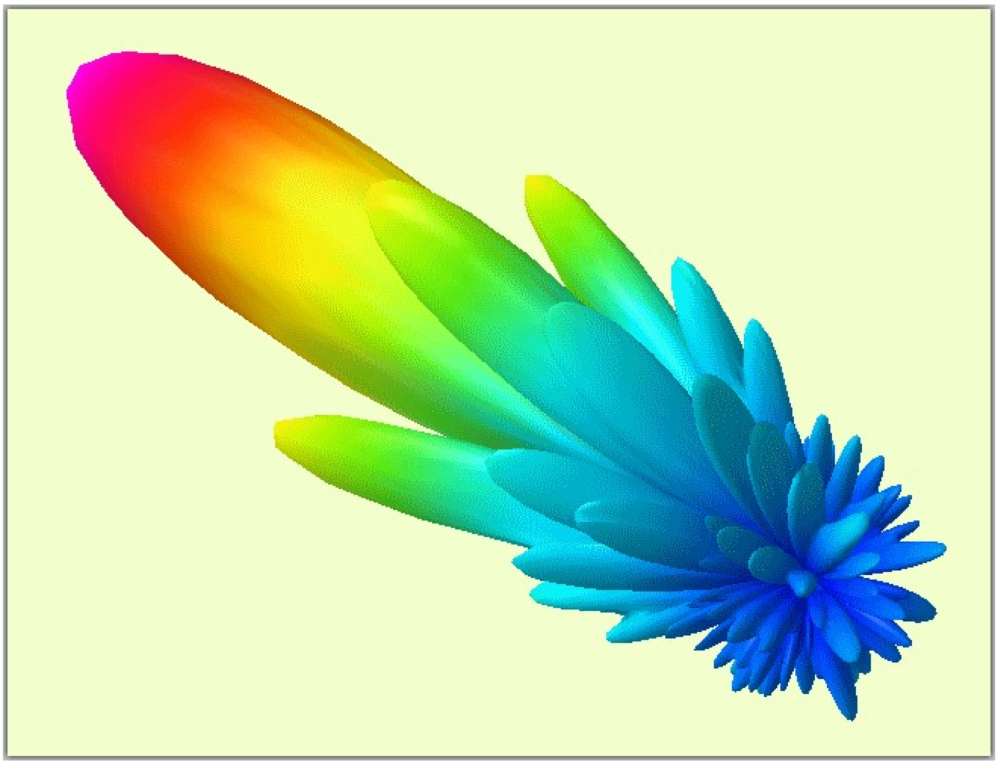
TANT Appendix

- 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 1.0
Written by Hartmut, DG7YBN on August 28 - 2011

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Acknowledgements

This article was assisted by input from DL6WU and VE7BQH. Both provided excellent material and knowledge that helped form the overall content. Thanks to both for all the discussions and to Lionel for help with the format.

Picture on front page:

Far Field Plot of a 4 Yagi bay of 16 elem. VDE Yagis at DL6WU spacing, delivering 22.85 dBi at a Tant of 221.4 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 16 element Yagi with V-shaped DE. 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 (#83). See EZNEC 'Wires' window for details. It is all important to meet the specified segmentation when a design analysis shall be copied or Yagi properties shall be compared to figures in the G/T chart. Not only SWR 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 DE according the actual designs specs.

Wires table of the DG7YBN 16 elem. VDE.

Wires

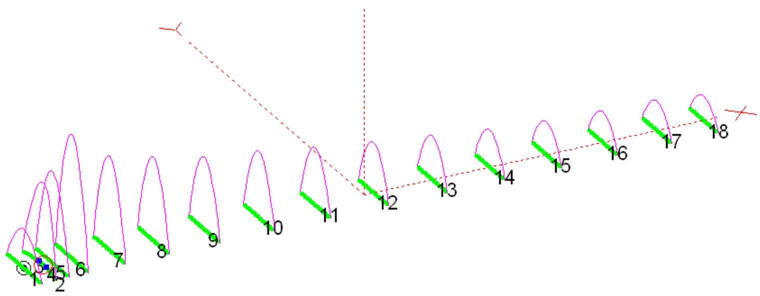
Wire Create Edit Other

Coord Entry Mode Preserve Connections Show Wire Insulation

Wires

No.	End 1				End 2				Diameter	Segs
	X (mm)	Y (mm)	Z (mm)	Conn	X (mm)	Y (mm)	Z (mm)	Conn	(mm)	
1	0	-510	0		0	510	0		8	25
2	274	-100	0	W4E1	215	-491	0		10	10
3	274	100	0	W4E2	215	491	0		10	10
4	274	-100	0	W2E1	274	100	0	W3E1	10	5
5	405	-480,5	0		405	480,5	0		8	24
6	690	-474,5	0		690	474,5	0		8	23
7	1236	-462,5	0		1236	462,5	0		8	23
8	1874	-455,5	0		1874	455,5	0		8	22
9	2615	-448	0		2615	448	0		8	22
10	3407	-444,25	0		3407	444,25	0		8	22
11	4227	-438	0		4227	438	0		8	22
12	5072	-436	0		5072	436	0		8	21
13	5927	-433,5	0		5927	433,5	0		8	21
14	6762	-429	0		6762	429	0		8	21
15	7585	-427	0		7585	427	0		8	21
16	8404	-426	0		8404	426	0		8	21
17	9190	-423	0		9190	423	0		8	21
18	9870	-416	0		9870	416	0		8	20
*										

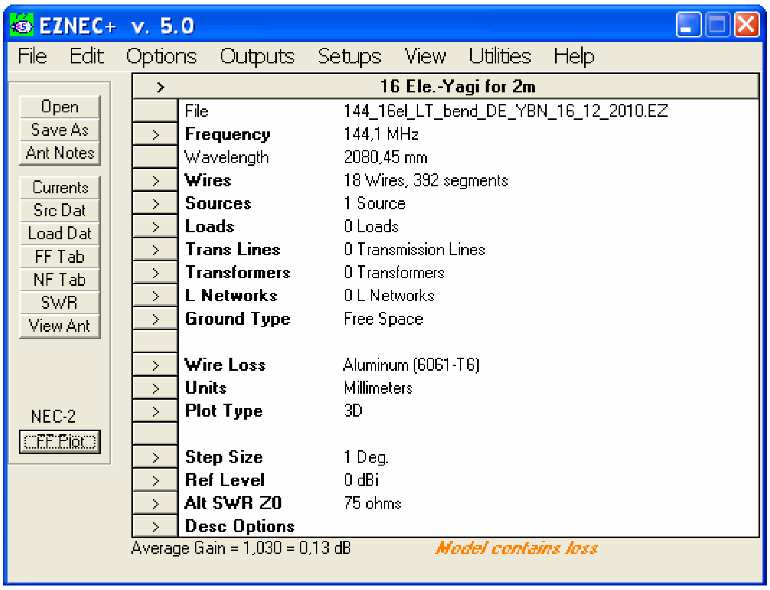
Antenna View: Note that the Yagi has 16 elements but 18 wires due to the modelling of the V-shaped DE employing wires 2 to 4.



