Yagi Antenna Design Sensitivity in Practice

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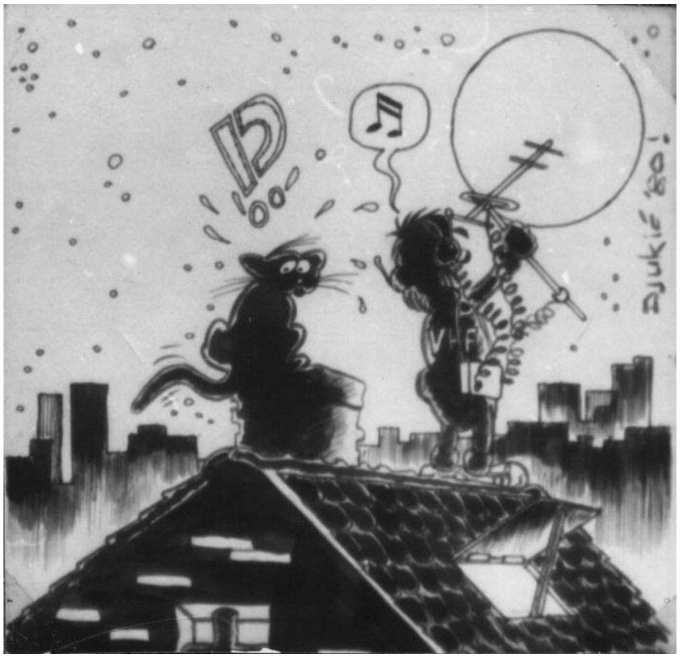
Introduction

All previous simulations of Yagi antennas in wet weather conditions that are described in my previous articles [1, 2, and 3] were conducted with the equivalent “water foam” thickness collected on antenna elements of 0.5 mm and the equivalent relative dielectric permittivity of Er=8.

In spite of my intention to estimate water-foam thickness as accurately as possible by careful visual inspection it appears that it is overestimated.

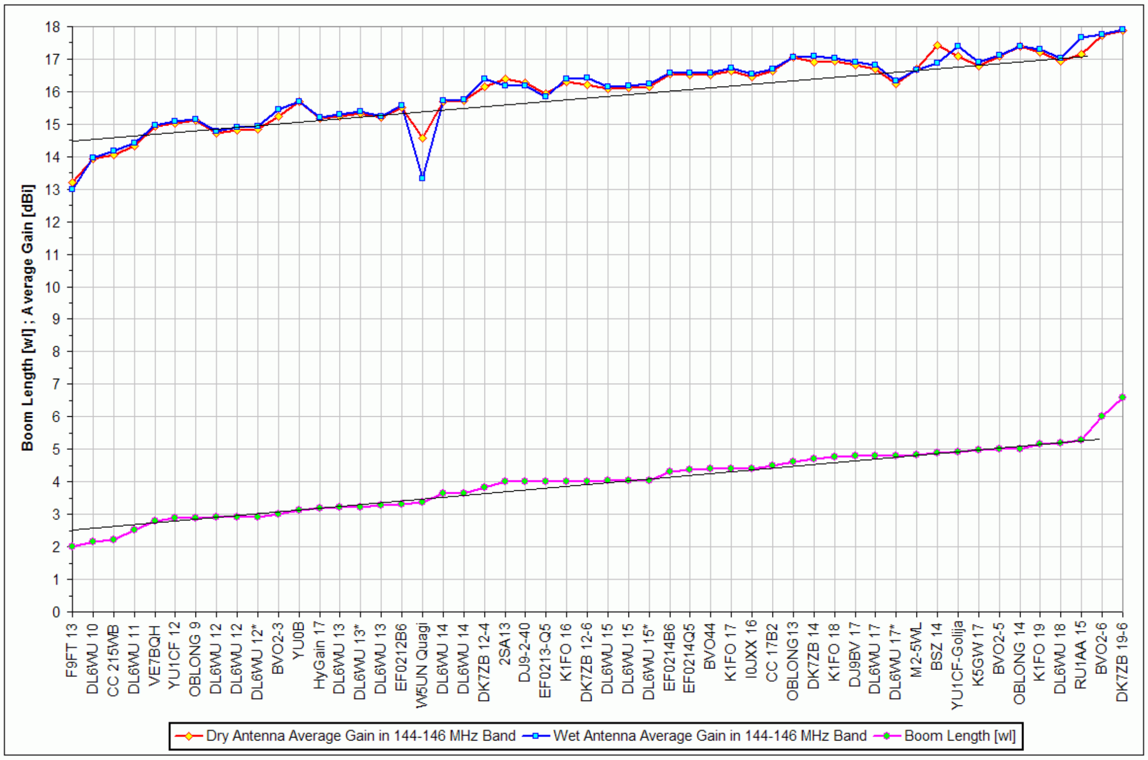
Practical measurements show that the real wet antenna performance frequency shift is between 200 and 450 kHz on the 2m band which corresponds to the water foam thickness of about five times smaller than my estimations!

