Antenna Interactions – Part 3
When Good Aluminum Goes Bad

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Part 1 introduced meta-tools that give a more comprehensive view and statistics about an antenna system's radiation pattern.[2] Part 2 applied those tools to twisted stacked Yagis where the antennas point in different directions, identifying some problem situations that contests may encounter.[3] This part examines self-interactions within a stack and siting problems that may come up in the design of a contesting station.

Note — Many figures are not included in the paper edition of *NCJ*. All figures and a complete copy of this article, as well as animations and software tools, are available from the bonus section of the NCJ website: www.ncjweb.com.

1 Perspective

In an exchange of email triggered by earlier parts in this series, Joe Johnson K3RR reminds all of us that antenna model output patterns cannot be taken literally. One can not run a NEC model, point to the main lobe, and say "If I build this system, I will get +14.3 dBi gain on 20m at this elevation and azimuth." In particular the NEC models assume flat ground of uniform characteristics. The shape and electrical characteristics of the terrain around the station greatly influences the actual radiation patterns. At low elevation angles, a patch of earth a couple of miles away (even on relatively flat terrain) will influence the pattern of high antennas (150 to 200 feet).

The Brian Beezley K6STI TA software[4] and Dean Straw N6BV YT software[5] packages offer a first level of insight into terrain effects on horizontally-polarized antenna systems with a vertical plane of symmetry along the main beam (such as stacked Yagis). However, TA and YT only examine radiation in that one vertical plane along the axis of the main beam. TA and YT consider only the component of slope of the terrain along this one azimuth. For these two reasons TA and YT cannot currently be used to analyze the full sky hemisphere as has been done with NEC4 in these articles. Nevertheless, within these limitations TA and YT have shown that terrain effects on patterns can be quite large: ten dB or more.

Properly designed models save considerable time and expense in designing or optimizing antenna systems for good patterns for the intended application. Real world terrain effects will modulate those patterns – sometimes substantially – but one is better off installing a good design, rather than a mediocre design, over that terrain. And, as tools like TA or YT get better, we may gain more insight about *where* the well-designed antenna system might be located over the available terrain to take advantage of terrain-induced enhancements and avoid terrain-induced impairments.

2 Difference meta-tool

A visual comparison of sky hemisphere pattern maps, such as the animations used in Part 2, yields a qualitative grasp of changes. Spot checks of the raw data provide quantitative numbers for the changes at locations of interest – but digging through many megabytes of data quickly becomes tedious.

An additional meta-tool, NOUDifference (available on the *NCJ* website), subtracts the sky hemisphere patterns of two antennas and displays the resulting difference in gain. Where the second pattern exhibits lower gain, red or, in extreme cases, orange appears in addition to contour lines; for greater gain, green or turquoise appears. (For clarity, color is omitted from the paper edition of the *NCJ;* all figures are available in full color on the website.) Within the target zones and untargeted region, the location and value of the largest increase and decrease in gain are summarized. The median changes in gain for the zones and untargeted region are also included in the statistics tables.

To avoid over-emphasizing changes in signals that are already relatively weak, NOUDifference excludes any differences that occur at levels below a floor of −15 dBi. (Remember, this is −15 dB relative to isotropic. For stacked Yagis under examination here, these parts of the antenna pattern are −25 dB or more below the main beam's peak gain.) If a minor lobe at −20 dBi increases to −16 dBi, that +4 dB increase in gain is ignored by NOUDifference. Similarly, if a minor lobe at −10 dBi drops to −20 dBi, NOUDifference plots only the first −5 dB of that drop. As was pointed out in Part 1, deep pattern nulls are unlikely to be completely realized in actual construction. This approach reduces the likelihood that the viewer's eye will be drawn to large changes in parts of the sky with very weak signals, and similarly avoids skewing the pattern change statistics.

3 Intra-stack interactions

Two and three Yagi stack models used to date have excluded any unfed antennas. Let's examine a stack of three 20m Yagis at K4JA's QTH where only one or two of the antennas are fed. The antennas are identical 6-element OWA designs at 50, 100 and 150 feet. The target zone is Europe.

Figure 1 contains two maps. The top is the pattern when all three Yagis exist, but with the top antenna's drive point current forced to zero.[6] Qualitatively this pattern remains quite clean and very similar to the reference pattern. The middle antenna's drive point impedance has increased very slightly from 28 to 29Ω.

To give a better understanding on interpreting a difference map, let's look at the lower part of the figure in some detail.

The difference statistics for the Europe target zone show a median change of 0 dB; i.e., net minimal effect overall. At some locations in this part of the sky the lower elevation angles drop by –0.4 dB, not operationally significant. At the higher angles of this zone gain has increased by +0.9 dB – again of very minor operational significance.

Elsewhere around the sky, signals at 30-40° elevation angles in the forward direction increase by as much as +4 dB. While a contest operator in New England has little concern with this higher angle forward lobe, DX contesters elsewhere in the USA may wish to minimize these high angle forward lobes – the lobes that deliver other domestic contest signals into their receivers.

Similarly, the rear lobe of this stack has increased +3 dB over the reference pattern. The energy for these increased minor lobes has been provided by a broad reduction of as much as –6 dB in the lobe that points straight up to the zenith. On 20m, the zenith lobe is unlikely to deliver much QRM to the operator as the ionosphere rarely exhibits very high elevation angle short skip propagation at this frequency.

From an operational perspective, compared to the reference, this system is the same towards Europe, with perhaps a bit more sensitivity to local, higher elevation signals. It is still a very clean system.

3.1 Driving the stack

To achieve this particular result the top Yagi drive point current must be forced to zero. This condition requires more than simply disconnecting the coax run for the top Yagi at the stack switch box. The stack feed system also must be designed to present an open circuit *at the center of the driven element*. The matching system (e.g., the gamma, hairpin, or T-match) ***and*** the balun ***and*** the coax to the stack switching system, as well as the switching system itself, must work together to deliver an open circuit condition at the center of the driven element. For example, a choke balun built from a 10-turn coil of coax 25cm in diameter adds 7.85m to the length of the line between the matching system and the switchbox; this length of line must be included when calculating the impedance at the driven element.

What happens when the stack feed system fails to force zero current at the top Yagi drive point – simply disconnecting the coax at the switch box, but not presenting an open circuit at the center of the top Yagi driven element? Depending on the impedance presented at the driven element, parasitic currents induced in the top Yagi by the lower antennas will be somewhat different than the open-circuit case.

For example, Figure 2 has the pattern (top) and difference from the reference case (bottom) with a short-circuited driven element. Surprisingly, the results are quite similar to the open-circuit scenario. Pattern changes within the European zone remain operationally insignificant. The rear lobe impact is the same. The increase in forward higher angle lobes is a few dB less than the open-circuit scenario. One could argue the short-circuit drive point is a marginally better scenario than the open-circuit case.

3.2 Twisting the unused antenna

In an effort to mitigate the already small parasitic effects from the top Yagi, in Figure 3 the top Yagi is twisted 90° off to the left. Figure 3's difference map demonstrates the twisted, short-circuited top Yagi no longer interacts with the two driven lower Yagis in any meaningful way. In Figure 4 the unused top Yagi feed point is open circuited (zero current); parasitic interactions remain insignificant at ±1 dB worst case.

The NCJ website contains an animation in which the unused, short-circuited top Yagi is incrementally twisted away in 10° azimuth steps until it points in the opposite direction, a scenario illustrated in Figure 5. Parasitic interactions in the Europe zone remain operationally insignificant. The rear lobe is down about –4 dB. Other minor lobes at higher takeoff angles increase by as much as +6 dB.

3.3 Bottom only

Figure 6 shows the pattern of the 3-Yagi stack with only the bottom antenna driven. The middle and top antennas are forced to have zero current at their drive points; e.g., open-circuit feedpoint impedance. The drive point impedance for the bottom antenna changes less than 1Ω, compared to the reference case of a single Yagi (with no other antennas). But parasitic interactions modify minor lobes by –9 to +7 dB. Within the Europe target zone, gain has decreased by a median amount of -½dB, which isn't operationally significant. Gain is down –1.6 dB at the bottom corners of the target zone.

When the unused Yagi drive points are short-circuited, parasitic impact on the pattern in the Europe target zone falls by more than half to insignificant levels. Minor lobes elsewhere are still affected by –10 to +7 dB.

Again the rear low elevation angles increase by as much as +7 dB at some lower elevation angles. The deterioration of the rear lobe will not be welcomed by an east coast contester trying to ignore the western USA competitors off the back of his antenna. (Don't be distracted by the –6 dB drop in rear lobe pattern between 30-40° elevation angles. The reference antenna pattern was already a weak –8 to –15 dBi in this region.)

