VHF Antenna Noise Temperature

Dragoslav Dobričić, YU1AW

Introduction

One of the criteria of receiving system is its ability to receive very weak signals: its sensitivity. For given bandwidth, the sensitivity is determined by only two factors: Antenna Gain (G) and System Noise Temperature (Tsys). The system noise temperature comprises the antenna noise temperature (Ta), the cable losses converted into noise temperature (Tcable), and intrinsic noise of the receiver or preamplifier (Trx). These parameters determine signal to noise ratio (S/N) which one linear receiving system has at its output.

There is no universal recipe and the receiving system must be tailored in order to meet the prevailing conditions as seen at the antenna output terminals. The first factor determining these conditions is the noise arriving with the signal, which cannot be influenced by the operator but must be coped with by the receiver.

Antenna noise

All objects with a temperature higher than absolute zero (0 K) radiate electromagnetic waves due to their temperature. This radiation is well known in physics and can be expressed mathematically as “black body radiation” according to Planck’s law. The equivalent antenna noise temperature (antenna temperature Ta) is the noise power received by the antenna, converted to the temperature of a resistor, whose value is equivalent to the radiation impedance of the antenna.

The noise temperature of objects within its beam width mainly determines the antenna noise temperature. If an object radiates noise due to its intrinsic temperature or due to other noise-generating mechanisms, the antenna will receive this noise and a certain power will be present at its connections. Since noise power and equivalent noise temperature are dependent on one another according to Boltzman’s constant, it is possible to express the received noise power as an increase in antenna noise temperature.

The antenna noise temperature has very little dependence on the physical temperature of the antenna itself that can be measured with the aid of a thermometer! The higher the efficiency of the antenna means that the greater is the ratio of radiation resistance to loss resistance, and thus the less will be the dependence.

The received noise power, or noise temperature of the antenna, not only depends on the temperature T of the object, but also on how much this object is present in the antenna diagram. In order to calculate this, it is necessary to operate with space angles of the object (Ω) and the antenna diagram (Ωa). This is given in equation: $Ta=T\ \Omega / \Omega a$. If Ω is equal to Ωa, or is greater, this will mean that the antenna will only “see” the object radiating with temperature T, and the antenna noise temperature will be equal to the temperature of the object: $Ta = T$. [6]

However, all practical antennas have unwanted lobes and a finite front to back ratio. If these are not suppressed considerably, the antenna will receive additional noise power with them. In the case of conventional antennas with beam widths of less than 25 degrees in both planes, a rule of thumb is given in [7] that takes the effects of unwanted side and back lobes into consideration: Ta=0.82 Tsky + 0.13 (T'sky + Te). Tsky is the mean value of the equivalent noise temperature of space within the main beam, T'sky is the mean value of the equivalent noise temperature of space within the side lobes and Te is effective noise temperature of the ground (~ 290 K). The given equation is only valid for antennas that are facing toward the sky; it then provides good results. This is the temperature of an antenna pointing towards sky and including the effect of side lobes facing towards the "warm" ground and to the side.

All these components were determined as a function of the antenna radiation pattern. In the VHF range the sky noise is the greatest natural contributor to the total antenna noise and this is inversely proportional to frequency. It cannot be influenced in any way but can be neglected at frequencies above 1 GHz. Above 1 GHz, the ground noise is constant but decreases towards lower frequencies owing to the increasing ground reflectivity and decreasing noise emittance. But the total noise level is the sum of noise radiated from the earth and sky noise that has been mirrored from the earth's surface. When the antenna is directed skywards, as in earth – moon – earth (EME) or satellite communications, the contribution of this noise is usually small and is largely dependent upon the distribution and suppression of the side-lobes. The need for an EME antenna to possess a clean lobe pattern, may now be appreciated.

When, on the other hand, "normal" or point-to-point VHF/UHF communication is carried out over the earth's surface, the antenna receives both ground and sky noise because the antenna lobes are directed to both sky and earth in about equal amounts. The noise temperature of that antenna is mean value of sky and ground noise.

Two further noise contributions are the man-made noise from large cities and industrial areas, which vary according to location, and atmospheric noise**.** The latter is much smaller at VHF/UHF than at HF and dependent upon the prevailing atmospheric conditions. See Fig. 1. The thermal noise across the loss resistance of an antenna may be neglected owing to the very high efficiency of VHF/UHF antennas.

