Coaxial Cable Influence on Yagi Antenna Array Noise Temperature

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Introduction

In this article I want to present results of an investigation on how the antenna array coaxial cable feeder which is arranged in two different and most usual ways in practice, influences antenna array performance and especially antenna system noise performances.

Previous investigation results given in past articles **[1, 2]**, show that the least influence between antenna and cable occurred when cable was tightened to the boom and support structure that is formed in a letter H shape as given on Fig. 1. Besides the forward oriented pyramidal form given on Fig. 2, this is the most common way of feeding a four-antenna array. This manner of feeding makes possible for a heavy power divider to be easily mounted on a support structure, and thus satisfy one of important mechanical demands.

In Fig. 1 and 2 we can see simulation models of antenna arrays of four stacked Yagi antennas, i.e., two vertically stacked bays of two horizontally stacked antennas with coaxial cable feeder that is arranged in two different ways. Investigations were conducted by computer simulations of six different antennas under the same conditions. Mechanical and electrical parameters and conditions of simulated antennas are more widely elaborated in past articles **[1, 2]**.

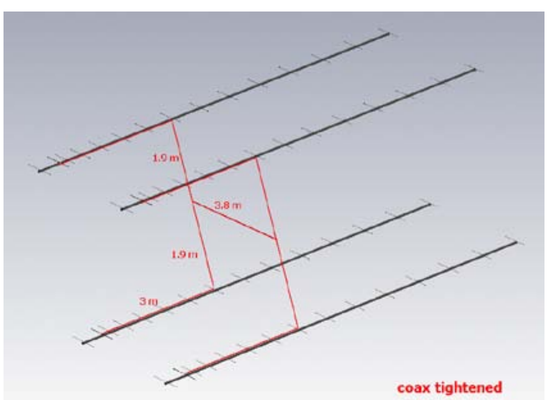


Fig. 1 Yagi system with tightened coax cable

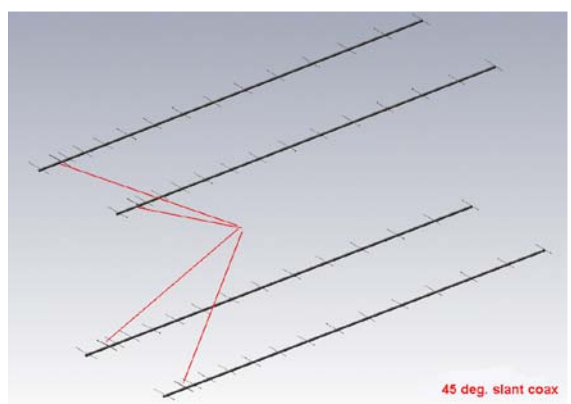


Fig. 2 Yagi system with 45 deg slant coax cable

Two different situations were simulated. The first one was when cable was kept close to the boom and antenna support structure which forms a letter H and lies in the plane which is perpendicular to antenna booms and is shifted ahead around 1.5 wavelengths from the plane where antenna active dipoles lay. The second one was where the coaxial cable approaches each antenna from the direction of the common power divider that is lying in the center between antennas and cables forming a pyramid shape, with the pyramid's tip oriented forward in relation to antenna's main beam direction. In the simulations, no metallic supporting structure of the antenna is used in the model. With its influence, the results realized would probably be even worse.

For this task, the antenna simulation software based on FIT method has been used once again instead of the usual MoM based software which has already been found inadequate due to a few unacceptable program limitations. Obtained results of a complete 3D antenna pattern from this program are used in another very useful program **[4]** which calculates antenna noise temperature according to the antenna's 3D pattern and specified environmental noise conditions. Coaxial cable influence has been monitored on two antenna parameters: antenna noise temperature and antenna G/T factor on 144.5 MHz.

Due to significant coaxial cable influence and radiation for some cable arrangements, antenna radiation diagrams in both planes are considerably distorted. The "cable tightened" arrangement generally shows the least distortion compared to "no coax" reference. But it is obvious that, as it was observed and noticed in previous articles **[1, 2]**, the intensity of the antenna directivity pattern disturbance is very much dependent on the particular antenna design.

Environment Noise Profile

The antenna noise temperature is mainly determined by the noise temperature of objects within its beam width. The received noise power, or noise temperature of the antenna, does not only depend on the noise temperature T of the object but also on how much this object is present in the antenna's generated pattern.

However, all practical antennas have unwanted lobes and a finite front to back ratio. So, this is the noise temperature of an antenna pointing upwards towards the sky and including the effect of side lobes facing towards the "warm" ground and to the side. This is a simple reason why antenna can't have the same noise temperature as the noise temperature of a cold spot in the sky where pointed **[3, 7,** and **8]**.

