

Antenna Interactions – Part 1

Stop Squinting! Get the Big Picture

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You are operating the ARRL DX contest from a well-equipped station on the USA's east coast. It's the middle of the European run and you're using a stacked Yagi array pointed northeast. Caribbean multipliers might be cruising the band, so you decide to improve your listening ability and transmitted signal strength in that region by rotating the low antenna southeast. The QSO rate starts to fade and you have difficulty holding your run frequency. What's wrong? Do you *really* know what your antenna pattern looks like after twisting the bottom Yagi down southeast?

Increasing personal computing power enables more comprehensive antenna models to be run quickly. During the last two years, as part of studies on phased arrays and stacked Yagis, I have assembled new meta-tools for antenna pattern analysis. In this series of articles, we'll apply these meta-tools to stacked Yagi systems as they are used in contests, identifying some situations where performance becomes impaired, and examining some approaches to reduce impairments.

This article focuses on understanding the meta-tools: what they do and the data provided. Future parts will apply these meta-tools to understand:

- Twisted stacks, where different Yagis are pointed in different directions.
- Pathological interactions between antennas on the same and different bands, and how these interactions can be minimized.
- Alternate feed systems for improved stack performance.

1 Introducing the sky hemisphere

We've become accustomed to examining antennas with plots of gain in azimuth (at a specific elevation angle, typically the angle with the greatest gain) and in elevation at a specific frequency; see Figure 1 and Figure 2 for an example. These plots limit our understanding of the antenna system's behavior. While Figure 2 shows the gain of the antenna at all elevation angles, it does so only for the direction along the boresight of the antenna and the direction 180° opposite, in the exact rear of the antenna. We do not see what is happening at various elevations in other directions. Similarly, the azimuth plot only shows gain at a specific elevation angle; we are missing information about gain at other elevations. We are squinting at just two slices of the overall pattern.

Many modeling software programs can produce a sketch such as Figure 3: a three-dimension, wire-frame outline of pattern lobes. Such sketches provide an overall impression of the pattern but contain no numeric data; we can't easily determine the exact gain in a lobe or null. Depending on the orientation of the image, some features may obscure others.

To better grasp the performance of an antenna system, we need to see what's happening in *all* directions at *all* elevation angles.

Imagine standing in the center of a transmitting system, looking around at the entire sky: from the horizon to the zenith, in all directions. This is the *sky hemisphere*.

2 Calculating sky hemisphere patterns

We want to see exactly how much power is radiated towards (or received from) each point of the sky hemisphere at all azimuths and all elevations.

To tackle this modeling problem, let's begin by breaking up the sky hemisphere into small patches. Conventional antenna modeling software will be used to calculate the pattern gain for each patch. I used NEC4 for all the models in this series of articles, but software packages based on NEC2 may also be used with the usual attention paid to the limitations of NEC2.

The results will be assembled into the big picture by processing the output file generated by the NEC engine (usually labeled with a .NOU extension).

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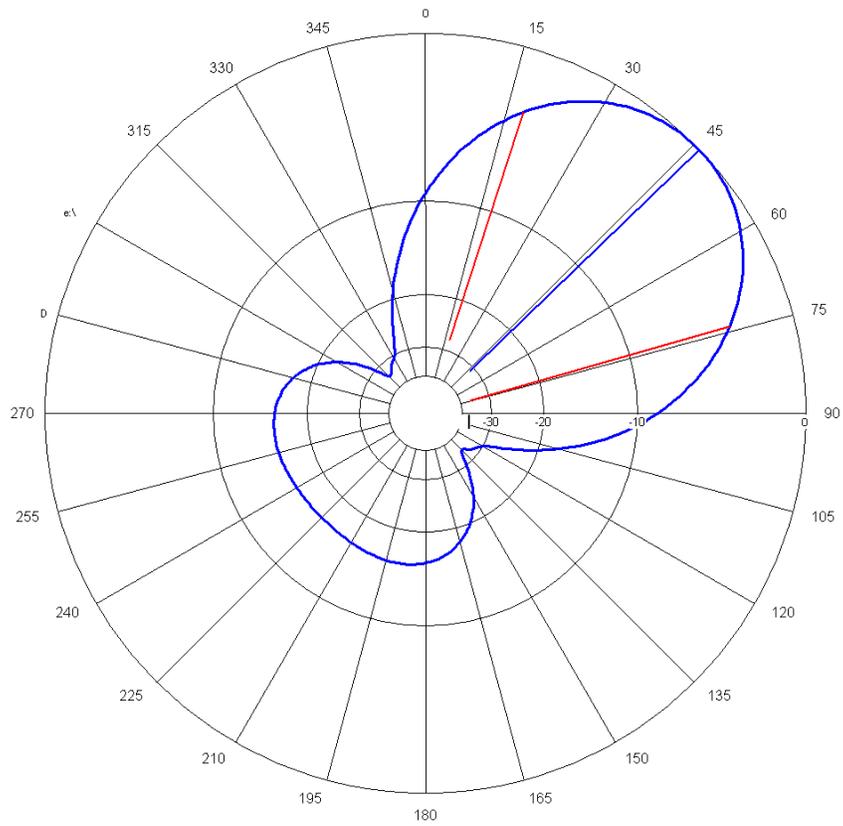
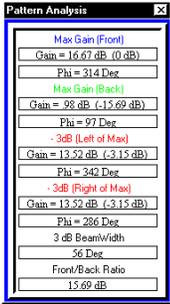


Figure 1: Azimuth pattern, at an elevation of 11°, for a stack of two Yagis on 20m. Each Yagi contains six elements on a 48-foot boom using an OWA design. The Yagis are mounted at 50 at 100 feet and pointed northeast.

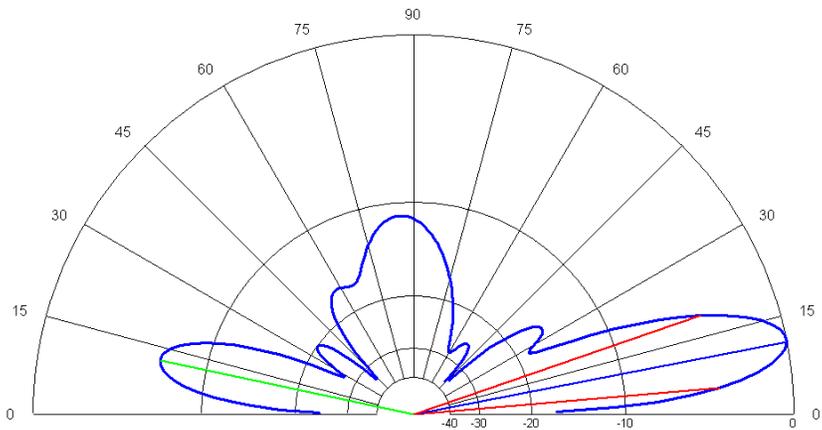
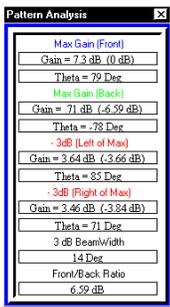


Figure 2: Elevation pattern, at azimuth 46°, for the antennas described in Figure 1.