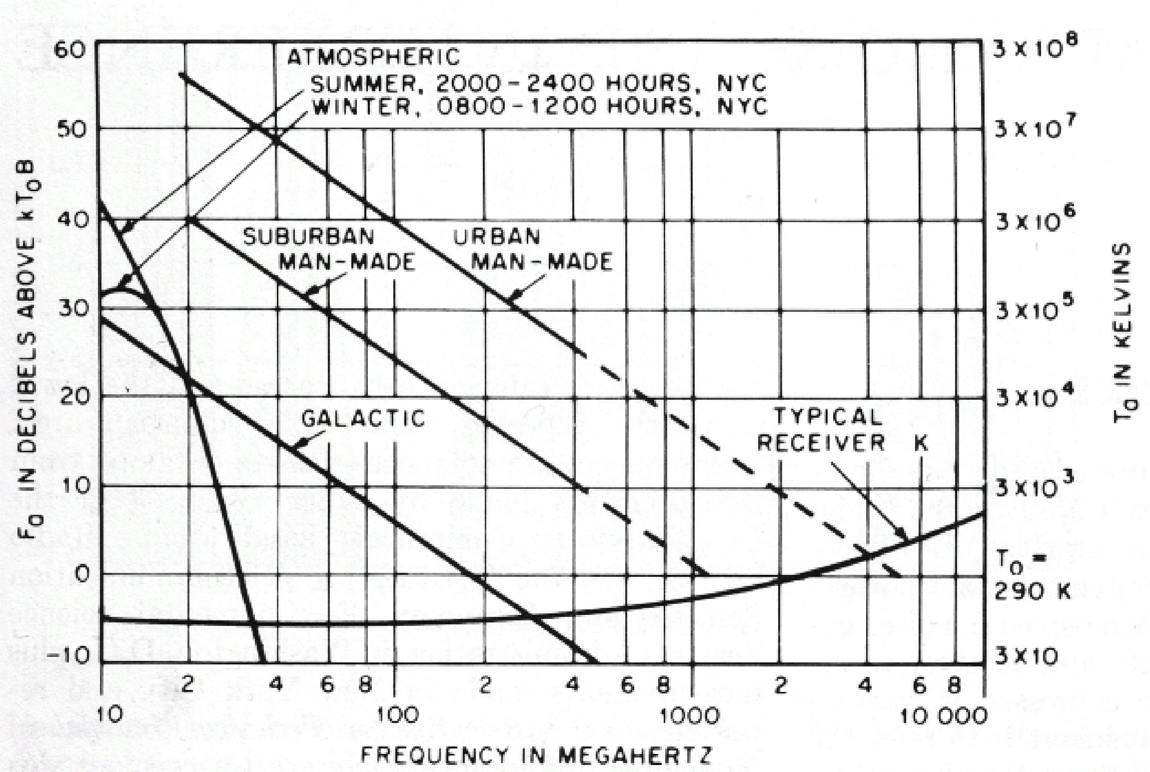
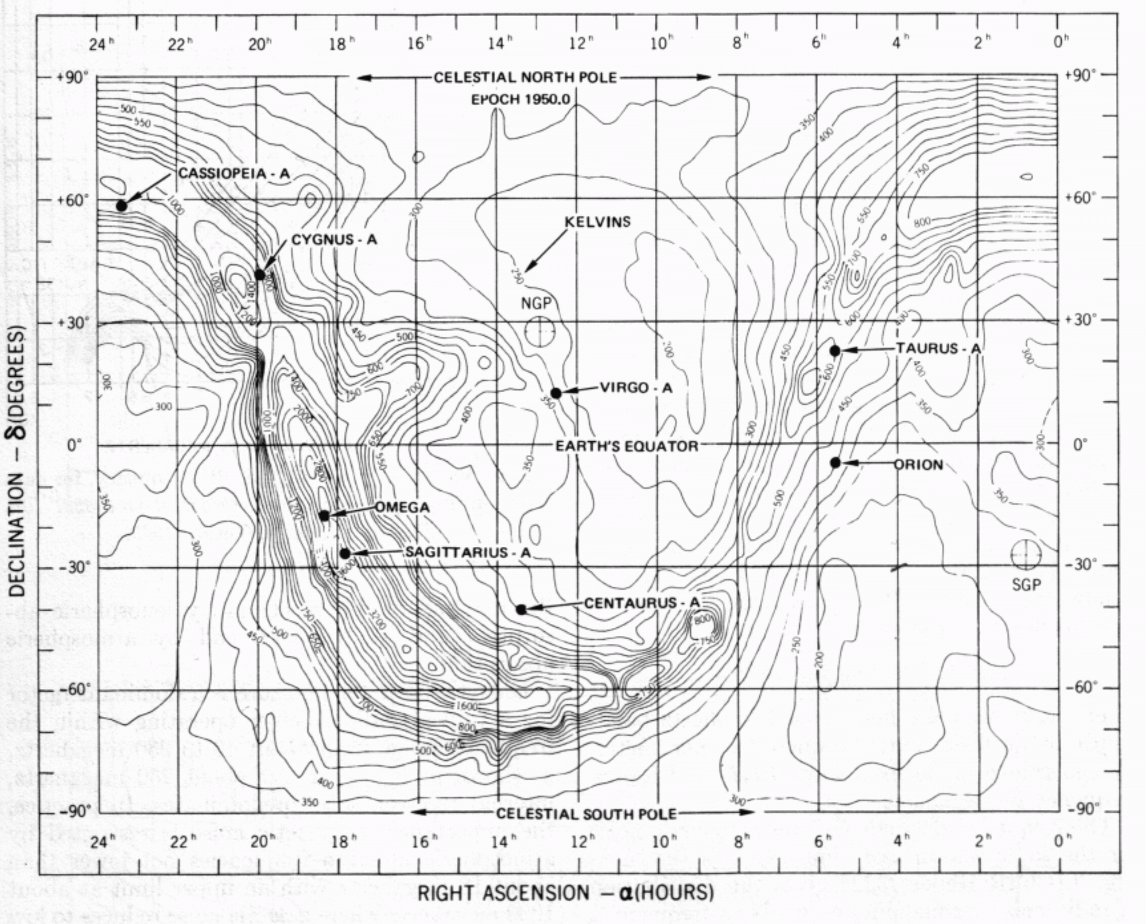


Fig.1: Median value of average noise power expected from various sources (omni directional antenna)

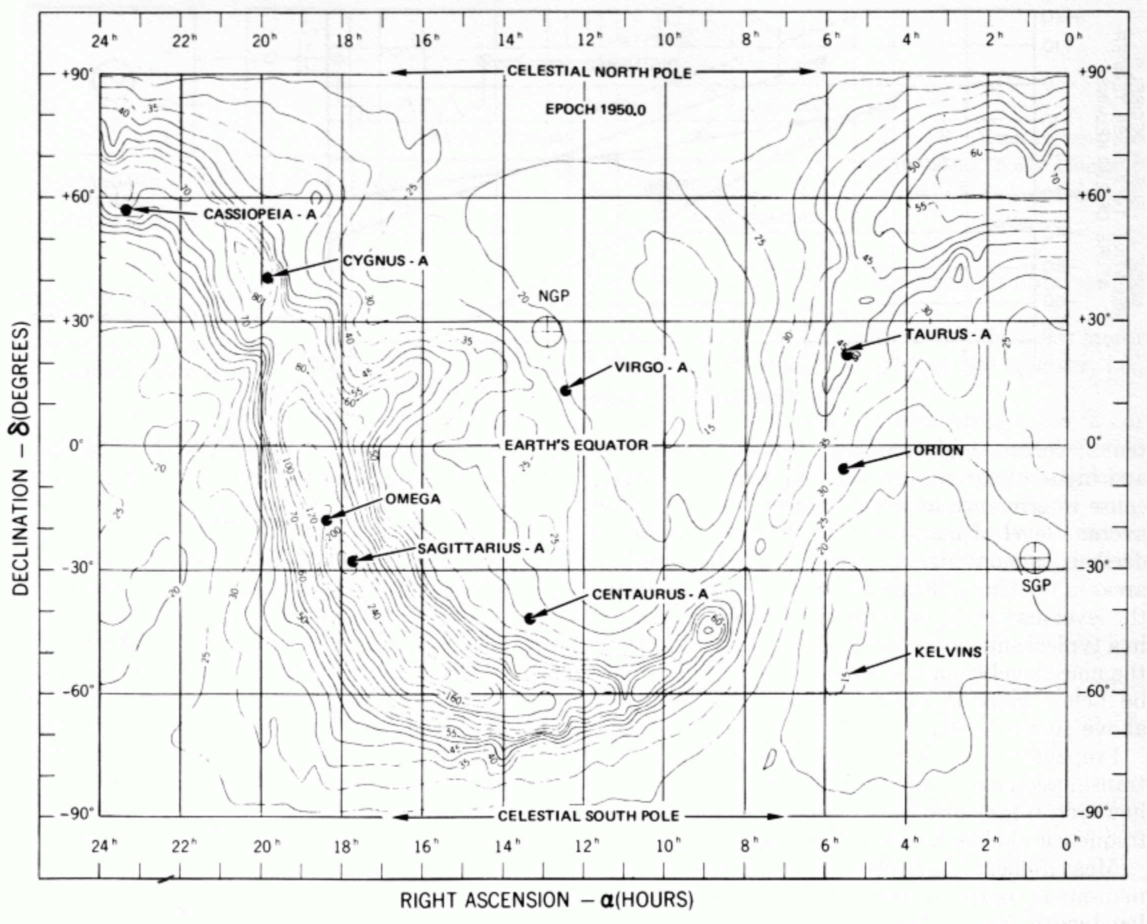
From what has been already said, it may be concluded that at the terminals of every antenna that is directed towards the horizon, a noise power may be measured. When the antenna is directed towards the sky this noise power should fall if the noise temperature of sky is low.