1.2 Average Gain Verification

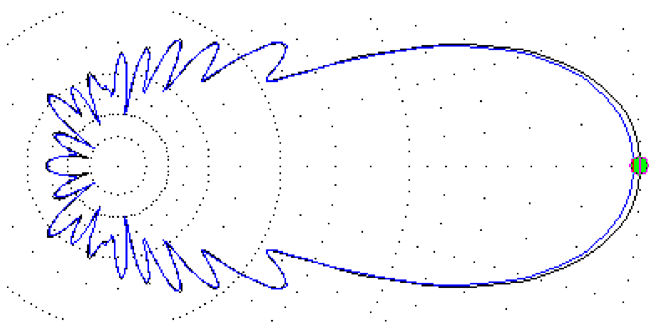
Average Gain (AG) is derived at by comparing the total input power to what amount of radiated power is found in the full 360 deg. 3D radiation pattern. The ratio shall be 1.000 or very close to that for lossless antenna materials. Any real antenna building material manifests itself in an Average Gain lower than 1.000, typically 0.97…0.98 and thus Tloss lower than zero Kelvin. However if the NEC kernel can not cope with our model correctly we may end up with an Average Gain that is higher than stated above.

Pc.: Average Gain with tapered DE



If the VDE’s tubes are tapered using a 10 mm piece in the middle and fitting 8 mm tubes into it on the sides NEC will not handle the tapered sections correctly. This model configuration results in an AG of 1,030 for Aluminium as material.
Since the computed total radiated power in this case is 1.030 or 103% of what we have fed into the antenna a Tloss of +8.70 Kelvin instead of real, thus negative (!) loss is the result. Consequently gain is expanded to 17.15 dBi instead of the correct figure of 16.94 dBi. Below you can see the higher gain due to a faulty positive Average Gain.

Pc.: Elevation Pattern comparison, AG = 1.030 (black), AG = 0.979 (blue line)



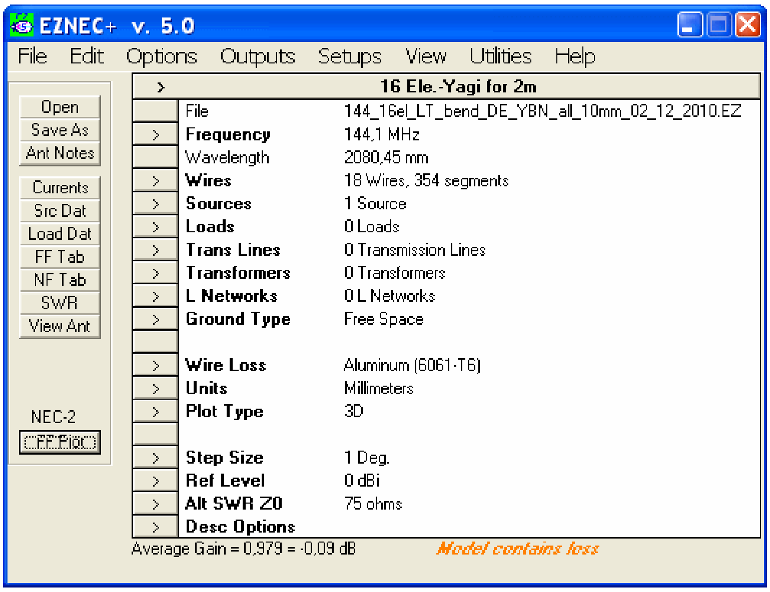
All in all taking this Yagi to the G/T table would result in a ‘real winner in its class’ on an unequal basis with a G/T of -0.30 instead the correct -0.60 dB for a proper model stacked per DL6WU formula:

Table: G/T table comparison, AG = 0.979 (row 1), AG = 1.030 (row 2)

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	15.00	4.39	4.19	20.91	+8.70	217.00	33.4	46.4	1.18:1	-0.30

As an AG of higher than 1.000 even for lossless materials chosen 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 to the chosen materials at given boom length or number of elements involved.

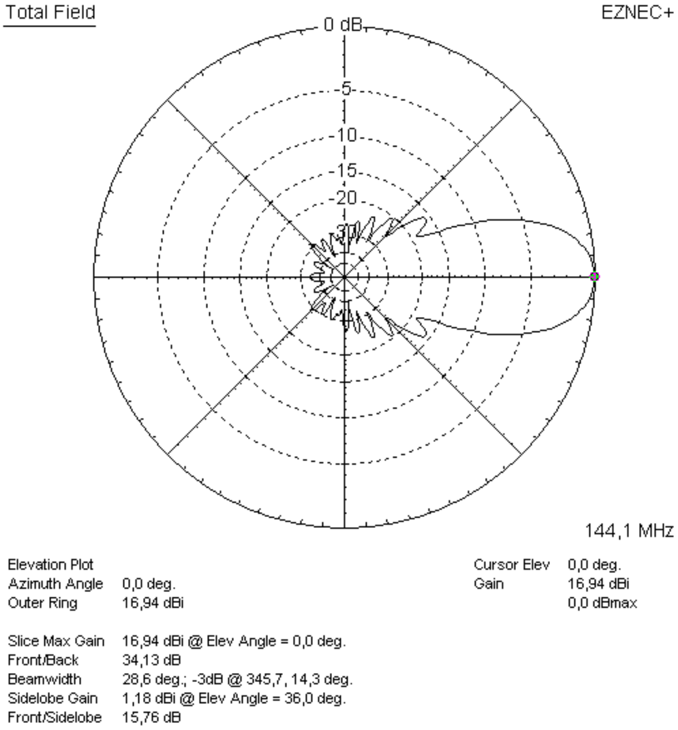
Pc.: Average Gain with DE using 10 mm tubes throughout



It must be mentioned that since the basis for setting up the G/T table is the NEC2 Kernel as used in EZNEC it is 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.

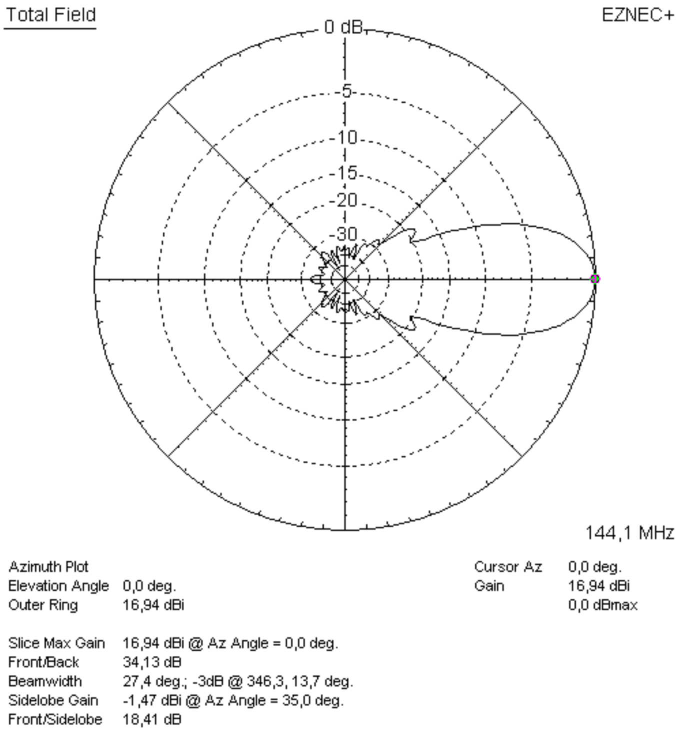
2. The Models Radiation Pattern Plots

A pattern relevant for the G/T tables <u>must be computed at 50.150 respectively 144.100 MHz</u> since the radiation pattern slightly varies with frequency.