Thinking about this disparity provoked me to more carefully examine how the water collects on antenna elements. The magnifying lens helped me to see that on the upper and side surfaces of the element there is almost no water at all because the water flowed down the surfaces. The only really thick water film was formed below the element. This water thickness is limited by adhesion to gravitational force ratio and it is almost the only relevant water which can influence the antenna work.

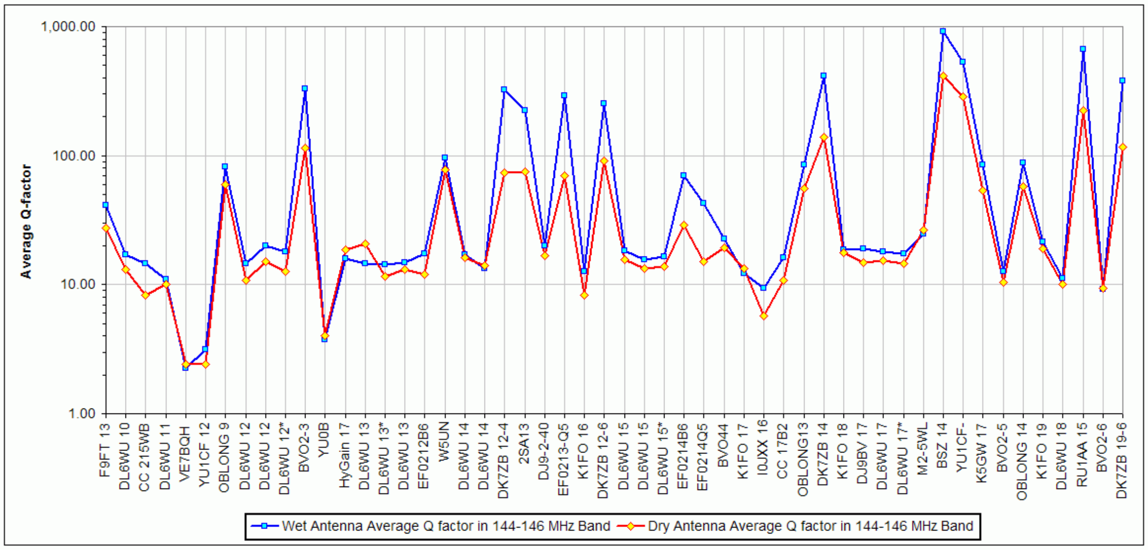


Measurements of the real wet antenna SWR and comparable simulations show that the equivalent thickness of water foam adequate to influence antenna performance is between 0.07 to 0.15 mm depending on the antenna design and the elements’ diameter. With this water foam thickness all simulations agree very well with the measurements of wet antenna SWR up to the possible measurements accuracy under the given conditions.

The mean value of 0.1 mm of water foam thickness and the equivalent relative dielectric permittivity of Er=8 show that they are acceptable for simulations of most antennas in the real wet weather conditions. The only exception is ice on elements during cold days when rain or mist turns into ice. This weather condition gives possibility for much higher ice thickness accumulation on all surfaces of the elements.



Boom length and average gain of dry and wet (0.1 mm)
Yagi antennas of various experimenters



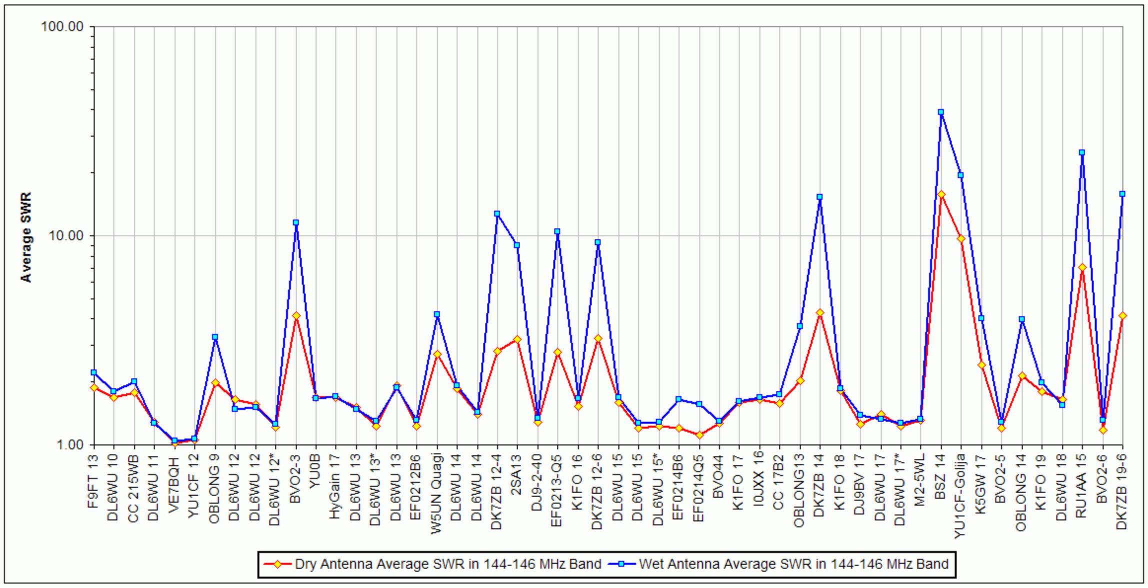
Average Q-factor of dry and wet (0.1 mm) Yagi antennas of various experimenters