Since it became known that the sky born noise fluctuated considerably, minimum values for certain areas were taken, other areas may have random noise power distribution. See Fig. 2 and Fig. 3. As can be seen from the figures there exists the possibility that the skyward directed antenna could be pointed to a particularly noisy part of the sky.
The noise introduced into antenna is, however, unavoidable and nothing much can be done about it once the antenna has been erected with the due attention paid to antenna elevation, location, working frequency, and gain. The signal to noise ratio (S/N) at the antenna output terminals to the receiver, is thus, the best that is available for that particular antenna.



Radio-sky map. 136-megahertz brightness temperature (Kelvins).

Fig. 2



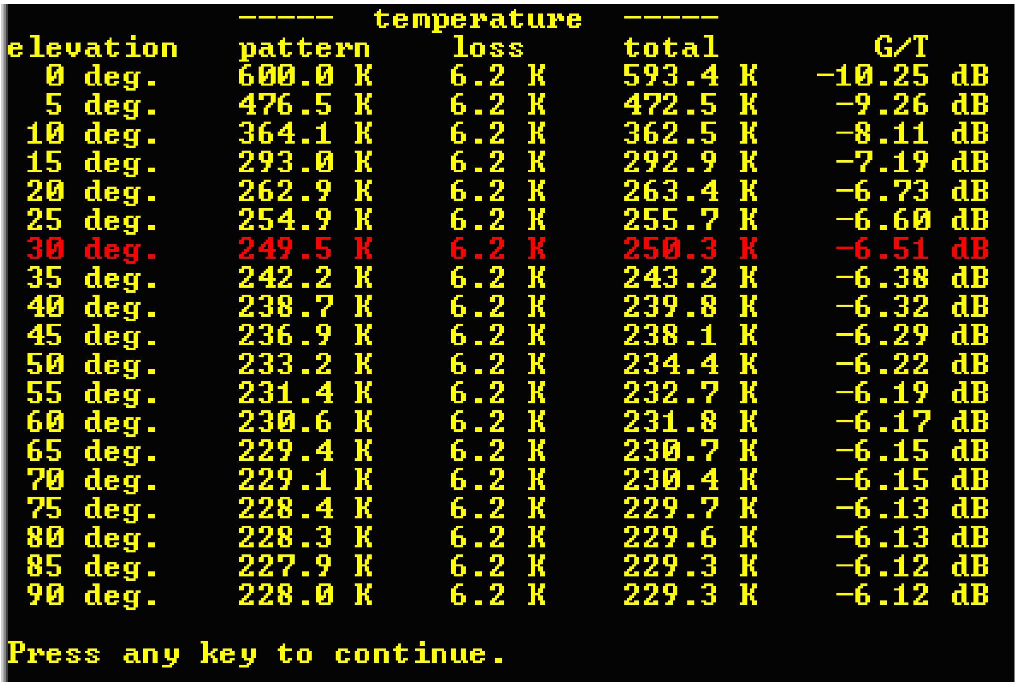
Radio-sky map. 400-megahertz brightness temperature (Kelvins).

Fig. 3

Low noise VHF antennas

Thanks to the wide availability of antenna simulation programs today, we are faced with the great number of Yagi antenna authors. Many authors give very high importance to the low antenna noise temperature of their yagi antennas at VHF bands. There is a list [1], given also in Appendix, where many 144 MHz antennas are ranked according to their receiving characteristics, which are expressed as the antenna gain divided by the effective noise temperature or G/T ratio. The antenna effective noise temperature can be calculated as described in [2] by DJ9BV in German *Dubus* magazine. Today, with wide-spread use of various antenna simulation programs, it becomes easy to calculate antenna effective noise temperature. Some authors have made small programs that use output data of an antenna simulation program to calculate very accurate effective antenna noise temperature. One of them, a DOS program TANT by Siniša Hristov, YT1NT (VA3TTN, VE3EA) uses this approach and calculates Ta for various antenna elevation angles, and different ground and sky temperatures as parameters. [3, 4, 5]

The program uses the EZNEC antenna analyzing program output file and by using antenna radiation pattern data and an arbitrary chosen ground and sky noise temperature calculates effective antenna noise temperature for different antenna elevations. It is uses 30 degrees of antenna elevation as a standard for calculating and comparing antenna noise temperatures. Also, ground noise temperature is standardized to Te=1000 K and sky noise to Tsky=200 K for the 144-MHz band. The ground noise temperature used is higher then its physical temperature of 290 K due to the contribution of man-made urban noise.



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            -----  temperature  -----
elevation   pattern    loss     total        G/T
  0 deg.    600.0 K    6.2 K    593.4 K   -10.25 dB
  5 deg.    476.5 K    6.2 K    472.5 K    -9.26 dB
 10 deg.    364.1 K    6.2 K    362.5 K    -8.11 dB
 15 deg.    293.0 K    6.2 K    292.9 K    -7.19 dB
 20 deg.    262.9 K    6.2 K    263.4 K    -6.73 dB
 25 deg.    254.9 K    6.2 K    255.7 K    -6.60 dB
 30 deg.    249.5 K    6.2 K    250.3 K    -6.51 dB
 35 deg.    242.2 K    6.2 K    243.2 K    -6.38 dB
 40 deg.    238.7 K    6.2 K    239.8 K    -6.32 dB
 45 deg.    236.9 K    6.2 K    238.1 K    -6.29 dB
 50 deg.    233.2 K    6.2 K    234.4 K    -6.22 dB
 55 deg.    231.4 K    6.2 K    232.7 K    -6.19 dB
 60 deg.    230.6 K    6.2 K    231.8 K    -6.17 dB
 65 deg.    229.4 K    6.2 K    230.7 K    -6.15 dB
 70 deg.    229.1 K    6.2 K    230.4 K    -6.15 dB
 75 deg.    228.4 K    6.2 K    229.7 K    -6.13 dB
 80 deg.    228.3 K    6.2 K    229.6 K    -6.13 dB
 85 deg.    227.9 K    6.2 K    229.3 K    -6.12 dB
 90 deg.    228.0 K    6.2 K    229.3 K    -6.12 dB