Results of an antenna's 3D pattern can vary depending on whether an antenna has a metal boom or not, how coaxial cable is arranged and how much particular antenna is sensitive to this. On the other side, results also depend very much on the distribution of the environmental noise temperature.

The usual way of defining environmental noise temperature distribution for frequencies higher than about 1 GHz is very straightforward. Lower hemisphere which represents a ground has noise temperature equal to the standard physical temperature Te = 290 K. This is because above 1 GHz the ground noise is constant but decreases towards lower frequencies owing to the increasing ground reflectivity and decreasing noise emissivity. But the total noise level is the sum of noise radiated from the earth and sky noise which has been mirrored from the earth's surface **[3, 7]**.

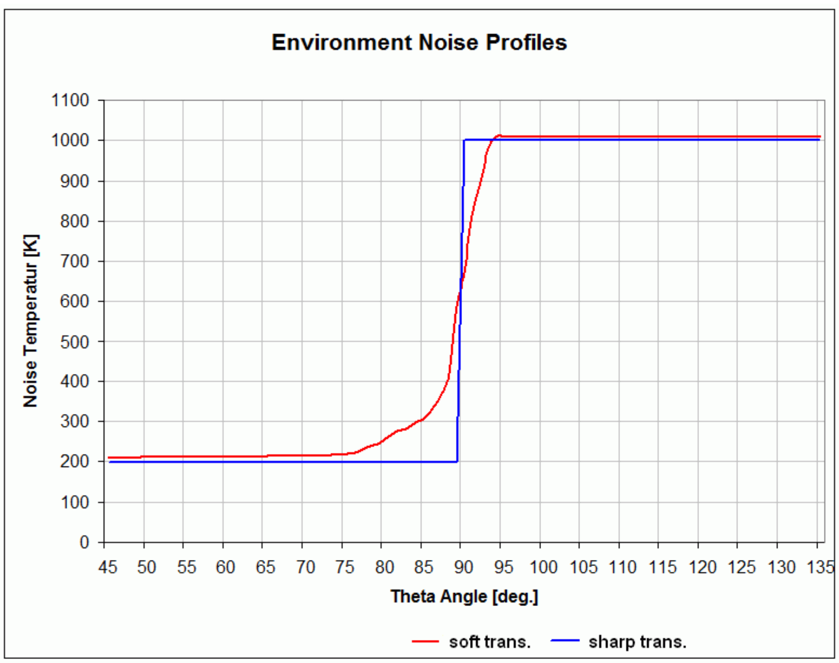
Upper hemisphere which represents the sky was used also as it has a uniform noise temperature of several Kelvin. On the boundary of these two hemispheres there was very sharp transition from one to another noise temperature.

However, on frequencies below 1 GHz, galactic sky noise increases very fast and below about 0.5 GHz, its distribution over the sky hemisphere from being relatively uniform becomes very irregular, with high amplitude of difference between coldest and hottest parts of sky.

As a consequence on the 2m band, sky noise is not uniform anymore and it can differ between 200-330 K on its coldest region of constellations Leo and Aquarius and about 3000-3500 K on its hottest region of Milky Way center **[3, 7]**.

Ground surface on this band has higher reflectivity, and thus has higher noise temperature due to significant contribution of reflected (mirrored) high galactic noise. Because of very large noise temperature difference of particular parts of the sky, temperature of ground noise can change depending on which part of the sky the ground surface mirrors.

In extreme situations, ground noise temperature can be around 300 K when the antenna is directed toward a ground that mirrors a cold part of the sky, and about 500 K when an antenna sees the "picture" of the hottest part of the sky in "ground surface mirror". This high variation of ground noise temperature together with tremendous variation of sky noise temperature gives a high degree of uncertainty during measurements of antenna noise temperature in practice.



Sl. 3 Two different environment noise distribution profiles

Considering all factors mentioned, one can easily conclude that a transition between ground and sky temperatures at its hemispheres boundary can't be very sharp due to the mentioned reflection of sky noise over the ground surface as a mirror (Fig. 3). This raises the average noise temperature for an antenna with low elevation angles because an antenna (in addition to the thermal "black-body" ground noise) also sees the "mirrored picture" of noisy part of the sky.

In practical terms, this means that antennas with a zero or very low angle elevation, that is usual in terrestrial or moon rise/set conditions, have higher noise temperature than the value which is given by simple mean value of sky and ground noise temperatures (Fig. 3).