The antenna simulation results with 0.1 mm water-foam thickness

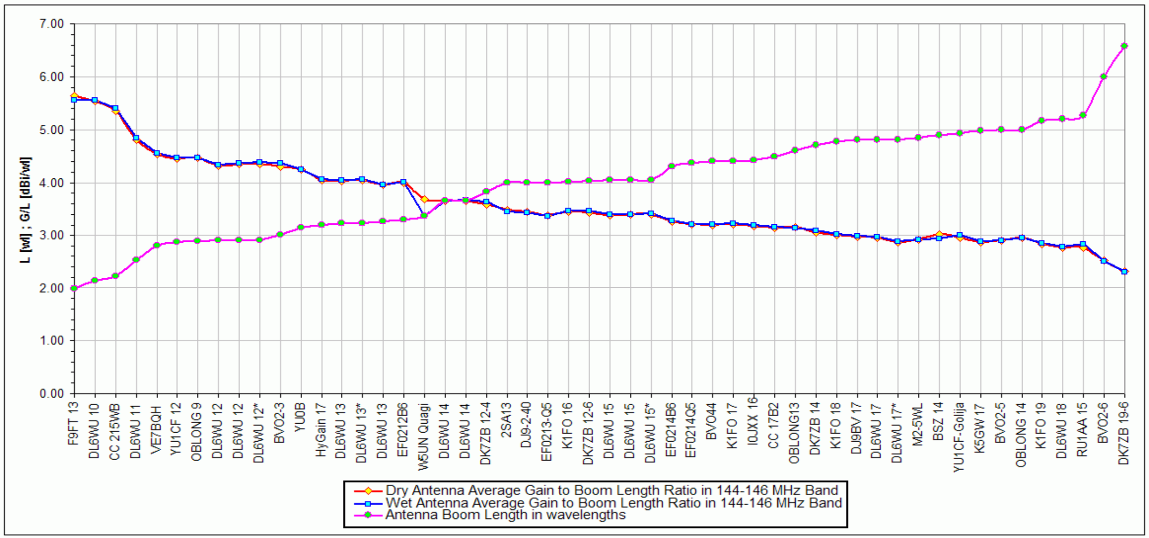
New antenna simulations using a newly estimated value of 0.1 mm for water foam thickness was a protracted and tedious effort.

All antennas that have previously been simulated are re-simulated again with the new water foam thickness. The results are averaged over 144-146 MHz band and sorted in the similar way as in my article [2] in order to be easier for making comparisons.

Because the boom length of Yagi antenna is probably the most suitable to be used as a reference parameter by which all antennas can be compared, I decided again to sort all analyzed antennas according to their boom length in wavelengths as an ascending series. This gives me a systemized set of antenna results and thus better insight in the antenna performances by comparing them to the antenna neighbors and to the other antennas in series but also to the results of previous simulation with 0.5 mm water foam thickness. This difficult and tedious work gave me satisfaction in the end when it turns out that my initial assumptions about Yagi antenna sensitivity, which I portrayed in my articles about Yagi antenna Q factors [1, 2 and 3], and possible antenna sensitivity testing by its behavior in wet weather conditions, were confirmed completely.



Average SWR of dry and wet (0.1 mm) Yagi antennas of various experimenters



Boom length and average gain to boom length ratio of dry and wet (0.1 mm) Yagi antennas of various experimenters

