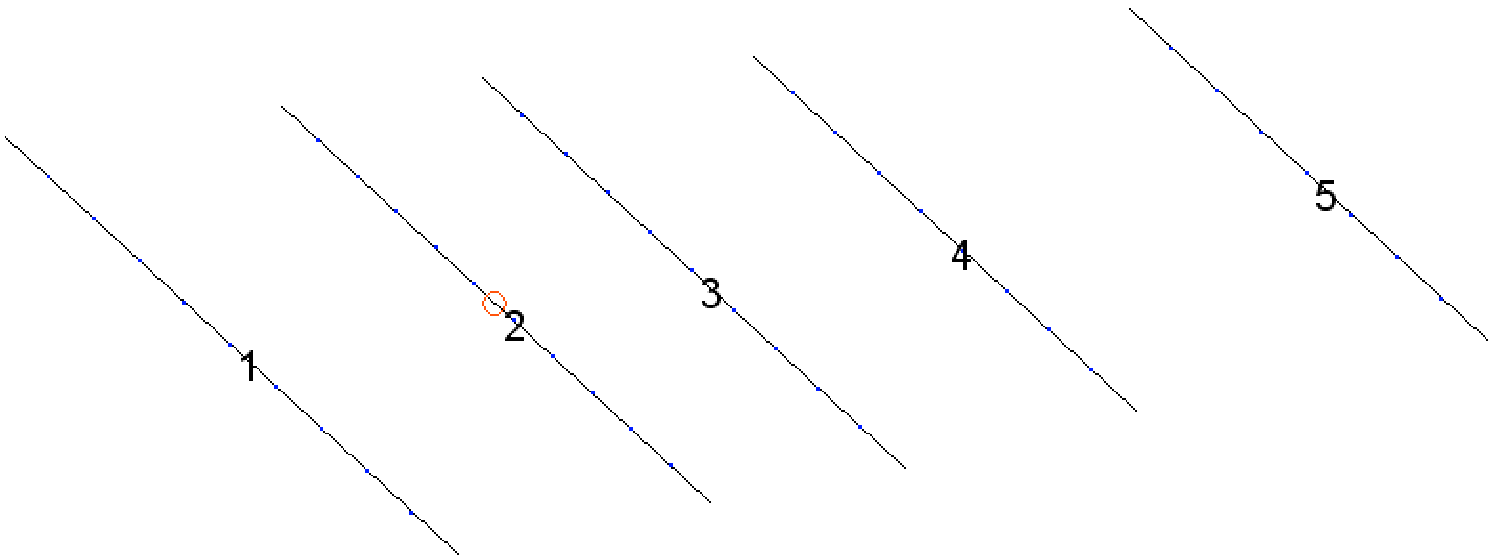
- For more gain
- To widen elevation coverage
- For azimuthal diversity
- For less fading

By the way, you could stack side-by-side for gain, but that isn't as practical as vertical stacking. More later.

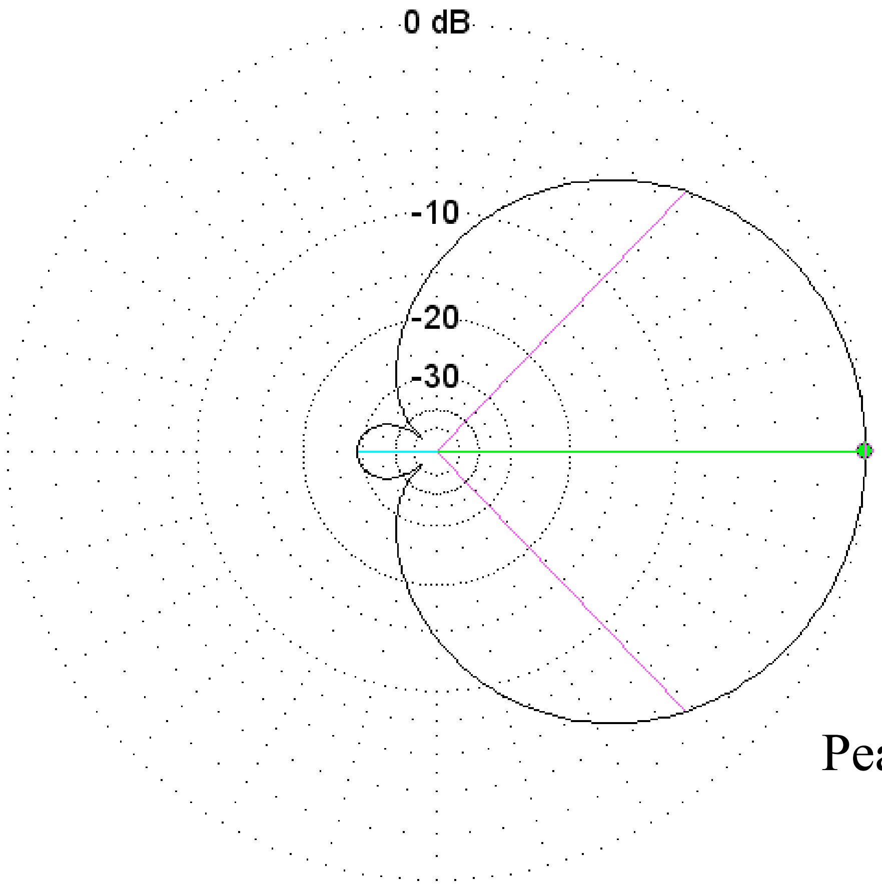


Gain and Stacks

- First, let’s look at a single 5-element 10-meter Yagi in free space.



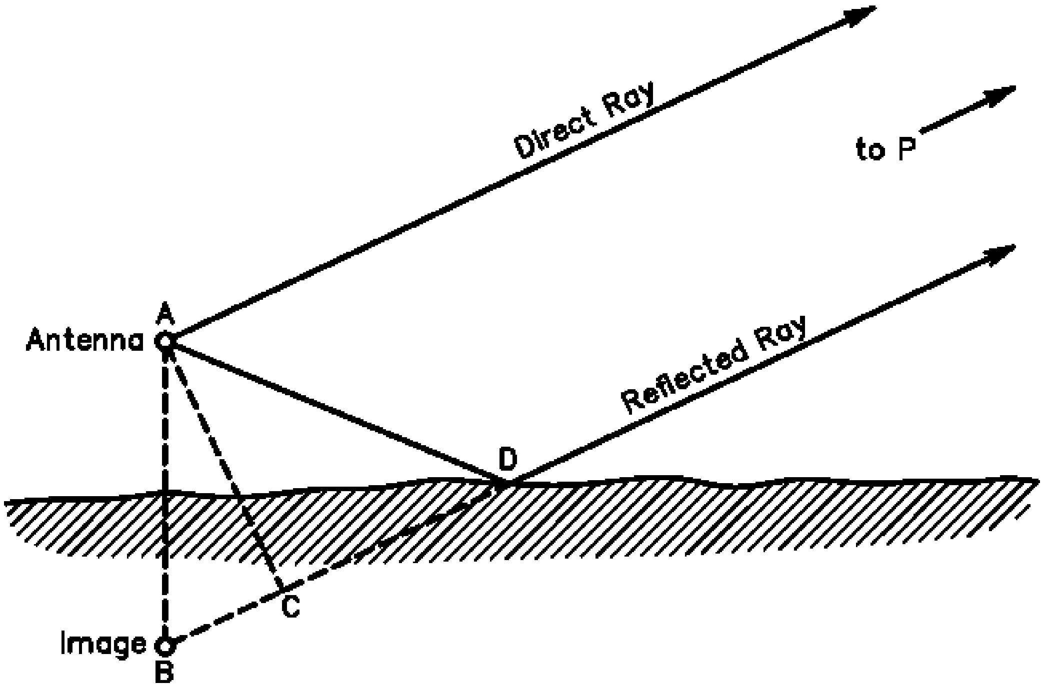
Gain in Free Space



Peak Gain = 8.9 dBi

The -3 dB H-Plane (Elevation-Plane) beamwidth is 92.4° for a 5-element 10-meter Yagi in free space.

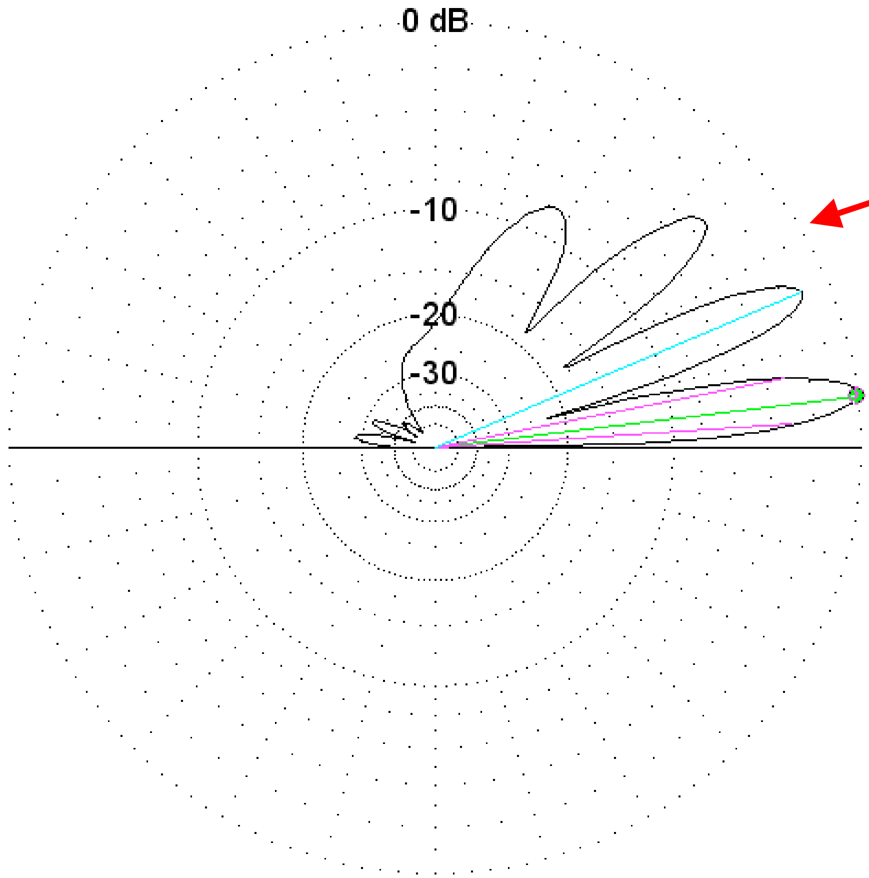
Gain Over Ground



Reflections, using theory of images.

The presence of ground *profoundly* modifies the elevation pattern of any antenna compared to free space, because of vector addition of the reflected and direct rays, which travel different paths.

Gain & Pattern Over Ground



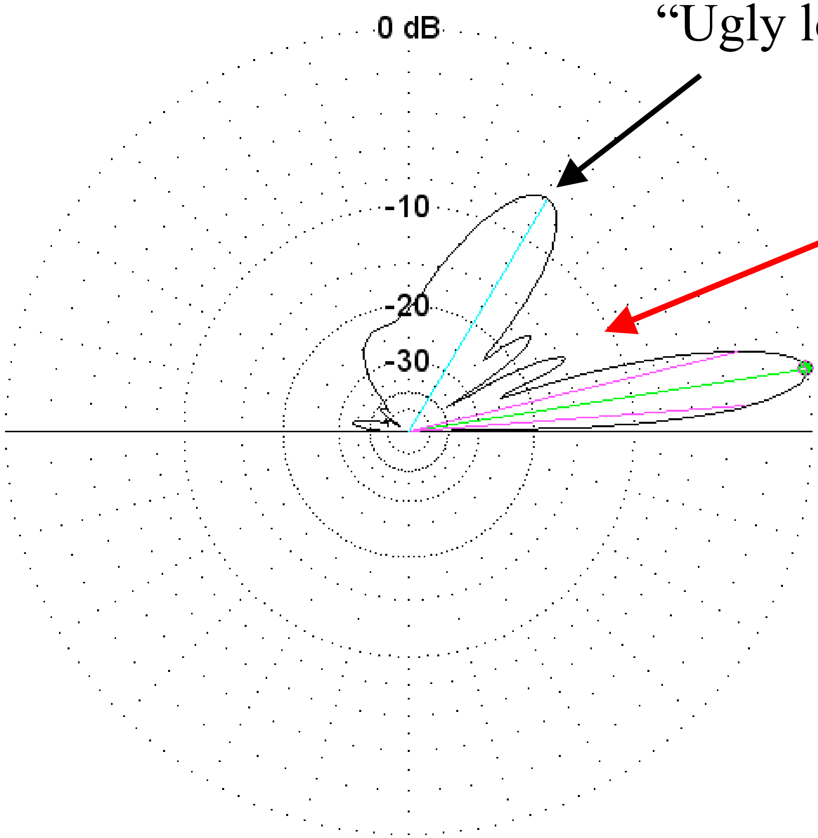
Big nulls now appear

The first lobe is very narrow

Peak Gain = 14.2 dBi

The -3 dB beamwidth is now only 8.3° for the same 5-element 10-meter Yagi mounted 66’ (2 λ) above average ground.

Now, 10-Meter Stack at 66’/33’



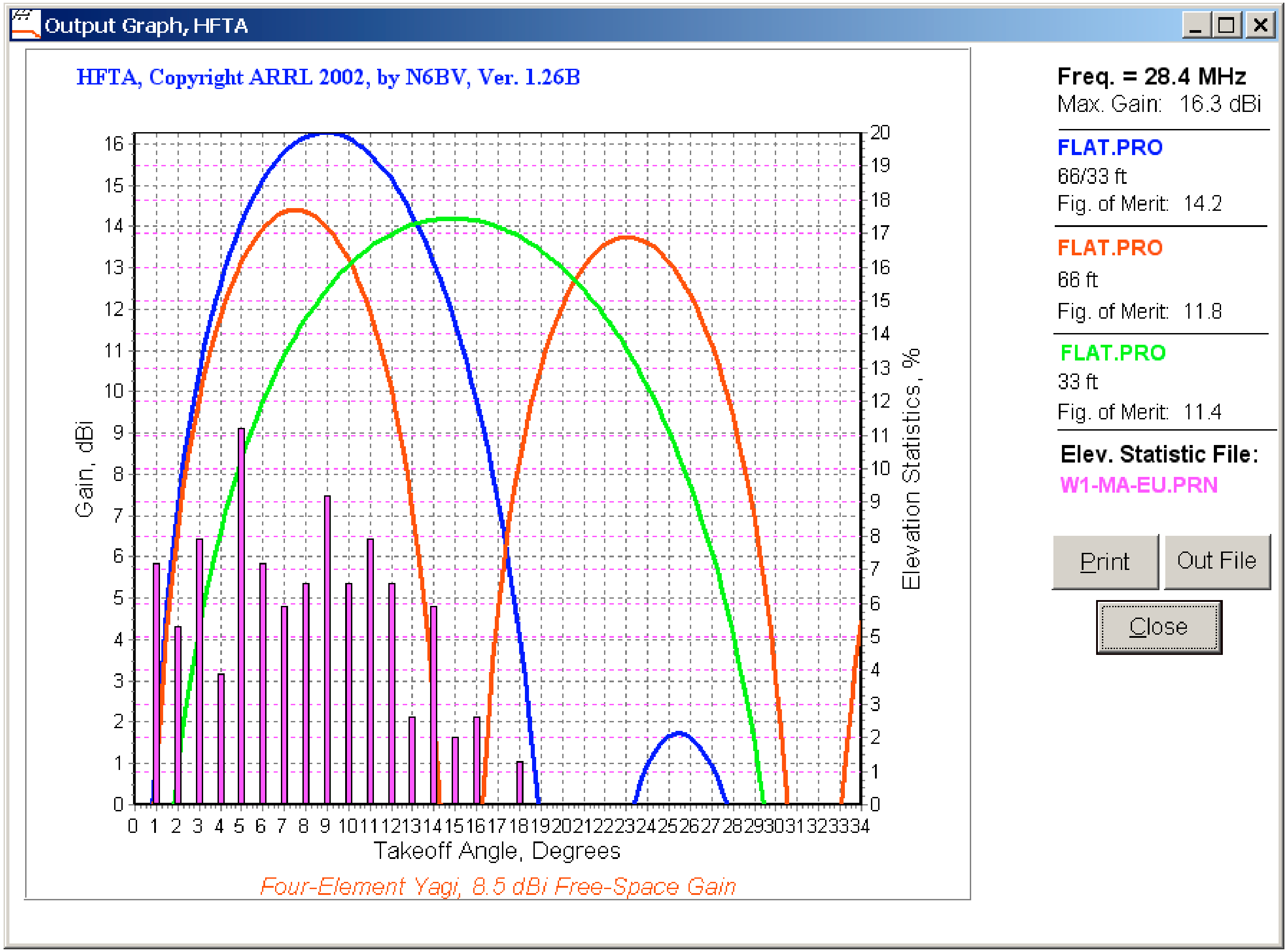
“Ugly lobe”--we’ll talk about this more later

Where did the gain come from? The higher-angles lobes are now compressed.