By now we are unsurprised to see in Figure 8 that rotating the unused top and middle antenna 90° reduces parasitic interactions to negligible levels.

3.4 Conclusions

The contest station designer and operator of a stacked Yagi system should be aware of the following:

- Disengaging the unused Yagi of a 3-Yagi stack with a feed system that presents either a short- or open-circuit at the center of the driven element does not introduce operationally significant impairments to the main beam of the remaining fed antenna(s).
- Choosing short-circuit drive point impedances on the unused antennas reduces the minor parasitic interactions with the main beam by half.
- Other parasitic interactions with the minor lobes range from –10 to +7 dB. For the case where only the top antenna is unused, these parasitic interactions may be cut in half by short-circuiting the top driven element feed point.
- All parasitic interactions can be minimized to no worse than ±1 dB by rotating the unused Yagi(s) 90° in azimuth with either a short- or open-circuit unused drive points.
- Presenting a short or open to the unused drive point requires a stack switching and feed design that takes into account the driven element matching system, balun and coax lines between the switchbox and the antennas.
- Despite intra-stack parasitic interactions, the radiation patterns remain clean. The main and minor lobes are smooth.

4 Intra-site interactions

Paul K4JA has graciously provided details of his extensive antenna farm to illustrate the meta-tools and explore stack Yagi design issues. In Figure 9 K4JA's complete 20m antenna farm has been modeled. The three-stack of 6-element OWA Yagis that we have been examining in these articles has now been rotated to face South America. The South America target zone for a station in the Washington DC area has been set to contain elevations up to 24° for undisturbed conditions. In order to fill the target, only the bottom two antennas are fed (equal currents in phase); the top Yagi of the stack is unused and open-circuited at the drive point. A quick glance at the figure shows a very messy pattern! Within the target zone, the main beam varies by more than ±4 dB from the reference case. Outside the target zone deviations of over ±14 dB exist on all the minor lobes. The rear lobe is especially bad, up over +9 dB at many points exposed to higher-angle short skip QRM. At lower angles the rear show shows +3 dBi gain at low angles, just 12 dB below the main lobe.

What's wrong here?

K4JA's station includes two more 20m Yagis on a tower 385 ft from the 20m stack, in the direction of South America. At 130 ft height is the station's multiplier chasing antenna: another 6-element OWA Yagi on a 48 ft boom. At 91 ft a 5-element Yagi on a 36 ft boom is fixed on South America. In the model these two Yagis are unused, with their drive point currents forced to zero (open circuit) and the multiplier antenna points to 340° azimuth, towards the 20m stack. Despite the 5½λ separation between the 20m stack and the multiplier/South America Yagis, significant undesired parasitic interaction occurs when the stack is pointed to South America, producing this messy result.

Despite interaction between these antennas, the drive point impedances of the two lower antennas have changed by only small amounts. The middle Yagi drive point impedance increased by 1Ω compared the reference case, and the low Yagi's impedance has increased by just 4Ω. Some people think a dramatic change in impedance is indicative of an interaction problem. While that can be true, here is one scenario where antenna interactions are occurring with only a very slight impedance variation.

In Part 4, we will examine intra-site interactions more systematically, and discuss steps to minimize the impact of other antennas at the station.

Annex I — Meta-tools for comparing patterns

This annex discusses the meta-tools used to compare antenna patterns. These tools are available on the *NCJ* website.

I.1 NOUDifference.bat

This batch file produces a full sky-hemisphere map of the difference between two antenna patterns and related statistics. It takes as input the .AEG files created by NOUTrim (discussed in the Annex II to part 1 of this series). The .AEG file contains azimuth, elevation, and gain values in ASCII text, one set of values per line.

NOUDifference.bat calls the GAWK program NOUDifference.awk (discussed below) to subtract the patterns. The difference in gain is recorded in a temporary file Difference.AEG. NOUDifference.awk also creates a special temporary file called a "mask" in FloorMask.xy. This file indicates each location in the sky hemisphere where both antenna patterns had gains below −15 dBi. Variations in gain at these weak signal levels are assumed to be relatively unimportant to the overall picture; the difference in the patterns in these areas is forced to be 0 dB.

Generic Mapping Tools (GMT) were introduced in Annex II of part 1 in this series. At this point NOUDifference.bat applies GMT utilities to generate the map:

- *gmtconvert* is used to convert the Difference.AEG and FloorMask.xy files into binary form for faster processing.
- *blockmedian* and *surface* interpolate the data to be mapped into an even grid of 1x1°.
- Because of the mathematical characteristics of the interpolation scheme, some areas with zero values will be disturbed into small values just above and below zero. *grdmask* creates a mask (based on FloorMask) which is then used by *grdmath* to force these areas back to zero.
- *grdview* then colors the map using the color spectrum specified in the file DeltadB.cpt. The color spectrum is designed to show white wherever there is no difference in gain between the two patterns. For areas where the second antenna pattern has increased gain, the color gradually fades in from white to a pale green tint by +1 dB… to half intensity green by +3 dB… to full intensity green at +9 dB… and then to teal of deepening hue for larger gain increases. Similarly areas with decreased gain develop a pale red tint at −1 dB… pink at −3 dB… full red at −9 dB… and then shifting to orange and darkening for further decrease in gain.
- *gmtcontour* draws solid contour lines on the map for areas of increased gain, beginning at +1 dB, and dotted contour lines for areas of decreased gain, beginning at −1 dB.
- *psscale* annotates the upper right corner of the map with the color bar defined by DeltadB_scale.cpt. This is the same color scale as DeltadB.cpt but clipped at ±21 dB.
- *psxy* and *pstext* draw and label the boxes below the map that show the azimuth ranges for the continents, and label the azimuths and elevations at the edges of the map.

Now the GAWK file target.awk is used to convert the specification of the target zones (contained in target.xy) into a two target description files target1.xy and target2.xy. More GMT processing follows:

- *psxy* plots the borders of the two target areas with a gray pen.
- *pstext* annotates the map with the information in the comment cards of the two NEC files which generated the two antenna patterns. This annotation is placed under the map as a left and a center column for the first and second pattern, respectively.

The GAWK file AEGBin.awk then sorts the pattern difference data into three groups: points lying within target zone #1, points lying outside of target zone #1 but inside target zone #2 (if defined), and points lying outside either target zone. Statistics are calculated for each group and reported, as ASCII text, in the temporary output file Difference.dat. AEGBin.awk is discussed in more detail below.

GMT's *pstext* then writes the statistics in the right column under the map.

Finally the temporary files are deleted.

I.2 NOUDifference.awk

This GAWK program begins by loading up memory with the pattern gain of the first antenna at each point in the sky. Any locations with a gain below -15 dBi, the floor value used for these analyses, are forced to −15 dBi.

It expects that the second antenna pattern will contain a data point at the same locations in the sky. Each data point in the second pattern is checked to verify that it is at the same location as the corresponding point in the first pattern. An error message is generated if this is not the case and the program aborts.

One of the responsibilities of NOUDifference.awk is to generate a mask for GMT around those areas of the sky where both antenna patterns have gains below −15 dBi. A mask is a polygon whose vertices are given as couplets of azimuth and elevation. For convenience in processing, NOUDifference.awk generates rectangular polygons, with each rectangle covering one row of elevation data. GMT barfs if polygons cross either North or South azimuth, so NOUDifference.awk tests for the rectangles crossing these azimuths and breaks each such rectangle into two adjacent rectangles.

The difference between the pattern gains at a point in the sky is calculated as follows:

- If both gains are below −15 dBi, the difference is 0.0 dB.
- If the first pattern's gain is above −15 dBi but the second pattern's gain is below −15 dBi, the difference is −15 dBi minus the first pattern's gain. For example, if the first pattern's gain was −3.7 dBi and the second pattern's gain was −21.2 dBi, the difference will be −11.3 dB.
- Similarly, if the first pattern's gain is below −15 dBi but the second pattern's gain is above −15 dBi, the difference is the second pattern's gain minus −15 dBi. For example, if the first pattern's gain was −22.0 dBi and the second pattern's gain was −8.0 dBi, the difference will be +7.0 dBi.
- If both patterns have gain above −15 dBi, the difference is the second pattern's gain minus the first pattern's gain. For example, if the first pattern's gain was +3.2 dBi and the second pattern's gain was +5.8 dBi, then the difference will be +2.6 dB.