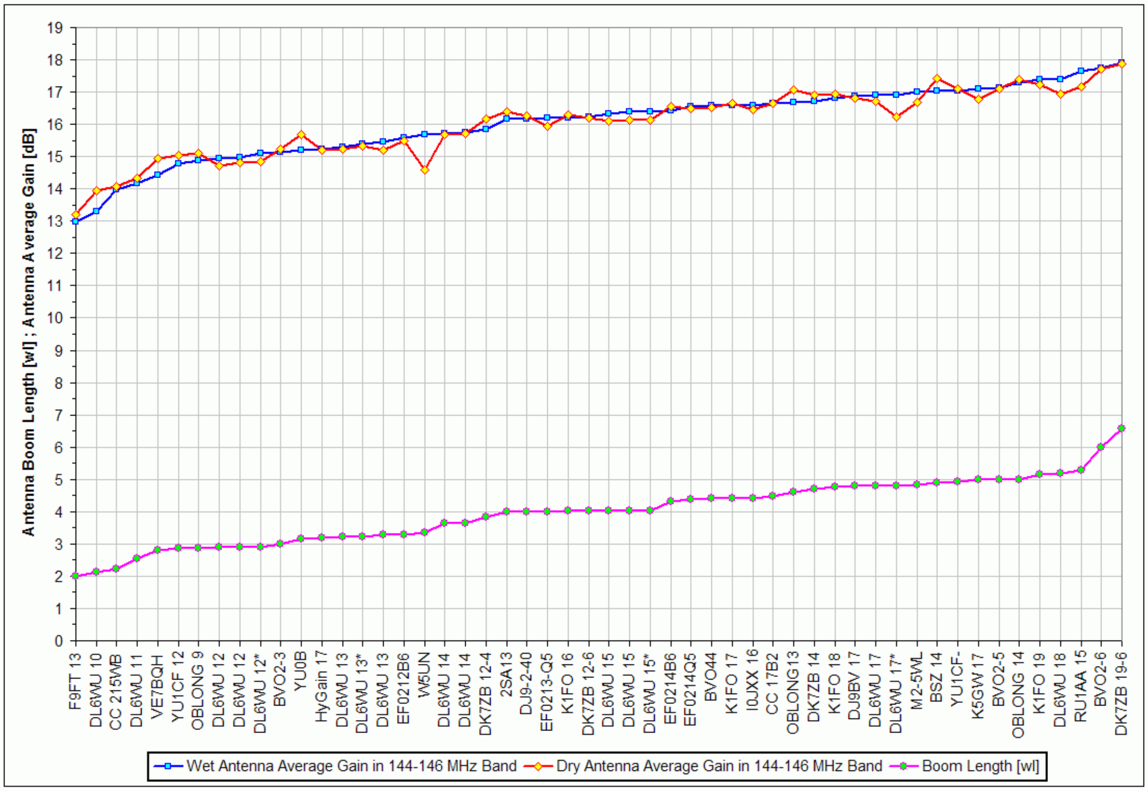
Analysis of the results

Because the gain of optimally designed Yagi antennas should increase about 2.3 dB for every boom length doubling according to DL6WU works from almost 30 years ago, I draw again two black colored lines of the average antenna gain for given Yagi antenna boom length.

It means that the poorly designed antennas are much below that line and the extraordinary high gain antennas are much above this line.

Some values for gain, Q factor or SWR may look strange, but don't forget that those values are averaged values in entire 144-146 MHz band!

If the SWR of some antenna is too high it usually means that this antenna has very high Q factor and narrow working band and that its SWR on upper part of 2 m band is high. With this antenna you can have good SWR at the beginning, and very often much below the band. It can be used for EME and DX work but high SWR can prevent work on FM, satellite and emergence frequencies.



Boom length and average gain of wet (0.1 mm) and dry Yagi antennas of various experimenters sorted according to wet antenna gain increase

Even at the first sight it is obvious from presented diagrams that there are no extraordinary high gain antennas at all!

That confirmed again my assumption stated in one of my previous articles [2] about the thirty-year old dead end for further significant Yagi antenna improvements.

All designs are very close to the average gain line! Small differences are usually due to longer or shorter antenna boom length.

There is nothing of spectacular performances which are very often advertised by many authors and manufacturers of Yagi antennas!

The tested antennas have very similar gain regardless of whether they are dry or have 0.1 mm water foam on its elements which is obvious from presented diagrams.

In the same time these antennas may have extremely different Q factor values. It is obvious that similar length Yagi antennas are much more different in Q factor than in gain!

The big difference in gain between dry and wet antennas for some antenna designs, which appeared in my previous test simulations with 0.5 mm water foam, in this new simulation disappeared!

Does it mean that all antenna designs, beside the almost same gain for same length, are also equally good and that all have the same sensitivity?

No, of course not!

The differences are just not visible, because it appeared that all antennas have enough margins to frequency where rapid drop of gain starts and, under the rain water thickness of 0.1 mm on elements, do not reach this point and gains stay more or less constant.

With my previous test with the five times higher water accumulation on elements some, but not all, antennas exceeded this point and their gains dropped down very severely.

It turned out that this test with five times thicker water foam than it usually is in practice was a very similar test for antennas sensitivity as the breakdown voltage test for high voltage capacitors. When we want to know which capacitor is good and can safely withstand high working voltage conditions we test it with higher than nominal working voltage. In that way we test and confirm the safe margin between capacitor’s working and breakdown voltage.

Very similar test methodology is used for testing devices and equipments for work in extreme ambient temperature. All solid state devices built in military and satellite equipments must be tested in very wide temperature range working conditions in order to confirm their stable performances and low sensitivity to these test conditions even though they will most probably never work under such extreme temperatures.