Peak Gain = 16.5 dBi

The -3 dB beamwidth has increased a little, to 9.3°, for two 5-element 10-meter Yagis stacked 66’/33’ over average ground. The peak gain of the stack is 2.3 dB more than the single Yagi.

10-Meter Stack at 66'/33'



HFTA graph, rather than polar graph, with angles to Europe.

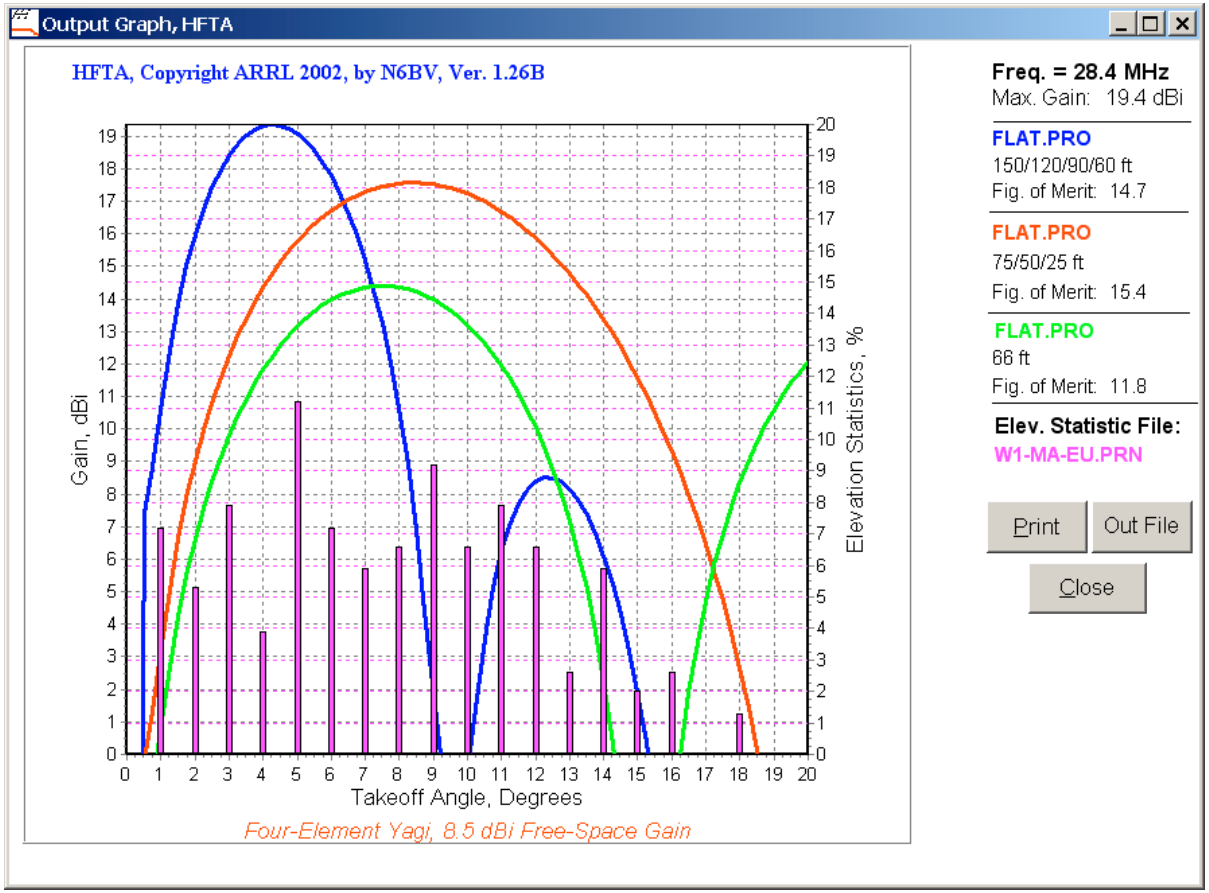
The *Figure of Merit* in *HFTA*

- The Fig. of Merit (FOM) shown in *HFTA* is the gain at each elevation angle multiplied by the elevation-angle percentage for that angle, summed and averaged over all angles from 1 to 35°.

- This is a statistical "weighted gain," calibrated in dBi.

- The FOM will vary depending on the target receiving area and the frequency band. You should also show the FOM over flat ground, for reference.

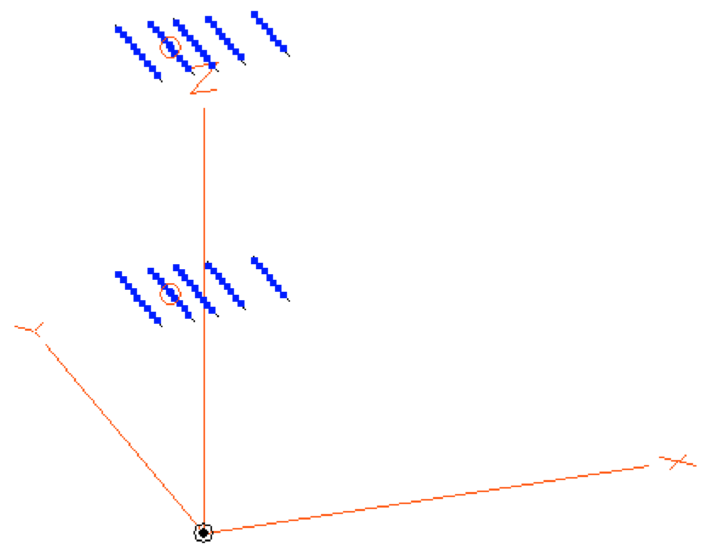
More Gain From Going Higher?



Higher is not necessarily better. The 150/120/90/60' stack shown here is too high to be effective over all the needed elevation angles (although it will certainly open and close 10 meters).

Why Do We Stack Yagis?

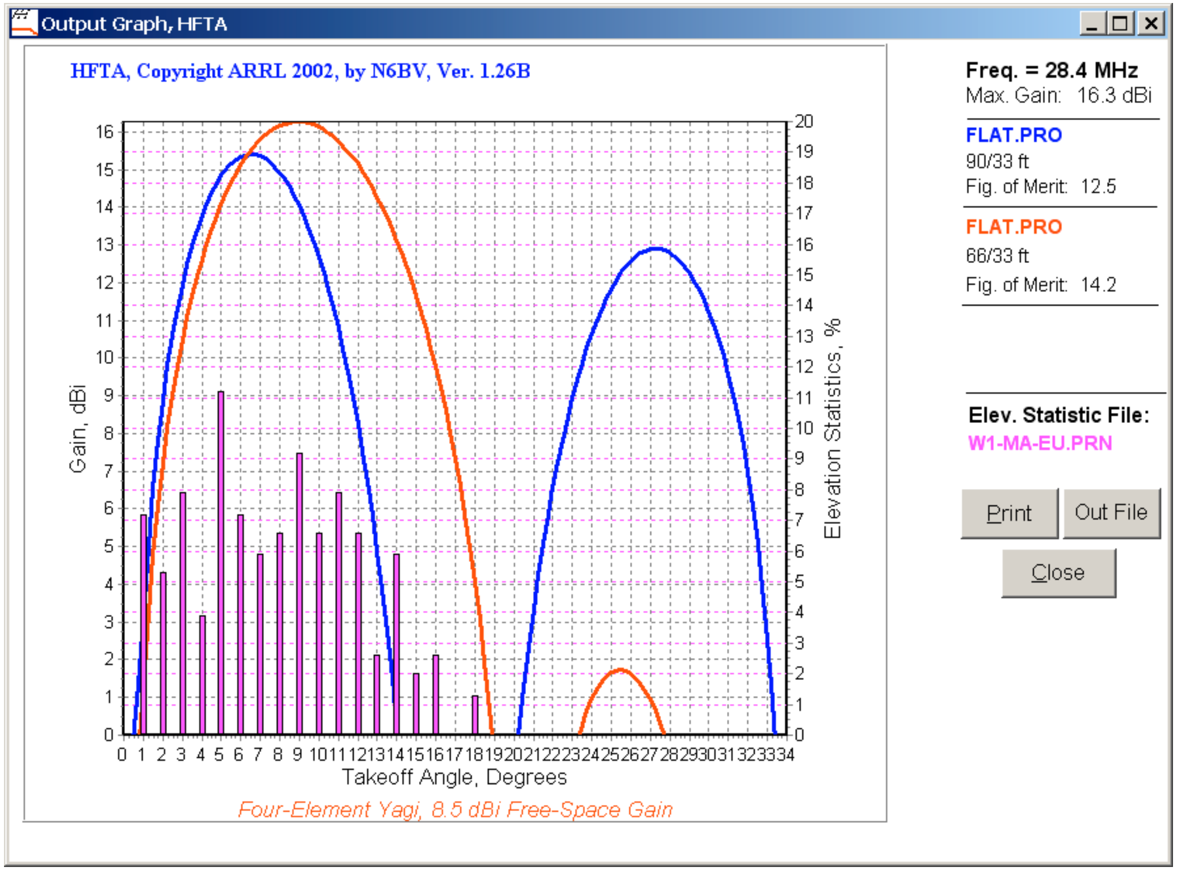
- For more gain
- For wider elevation coverage
- For azimuthal diversity
- For less fading



Wider Elevation-Angle Coverage

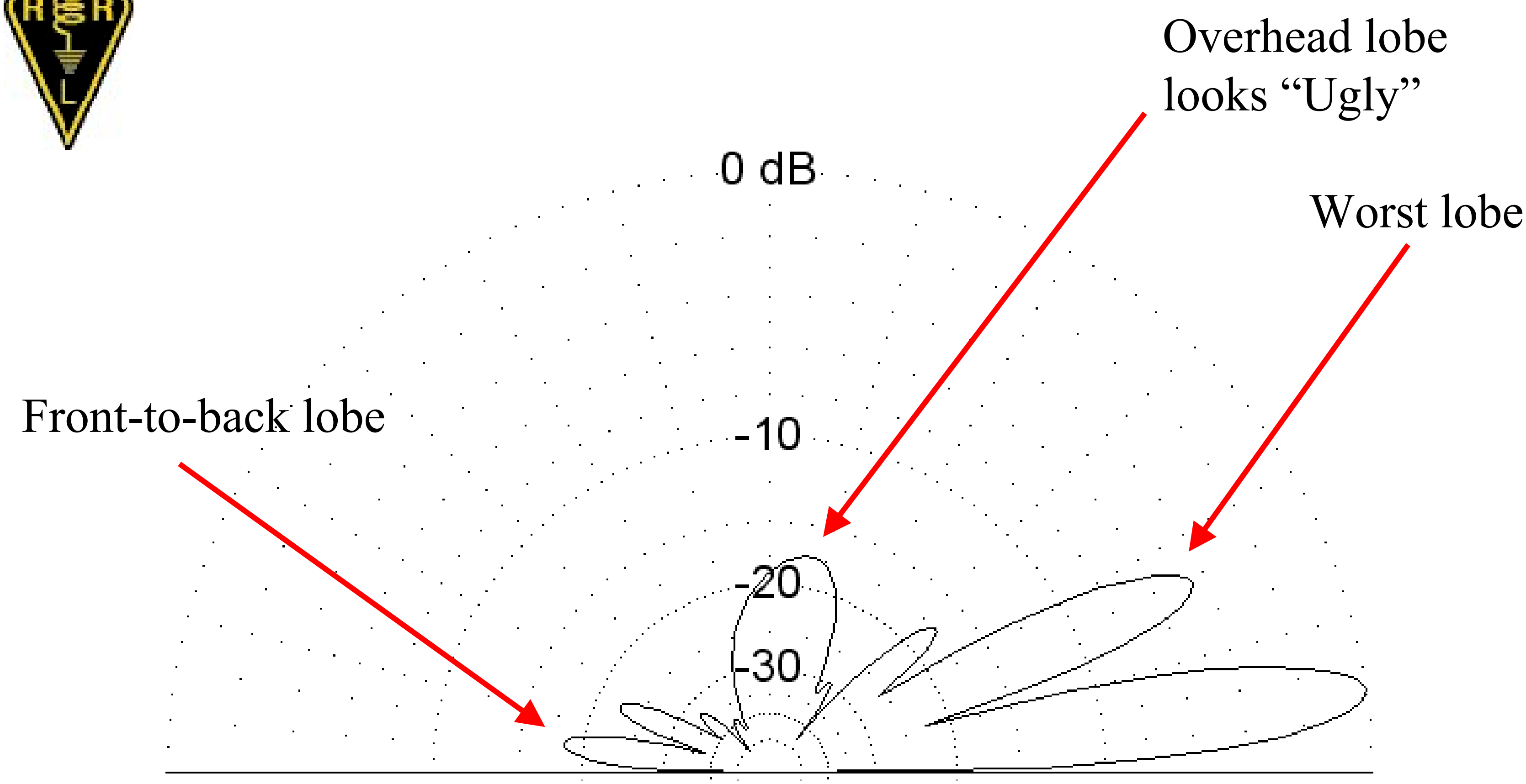
- You can see that higher stacks are not necessarily always better. The gain is good at low angles, but the nulls can really hurt you. You need to cover all the angles, preferably with a single stack so you don't have to switch all the time.
- It's easy to be too high, especially on hilltops. We'll look at this more later.
- By the way, a side-by-side stack will narrow down the azimuth coverage to get gain.

What About Wider Spacing?



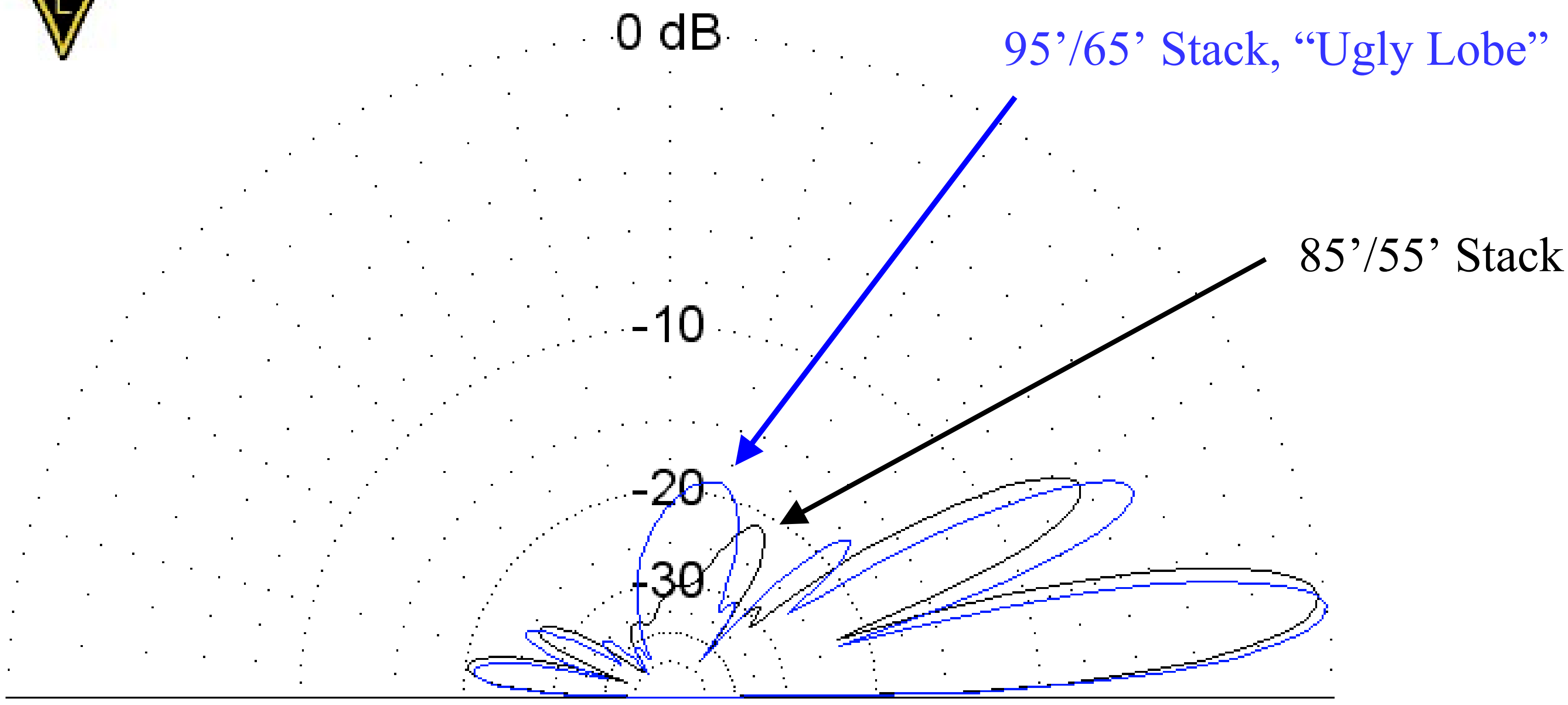
Wider stack spacing is not necessarily better either. The 90’/33’ stack has less gain compared to the 66’/33’ stack and the elevation-angle coverage suffers too -- note the huge sidelobe at 28° for the overly wide-spaced stack.