Antenna noise temperature programs usually use an ideal noise environment where the lower hemisphere has *Tgnd* and the upper one has *Tsky* with a very sharp transition from one to the other.

But in reality, on lower frequencies due to increased ground reflectivity, *Tgnd* is the sum of "black body" thermal radiation *Te* and reflections of *Tsky* from the ground mirror surface. Because of that, it is normal that under very low elevation angles antenna sees sky noise reflected from ground surface. If mirrored *Tsky* noise is higher than ground thermal noise *Te*, equivalent antenna noise temperature is higher than (*Tsky* + *Te)/2* mean value. Manmade noise contribution is another reason why one can expect in reality much higher than average noise temperature at low elevation angles of antenna.

Besides the sharpness of noise temperature transitions between ground and sky hemispheres there are also wide determinations of average sky and ground temperatures in calculations of antenna noise temperatures according to its radiation pattern.

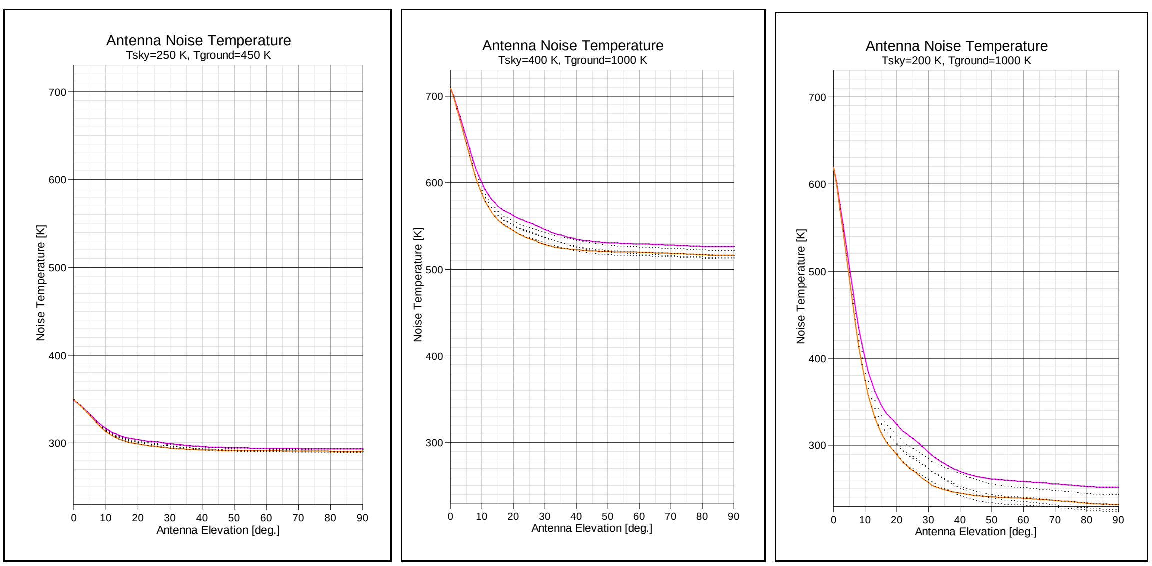


Fig. 4 Two antennas noise temperatures calculated in three different environment noise profiles

In Fig. 4 are given noise temperatures for two different antennas calculated in three different environment noise temperature profiles, among many other possibilities.

The left graph for sky temperature uses a noise temperature in which an antenna with a narrow main beam can only have if it is directed in very specific and very localized part of the sky “cold spot” in constellation Leo. Ground noise temperature is used as to have a contribution of the most probable average sky noise reflections of all but the hottest parts of sky in the center of our galaxy.

The middle graph uses the most probable average sky noise temperature without the hottest part of galaxy center and ground noise temperature with contribution of the hottest parts of sky mirrored and also contribution of terrestrial urban manmade noise.

The right graph gives a situation when ideal antenna is pointed exactly at the lowest possible temperature of sky, cold spot in constellation Leo, with extremely narrow main beam and absolutely no side and back lobes **[3, 7]**. Ground noise is used as to be very similar as with the middle graph. This profile exaggerated the difference between noise temperatures for two antennas compared to the previous two extreme environmental noise conditions.

We can see that environmental noise temperature values and its distribution influence the results of noise temperature to a considerable extent.

For these simulations I used a environmental noise profile that is given on the graph on the right with relatively sharp ground to sky hemisphere noise temperature transition, but not because I think that is the best one.