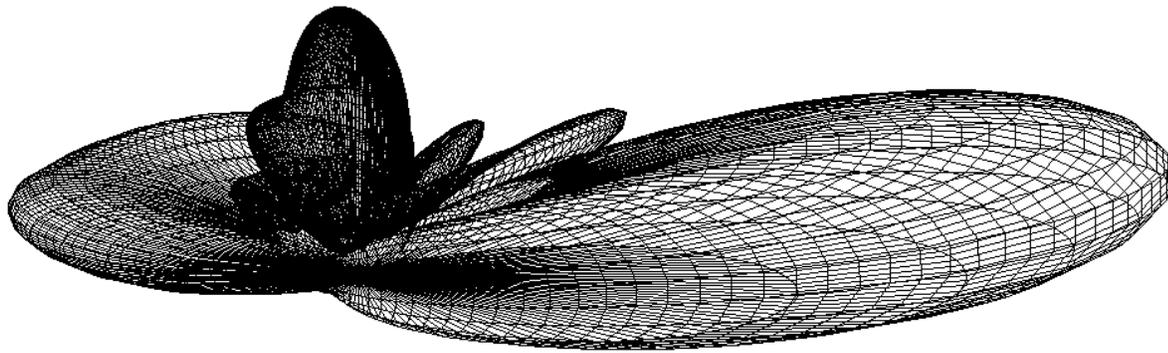


Figure 3: Three dimensional wire-frame outline of pattern for the antennas described in Figure 1.

3 Choosing patches

Several criteria apply to the division of the sky hemisphere into patches:

- a) The location of patches should be easy to describe to the NEC engine.
- b) The quantity of patches should be small enough to avoid long computing times.
- c) To facilitate the calculation of pattern statistics, the patches should be of equal area.
- d) Enough patches should be used to reveal the details of the antenna system pattern.

NEC uses the "RP" instruction to calculate pattern data. One convenient approach to instructing the NEC engine uses rows of patches, each row at the same elevation angle. Each row requires one RP instruction card, specifying an elevation angle and the number of equal-spaced azimuths to calculate at that elevation.

For HF systems, one degree steps are usually adequate to resolve pattern detail in the vertical (elevation) direction. To resolve pattern details in the horizontal direction, a one degree step in azimuth is adequate at low elevation angles. I have selected a $1^\circ \times 1^\circ$ patch at the horizon as the basic patch area. Figure 4 illustrates the shape of one patch at the horizon, centered around the location for which NEC will calculate gain.

The area of the sky hemisphere covered by successively higher elevation angles decreases, until one reaches a single point at the zenith (90° elevation). Therefore if one uses equal area patches, fewer patches are required for rows at successively higher elevation angles. Annex I explains how to calculate patch area and the number of patches required at each elevation angle. For this study the sky hemisphere was tiled with 89 rows containing 20,629 patches. Table 1 lists the elevation angles and corresponding number of azimuths. The NCJ website contains a file with the 89 RP cards needed to calculate antenna patterns for the sky hemisphere.

4 Meta-tools for pre- and post-processing NEC data

My meta-tools work sequentially, preparing instructions for the NEC engine, running the NEC engine, and then manipulating the results. The basic steps are:

- Clean up the NEC instruction file.
- Run the NEC engine.
- Sort through the NEC output file, compiling statistical data and extracting the gain at each azimuth and elevation.
- Create a map showing gain on the sky hemisphere, annotating the map with statistics and other useful data.

The NEC instructions for many of my models are generated by custom Excel spreadsheets. I build these spreadsheets to generate NEC instructions for a family of models based on a similar scenario. During this series many examples use Paul K4JA's 20m antenna farm. All of Paul's 20m antennas are described in one of my custom Excel spreadsheets. By setting a few parameters, I can include or exclude certain antennas, specify which direction each antenna is pointing, and specify the current and phase fed into each antenna. The spreadsheet then creates a text page with the necessary NEC instructions to analyze the situation.

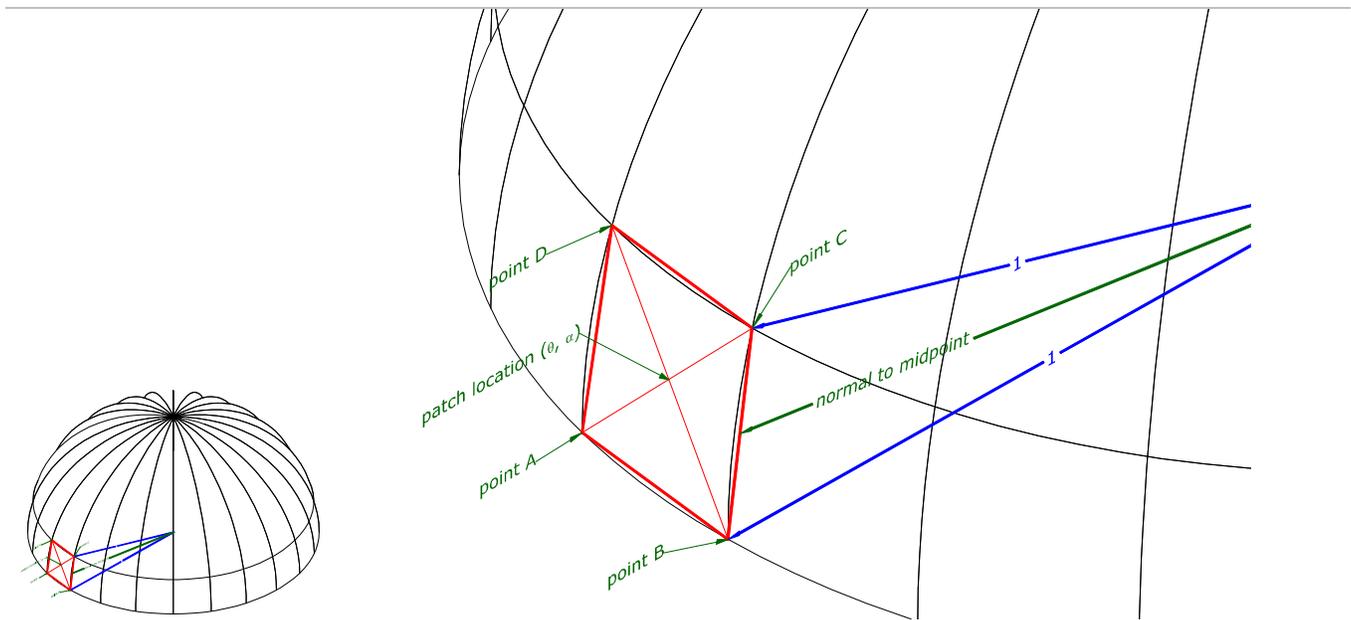


Figure 4: Left: the sky hemisphere. Right: sample patch on the sky. The four vertices of a rhombus, including points A, B and C, lie on the hemisphere representing the sky. The center of the patch represents the azimuth θ and elevation α for which NEC calculates gain. For clarity in the figure, this sample patch is 100 times larger in area than the patches used in the actual calculations.