In a similar way we tested antennas with higher then usual water foam thickness, checked their sensitivity and confirmed the safe margin to performances breakdown.

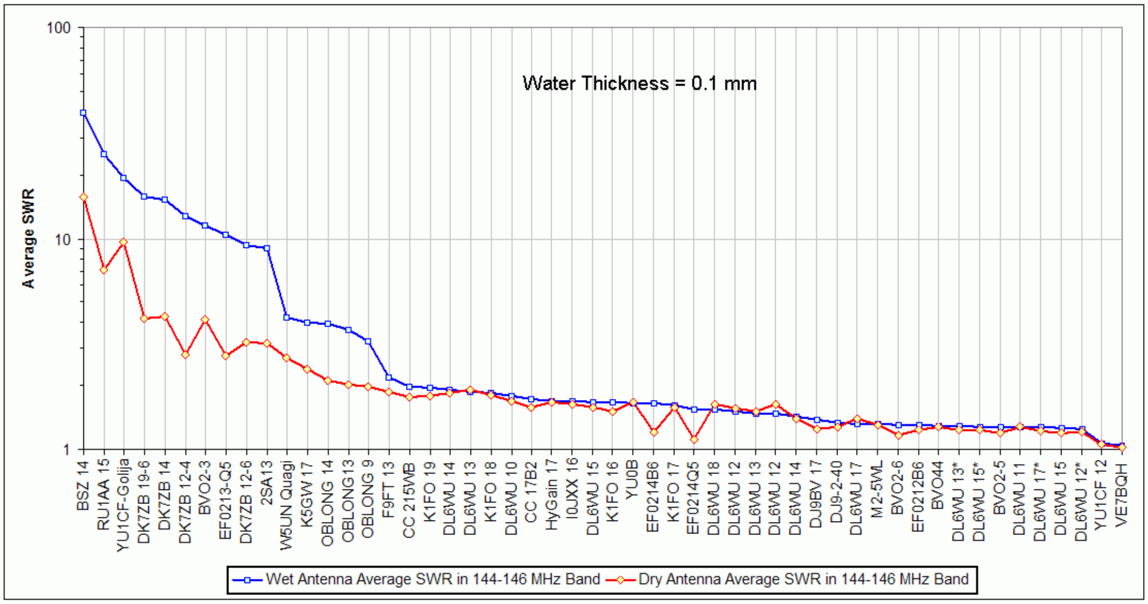
All antennas that didn’t change their performances under so severe test conditions are surely less sensitive and have larger safe margin to performances breakdown than those antennas that changed their performances significantly.

As expected, some antennas can have even a little higher gain when they are wet than when they are dry because of moving gain characteristic to the lower frequency due to moisture and the antenna reaches the absolute maximum of the gain curve.

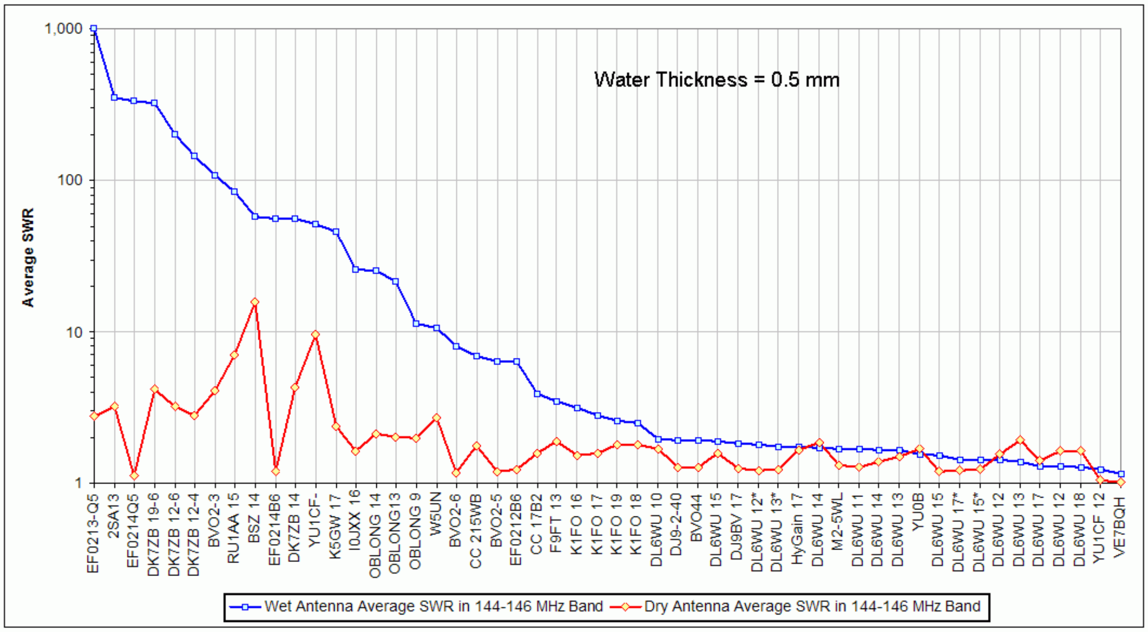
Of course, this is just for very thin water accumulation, because such antennas are just in front of the rapid gain drop point and, with the little higher water thickness, their gain could fall severely. It depends on the shape and width of the antenna gain curve.