On the contrary, I think that it is quite “artificially expanded” and not very useful in practical comparisons and operating, but it is perhaps, good only as rule for some “antenna designers contesting” and “antenna ranking” because it gives exaggerated differences between antenna noise temperatures compared to those that can be achieved in practice.

Operating in rural and quiet suburban locations, noise difference between cold sky and ground noise on 2m band, measured by many EME amateurs, is around 1 to 2 dB. This gives for an antenna pointed at cold sky actually possible antenna noise temperatures of 250-320 K and looking at ground around 350-500 K including (besides ground thermal radiation) ground surface sky noise mirroring and moderate manmade noise contribution **[3, 7]**.

With an “artificially expanded” environmental noise profile, it would be necessary to have a difference of even 7 dB for the same measurement! But besides that, I wanted my simulations to be comparable with other results obtained in the same environmental conditions and that given conclusions can be related to them. Using normal, not expanded environmental noise profile renders less difference between antenna noise temperatures and corresponding S/N ratios and thus even further strengthens and emphasizes given conclusions (Fig. 4).

Results of antenna noise temperatures

From the graphs in Fig. 5 we can see that for low elevation angles up to about 5 deg. all antennas have practically the same noise temperature that is not dependent on type of antenna and coaxial cable arrangement.

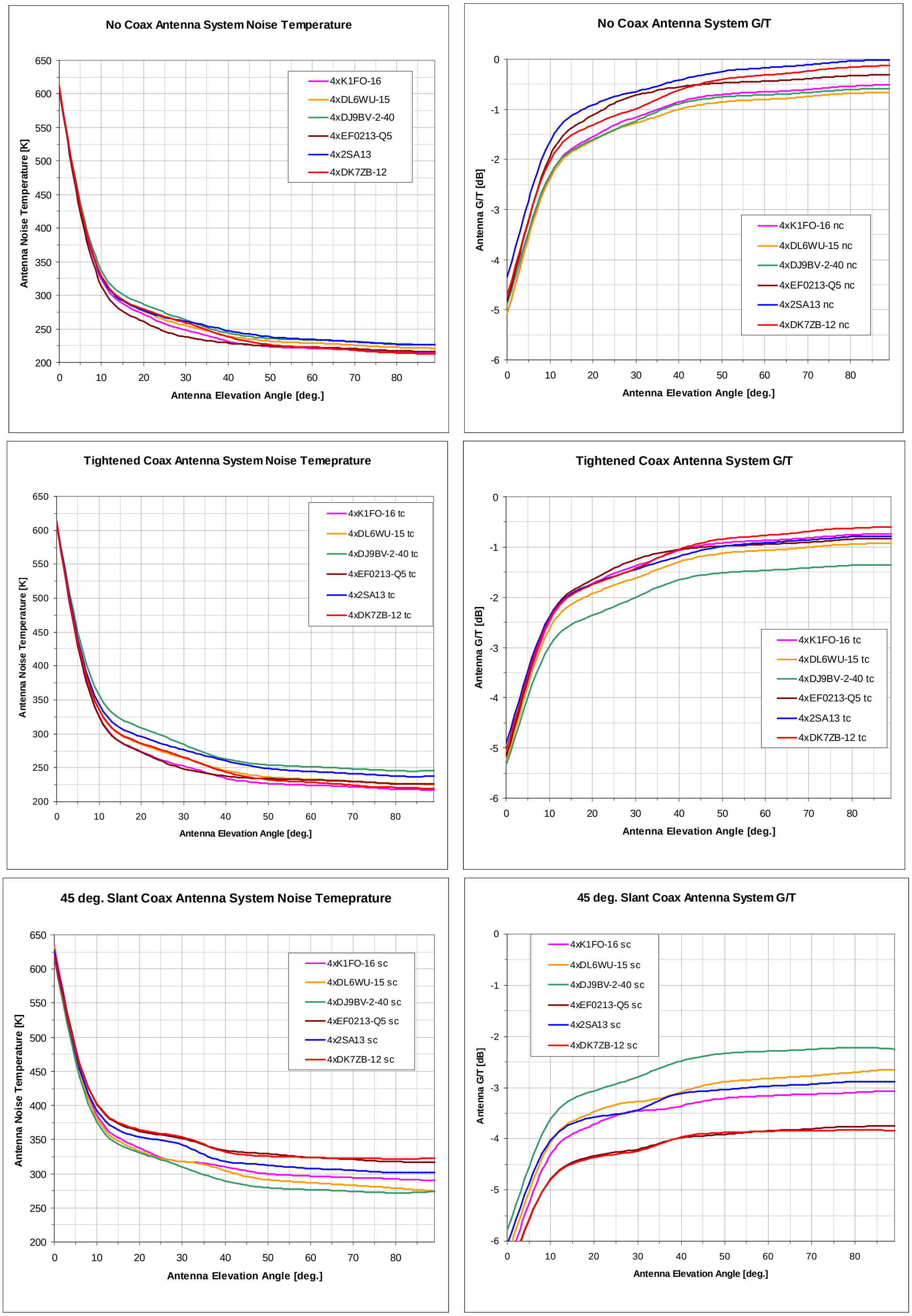


Fig. 5 Noise temperature and G/T factors results for "no coax" and two usual cable arrangements