<u>Elevation Plot</u> of the16 elem. VDE

- **H-plane** -3 dB beam width = 28.6°



<u>Azimuth Plot</u> of the 16 elem. VDE

- **E-plane** -3 dB beam width = 27.4°

<u>Further key data for the G/T table that we read from the plots:</u>

- Gain = 16.94 dBi = 14.79 dBD
- F/B = 34.13 dB

And a manually figured out
- F/R ≈32.7 dB

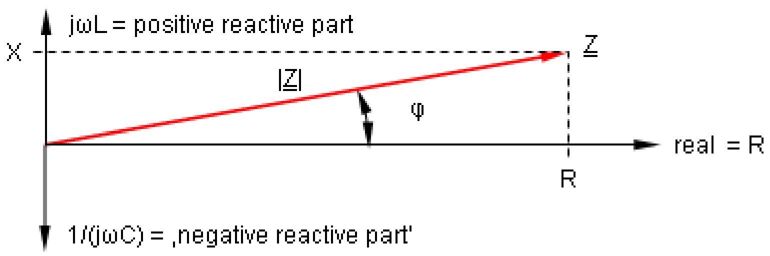
3. Determination of Bandwidth for the G/T Table

3.1 Impedance at desired frequency

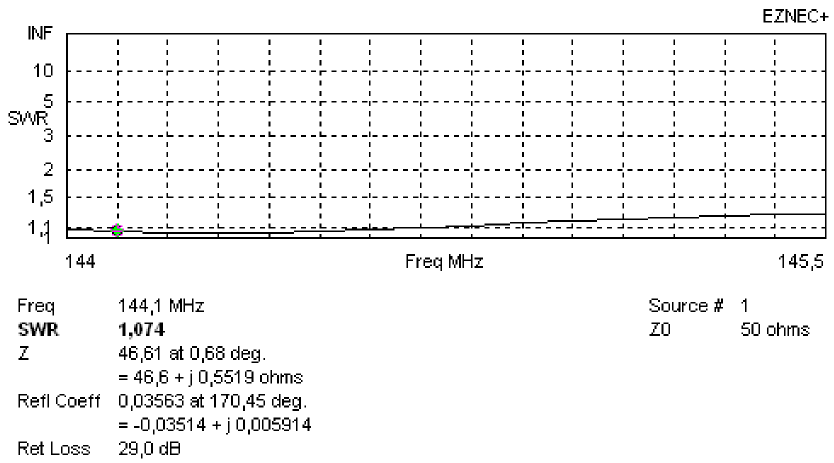
Impedance Z has a real and an imaginary part, it is a complex number. The real part represents the ohmic side whereas the imaginary part shows the capacitive or inductive fraction that may come along if the Yagis resonance is not 'spot on'. Complex numbers can be written using Cartesian or polar coordinates:

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

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)



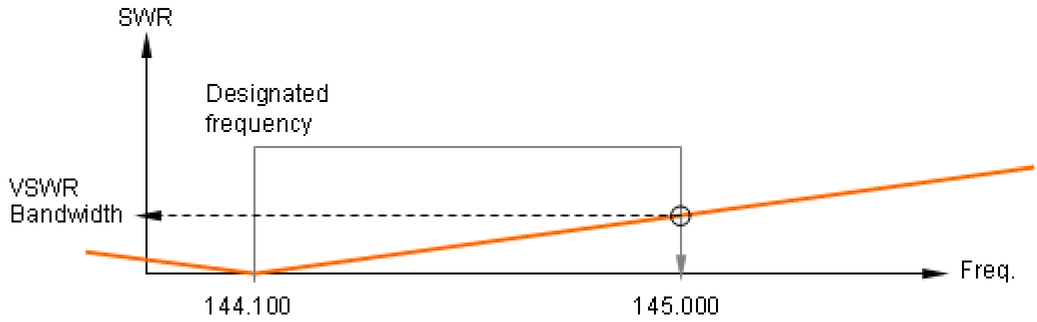
The G/T tables use 50.150 MHz / 144.100 MHz as the target frequency throughout, so we place the marker there and read out the complex impedance Z [Ohm]. In our example we read Z = (46.6 + 0.55) Ohm or in Euler's notation 46,61Ohm at 0.68 deg. as the apparent impedance |Z| from the data displayed in the EZNEC SWR plot window:

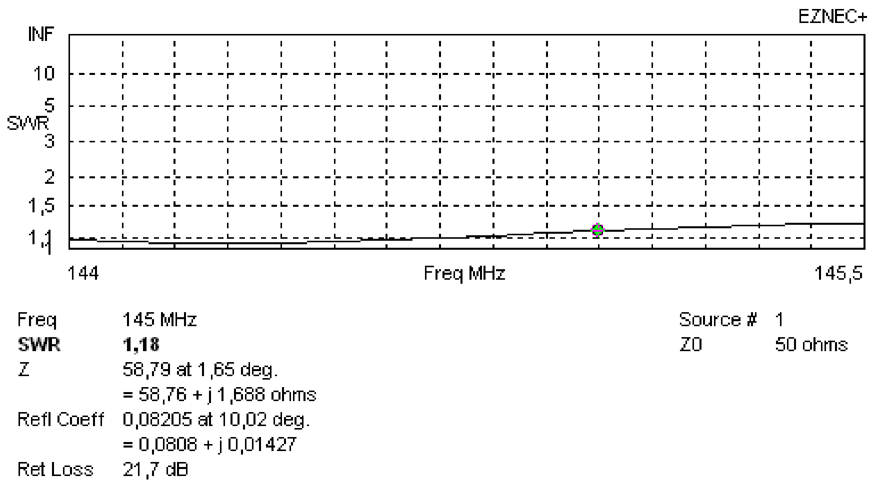


However, VE7BQH uses just the real part, the resistance R picked from complex impedance Z for the G/T table. It will not make a significant difference what figure to use as long as the Yagi is not far from the wanted impedance since small angles φ provide very small changes only. => Consequently we note 46.6 Ohm as our Z for the G/T table.

3.2 VSWR Bandwidth in the G/T table

What this parameter determines is 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. Therefore, we use VSWR 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 SWR from the Charts Data box. We find an SWR figure of 1.18 in the EZNEC SWR plot for the example Yagi. VE7BQH declares this figure as 'VSWR Bandwidth = 1.18:1' 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-Factor is only achieved in dry conditions or if real build might be out of that narrow bandwidth.

> *"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 that 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

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 vertical polarisation this is all to be inverted, see § Stacking.

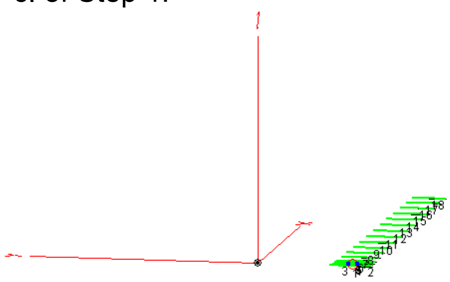
E-plane [H-pol] = electric field // side-by-side (azimuth plot)
H-plane [H-pol] = magnetic field // top-to-bottom (Elev. plot)

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 according DL6WU stacking most Yagis will be stacked wider side by side than on top of each other.

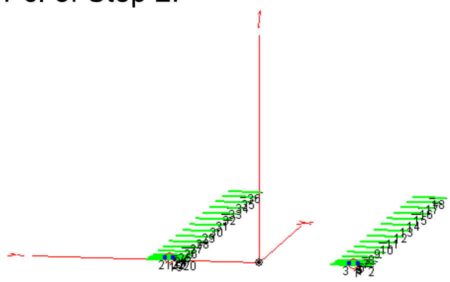
Using the DL6WU formula (§ Stacking) at our target frequency of 144.100 MHz we derive at:
E-plane: Azim. Pattern -3 dB beam width = 27.4 deg. => 4.39 m as distance side-by-side
H-plane: Elev. Pattern -3 dB beam width = 28.6 deg. => 4.21 m as distance top-to-bottom

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’ by 4,390 / 2 = -2,195 mm along the Y-axis.
Step 2: Next we copy all wires using ‘Offset copy Y by’ 4,390 mm.