Magic Spacings?



Some folks talk about needing critical spacings to minimize higher elevation-angle lobes, particularly with tribanders

Magic Spacings?



Two 5-Ele. 15-m Yagis -- Same 30' spacing but different heights. Clearly the spacing is not causing this ugly lobe, but height above ground is.

Magic Spacings for Different Boom Lengths?

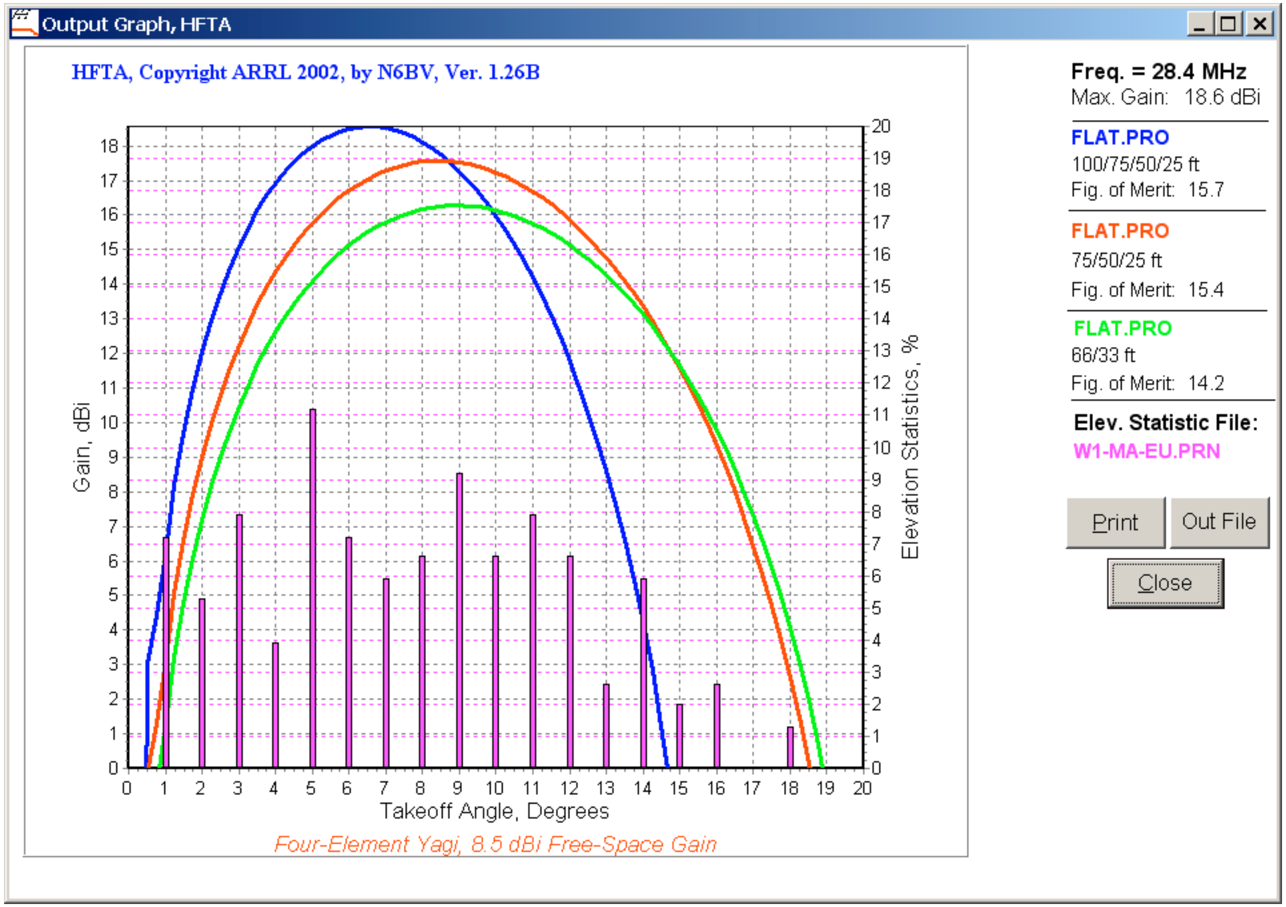
Stacking 15-m Yagis					
3-Ele., 12' boom	Gain	Worst Lobe	Angle	F/B	Overhead
By itself 95'	13.2	-0.9	21	28.8	-17.5
95'/65' (30' spacing)	16.08	-4.5	25	14.9	-14.7
95'/60' (35' spacing)	16.01	-6.2	24	15.1	-10.9
95'/70' (25' spacing)	15.81	-3.2	24	14.8	-28
95'/75' (20' spacing)	15.34	-2.3	23	16.3	-17.2
4-Ele., 18' boom					
By itself 95'	13.92	-1	21	28.3	-20.4
95'/65' (30' spacing)	16.63	-4.5	23	18.5	-17.3
95'/60' (35' spacing)	16.6	-6.2	24	18.2	-13.1
95'/70' (25' spacing)	16.36	-3.3	24	20.4	-31.8
95'/75' (20' spacing)	15.92	-2.5	23	25.9	-19
5-Ele., 23' boom					
By itself 95'	14.26	-1.1	21	27.9	-22.3
95'/65' (30' spacing)	16.86	-4.6	24	20.8	-19
95'/60' (35' spacing)	16.86	-6.3	24	20.7	-14.4
95'/70' (25' spacing)	16.59	-3.4	24	24.9	-34.4
95'/75' (20' spacing)	16.18	-2.6	23	34.3	-20.2
7-Ele., 64' boom					
By itself 95'	17.93	-2.2	21	28.9	-17.1
95'/65' (30' spacing)	19.39	-6.9	24.3	21.4	-21.9
95'/60' (35' spacing)	19.38	-8.6	24	21.4	-16.9
95'/70' (25' spacing)	19.26	-5.5	23	24	-35.3
95'/75' (20' spacing)	19.08	-4.6	23	27	-23.4

Highest stack gain at 30' spacing, despite length of boom. Worst lobe is always second lobe due to height (not due to spacing).

Magic Spacings?

- You should vary spacing to optimize the elevation-angle coverage you need.
- You've got to avoid practical things, like guy wires, other antennas, etc., so you have limited places to put the antennas on the tower.
- DX propagation doesn't occur at high elevation angles, certainly not straight up.
- High-angle lobes could contribute to QRM from close stations -- but they're already 50 over S9. Does it really matter, even if they drop 10 dB?!

What About More Yagis?

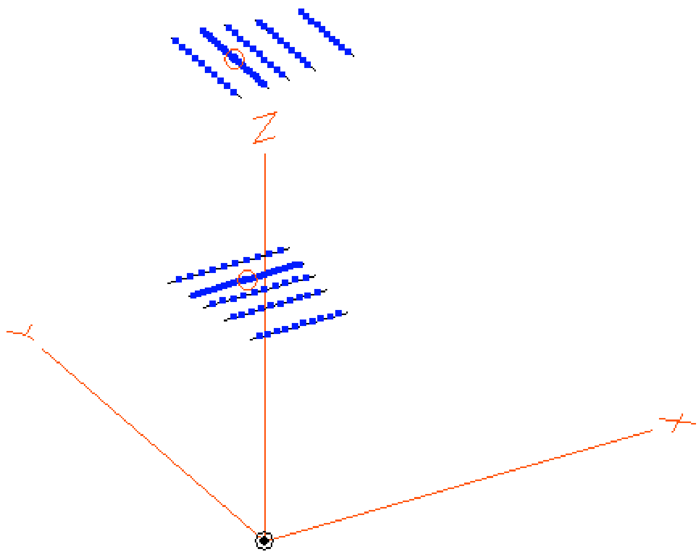


Note close FOMs.

The 100/75/50/25' four-stack is great for gain, but doesn't cover higher angles that well. You could use a StackMatch to switch out the 100' antenna when the angles are high, however.

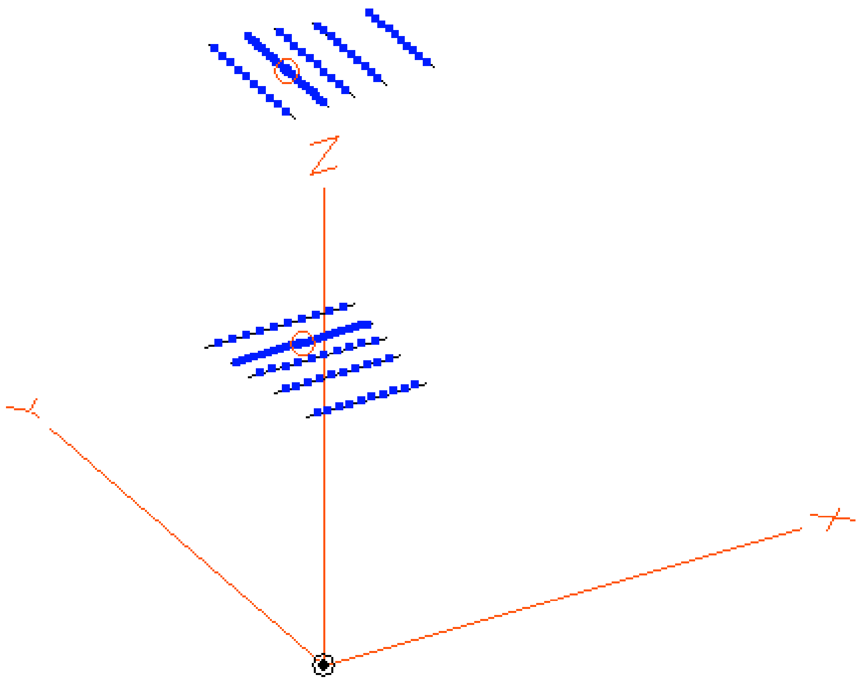
Why Do We Stack Yagis?

- For more gain
- For wider elevation coverage
- For azimuthal diversity
- For less fading



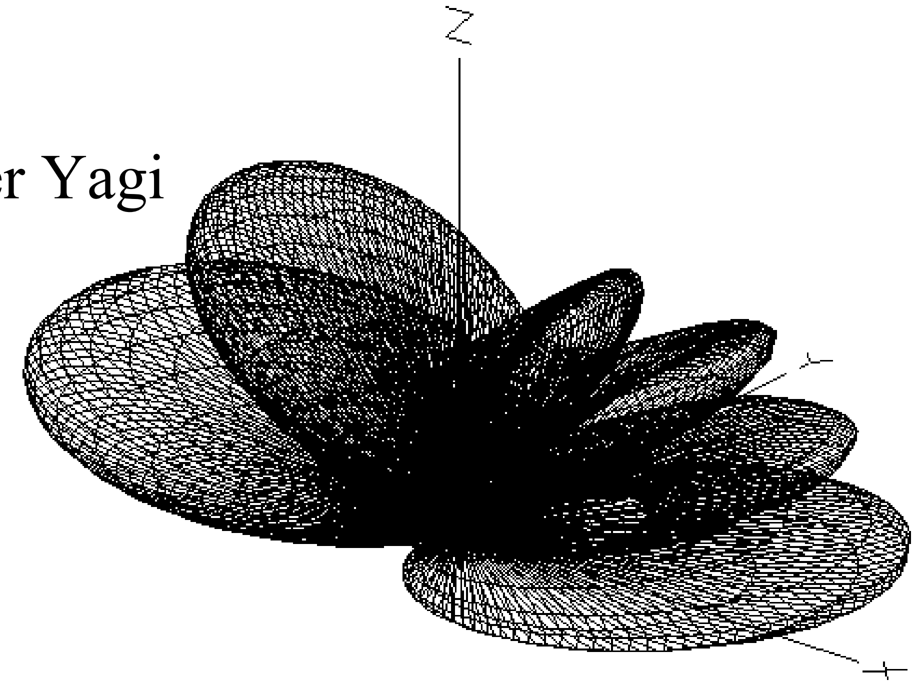
Azimuthal Diversity

If you turn one antenna in the stack you can beam simultaneously in two directions. If you have more than two Yagis in a bigger stack you can cover even more directions simultaneously.



Azimuthal Diversity, Turned 180°

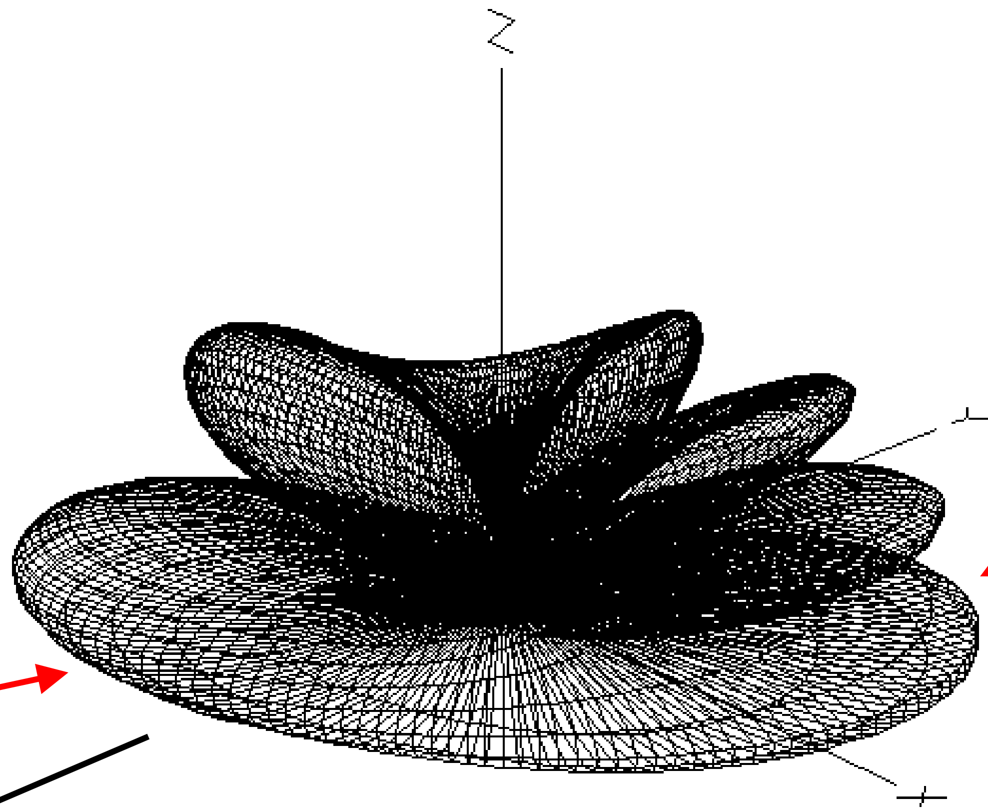
Boom of lower Yagi



Boom of top Yagi

You may want to turn the lower Yagi rather than the top one, depending on the angles involved to the target locations.

Azimuthal Diversity, Turned 90°



Lower angles

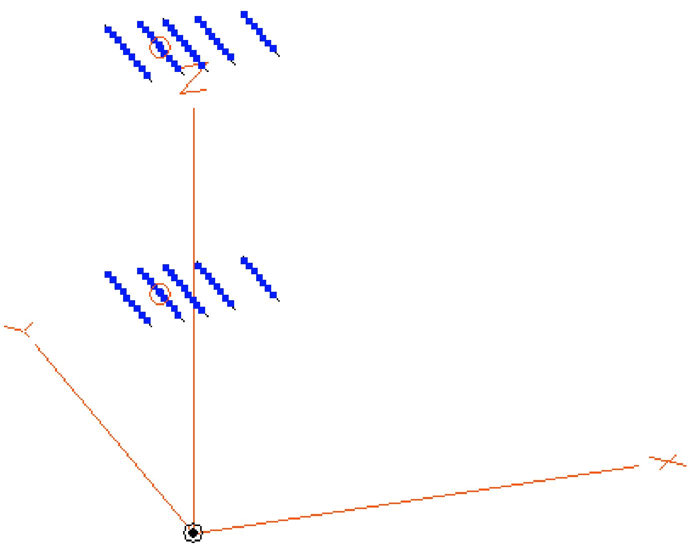
Higher angles

Boom of lower Yagi

Boom of top Yagi

Why Do We Stack Yagis?

