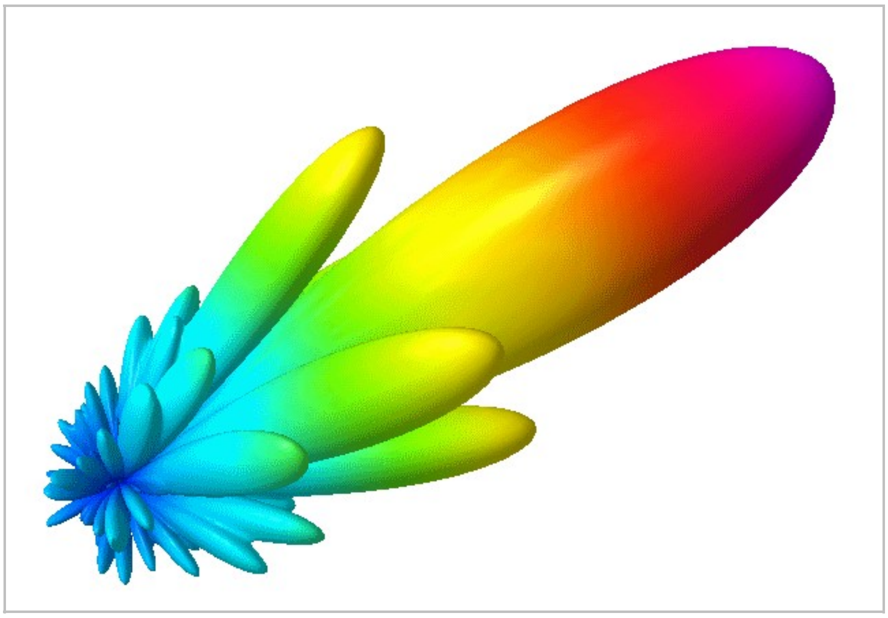
TANT Appendix

- Towards the G/T Table -

An extension to the TANT Manual



- ■ How to build a 4 Yagi Bay conform to TANT and G/T Table
- ■ How to interpret the G/T Table in full details
- ■ How to stack Yagis using the DL6WU formula
- ■ How to choose Tearth and Tsky for all Bands

TANT Appendix Version 1.1
Written by Hartmut Kluever, DG7YBN in December 2017

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Introduction

The TANT Appendix builds on the TANT Manual, which I wrote with YU7EF and the programmer of TANT, YT1NT. The TANT Manual introduces the key program for computing Antenna Temperature from EZNEC or 4nec2 Far Field Table files. Showing the most likely application of Antenna Temperature numbers the TANT Appendix goes beyond that. It gives explanations on all details of the VE7BQH G/T Table. It shows how to set up a bay of Yagis in the right way to yield results similar to what Lionel Edwards gives in his G/T Tables. Further it explains the meanings of all columns of the G/T Tables one by one. It might have been entitled G/T Manual but since the main parameter next to gain is Antenna Temperature it came the way it is. New passages in Version 1.1 are marked with a left side bar.

Read the TANT Manual first if you are not very familiar with what TANT does. It is the starting point for this lecture.

Acknowledgements

Issue 1.0 of this Manual was assisted by DL6WU and VE7BQH. Both contributed valuable input, excellent material and knowledge that helped in forming the overall content. Thanks to both for all the discussions and to Lionel for help with the initial versions format. Finally: Thanks to F5FOD for uncomplainingly sorting the basic imperfections in version 1.1

Picture on front page:

Far Field Plot of a 4 Yagi bay of 12 elem. GTV 2-12nYagis at DL6WU spacing, delivering 21.60 dBi at a Tant of 220.4 K. Generated with 4nec2X (3D viewer extension plot).

1 A NEC model for a 4 bay matching the G/T table

1.1 Geometry, Segmentation, Orientation

The model is a 12 element Yagi with V-shaped DE (GTV 2-12n) for the 2 m band. As shown in the TANT manual the boom must be in line with the x-axis, so the elements must be symmetrical either side of the x-axis.

Segmentation is close to 25 per element, almost in compliance with what is common segmentation base for the current issue of the G/T table (#105). See EZNEC 'Wires' window for details. It is all important to meet the specified segmentation when a design analysis will be copied or Yagi properties will be compared to figures in the G/T chart. Not only VSWR would shift some 100 kHz at least, but slightly different pattern and thus gain, Tant etc. will be computed using a deviating segmentation. Make sure to meet the correct diameter of elements and Driven Element according the actual designs specs.

Wires table of the DG7YBN GTV2-12n Yagi.

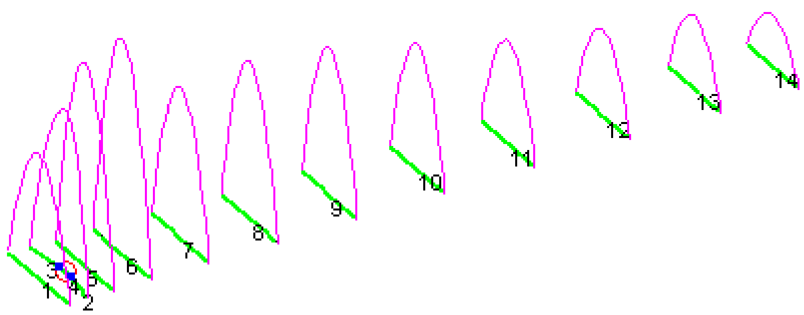
Wires

Wire Create Edit Other

☐ Coord Entry Mode ☐ Preserve Connections ☐ Show Wire Insulation

No.	End 1				End 2				Diameter	Segs
	X (mm)	Y (mm)	Z (mm)	Conn	X (mm)	Y (mm)	Z (mm)	Conn	(mm)	
1	0	-504	0		0	504	0		8	26
2	243	-100	0	W4E1	184	-476	0		10	10
3	243	100	0	W4E2	184	476	0		10	10
4	243	-100	0	W2E1	243	100	0	W3E1	10	7
5	428	-474	0		428	474	0		8	25
6	780	-470,5	0		780	470,5	0		8	24
7	1323	-459	0		1323	459	0		8	24
8	1968	-451	0		1968	451	0		8	23
9	2719	-445,5	0		2719	445,5	0		8	23
10	3542	-440	0		3542	440	0		8	23
11	4394	-434,5	0		4394	434,5	0		8	23
12	5284	-432	0		5284	432	0		8	22
13	6139	-428,5	0		6139	428,5	0		8	22
14	6874	-417	0		6874	417	0		8	22

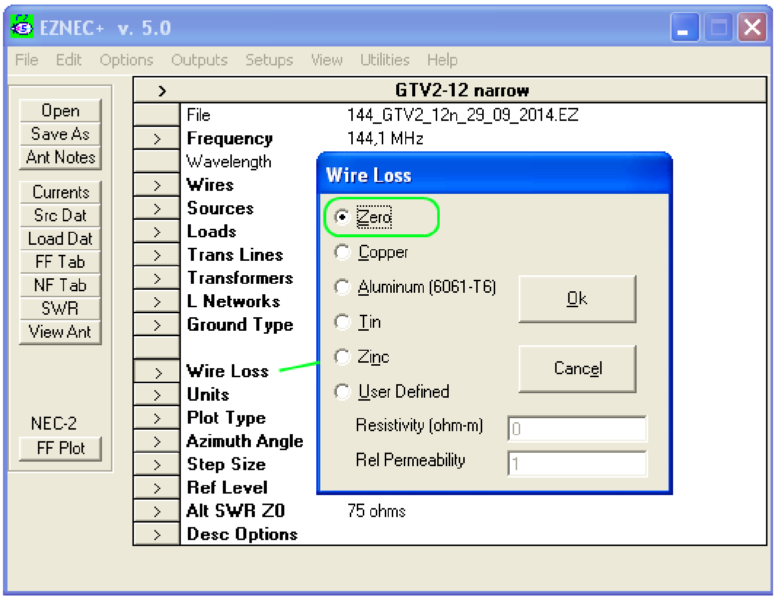
Antenna View: Note that the Yagi has 12 elements but 14 wires due to the modelling of the V-shaped bent DE employing wires 2 to 4.



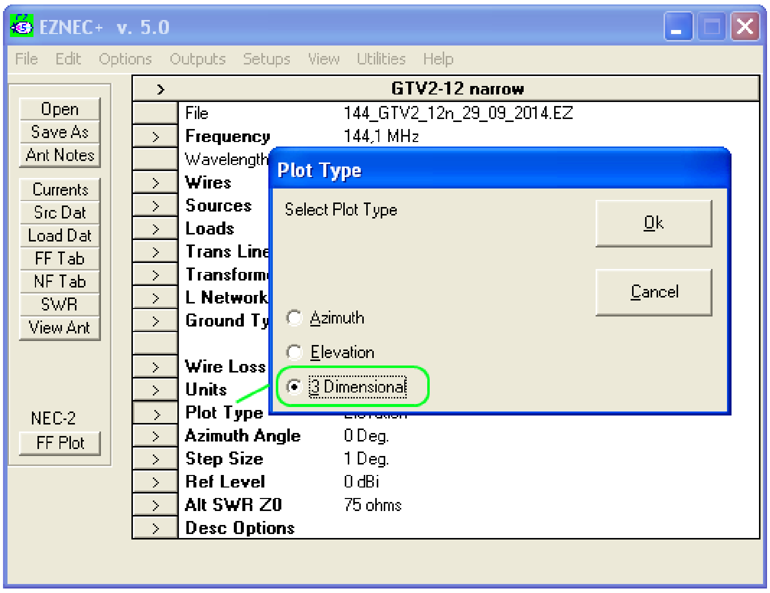
1.2 Average Gain Verification

Average Gain (AG) is derived by comparing the total input power to what amount of radiated power is found in the full 3D radiation pattern in all directions. The ratio will be 1.000 or very close to that for lossless antenna elements. Any real antenna building material manifests itself in an Average Gain lower than 1.000, typically 0.97…0.98 and thus a Tloss higher than zero Kelvin. However if the NEC kernel cannot cope with our model correctly we may end up with an Average Gain that is higher than stated above and Tloss swaps its sign.

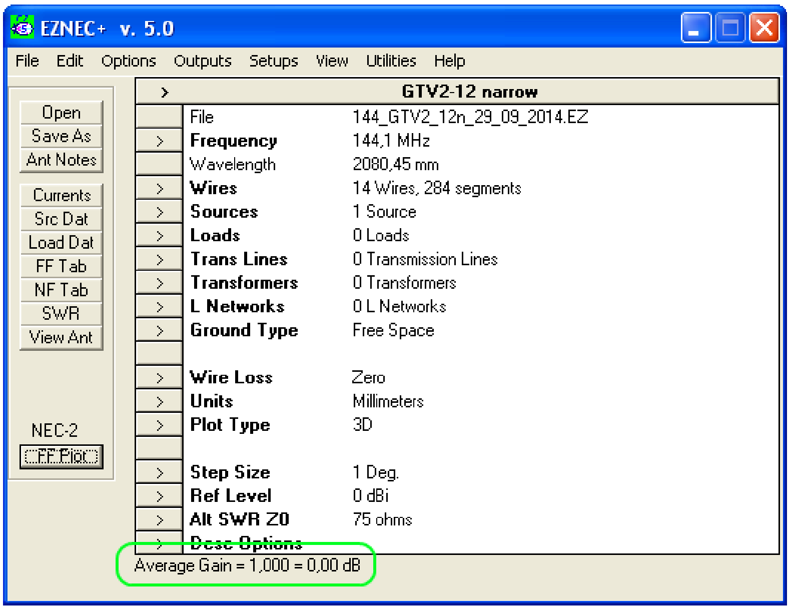
Settings for Average Gain Check (1): select Wire Loss = Zero



Settings for Average Gain check (2): select Plot Type = 3D

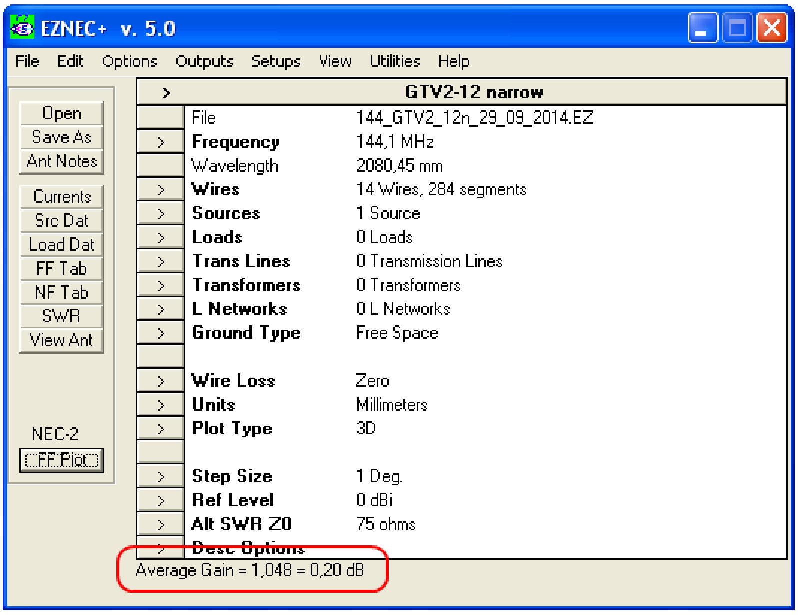


Average Gain with non tapered DE (all three wires 10 mm)



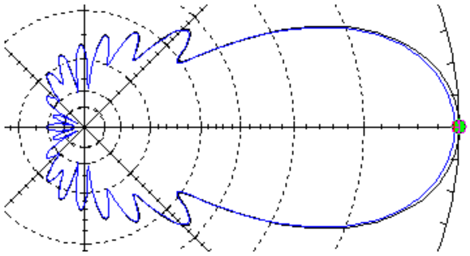
If the bent DE's tubes are tapered using a stretch of 10 mm in diameter in the middle and fitting 8 mm tubes into it to the sides, NEC will not handle the tapered sections correctly.

Average Gain with tapered DE (mid wire 10 mm, sides 8 mm)

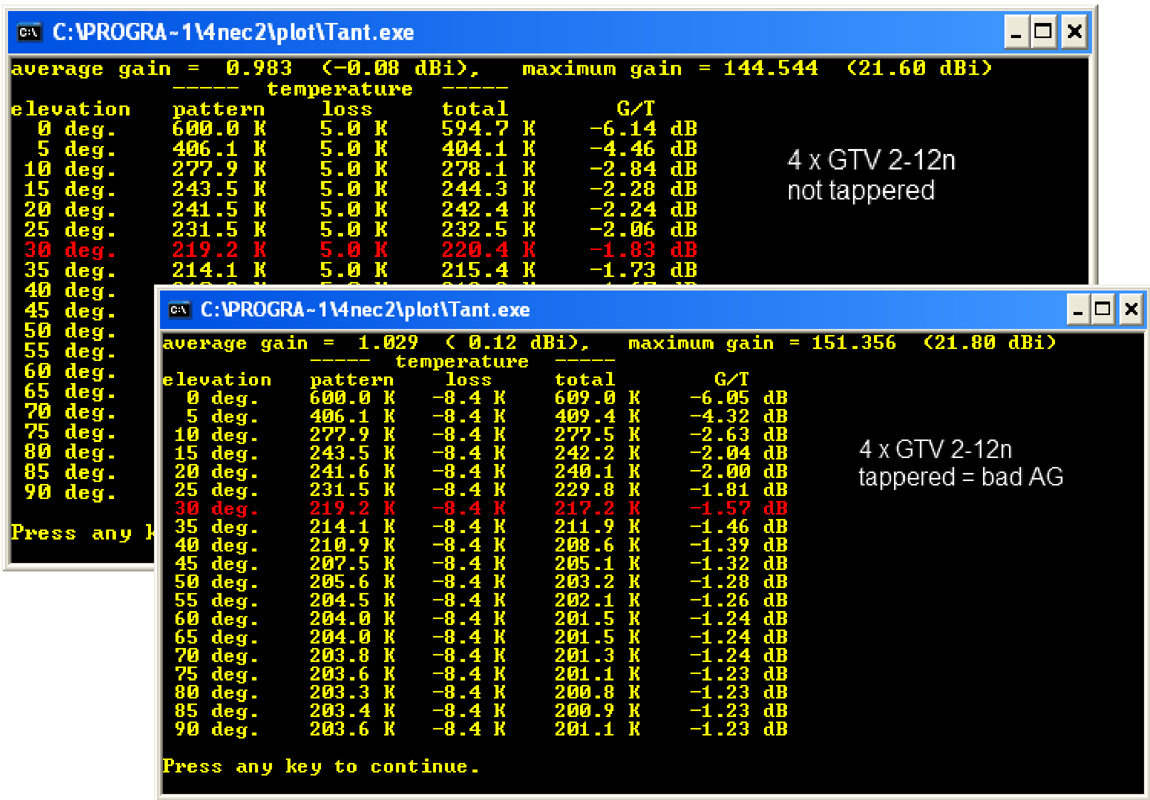


This model configuration results in an AG of 1.048 for Aluminium as material.
Since the computed total radiated power in this case is 1.048 or 105% of what we have fed into the antenna a negative Tloss of -8.4 Kelvin instead of real, thus positive (!) loss temperature is the result. Consequently gain is boosted to 15.95 dBi instead of the correct number at an Average Gain if 1.000 of 15.75 dBi for the lossless Yagi-Uda. On the following image I show what the higher gain due to a faulty positive Average Gain looks like in relation to the true number in a radiation plot.