Press any key to continue.
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Fig. 4: Sample results of the TANT program showing Ta for various antenna elevation angles

There is another program for antenna noise temperature calculation, Yagi Analysis v.3.54 by Peter Sundberg, which is also frequently used for antenna noise calculations. It is important to say that noise temperature of sky at 144 MHz has a minimal value only in very limited parts of the sky in the constellation Leo 195-250K, and in the constellation Aquarius 275-350K. The rest of the sky, visible from northern hemisphere and having a high enough elevation to escape ground noise contribution, is between 500-1000K in all other areas. The exception is the part of the sky near our Milky Way galaxy center. In that part of the sky, there is an immense number of stars; new stars appear and old stars disappear all the time. These processes are especially frequent in central regions of the approximately lens-shaped Milky Way and for this reason a relatively very strong noise that covers virtually the whole radio spectrum arrives at the Earth from this direction. In addition to this diffuse radiation, there are discrete sources, so called radio stars, with very strong radio radiation. Noise temperature of the center of our galaxy is several thousands of Kelvin's at 144 MHz.

Statistically, for antenna noise temperature calculations, it will be more correct to use a mean value for the sky noise temperature on the order of 400 K on 144 MHz, instead of 200 K which is the lowest possible temperature of just one very limited region of the sky. At 432 MHz noise temperature Tsky should be adopted to be 40 K. Even these proposed higher sky noise temperatures are valid only if the antenna is not pointed directly at galaxy center, which is in constellation Sagittarius, where sky noise temperatures are several times higher.

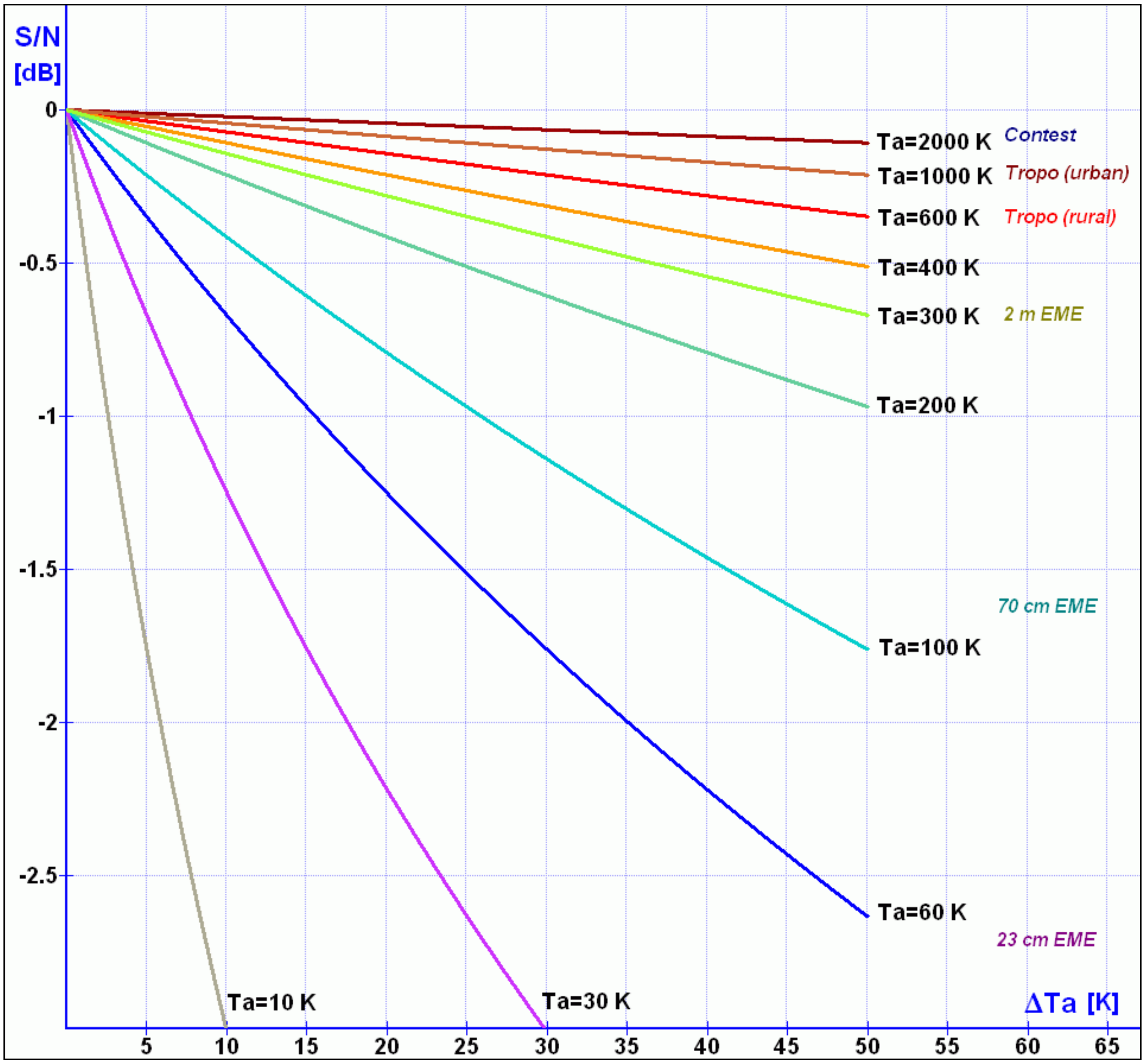

Fig. 5: Relative S/N versus antenna noise difference ΔTa

How antenna noise is important at VHF?

From given list [1] in the Appendix it is easy to see antennas that have similar boom lengths and gains but whose antenna noise temperatures differ usually 20 to 30 K. The maximum difference in antenna noise temperatures of all antenna on the list are less than about 60 K.

I was curious to see if this difference of 20-30 K for similar antennas is important in the terrestrial and the space communication on 144 MHz. The main reason for such curiosity is high ground and sky noises on VHF bands which are unavoidable limiting parameters of any VHF receiving system. For easier comparison I drew a diagram which is given in Fig. 5. The diagram shows the relative signal to noise ratio (S/N) dependence of the increasing antenna noise temperature (ΔTa). Signal to noise ratio is power ratio of signal power Ps to noise power Pn both received by antenna: S/N=10 log (Ps/Pn).

We can set, for easier comparison, the powers of received signal Ps and antenna noise Pn equal. This means that equivalent noise temperature of the received signal Ts and effective antenna noise temperature Ta are same, Ts=Ta. Then we can compare similar antennas according their S/N degradation only due to their increased value of Ta (ΔTa). S/N=10 log (Ts/(Ta+ΔTa))=10 log (Ta/(Ta+ΔTa)).