The water on the elements has the effect to slow down RF propagation, similar to coaxial cables filled with plastic insulators. The velocity factor shows us how big this effect to RF propagation is. The lower velocity factor of antenna elements make them electrically longer and on the designed working frequency they behave as they work on some higher frequency.

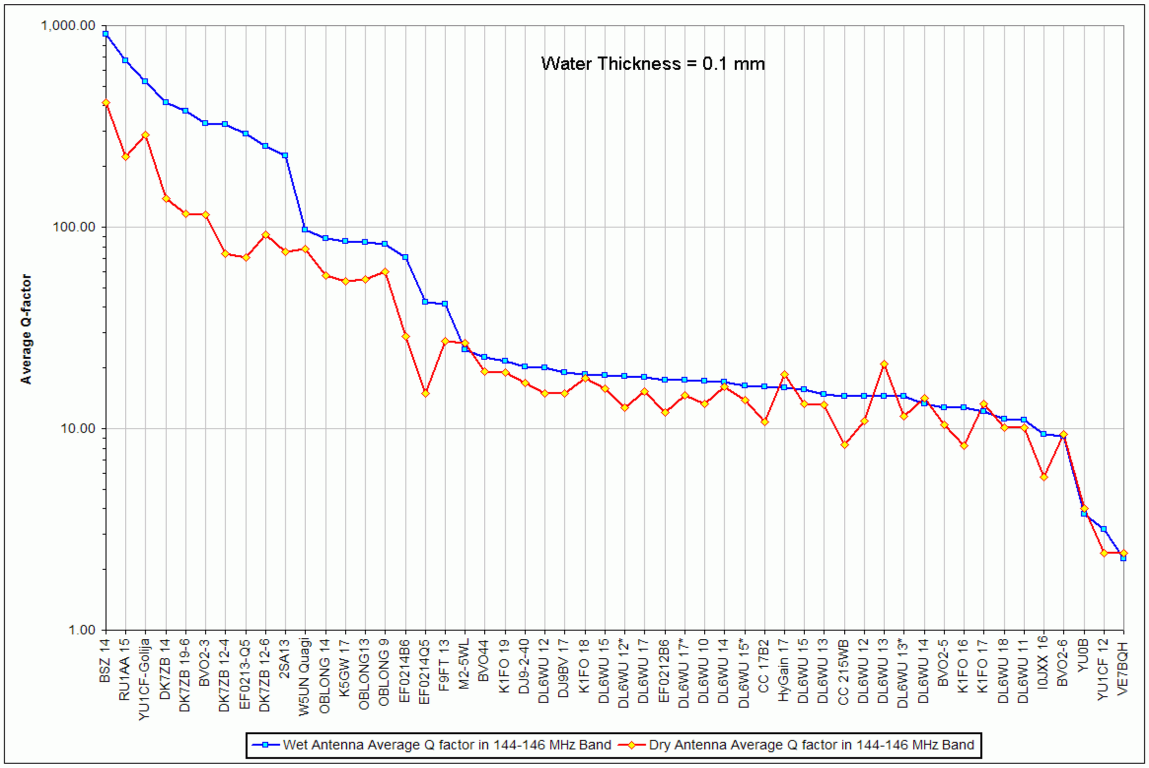
Increasing of the water thickness on antenna elements shifts antenna performances lower in frequency which is equivalent to increasing of the antenna working frequency.
How will the antenna behave in the wet weather conditions depends on its performances on the higher frequencies that are immediately above the antenna's working band. How low in frequency the antenna's performances will shift depends on the antenna design, the elements diameter, the water thickness on them and also on the other environmental influences to the antenna.
Where can we see sensitivity of particular antenna when it is not always visible in gain degradation under the wet weather conditions?