Elevation Pattern comparison, AG = 1.048 (black), AG = 1.000 (blue line)



All in all taking this Yagi to the G/T table would result in a ‘real winner in its class’ on an unequal basis with a G/T of -0.30 instead the correct -0.60 dB for a proper model stacked per DL6WU formula:



C:\PROGRA~1\4nec2\plot\Tant.exe

average gain = 0.983 (-0.08 dBi), maximum gain = 144.544 (21.60 dBi)

elevation	pattern	loss	total	G/T
0 deg.	600.0 K	5.0 K	594.7 K	-6.14 dB
5 deg.	406.1 K	5.0 K	404.1 K	-4.46 dB
10 deg.	277.9 K	5.0 K	278.1 K	-2.84 dB
15 deg.	243.5 K	5.0 K	244.3 K	-2.28 dB
20 deg.	241.5 K	5.0 K	242.4 K	-2.24 dB
25 deg.	231.5 K	5.0 K	232.5 K	-2.06 dB
30 deg.	219.2 K	5.0 K	220.4 K	-1.83 dB
35 deg.	214.1 K	5.0 K	215.4 K	-1.73 dB
40 deg.				
45 deg.				
50 deg.				
55 deg.				
60 deg.				
65 deg.				
70 deg.				
75 deg.				
80 deg.				
85 deg.				
90 deg.				

Press any k

4 x GTV 2-12n
not tappered

C:\PROGRA~1\4nec2\plot\Tant.exe

average gain = 1.029 (0.12 dBi), maximum gain = 151.356 (21.80 dBi)

elevation	pattern	loss	total	G/T
0 deg.	600.0 K	-8.4 K	609.0 K	-6.05 dB
5 deg.	406.1 K	-8.4 K	409.4 K	-4.32 dB
10 deg.	277.9 K	-8.4 K	277.5 K	-2.63 dB
15 deg.	243.5 K	-8.4 K	242.2 K	-2.04 dB
20 deg.	241.6 K	-8.4 K	240.1 K	-2.00 dB
25 deg.	231.5 K	-8.4 K	229.8 K	-1.81 dB
30 deg.	219.2 K	-8.4 K	217.2 K	-1.57 dB
35 deg.	214.1 K	-8.4 K	211.9 K	-1.46 dB
40 deg.	210.9 K	-8.4 K	208.6 K	-1.39 dB
45 deg.	207.5 K	-8.4 K	205.1 K	-1.32 dB
50 deg.	205.6 K	-8.4 K	203.2 K	-1.28 dB
55 deg.	204.5 K	-8.4 K	202.1 K	-1.26 dB
60 deg.	204.0 K	-8.4 K	201.5 K	-1.24 dB
65 deg.	204.0 K	-8.4 K	201.5 K	-1.24 dB
70 deg.	203.8 K	-8.4 K	201.3 K	-1.24 dB
75 deg.	203.6 K	-8.4 K	201.1 K	-1.23 dB
80 deg.	203.3 K	-8.4 K	200.8 K	-1.23 dB
85 deg.	203.4 K	-8.4 K	200.9 K	-1.23 dB
90 deg.	203.6 K	-8.4 K	201.1 K	-1.23 dB

Press any key to continue.

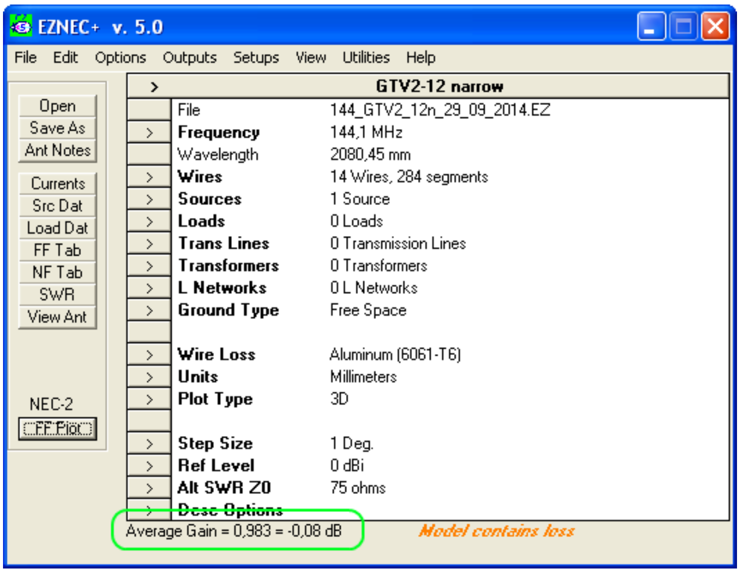
4 x GTV 2-12n
tappered = bad AG

Let us look at what a difference this wrong AG does to the Yagi in the G/T tables.
Table: G/T comparison in a fictive table, #1:Yagi that as lossless model shows AG = 1.000, #2: Yagi with tapered dipole AG = 1.048

TYPE OF ANTENNA	L (WL)	GAIN (dBD)	E (M)	H (M)	Ga (dBd)	Tlos (K)	Ta (K)	F/R (dB)	Z (ohms)	VSWR Bandwidth	G/T
#1 +GTV 2-12n	3.30	13.53	3.82	3.56	19.45	5.0	220.40	25.7	50.4	1.49:1	**-1.83**
#2 +GTV 2-12n	3.30	13.73	3.82	3.56	19.65	-8.4	217.20	25.7	46.4	1.49:1	**-1.57**

As even for lossless materials chosen an AG of higher than 1.000 is unreal and the computed figures will lead to incorrect results, model entries to the G/T table must yield a rational AG that totals a reasonable loss for chosen materials at given boom length and the number of elements involved.

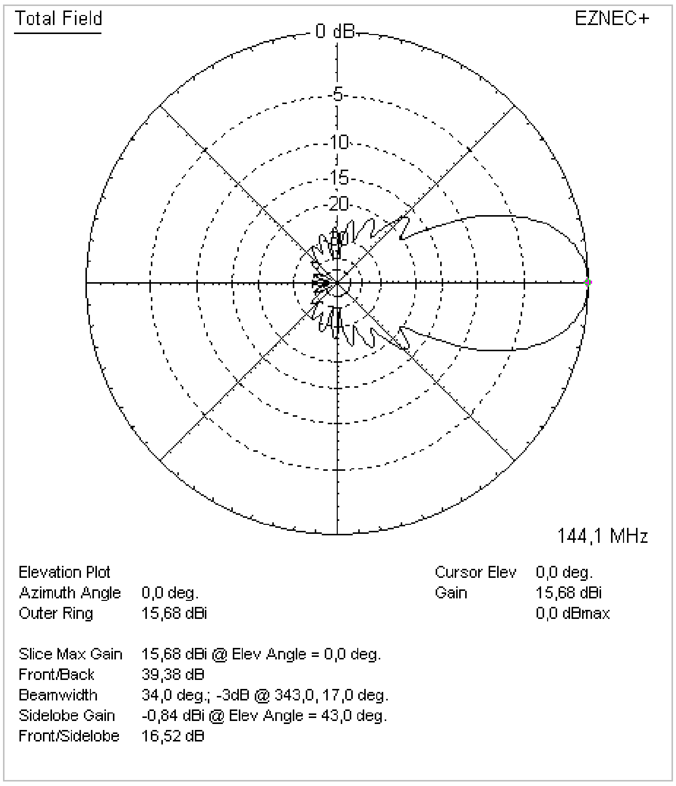
Average Gain with wire losses and DE using 10 mm tubes throughout = 0.983



It must be mentioned that since the basis for setting up the G/T table is the NEC2 Kernel as used in EZNEC or standard 4nec2 installations, it is of no help if a model with too high AG computes correctly in any other advanced antenna design program. It may prove the model to be fine in general but does not help in putting up a table on an equal base since the NEC2 based EZNEC would still deliver overoptimistic results in relation to the other Yagis enclosed in the G/T table.

2 The Models Radiation Pattern Plots

A pattern relevant for the G/T tables must be computed at given frequency, see below, since the radiation pattern slightly varies with frequency.

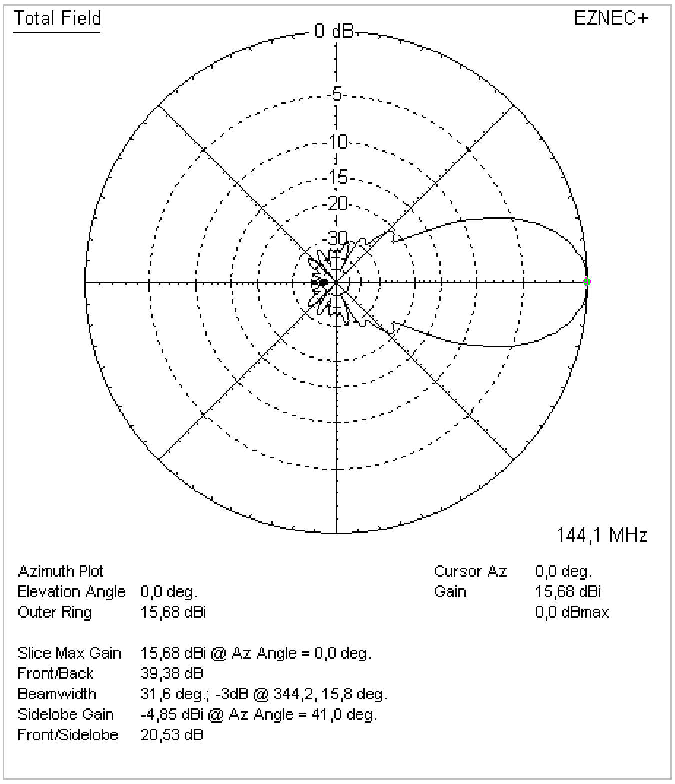


Elevation Plot of a GTV 2-12n

● **H-plane** -3 dB beam width = 34.0°

Given Frequencies for G/T Table

5 m : 50.150 MHz
2 m : 144.100 MHz
70 cm : 432.100 MHz



Azimuth Plot of a GTV 2-12n

● **E-plane** -3 dB beam width =31.6°

Further key data for the G/T table we can read from these plots are:

● Gain = 15.68 dBi = 13.53 dBD
● F/B = 39.4 dB

And a manually figured out

● F/R = 25.7 dB

by looking for the largest lobe inside the rear sector (90…270 respectively 90/-90 degree). See next page for how to derive the F/R.

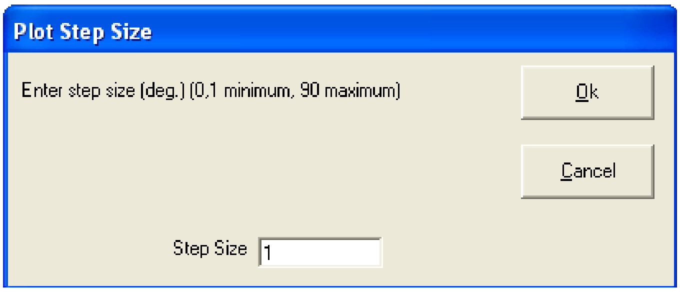
Determination of F/B and F/R ratio

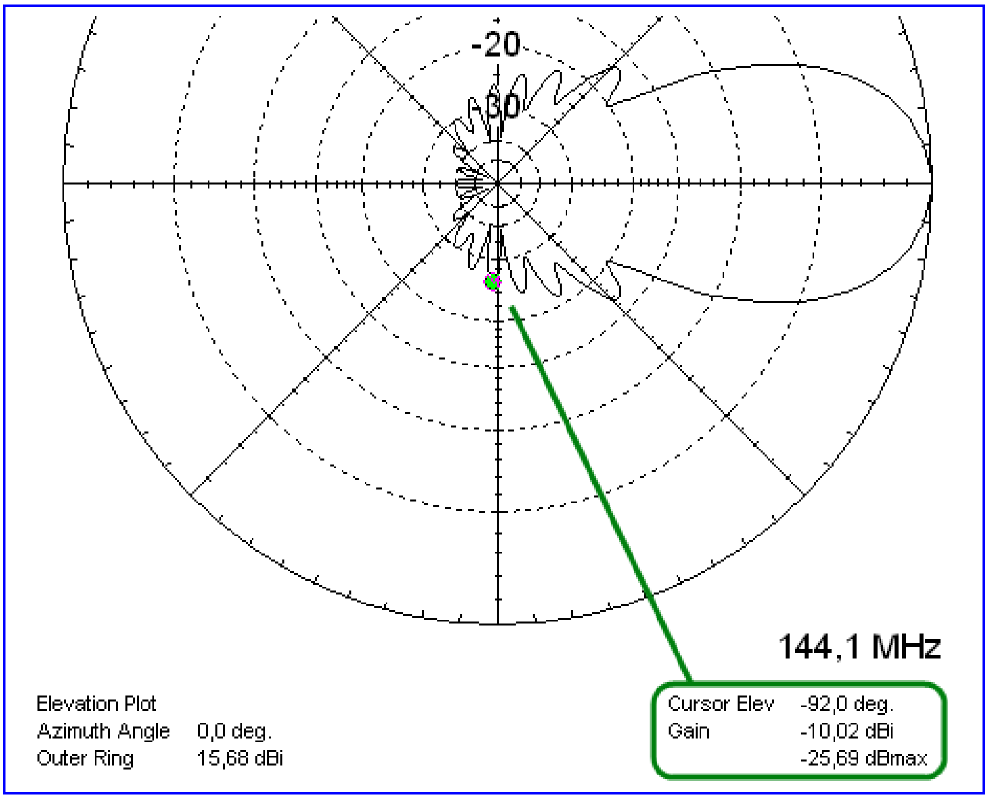
How is it done in the G/T table?

In EZNEC we produce an elevation plot with plot resolution set to 1 degree (side menu: '*Step size*'). Click onto the plot line close to what looks as the largest lobe in rear section from -90 to +90 degrees of beam angle. Then find the absolute maximum number by ticking through a few degrees either side of that lobe by use of the left and right arrow keys of your keyboard.

EZNEC Step Size Window

Elevation Plot of the GTV 2-12n





For the GTV 2-12n the F/R is close to the threshold of the rear half of the plot circle. We find an F/R ratio in compliance to the G/T Tables (-)25.69 dB at 92 degrees for this design. If we calculate this we get 15,68 dB - (-10,02 dB) = 25.70 dB.

● Which plane to use? Elevation or Azimuth?
We have to look out for the largest lobe there is in both planes. Ordinary Yagi structures hold their largest back lobe in the Elevation pattern but you better check both planes.

F/B vs. F/R - Background information

The general definition of F/B ratio uses radiated power in beam- and opposite direction

$$(2.1) \quad F/B\,[dB] = 10\,\log\left(\frac{P_{Forward}}{P_{Backward}}\right)$$

$$(2.1b) \quad or\ using\ Gain: \quad F/B\,[dB] = G_{forward} - (\,G_{backward}\,)\,[dB]$$

The definition of how to determine F/R is not a uniform one among antenna technicians. It is a difficult task to find a calculation base that does a weighting of the rear lobes that pleases everyone. Here we stick to how it is done in the G/T table, which is also as Arie Voors has programmed it in 4nec2:

Definition of F/R in compliance with 4nec2 - citing the 4nec2 help file we find:

> *"For default settings of gain angles and backward angle i.e. 0 respectively 180 degrees, the largest gain value for angles between 90 and 270 degrees is used as the Rearward gain value. The F/R value is the Forward-Gain value minus this Rearward-Gain value."*

In a formula similar to (2.1) but aiming at F/R we find a definition as follows:

$$(2.2) \quad F/R\,[dB] = 10\,\log\left(\frac{P_{Forward}}{P_{Largest\ Rearbound.}}\right)$$

$$(2.2b) \quad or\ using\ Gain: F/R\,[dB] = G_{Forward} - (-\,G_{Largest\ Rearbound})\,[dB]$$

How can we calculate this by hand from what we can read from the radiation plot?