Antenna noise temperature Ta, which entirely depends on antenna environment, type of communications and on working frequency, is used as a parameter. Analysis shows that the effects of antenna noise temperature Ta on antenna receiving capability expressed as signal to noise ratio S/N is marginal at VHF bands. Even for space communications, such as EME, this effect is not as important as one expects. The difference in antenna noise temperature, between similar antennas with similar boom length, of about 20-30 K produced on 2-meter EME communication systems yields a difference in S/N of only 0.3 dB! On terrestrial work using tropo-scatter, due to higher antenna noise temperature Ta, this difference is even smaller, especially for people working from urban areas with high levels of man made urban and industrial noise. In contests, the wideband noise power of final amplifiers together with a high level of IMD completely swept away any difference in antenna noise temperature, and the gain of the antenna remains as the most important factor for S/N. Even at 70 cm EME the difference is not very high. Signal to noise degradation for ΔTa =20-30 K is only 1-1.5 dB for very quiet rural location!

It is obvious that the currently used G/T ratio as figure of merit for Yagi antenna comparison at VHF is not adequate. At higher frequencies it can be useful, but only for space communications and frequencies above 1 GHz. Even there, it can be only a figure of merit of a receiving antenna. This says nothing about transmitting properties of antenna.

From diagram which is given on Fig. 6, it is obvious that gain of the antenna is the most important factor for good S/N on VHF and lower UHF bands for both terrestrial and space communications. But it is also obvious that for determining the S/N for space communications on frequencies above 1GHz, the noise temperature of antenna becomes as important as the gain of the antenna. Having this in mind I decided to try to find different and better suited figure of merit for Yagi antenna comparisons at VHF/UHF bands which will fit most of these demands.

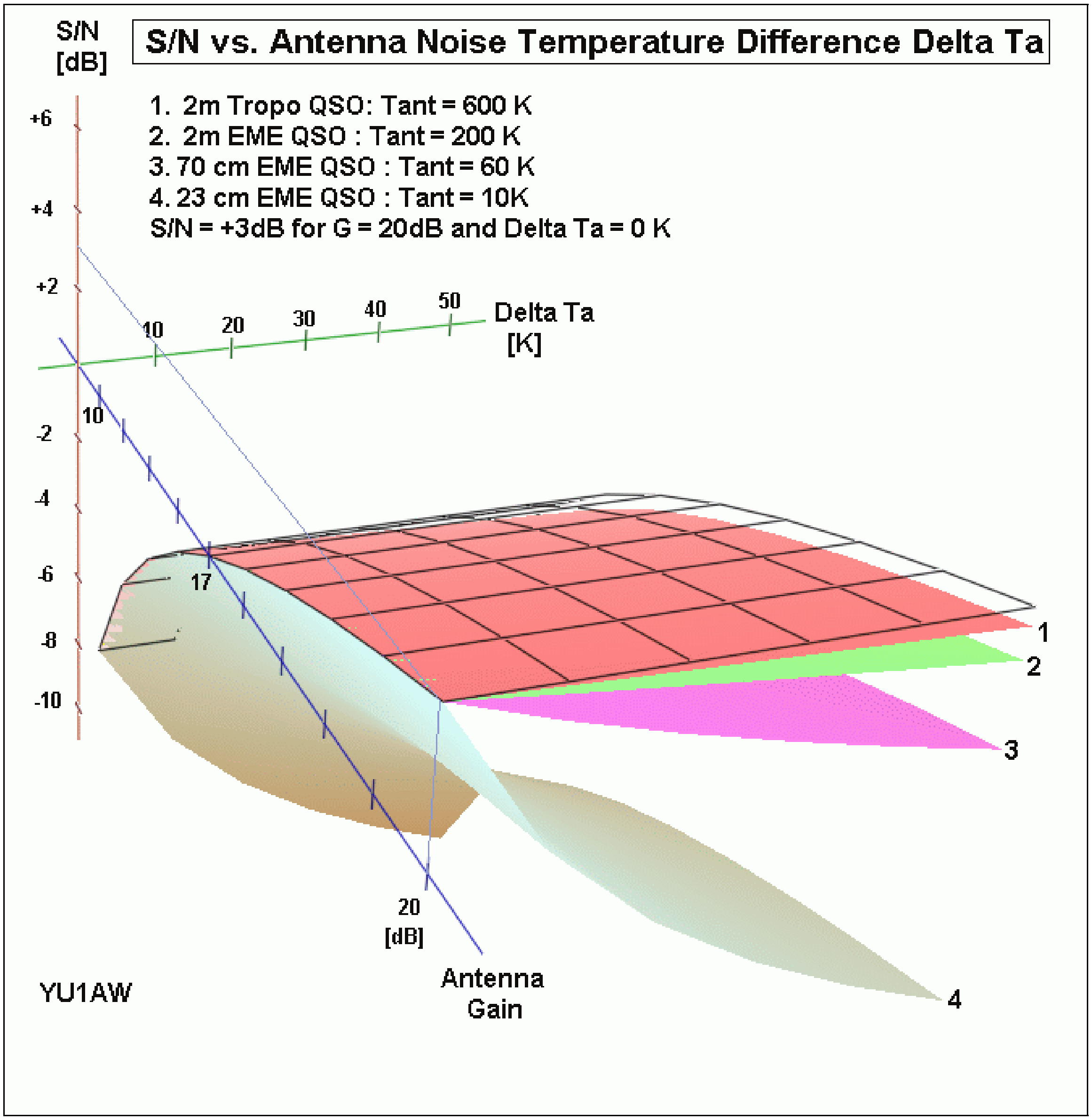

Fig. 6: Relative S/N dependence to antenna gain and noise difference ΔTa for different antenna noise temperature Tant

New figure of merit for Yagi antenna comparison

I would like to propose new figure of merit for yagi antenna comparisons according to the results presented above. The new figure of merit (M) is based not only on receiving demands of antenna gain and noise temperature ratio G/T, but also on other important parameters of antenna which takes play on transmitting. Among the most important are SWR bandwidth, antenna efficiency, gain bandwidth, antenna Q factor, radiation resistance, etc. This new concept can be justified by the physical properties of antenna and its use both as a receiving and as a transmitting antenna.

For evaluating of figure of merit M for a transmitting antenna, we can take its gain and relative working SWR bandwidth product, G*B, which is the measure of antenna total efficiency, antenna losses and response of antenna to different environmental effects. For a receiving antenna we can take for M the gain and equivalent noise temperature ratio G/T, which is the measure of antenna signal sensitivity and cleanliness of its radiation pattern. Then we get:

$M = G*B * G/T = G^2 B / T$
or expressed in dB
$M = 20 \log (G) + 10 \log (B) – 10 \log(T)$ [dB]

Relative working SWR bandwidth B can be calculated from antenna SWR diagram according formula B = (Fh - Fl) / Fo, where Fh and Fl are higher and lower frequencies at which the antenna SWR=1.5, and Fo is resonant frequency of antenna. The SWR value for relative working bandwidth calculation can be arbitrarily chosen, although SWR=2.62 is equivalent to -3dB bandwidth for single dipole antenna. Multi-element arrays like Yagi antennas can have very different SWR curve with few SWR minimums. So it is better to choose some low value for SWR to reduce its number and get more uniform data.