elev- ation	nr of patches										
0.50	360	15.51	347	30.54	311	45.59	253	60.68	178	75.84	90
1.50	360	16.51	346	31.54	308	46.60	249	61.68	172	76.86	83
2.50	360	17.52	344	32.54	304	47.60	244	62.69	167	77.88	77
3.50	359	18.52	342	33.54	301	48.61	239	63.70	161	78.90	71
4.50	359	19.52	340	34.55	297	49.61	234	64.71	155	79.92	65
5.50	358	20.52	338	35.55	294	50.62	230	65.72	149	80.94	58
6.50	358	21.52	335	36.55	290	51.62	225	66.73	144	81.97	52
7.50	357	22.52	333	37.56	286	52.63	220	67.74	138	83.01	45
8.50	356	23.52	331	38.56	282	53.63	215	68.75	132	84.05	39
9.51	355	24.53	328	39.57	279	54.64	210	69.76	126	85.10	32
10.51	354	25.53	326	40.57	274	55.64	204	70.77	120	86.16	26
11.51	353	26.53	323	41.58	270	56.65	199	71.79	114	87.23	19
12.51	352	27.53	320	42.58	266	57.66	194	72.80	108	88.35	12
13.51	350	28.53	317	43.58	262	58.66	189	73.81	102	89.46	5
14.51	349	29.53	314	44.59	257	59.67	183	74.83	96		

Table 1: Number of equal area patches at each elevation angle. At the horizon, a patch occurs every 1° in azimuth.

Frequently, these Excel spreadsheets provide text with blank lines (instructions which have been suppressed as not relevant for a particular run of the model). NEC engines barf when a blank line is found in the instruction set. My first meta-tool, NECInputClean, combs through the text file and removes any blank lines. At this point I often use NECWin to visually verify the wire and segment geometry.

You don't need to create custom Excel files in order to use the remaining meta-tools. Any NEC modeling software package such as NECWin or EZNEC may be used to generate a NEC instruction file. I build custom Excel spreadsheets simply to save time when running many models of complex antenna systems.

After the NEC engine runs, another meta-tool NOUTrim sorts through the .NOU output file to extract into separate files:

- The "CM" comment cards; these lines of text usually describe the scenario being modeled.
- A list of all feedpoints in the system, with their drive point voltage or current levels and phase.
- Gain at each azimuth and elevation.
- Additional pattern statistics discussed below.

The meta-tool NOUPlot then creates the annotated map of the gain over the sky hemisphere. This information is stored in a .PS PostScript file. The .PS file can be printed directly by PostScript-compatible printers. It can also be viewed on the screen using the GhostView/GhostScript utilities.

Why do I call NECInputClean, NOUTrim and NOUPlot “meta-tools”? A meta-tool is a “tool of tools”. My meta-tools are instructions to the following software packages, created and maintained by other dedicated programmers:

- GNU AWK (GAWK): a utility which parses text files to extract data that fits user-specified patterns. GAWK is available at <http://www.gnu.org/software/gawk/gawk.html>. The GNU software is free under the terms of the GNU public license.
- Generic Mapping Tool (GMT): a comprehensive toolkit for mapping data found at <http://gmt.soest.hawaii.edu>. GMT is also free under the terms of the GNU public license.^{1, 2, 3, 4, 5}
- GhostScript and GhostView: utilities for manipulating PostScript files. These utilities are available at <http://www.cs.wisc.edu/~ghost/> under the Aladdin free public license system. Registration is not required but the author would appreciate a \$40 (Australian) registration (about US\$25).

The NCJ website contains a sample of each of my meta-tools. The tools are annotated so that you can modify them for your projects and computing environment. I use a batch file to run all the meta-tools and the NEC engine in the proper order; the batch file is also on the website.

5 Example: 20m Yagi stack

Figure 5 shows the results for a 20m stacked Yagi system over very good ground. Two 6-element aluminum Yagis on 48 foot booms, mounted at 50 and 100 feet, are fed with equal currents in phase. The stack is pointed towards Europe from Virginia. A color version of this map is on the NCJ website. A 750 MHz laptop with 512 MB memory consumed 35 seconds to run NEC and all meta-tools for this example.

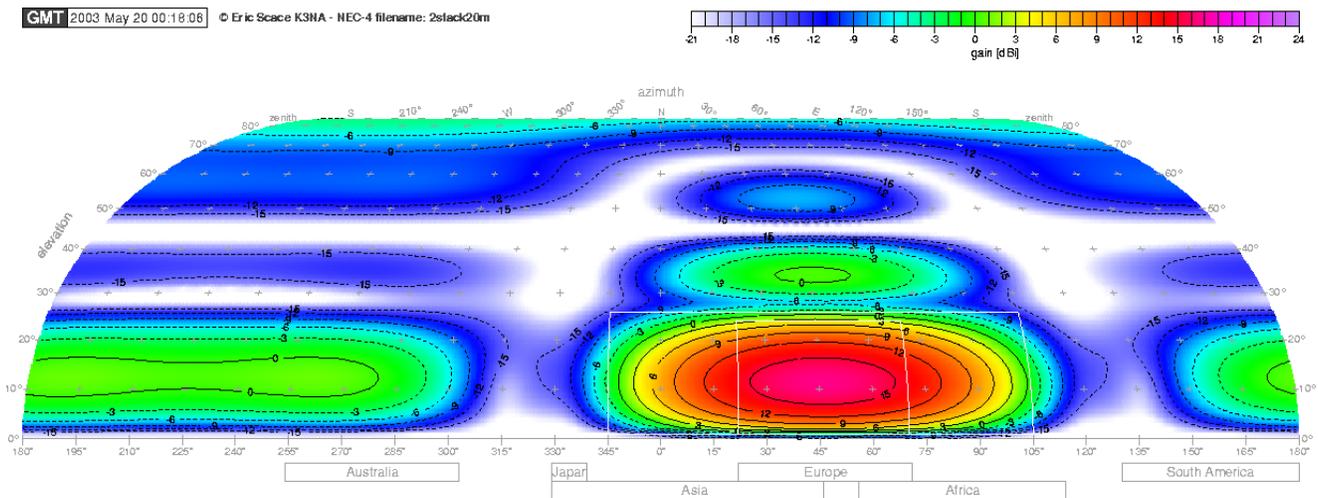


Figure 5: Map of gain over the entire sky hemisphere for the same 20m stacked Yagis described in Figure 1. See text for detailed explanation of the map features.

The map is a Eckert IV projection of the sky hemisphere. The horizontal direction represents azimuth, with North located in the center, East towards the right, and West towards the left. South is the extreme right and left edge of the map. The actual azimuth bearing in degrees is labeled at the top and bottom of the map. Rectangular boxes below the map show the span of azimuths needed to cover a particular continent from a location around Washington DC.