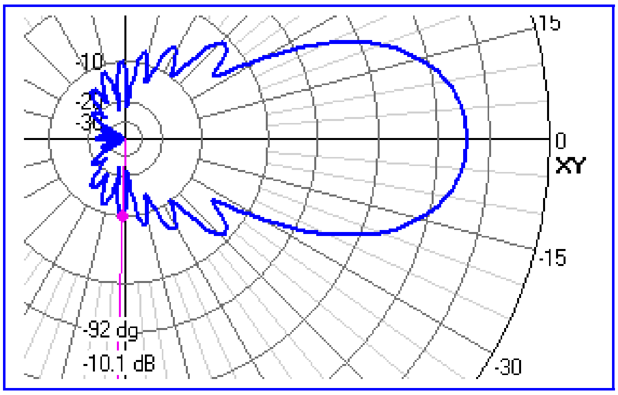
1. In EZNEC go straight ahead since the pattern plot window does not hold an option for normalised / not normalised levels, in 4nec2 switch far field options to ‘no normalisation’.

2. From the not normalised pattern plot we take measures of forward gain and the largest lobe we find between 90 and -90 degrees (EZNEC) respectively 90 and 270 degrees (4nec2 default Theta and Phi) - simply put, the rearward half of the plot scale.

$$Boundary\ Conditions \quad [a,b] = \{\,a \le x \le b\,\} \quad with \quad a,b = +/-\ 90^{\circ}$$

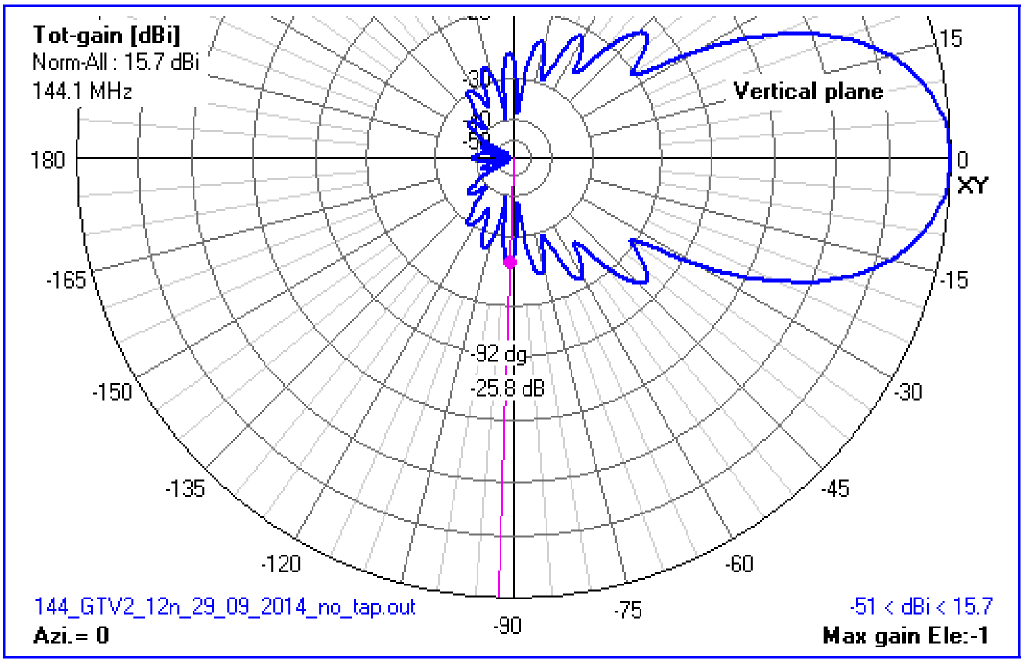
Reading these numbers from the radiation pattern chart and filling them into (2.2b) leads to the hand made F/R:

• Non normalised ARRL Style



$$F/R = 15.68\ dB - (-10.10\ dB) = 25.78\ dB$$

• Normalised ARRL Style (other antenna as second example)



1. Click somewhere near to the suspected lowest F/R in the rear half of the plot and tick towards the maximum from -90 to +90 degrees using the left/right arrow keys.

2. Gain in beam direction is normalised to 0 dBi. When turning the antenna so that the signal strength is maximum of what we find in the entire rear sector we yield a loss in signal strength by a theoretical number of -25.78 dB in free space conditions

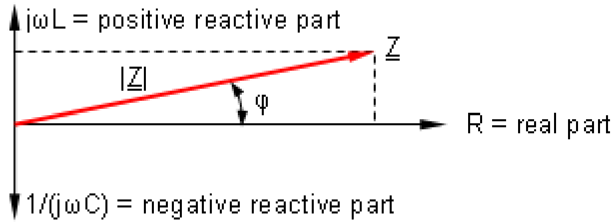
3 Determination of Bandwidth for the G/T Table

3.1 Impedance at desired frequency

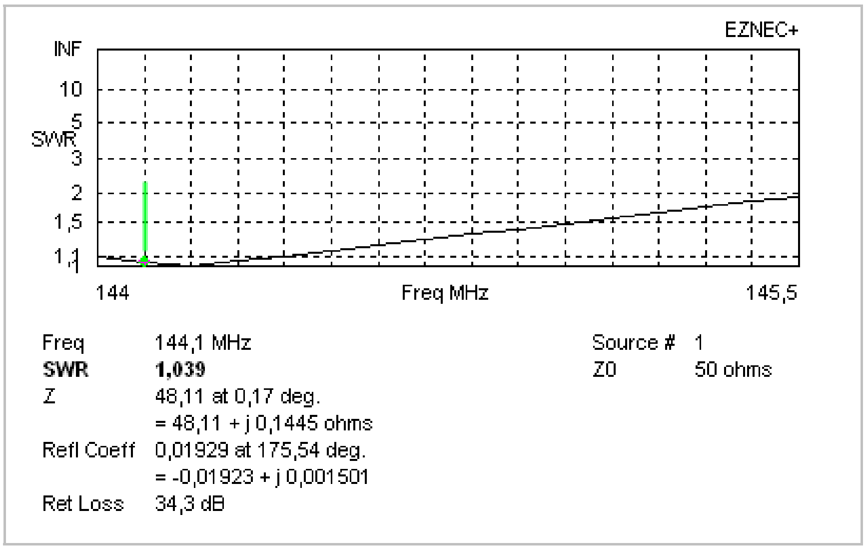
Impedance Z has a real and an imaginary part, it is a complex number. The real part represents the ohmic side whereas the imaginary part shows the capacitive or inductive fraction that may come along when the Yagis resonance is not 100% 'spot on'. Complex numbers can be written using *Cartesian* or *polar* coordinates:

$$(3.1) \quad \underline{Z} = (R + jX) \text{ in cartesian coordinates} \qquad (3.2) \quad \underline{Z} = |\underline{Z}| \cdot e^{j\varphi} \text{ in polar coordinates (Euler)}$$

Z = complex impedance (what we commonly name impedance Z), |Z| = apparent impedance, R = (ohmic) resistance, X = reactance (due to fraction of L and/or C)



The G/T tables use 50.150 MHz / 144.100 MHz / 432.100 MHz as the target frequencies throughout, so we place the marker there and read out the complex impedance Z [Ohm]. In our example (GTV 2-12n) we read Z = (48.11 + j 0.14) Ohm or in Euler's notation 48.11Ohm at 0.17 deg. as the apparent impedance |Z| from the data displayed in the EZNEC VSWR plot window:

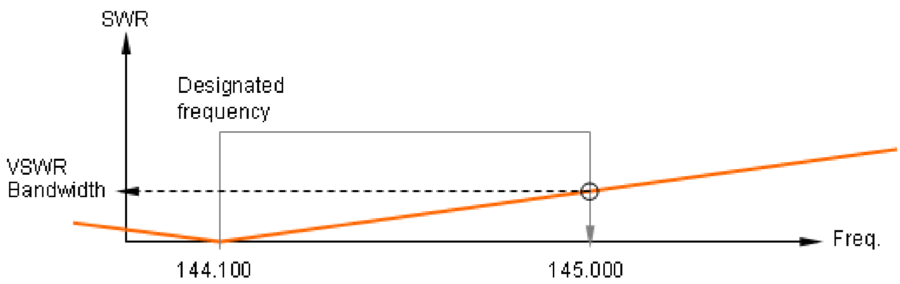


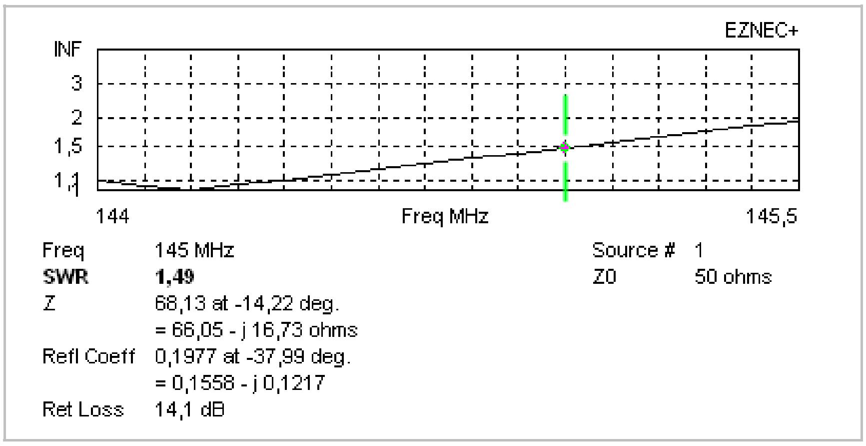
However, VE7BQH uses just the real part, the resistance R picked from complex impedance Z for the G/T table. It will not make a significant difference what figure to use as long as the Yagi is not far from the wanted impedance. Since small angles φ provide very small changes only. => Consequently we note 48.1 Ohm as our Z for the G/T table.

3.2 VSWR Bandwidth in the G/T table

This parameter determines how forgiving the modelled design is against influences from the real world on its designated frequency. In designing an EME Array the needed band width is quite narrow. But we must realise that very narrow band Yagis will be quite difficult to build and preserve all of the properties of the antenna. The actual VSWR is not the only important mark as pattern properties such as gain and F/R are a frequency depending too. Commonly VSWR bandwidth reflects on pattern behaviour. Therefore, we use VVSWR_over the measured band to give a sensitive indicator of its useable band width:

Determination of the G/T tables VSWR bandwidth: Place the marker at 145.000 MHz and read the VSWR from the Charts Data box. We find an VSWR figure of 1.49 in the EZNEC VSWR plot for the example Yagi. VE7BQH declares this figure as 'VSWR Bandwidth = 1.49:1' in his G/T table





As VE7BQH writes in his description below the G/T table a Yagi with outstanding pattern may be worth little if a high Q-Factors designs pattern quality is only achieved in dry conditions or if real build might be out of that narrow bandwidth by not meeting Boom Correction specs fully.

> *"While Gain is important, other factors like ease of matching and wet weather performance should be considered in your decision making."*

Instead of the complex parameter of Yagi Q-Factor [1] he settled on a very simple but effective figure. With approximately 5 mm of element length between ideal resonance on either 144.1 or 145.0 MHz a build within these specs is very likely to be realised even if compensation for boom or insulators is not fully achieved.
[1] see: Dobricic, D., YU1AW: Yagi Antenna Q Factor, Antennex #135, 08-2008)

4 Building the 4 Yagi bay

4.1 Building a 4 Yagi by in EZNEC

The denotation of stacking distances as E and H can be confusing for newcomers in antenna array designing. Given a horizontal polarisation of the Yagis the nomenclature is as shown below, for V-pol this is all to be inverted, see § Stacking.

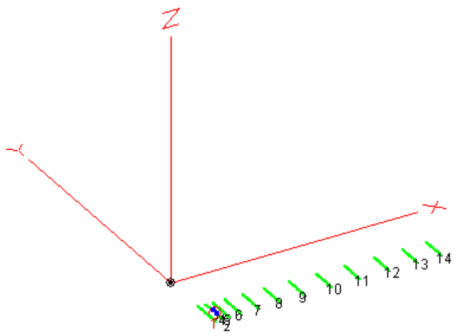
E-plane [H-pol] = electric field // side-by-side (azimuth plot)
H-plane [H-pol] = magnetic field // top-to-bottom (Elev. plot)

Given a horizontal polarisation on an average Yagi the elevation pattern slices -3 dB beam width is larger than the one of the azimuth pattern. Larger beam width leads to less stacking distance. So that following the DL6WU stacking scheme most Yagis will be stacked wider side by side than on top of each other.

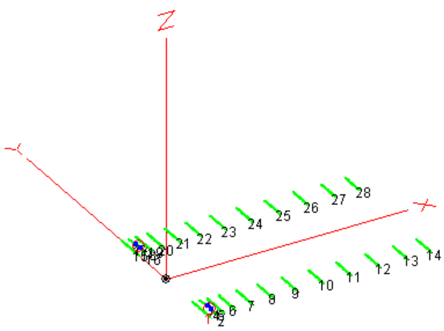
Using the DL6WU formula (§ Stacking) at our target frequency of 144.100 MHz we derive at:
E-plane: Azim. Pattern -3 dB beam width = 31.6 deg. => 3.82 m as distance side-by-side
H-plane: Elev. Pattern -3 dB beam width = 34.0 deg. => 3.56 m as distance top-to-bottom
for the GTV 2-12n model.

Step 1: Starting with the single Yagi NEC file we use half the side-by-side distance to move the Yagi sideways using 'Move Wires' -3.820 / 2 = -1.910 mm along the Y-axis.
Step 2: Next we copy all wires using 'Offset copy Y by' 3.820 mm.

Step 1:

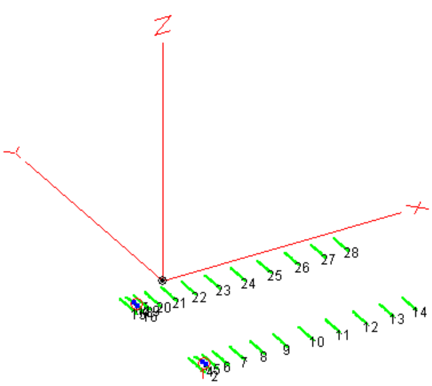


Step 2:



Step 3: Following that we lower the 2 Yagis by half the H-stacking distance of -(3,558 mm / 2) = -1,779 mm by using 'Move Wires XYZ' in Z-direction.

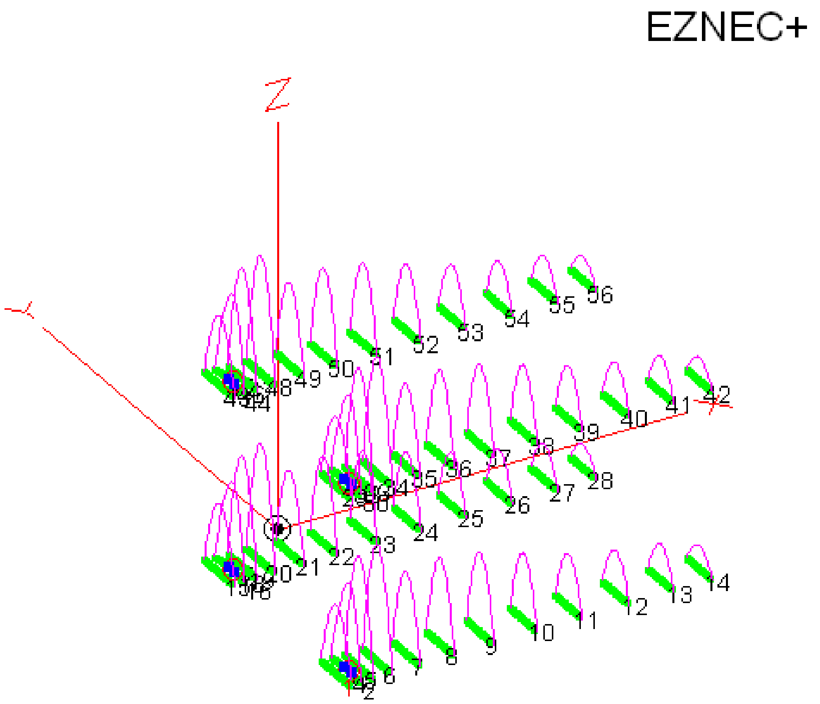
Step 3:



Step 4: Last we copy the 2 Yagis using ‘Offset copy Z by’ 3,558 mm.