- For more gain
- For wider elevation coverage
- For azimuthal diversity
- For less fading



Fading

"On all three bands, the stack is always better on NE paths than either antenna by itself. The average signal level benefits from lower and less frequent fades. Peak signal level is sometimes no better on the stack, but it is very seldom inferior."

"It's surprising how well the stack performs on 20M, considering the modest 22-ft spacing…but it consistently outperforms the top antenna alone."

-- *Don, K2KQ*.

[Don's stack is a pair of A3S tribanders at 82'/60'.]

Fading

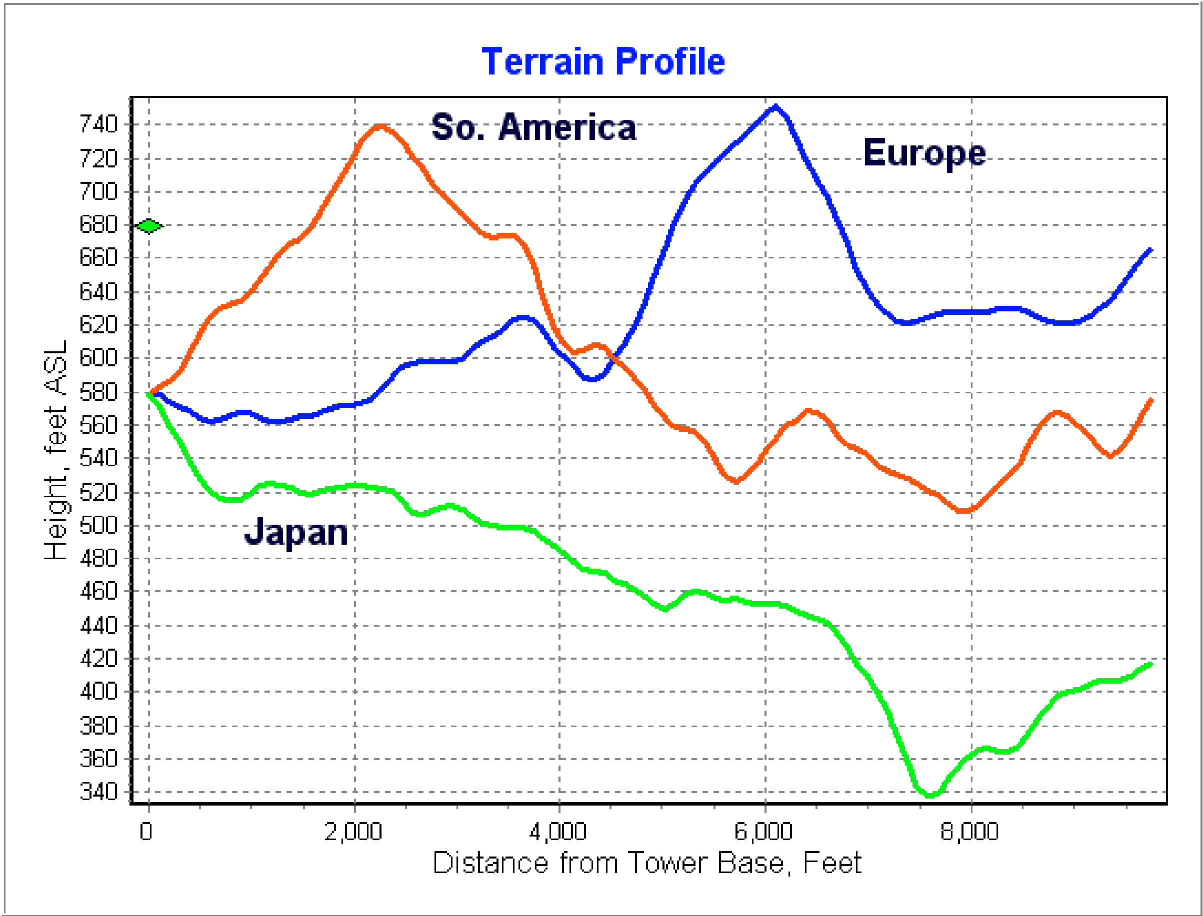
"As others have observed, the largest benefit of the stacks is that they essentially eliminate short-term fading. Operating with them is a pleasure! I would hate to go back to single antennas."

-- *Rus, K2UA*.

What Can You Vary Using *HFTA*?

1. Antenna height above ground.
2. Stack two (or more) Yagis.
3. Change spacing between stacked Yagis.
4. Move tower back from a cliff (or a hill).
5. Do BIP/BOP (Both In Phase/Both Out of Phase).

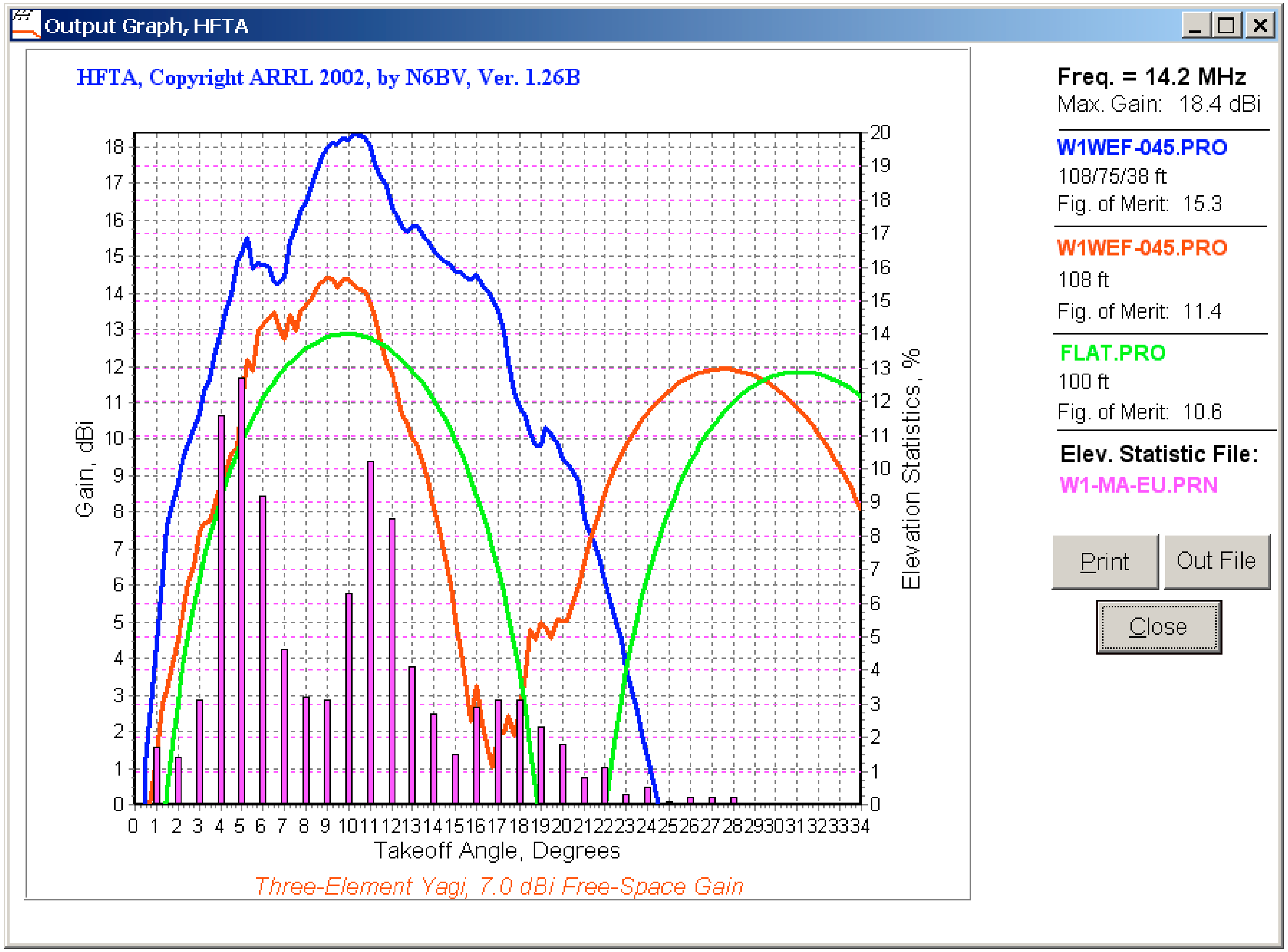
Local Terrain, an Example



- Good to Europe
- Great to Japan
- Not-so-good to South America

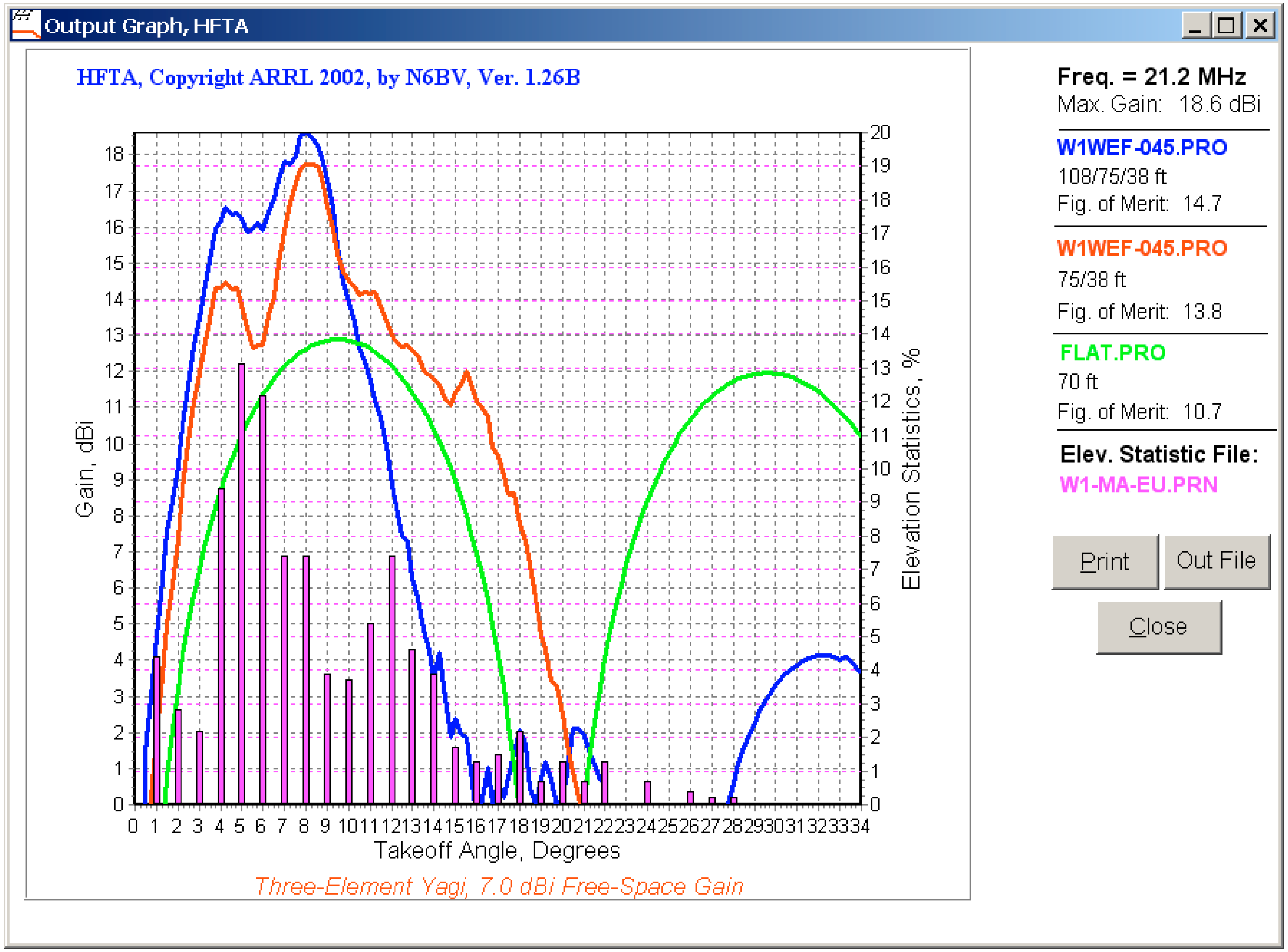
Terrain at W1WEF in Glastonbury, Connecticut. Jack's 105' high tower is populated with *lots* of antennas!

20 Meters, W1WEF to Europe



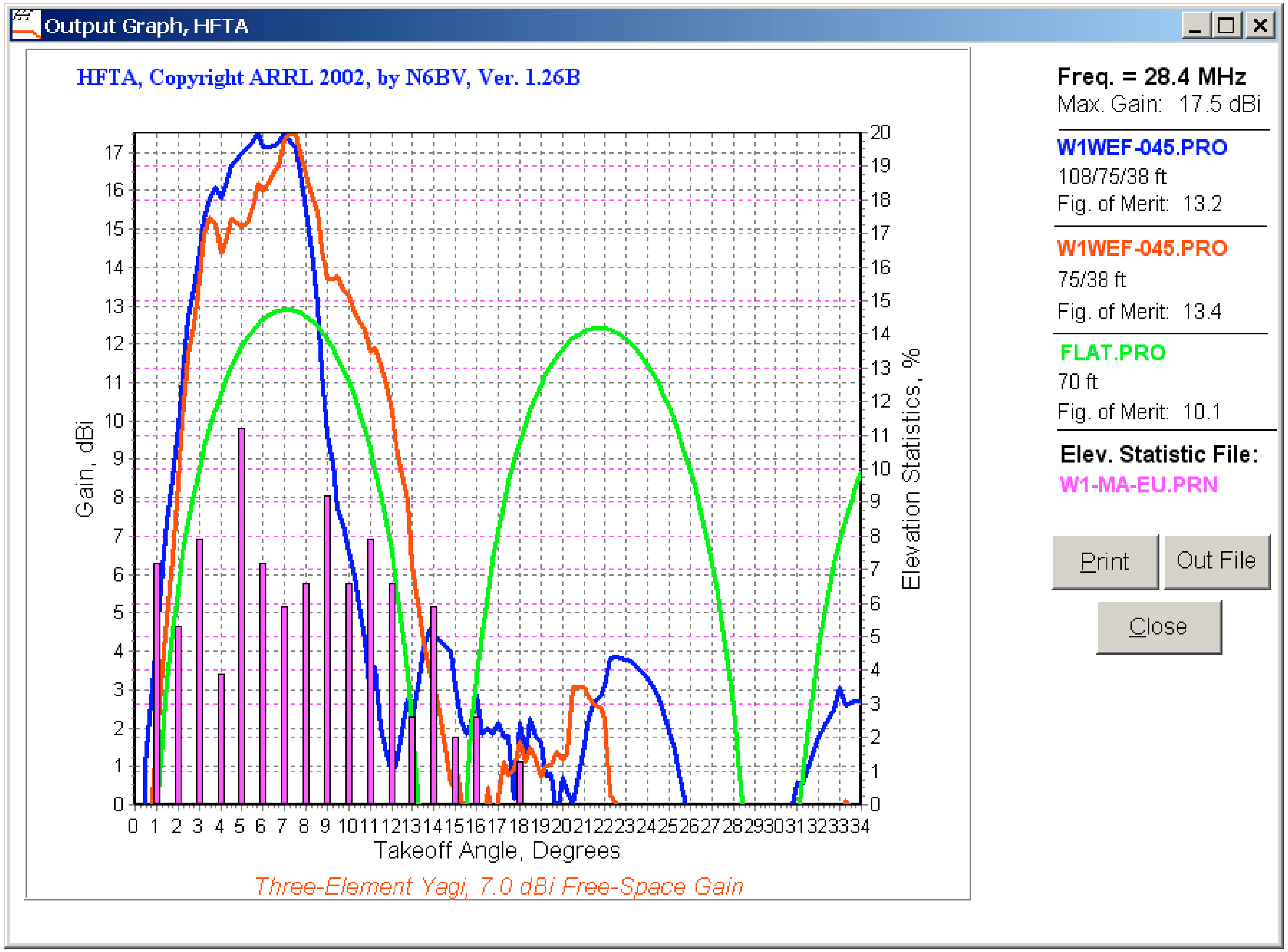
TH7DXs at 108'/75'/38'