The vertical direction is elevation, with the horizon at the bottom and the zenith at the top. Elevation angles are marked on the sides of the map. Note that the projection tapers from the horizon to the zenith!

The antenna gain is represented by color (on the website image) or intensity of gray. Color/gray blobs on the map represent the lobes of the antenna. White areas have very low power: less than -21 dBi. A color- or

gray-scale bar in the upper right corner shows the relation between color/gray and dBi of gain. Contours of equal gain in steps of 3 dBi also map out the pattern gain; contours for gains less than 0 dBi are dashed.

In this example the main lobe is pointed towards Europe with a peak at 11° elevation. There is also a minor lobe pointed to Europe with about +1 dBi of gain at 34° elevation, and a faint lobe of -7 dBi even higher in the sky.

The rear lobe of the antenna is very broad, covering from 160° to 295° azimuth with a signal between -3 dBi up to a maximum of +1 dBi. And there is a minor lobe pointing straight up at the zenith of -4 dBi.

In Eckert projections equal areas on the page correspond to equal areas in the sky, regardless of azimuth or elevation. That means you can compare the relative coverage of lobes by looking at the area covered by the blobs of color/gray.

Table 2 provides statistics about this antenna system.

6 Antenna system efficiency

Antenna system efficiency describes how well the system converts transmitter power to radiated signals (or received signals gathered by the antenna into power into the receiver). The NEC output provides a figure for “antenna efficiency”, but this figure excludes ground losses.

A more direct way to measure the efficiency of the modeled antenna system is to analyze how much power is radiated to the entire sky hemisphere. An ideal antenna will radiate all of its power; a very lossy antenna will radiate only a small portion of applied power.

The power radiated to the entire sky can be compared to an isotropic antenna in free space to calculate power gain to the entire sky, G_{sky} . A perfect, lossless antenna over perfect ground would radiate all of its applied power into the sky hemisphere, yielding twice the signal of an isotropic radiator that must fill a sphere of free space. A perfect antenna over perfect ground therefore has a $G_{sky-perfect} = +3.01$ dBi.

“Power Efficiency” compares an antenna’s G_{sky} to that a perfect antenna over perfect ground:

$$\text{Power Efficiency} = 100\% \times \frac{10^{G_{sky}}}{10^{G_{sky-perfect}}}, \text{ which simplifies to } 100\% \times \left(\frac{10^{G_{sky}}}{2.00} \right)$$

Antenna	Height	Az	Drive conditions		
			Impedance	Current	Phase
Middle 6-el 48-ft Yagi	100 ft	46°	29.2 - j 6.1 Ω	1.000 A	-90.0°
Bottom 6-el 48-ft Yagi	50 ft	46°	29.8 - j 5.2 Ω	1.000 A	-90.0°

Power efficiency:	87.0%
max gain:	16.67 dBi
azimuth:	46°
elevation:	11°

Frequency:	14.025 MHz
Ground:	Finite
Solution:	Sommerfeld
Ground:	Very good
Dielectric (σ):	13.0
Conductivity:	5.0 mS/m

target:	zone 1	zone 2	non-target area
name:	Europe	transition	
azimuth:	22 - 70°	345-105°	
elevation:	1 - 24°	1-26°	
mean gain*:	13.37 dBi	7.05 dBi	-7.14 dBi
average dev from mean:	±4.90 dB	±7.54 dB	±7.36 dB
max gain:	16.67 dBi	14.32 dBi	1.02 dBi
azimuth:	46°	70°	261°
elevation:	11°	11°	12°
min gain:	1.08 dBi	-15.60 dBi	-39.60 dBi
azimuth:	70°	345°	310°
elevation:	1°	1°	43°

Table 2: Post-processing meta-tools statistical results.

To average together the power gains across the entire sky, a conversion from gain (in dBi) to relative power must occur before averaging:

$$P_{a,q} \equiv 10^{G_{a,q}}$$

where:

$G_{a,q}$ \equiv gain calculated by NEC - 4 at elevation angle a and azimuth q .

With values of relative power for each patch of sky in hand, the values can be averaged together and converted back to gain:

$$G_{sky} = 10 \log \left(\frac{\sum_{a=0^\circ}^{90^\circ} \sum_{q=0^\circ}^{360^\circ} P_{a,q}}{m_{total}} \right)$$

where:

m_{total} \equiv total number of patches.

$P_{a,q}$ \equiv power radiated at elevation a and azimuth q .

The meta-tools do all this work for you. Table 2 shows this stacked Yagi system has a power efficiency of 87%.

7 Target zones

Frequently one wishes to compare antenna systems for a specific application. The meta-tools allow you to specify one or two target zones. Zones appear on the map as white rectangles and are described in the statistics table.

Table 2 shows both target zones were used. The first is identified as "Europe" and covers the European azimuth range. This zone includes elevation angles from the horizon to 24°. The current *ARRL Antenna Book* contains the results of propagation modeling studies by Dean Straw N6BV. These show that signals from the Washington DC area to Europe on the 20m band have elevation angles of 24° or less 99% of the time under undisturbed conditions.

Note that undisturbed conditions occur only about half the time. Table 3 shows the time distribution of K_p values. Since 1994 January 1, K_p values of 0, 1 or 2 occurred 56% of the time. Although N6BV's data does not include disturbed conditions, one could defend an assumption that high elevation angles are less usable during many disturbed conditions. If this assumption is true, N6BV's elevation angle data overstates the times when higher angles may be used.

K_p value	Number of 3-hr periods	% of 3-hr periods
0	1,533	5.6%
1	5,276	19.3%
2	8,590	31.4%
3	7,569	27.6%
4	2,911	10.6%
5	1,055	3.9%
6	319	1.2%
7	99	0.4%
8	20	0.1%
9	8	0.03%

Table 3: Distribution of K_p values during 1994 January 1 through 2003 May 19.

Returning to Table 2, the average gain of this stacked Yagi system across Europe is +13.4 dBi, with an average variation of ± 4.9 dB from the mean. The table identifies locations of the maximum and minimum gain within the zone. The minimum gains tend to occur at the corners of the zone box; e.g., highest and lowest angles to Spain and northern Scandinavia are down -12 dB from the peak gain. An ideal antenna for Europe would have high maximum gain (loud is good!)... low deviation (i.e., a uniform pattern throughout the zone)... and high minimum gain (no holes in the pattern within the target zone).

The second target zone in this example is a transition zone around the main beam. When calculating the statistics for the second target zone, the meta-tools exclude points that fall within the first target. The second target zone is useful for excluding the sides of the main lobe from the statistics for the rest of the sky hemisphere (non-targeted area). The second zone is also useful when evaluating performance while pointing to two different areas (e.g., twisted stacks to be examined in a future part).

8 Non-targeted area

The last set of statistics is for the non-targeted area; i.e., the areas of the sky outside of the two target zones. For this stacked Yagi system, the mean gain to the rest of the world is -7.1 dBi with the worst value of $+1.0$ dBi located at 261° azimuth 12° elevation. Clean patterns will have minimum average gain throughout the non-targeted area and very low value of gain in the worst minor lobe.