Now we have created a 4 Yagi bay that is all symmetrical around the x-axis, and thus will deliver its maximum gain at an angle of 0 deg. to the x-axis exactly as TANT wants it to be.

Step 4:



Note on stacking distances:

Besides stacking dimensions according to the DL6WU formula the bay might be stacked at different distances too. VE7BQH writes in his description at the end of the G/T table:

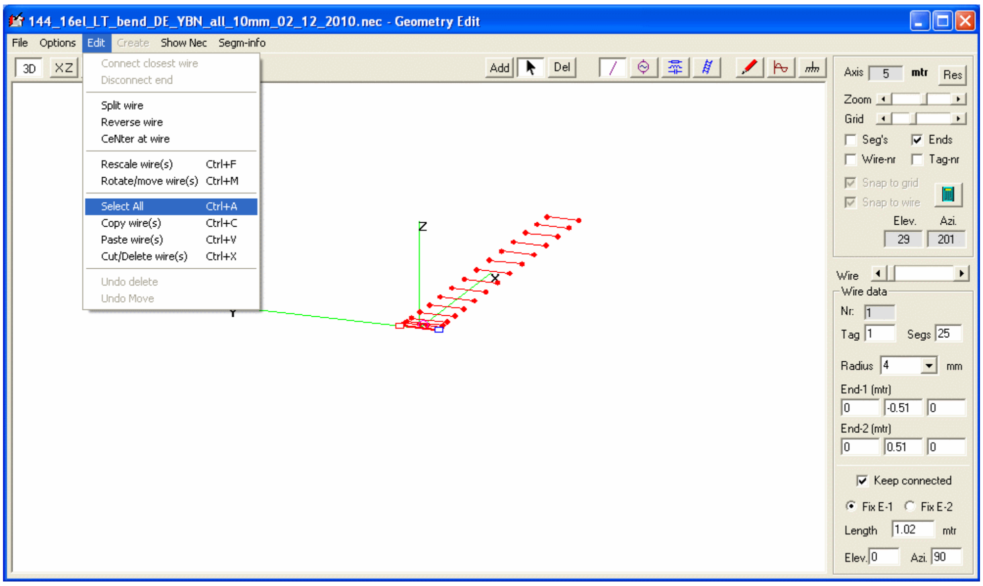
> *5. All stacking dimensions* ***EXCEPT*** *those marked with a "*" and "#" are calculated from the DL6WU stacking formula.*
>
> *6. Antennas marked with a "*" have stacking dimensions recommended by the manufacturer or designer.*

Some designers prefer other spacing since the DL6WU formula does not serve all pattern forms equally to the last couple of 10th dB and best G/T ratio.

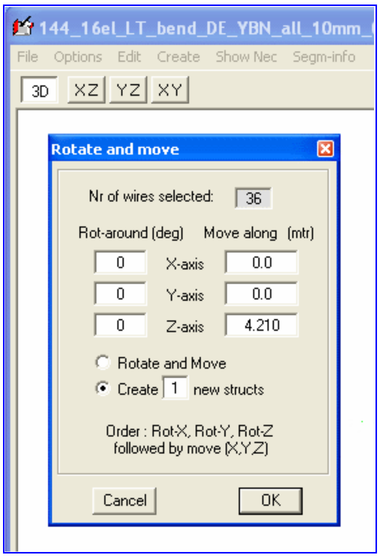
See § Stacking -> Notes on ‘Over Stacking’.

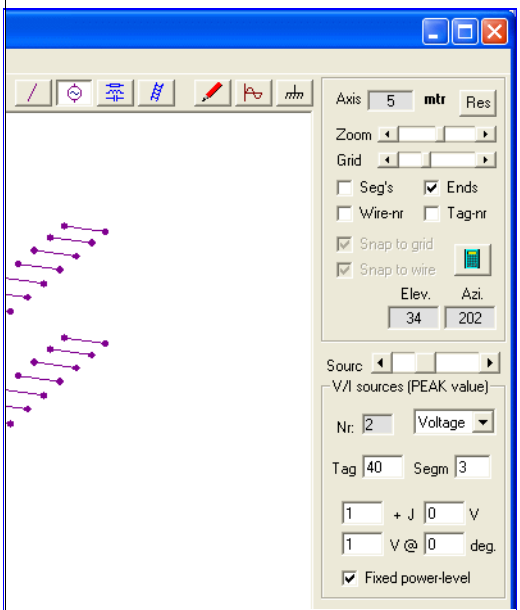
4.2 Building the 4 Yagi bay in the 4nec2 Geometry Editor

Please follow steps and use distances as described for EZNEC in previous chapter.



Use *menu* => *Edit* => *'Select All'*. Move and copy Yagi(s) using window '*Rotate and Move'* above *'Select All'*. '*Move*' is self explaining whereas '*Create n new structs'* is what is called '*Copy Wires'* in EZNEC. Fill in '1' for a single copy and a number for displacing distance on the right axis. Before next '*Move*' command make sure to have selected all new and old wires you want to move. Repeat 'Select All' or mark by hand using 'ctrl' and mouse clicks.

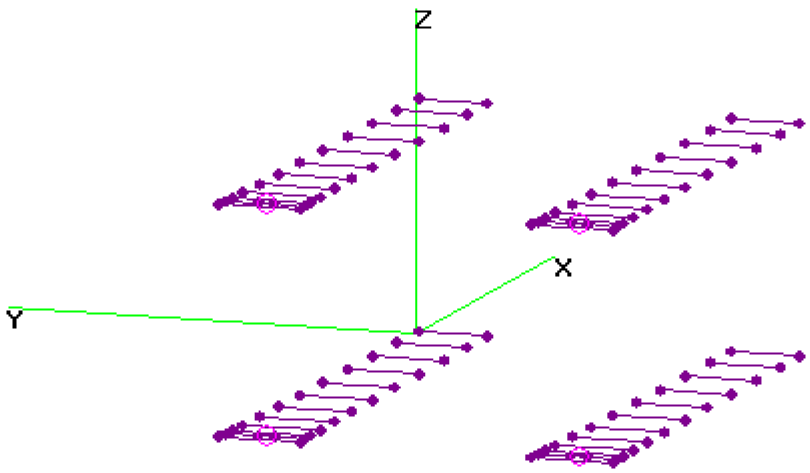




Unlike EZNEC <u>*4nec2 does not copy sources*</u>, just wire structures, hence the name. We have to add sources to all copied Yagis now.

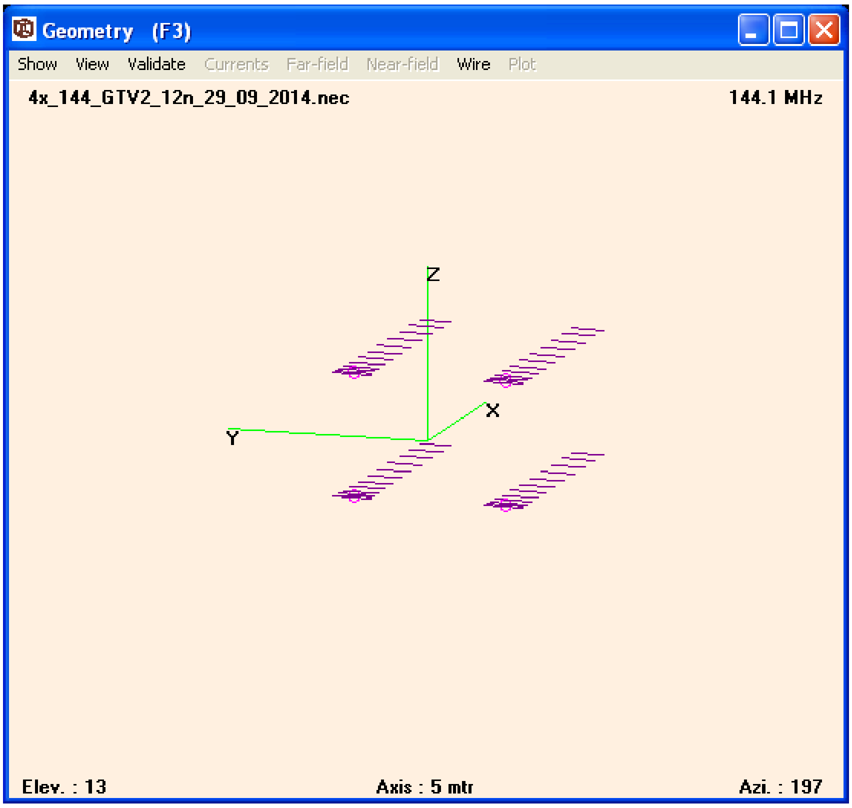
Since placement of the new sources on the same segment of the wire (Tag) is critical I recommend controlling their positions one by one. To do that mark the source icon in the menu and use the slider bar on left to go through source 1 to 4. Make sure they are all on same segment as the one on the initial Yagi. If not, edit segment in window 'Segm' in the 'Source' frame. That is far easier then shoving them around on the wire by mouse action.

Finally we have created a similar 4 Yagi bay using 4nec2's Geometry Edit. Note that the view in Z orientation is distorted in the 'geometry' window. Yagis seem to be stacked too closely. In fact distances are in order, only the perspective is not proportional.



For a visual inspection of the stacking distances and proportions the 'Geometry' Window (F3 - key) is more suitable and displays without distortion.

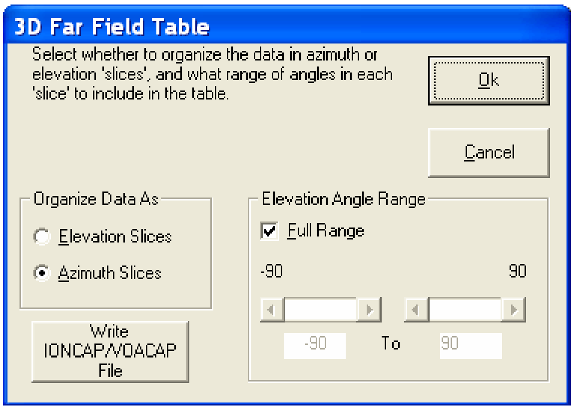
4nec2 'Geometry' Window:



5 Computing the G/T ratio

Now that we have a Bay of Yagis with specific element diameters, segmentation, stacking dimensions and orientation of the main beam AND calculating stacking distance + pattern plot done on right frequency we run a 3D plot of that model. The computed Far Field data must be transferred into a file in .txt format.

5.1 Deriving the FFtab file using EZNEC

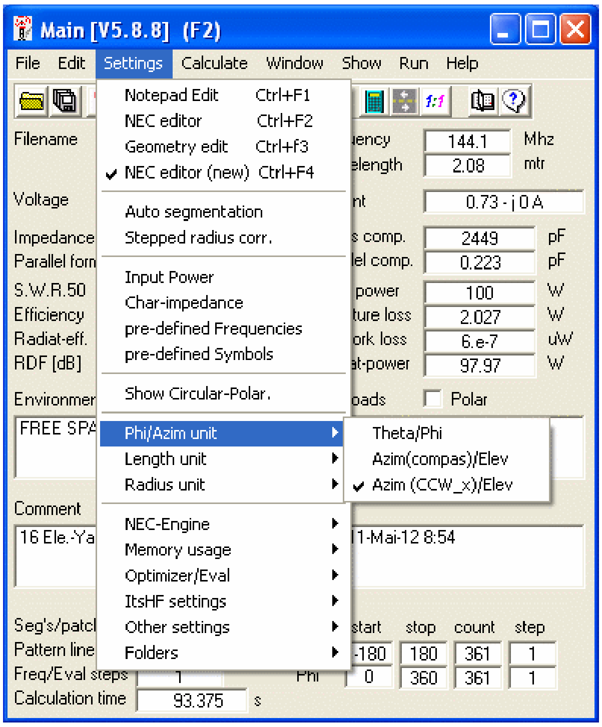


Use the 'FF Tab' button on the left side of the EZNEC main window. Opt for 'Azimuth slices' and check 'Full Range'. Proceed in same way to produce an FFtab file for AGTC_lite.
Save the file using a filename with 6 plus 3 characters (example: d16vde.txt). Make sure that the file contains period and not comma as decimal separator. Now opt for '*Azimuth Slices'* and check '*Full Range'* for *Elevation Angle Range*. A detailed description of this procedure is given in the TANT Manual.

5.2 Deriving the FFtab file using 4nec2

1. Adjusting 4nec2 Default Settings

● Set pattern degree orientation to „*Azim (CCW_x)/Elev*"

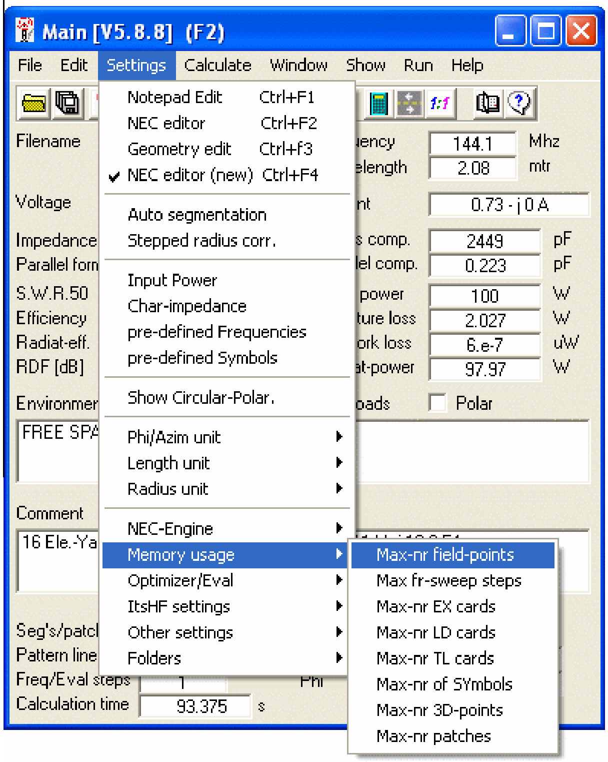


Menu -> Settings -> Phi/Azim unit -> Azim (CCW_x)/Elev

This will set the 4nec2 program to count radiation pattern angles counter clockwise (*CCW*) and produce pattern slices in elevation orientation = azimuth slices

And most important: to set the models x-axis to be zero degrees and thus maximum gain to occur at zero degrees if our models orientation is right. This is as TANT needs the far field data for processing them.

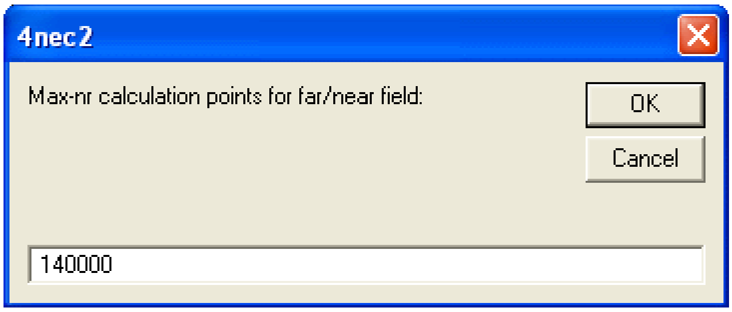
● Set maximum number of field points



-> *Memory Usage -> Max-**nr** field-points ->* …

The maximum number of field points correlates with the limit of how exact by means of what pattern resolution in degrees we may calculate. As TANT needs a high resolution of at least 3 degrees or for best results one degree we change from default of *66,000 to 140,000*.

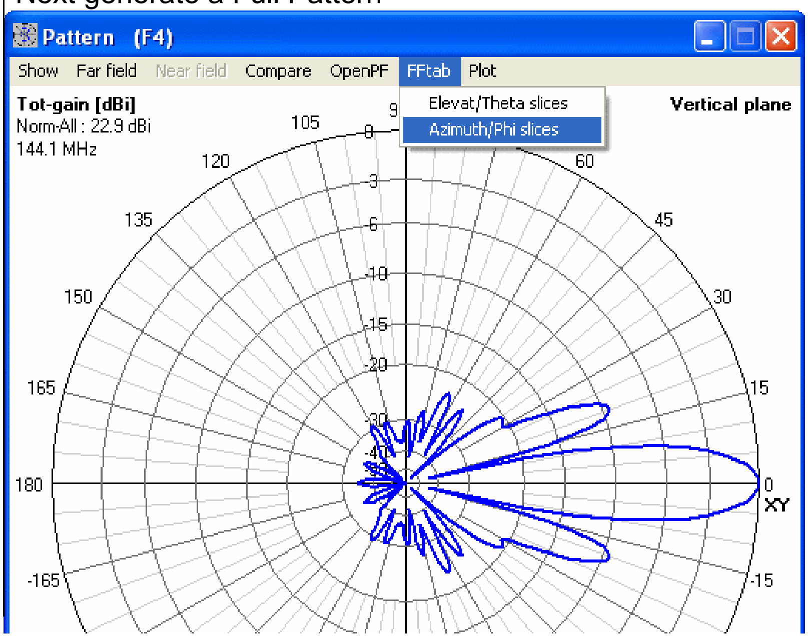
Now 4nec2 is set to produce a Far Field Table that is valid for processing it in TANT.