I.3 Target.awk

Target.awk is a relatively straightforward GAWK program that reads the target.xy file (which specifies the name, azimuth range and elevation range of the two target zones; see Part 1 Annex II for details). A separate file is created giving the rectangle corners' azimuth and elevations for each target zone: Target1.xy and Target2.xy. If one target zone is not defined, a dummy rectangle of zero size is created as a placeholder for Target2.xy. If the rectangle straddles North or South azimuth, it is broken into two rectangles to avoid GMT processing problems.

Two other files, targethorizontal.xy and targetvertical.xy, are created with descriptions of the horizontal lines and vertical lines used to draw the target rectangle boundaries on the maps.

I.4 AEGBin.awk

This GAWK program bins the gain difference data into three groups: points falling in target zone #1, points outside of target #1 but inside target #2, and points not located inside either target zone.

The value and location of the largest increase and decrease in gain within each of these three data sets are identified. These values and locations are written out to the Difference.dat file.

The median value within each data set is also determined and written out to the Difference.dat file. The algorithm for calculating the median is essentially identical to that used in NOUTrim.awk, described in Part 1 Annex II in this series.

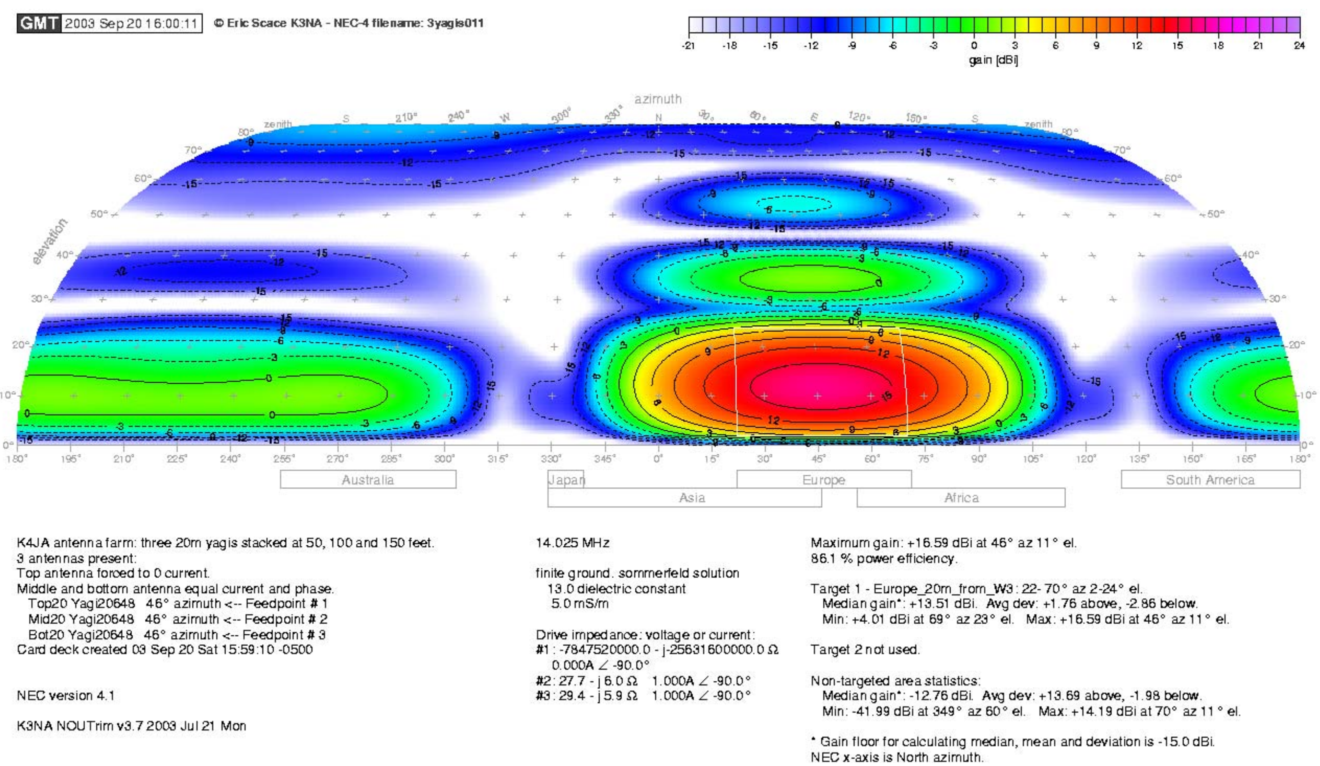
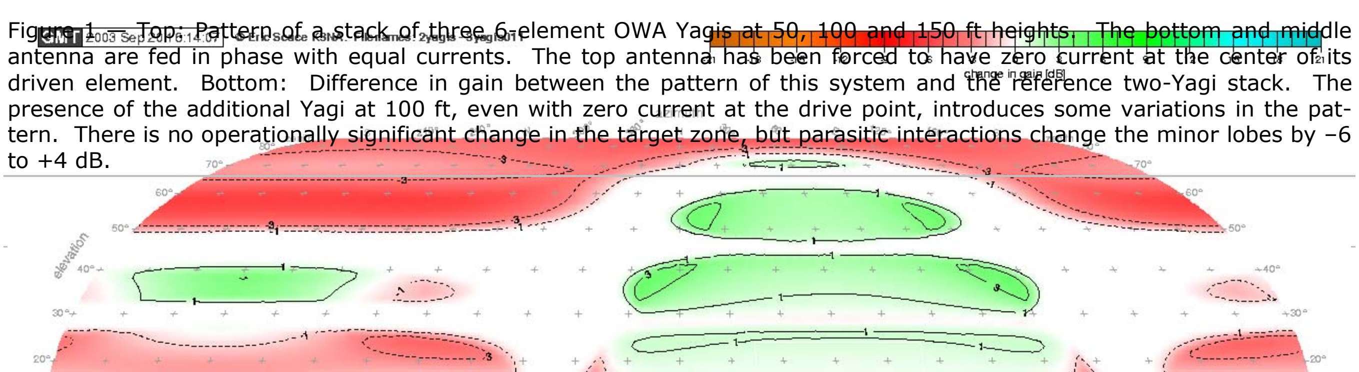


Figure 1 — Top: Pattern of a stack of three 6-element OWA Yagis at 50, 100 and 150 ft heights. The bottom and middle antenna are fed in phase with equal currents. The top antenna has been forced to have zero current at the center of its driven element. Bottom: Difference in gain between the pattern of this system and the reference two-Yagi stack. The presence of the additional Yagi at 100 ft, even with zero current at the drive point, introduces some variations in the pattern. There is no operationally significant change in the target zone, but parasitic interactions change the minor lobes by –6 to +4 dB.