Note that the meta-tool uses a floor value in calculating mean gain and deviation from the mean. For this study, the floor is set to -15 dBi. Any patch in the sky whose modeled gain is less than the floor will be treated as having the floor value when calculating statistics. Variations in construction methods, accuracy in cutting to modeled dimensions and other factors conspire to make it difficult to achieve deep nulls in antenna patterns. In this example, the floor is over -30 dB below the peak gain of the main lobe. By setting a floor, we avoid optimizing designs based on unachievable pattern nulls.

9 Drive impedance, matching systems and baluns

Using data from the NEC engine, the meta-tools also calculate drive impedances. Current feed situations are detected and the impedances are corrected for the common workaround used to describe current feeds to NEC. In our example, Table 2 shows both antennas have nearly identical drive impedances of about $29 - j5 \Omega$. This stack is easy to feed with identical, in-phase currents – but identical matching system and balun construction must be used! If the Yagis have a different baluns or matching systems, an unplanned difference in phasing and current levels could be introduced to the system, resulting in a different (probably worse!) pattern.

10 Conclusion

We've been introduced to meta-tools, based on publicly available software utilities, to generate a comprehensive picture of antenna patterns, along with statistics relevant to contest station design objectives. Next time we'll apply these tools to reveal how stacked Yagis can be abused to improve (and sometimes degrade) contesting performance.

Annex I — Dividing the Sky into Patches

In the main article, Figure 4 represents a patch as a rhombus with four vertices lying on the sky hemisphere, centered on the data point whose gain NEC calculates. To calculate the area of this rhombus, begin by calculating the length of the sides. Assume the sky forms a hemisphere with unit radius; i.e., radius = 1. Referring to Figure 4, let $\Delta\alpha$ represent the vertical (elevation) angle between points B and C, measured from the origin of the hemisphere (the location of the antenna). The vertical distance between points B and C is the base of an isosceles triangle; the other two sides are the radii shown in the figure. The vertical distance between points A and D is identical. From trigonometry, find the vertical distances BC and AD as follows:

$$BC = AD = 2 \sin\left(\frac{\Delta\alpha}{2}\right)$$

The meridians (lines of equal azimuth) converge together as they reach the zenith. Horizontal distance AB is larger than CD. Find the horizontal distances as follows:

$$AB = 2 \cos(\alpha_{AB}) \sin\left(\frac{\Delta\alpha}{2}\right) \text{ and } CD = 2 \cos(\alpha_{CD}) \sin\left(\frac{\Delta\alpha}{2}\right)$$

where α_{AB} is the elevation angle at points A and B, and α_{CD} is the elevation angle at points C and D.

Having now found the lengths of all sides of the parallelogram, refer to Figure 6 in this Annex and find the area as follows:

$$\text{area} = (h \times CD) + \left(h \times \frac{AB - CD}{2} \right) \text{ the sum of the area of two rectangles shown in the figure.}$$

$$\text{area} = h \left[CD + \frac{AB - CD}{2} \right]$$

$$\text{area} = h \left[\frac{AB + CD}{2} \right]$$

$$\text{where } h = \sqrt{BC^2 - \left(\frac{AB - CD}{2}\right)^2} \text{ from the properties of right triangles.}$$

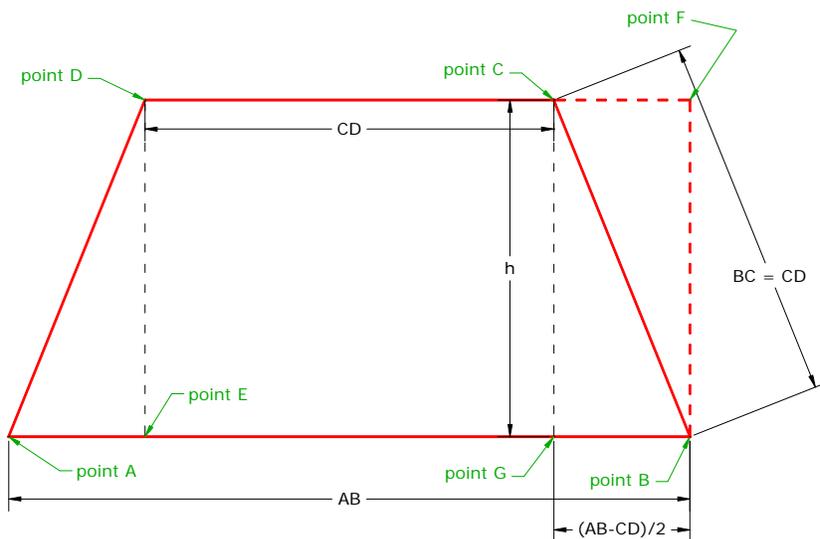


Figure 6: Patch area as a rhombus. To calculate the area, clip the triangle formed by points ADE on the left side and move it to the dotted location BCF on the right side. The area BFCG is now a rectangle whose area is height h multiplied by width $\frac{1}{2}(AB - CD)$. Add this area BFCG to the area of the second rectangle EFCD to get the complete area of the rhombus.

For this series, the area covered by one patch was set to equal 1° width in azimuth on the horizon and 1° height in elevation on the horizon. 360 patches were defined all around the compass, centered at $\frac{1}{2}^\circ$ elevation. An Excel spreadsheet, available on the NCJ website, calculated the dimensions and area

of these patches, and then created similar rows of patches of identical area all the way up to the zenith. Figure 7 contains an extract from this spreadsheet. For each row, the central columns of the spreadsheet show the dimensions (based on a sphere of unit radius) of the patch rhombus and patch area.

layer	patch mid-pt elevation	azimuth steps	elevation angles		dimensions			area		
			bottom	top	bottom	top	height	patch	variance ratio	variance
1	0.50	360	0	1.00000000	0.00872654	0.00872521	0.00872654	0.00007615	1.00000000	
2	1.50	360	1.00000000	1.99984769	0.00872521	0.00872122	0.00872521	0.00007611	1.00045701	-0.00000003
3	2.50	360	1.99984769	2.99923860	0.00872122	0.00871458	0.00872122	0.00007603	1.00152412	-0.00000012
4	3.50	359	2.99923860	4.00065049	0.00873886	0.00872952	0.00873886	0.00007633	0.99763913	0.00000018
5	4.50	359	4.00065049	5.00099241	0.00872952	0.00871753	0.00872952	0.00007615	0.99992685	0.00000001
6	5.50	358	5.00099241	6.00275083	0.00874188	0.00872717	0.00874188	0.00007636	0.99725533	0.00000021
7	6.50	358	6.00275083	7.00282353	0.00872717	0.00870982	0.00872717	0.00007609	1.00077258	-0.00000006
8	7.50	357	7.00282353	8.00370415	0.00873422	0.00871415	0.00873423	0.00007620	0.99931276	0.00000005
9	8.50	356	8.00370415	9.00508948	0.00873862	0.00871582	0.00873863	0.00007626	0.99846140	0.00000012
10	9.51	355	9.00508948	10.00667450	0.00874037	0.00871482	0.00874038	0.00007628	0.99821944	0.00000014
11	10.51	354	10.00667450	11.00815294	0.00873944	0.00871115	0.00873945	0.00007625	0.99858860	0.00000011
12	11.51	353	11.00815294	12.00921763	0.00873583	0.00870480	0.00873584	0.00007618	0.99957135	0.00000003
13	12.51	352	12.00921763	13.00956107	0.00872953	0.00869578	0.00872955	0.00007606	1.00117093	-0.00000009

Figure 7: Portion of spreadsheet that calculates sample patch elevations, azimuths, dimensions, areas and variance in area for nearly-equal area patches covering the sky.