Pc. of Step 1:

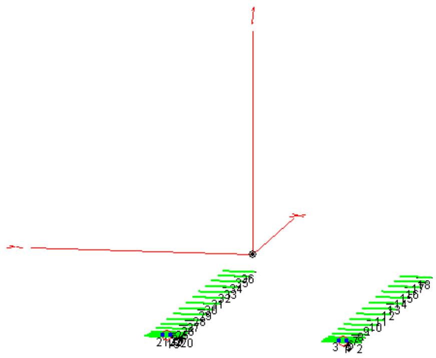


Pc. of Step 2:



Step 3: Following that we lower the 2 Yagis by half the H-stacking distance of -(4,210 mm / 2) = -2,105 mm by using ‘Move Wires XYZ’ in Z-direction.

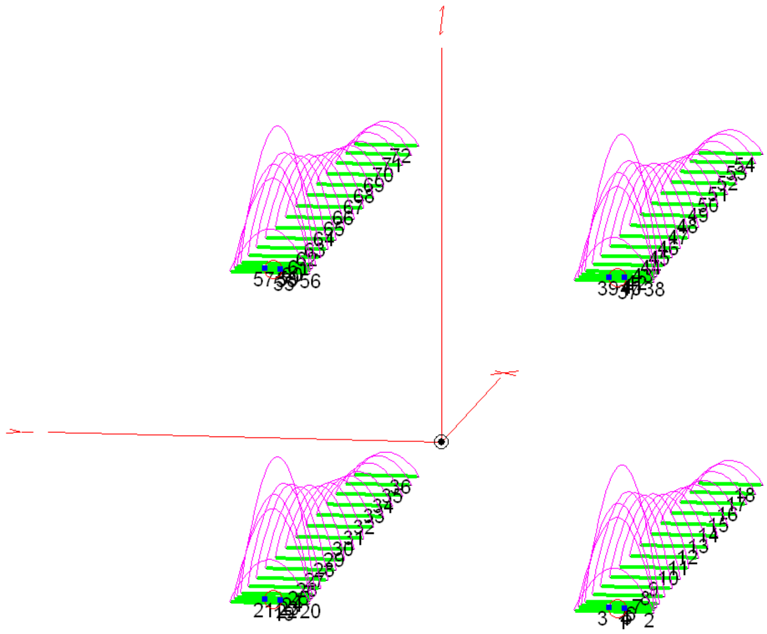
Pc. of Step 3:



Step 4: Last we copy the 2 Yagis using ‘Offset copy Z by’ 4,210 mm.

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

Pc. of Step 4:



<u>Note on stacking distances:</u>

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

*5. All stacking dimensions **EXCEPT** those marked with a "*" and "#" are calculated from the DL6WU stacking formula.*

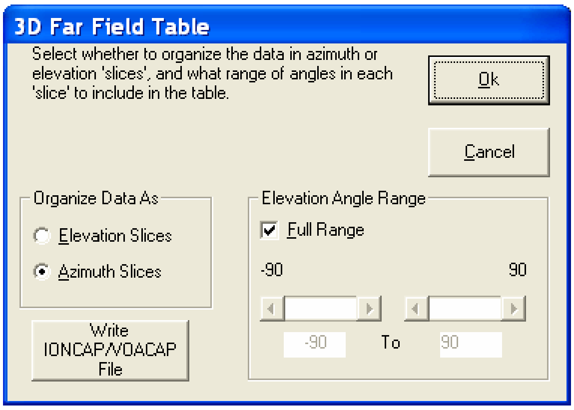
6. Antennas marked with a "" have stacking dimensions recommended by the manufacturer or designer.*

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.

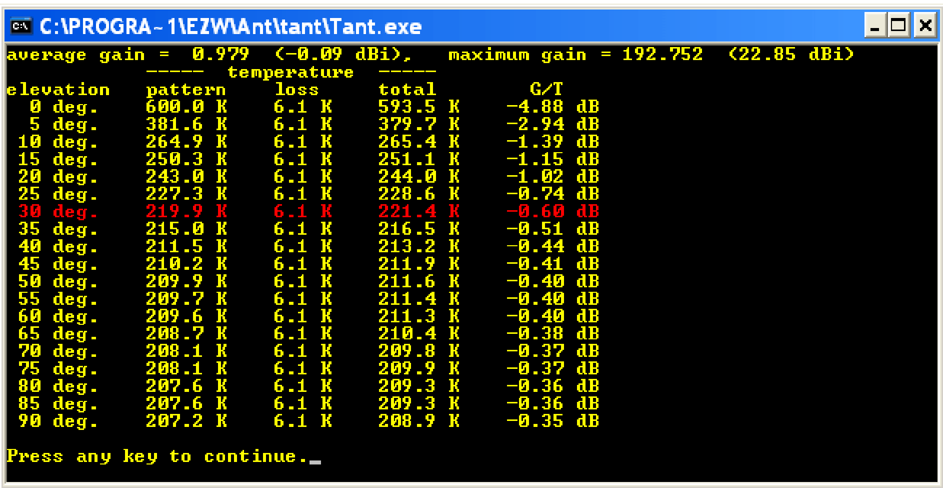
See § Stacking -> Notes on ‘Over Stacking’.

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 we run a 3D plot of that model. The computed Far Field data must be transferred into a file in .txt format by using the ‘FF Tab’ button that we find on the left side of the EZNEC main window. Select options as shown below:



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. A detailed description of this procedure is given in the TANT Manual. Open the file in TANT and compute.



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	22.85 dBi = 20.70 dBD
temperature loss	Tlos	6.1 K
temperature total	Ta	221.4 K
G/T	G/T	-0.60 dB

6. The G/T Table in Detail

In the VE7BQH G/T Table this 16 elem. VDE - 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)	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

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. VDE has its Reflector at pos. 0 mm and the last element at 9870 mm. We calculate its length in WL as follows:

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

2. Gain = Gain in dBD of a single antenna

Gain in dBD is Gain dBi - 2.15 dB. For the 16 elem. VDE that is

$$G_{dBD} = 16.94\,dBi - 2.15\,dB = 14.79\,dBD$$

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 16 elem. VDE = 27.4 deg. => 4.39 m.

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 16 elem. VDE = 28.6 deg. => 4.21 m.

(*) inverse for any vertically polarised Yagi

5. Ga = Gain in dBD of a 4 bay array

Gain in dBD is Gain dBi - 2.15 dB. For the 16 elem. VDE bay that is
22.85 dBi = 20.70 dBD

$$G_{a,dBD} = 22.85\,dBi - 2.15\,dB = 20.70\,dBD$$

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’ shall be 1.000; the Average Gain employing real Material Losses must be < 1.000. 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.

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 16 elem. VDE’s Tpattern = 219.9 K and Tloss = 6.1 K

$$L = \frac{6.10\,K}{290\,K} + 1 = 1.0210345\,[/]$$

$$T_{total} = \frac{219.9\,K + (1.0210345 - 1)\,290\,K}{1.0210345} = 221.34\,K$$

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

$$221.34 - 219.9 = 1.44\,K$$

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

9. 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)

10. 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 VSWR is for one antenna (see § Determination of Bandwidth for the G/T table)

11. 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.

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

$$G_{dBi}/T_{Ant} = 22.85\,dBi - 10\log 221.34\,K$$

$$G_{dBi}/T_{Ant} = 22.85\,dBi - 23.45\,dB = -0.60\,dB$$

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.