Generating Pattern and Far Field Table

Set resolution to 1 degree and be sure to have set frequency right for your purpose. If the Far Field Table is to produce Antenna Temperature and G/T as per 2 m VE7BHQ G/T Table it must be set to 144.1 MHz. The Yagi orientation must stretch along the x - axis.

Next generate a Full Pattern



Note: Computing that amount of data needs some time. Using a file of a large 4 bay Yagi containing 1400 segments takes approx. 1 min 30 sec. on a 2 GHz Centrino Duo + 3 Gb RAM.

Find the FFtab option in the "*Pattern*" windows menu, use "*Azimuth/Phi slices*" for TANT and AGTC_lite

Now use new menu selection ‚*FFtab*' in the Pattern window and pick ‚*Azimuth/Phi slices'* to create the FFtab.txt file.

Handling FF-tab file and TANT respectively AGTC_lite

4nec2 will save the FFtab.txt file in its plot folder, which is located in the root path of 4nec2 in c:\programs\4nec2.

- Place a copy of Tant.exe or AGTC_lite.exe in the same folder.
- Create a shortcut to plot folder on desktop.
- Open plot folder, rename the actually created FFtab.txt to something meaningful by using an 8+3 DOS filename. That means that your filename must contain a combination of six characters or/and numbers followed by .txt (example: 'dg16f1.txt'). Note: AGTC_lite has no restriction to a 8+3 DOS filename.

5.3 Deriving the Antenna-G/T using TANT

Open the file in TANT and compute

```
C:\PROGRA~1\4nec2\plot\Tant.exe
average gain =  0.983  (-0.08 dBi),   maximum gain = 144.544  (21.60 dBi)
                 ----- temperature -----
elevation    pattern     loss       total        G/T
  0 deg.     600.0 K     5.0 K     594.7 K     -6.14 dB
  5 deg.     406.1 K     5.0 K     404.1 K     -4.46 dB
 10 deg.     277.9 K     5.0 K     278.1 K     -2.84 dB
 15 deg.     243.5 K     5.0 K     244.3 K     -2.28 dB
 20 deg.     241.5 K     5.0 K     242.4 K     -2.24 dB
 25 deg.     231.5 K     5.0 K     232.5 K     -2.06 dB
 30 deg.     219.2 K     5.0 K     220.4 K     -1.83 dB
 35 deg.     214.1 K     5.0 K     215.4 K     -1.73 dB
 40 deg.     210.9 K     5.0 K     212.3 K     -1.67 dB
 45 deg.     207.5 K     5.0 K     208.9 K     -1.60 dB
 50 deg.     205.6 K     5.0 K     207.1 K     -1.56 dB
 55 deg.     204.5 K     5.0 K     206.0 K     -1.54 dB
 60 deg.     204.0 K     5.0 K     205.5 K     -1.53 dB
 65 deg.     203.9 K     5.0 K     205.4 K     -1.53 dB
 70 deg.     203.8 K     5.0 K     205.3 K     -1.52 dB
 75 deg.     203.6 K     5.0 K     205.0 K     -1.52 dB
 80 deg.     203.3 K     5.0 K     204.8 K     -1.51 dB
 85 deg.     203.4 K     5.0 K     204.9 K     -1.51 dB
 90 deg.     203.6 K     5.0 K     205.0 K     -1.52 dB

Press any key to continue._
```

From the TANT output line at 30 deg. of array elevation we read the following numbers used in the G/T table:

Denomination TANT	Denomination G/T Table	Numerical Value
maximum gain	Gain	21.60 dBi = 19.45 dBD
temperature loss	Tlos	5.0 K
temperature total	Ta	220.4 K
G/T	G/T	-1.83 dB

5.4 Deriving the Antenna-G/T using AGTC_lite

The AGTC_lite DOS Console program is developed in Basic by F5FOD with DG7YBN. Release at date of issuing this manual is v1.55. Basically it can be operated like TANT and reads same FFTabs from EZNEC or 4nec2.

The key benefits of AGCT_lite are:
FF Table file names not restricted to 8+3 DOS names. If the decimal separator in the FFTab is a comma it is automatically replaced by a dot for the computation. The pattern does neither have to be fully symmetrical nor must max. gain occur on x-axis exactly.

Below: Start up screen (1) - enter numbers for T_sky and T_earth
(2) After entering the FFtab file name it appears in the frames header of the program

```
AGTC_lite v1.55: G/T computed with noise sphere rotation
AGTC_lite_V1-55
Computation of G/T from Far Field Table by F5FOD with DG7YBN, vers. 1.55

Enter   Sky Temperature (K)? 200
Enter Earth Temperature (K)? 1000

Enter FFTab's file name  _ _ _ .txt?
```

AGTC_lite's output table: results plotted in TANT style, showing for what FFtab file it was computed in the header still

```
AGTC_lite v1.55       FFTab: 4x_GTV2_12n_non_tapered_6wu.txt
Average Gain = 0.983 (/) = -0.08 dBi
Max Gain = +21.60 dBi at azimuth =   0 degree(s) and elevation =   0 degree(s)
 T_sky =  200.00 K                                       T_earth = 1000.00 K
Alpha (deg.)  T_pattern (K)   T_loss (K)   T_total (K)     G/T (dB)
     0           600.00         5.08         594.66        - 6.143
     5           389.62         5.08         387.90        - 4.287
    10           271.14         5.08         271.46        - 2.737
    15           242.80         5.08         243.61        - 2.267
    20           240.92         5.08         241.76        - 2.234
    25           229.58         5.08         230.62        - 2.029
    30           216.96         5.08         218.22        - 1.789
    35           211.58         5.08         212.93        - 1.682
    40           208.42         5.08         209.83        - 1.619
    45           205.27         5.08         206.73        - 1.554
    50           203.90         5.08         205.38        - 1.526
    55           203.66         5.08         205.15        - 1.521
    60           203.62         5.08         205.11        - 1.520
    65           203.61         5.08         205.10        - 1.520
    70           203.62         5.08         205.11        - 1.520
    75           203.55         5.08         205.04        - 1.518
    80           203.40         5.08         204.89        - 1.515
    85           203.50         5.08         204.99        - 1.517
    90           203.57         5.08         205.06        - 1.519

Press any key to continue!
```

6 The G/T Table in Detail

In the VE7BQH G/T Table this 16 elem. Bent DE - Yagi is listed with the following figures:

TYPE OF ANTENNA	L (WL)	GAIN (dBD)	E (M)	H (M)	Ga (dBd)	Tlos (K)	Ta (K)	F/R (dB)	1st SL (dB)	2nd SL (dB)	Z (ohms)
+DG7YBN GTV2-12n	3.30	13.53	3.82	3.56	19.45	5.0	220.4	25.7	16.5	21.1	48.1

VVSWR Bandwidth	G/T	Feed System	KF2YN Convergence Correction req.	Polarity
1.49:1	-1.83	Bent Dipole	No	

6.1 L = Length in Wavelengths

L is the electrical length from first to last elements position, <u>not</u> the mechanical length of the boom, divided by wavelength λ at designated frequency.

$$\lambda = \frac{299.792}{144.100} = 2.080444\, m$$

The 16 elem. GTV Yagi has its Reflector at pos. 0 mm and the last element at 9870 mm. We calculate its electrical length in wave length (WL or wl often) as follows:

$$WL = \frac{9.870\, m}{2.0804\, m} = 4.7443$$

6.2 Gain = Gain in dBD of a single antenna

Gain in dBD is Gain dBi - 2.15 dB. For the GTV 2-12n that is

$$G_{dBD} = 15.68\, dBi - 2.15\, dB = 13.53\, dBD$$

6.3 E = E plane (Horizontal) stacking in Meters

Side-by-side (azimuth plot) stacking distance for any horizontally polarised Yagi *. Standard is distance per DL6WU formula unless row is marked with a * indicating an individual stacking distance. Azim. Pattern -3 dB beam width of the GTV 2-12n = 31.6 deg. => 3.82 m.

6.4 H = H plane (Vertical) stacking in Meters

Top-to-bottom (Elev. plot) stacking distance for any horizontally polarised Yagi *. Standard is distance per DL6WU formula unless row is marked with a * indicating an individual stacking distance . Elev. Patterns -3 dB beam width of the GTV 2-12n = 34.0 deg. => 3.56 m.

(*) inverse for any vertically polarised Yagi

6.5 Ga = Gain in dBD of a 4 bay array

Gain in dBD is Gain dBi - 2.15 dB. For the 4-Yagi-Bay of GTV 2-12n Yagis that is

$$G_{a,dBD} = 21.60\,dBi - 2.15\,dB = 19.45\,dBD$$

6.6 Tloss = The internal resistance of the antenna in degrees Kelvin

Tloss = Ttotal – (Tpattern attenuated by the loss in the bay of Yagis)

The information on ohmic losses is contained in the EZNEC Far Field Table. It is the difference between 0.00 dBi and power gain averaged over all directions = Average Gain. The Average Gain with Wire Losses turned to 'Zero' will be 1.000; the Average Gain employing real Material Losses must be < 1.000. Else AVG Correction per KF2YN (see further down) will be applied. The difference is the Loss expressed in Tloss [K]. To add the temperature of the Loss to the Pattern temperature it has to be converted into Loss L [/], see formulas below.

6.7 Ta = The total temperature of the antenna or array in degrees Kelvin. This includes all the side lobes, rear lobes and internal resistance of the antenna or array.

$$T_{total} = \frac{T_{pattern} + (L-1)\,290\,K}{L}$$ with L [/] expressed as $$L = \frac{T_{loss}}{290\,K} + 1$$

An example using the GTV 2-12n's Tpattern = 219.2 K and Tloss = 5.0 K

$$L = \frac{5.0\,K}{290\,K} + 1 = 1.01724138\,[/]$$

$$T_{total} = \frac{219.2\,K + (1.01724138 - 1)\,290\,K}{1.01724138} = 220.4\,K$$

The real world materials resistance (Aluminium 6061 = AlMgSi0.5) causes losses that increase the total Antenna Temperature Ttotal or simply put Tant of the bay by

$$220.4 - 219.2 = 1.2\,K$$

6.8 F/R = Front to Rear in dB over the rear 180 degrees of an antenna using either E or H plane

Column F/R (dB) is for one antenna. The F/R of the GTV 2-12n is 25.7 dB - see § 2.

6.9 1st SL = First Sidelobe from Main Beam

Column 1st SL is the magnitude of the first Sidelobe on the Elevation Pattern of the single Yagi

6.10 2nd SL = Second Sidelobe from Main Beam

Column 2nd SL is the magnitude of the second Sidelobe on the Elevation Pattern of the single Yagi

6.11 Z ohms = The natural impedance of a single antenna in free space

Column Z(ohms) is for one antenna (see § Determination of Bandwidth for the G/T table)

6.12 VSWR = VSWR Bandwidth is based a single antenna over 144.000 - 145.000 MHz with a reference of 1.00:1 at 144.100 MHz. This parameter gives an indicator of the antenna "Q" and what to expect with stacking and wet weather.

Column VVSWR is for one antenna (see § Determination of Bandwidth for the G/T table)

6.13 G/T = Figure of merit used to determine the receive capability of the antenna or array = (Ga + 2.15) - (10*log Ta). The more positive figure the better.

$$G_{dBi}/T_{Ant} = G_{dBi} - 10\log T_{total}$$

$$G_{dBi}/T_{Ant} = 21.60\,dBi - 10\log 220.40\,K$$

$$G_{dBi}/T_{Ant} = 21.60\,dBi - 23.43\,dB = -1.83\,dB$$

As Signal/Noise - ratio is proportional to the G/T - ratio it is a true figure of merit for any receiving system. See http://www.vk1od.net/rx/gt/index.htm for details.

See § Relevance of Tearth
See § From Y-Factor to G/T

6.14 Feed System

Column Feed System gives Information about the employed Driven Element of the Yagi.

Dipole	Straight Split Dipole
Folded Dipole	Folded Dipole, whether 200/50 ohms or 50/12.5 ohms
LFA Loop	Rectangular Loop in element plane wider than a Folded DE
LFA FD	Flat Folded Dipole
T Match	Straight Split Dipole with added T-Match
Horiz. Dipole	Rectangular Loop in element plane of approx. same size as a Folded DE
Gamma Match	Straight Split Dipole with added Gamma-Match
Bent Dipole	Straight Split Dipole with sides bent in element plane
Dual Driven	Phased fed pair of Straight Split Dipoles

6.15 KF2YN Convergence Correction req.

Column ‘KF2YN Correction Required’ holds information whether the Average Gain of the single Yagis lossless model exceeds 1.000 or 100% of radiated power. In that case a Correction via the KF2YN set of formulas is required.

Gain of single Yagi and Bay, T_ant, T_loss and G/T are downsized to the equivalent of 100% of radiated power for the lossless Antenna in order to represent fair numbers for comparing them with other antennas in the table. The columns entry is “Yes”. If the antenna does not require an AG or sometimes also referred to as AVG Correction this columns entry is “No”.

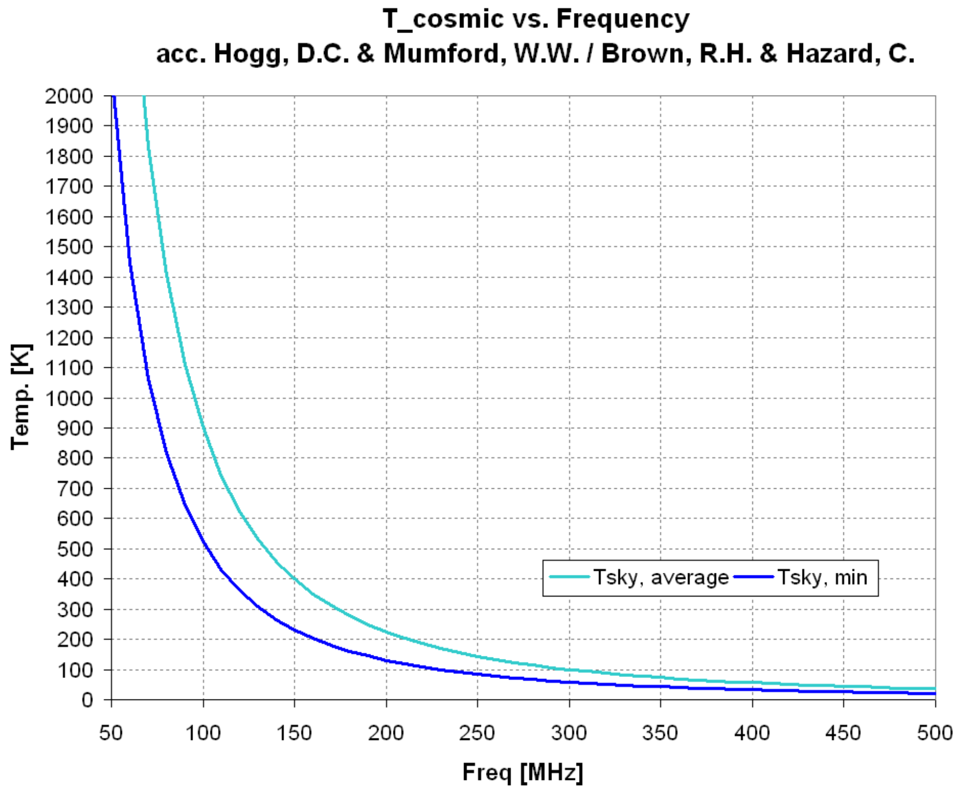
7 Tsky Grass Roots – Jansky's Measurements and beyond

In its scientific meaning Tsky must be called Cosmic Noise. It was discovered and first methodically experienced by Karl G. Jansky in 1933 [1], basically confirmed and refined by G. Reber, W9GFZ [2] and continued by D.C. Hogg + W.W. Mumford (3) and R.H. Brown + C. Hazard (4, 5) three decades later. Their efforts lead to a set of three formulas of with Hogg and Mumford contributed the average temperature (7.2) whereas Brown and Hazard contributed the estimations on maximum and minimum temperatures (7.1/7.3). That set of formulas represents the state of evolution of scientific approach to Cosmic Noise in the 1960ties:

Table 1:

(7.1) $T_{\min} = 58 \cdot \lambda^2$ (7.2) $T_{average} = 100 \cdot \lambda^2$ (7.3) $T_{\max} = 1450 \cdot \lambda^2$

For mathematical correctness the number factors would need to have the units *K/m2* added.