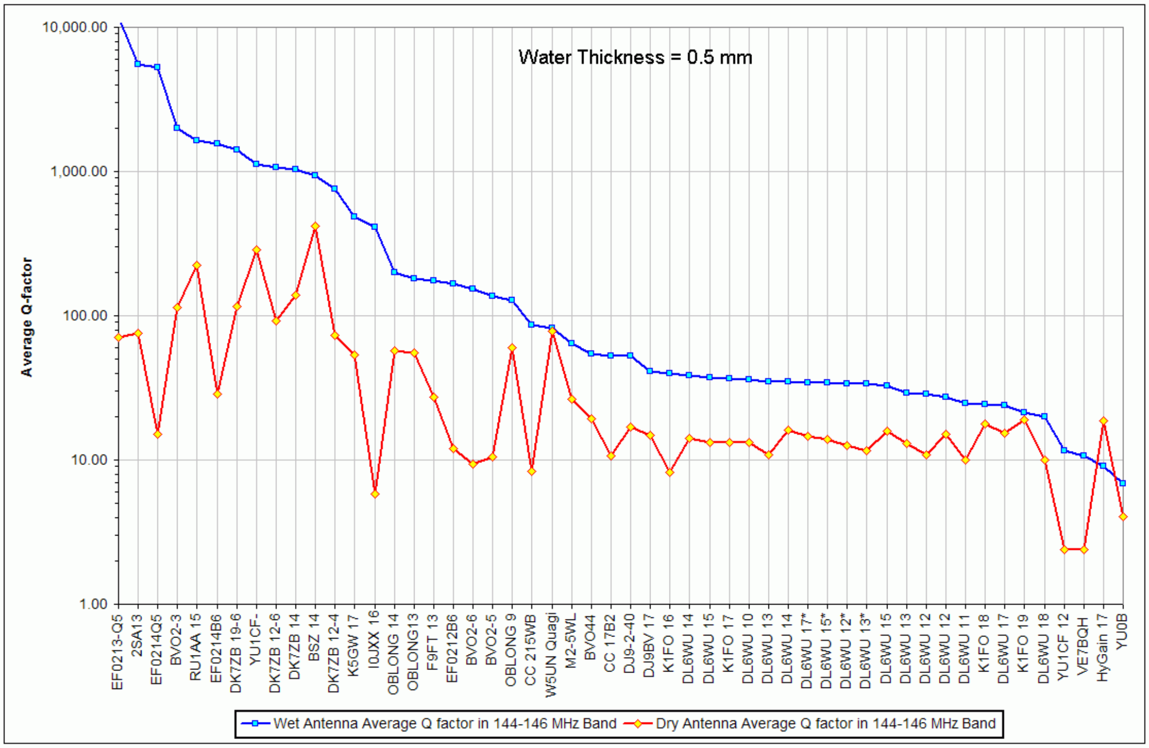
Average SWR of wet (0.1 mm) and dry Yagi antennas of various experimenters sorted according to wet antenna SWR decrease



Average SWR of wet (0.5 mm) and dry Yagi antennas of various experimenters sorted according to wet antenna SWR decrease



Average Q factor of wet (0.1 mm) and dry Yagi antennas of various experimenters sorted according to wet antenna Q factor (sensitivity) decrease



Average Q factor of wet (0.5 mm) and dry Yagi antennas of various experimenters sorted according to wet antenna Q factor (sensitivity) decrease

The wet antenna Q factor – measure of antenna sensitivity

As I pointed out in my article [4], there are many antennas with almost identical gain but with very different Q factors.

Before you look at the Q factor of the tested antenna you can't see any difference between results when it is dry or wet. It has very similar gain, up to a few tenths of dB, and seemingly there is no way to know how it behaves in real environmental conditions and how compare it with other similar antennas in the same environment.

The antenna Q factor as a measure of antenna sensitivity is obvious as it is obvious for any other resonant structure.

But the problem with antennas is how to measure the Q factor. It's a quite difficult task. The concept of doing antenna simulation in entire working band and calculating antenna Q factor from its input impedance values looked very promising.

But just using water on antenna elements as impact factor for testing antenna sensitivity gives the missing link.

Antennas with very similar gain can have extremely different Q factors. Actually, antennas with similar boom length have much more different Q factor than gain!

The antenna Q factor shows antenna tendency or susceptibility to change its performances under any environmental impact. If there are no environmental impacts there is no realized tendency to performances change. The antennas are usually simulated in idealized free space conditions without any real environmental impact, so the Q factor of simulated dry antenna in idealized free space is just an antenna characteristic and there is only potential possibility for antenna performance change under environmental impact. This is only possible in simulations and optimizations of antennas in idealized free space environment without any real impact to antenna.

In manual optimization by "cut and try" method and measurements in practice this is not possible because the Q factor of a dry antenna and real environment around the antenna always give their effects to antenna performance.

Only in the pure virtual optimization this is not so and because of that dry antenna Q factor doesn't have any effects to antenna performance during simulations and optimizations of the antenna!

In the pure virtual optimization in an idealized environment with no impact to the antenna the antenna Q factor is never in effect and never changes performances of the antenna! Working bandwidth dependence is the only effect of Q factor to antenna performance.

But in real life, manual optimization of the Q factor of the antenna and its real environment are always in effect. They always and permanently change antenna performances. Now it is obvious why computer simulated and optimized antennas are usually more critical and sensitive than manually optimized antennas in practice.