It means that for terrestrial work with antenna elevation angles up to 5 degrees, all antennas have similar noise performances and the only important factor for communication is **actually attained** antenna gain under given environmental conditions! There are **no** "low noise" VHF antennas for terrestrial communications whatever their author may claim **[3, 7]**.

"No coax" conditions
Conducted noise temperature simulations of antenna system alone, i.e., without coaxial cable and any metallic supporting structures render the best results and only serve as reference for comparisons.

For hypothetical "no coax" conditions and no metallic supporting structure or any other metallic objects in antenna vicinity, YU7EF antenna, which is declared from its author as "low noise" antenna, really has lowest noise temperature between 5 and 50 degrees of elevation angle. At 30 deg. of elevation, the EF0213-Q5 antenna has 237 K, the K1FO-16 antenna has 248 K and the DL6WU-15 antenna a 254 K, while other antennas have about 260 K. The maximum difference between all simulated antenna systems without coax cables is 26 K. G/T factor gives a little bit different picture because of slightly different gains of the antenna systems.

"Tightened coax" conditions
The most noticeable difference in noise temperature between different antennas with tightened coaxial cable to support structure is between 20 and 30 deg. of elevation angle.

Adding a coaxial cable, that is tightened to an H-frame metallic support structure, shows a changed picture. K1FO-16 antenna at 30 deg. elevation changed its noise temperature due to cable influence for 4 K (from 248 to 252 K), while EF0213-Q5 antenna noise temperature raises by 11 K (from 237 to 248 K). The difference between EF0213-Q5 and K1FO-16 antennas is now just 4 K. DL6WU-15 and DK7ZB-12 antennas have almost the same noise temperature of 264 and 265 K, respectively. Other two antennas 2SA13 and DJ9BV-2-40 have 276 and 284 K, respectively. The maximum difference is 36 K. G/T factor changed again because of slight changes of system gain due to cable influence.

"45 deg. slant coax" conditions
With addition of coaxial cable, formed as on Fig. 2, changes are more visible because the influence of a coaxial cable is much more pronounced. Antennas react differently on cable presences and results are pretty instructive. Antennas are separated in two clearly distinguished groups. There are three antennas K1FO-16, DL6WU-15 and DJ9BV-2-40 with noise temperatures, at elevation angle of 30 deg., between 310 and 317 K and EF0213-Q5, 2SA13 and DK7ZB-12 whose noise temperatures rise on 342 to 353 K. Maximum difference is 43 K. G/T factor spreads more than with tightened coax due to a much stronger influence from the cable.