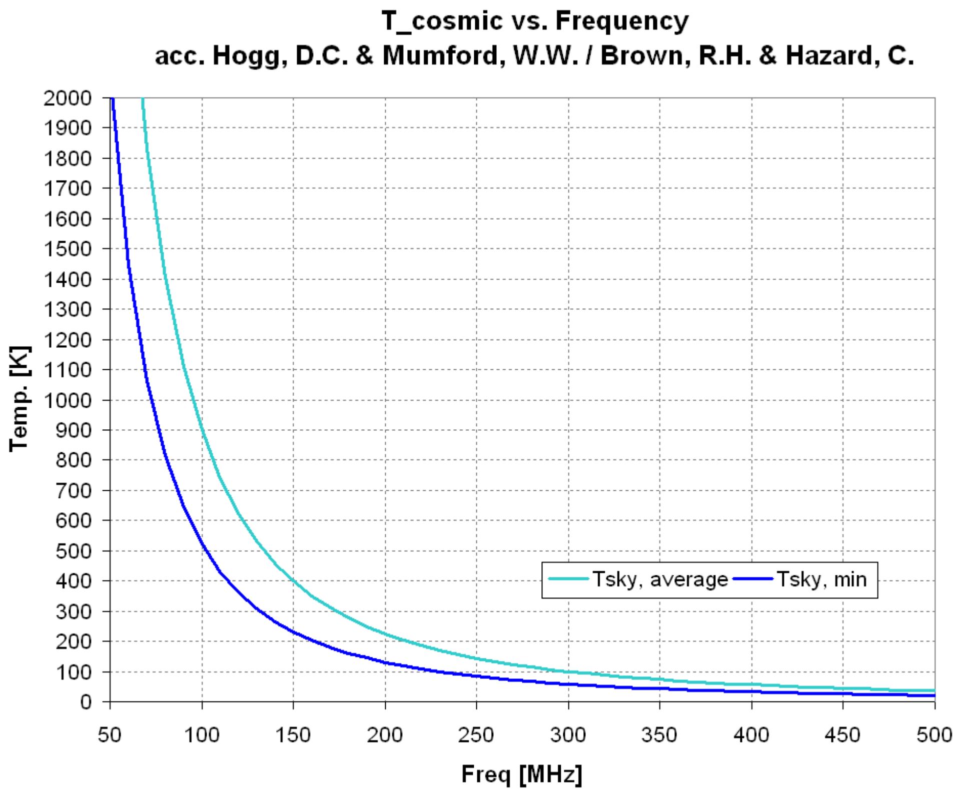
See § Relevance of Tearth
See § From Y-Factor to G/T

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 1932 (1), basically confirmed and refined by G. Reber, W9GFZ (!) 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) $T_{\min} = 1450 \cdot \lambda^{2}$ (7.2) $T_{average} = 100 \cdot \lambda^{2}$ (7.3) $T_{\max} = 58 \cdot \lambda^{2}$



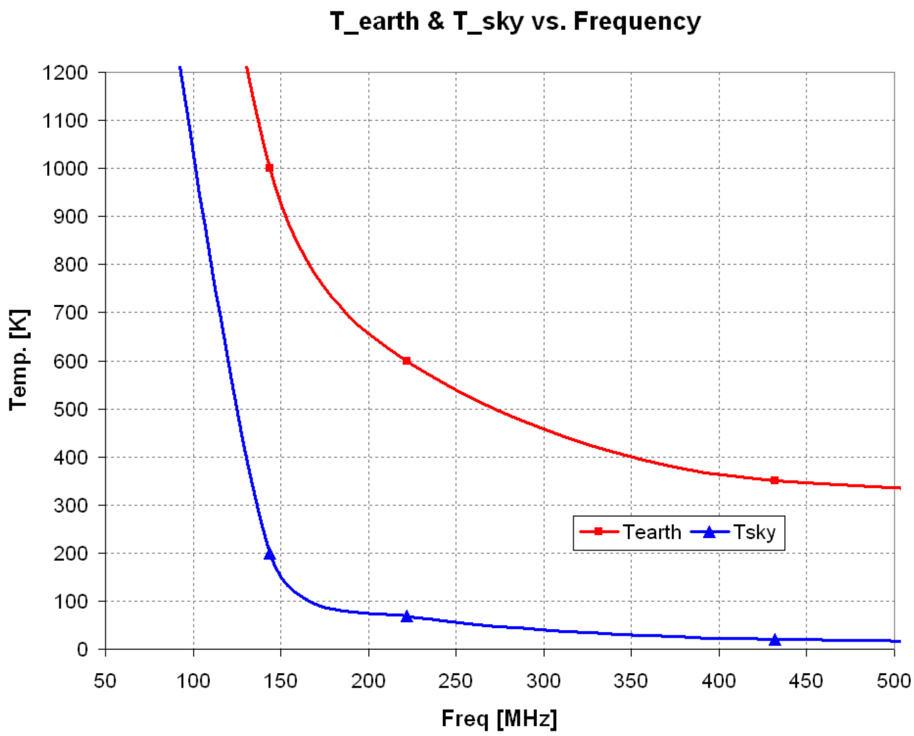
8. Tsky and Tearth - Further Research and Development

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 Janskys 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.

A standard for today (2011) may be the following figures derived at by the works of DJ9BV, VK3UM, VE7BQH and others.



The figures this chart is based upon may be found in table 2.

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 Temperature of 4-Yagi-Arrays for 432 Mhz EME” in 1987.

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 273 K + 17 K = 290 K representing an earth temperature of 17 degree 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 Janskys 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 shall 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 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 down 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) 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.

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

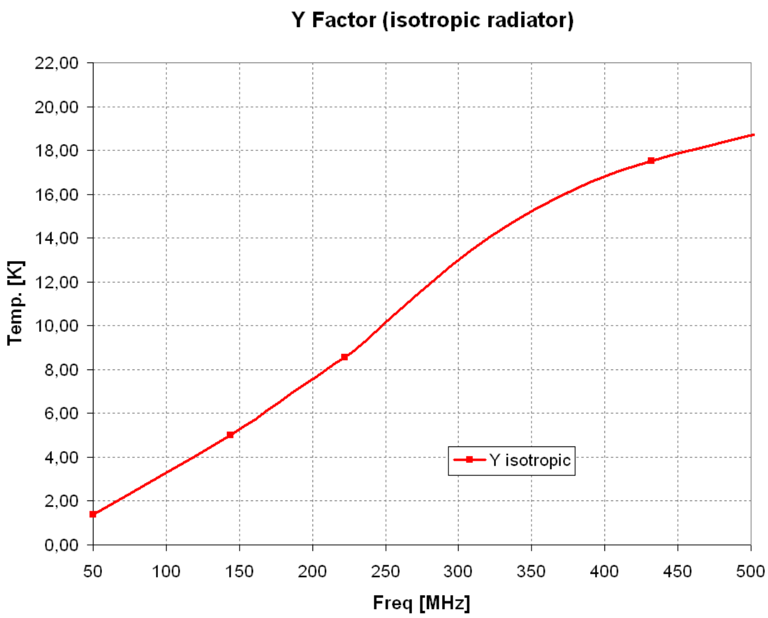
Often the Noise Temperature of the Receiver is included:

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

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 this when using temperatures as given in table 2:



The chart indicates that caring for the G/T - ratio is approximately 3 times more important on 144 MHz than on 50 MHz and 9 times on 432 MHz.