Comparing multi element antennas like Yagis according their SWR curve may be problematic due to interpretation of SWR values relative to other physical properties of such antenna. But because we compare very similar antennas with usually very similar number of elements and similar boom lengths, relative working SWR bandwidths can be used as a relative criterion of antenna Q factor. This criterion is not always straightforward and adequate to the real Q factor value of yagi antenna but it can be used as guideline. At least the working SWR bandwidth is very valuable property of every transmitting antenna by itself.

The noise temperature of the antenna can be calculated by add of TANT or any other suitable program for antenna noise calculation. Also I propose that sky temperatures as parameters for antenna noise calculation will be as follows:
144 MHz: Ta = 400 K
432 MHz: Ta = 40 K
1296 MHz: Ta = 10 K

Example:
For an antenna having SWR=1.5 at Fh=146 MHz and Fl=138 MHz, resonant frequency Fo=144 MHz, gain G=50 (17dBi), and antenna effective noise temp. T= 250 K, we get:

B= (Fh - Fl) / Fo = (146 - 138) / 144)) = 0.0556

$M = 20 \log (G) + 10 \log (B) - 10 \log (T)$ [dB]
$M = 20 \log (50) + 10 \log (0.0556) - 10 \log (250)$ [dB]
$M = 34 + (-12.5) – 24 = - 2.5$ dB

Or, all expressed in dB:

M =2 G + B - T = 34 dBi + (-12.55 dB) - 23.97 dB = - 2.5 dB

The larger the number, the better the antenna, similar to previous G/T comparison.

Conclusion

According to analysis presented in this paper I show that the currently used antenna G/T for comparison of Yagi antennas given in [1] and Appendix is not suitable due to high values of antenna noise temperature even in space communications on VHF bands. Many important transmitting properties of antenna are not included in present G/T figure of merit. At the end I proposed a new figure of merit for antenna comparisons which is better suited to antennas as receiving and transmitting devices. Also some modification of values used for sky temperatures on particular bands is proposed due to specific sky noise temperature distribution.

Reference:

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3._Antenna Temperature & G/T program v1.2, http://www.geocities.com/va3ttn/Tant.zip
4. TANT software by YT1NT, http://www.yt6a.com/sr/vhf/tant-software-by-yt1nt.html
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6. D. Dobričić, Determining the Parameters of a Receive System in Conjunction with Cosmic Radio Sources, VHF Communications, Vol. 16, Ed. 1/1984, p. 35-50. http://yu1aw.ba-karlsruhe.de/CosmicSrcs.zip
7. R.F.Taylor/F.J. Stocklin, VHF/UHF stellar calibration error analysis 1971.

Appendix:

VE7BQH G/T chart

144 MHz Yagi antenna comparative chart and G/T simulations of a 4 bay array of Yagi antennas on 2 meters, 144.1 MHz
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TYPE OF ANTENNA	L (WL)	GAIN (dBd)	E (M)	H (M)	Ga (dBd)	Tlos (K)	Ta (K)	G/T .
W1JR 8 MOD	1.80	11.17	3.09	2.76	17.15	3.04	266.57	-4.96
DJ9BV 1.8	1.81	11.38	3.16	2.80	17.31	3.16	267.12	-4.81
YU7EF 8	1.87	11.28	3.02	2.69	17.22	4.47	253.52	-4.68
BQH8B	1.88	11.66	3.29	2.98	17.67	4.96	263.60	-4.39
I0JXX 8	2.04	12.16	3.46	3.17	18.18	11.33	267.91	-3.95
DK7ZB 8	2.09	12.15	3.41	3.12	18.08	4.34	260.41	-3.93