Because antenna patterns at HF vary more rapidly for each degree of elevation change than for a degree of azimuth change, the height of each row was kept as close as possible to 1° in elevation. Each row must contain an integral number of patches, and an integral number of rows must fit between horizon and zenith. The number of patches in each row was set to make the patch areas as nearly identical as possible. The spreadsheet's far right column shows the variance in area compared to patches on the horizon. The second column from the right provides the ratio of each row's patch area to the area for patches on the horizon.

The twin constraints of integral number of patches per row and integral number of rows require the patch area to vary slightly. For elevation angles below 62° the worst patch area variation is less than ±½%. Patch areas between 62° and 76° elevation have a worst-case variation of less than ±1%. Above 76°, the worst patch area variation is less than ±1½%, except for the last five patches that meet at the zenith. These last five patches are 2.2% smaller than the mean patch size.

For the entire set of patches, the average error in patch area is less than 0.0019%. Even for patches at elevation angles above 75°, the average error is less than 0.038%. This error lies well within the overall error limits of NEC-4 modeling.

Annex II — Additional Information on the NCJ Website www.ncjweb.com

The following files are included on the NCJ website:

- A copy of this article.
- Programs and supporting files representing the meta-toolset.
- Example of source data files and resulting output files generated by the meta-toolset.

This Annex contains a brief description of each file.

II.1 Big Picture.PDF

This file contains the PDF of this article.

II.2 Meta-tool and utility programs

The batch files and utilities described here are a work in progress. They can be improved by using switches for some of the parameters or input file specifications, for example. Hopefully you will find the internal file comments sufficiently clear to make improvements or to tailor these utilities for your own purposes.

II.2.1 NECRun.bat

This batch file runs at the Windows command prompt in the directory containing the meta-tool and utility programs and supporting data files listed here in §II.2.

The batch file command is:

```
necrun filename
```

where *filename* is an ASCII file (assumed to have *.txt* as a suffix) containing the NEC card deck. NECRun performs the following steps:

- Runs NECInputClean.bat, which cleans up the blank lines in the NEC card deck.
- Switches to the directory containing the NEC4 executable binary. On my system this is D:\Program Files\GNEC\BIN.
- Runs NEC4. NEC4 takes *filename.nec* as input and generates *filename.nou* as an ASCII output file. This file can be quite large – a couple of megabytes.
- Switches back to the original directory.
- Runs NOUPlot.bat, which sorts through the NEC output file and generates the map and statistics.

I wrote this batch file to streamline the generation of a map and its statistics into a single command. However, each of the internal steps described below can be run individually when you wish to verify the results of each utility or to modify the final plot (e.g., to use a gray scale rather than a color scale).

II.2.2 NECInputClean.bat

This batch file runs the AWK utility NECInputClean.awk with the appropriate parameters. The batch file command is:

```
NECInputClean filename
```

where *filename* is an ASCII file (assumed to have a *.txt* suffix) containing the NEC card deck. The output of this utility is named *filename.nec*, an ASCII file.

II.2.3 NECInputClean.awk

This AWK utility eliminates blank lines from the *filename.txt* file. Tab characters (inserted by Excel to delimit columns of data) are replaced by space characters. A timestamp is added to the CM comment cards to annotate when the NEC run occurred. For NEC wire coordinates, this AWK utility aligns all the coordinates into neat columns in the card.

The output of this utility is named *filename.nec*. The output can be examined by NEC utility software such as GNEC or NECWin to verify that the wire geometry has been accurately described.

II.2.4 NOUPlot.bat

The batch file command is:

nouplot *target filename*

Target is an ASCII file which NOUPlot assumes contains *.xy* as a suffix; it contains a description of the two target zones. See §II.2.9 for more details. *Filename* is assumed to have *.nou* as a suffix and is the NEC ASCII output file.

This batch file performs the following steps:

- Removes previous versions of the various output files.
- Runs NOUTrim.awk, an AWK utility which extracts data needed for the next steps from the ASCII files *filename.nou* and *target.xy*. This utility is described in §II.2.5 below. The extracted data is placed in several files:
 - *filename.aeg*, an ASCII file containing elevation, azimuth, and gain data.
 - *filename.cm*, an ASCII file containing the contents of the NEC CM comment cards.
 - *filename.con*, an ASCII file containing the frequency and ground characteristics used in the model. The drive impedances calculated by NEC for each antenna's feedpoint are also extracted into this file, along with an indication of whether voltage or current feed was used and the value and phase of the voltage or current for each feedpoint.
 - *filename.dat*, an ASCII file containing statistics about the antenna pattern in each of the two target zones and for the remainder of the pattern that lays outside the targets. NOUTrim calculates these statistics while parsing through the NEC output file.
- Runs GMTconvert, a GMT utility which converts azimuth, elevation and gain data from *filename.aeg* into a binary format located in *filename.bin*. This utility, like all of the GMT utilities, is described in the GMT documentation.
- Runs Blockmean and Surface, two GMT utilities which sample and smooth the binary data in preparation for plotting the map. Blockmean uses the input file *filename.bin* and produces the binary output file *filename.b*. Surface scarfs up the binary data from *filename.b* and produces another binary file *filename.grd*.
- Runs GMT utilities GMTset and GRDView to plot the map in a Postscript output file *filename.ps*. The color scale specified in *dbi.cpt* is used to color the areas of the map.
- Runs the GMT utility PSText to plot axis labels around the map contained in *filename.ps*. The axis labels are specified in the ASCII input file *AxisLabel.txt*. Refer to the GMT documentation for the description of this utility and the format of the input file.
- Runs GMT utilities PSXY and PSText to plot the boxes containing each continent's azimuth range just below the map. Presently the call to this utility is hard-coded to get the specifications for these boxes from the ASCII input files *ContinentBoxesW3.xy* and *ContinentsW3.txt*. Obviously that's not very flexible; an improvement would use an additional specification in the batch files to select the appropriate description of these boxes.
- The GMT utility GrdContour is called twice, once to plot the positive gain contour lines using solid black lines and then again to plot the negative gain contour lines using black dashed lines. GrdContour takes *filename.grd* as its binary input and adds the contours to the map contained in *filename.ps*.
- The two target areas are then plotted on the map using two calls to the GMT utility PSXY. The first call plots the vertical boundaries specified in the ASCII input file *targetvertical.xy*. The second call plots the horizontal parts of the boundaries, as specified in *targethorizontal.xy*.
- The GMT utility GrdMath is called to locate local maxima and minima on the map; these values and locations are stored in *maxmin.grd*.
- The color scale used in the map is added to *filename.ps* with the GMT utility PSScale.
- Three columns of data are then annotated in *filename.ps* below the map in *filename.ps*. The first call to GMT utility PSText writes the contents of the NEC CM comment cards (previously extracted into *filename.cm*) in the left column. A second call to PSText fills in the middle column with frequency, ground characteristics, feedpoint impedances and drive conditions previously extracted by NOUTrim.awk into *filename.con*. The final call to PSText writes pattern statistics, extracted earlier by NOUTrim.awk into *filename.dat*, in the right column under the map.