15 Meters, W1WEF to Europe



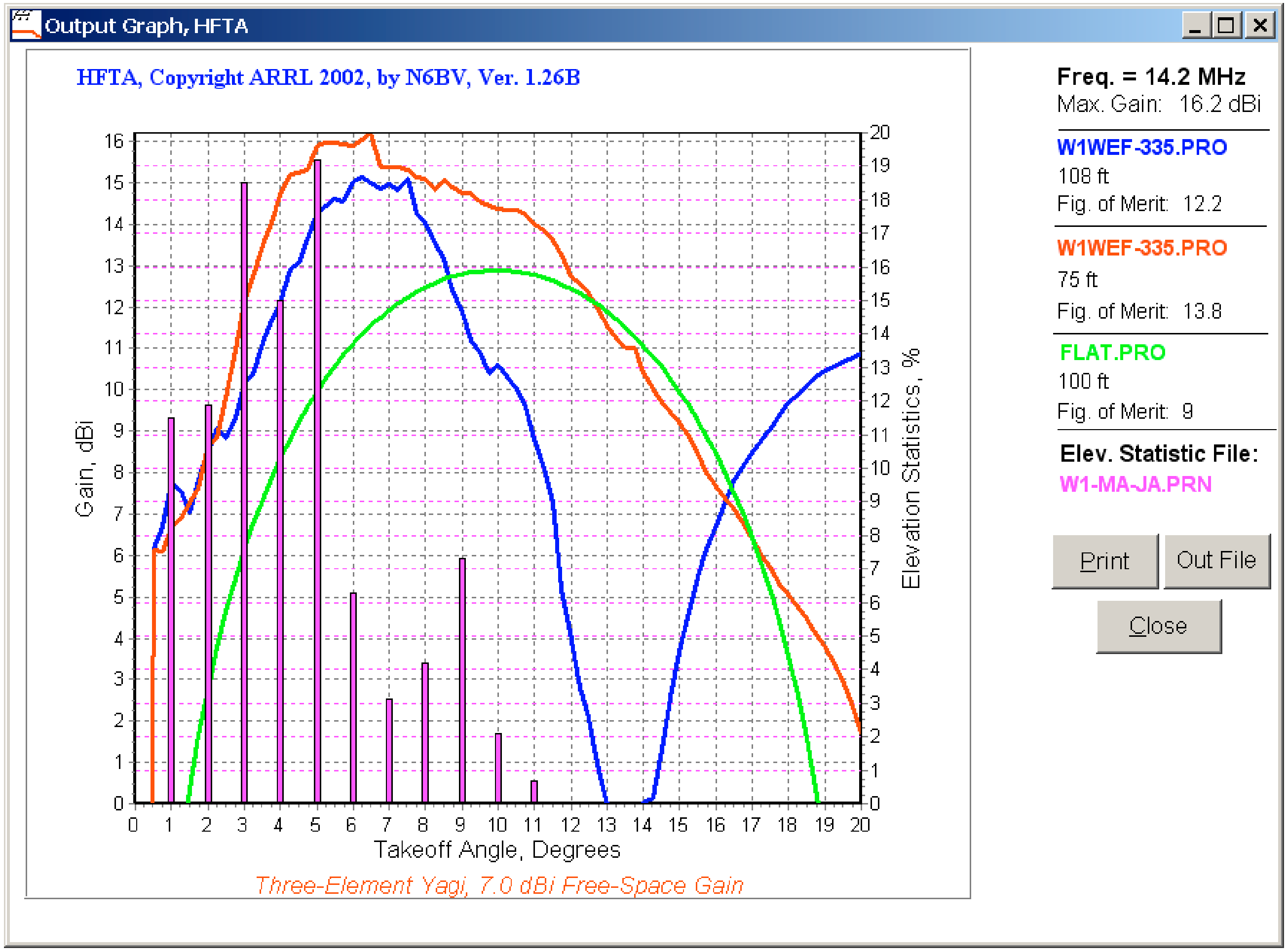
The 75'/38' stack may be better in the afternoon when angles typically go higher.

10 Meters, W1WEF to Europe



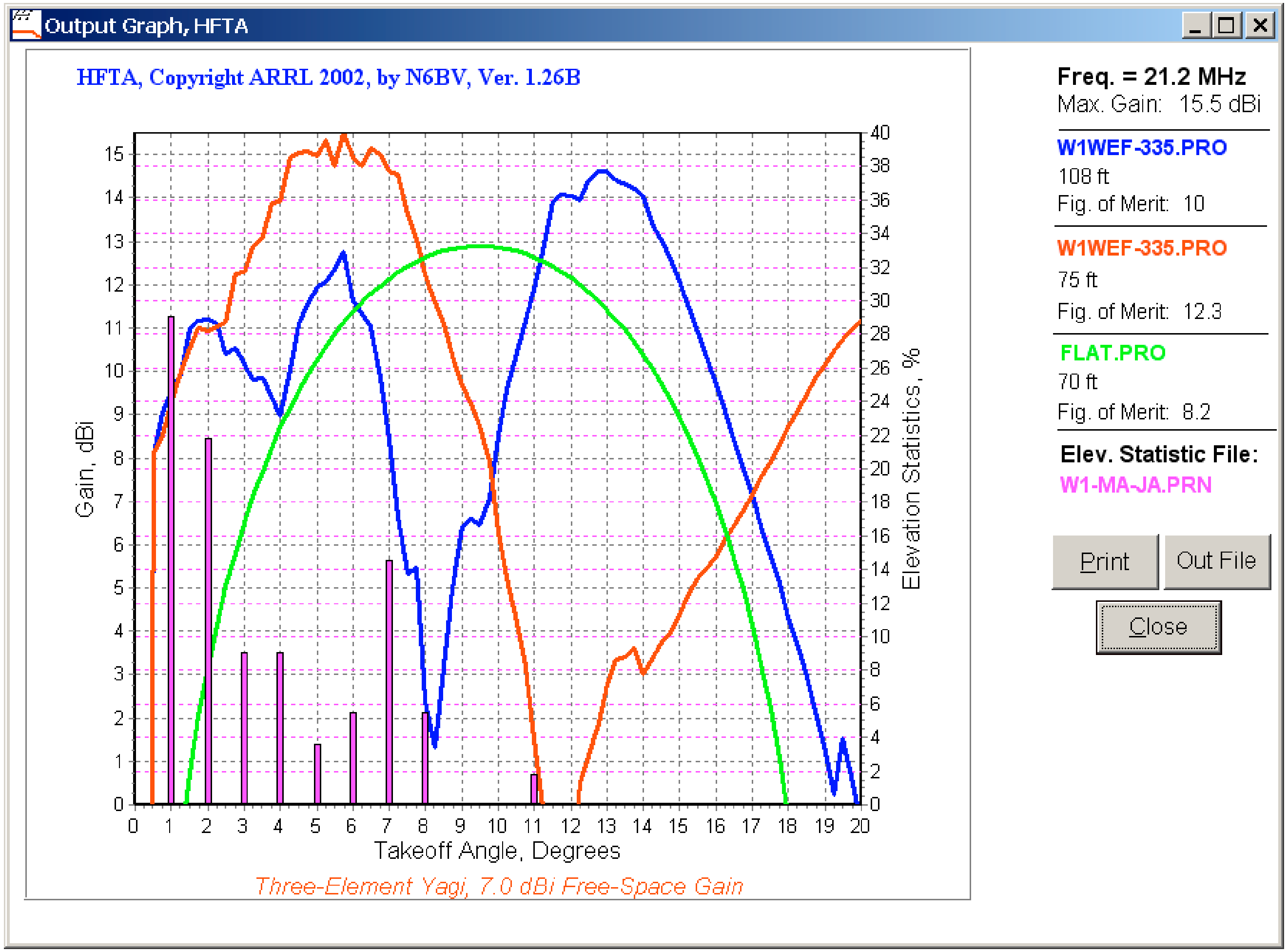
Agin, the 75'/38' stack may be better in the afternoon.

20 Meters, W1WEF to Japan



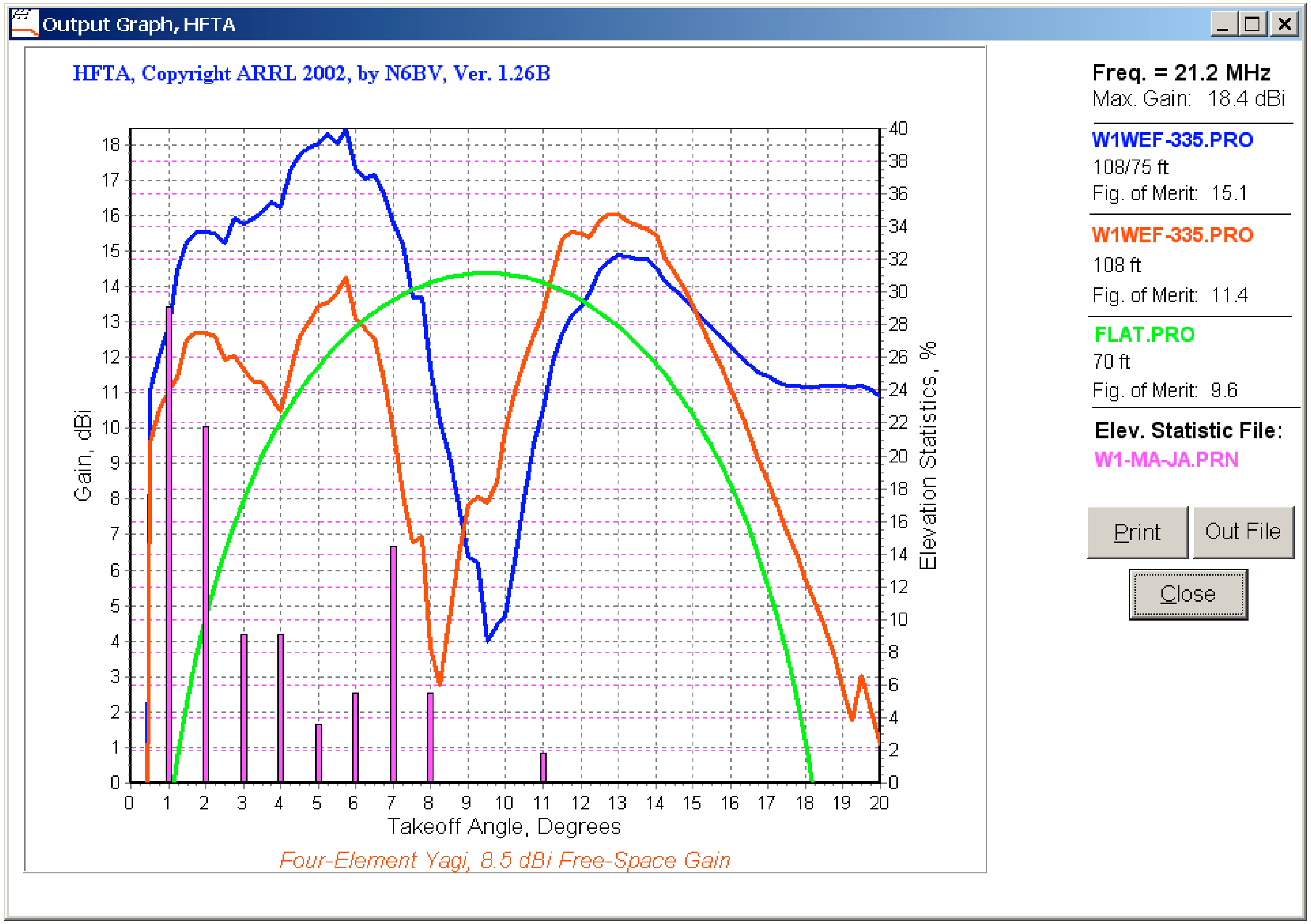
Note: change to X-axis, for max. 20° of elevation. The takeoff angles to Japan from New England are very low.

15 Meters, W1WEF to Japan



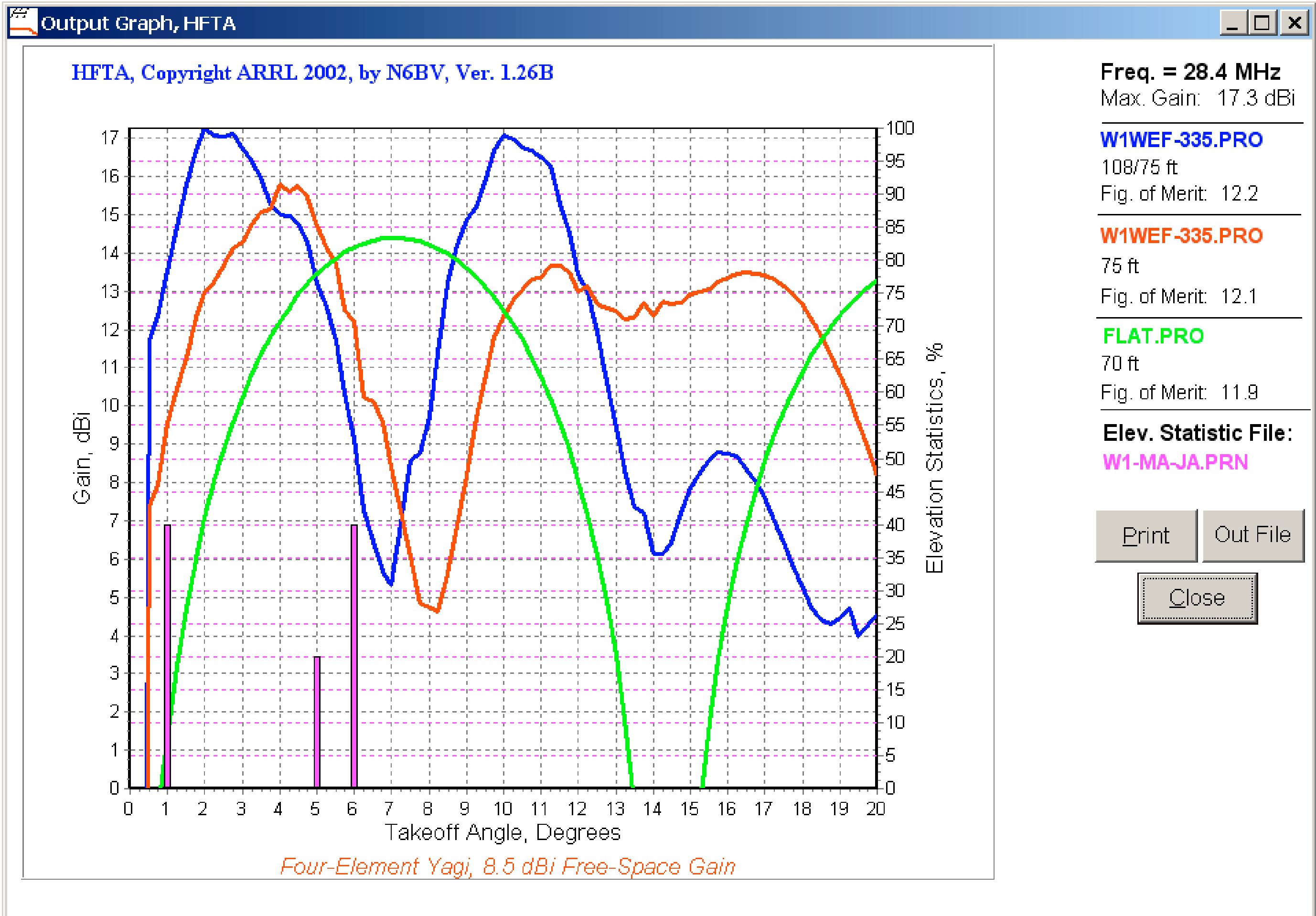
Now, 75’ TH7DX is best. 108’ TH7DX is too high.