8 Tsky and Tearth - Further Research and Development

Having laid a fundamental with pre-war technique Jansky and Reber did excellent pioneering work. As the technical development moved on Hogg, Mumford, Brown and Hazard where able to refine these initial findings using up to date gear as it was available in the 1960ties. The importance of both antenna and receiver limitations are crucial ones for radio astronomy; so it was in early days and so it is today:

> *“It was obvious to Reber that Jansky had made a fundamental discovery, and realized the limit of Jansky's equipment had been reached” N1MAA [2]*

What Reber recognised so early when reflecting on Jansky’s findings is what Radio Amateurs using GaAs Fet Low Noise Amplifiers and more realised in the 80ties on what Hogg, Mumford, Brown and Hazard found in the 60thies [3,4,5].

A standard for 2011 were the following figures derived at by the works of DJ9BV, VK3UM, VE7BQH and others.

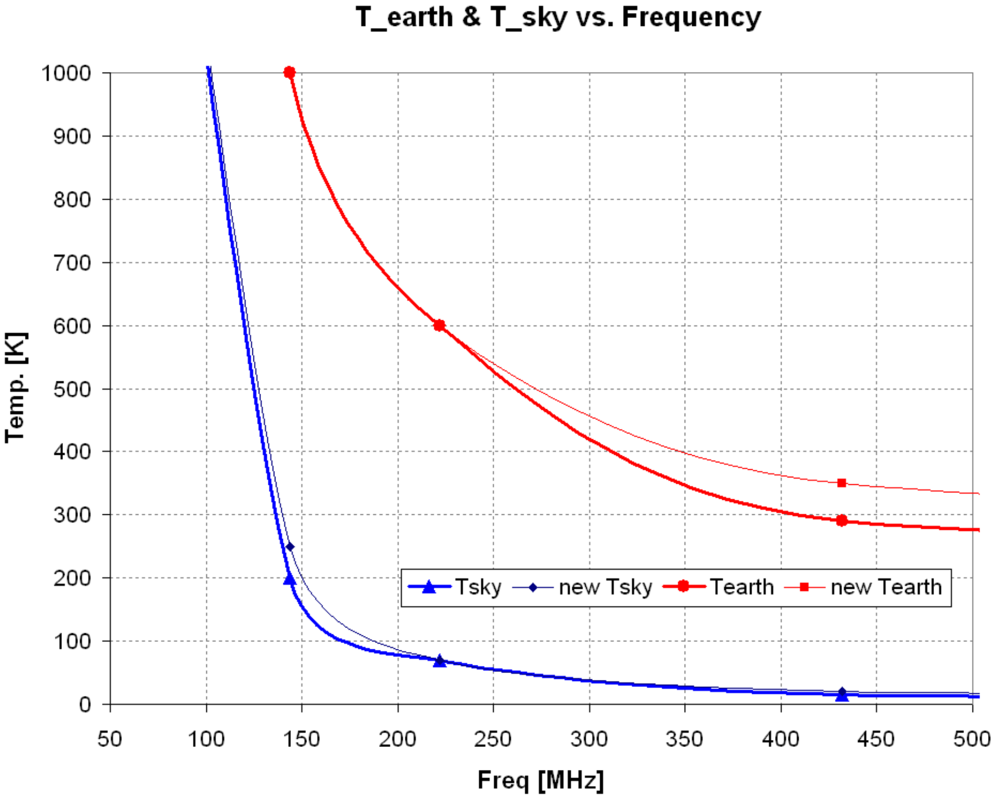


Table 2: The figures this chart is based upon: T_{earth} and T_{sky}, => aligned numbers as published in Dubus 2/2012 [6]

Band	Tearth	Tsky
50 MHz	**3000 K**	**2200 K**
144 MHz	**1000 K**	200 K **=> 250 K**
222 MHz	**600 K**	**70 K**
432 MHz	290 K **=> 350 K**	15 K **=> 20 K**
1296 MHz	**290 K**	**10 K**

A note on the 144 MHz temperatures:

We see a little wobble following the lines when going from 50 to 222 MHz, which may indicate that the actual value for Tearth is a bit low in context to the other bands values. It might be adapted to the other bands noise levels sometime.

A note on the 432 MHz temperatures:

Emphasising the importance of technical progress in measurement equipment it is understandable that DJ9BV moved from what he initially put down as reasonable temperatures in his well recognised article “Effective Noise Temperatures of 4-Yagi-Arrays for 432 MHz EME” in 1987 [7].

Asking Lionel Edwards, VE7BQH on why the Tearth on 432 MHz was assumed to be 290 K only in DJ9BV’s article he writes the following:

> *“Yes he did in 1987 but by the 1990s when we were discussing 144 MHz we touched on 432 numbers and he said he thought his T earth in Hamburg was about 600 K on 432! No doubt Hamburg mid city could be very noisy!*
> *In 1987 he was using the theoretical numbers which was the basis for his article. As the Y-factor is large on this band the article results are still very meaningful. By the 1990s he and I realized that the "real" world did not have that low a numbers hence the numbers you see today.”*

The theoretical figure of 17°C + 273 = 290 K representing an earth temperature of 17 degrees Celsius did not fit for a proper prediction of the real behaviour of the receiving system, consequently Tearth needed to be adjusted away from full theory to practise values.

Debriefing

As it became apparent even quite early in the history of Cosmic Noise measurement there are adjustments to be made whenever measurement equipment develops and, speaking for Tearth, the noise level keeps on rising in non rural areas. These figures are ‘on the move’ by a few Kelvin all the time since Jansky’s pioneering work.
The challenge for the Radio Amateur is to adopt in time and find a consensus on with antennas and receiving system performances may be compared whenever the figures need to be corrected. Clearly the figures found must form a line of similar swing as the initial Cosmic Noise figures do when resembled in a chart. Issuing the locally differing noise level they will represent an average mean value.

An error that is encountered frequently is giving a figure in Kelvin using the term “degree” with it. The fact that 1 K does have the same magnitude span as 1 degree Celsius does not justify the enclosure of a “degree” or ‘°’ to the Kelvin. Kelvin is a unit in its own, just ‘**K**’ is the official unit for the Thermodynamic Temperature.

Actual figures to use for G/T calculations are to be found up the text in table 2.

References

[1] "Electrical Disturbances of Apparently Extraterrestrial Origin" (Jansky, K. J. 1933, Proc. IRE, 21, 1387) ISSN: 0731-5996
[2] http://www.n1maa.com/Reber.html
[3] Hogg, D.C., and Mumford, W.W., 'The Effective Noise Temperature of the Sky,"
[4] The Microwave Journal 3:80-84 (Mar. 1960)
[5] Brown, R.H., and Hazard, C., "A Model of the Radio-Frequency Radiation from the Galaxy," Phil. Mag. 44:939 (Sept 1953)
[6] Kluever, H. DG7YBN: Notes on HVF/UHF Antenna G/T, Dubus 2/2012
[7] Dubus-magazine 4/87 or http://www.mrs.bt.co.uk/dubus/8704-1.pdf

9 Relevance of Tearth and Tsky

9.1 Y-Factor

The ratio of two noise levels is called Y factor. As noise power level 'N' is proportional to noise temperature it can either be defined as noise to noise or a temperature to temperature level. Replacing T_{hot} by T_{earth} and T_{Cold} by T_{sky} we can use the Y factor equation as a ratio between antenna pointed down to earth and towards a cold patch of sky.

$$(9.1)\quad Y = \frac{N_{On}}{N_{Off}} = \frac{N_{Hot}}{N_{Cold}} = \frac{T_{Hot}}{T_{Cold}} = \frac{T_{earth}}{T_{sky}}$$

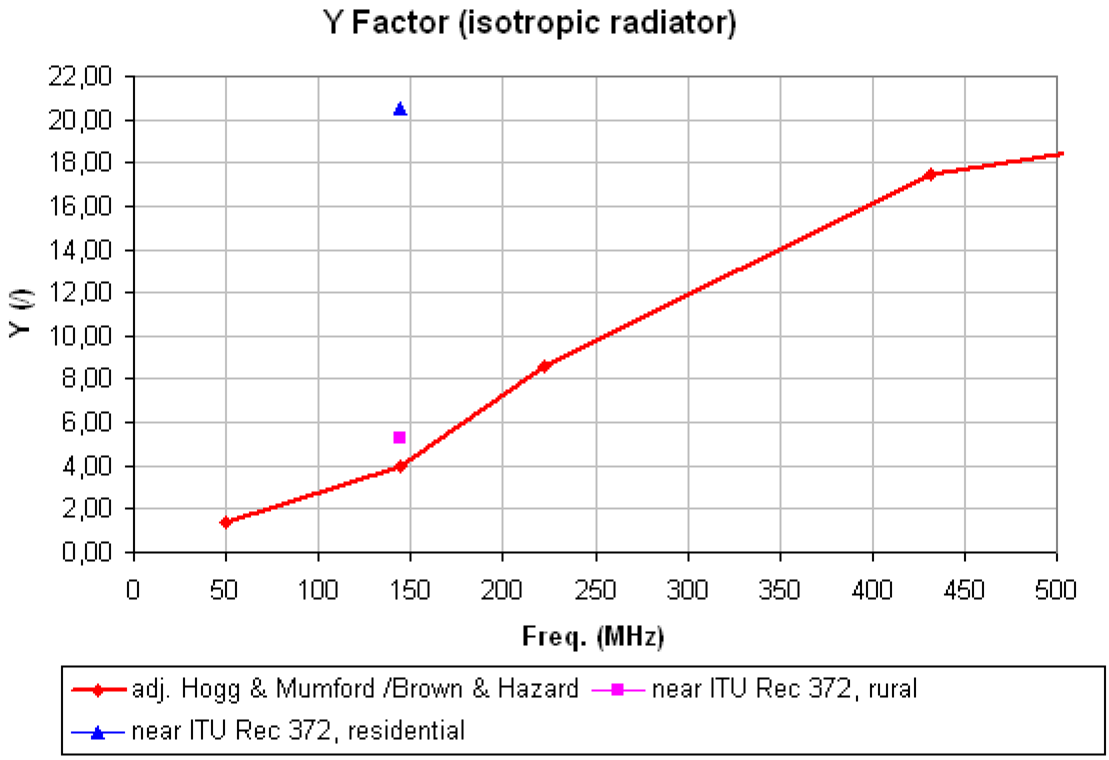
Often the Noise Temperature of the Receiver is included:

$$(9.2)\quad Y = \frac{T_{Hot} + T_{RX}}{T_{Cold} + T_{RX}}$$

Engaging a known Y Factor the Noise Temperature and thus Noise Figure of an RX can be determined:

$$(9.3)\quad T_{RX} = \frac{T_{Hot} - Y \cdot T_{Cold}}{Y - 1}$$

Applying equation (9.1) on an isotopic radiator we would find Y factors as follows in a chart on the next page when using temperatures as given in table 2 using the aligned numbers (in bold) as published in Dubus 2/2012 [1]:



The chart indicates that caring for the G/T - ratio at the antenna fed point is approximately 3 times more important on 144 MHz than on 50 MHz and 9 times on 432 MHz. However newer findings for man-made-noise on VHF in accordance with the ITU recommendations [2] issued 2016 shows a Tearth as man-made-noise of 1308 K for rural areas and 5127 K for residential areas. Which highlights the importance of Antenna G/T on 144 MHz in such environments.

9.2 From Y-Factor to G/T

Lionel Edwards, VE7BQH

> *"Because of the Y factor to achieve meaningful G/T, only 144 MHz is critical as the Y factor on this band is just critical enough to make G/T meaningful. 50 MHz G/T means nothing as the Y factor is virtually 1:1. All the higher bands have large Y factor making G/T a critical performance indicator."*

G/T and Y-Factor are proportional, all linked by the antennas pattern and thus noise pick up from sky and earth. The relation between Y-Factor and G/T (formula 9.4) is taken from DJ9BV and F6HYE [3] if using cold sky vs. sun to determinate the complete RX systems Y-Factor:

$$(9.4)\quad \frac{G}{T_{system}} = \frac{Y-1}{I_{sf}} \qquad I_{sf} = solar\ flux; G = (/) = numerical\ gain$$

The whole picture now using Gain in (dB) is given below

(9.5) $$\frac{G_{System,dB}}{T_{System}} = G_{Ant,dBi} - 10\log_{10} T_{System}$$

Wherein T_{system} is the sum of Noise Temperatures in the system

(9.6) $$T_{System} = T_{Ant} + T_{RX\_Line}$$

And with (9.6) in (9.5)

(9.7) $$\frac{G_{System,dB}}{T_{System}} = G_{Ant,dBi} - 10\log_{10}\left(T_{Ant} + T_{RX\_Line}\right)$$

For (9.5) and (9.6) also see [4] 'Fundamentals of Telecommunication' chapter 9.3.6.2 .
And Antenna Gain (dBi) to Antenna Temperature ratio alone as "Antenna G/T":

(9.8) $$\frac{G_{Ant,dBi}}{T_{Ant}} = G_{Ant,dBi} - 10\log_{10} T_{Ant}$$

Using average equipment for EME we yield the following G/T figures when applying (9.5) for deriving G/T-system and (9.8) for G/T-ant:

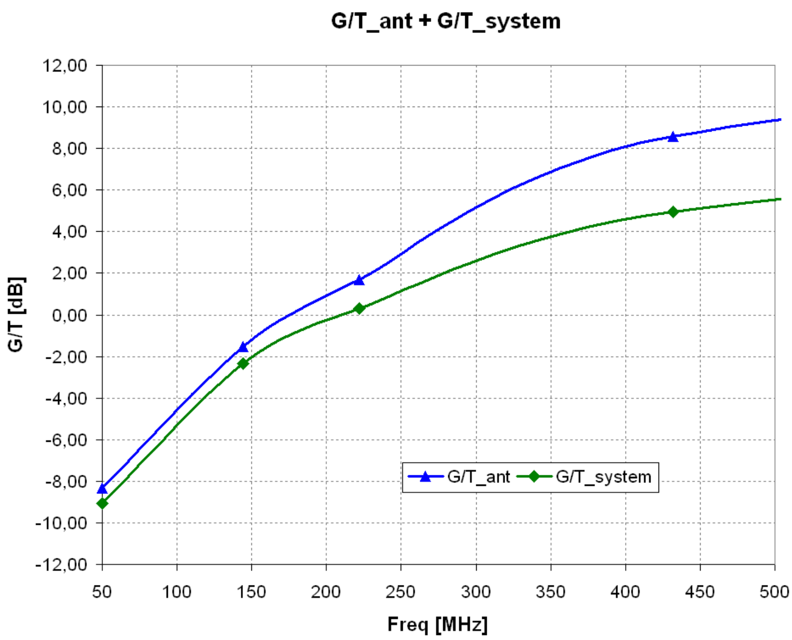


Table 3: Figures used for creating the above Chart:

50 MHz	G_ant= 16.0 dB	T_ant = 270 K	T_rx = 50 K
144 MHz	G_ant= 21.9 dB	T_ant = 220 K	T_rx = 45 K
222 MHz	G_ant= 22.5 dB	T_ant = 120 K	T_rx = 45 K
432 MHz	G_ant= 24.0 dB	T_ant = 35 K	T_rx = 45 K
1296 MHz	G_ant= 28.0 dB	T_ant = 18 K	T_rx = 40 K

9.3 Additional Formulas

Definitions:

Noise Temperature T (K)
Noise Factor F (/) as a ratio of a noise temperature and ambient reference temperature
Noise Figure NF (dB)

Gain G (/)
Gain G_{dB} (dB) resp. G_{dBi} (dBi)

$$(9.9) \quad F(/) = 1 + \frac{T}{T_0} = 1 + \frac{T}{290\,K} = \frac{SNR_1}{SNR_2} = \frac{S_1/N_1}{S_2/N_2} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$$

T_0 is referred to as 290 K with respect to the lowest temperature attainable (-273°C or 0 K) makes a 290 K = 17°C + 273 to meet an ambient temperature of 17° Celsius.