Three variations of NOUPlot.bat are also included on the website:

- NOUPlotGray.bat plots a map using a gray scale contained in *dbiGray.cpt*. This map is suitable for publication in monochrome.
- NOUPlotNoStats.bat plots the map but excludes the three columns of data underneath.
- NOUPlotHiResColor.bat plots a high-resolution map suitable for printing with a high resolution printer using 1200 dots per inch and 124 lines of resolution. The output map *filename.ps* is just large enough to email to ARRL for publication without violating maximum email message limits!

Gray lines and annotations were switched over to black in order to show up more clearly after publication. This version was used to generate the *National Contest Journal* cover page image. For local printing, the rasterization (lines of resolution) may be further increased to match the abilities of your printer and paper. Warning – The size of *filename.ps* can become quite large as a result of increasing the rasterization!

II.2.5 NOUTrim.awk

The batch file command is:

```
noutrim target filename
```

Target is an ASCII file which NOUTrim assumes contains *.xy* as a suffix; it contains a description of the two target zones. See §II.2.9 for more details. *Filename* is assumed to have *.nou* as a suffix and is NEC's ASCII output file.

GAWK is an interpreted programming language of moderate power that does not provide for sub-routines. NOUTrim therefore is a rather lengthy, linear program with an initialization phase, a file-parsing phase (constructed as a large loop), and a termination phase. From the standpoint of good programming practice, NOUTrim pushes beyond the limits: it's long, lacks subroutines, and does ordinary statistical calculations by brute force arithmetic. NOUTrim begs to be rewritten in a more powerful language such as C++.

NOUTrim works through the following steps:

- Initializes a large number of internal constants and variables.
- Parses the *target.xy* file for the azimuths and elevations of the corners of the two target zones and the names of each zone. The vertical boundaries are transcribed into the ASCII file *TargetVertical.xy* and the horizontal boundaries are transcribed into a separate ASCII file *TargetHorizontal.xy*. This separation is required because of the manner in which a GMT utility in NOUPlot.awk actually plots these lines. NOUTrim notes if either zone spans across North (0° azimuth) so that subsequent statistics data collection functions properly.
- Four output files are opened:
 - *filename.aeg*, an ASCII file to receive elevation, azimuth, and gain data.
 - *filename.cm*, an ASCII file to receive the contents of the NEC CM comment cards.
 - *filename.con*, an ASCII file to receive the frequency and ground characteristics used in the model. The drive impedances calculated by NEC for each antenna's feedpoint are also extracted into this file, along with an indication of whether voltage or current feed was used and the value and phase of the voltage or current for each feedpoint.
 - *filename.dat*, an ASCII file to receive statistics about the antenna pattern in each of the two target zones and for the remainder of the pattern that lays outside the targets. NOUTrim calculates these statistics while parsing through the NEC output file.
- Parses the NEC output file *filename.nou*. NOUTrim works through the file line by line, looking for specific sets of information in each part of the NEC output. After each set of data is located and extracted to the proper place, NOUTrim continues on to search for the next set. A state variable keeps track of which information is being sought. The information extraction occurs in the following sequence of states:
 - FindVersion: Searching for an indication as to whether NEC2 or NEC4 was used. The output file organization is slightly different between NEC2 and NEC4.
 - Pre-Comment: Searching for the start of the listing of NEC CM comment cards.
 - Comment: The location of the CM comment card listed has been discovered. NOUTrim removes trailing spaces, which cause errors when annotating the maps, from each comment lines. Each line of comment is placed in the *filename.cm* file. If no comment cards exist in the listing, the statement "No comments." is inserted in *filename.cm*. The NEC version and NOUTrim version number are appended to the end of the comments in this file.
 - PreEXCard: Searching for the beginning of the structure excitation section. While in this state, NOUTrim counts the number of EX cards in the NEC output; this reveals the number of feedpoints in the array.
 - PreFrequency: Searching for the frequency used in the model. The frequency is written into the *filename.con* file.
 - PreGround: Searching for the ground characteristics used in the model. The ground type, dielectric constant and conductivity are all written into the *filename.con* file. Note – Since I haven't used these tools with free space or perfect ground models, this part of NOUTrim doesn't

yet test for a perfect ground or free space. This test will be easy to add once one has a copy of NEC2 and NEC4 outputs for perfect ground and free space models.

- PreImpedance: Searching for the feedpoint impedance data. NOUTrim assumes that feedpoint tag numbers are assigned according to the convention that tags above 900 represent the current source workaround technique. A feedpoint with a tag number larger than 900 is assumed to be a current source workaround and is labeled accordingly in filename.con. In this case, the dummy wire's admittance is actually the drive impedance and the voltage is actually the drive current plus a 90° shift in phase angle. The appropriate adjustments are made in order to write out the proper current (or voltage, for voltage feeds) and phase angle for each feedpoint into filename.con. Each feedpoint is numbered in the order in which it was discovered. I usually place a NEC CM comment card in the NEC input file describing each feedpoint in the order in which it appears in the model.
- PreAEGHeader: Searching for the start of pattern gain data.
- AEGData: NOUTrim assumes the x-axis represents North. Since NEC uses the convention that x increases in the counter-clockwise direction, NOUTrim converts NEC's azimuth (θ) to a compass azimuth. NOUTrim also converts NEC's declination from the zenith (ϕ) to elevation above the horizon. Azimuth, elevation and gain (dBi) are written out in ASCII to filename.aeg. NOUTrim counts the number of data points in the sky horizon and keeps a running total of powers (converting gain to power); for locations where the gain is below -15 dBi, a floor value of -15 dBi is assumed. See §8 for an explanation of the floor value. The location (azimuth and elevation) of the largest gain point discovered to date is maintained here. NOUTrim tests each location to see if it falls within the first or second target zone; if so, its power (taking the floor gain value into account) is added to a running total for that zone and the count of data points within the zone is incremented. Maximum and minimum gain values and locations within each zone are also tracked. For data points lying outside the zones, their cumulative power, number of data points, and maximum and minimum gains and locations are also aggregated as NOUTrim works through this part of the NEC output file. Three temporary arrays contain individual power values for each point in the two target zones and the area outside the targets; these arrays are used later to calculate deviations from mean power.
- Having finished parsing the *filename.nou* NEC output file, NOUTrim wraps up as follows:
 - The number of data points discovered is displayed on the screen. This serves as a double-check for the user that all 20,629 data points were uncovered.
 - The location and value of maximum gain for the entire pattern is displayed on the screen and written out to the statistics file *filename.dat*.
 - The antenna system's power efficiency is calculated, displayed on the screen, and written out to the statistics file.
 - Statistics for the two target zones and the non-target area are calculated, displayed on the screen, and written out to the statistics files:
 - ⇒ Mean gain across the target zone.
 - ⇒ Mean deviation above and below the mean gain, an indication of how much the pattern varies within the target zone (or area outside the targets).
 - ⇒ Location and value of maximum gain.
 - ⇒ Location and value of minimum gain.
 - The floor value used in calculating means and deviations is displayed on the screen and written to the statistics file.
 - The statistics file is annotated with a statement that the x-axis was assumed to be North.
 - The output files are closed.