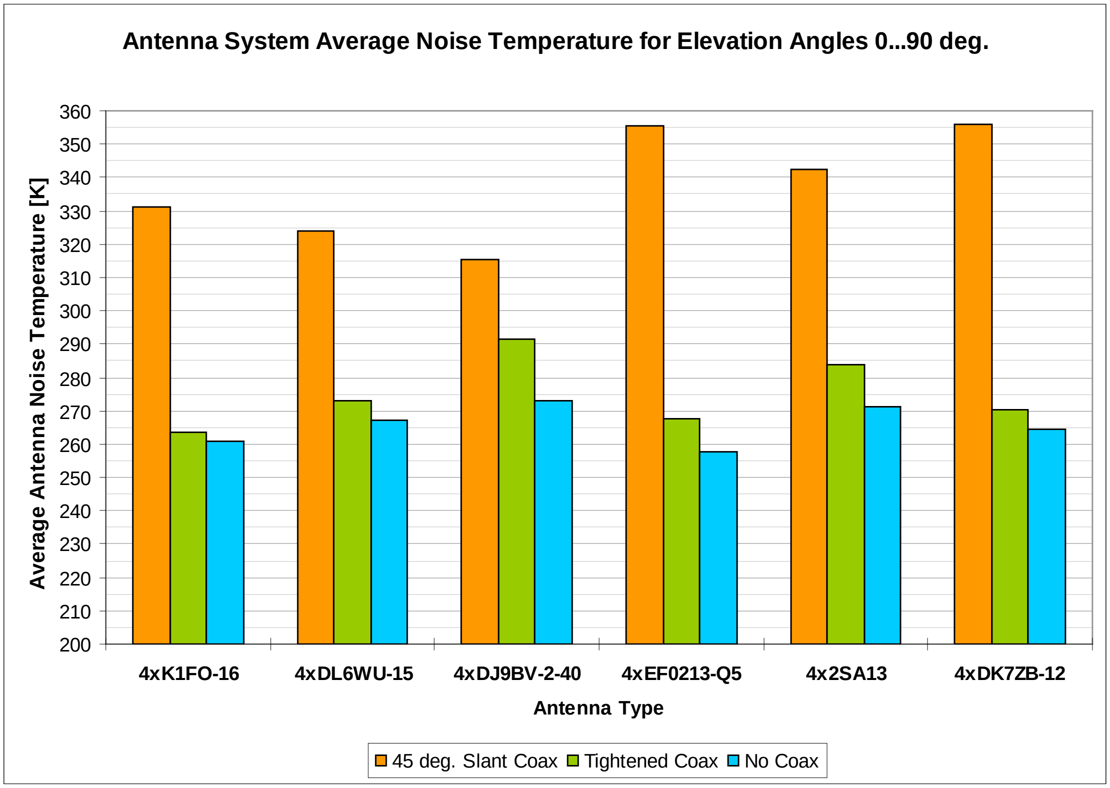

Antenna System Average Noise Temperature for Elevation Angles 0...90 deg.
Average Antenna Noise Temperature [K]
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
4xK1FO-16
4xDL6WU-15
4xDJ9BV-2-40
4xEF0213-Q5
4x2SA13
4xDK7ZB-12
Antenna Type
45 deg. Slant Coax
Tightened Coax
No Coax

Fig. 6

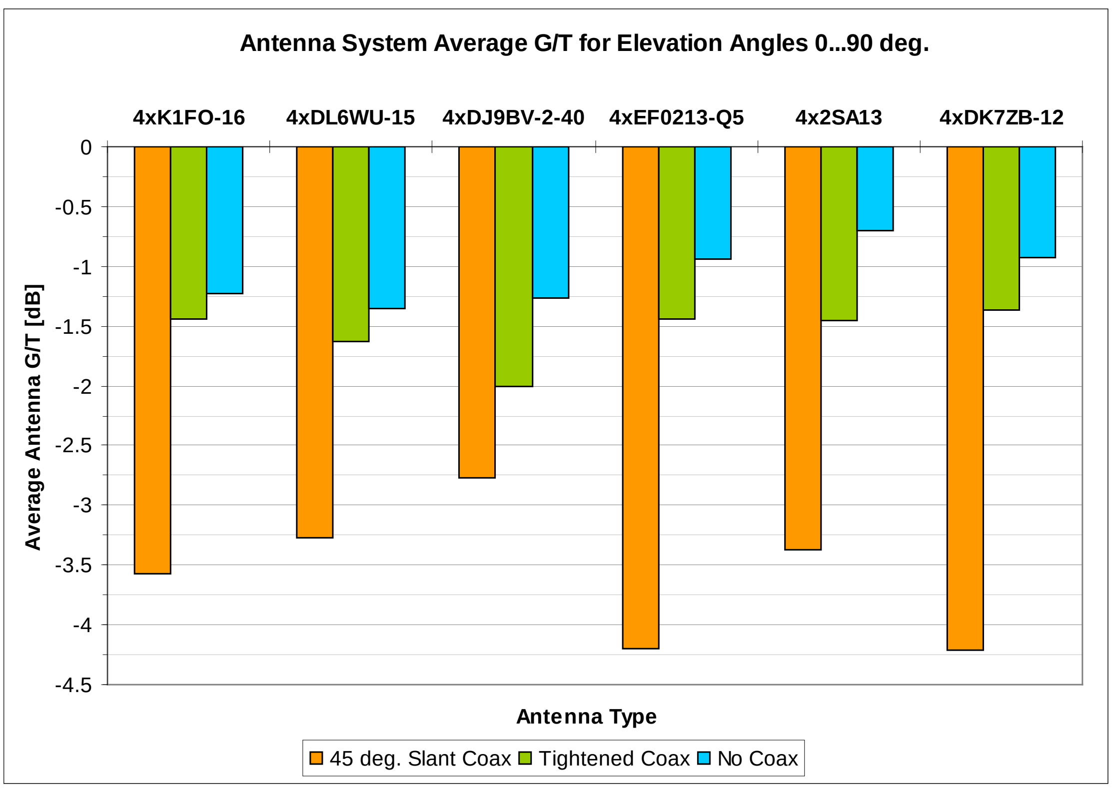

Antenna System Average G/T for Elevation Angles 0...90 deg.
4xK1FO-16
4xDL6WU-15
4xDJ9BV-2-40
4xEF0213-Q5
4x2SA13
4xDK7ZB-12
Average Antenna G/T [dB]
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
Antenna Type
45 deg. Slant Coax
Tightened Coax
No Coax