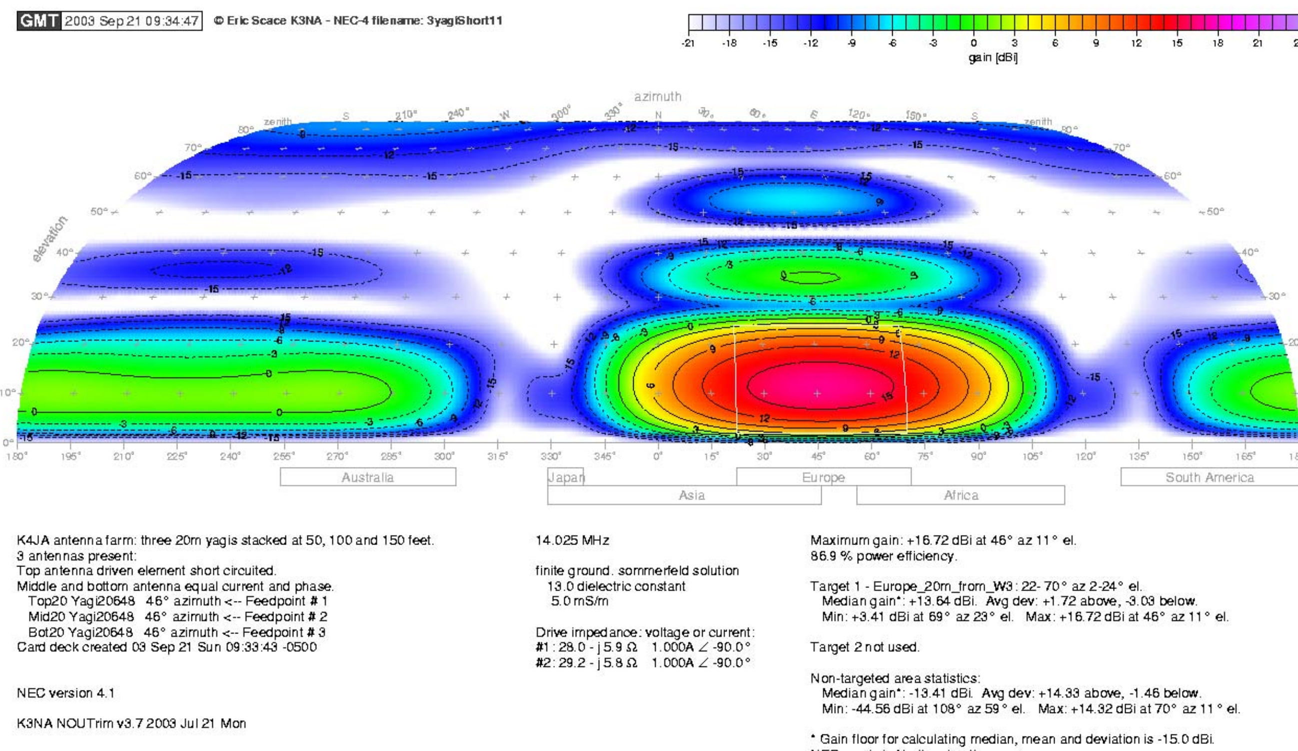
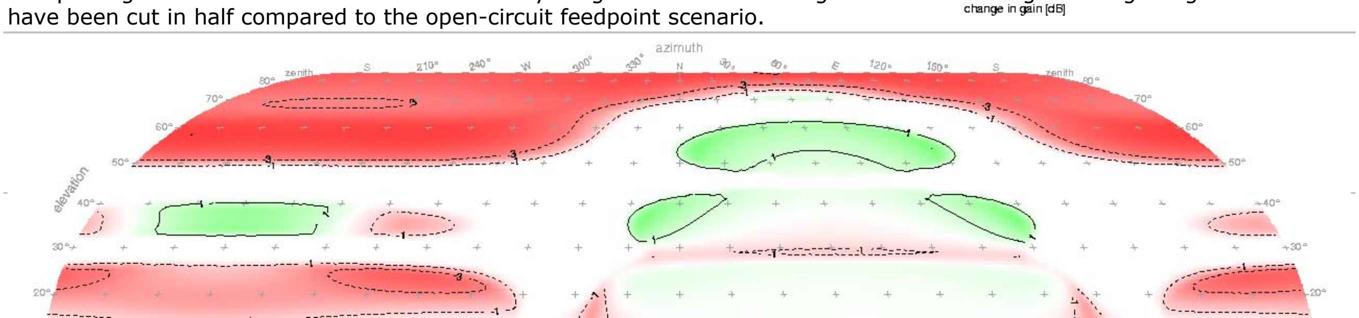


Figure 2 — Same as Figure 1 except the top Yagi driven element feedpoint is short circuited. Parasitic interactions in the Europe target zone are even less that the already insignificant values of Figure 1. Increased gain in high angle minor lobes have been cut in half compared to the open-circuit feedpoint scenario.



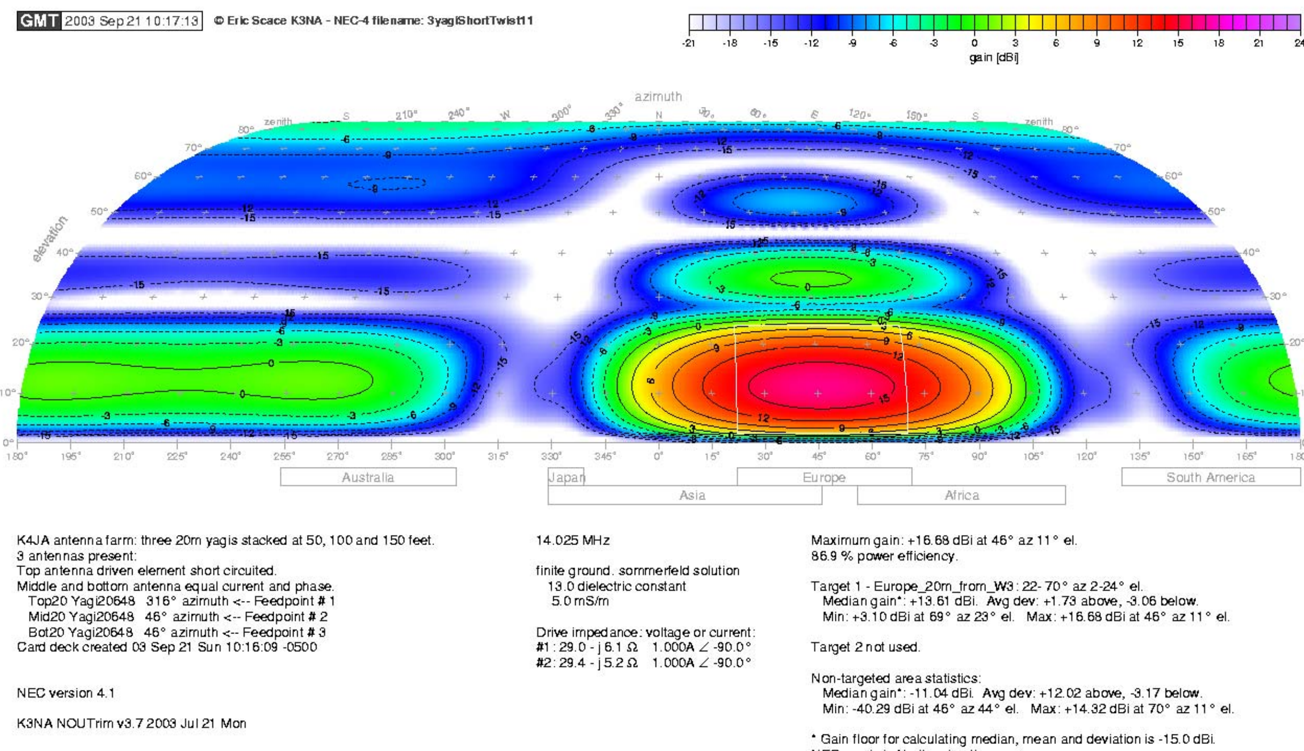
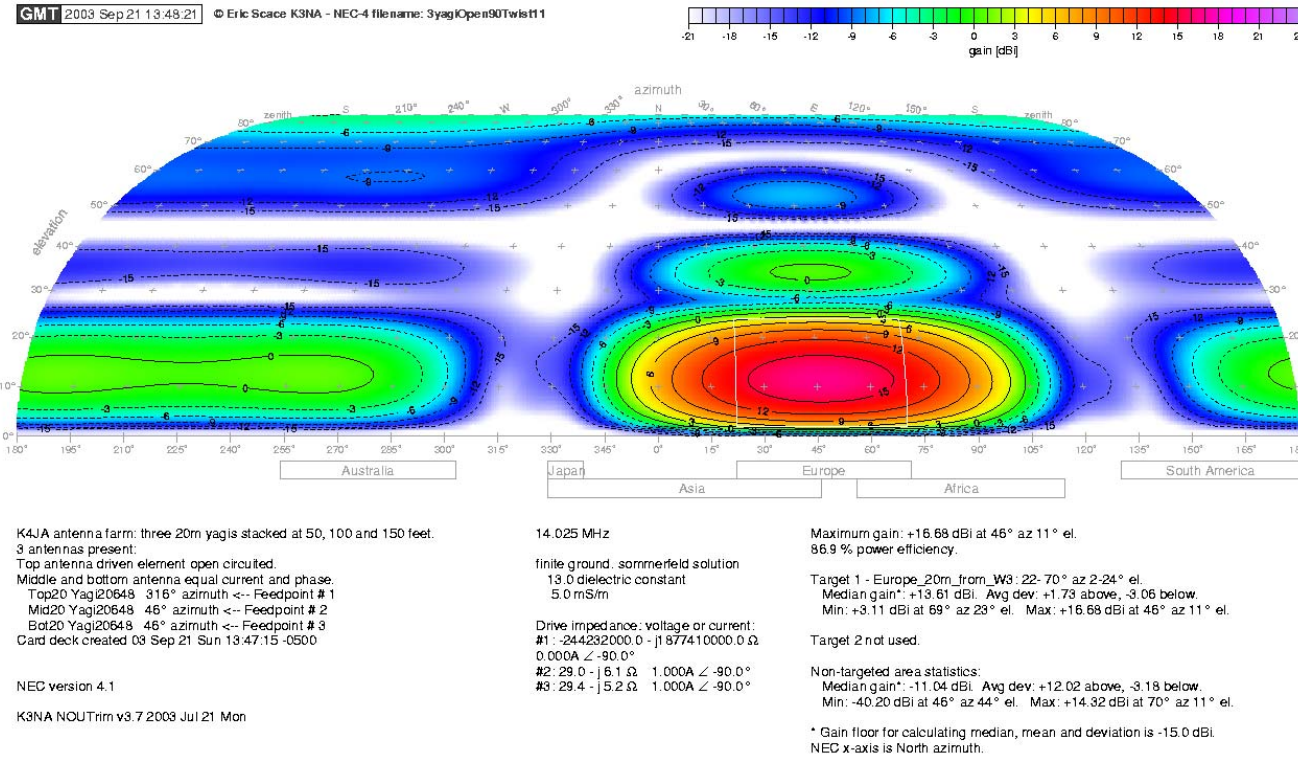


Figure 3 — Same as Figure 2, except the unused, short-circuited top Yagi has been twisted 90° to the left. All parasitic interactions have been reduced to <=1 dB. Within the Europe target zone parasitic interactions are zero.