II.2.6 dBi.cpt, dBiGray.cpt, dBi_scale.cpt and dBi_scale_gray.cpt

The ASCII files *dBi.cpt* and *dBiGray.cpt* contain descriptions of the color and gray scales used to color the map. See the GMT documentation of color and gray scales, and of the GMT utility MakeCPT, for the details of these file formats.

The ASCII files *dBi_scale.cpt* and *dBi_scale_gray.cpt* contain a subset of the color and gray scales used by NOUPlot to create the color or gray scale legend bar in the upper right corner of the Postscript map file *filename.ps*. These subsets exclude values below -21 dBi, which are always white.

These four files are used by the various forms of NOUPlot. You should not need to fiddle with their contents.

II.2.7 AxisLabel.txt

This ASCII file contains GMT plotting instructions used by NOUPlot for annotating the top and bottom of the map. You shouldn't modify this file.

II.2.8 ContinentBoxesW3.xy and ContinentsW3.txt

These ASCII files contain GMT plotting instructions used by NOUPlot for drawing boxes and labels below the map spanning the azimuths occupied at Washington DC by each continent and by Japan. If your location is elsewhere, you will want to change the coordinates in these files.

In *ContinentBoxesW3.xy*, the two columns are (x,y) values on the Postscript plotted image, relative to the lower left corner of the map image. Positive x is to the right and positive y is up. The values are in inches, and the assumed image size is 11 in x 8.5 in (landscape orientation). The negative y values in this file place the boxes below the lower edge of the map. There are four corner coordinates for each box, separated by a line containing ">".

In *ContinentsW3.txt*, the left two columns contain (x,y) coordinates for the center of each box's label. These are the only columns you need to modify to customize the box label locations for your location.

See the GMT documentation for PSXY if additional details are needed. I found that a little experimentation is the most rapid way to make matters line up neatly.

II.2.9 Target.xy

This ASCII file contains the corner coordinates of the two target zones and a name for each zone. The columns represent left compass azimuth, right compass azimuth, lowest elevation, highest elevation, and zone name (no spaces allowed).

Target.xy is the file used by NOUPlot and NOUTrim. To quickly switch target zones, I made up several other files that contain the target descriptions for various regions of the world from Washington DC, using 20m elevation angle data. To change target zones, I simply copy the desired target description file to become *Target.xy*. The following examples are included:

- Target Africa 20m W3.xy
- Target Asia 20m W3.xy
- Target Europe 20m W3.xy
- Target Japan 20m W3.xy
- Target Oceania 20m W3.xy
- Target SouthAmerica 20m W3.xy
- Target USA west central 20m W3.xy

II.2.10 GMTEnv.bat, .gmtcommands, and .gmtdefaults

The batch file *GMTEnv.bat* must be run in the command window before using any GMT utility; it sets up Windows to look in the proper locations for the GMT utilities. You will need to change these to suit your computing environment.

.gmtcommands and *.gmtdefaults* are used by GMT utilities to set up their operating parameters. You don't have to change these files.

These three files should be included in the directory where you run the meta-tools.

Check the GMT documentation for more details about these files.

II.3 Example of input and output files

II.3.1 K4JA.xls

This custom Excel spreadsheet generates a NEC4 card deck for modeling a specific subset of K4JA's yagis. This version of the spreadsheet will only model the 20m antennas at the site.

On the "parameters" worksheet, the "include?" column is used to select which antennas will be included in the model. The "az" column is used to specify the direction for each antenna. Other data on this page (in gray) calculate the coordinates of each antenna, taking into account the rotation of the antenna around its tower. The feedpoint current and phase are entered in their respective columns for each antenna.

The “yagis” worksheet contains descriptions of the element geometry for each type of 20m antenna used in the model. The elements have been converted to non-tapered elements using Dean Straw N6BV’s SCALE utility in the *ARRL Antenna Book*. This sheet does not need to be modified by the user.

The “farm” worksheet calculates endpoints for each element. No user inputs exist on this worksheet.

The “NEC4” worksheet contains the NEC4 card images in the area shaded teal. Gray areas contain annotations to help understand the card deck. The user selects all the cells shaded teal, and then pastes them into an ASCII file using, e.g., the Windows Notepad utility.

This spreadsheet is not part of my meta-tools. I’ve included it as an example of how Excel can be used to speed the customization of NEC card decks for some studies. More recently MultiNEC has become available; it might be suitable for the same purpose, but I haven’t tried it yet. Ideally MultiNEC should gobble up the statistics generated by these meta-tools – but that will take some further investigation and development work.

II.3.2 2stack20m.txt

NEC4 card file including the 89 RP cards used to generate data for the sky hemisphere. This file models the 20m 3-yagi stack shown in Figure 5. This is the raw ASCII file created by the custom Excel spreadsheet.

The RP cards at the end of the file can be used for any model to generate the data for the sky hemisphere.

II.3.3 2stack20m.nec

Here is the NEC card file created by the NECInputClean utility, ready for NEC processing.

II.3.4 2stack20m.aeg, 2stack20m.cm, 2stack20m.con and 2stack20m.dat

These four ASCII files were created by NOUTrim as it parsed the NEC4 output file *2stack20m.nou* (also included).

— end —

¹ Wessel, P., and W. H. F. Smith, New, improved version of Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U.*, vol. 79 (47), pp. 579, 1998.

² Wessel, P., and W. H. F. Smith, New version of the Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U.*, vol. 76 (33), pp. 329, 1995.

³ Wessel, P., and W. H. F. Smith, New version of the Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U. electronic supplement*, http://www.agu.org/eos_elec/95154e.html, 1995.

⁴ Wessel, P., and W. H. F. Smith, Free software helps map and display data, *EOS Trans. Amer. Geophys. U.*, vol. 72 (41), pp. 441, 445-446, 1991.

⁵ Smith, W. H. F., and P. Wessel, Gridding with continuous curvature splines in tension, *Geophysics*, vol. 55 (3), pp. 293-305, 1990.