Fig. 7

Averaged results

So far we have compared antennas noise temperatures on a single elevation angle of 30 degrees. For more accurate antenna evaluation it is much better to use averaged noise temperatures or averaged G/T factors over the whole elevation angle range from 0 to 90 degrees. Results of this averaging are given in Fig. 6 and Fig. 7. As can be noticed, results roughly follow results for elevation angle of 30 degrees. Different antenna sensitivity to cable influence and thus changing the radiation pattern reflects to noise temperature and G/T factor change. With 45 deg. slant coax cable arrangement, all antennas suffer from strong cable effects but some very sensitive antennas change average noise temperature for almost 100 K and G/T factor for more than 3 dB compared to hypothetical "no-coax" conditions. Please remember that these simulations hadn't taken into account any influence of antenna supporting structure or any other metallic object within the antenna's vicinity!

Practical consequences

We see that simulated antennas have different noise temperatures and G/T factors, depending on antenna type, coaxial cable arrangement and even on different environment noise profile which we arbitrary chose. How can we know what is really good, what is less than good, and what is really bad? And more, how can we find out how much all those things and numbers are important for our every day practical work with these antennas? We must give physical meanings to such results and calculate how these various numbers influence the signal to noise ratio of the signal received. For this purpose we can use the Fig. 8 chart which can easily give answers to these questions **[3, 7]**.

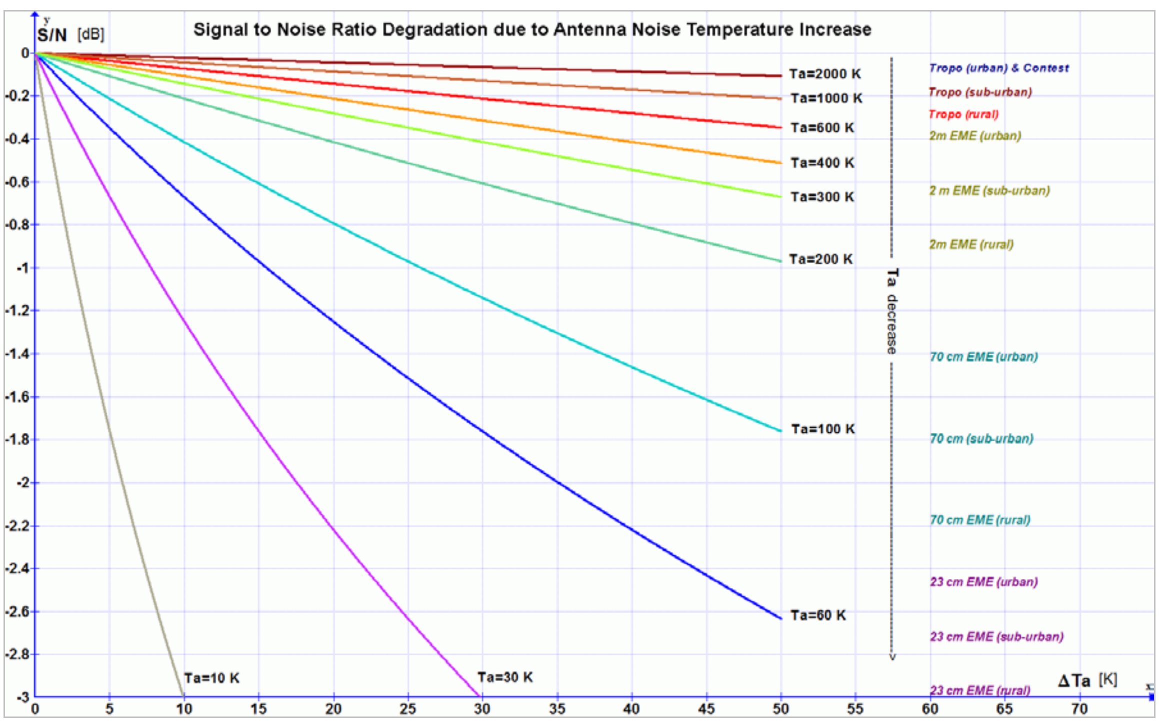


Fig. 8

If we know noise temperature difference of two antennas with the same or very similar gain we can easily find how big will be the difference in S/N ratio when we use these two antennas for receiving under identical all other conditions.