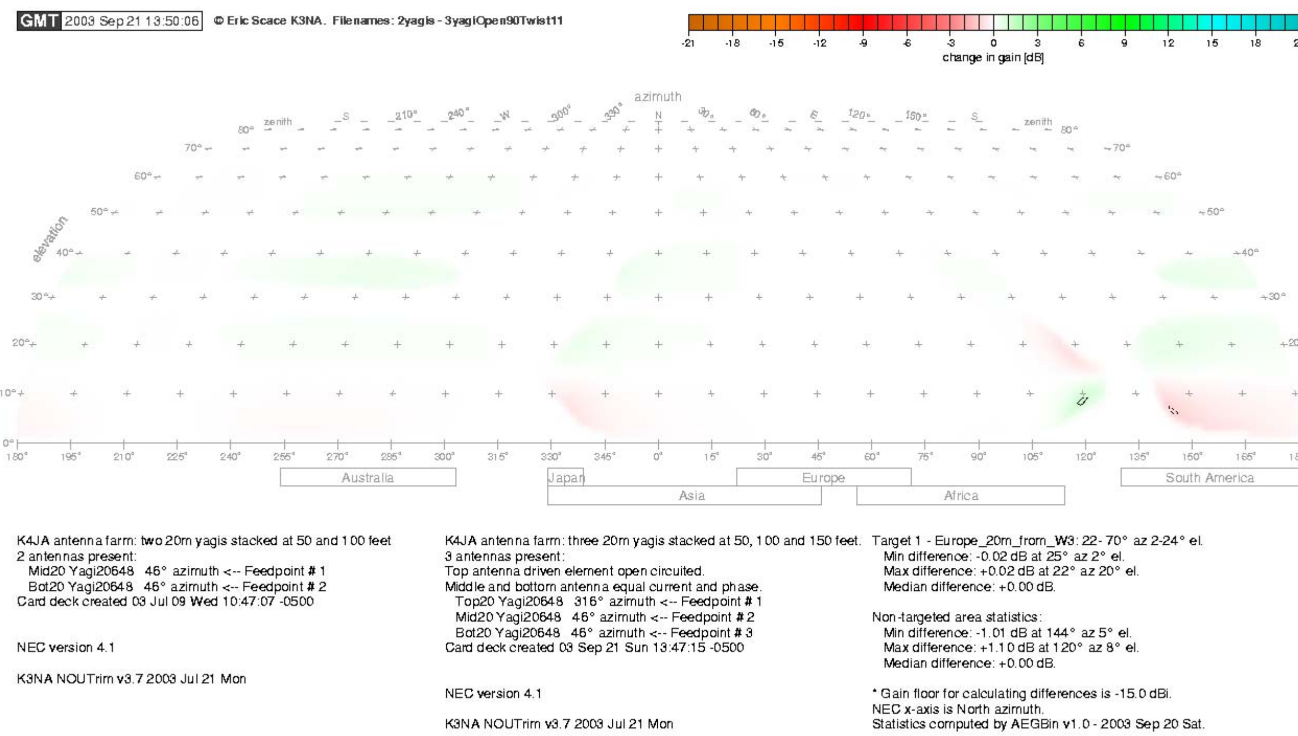


Figure 4 — Same as Figure 3 except the unused top Yagi driven element feed point is an open-circuit (zero current).

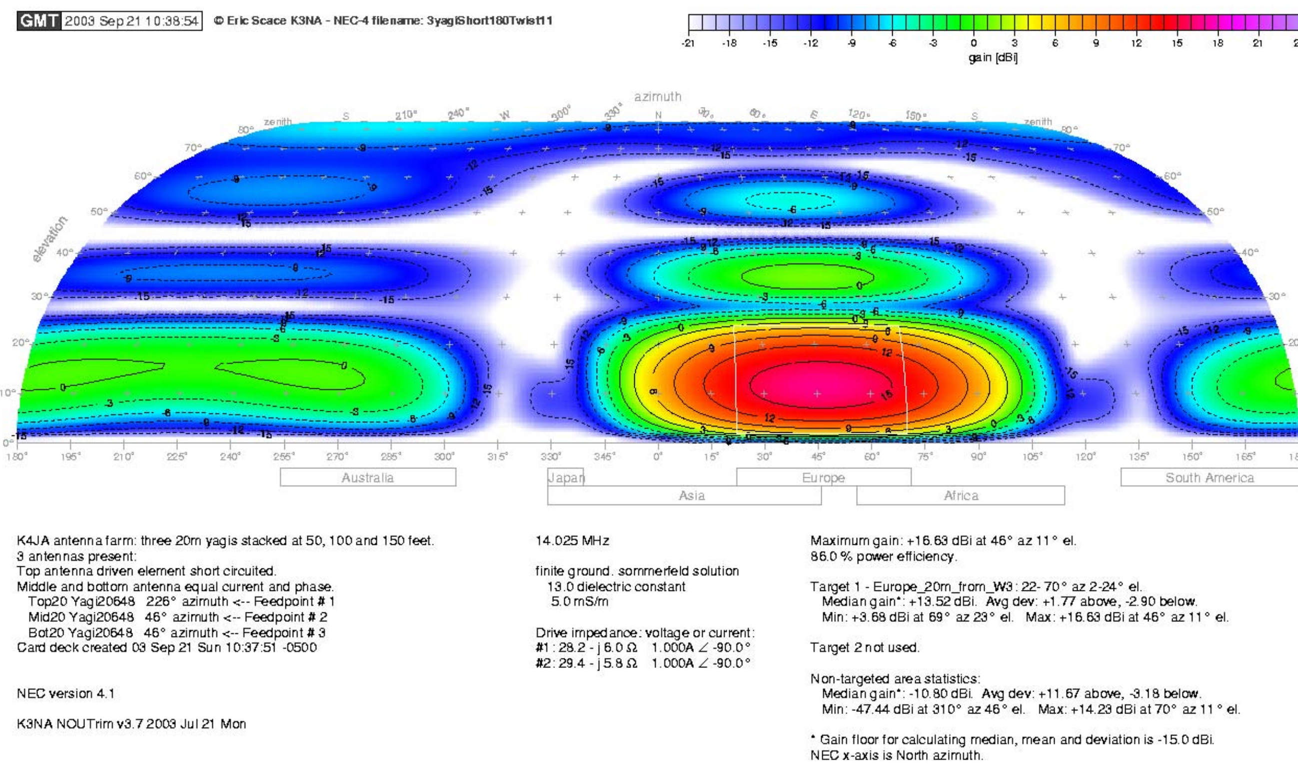
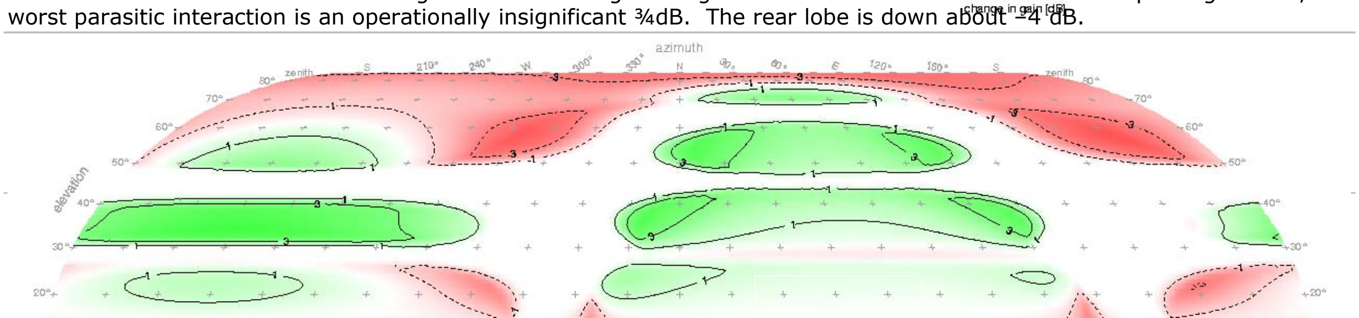


Figure 5 — Same as Figure 2, except the unused, short-circuited top Yagi has been twisted 180° to point in the opposite direction. Parasitic interactions at higher elevation angles range from –5 to +5 dB. Within the Europe target zone, the worst parasitic interaction is an operationally insignificant ¾dB. The rear lobe is down about –4 dB.