M2 9	2.12	12.08	3.34	3.04	18.08	8.77	254.38	-3.83
DJ9BV 2.1	2.14	11.92	3.33	3.04	17.92	4.66	260.72	-4.10
*OZ5HF 9	2.16	11.75	2.70	2.50	17.21	2.95	264.46	-4.87
OZ5HF 9	2.16	11.75	3.25	2.96	17.71	2.99	262.13	-4.33
YU7EF 9	2.16	11.86	3.18	2.87	17.79	3.23	243.83	-3.94
F9FT 11	2.17	11.71	3.27	2.97	17.70	5.21	262.64	-4.35
*CC 13B2	2.17	11.83	2.90	2.79	17.67	4.40	256.63	-4.28
CC 13B2	2.17	11.83	3.33	3.04	17.83	4.46	263.15	-4.23
*CC 215WB	2.19	11.86	3.05	3.05	17.80	4.34	286.14	-4.62
CC 215WB	2.19	11.86	3.48	3.19	17.87	4.40	287.83	-4.58
RA3AQ-9	2.35	12.34	3.40	3.11	18.30	4.45	238.76	-3.33
#RA3AQ-9	2.35	12.34	3.26	3.26	18.37	4.44	240.91	-3.30
Eagle 10	2.38	12.28	3.44	3.15	18.29	6.07	249.46	-3.54
DK7ZB 9	2.39	12.49	3.62	3.35	18.53	4.93	262.30	-3.51
*Flexa 224	2.49	11.90	3.50	3.30	18.01	8.29	264.66	-4.07
Flexa 224	2.48	11.90	3.30	3.31	17.87	8.32	257.77	-4.10
K5GW 10	2.49	12.57	3.45	3.16	18.53	5.72	241.20	-3.15
#K5GW 10	2.49	12.57	3.30	3.30	18.58	5.76	242.35	-3.12
K1FO 12	2.53	12.49	3.46	3.18	18.44	3.51	245.43	-3.31
YU7EF 10	2.54	12.48	3.38	3.09	18.42	4.72	233.43	-3.12
*YU7EF 10	2.54	12.48	3.35	3.15	18.44	4.72	233.82	-3.10
I0JXX 12	2.68	12.69	3.59	3.32	18.68	4.45	247.49	-3.11
BQH 12J	2.80	12.82	3.66	3.40	18.85	3.09	252.88	-3.03
#BQH 12J	2.80	12.82	3.53	3.53	18.88	3.06	252.93	-3.06
*M2 12	2.84	12.79	3.05	3.05	18.59	5.19	237.40	-3.02
M2 12	2.84	12.79	3.48	3.21	18.71	5.15	237.98	-2.91
BQH 10	2.86	13.07	3.70	3.44	19.05	6.59	240.48	-2.62
#BQH 10	2.86	13.07	3.57	3.57	19.11	6.56	242.58	-2.59
DK7ZB 10	2.87	13.19	3.89	3.65	19.20	5.94	259.91	-2.80
YU7EF 11B	2.87	12.90	3.55	3.28	18.85	4.18	239.00	-2.62
WB9UWA 12	2.90	12.82	3.45	3.17	18.73	6.93	227.71	-2.70
BQH 13	2.92	13.09	3.69	3.44	19.07	3.92	241.77	-2.62
#BQH 13	2.92	13.09	3.57	3.57	19.11	3.95	243.09	-2.60
*M2 20 XPOL	2.97	13.19	3.65	3.65	19.20	6.74	252.79	-2.68
#M2 20 XPOL	2.97	13.19	3.65	3.65	19.20	6.74	252.79	-2.68
M2 20 XPOL	2.97	13.19	3.77	3.52	19.16	6.77	251.00	-2.69
*BVO-3WL	3.00	13.50	3.90	3.70	19.48	5.35	264.59	-2.60
BVO-3WL	3.00	13.50	4.01	3.77	19.49	5.38	266.39	-2.62
#BVO-3WL	3.00	13.50	3.89	3.89	19.52	5.45	265.97	-2.58
YU7EF 11	3.04	13.07	3.56	3.30	18.99	3.32	226.79	-2.42
*CD15LQD	3.11	12.87	4.00	3.80	18.96	4.57	261.85	-3.08
CD15LQD	3.11	12.87	3.68	3.42	18.86	4.49	259.53	-3.14
CD15LQD MOD	3.11	13.24	3.83	3.58	19.24	3.73	253.86	-2.66
MBI FT17	3.12	13.34	3.84	3.59	19.31	6.02	246.36	-2.46
*CC3219	3.14	12.66	4.27	3.66	18.64	4.62	349.69	-4.65
CC3219	3.14	12.66	4.05	3.80	18.65	4.65	354.61	-4.70
CC3219 MOD	3.14	13.32	3.91	3.67	19.32	3.74	258.52	-2.66
*F9FT 17	3.15	12.87	3.68	3.50	18.92	5.74	243.96	-2.81
F9FT 17	3.15	12.87	3.57	3.30	18.84	5.74	240.69	-2.83
DJ9BV 3.2	3.22	13.36	3.85	3.58	19.34	3.99	246.42	-2.42
K1FO 14	3.25	13.36	3.78	3.54	19.30	4.26	243.48	-2.42
MBI 3.4	3.41	13.69	3.88	3.63	19.63	7.68	235.12	-1.94
YU7EF 12	3.49	13.67	3.83	3.58	19.60	4.40	224.97	-1.78
*SM5BSZ 11	3.51	13.86	3.50	3.50	19.71	3.16	232.02	-1.80
SM5BSZ 11	3.51	13.86	3.96	3.72	19.79	3.13	238.58	-1.84
*SM5BSZ 11A	3.52	13.97	4.00	4.00	19.96	3.13	244.17	-1.77
SM5BSZ 11A	3.52	13.97	4.05	3.81	19.91	3.07	244.00	-1.82
17LQD EKM	3.59	13.37	3.83	3.59	19.35	4.57	252.49	-2.53
17LQDE BQH	3.59	13.79	4.04	3.81	19.77	3.95	248.40	-2.04
DJ9BV 3.6	3.61	13.73	4.00	3.77	19.64	4.25	258.21	-2.33
K1FO 15	3.65	13.78	3.94	3.70	19.70	3.33	238.55	-1.93
DK7ZB 12	3.83	14.25	4.30	4.08	20.26	5.69	250.62	-1.64
YU7EF 13	3.92	14.09	4.01	3.77	20.03	5.13	222.70	-1.30