15 Meters, W1WEF to Japan



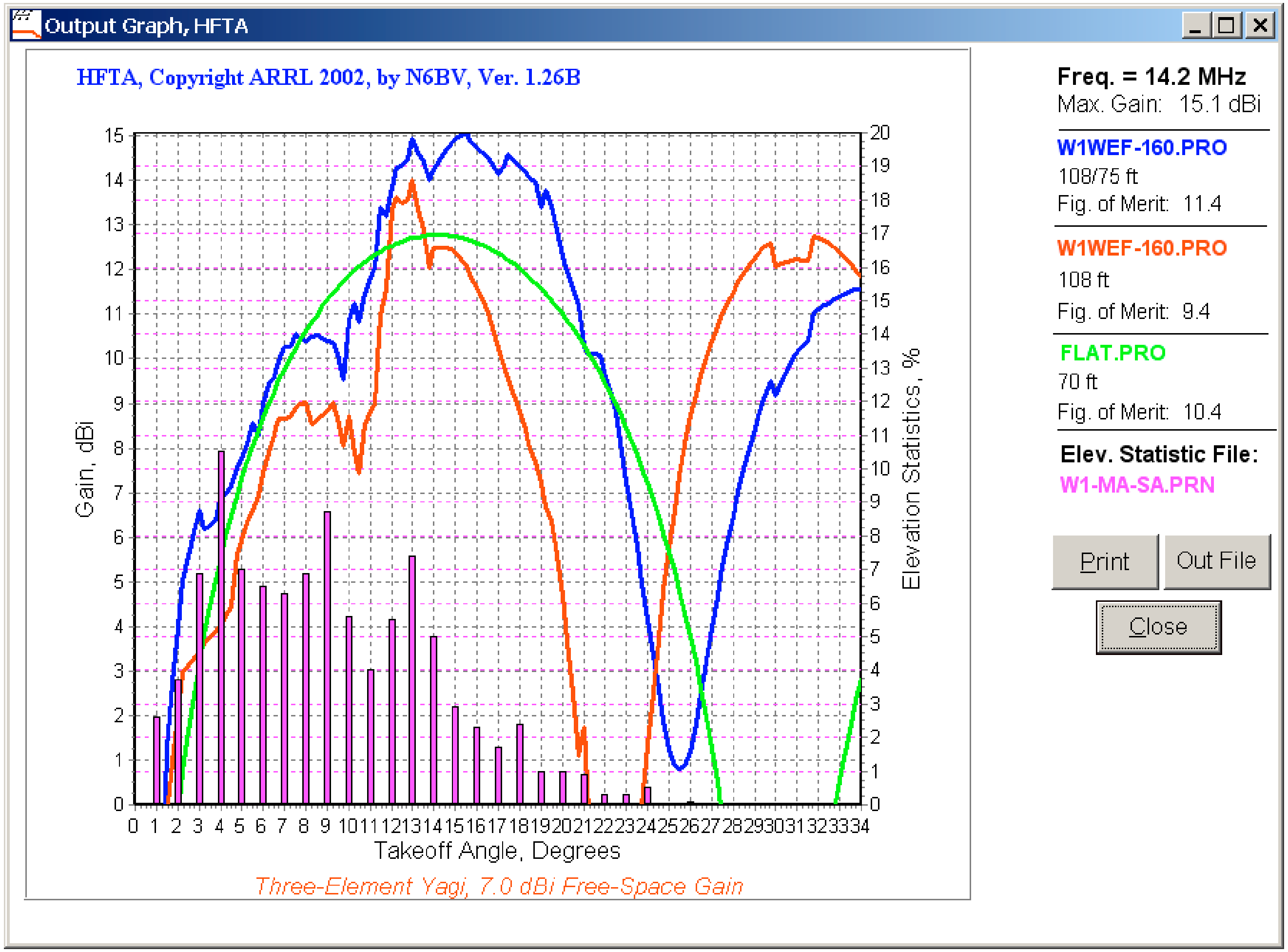
Did I mention that stacks rule? !

10 Meters, W1WEF to Japan



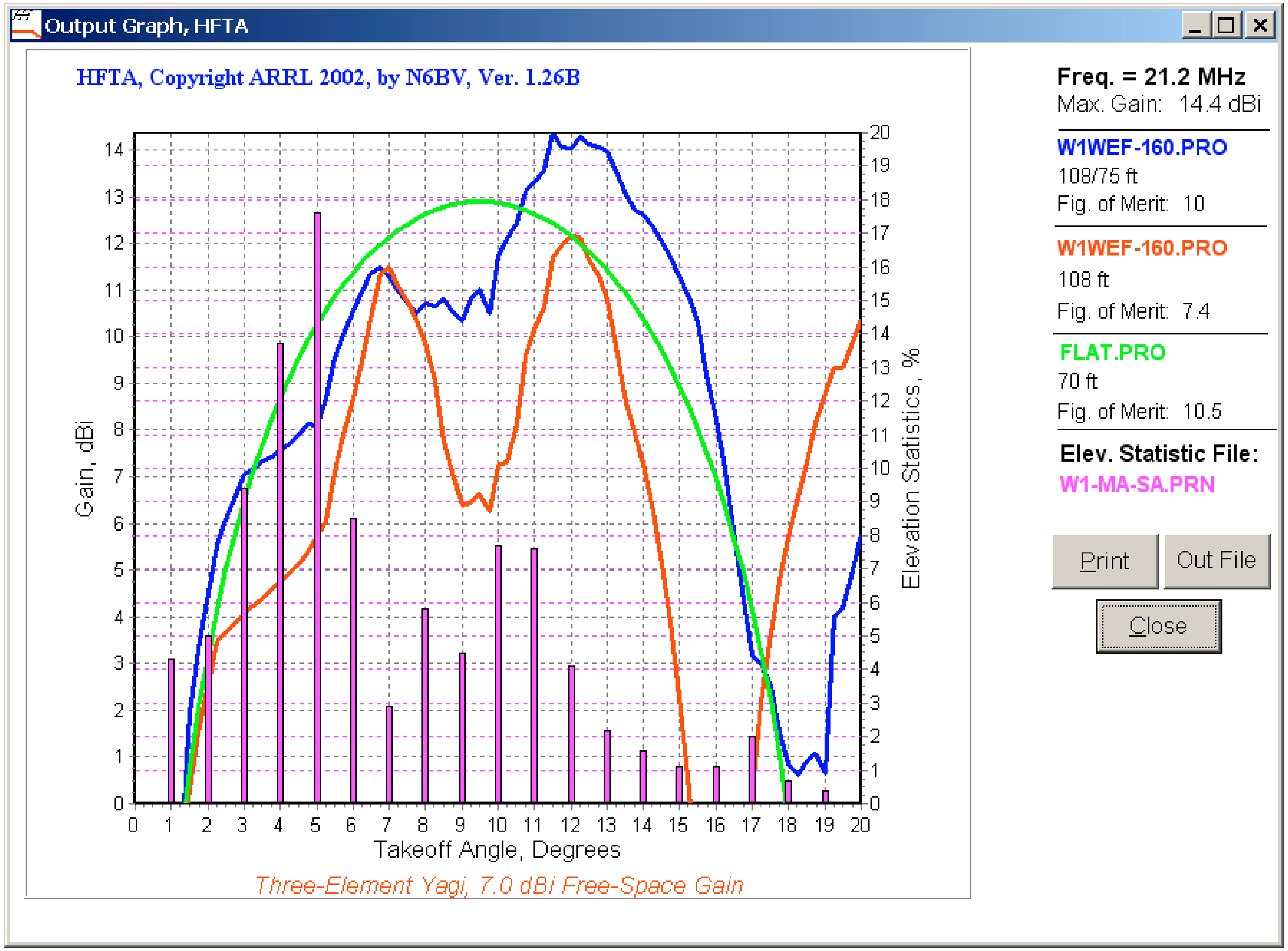
The 75' TH7DXX is not bad. The top antenna could be pointed somewhere else for azimuthal diversity.

20 Meters, W1WEF to So. America



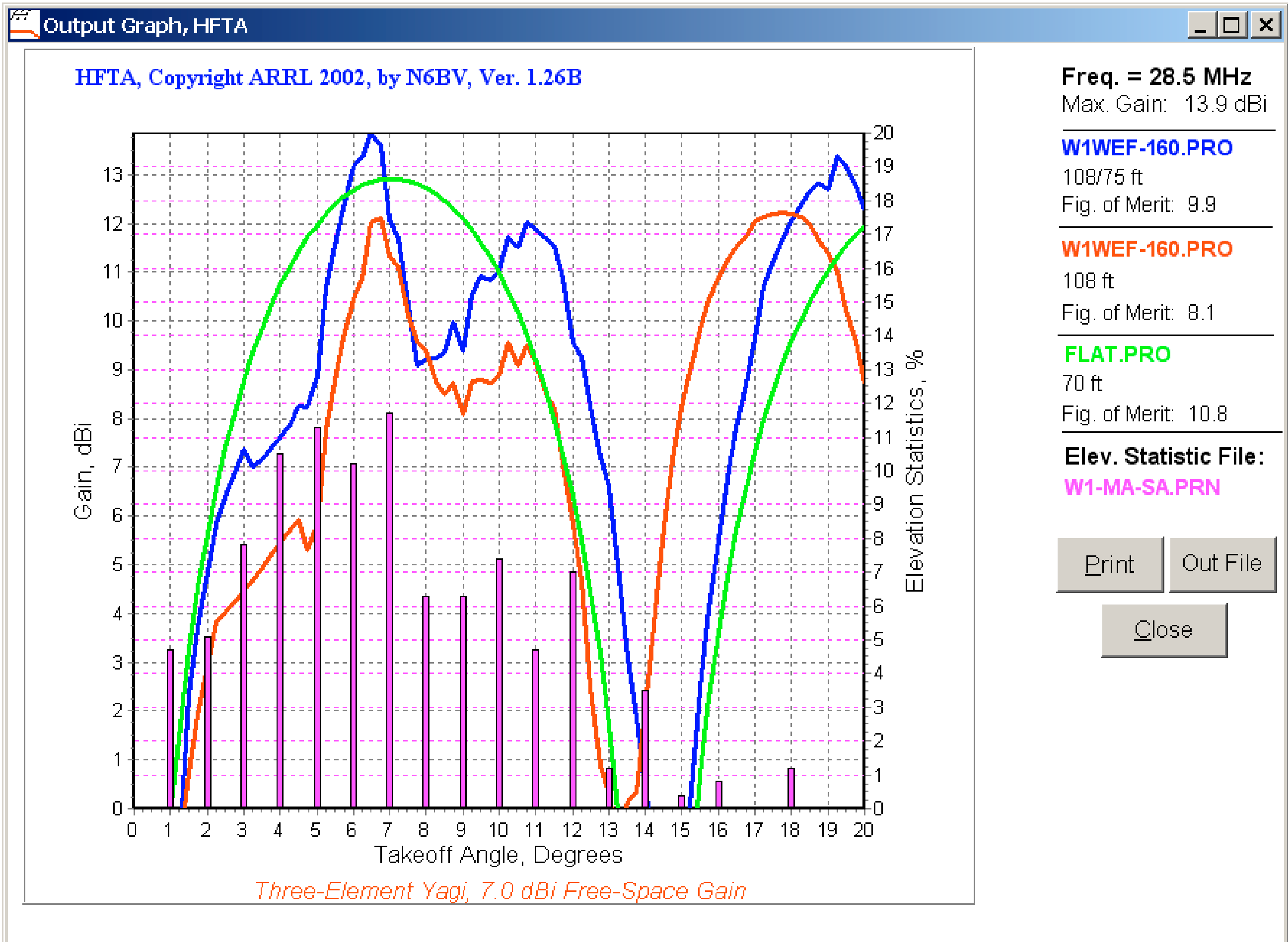
Nearby hill is a problem into South America.

15 Meters, W1WEF to So. America



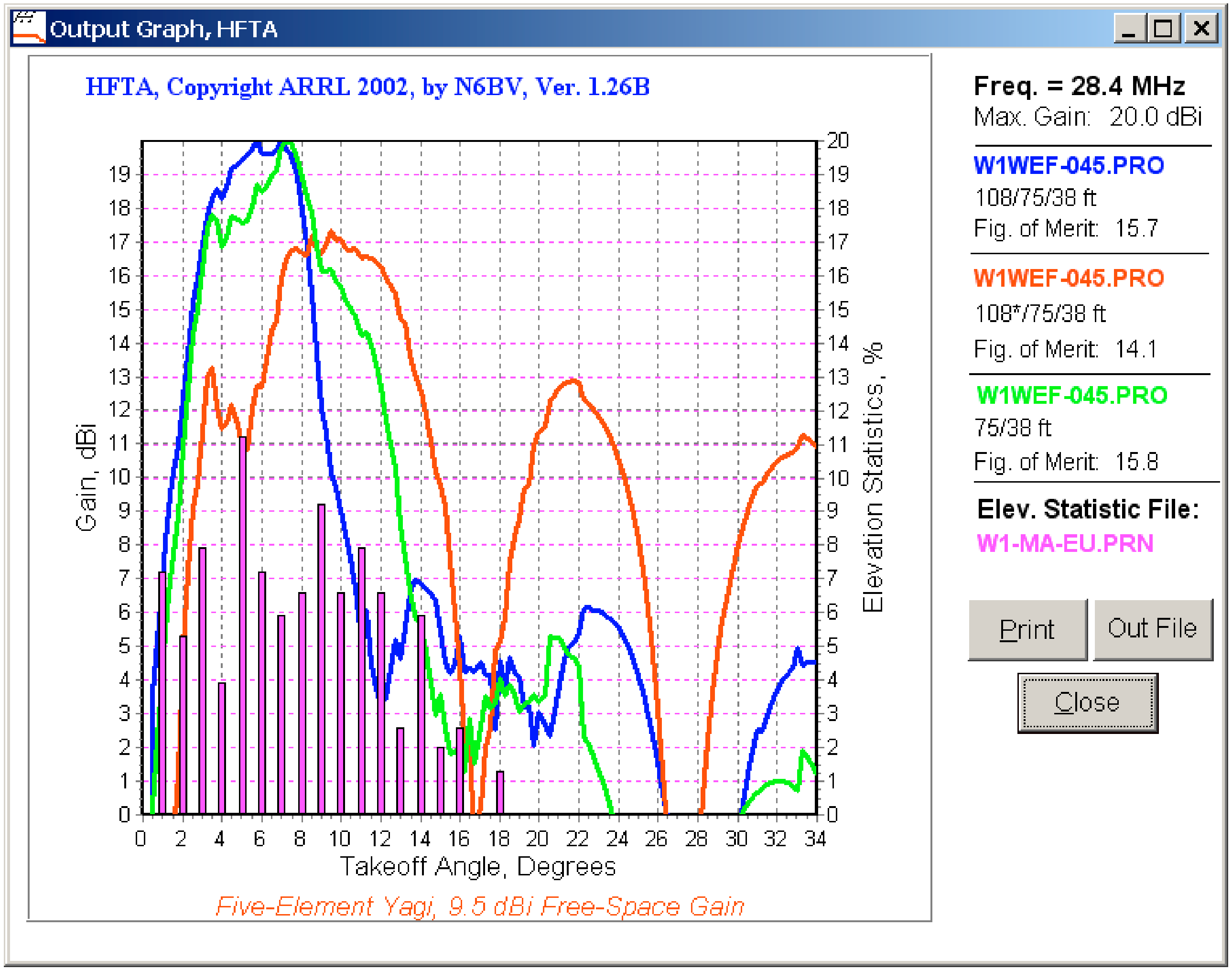
The stack is almost as good as 70’ antenna over flat ground.

10 Meters, W1WEF to So. America



Statistically, Jack's 10-meter stack into South America is about 1.9 dB down from a 60' high flatlander.

BIP/BOP for W1WEF to Europe



BIP/BOP could be useful for higher angles.

Terrain Data for *HFTA*

Making it the old-fashioned way: You supply terrain data, by hand, from a 7.5-minute USGS topographic map.

Windham, NH
N6BV/1 QTH.

Making a Terrain Profile

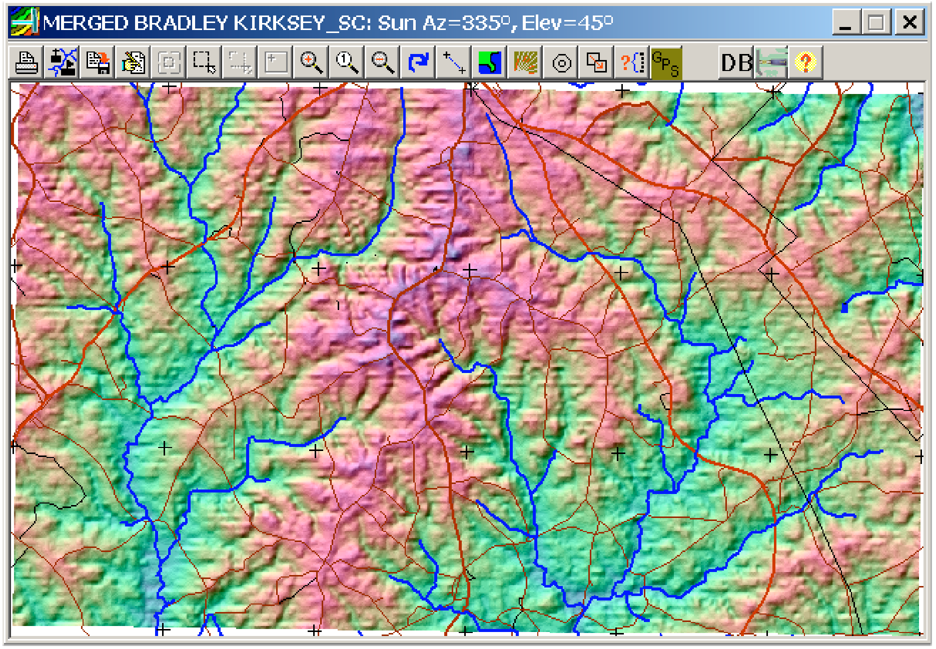
- Doing it by hand from a paper topographic map is *not* fun!