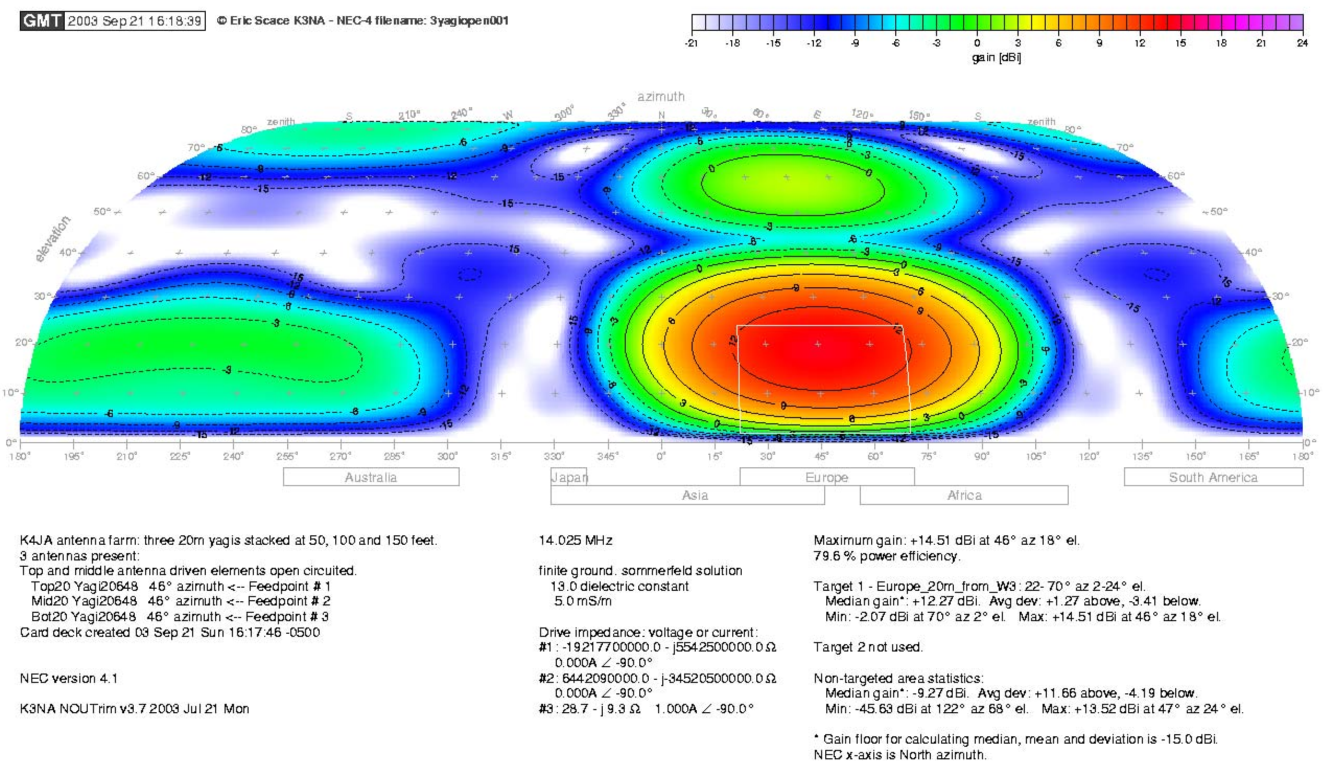
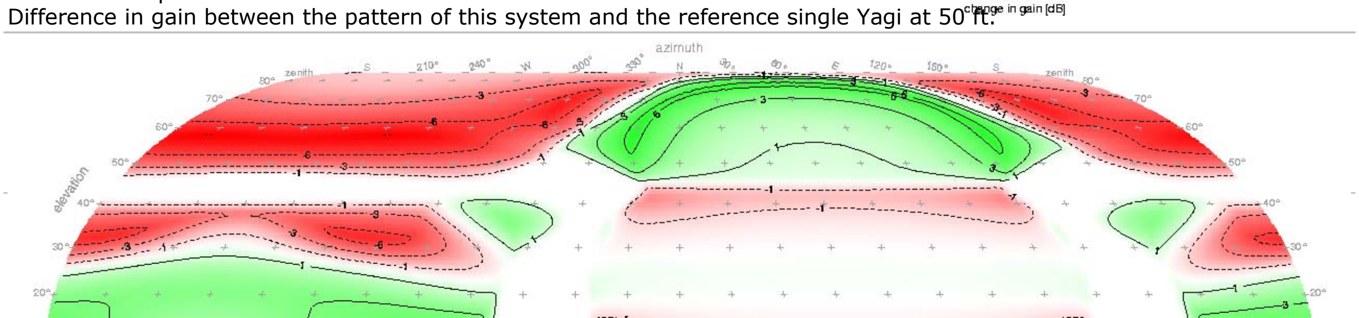
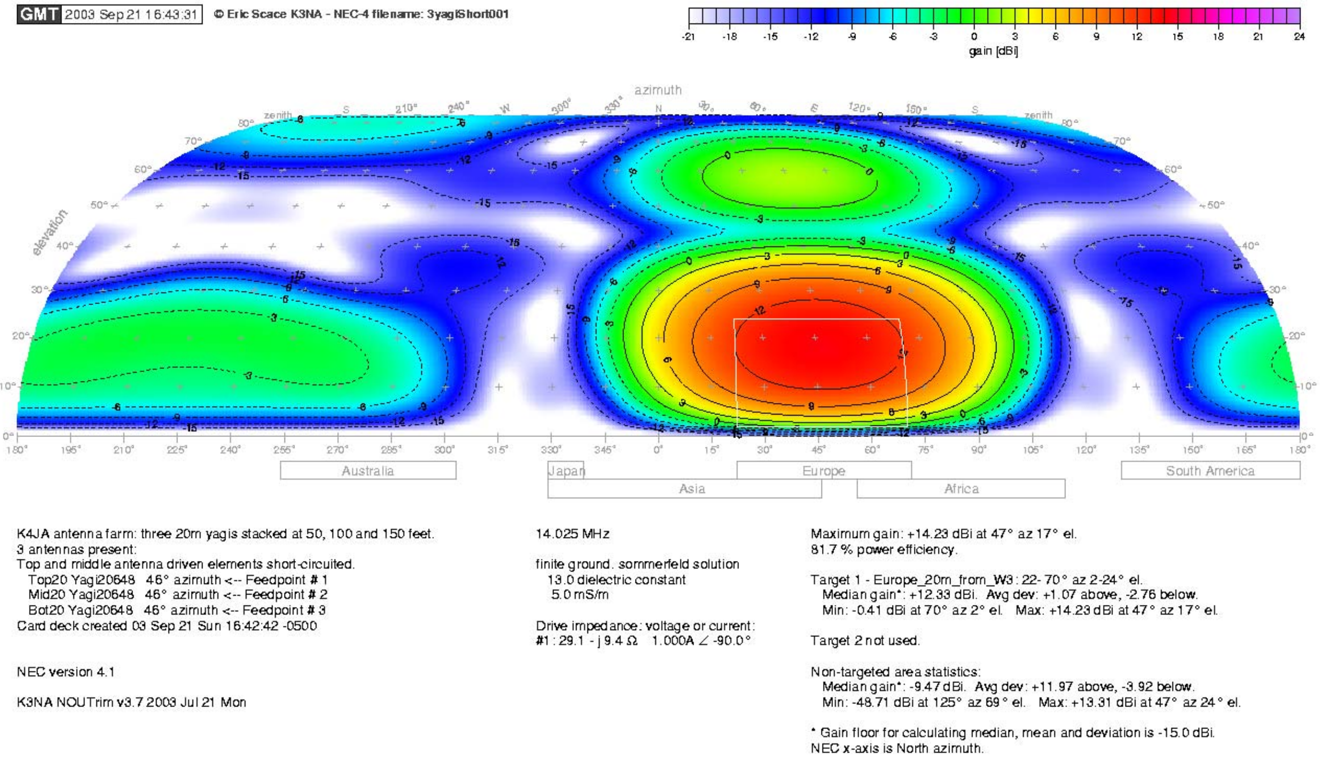


Figure 6 — Top: Pattern of a stack of three 6-element OWA Yagis at 50, 100 and 150 ft heights. Only the bottom antenna is fed. The top and middle antennas have been forced to have zero current at the center of their driven elements. Bottom: Difference in gain between the pattern of this system and the reference single Yagi at 50 ft.