Since S_{out} can be expressed as $S_{out} = S_{in} \cdot G$ we may write the Noise Factor as

$$(9.10) \quad F(/) = \frac{N_{out}}{N_{in} \cdot G}$$

Converting Noise Factor (/) in Noise Figure (dB)

$$(9.11) \quad NF_{dB} = 10\log_{10} F$$ or vice versa $$(9.12) \quad F = 10^{(NF_{dB}/10)}$$

Converting Gain (/) in Gain (dB)

$$(9.13) \quad G_{dB} = 10\log_{10} G$$ or vice versa $$(9.14) \quad G = 10^{(G_{dB}/10)}$$

Noise Figure of a Device under Test (DUT)

$$(9.15) \quad NF_{dB} = 10\log\left((T_{Dut}/290K) + 1\right)$$

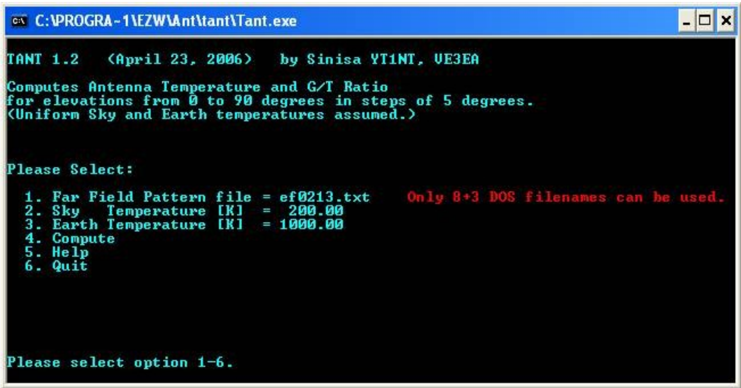
The Noise Temperature of a DUT

$$(9.16) \quad T_{DUT} = 290\,K\left(10^{(NF/10)} - 1\right)$$

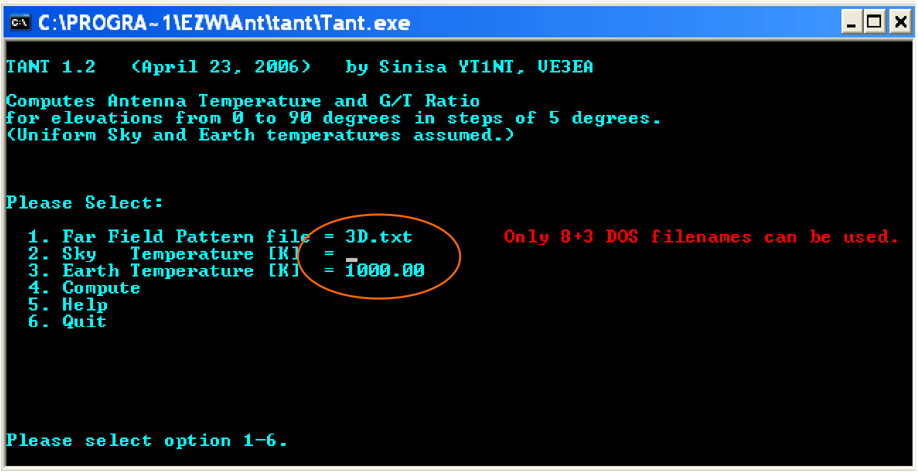
References
[1] Hartmut Klüver, DG7YBN: Notes on VHF/UHF Antenna G/T, Dubus 2/2012
[2] International Telecommunication Union: ITU-R P.372-13 Radio Noise, 09/2016
[3] Rainer Bertelsmeier, DJ9BV & Patrick Magnin, F6HYE: Performance Evaluation for EME-Systems, Dubus 3/1992
[4] Roger L. Freeman: Fundamentals of Telecommunication Wiley-IEEE Press 2013

10 Setting Tearth and Tsky for G/T determination on other bands

TANT's preset is to Tearth and Tsky useful for 144 MHz. However TANT offers a simple ability to enter other then the preset Tsky and Tearth from its start up screen:



Enter 2 to edit 'Sky Temperature' (Tsky) in Kelvin. Note the cursor blinking in line 2 as shown on the screenshot below:



Enter 3 to edit Tearth in similar way.

Below is a table holding temperatures that should be in convention with most serious users of G/T figures. It would not make sense to give Tant or G/T figures for general comparison derived at by computing TANT with diverging Tearth or Tsky.

Table 4: Corrected numbers (2012), the 432 MHz ones are used for the 432 MHz G/T Table

Band	Tearth	Tsky
50 MHz	3000 K	2200 K
144 MHz	1000 K	200 K (250 K)
222 MHz	600 K	70 K
432 MHz	350 K	20 K
1296 MHz	290 K	10 K

11 Stacking

11.1 Background - History and new approaches

Günter Hoch, DL6WU on creating the stacking formula

> *“The formula was set up long before the measurements, on a theoretical basis: If one calculates the effective area for a circular chart from the gain, the distance is such that the effective areas just touch.”*

If we take a close look at the DL6WU formula and compare it to the wave optics formula for diffraction maxima intensity on a double slit (Young’s experiment) we may find it to be similar. That is no surprise at all since Günter’s approach was based on the effective aperture areas A_{eff} (1) which considers but gain and wavelength:

$$(11.1) \quad A_{eff} = \frac{\lambda^2}{4\pi} \cdot G \qquad \textit{where G is Power Gain} \; [/]$$

Hence we solely do take into account the gain in beam direction as an equivalent to the double slits coherent light source. Intensity maxima will appear at angles θ acc. (11.2):

$$(11.2) \quad d \cdot \sin\theta = \frac{2n+1}{2} \cdot \lambda \qquad \textit{with } n = 0, 1, 2, ...$$

Looking at the very maximum (0th order, n = 0) only we may rewrite the formula as below:

$$(11.3) \quad d = \frac{\lambda}{2 \sin \theta} \quad \textit{for } n = 0$$ and the DL6WU formula (1): $$D = \frac{W}{2 \cdot \sin(B/2)}$$

d or D = slit width respectively stacking distance, λ or W = wavelength, θ or B = angle of observation respectively beam width.

B/2 is just half the well known HPBW = Half Power Beam Width. In Youngs Experiment and Wave Optics in general the derivation angle from the straight line that the light beam takes after having passed the slot is angle θ. Whereas antenna beams show double that number. Hence we divide the HPBW by 2.

This traditional approach might be missing out on possible constructively interfering first side lobes that turn in same direction as the main beam. These fractions can add a few 10th of dB to the obligate stacking gain of 3.01 dB when a Yagi with suitable pattern is chosen.

Read what DL6WU says on being asked if his formula would fit different than typical DL6WU Yagi patterns equally:

> **“You have developed the formula using 6WU Yagis. Other Yagis have a radiation pattern which varies in detail whilst having an identical -3 dB beam width. Would the optimum stacking distance vary here slightly as well?”**

Günter Hoch, DL6WU:

> *“On the challenge of antennas with a ‘grubby’ pattern you are right; here the optimum distance is probably the one where the first side lobes are suppressed in best way.”*

According to this and NEC analysis we may note that DL6WU stacking is a compromise for most Yagis but we can expect derivations when searching for the optimum for other Yagis.

11.2 What to expect from optimum stacking according the ordinary formula?

Adding a second and similar source i.e. Yagi is equal to a double effort when the stacking distance is right.
The gain achieved is a relative order. It does not depend on dBi or dBD. We are not investigating in the rest of the pattern design. Only the intensity of that fraction in beam direction counts. We end up with double Power Gain.

A simple example is a pair of equal light emitting sources. Since light in this experiment shows its wave-like character the distance between the two sources in relation to the wavelength of the emitted light are determination parameters.
No matter if the light sources do emit their beams orderly or not by means of a homogeneous or isotropic pattern, as long as their main beam orientation is in line the maximum of intensity will be ‘double bright’. Two sources in the right distance to another will make the intensity in beam direction twice as intensive as if the single sources power would have been doubled.
The basic formula according Decibel per Power ratio is as follows:

$$L_{dB} = 10\log\left({P_{out}}/{P_{in}} \right) \qquad note: \text{"log"}\ is\ base - 10$$

$$L_{dB} = 10\log\left({20\,W}/{10\,W} \right) = 3.0103\ dB$$

Günter Hoch, DL6WU:

> *“Nevertheless I have never experienced a stacking gain higher than 2.9 dB.”*

How is it possible, that some Yagi Bays provide more than that in EZNEC? To that good question I give an answer in § Where does Over Stacking extra gain emerge from?

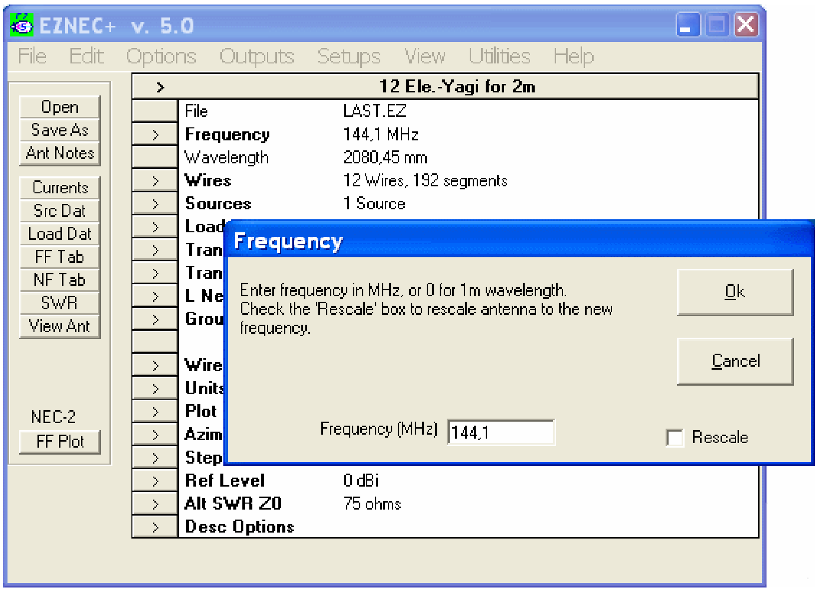
11.3 Applying the DL6WU Stacking Formula

The VE7BQH G/T table uses the DL6WU stacking formula in first place; if the designer gives a different stacking recommendation it is marked as an exception and given in the table as an additional row below the G/T achieved with stacking dimensions per DL6WU formula. To work out a stacking distance per DL6WU formula we need to calculate the applicable wavelength first:

W = Wavelength [m]
c = speed of light in vacuum (299,792,458 m/s)

$$W = \frac{c}{f} \quad Units: \frac{[m/s]}{[1/s]}$$

The same frequency that was intended for the Yagis best performance issuing its pattern shall be used for the stacking formula. The same frequency as used for producing the radiation pattern in EZNEC or 4nec2 must also be used for the stacking formula.



For the 6 m band G/T that does mean 50.150 MHz strictly

$$W = \frac{299.792}{50.150} = 5.977906\ m$$

For the 2 m band G/T Table that does mean 144.100 MHz strictly.

$$W = \frac{299.792}{144.100} = 2.080444\ m$$

For the 70 cm band G/T that does mean 432.100 MHz strictly

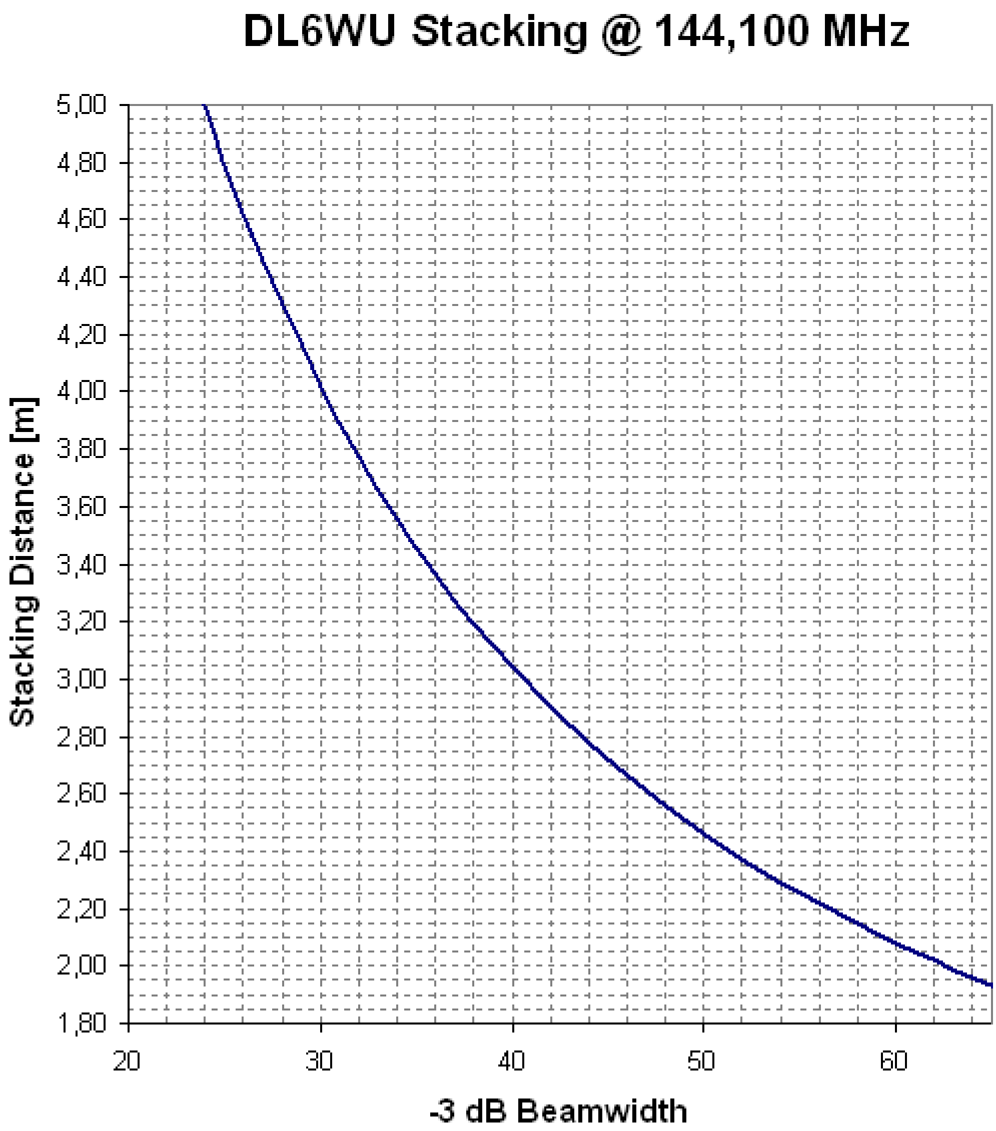
$$W = \frac{299.792}{432.100} = 0.693802\ m$$

Now we may proceed calculating the stacking distance as given by the DL6WU formula [1]:

$$D = \frac{W}{2 \cdot \sin\left(\frac{B}{2}\right)}$$

D = Stacking Distance, B = -3 dB Beam width, W = wavelength

- The formula gives a very close approximation from about 0.7 wL on for the E-plane. The H-plane is missing in a matter of being too closely spaced by approx. 0.1 wL for short Yagis until up to 2 wL that is overcome, see next page.
- Measured maximum gain by either Peter V. Viezbicke or DL6WU due to stacking this way is 2.9 dB without cable and transformation losses in either plane. See also charts 11+12 in NBS Technical Note 688 by Peter P. Viezbicke [2].