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 (9.4) is taken from DJ9BV and F6HYE (1) if using cold sky vs. sun to determinate the complete RX systems Y-Factor:

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

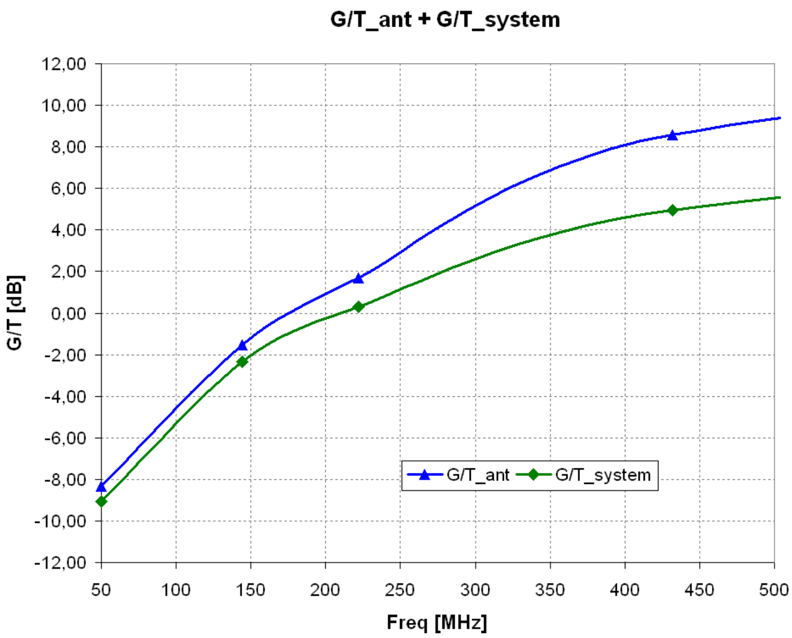
Gain [/] to Temperature using the dimensionless Gain [/]:

$$(9.5) \quad G/T = \frac{G}{T_{System}} \quad or \quad = \frac{G}{T_{Ant}} \qquad specify\ this\ correctly...$$

Gain [dB] to Antenna Temperature and Gain [dB] to System Temperature:

$$(9.6) \quad G_{dB}/T_{Ant} = G_{dB} - 10\log T_{Ant} \qquad (9.7) \quad G_{dB}/T_{System} = G_{dB} - 10\log T_{System}$$

Using mean equipment for EME we yield the following G/T figures when applying (9.5 / 9.6):



Figures used for Chart above:

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]

$$(9.8) \quad F[/] = 1 + \frac{T}{T_0} = 1 + \frac{T}{290\,K} = \frac{SNR_1}{SNR_2} = \frac{S_1/N_1}{S_2/N_2} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$$

T_0 is referred to as 290 K with respect to the lowest temperature attainable (-273 K) plus 17 K to meet a mean 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

$$(9.9) \quad F[/] = \frac{N_{out}}{N_{in} \cdot G}$$

Converting Noise Factor [/] in Noise Figure [dB]

$(9.10) \quad NF_{dB} = 10\log_{10} F$ or vice versa $(9.11) \quad F = 10^{(NF_{dB}/10)}$

Converting Gain [/] in Gain [dB]

$(9.12) \quad G_{dB} = 10\log_{10} G$ or vice versa $(9.13) \quad G = 10^{(G_{dB}/10)}$

Noise Figure

$$(9.14) \quad NF_{dB} = 10\,\log\left((T_{Dut}/290K) + 1\right)$$

Noise Temperature of Device under Test (DUT)

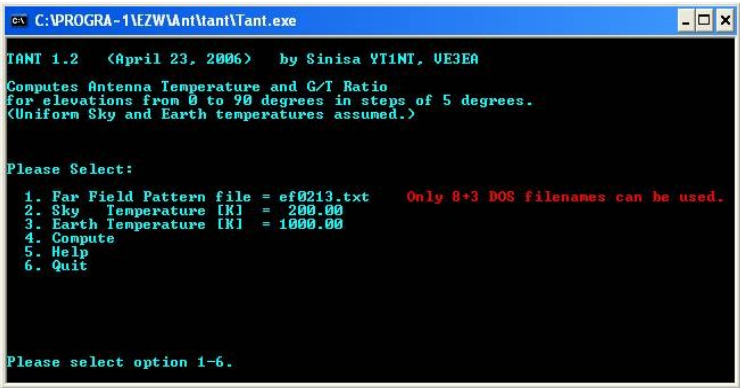
$$(9.15) \quad T_{DUT} = 290\,K\left(10^{(NF/\ 10)} - 1\right)$$

References

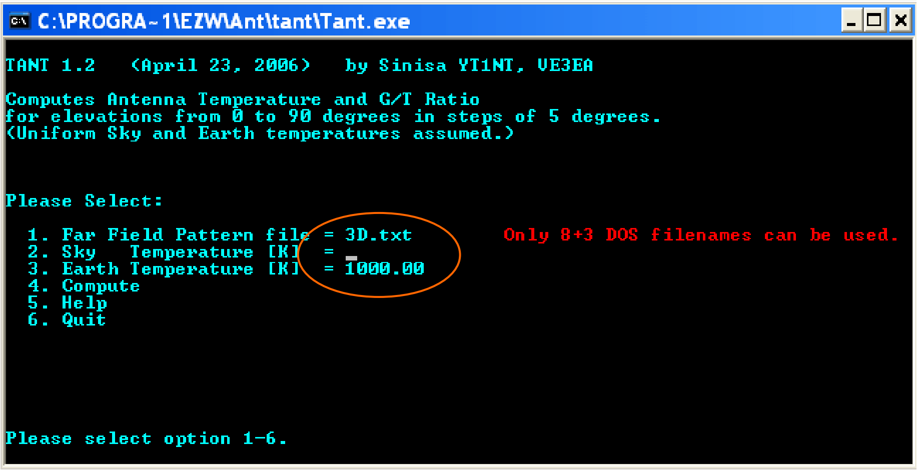
(1) Rainer Bertelsmeier, DJ9BV & Patrick Magnin, F6HYE: Performance Evaluation for EME-Systems, Dubus 3/1992

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

TANT's preset is on Tearth and Tsky usefull 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 a table holding temperatures that should be in convention with most serious users of G/T figures is given. 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 2:

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

*) for 432 MHz the value of Tearth = 290 K still is widely spread due to DJ9BV mentioning that figure in his constitutive article on 432 MHz Antenna Noise in 1987. According to VE7BQH he later revoked that as being far too low. See § Tsky and Tearth

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 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

The 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.

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?