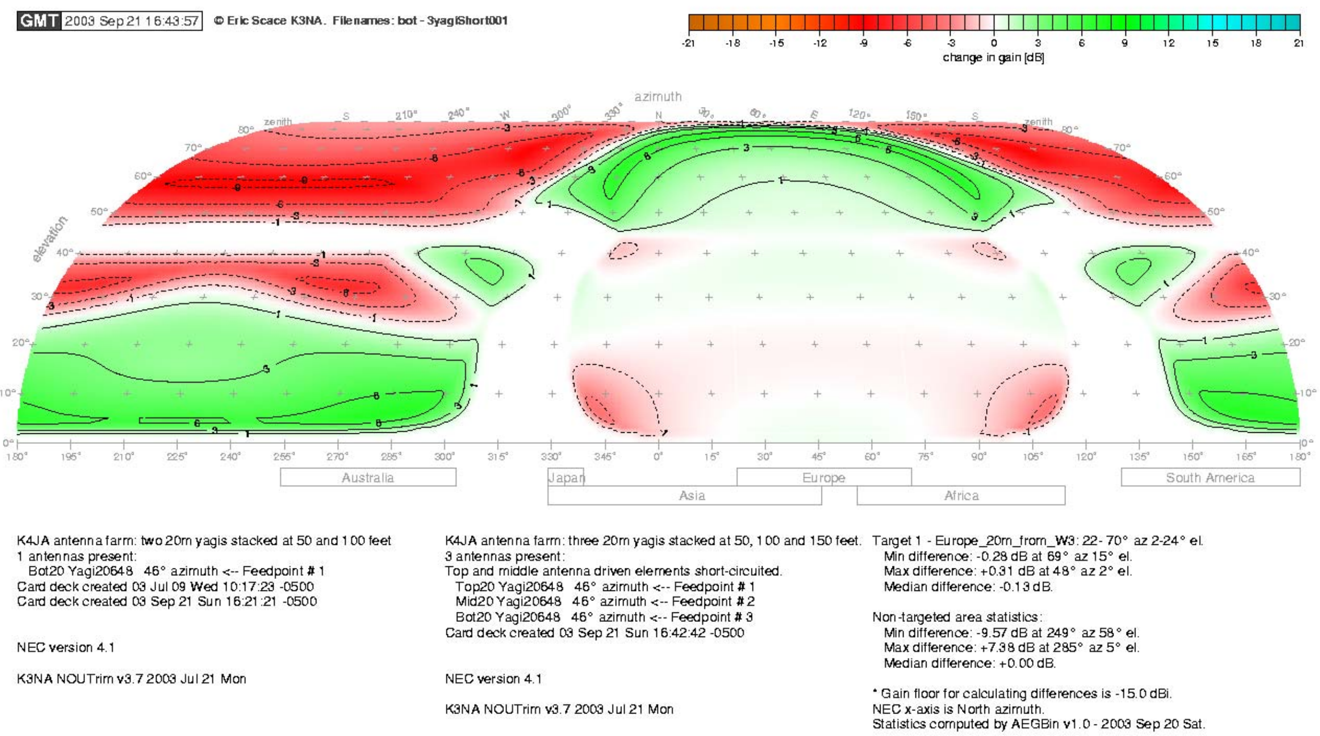


Figure 7 — Same as Figure 6 except top and middle driven elements are short-circuited at their drive points

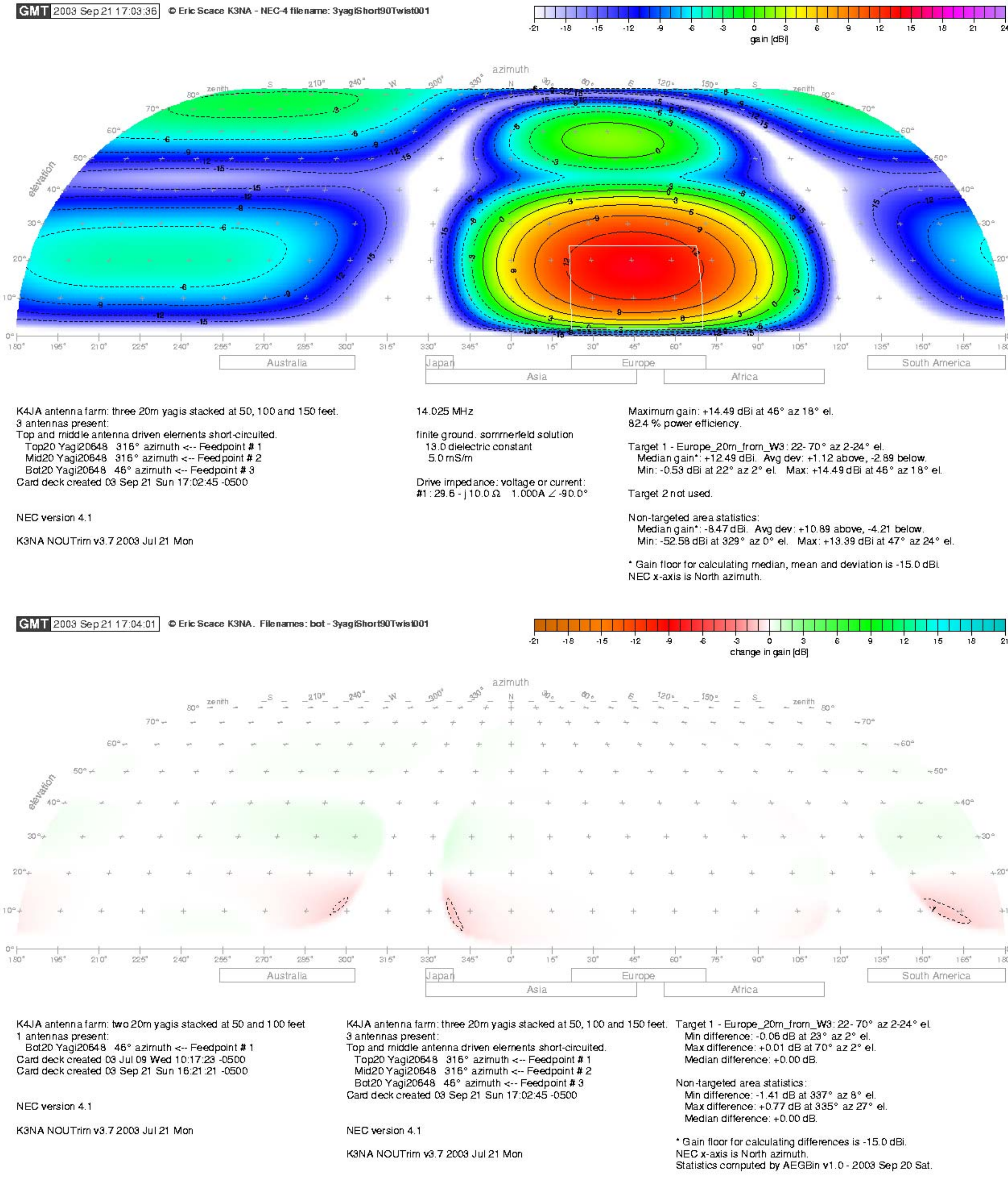
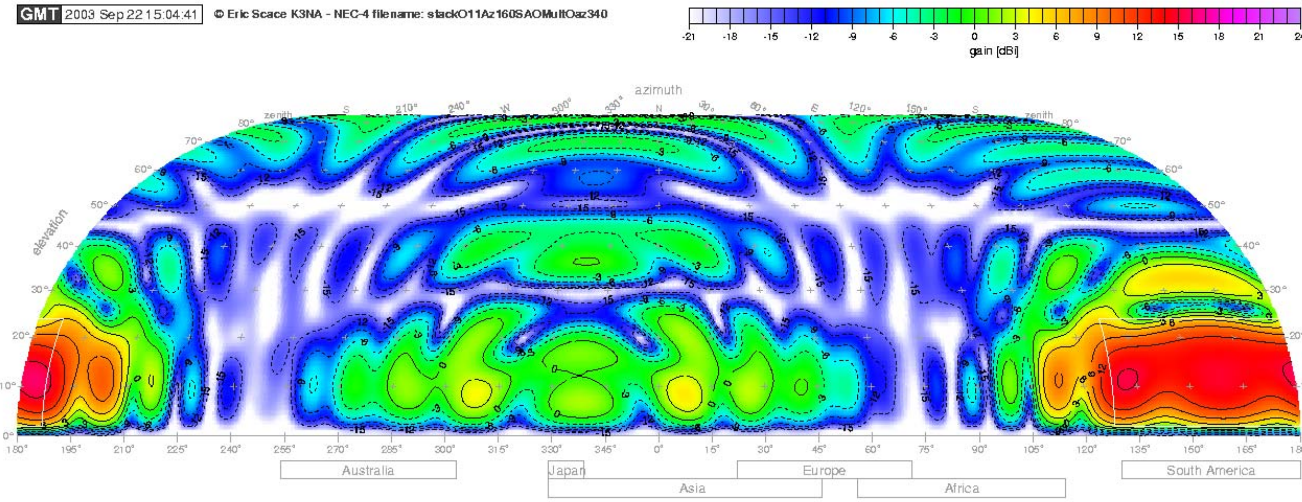


Figure 8 — Same as Figure 7 except the unused top and middle antennas have been twisted 90° to the left.