- A magnifying glass, a steady hand and at least an hour is needed for each azimuth of interest, maybe more.

Making a Terrain Profile

- *MicroDEM* is a free program written by Dr. Peter Guth at the US Naval Academy.

- *MicroDEM* uses USGS DEM (Digital Elevation Model) and US Census TIGER files.

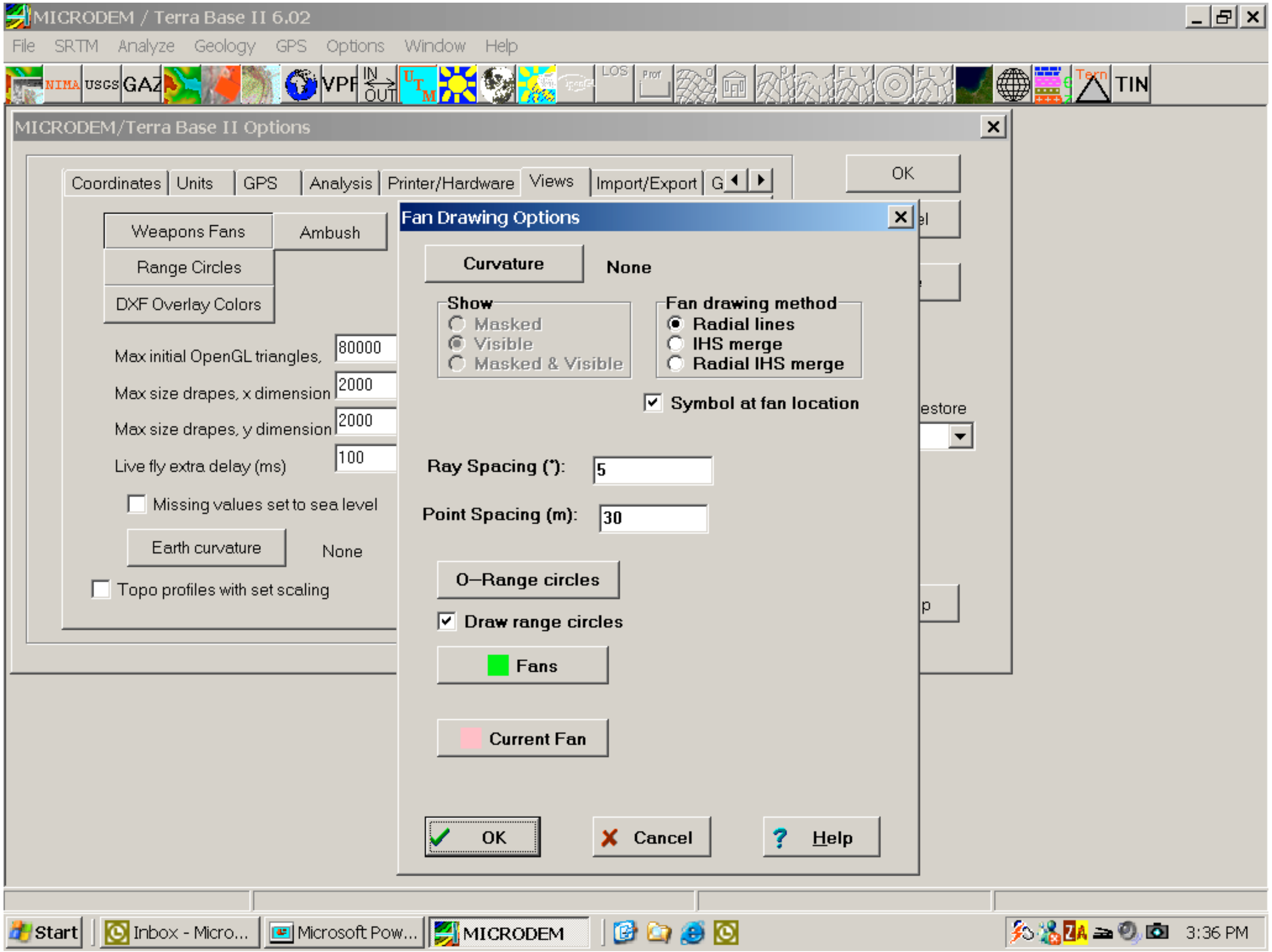


MicroDEM

• Since my talk at Boxboro, Dr Guth, the man behind *MicroDEM*, has graciously added a really cool feature -- automatically creating *HFTA* *.PRO files. Thank you, Dr Guth!

• To set this up initially, I specify radials at 5°intervals of azimuth, out to 3000 meters from the tower base, set using the **Options, Views, Weapon Fans** menu.

MicroDEM



MICRODEM / Terra Base II 6.02
File SRTM Analyze Geology GPS Options Window Help
MICRODEM/Terra Base II Options
Coordinates Units GPS Analysis Printer/Hardware Views Import/Export
Weapons Fans
Ambush
Range Circles
DXF Overlay Colors
Max initial OpenGL triangles, 80000
Max size drapes, x dimension 2000
Max size drapes, y dimension 2000
Live fly extra delay (ms) 100
Missing values set to sea level
Earth curvature None
Topo profiles with set scaling
OK
Fan Drawing Options
Curvature None
Show
Masked
Visible
Masked & Visible
Fan drawing method
Radial lines
IHS merge
Radial IHS merge
Symbol at fan location
Ray Spacing (°): 5
Point Spacing (m): 30
0–Range circles
Draw range circles
Fans
Current Fan
OK
Cancel
Help
Start
Inbox - Micro...
Microsoft Pow...
MICRODEM
3:36 PM

MicroDEM

- Using the **Calculate, Viewshed** menu (also called **Weapons Fan**), you specify the latitude and longitude at the base of your tower and then quickly create *HFTA* *.PRO terrain files.

- It takes maybe 60 seconds to do 72 azimuths for each tower.

- *MicroDEM* places the *.PRO files in the subdirectory:

c:\Program Files\Microdem--6.0\MD-PROJ\FANS

Some Nitty Gritty Stuff: Finding the Right Topos

- The USGS (US Geological Survey) topographic maps ("quads") for the US are free on the Web.

- However, finding the ones you need can be challenging, particularly if a QTH is near the edge of a topo map. This may require you to ***merge*** several maps together using *MicroDEM*.

Finding the Right Topos

- You need to know the Latitude and Longitude of your tower(s). Use a GPS to determine lat/long accurately.
- You need your county, since the USGS sites are usually organized by state and county.
- You need to know the “quad” name(s) -- the 7.5-minute quadrangle name(s).

Finding the County

- First, if you don’t know your county, go to: **http://quickfacts.census.gov/cgi-bin/lookup?state=36000**
- Enter by city and state, or by ZIP code
- Or look up call under Details on QRZ.COM

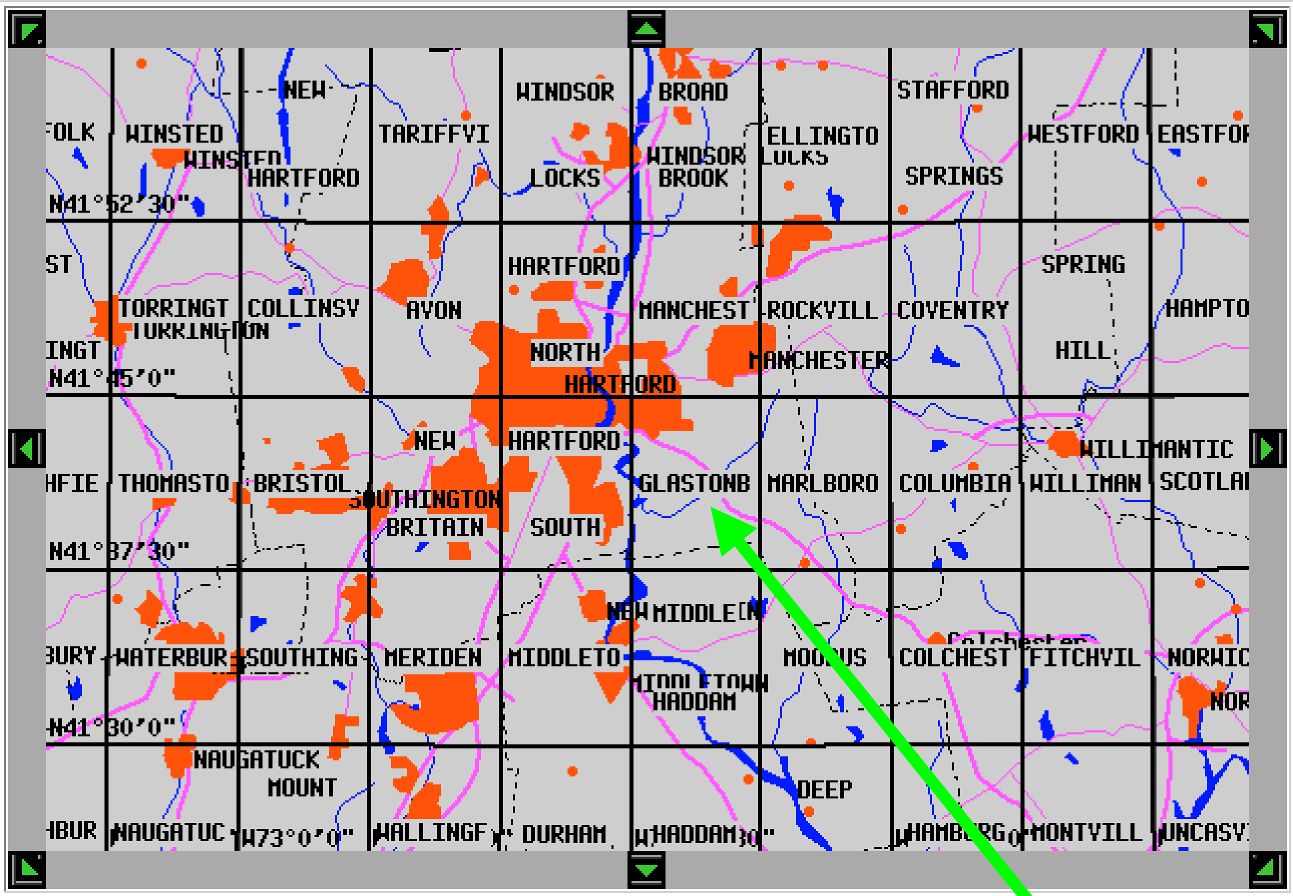
Finding the Right Quads

- To see a map showing nearby quads (for merging), enter by city and state, or by ZIP code at:

http://edc.usgs.gov/Webglis/glisbin/finder_main.pl?dataset_name=MAPS_LARGE

Finding Adjacent Quads

Do not click to enlarge. Clicking within a map quadrangle will add an item to the shopping basket.

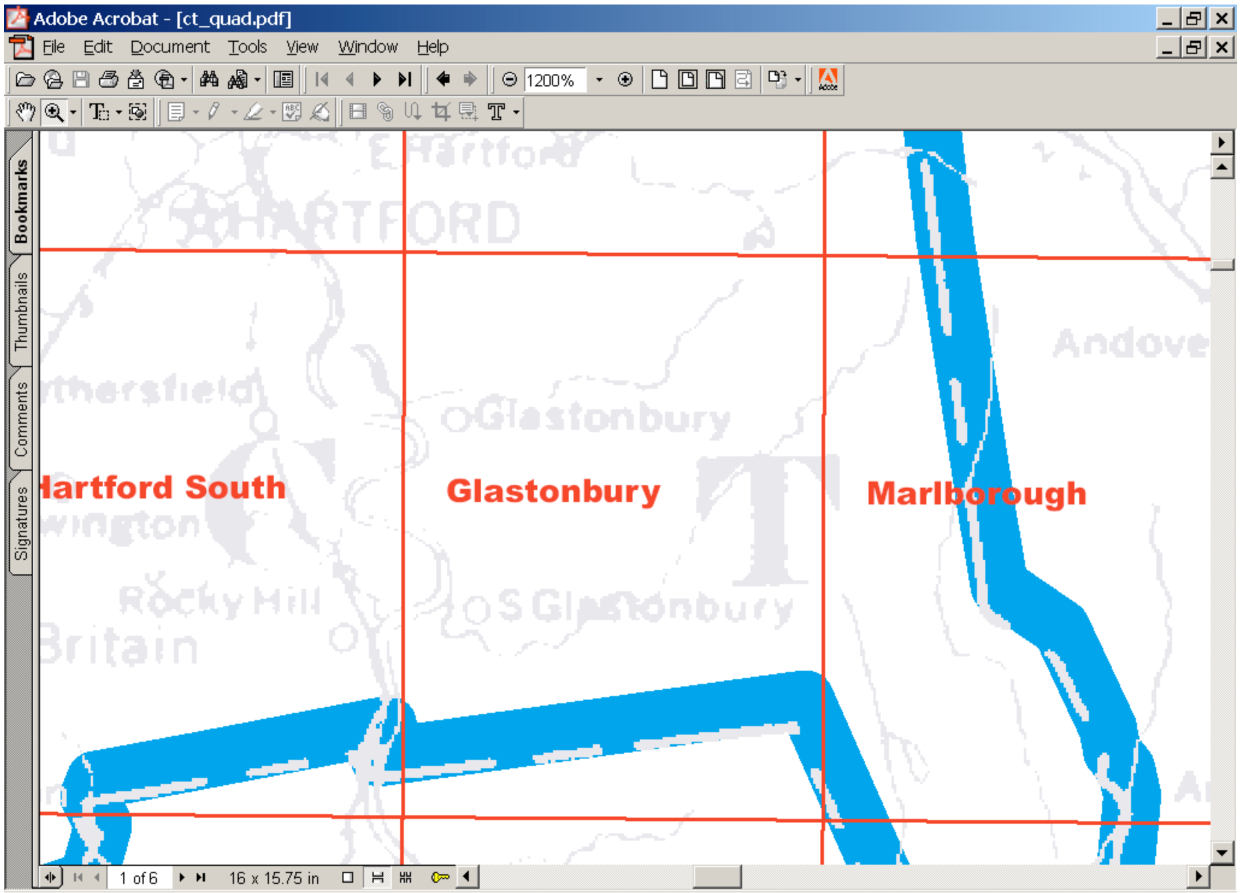


Example: Quad maps surrounding Glastonbury, CT.

Nearby Quads

Another way to find nearby quads is by going to:

http://www.digitaldataservices.com/mapfinder/mapfinder_online.htm



This example zooms in to show county lines and quad names. You can save to a PDF for later referral offline.

Downloading Quads

- You have now identified the quads you may need to “merge” when you make terrain files covering all the azimuths of interest.

- Finally, go to:

http://data.geocomm.com/dem/demdownload.html

and select the state, county, 24K DEM and finally the quad name(s) you need.

- Click on the green download button for free downloads!

Downloading Quads

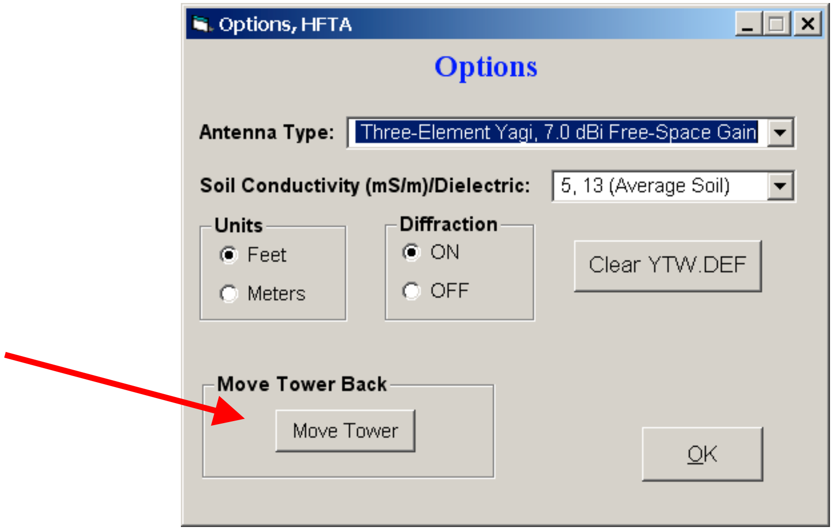
Click here and save to disk

Move Your Tower

• *HFTA* has a new function that allows you to move the base of a tower back along flat ground away from, say, the edge of a cliff.