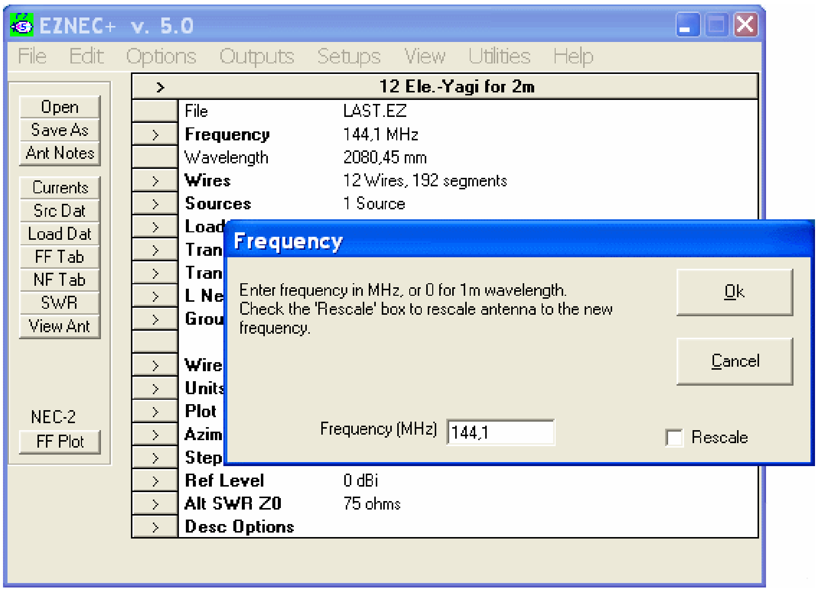
11.3 Applying the DL6WU Stacking Formula

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 frequency used the acquisition of the radiation pattern shall 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

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

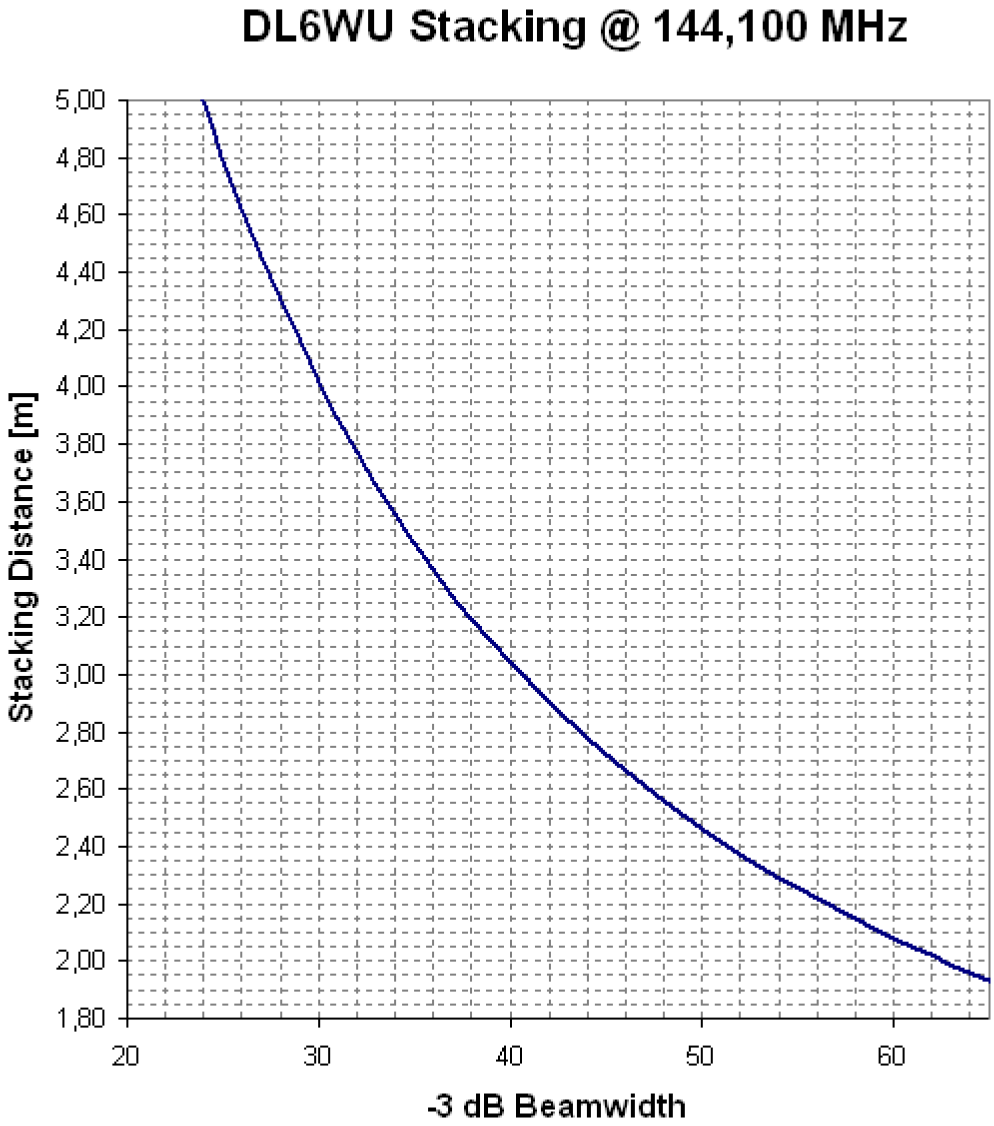
Now we may proceed calculating the stacking distance as given by the DL6WU formula (1):

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

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 to 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 <u>without</u> cable and transformation losses in either plane. See also charts 11+12 in NBS Technical Note 688 by Peter P. Viezbicke (2).