Let us calculate maximum S/N difference for maximum difference between all antennas with different coaxial cable arrangements. For "no coax" we found that maximum difference between average noise temperatures according to Fig. 6 is 257.7 K for EF0213-Q5 antenna and 273.2 K for DJ9BV-2-40, which renders a difference $\Delta Ta=15.5$ K. If we find 15.5 K on horizontal x-axis and draw a vertical line up to value of the antenna temperature Ta of 257.7 K, we can read on vertical y-axis degradation of S/N ratio of higher noise temperature antenna compared to the lower noise temperature antenna. In our case S/N degradation is about 0.3 dB.

This means that highest noise temperature antenna DJ9BV-2-40 will receive the same signal under identical all other conditions about 0.3 dB worse than the lowest noise temperature antenna EF0213-Q5. But usually the compared antennas don't have exactly the same gain and their gain might also change in different conditions, so difference in G/T factor value, as a measure of antenna receiving performances can give us more precise results. In this case it gives a 0.33 dB difference for hypothetical antenna systems without coaxial cables and any other metallic supporting structures!

In the same way we can calculate S/N degradation for all other antennas and cable arrangements. For tightened coax cable to metallic support structures maximum $\Delta Ta=28$ K is between K1FO-16 antenna with average noise temperature of 263.6 K and DJ9BV-2-40 with 291.6 K. This gives S/N ratio degradation of about 0.5 dB. G/T factor give a difference of 0.56 dB due to slight change in antenna gains too.

Finally for a 45 deg. slant coaxial cable arrangement, maximum $\Delta Ta=40.5$ K is between DJ9BV-2-40 with 315.3 K and DK7ZB-12 with 355.8 K. This gives S/N degradation of about 0.53 dB. The G/T factor difference is 1.43 dB which shows that besides the change of noise temperature of antennas there are also considerable changes in antenna gains due to unfavorable influences of the cable arrangement.

Conclusion

As the final result of all those claims about "low noise VHF antennas" we came to result that only in hypothetical conditions without cable and any metallic antenna system supporting structure influence, so called "low noise VHF antenna" can have at most about 0.33 dB better S/N ratio than other regular "high" noise antennas.

With coaxial cable and any metallic structure supporting-type antenna system, no advantages at all are apparent compared to the normal low Q antennas!

And finally, with very unfavorable cable and structure arrangement (which is today very common with many antenna systems on the same pole) they show inferior behavior due to its high sensitivity to environmental effects.

From these simulations we can conclude that a calculation of antenna effective noise temperature, for stacked antennas in a system without including coaxial cable, boom and mechanical support structures in consideration, is completely misleading.

Even for a single antenna, calculation of antenna effective noise temperature without considering cable position, boom and pole structure might be very inaccurate. Any "ranking" of antennas according to such results of antenna noise temperature and G/T factors seems quite illusory. This is even worse because all calculations are made according to an "artificially expanded" environmental noise profile which doesn't compare well to reality.

Simply speaking, so called "low noise" VHF antennas don't have any advantage in receiving S/N under low elevation angles in terrestrial communications because they have the same noise temperature as all other antennas in the same noise environment, that almost completely determines its noise temperature.

For all other higher antenna elevations used for space communications, so called "low noise" VHF antennas in real operation with coaxial cable and antenna supporting structure show similar or very often inferior performances compared to all other low Q antennas, due to its higher sensitivity to environmental influences.

These simulations unambiguously confirmed that lower Q factor antennas and their arrays under all circumstances have less performance degradation **[5, 6]**. All of these factors affect an antenna's most important performance and obviously illustrates the antenna's very probable behavior and sensitivity to environmental impacts in real operating conditions. **-30-**

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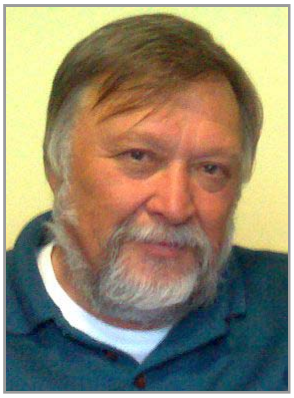
BRIEF BIOGRAPHY OF THE AUTHOR

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 professional 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. He is married with two grown up children, a son and a daughter.