K4JA antenna farm: three 20m yagis stacked at 50, 100 and 150 feet.
5 antennas present:
Stack middle + bottom fed.
Other antennas open-circuit at drive points.
Top20 Yagi20648 160° azimuth <-- Feedpoint # 1
Mid20 Yagi20648 160° azimuth <-- Feedpoint # 2
Bot20 Yagi20648 160° azimuth <-- Feedpoint # 3
Mult20 Yagi20648 340° azimuth <-- Feedpoint # 4
SA20 Yagi20536 155° azimuth <-- Feedpoint # 5
Card deck created 03 Sep 22 Mon 15:03:19 -0500

NEC version 4.1

K3NA NOUTrim v3.7 2003 Jul 21 Mon

14.025 MHz

finite ground. sommerfeld solution
13.0 dielectric constant
5.0 mS/m

Drive impedance: voltage or current:
#1: -537323000 0.0 - j-46467000000.0 Ω 0.000A ∠ -90.0°
#2: 28.1 - j 6.1 Ω 1.000A ∠ -90.0°
#3: 33.0 - j 5.7 Ω 1.000A ∠ -90.0°
#4: -130602000000.0 - j53145900000.0 Ω 0.000A ∠ -90.0°
#5: -7935240000.0 - j-14852100000.0 Ω 0.000A ∠ -90.0°

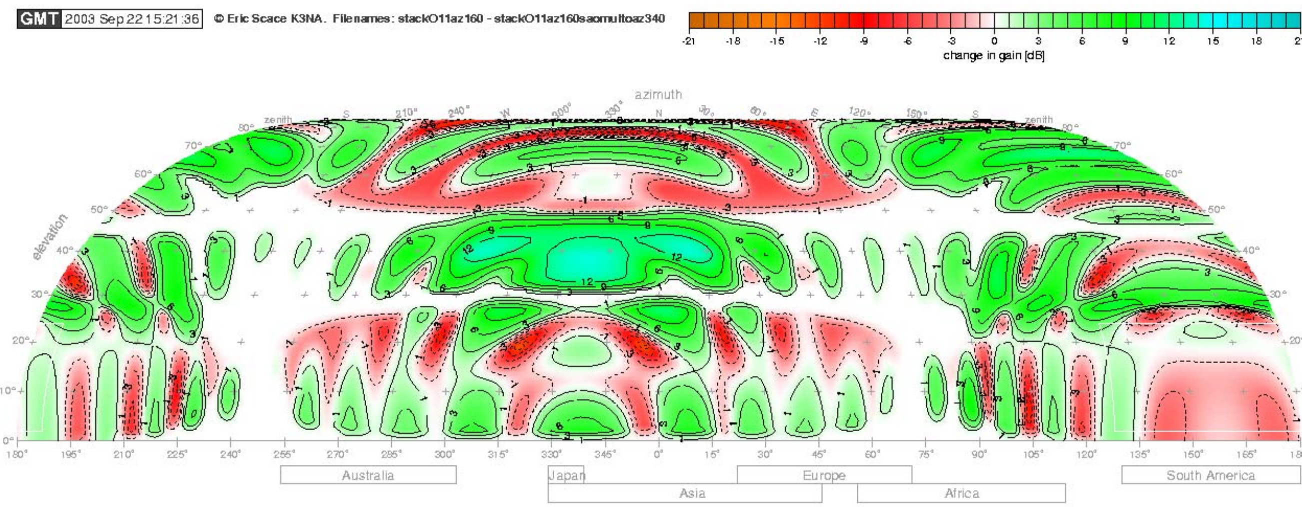
Maximum gain: +16.06 dBi at 183° az 11° el.
82.9 % power efficiency.

Target 1 - SouthAmerica_20m_from_W3: 128-187° az 2-24° el.
Median gain*: +12.58 dBi. Avg dev: +1.58 above, -2.99 below.
Min: +0.59 dBi at 140° az 23° el. Max: +16.06 dBi at 183° az 11° el.

Target 2 not used.

Non-targeted area statistics:
Median gain*: -8.57 dBi. Avg dev: +9.37 above, -4.05 below.
Min: -48.87 dBi at 234° az 0° el. Max: +15.52 dBi at 187° az 10° el.

* Gain floor for calculating median, mean and deviation is -15.0 dBi.
NEC x-axis is North azimuth.



K4JA antenna farm: three 20m yagis stacked at 50, 100 and 150 feet.
2 antennas present:
Mid20 Yagi20648 160° azimuth <-- Feedpoint # 1
Bot20 Yagi20648 160° azimuth <-- Feedpoint # 2
Card deck created 03 Sep 21 Sun 18:14:36 -0500

NEC version 4.1

K3NA NOUTrim v3.7 2003 Jul 21 Mon

K4JA antenna farm: three 20m yagis stacked at 50, 100 and 150 feet.
5 antennas present:
Stack middle + bottom fed.
Other antennas open-circuit at drive points.
Top20 Yagi20648 160° azimuth <-- Feedpoint # 1
Mid20 Yagi20648 160° azimuth <-- Feedpoint # 2
Bot20 Yagi20648 160° azimuth <-- Feedpoint # 3
Mult20 Yagi20648 340° azimuth <-- Feedpoint # 4
SA20 Yagi20536 155° azimuth <-- Feedpoint # 5
Card deck created 03 Sep 22 Mon 15:03:19 -0500

NEC version 4.1

K3NA NOUTrim v3.7 2003 Jul 21 Mon

Target 1 - SouthAmerica_20m_from_W3: 128-187° az 2-24° el.
Min difference: -4.22 dB at 143° az 2° el.
Max difference: +4.14 dB at 128° az 23° el.
Median difference: -0.56 dB.

Non-targeted area statistics:
Min difference: -13.51 dB at 318° az 18° el.
Max difference: +14.29 dB at 338° az 38° el.
Median difference: +0.65 dB.

* Gain floor for calculating differences is -15.0 dBi.
NEC x-axis is North azimuth.
Statistics computed by AEGBin v1.0 - 2003 Sep 20 Sat.

Figure 9 — Same three-Yagi stack rotated to South America (160° azimuth). The middle and bottom Yagis are fed with equal current in phase. The top Yagi is open-circuited at the drive point. In the foreground, 385 ft away, another tower supports two unused 20m Yagis with open-circuited drive points. Despite the 5½λ separation between the antennas, substantial parasitic interactions occur.

[1] K3NA@arrl.net

[2] Scace, Eric K3NA; "Antenna Interactions – Part 1: Stop Squinting! Get the Big Picture", *National Contest Journal*, 2003 Jul/Aug; ARRL, Newington CT USA.

[3] Scace, Eric K3NA; "Antenna Interactions – Part 2: Twisting Stacks", *National Contest Journal*, 2003 Aug/Sep; ARRL, Newington CT USA.

[4] TA is a DOS-based program; it's unclear if TA is still supported. Try Brian Beezley K6STI; 3532 Linda Vista; San Marcos CA 92069.

[5] Available with *ARRL Antenna Book 19th Edition*, Dean Straw N6BV editor, ARRL, Newington CT USA, 2000.

[6] A little trick is required here. If 0.00000 current is supplied on the EX card, NEC forces the current to be 1A at 0° phase. One workaround is to specify a tiny current, e.g., 10^{-10}A, to NEC-4. Another is to break open the driven element geometry with a tiny gap. The difference in pattern was below 0.02 dB throughout the sky hemisphere between these two approaches. This difference is insignificant.