• You can evaluate the effect of a cliff on the launch angles from your antennas.

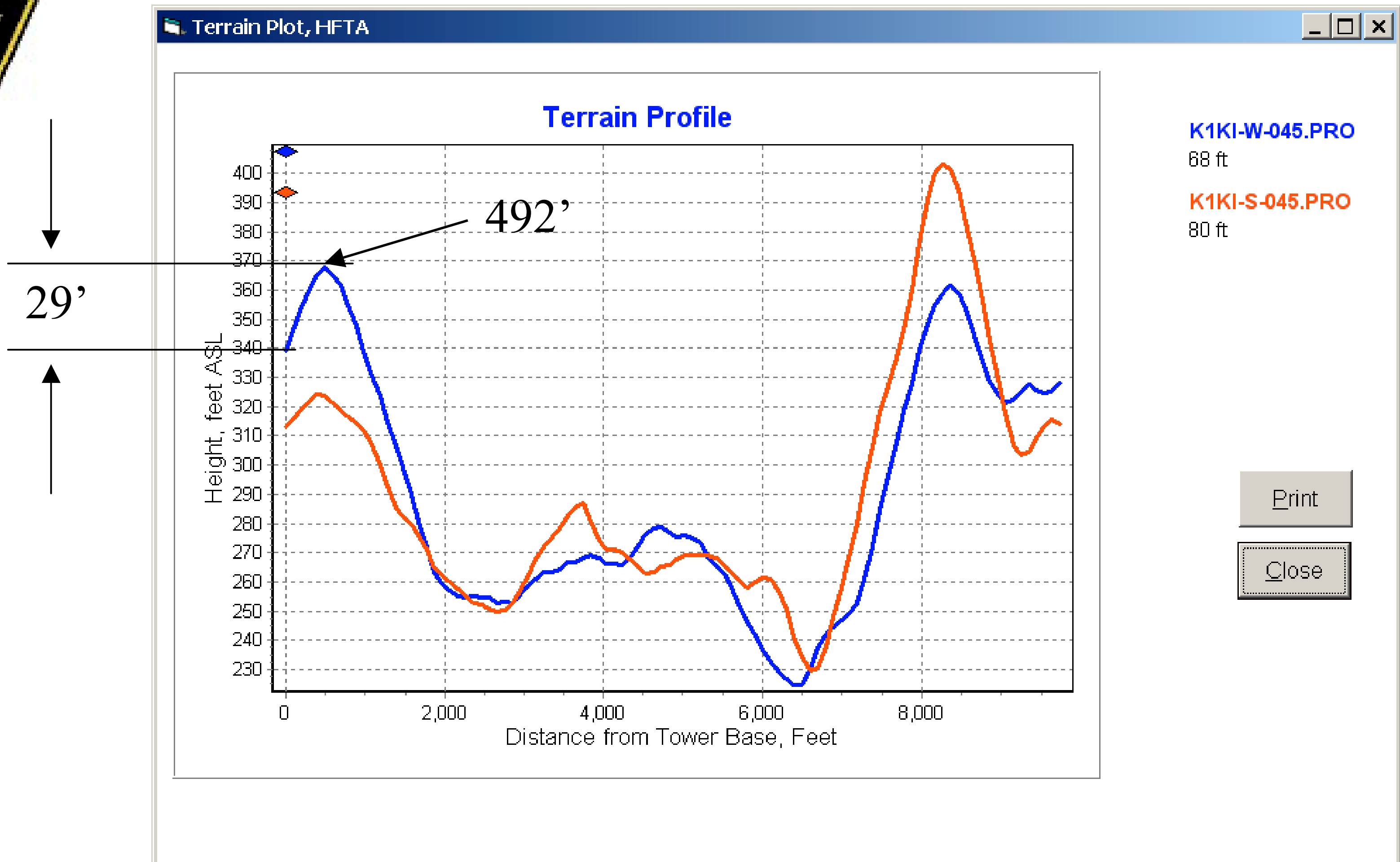
Move Tower button



So Near, Yet so Far

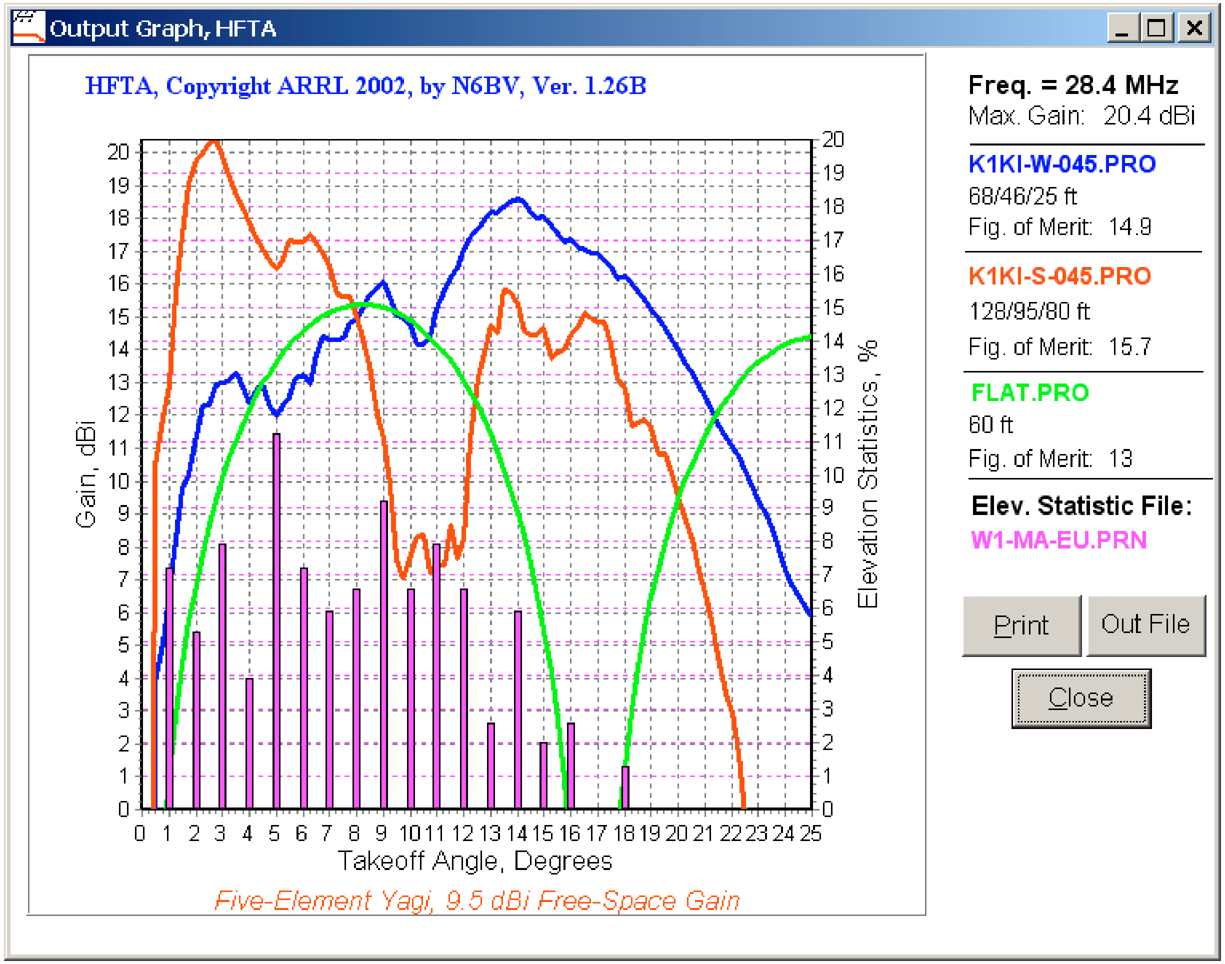
- Something that often amazes me is how two towers located on the same property can have very different terrain profiles.
- Take K1KI's magnificent location on a ridge just south of the Massachusetts border.
- Tom reported that his lower 10-meter Yagis are never as effective as his higher ones -- even well into the opening, when the angles go high. [This started a great thread on the YCCC reflector!]

Very Different Terrain Profiles



K1KI’s West and South Towers, 630’ Away.
Beware, however, of different X- and Y-axis scales.

The Towers are Only 630' Apart



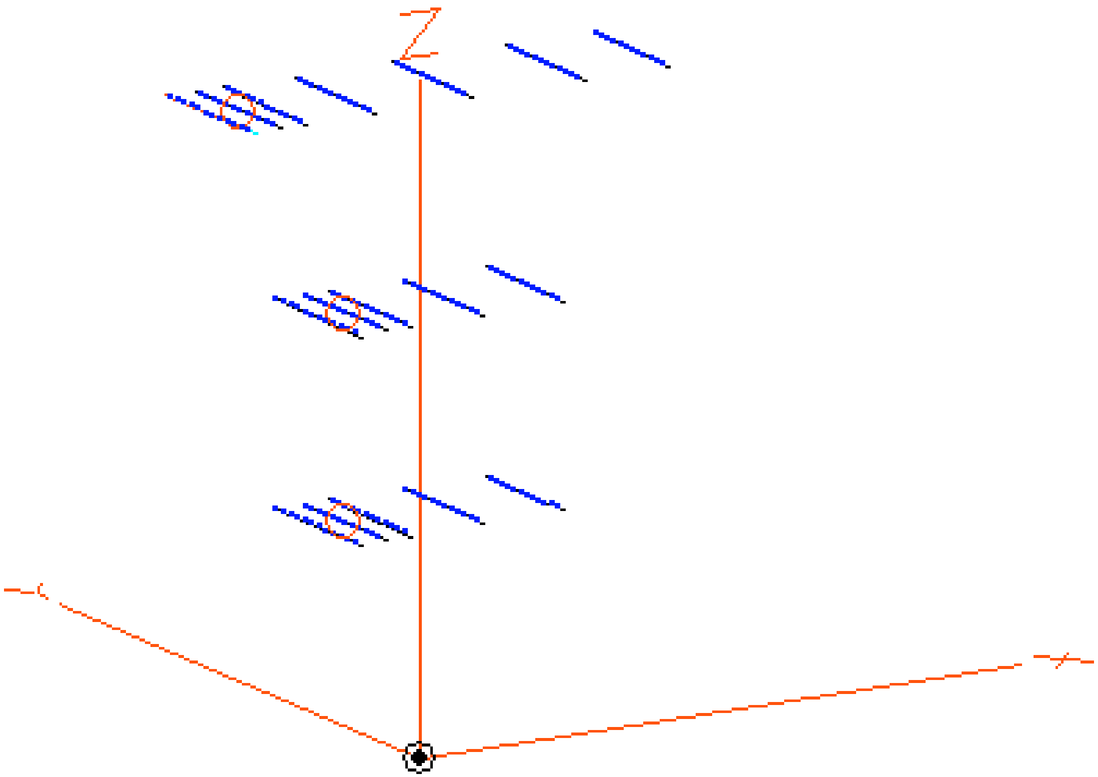
The West tower's Yagi stack (blue) is not as effective as the South tower's high stack (red).

What Happens if You Stack Dissimilar Yagis?

For example, you might stack a 7-element 10-meter beam (48-foot boom) over a pair of 510CA 5-element beams (with 24-foot booms).

What happens when these are fed with equal lengths of coax?

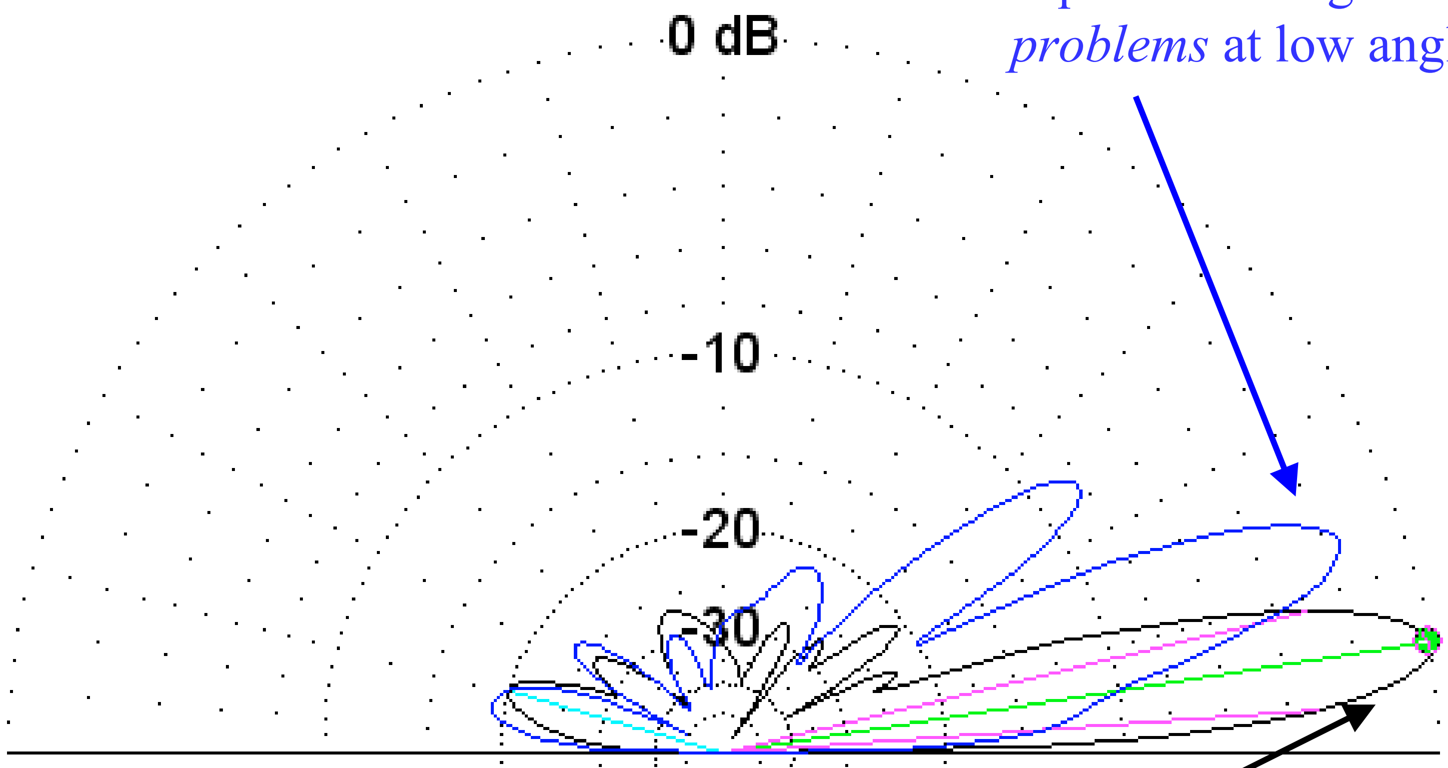
7L10 @ 68'/5L10 @46'/5L10 @25'



The phase center for the 7L10 is different from the two 5L10s.

You May Have a Problem!

Equal coax lengths: *big problems* at low angles



Compensated length of coax to 7L10 beam (+150° phase shift)

Putting It All Together

✓ You need to know the range of elevation angles for full coverage to your target destinations.

✓ You should know how your antennas work under ideal conditions (free space, or flat ground).

✓ Then, you can analyze the effects of irregular local terrain and optimize heights, stacks or tower placement on your property.

Some Useful URLs

- ***MicroDEM*:** **http://www.nadn.navy.mil/Users/oceano/pguth/website/microdem.htm**

- **Find a county: http://quickfacts.census.gov/cgi-bin/lookup?state=36000**

- **Locate nearby quads: http://edc.usgs.gov/Webglis/glisbin/finder_main.pl?dataset_name=MAPS_LARGE or http://www.digitaldataservices.com/mapfinder/mapfinder_online.htm**

- **Download quads: http://data.geocomm.com/dem/demdownload.html**

And Keep Your Perspective!

I’ve got to keep reminding people that it’s very easy to get very involved, even consumed, in antenna modeling and terrain analysis.

If you’re already S9 + 20 dB into Europe, *bulldozing* your terrain to get another 2 dB of gain might result in a S9 + 22 dB signal…That might (or might not) open up another layer of weak Europeans. Hmmm...