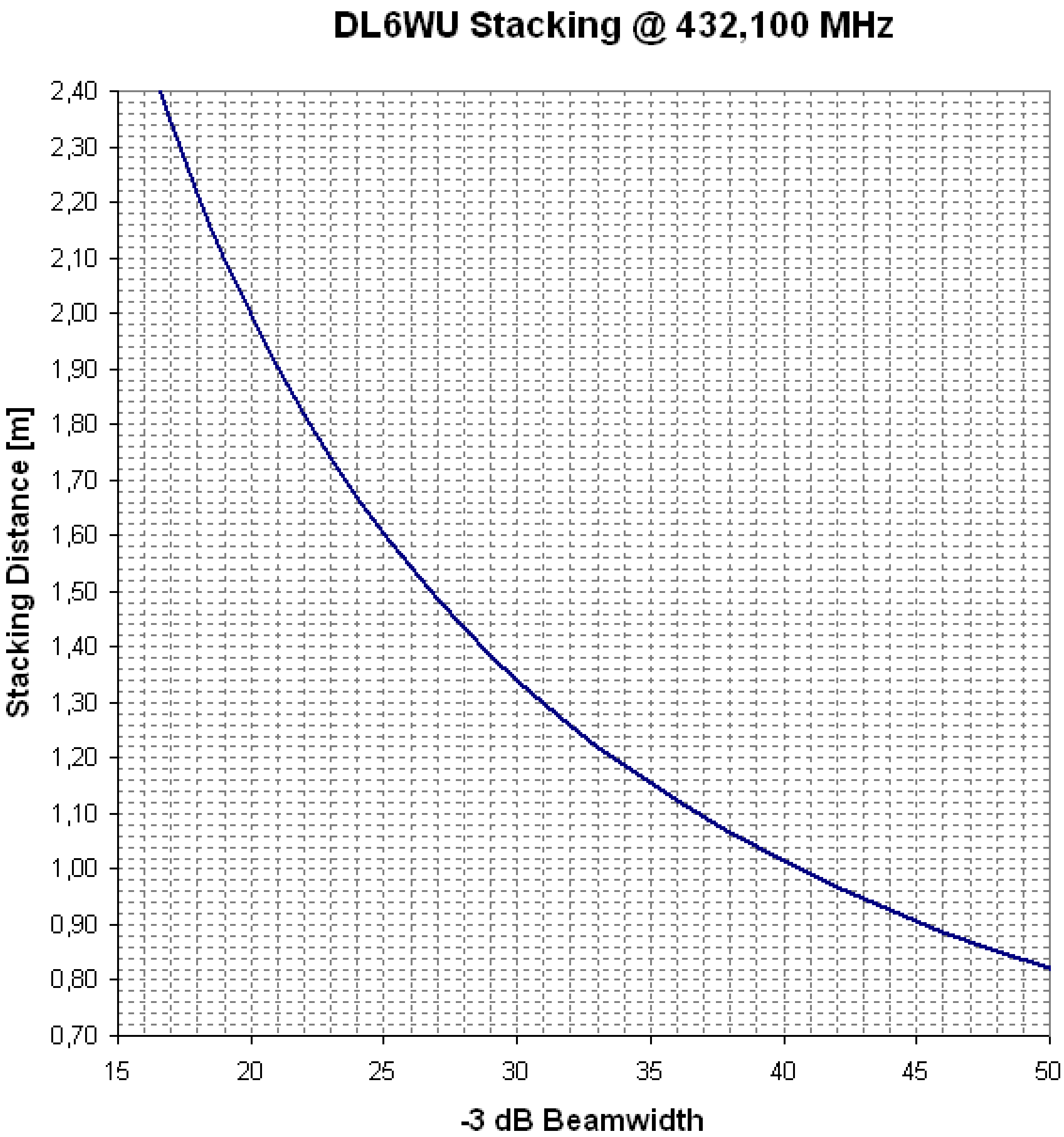


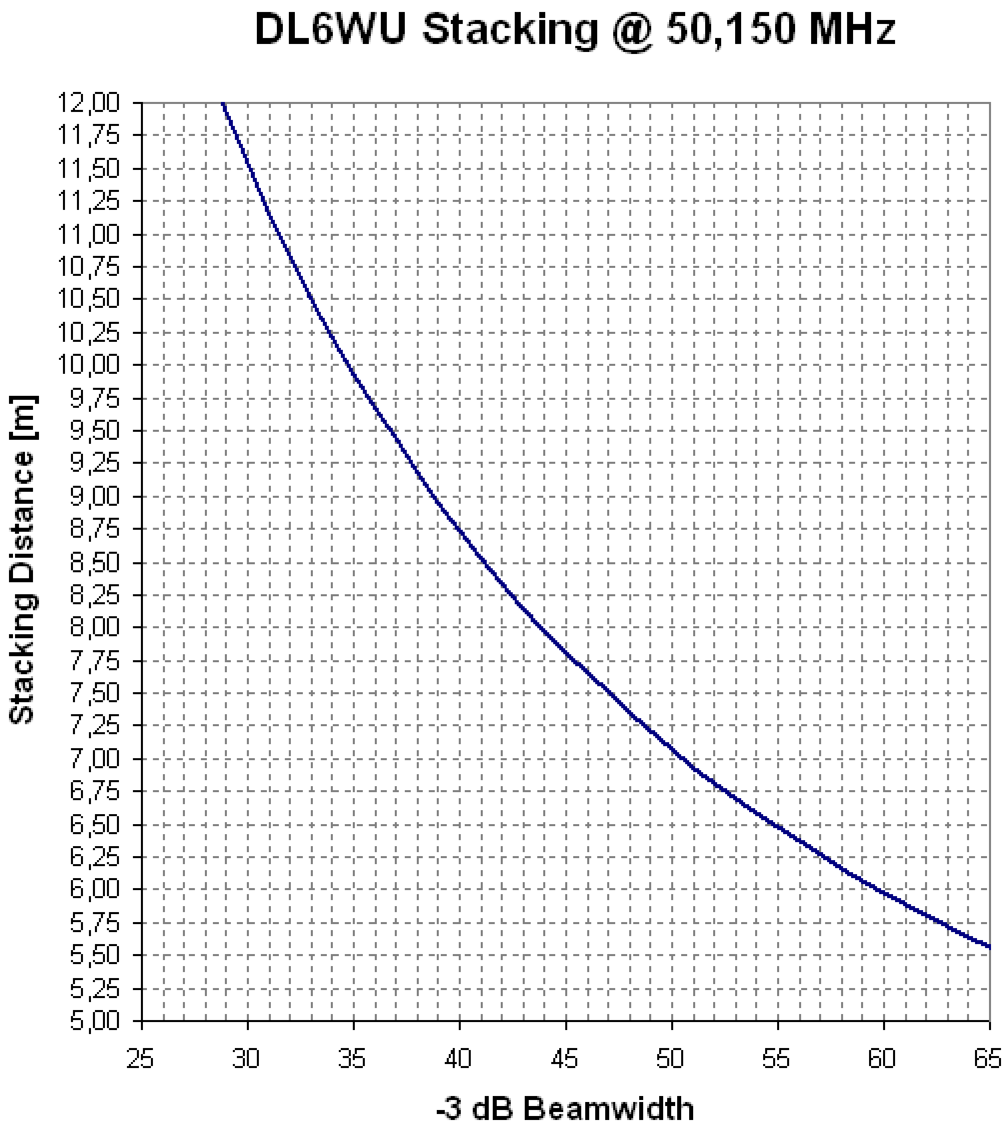
Today it has established itself that the DL6WU formula would be valid from a Yagi's length of 10 elem. on only. DL6WU provides a plain explanation:

> *"The 2 wL regulation [was] because the primarily WU-concept was [starting] from 2 wL."*

In fact the DL6WU formula is delivering finely from about 1 wavelength Yagis (-3 dB beam width < 65 degree) on with a single exception: The H-plane stacking distance might be a little low for short Yagis.

Many short Yagis may be stacked further apart than the DL6WU formula predicts. Doing so will result in extra gain in the region of 0.1 … 0.2 dB but will pay the price in the form of quite high levels of side lobes. There does not seem to be a special rule to achieve this nor is there a general formula. Individual short Yagi patterns call for individual optimum stacking distances which have to be calculated in NEC, see § 'Over stacking'. For very short Yagis (below 5 elements) or stacking below one wavelength we must be aware that mutual coupling between the elements will influence impedance and pattern as well.


DL6WU Stacking @ 432,100 MHz
Stacking Distance [m]
2,40
2,30
2,20
2,10
2,00
1,90
1,80
1,70
1,60
1,50
1,40
1,30
1,20
1,10
1,00
0,90
0,80
0,70
15
20
25
30
35
40
45
50
-3 dB Beamwidth


DL6WU Stacking @ 50,150 MHz
Stacking Distance [m]
12,00
11,75
11,50
11,25
11,00
10,75
10,50
10,25
10,00
9,75
9,50
9,25
9,00
8,75
8,50
8,25
8,00
7,75
7,50
7,25
7,00
6,75
6,50
6,25
6,00
5,75
5,50
5,25
5,00
25
30
35
40
45
50
55
60
65
-3 dB Beamwidth

11.4 Over stacking

What is Over Stacking all about? I found the following exchange on this topic with VE7BQH that good in both, in him explaining the advantages and limits as well as the context or correspondence to DL6WU stacking, that I said I would love to see that printed. Here it is:

DG7YBN puts forward challenging questions on over stacking a bay of Yagis to VE7BQH:

Isn't over stacking just a word that reflects on 6WU's findings for best stacking distance as a sort of common wisdom? Am I right to assume that generalised there is no thing [such as] as over stacking?

> ”*DL6WU stacking is a good compromise between gain and side lobes. My experience stacking in software is depending on the antenna, you can increase the spacing and the G/T rises to a point that it stops going up any appreciable amount or the G/T starts to reverse. Again this depends on the design. The typical point that the G/T more or less evens out is about 8 dB side lobes which is exactly what Leif [SM5BSZ] said. He did qualify that with "for EME use"*
>
> *We seem to live in this world where people quote G/T on one hand and turn about and say they stacked for "low noise" yet that very low noise stacking does not give as good a G/T as DL6WU stacking. If you take a good low noise antenna which produces better G./T such as G0KSC, YU7EF and DG7YBN designs that is a step forward but if you under stack these designs for "low noise low first side lobe " you are taking step backward in most cases.*
>
> *I love it when somebody tells me they have "improved on DL6WU stacking". How do you improve on a compromise? It is all in the eyes of the designer!!*
>
> *This always then leads back to what is a good compromise?? DL6WU of course!”*

To me the G/T increases and increases with more distance, it virtually never stops. If that would make sense or not, if it would be better to start the next bay on top of the initial one is a different matter?

> *“True, but it does even out about 8 dB side lobes as a practical point.”*

Oh dear, now it has become complicated again, hi, hi.

> *“DL6WU stacking is the anchor. Wider stacking is for specialized use like EME.”*

\- - -

11.5 Where does Over Stacking extra gain emerge from?

Once we stop looking at the effective aperture areas just not touching objective we may include more that the doubled Power Gain (see formula 11.1). Some Yagis evolve relatively large first side lobes which are quite frontward orientated. When stacking these lobes wave fronts will be subject to interference. If constructive interference takes place in beam direction and these lobes are intense enough we may see them as extra Power Sources. Explicit as a small portion of additional Power Gain to the ordinary doubled Gain from double effort by stacking. That is why some Yagis may reach a stacking gain up to approximately 3.5 dB depending on the forming of their first side lobes.

11.6 Challenges in Over Stacking

Whether Over Stacking suits a specific design or not is very much up to its pattern and to the targeted use too. There is no fixed rule here but a few facts are highly visible.

Back and side lobes can grow large vastly when Over Stacking Yagis. Thus not only significant or aiming much forward first side lobes are mandatory but a high F/R is probably of similar importance to make Over Stacking a success. Determination of best Over Stacking distance in a fixed formula may not work since the influence of specific lobe magnitudes is varying a great deal from design to design but is important to Over Stacking. As Lionel pointed out, DL6WU stacking is the anchor - wider stacking must be carefully arranged and simulated in a NEC program.

Below we see the results of slight over stacking applied to a 16 elem. GTV 2-16w in comparison to DL6WU stacking:

TYPE OF ANTENNA	L (WL)	GAIN (dBD)	E (M)	H (M)	Ga (dBd)	Tlos (K)	Ta (K)	F/R (dB)	Z (ohms)	VSWR Bandwidth	G/T
+DG7YBN 16	4.74	14.79	4.39	4.21	20.70	6.10	221.40	28.9	46.6	1.18:1	-0.60
*DG7YBN 16	4.74	14.79	4.45	4.60	20.79	6.10	222.40	28.9	46.6	1.18:1	-0.53

The upper row contains the results with DL6WU stacking applied. It is marked with '+' as an indicator that the design employs elements which are thicker than 6 mm. The lower row marked with * holds the results from freestyle Over Stacking. It was achieved by carefully varying the stacking distances in EZNEC, running TANT and repeating that in iteration steps aiming for best G/T solely.

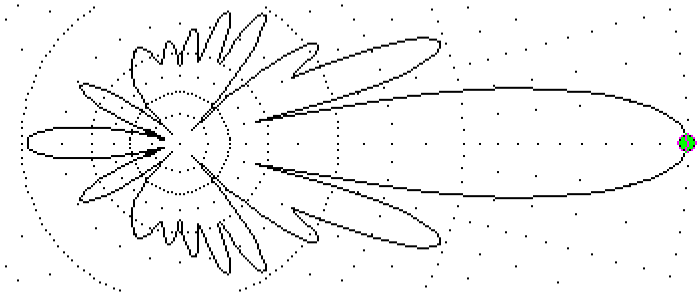
Despite Tant or Ttotal has increased by 1 Kelvin Over Stacking leads to improved G/T for this bay since the Gain of the bay increases as well by almost 0.1 dB at the same time whereas due to the respectable F/R of the single Yagis pattern we find that figure almost unchanged.

What makes a Yagi suitable for over stacking?

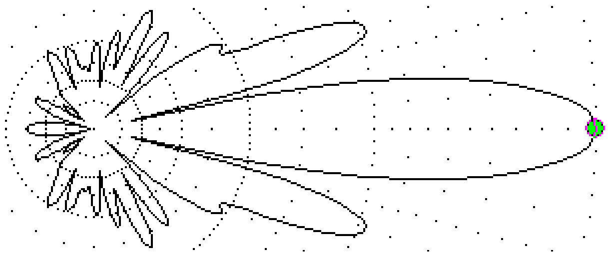
Referring to the degree of suppression of back and side lobes of the single 16 elem. GTV Yagi it is plain to see that the bay of 4 keeps on with that characteristics even under wider than the DL6WU stacking distances.

Simply put, there is no fixed rule about what design to over stack and to what degree but all Yagis with very good F/B or F/R are potential candidates for it. On the following page some examples that give a better performance when over stacked are given.

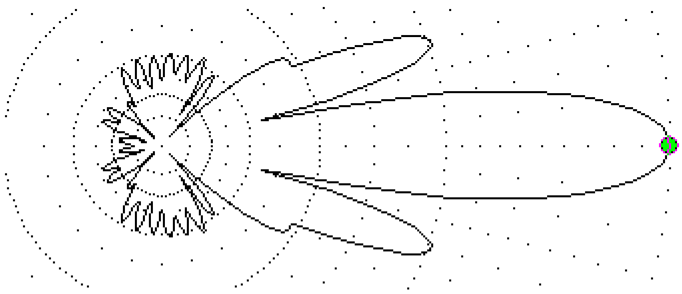
Pic.: Elevation Plot - 2SA 13 elem. (SM5BSZ) bay over stacked by 0.2 m



Pic.: Elevation Plot - 16 elem. GTV 2-16 (DG7YBN) bay over stacked by 0.4 m



Pic.: Elevation Plot - 15 elem. LFA bay (G0KSC) over stacked by 0.4 m



Note:

For some very low noise Yagis with outstanding back and side lobe suppression the increase of G/T will go on and on with increased stacking distance. Obviously at some point it would not make sense to go on in stacking even further apart but chose either longer Yagis or start with the next pair of Yagis to add to the array. Mechanical complexity should have its place in the total equation of effort to gain or G/T.

References

[1] Hoch, Günter, DL6WU, “Optimale Stockung von Richtantennen“, UKW-Berichte 4/1978
[2] Peter P. Viezbicke ,NBS Technical Note 688 “Yagi Antenna Design”, U.S. Department of Commerce / National Bureau of Standards, December 1976

History:

V1.0: released August 28, 2011

V1.1: written Dec. 2017

1. Added introduction
2. Added how to derive the F/R, comments and formulas in chapter 2
3. Revised chapter 3.2 VVSWR Bandwidth
4. Added description ‘Building the 4 Yagi bay in 4nec2’s Geometry Editor
5. Corrected order index of formula set 1 in chapter 7
6. Replaced chart Tsky & Tearth vs. Frequency in chapter 8 by a more detailed one and added table holding the numbers it is based on.
7. Added explicit specification of G/Tant and G/Tsystem in chapter 9.2
8. Added recommended number for 144 MHz Tsky in temperature table2 in chapter 10
9. Added 5.2 How to derive an FFtab from 4nec2 to chapter 5
10. Added 5.4 Deriving the Antenna-G/T using AGTC_lite