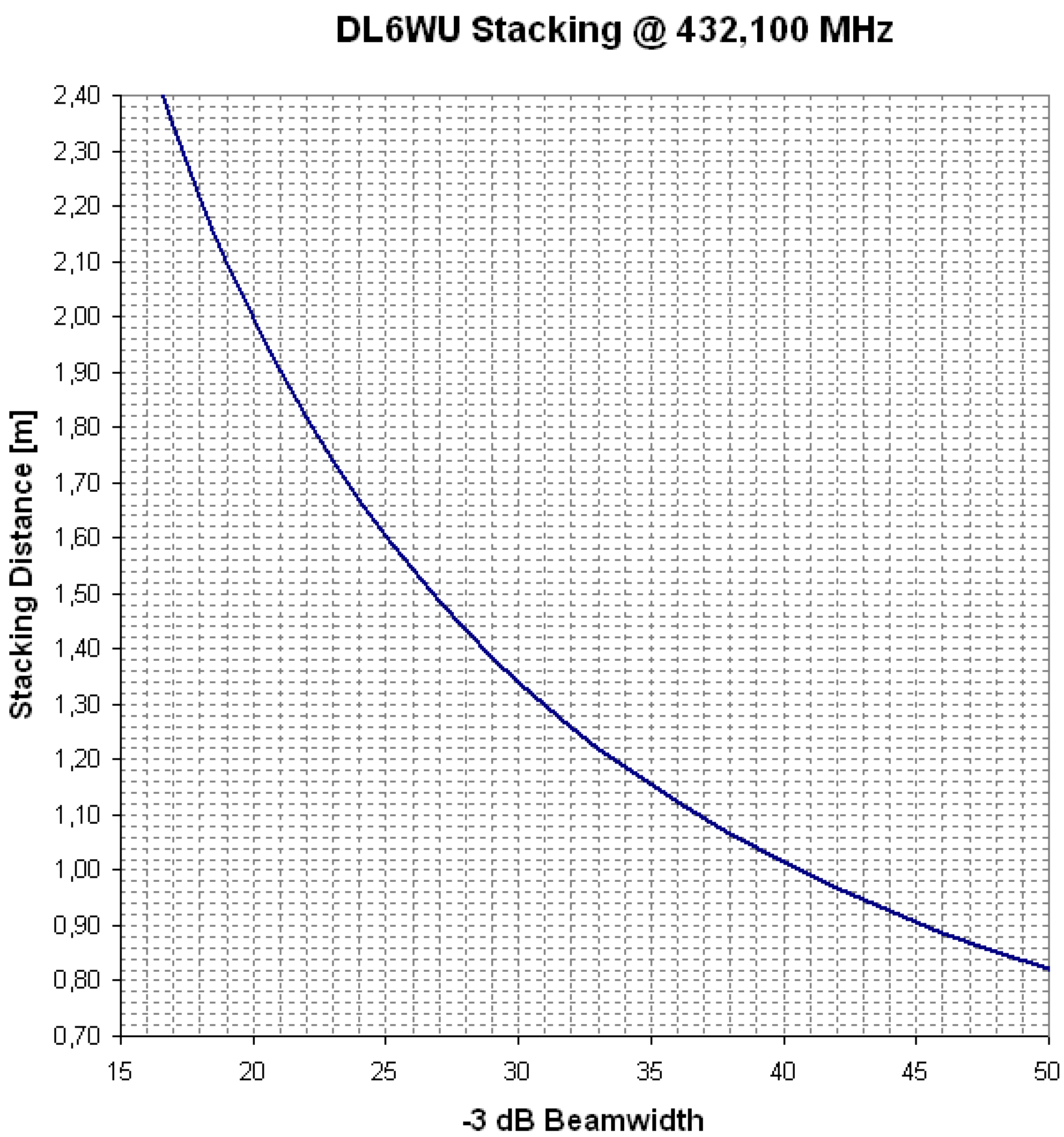


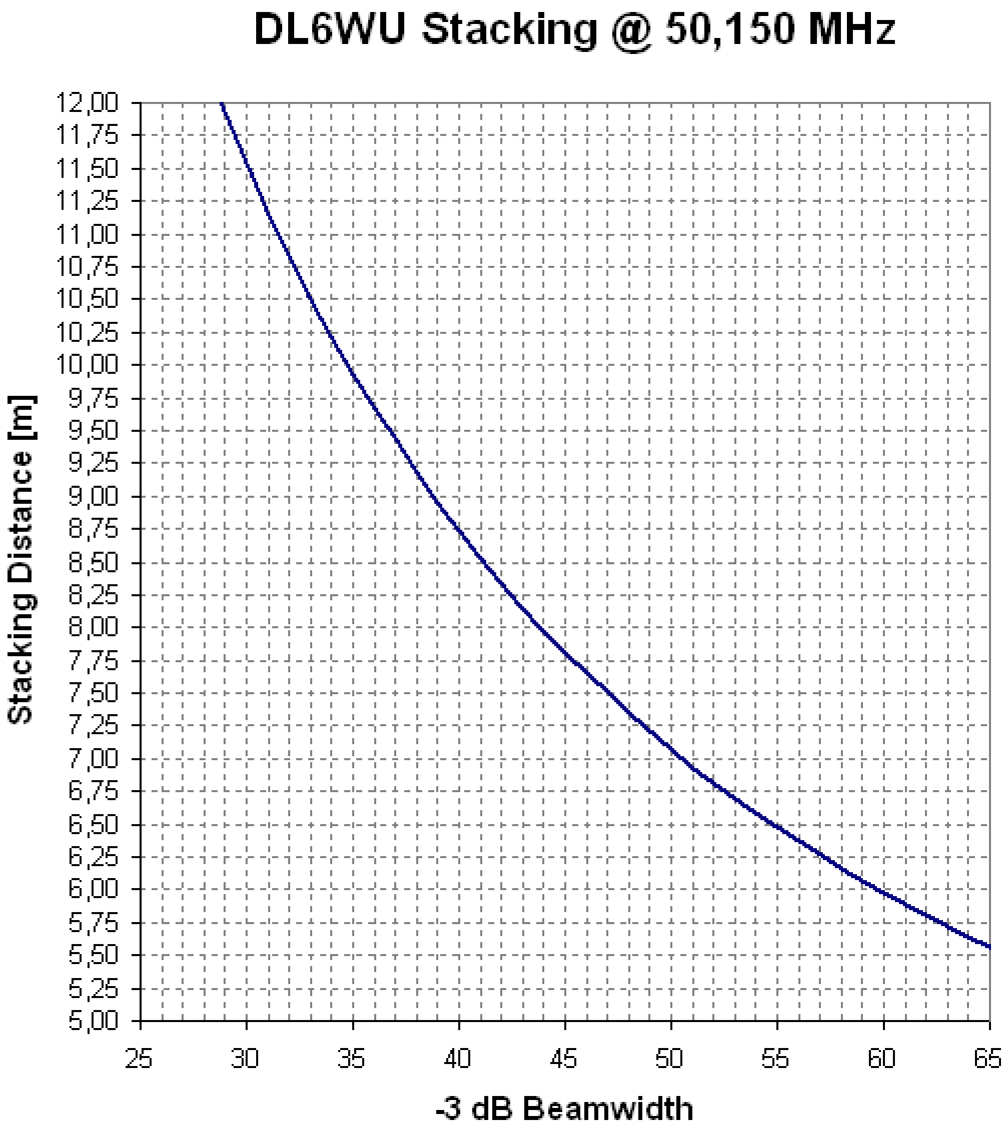
Today it has established itself that the DL6WU formula would be valid from 10 elements on only. DL6WU provides a plain explanation:

> *"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 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

Weather 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 lobes 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 the 16 elem. VDE 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.

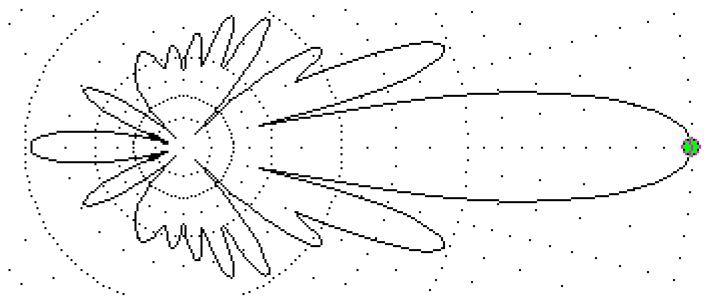
Despite Tant or Ttotal has increased by 1 Kelvin Over Stacking leads to improved G/T for this bay since the Gain of the bay increases as well by almost 0.1 dB at the same time whereas due to the respectable F/R of the single Yagis pattern we find that figure almost unchanged.

What makes a Yagi suitable for over stacking?

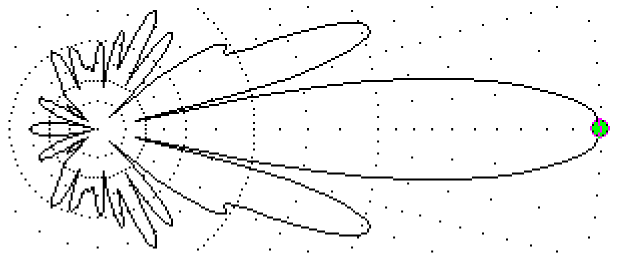
Referring to the degree of suppression of back- and side lobes of the single 16 elem. VDE Yagi it is plain to see that the bay of 4 keeps on with that characteristics even under wider than the DL6WU stacking distances.

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.

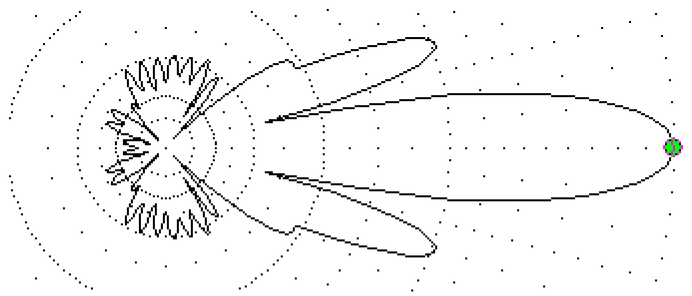
Pc.: Elevation Plot - 2SA 13 elem. (SM5BSZ) bay over stacked by 0.2 m



Pc.: Elevation Plot - 16 elem. VDE (DG7YBN) bay over stacked by 0.4 m



Pc.: 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