DJ9BV OPT	3.99	14.22	4.29	4.08	20.18	4.99	248.48	-1.63
#DJ9BV OPT	3.99	14.22	4.19	4.19	20.21	5.03	247.16	-1.57
#SV 2SA13	4.01	14.46	4.20	4.20	20.44	4.67	246.84	-1.34
SV 2SA13	4.01	14.46	4.37	4.16	20.43	4.67	247.35	-1.36
DJ9BV 4.0	4.02	14.07	4.15	3.92	19.98	5.67	255.50	-1.95
HG215DX	4.02	14.20	4.25	4.03	20.14	6.44	258.47	-1.84
CC3219 MOD	4.05	14.20	4.34	4.13	20.17	4.28	256.17	-1.77
*CC4218XL	4.15	14.14	4.08	3.85	20.03	7.25	265.93	-2.07
CC4218XL	4.15	14.14	4.45	4.23	20.11	7.17	266.22	-2.00
WB9UWA 15	4.18	13.62	3.69	3.43	19.48	8.00	214.69	-1.69
CC4218 MOD	4.18	14.29	4.24	4.02	20.24	5.25	244.97	-1.51
YU7EF 14	4.37	14.58	4.23	4.00	20.51	4.63	223.20	-0.83
K1FO 17	4.41	14.44	4.22	4.00	20.35	4.34	234.51	-1.21
DJ9BV 4.4	4.42	14.36	4.28	4.06	20.25	6.19	256.51	-1.70
SHARK 20	4.46	14.39	4.32	4.10	20.26	2.90	264.04	-1.81
I0JXX 16	4.47	14.39	4.17	3.94	20.32	6.09	223.60	-1.03
#I0JXX 16	4.47	14.39	4.06	4.06	20.35	6.11	223.23	-0.99
*CC17B2	4.51	14.53	3.66	3.51	20.22	4.83	233.29	-1.31
CC17B2	4.51	14.53	4.28	4.06	20.47	4.99	234.82	-1.08
DK7ZB 14	4.71	15.04	4.73	4.54	21.02	6.90	245.10	-0.73
K1FO 18	4.77	14.72	4.35	4.14	20.63	4.54	234.66	-0.93
*M2 28 XPOL	4.80	15.22	4.50	4.50	21.14	17.04	258.67	-0.84
#M2 28 XPOL	4.80	15.22	4.76	4.76	21.22	17.15	257.77	-0.76
M2 28 XPOL	4.80	15.22	4.86	4.66	21.19	17.11	257.51	-0.77
HG217DX	4.82	14.81	4.63	4.43	20.78	8.14	256.05	-1.16
DJ9BV 4.8	4.83	14.65	4.40	4.18	20.57	5.85	255.84	-1.37
*M2 5WL	4.83	14.80	4.15	3.84	20.56	8.49	254.92	-1.36
M2 5WL	4.83	14.80	4.56	4.35	20.74	8.70	251.18	-1.11
YU7EF 15	4.84	14.98	4.44	4.23	20.92	4.89	221.29	-0.38
*SM5BSZ 14A	4.89	15.14	4.00	4.00	20.93	4.33	232.02	-0.58
SM5BSZ 14A	4.89	15.14	4.54	4.33	21.03	4.43	238.02	-0.59
RA3AQ-15	4.92	15.14	4.67	4.48	21.10	4.42	239.26	-0.54
#RA3AQ-15	4.92	15.14	4.56	4.56	21.12	4.43	239.19	-0.52
*SM5BSZ 14	4.95	15.29	5.20	5.20	21.37	3.13	246.72	-0.41
SM5BSZ 14	4.95	15.29	4.72	4.51	21.19	3.02	233.77	-0.68
SM2CEW 19	4.98	14.91	4.47	4.26	20.84	9.38	233.77	-0.70
#SM2CEW 19	4.98	14.91	4.37	4.37	20.87	9.00	232.88	-0.66
*BVO-5WL	5.02	15.05	4.58	4.40	20.99	5.21	243.42	-0.73
#BVO-5WL	5.02	15.05	4.59	4.59	21.04	5.24	242.36	-0.66
BVO-5WL	5.02	15.05	4.69	4.49	21.01	5.23	242.70	-0.70
K5GW 17	5.06	14.99	4.64	4.44	20.96	6.16	244.55	-0.78
K1FO 19	5.18	15.01	4.47	4.27	20.92	4.04	232.19	-0.59
#RU1AA 15	5.27	15.55	4.85	4.85	21.55	6.02	235.76	-0.03
RU1AA 15	5.27	15.55	4.85	4.65	21.50	5.99	236.28	-0.09
*M2 18XXX	5.32	15.07	4.27	3.96	20.85	7.90	243.30	-0.87
M2 18XXX	5.32	15.07	4.55	4.35	21.01	7.95	240.56	-0.66
YU7EF 16	5.42	15.22	4.49	4.28	21.10	5.41	223.39	-0.25
M2 32 XPOL	5.62	15.70	5.23	5.04	21.69	15.02	250.74	-0.16
#M2 32 XPOL	5.62	15.70	5.13	5.13	21.71	15.04	251.20	-0.15
*M2 19XXX	5.73	15.41	4.27	4.04	21.15	8.75	238.80	-0.49
M2 19XXX	5.73	15.41	4.70	4.51	21.36	8.75	235.52	-0.22
#M2 32 XPOL	5.73	15.88	5.07	5.07	21.87	16.03	248.46	+0.06
M2 32 XPOL	5.73	15.88	5.16	4.98	21.84	16.03	248.11	+0.04
DK7ZB 17	5.81	15.69	5.16	4.98	21.68	6.16	234.46	+0.12
YU7EF 17	5.87	15.78	4.84	4.64	21.68	5.29	229.75	+0.21
#YU7EF 17	5.87	15.78	4.74	4.74	21.71	5.31	229.47	+0.25
BVO-6WL	6.00	15.69	4.75	4.93	21.63	5.12	231.63	+0.13
#BVO-6WL	6.00	15.69	4.84	4.84	21.66	5.13	231.84	+0.15
AF9Y 22	6.15	15.75	5.04	4.86	21.72	10.04	230.73	+0.23
RA3AQ-18	6.28	16.11	5.13	4.96	22.05	4.97	227.80	+0.62
*RA3AQ-18	6.28	16.11	5.30	5.30	22.13	4.99	227.28	+0.71
#RA3AQ-18	6.28	16.11	5.05	5.05	22.08	4.98	227.31	+0.64
MBI 6.6	6.6	16.14	5.46	5.29	22.14	13.09	238.73	+0.51

#MBI 6.6	6.6	16.14	5.38	5.38	22.17	13.07	239.28	+0.53
BQH 25	7.29	16.31	5.22	5.04	22.25	9.83	224.18	+0.89
#BQH 25	7.29	16.31	5.13	5.13	22.28	9.86	224.61	+0.91
K2GAL 21	7.65	16.80	5.75	5.59	22.75	19.58	245.81	+0.99
M2 8WL(old)	7.71	16.55	5.28	5.10	22.40	9.52	231.46	+0.90
M2 8WL(new)	8.05	17.05	5.82	5.67	23.01	11.53	237.20	+1.40

Legend:
L = Length in Wavelengths
Gain = Gain in dBd of a single antenna
E = E plane (Horizontal) stacking in Meters.
H = H plane (Vertical) stacking in Meters.
Ga = Gain in dBd of a 4 bay array
Tlos = The internal resistance of the antenna in degrees Kelvin.
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.
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.

Notes:

1. The Program used to calculate E/H Stacking,G,Ga and G/T is YAGI ANALYSIS 3.54 by Goran Stenberg,SM2IEV.
2. Temperatures used: Tsky=200 degrees;Tearth=1000 degrees
3. All dipoles have been adjusted to give a J of under +/- .5
4. No stacking harness losses or H frame effects are included in the gain figures.
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.
7. Antennas marked with a "#" have stacking dimensions for XPOL antennas by VE7BQH.
8. Antennas marked with a "@" have some or all 10MM elements. All others are 4MM to 6MM.
9. Manufacturer/Designer Legend:
   AF9Y = AF9Y
   BVO = Eagle/DJ9BV
   BQH = VE7BQH
   CC = Cushcraft
   CC MOD = VE7BQH
   CD = CUE DEE
   CD MOD = VE7BQH
   DJ9BV = DJ9BV
   DJ9BV OPT = DJ9BV
   DK7ZB = DK7ZB
   EKM MOD = SM2EKM
   F9FT = F9FT
   HG = HYGAIN
   Flexa = FlexaYagi
   I0JXX = I0JXX
   K1FO = K1FO
   K2GAL = K2GAL
   K5GW = Texas Towers/K5GW
   M2 = M^2
   MBI = F/G8MBI
   OZ5HF = Vargarda
   RA3AQ = RA3AQ
   RU1AA = RU1AA
   SHARK = SHARK (Italian)
   SM2CEW = SM2CEW/VE7BQH
   SV = Svenska Antennspecialisten AB
   W1JR = VE7BQH (Mininec error)
   WB9UWA = WB9UWA
   YU7EF = YU7EF

BRIEF BIOGRAPHY OF THE AUTHOR

Dragoslav Dobričić, YU1AW, is a retired electronic engineer and worked for 40 years in Radio Television Belgrade on installing, maintaining and servicing radio and television transmitters, microwave links, TV and FM repeaters and antennas. At the end of his career, he mostly worked on various projects for power amplifiers, RF filters and multiplexers, communications systems and VHF and UHF antennas.

For over 40 years, Dragan has published articles with different original constructions of power amplifiers, low noise preamplifiers, antennas for HF, VHF, UHF and SHF bands. He has been a licensed Ham radio since 1964. Married and has two grown up children, a son and a daughter.

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Send mail to webmaster@antennex.com with questions or comments.