Manually optimized antennas are already optimized with numerous environmental impacts that were in effect during optimization. For them, simulation under wet weather condition is a very similar situation under which they are optimized. But for "virgin" antennas which are computer optimized only under idealized free space conditions without any environmental impact, simulation under wet weather condition is difficult!

That was the main reason why it was necessary to simulate antenna in non-idealized environmental conditions and put Q factor in effect to change antenna performance and show its sensitivity! That is why I decided to simulate antennas in wet weather conditions and to estimate their sensitivity according to their behavior.

When an antenna becomes wet due to high relative dielectric permittivity of water on its elements, the antenna really changes its electrical characteristics and thus changes performance. This change of electrical characteristics and performance also changes its Q factor value which is in close relationship with basic principles of antenna function. All changes of antenna function due to moist or any other environmental impact are reflected in a change of the antenna Q factor value. This changed Q factor is still a measure of an antenna tendency or susceptibility to again change its performance under any new environmental impact.

We can say that Q factor of wet antenna, or antenna, which in any other way suffers from environmental effects, is a very good indicator of antenna susceptibility to change its performance due to such effect. Because of that we can use the wet antenna Q factor as a measure of antenna sensitivity to the environmental influences in practice if we relate it to other antennas under the same conditions.

Of course, we can use many other methods to simulate environmental influences to the antenna. The close proximity of other resonant and non resonant antennas, a large tower and other support constructions and structures etc., can also give us the ability to calculate Q factor. Also, according to obtained results and comparisons with results of other similar antennas in the same environmental conditions help to estimate the antenna sensitivity.

On the presented diagrams we can see all simulated antennas which are sorted according to wet antenna Q factor and SWR in descending order. There are two simulations, one for water foam thickness of 0.5 mm and other for 0.1 mm.

The diagram of wet antenna Q factor in descending order distinguished all antennas to the more sensitive (on the left hand) and to the more tolerant (on the right hand).

As can be seen from both simulation diagrams, most antennas didn’t change their position too much. This was expected because the antenna positions in both tests show the antenna sensitivity which does not depend on water thickness but on their design and construction!

The absolute performance degradation of certain antennas depends on both water thickness and antenna Q factor. When water thickness is same for all tested antennas then the **relative** degradation of performances to the other similar antennas depends only on the antenna Q factor and it is the measure of antenna sensitivity! So, the antenna sensitivity is a **relative value** and shows relation between performances of similar antennas under the same water thickness conditions and thus it does not depend on the water thickness itself. Some small changes in antenna positions in the two tests show that some behaviors of certain antennas stayed hidden under smaller water thickness test.

Conclusion

From everything presented in this series of articles [1, 2, 3, 4, 5 and 6] we can conclude that:

1. There is no new high gain Yagi antenna which would be considered as a significant breakthrough in Yagi antenna performances. All antennas, those thirty-years old and the newly designed have very similar gain performances and maximum gain difference between the same boom lengths antennas is only about 0.5 dB. This negligible improvement is usually paid by sacrificing some other important performance, most often the Q factor, i.e., the antenna sensitivity,

because it is not directly noticeable and measurable. Presented diagrams clearly confirm this claim. As can be seen on the presented diagrams there are no two or more antennas with same boom length but with a gain which differs more than about 0.5 dB and that this is not paid by higher Q factor. **It is clearly confirmed that improving of Yagi antenna performances is thirty-year old dead end effort!**

2. The antenna sensitivity is proportional to the Q factor of the antenna situated in real environment with real effects and shows antenna performance degradation relative to other antennas under the same environmental effects. By using the moisture as an environmental impact to the antennas in order to provoke some effects to their performances, and by comparing these effects in order to estimate their sensitivity, this assertion can be confirmed. This is only one of many other possibilities to make effects to the antenna by some environmental impact and to simulate the antenna response to these effects. The performance degradation of some, but not all, antennas shows clearly that there is big difference between them in their behavior under the same environmental conditions! This clearly points out a different sensitivity of tested antennas to the environmental impacts. Excellent correlation between antenna performances degradation and Q factor values are obvious on presented diagrams. The simulation test with five times thicker water foam on elements gives similar antenna results but more pronounced results than the simulation test with more real water thickness of 0.1 mm. These pronounced results show some antenna behaviors which remained hidden for test with 0.1 mm of the water foam thickness. With very small thickness of water, or for dry antennas in idealized free space environment, it is not possible to get the difference in performance to clearly separate sensitive from tolerant antennas due to absence of the environmental and the antenna Q factor effects. It is analogous to any research testing which is conducted in more extreme conditions than normal working ones to check and confirm a safe margin to point where the breakdown of performance starts. **As is expected: more sensitive antennas stay more sensitive and less sensitive antennas stay less sensitive in both tests!**
3. The computer optimization of antennas gives usually very narrow, sensitive and critical design results unless the designer takes measures to avoid falling into this trap. The computer optimization process gives results as the unique set of Yagi antenna dimensions which best satisfy optimization goals, but it does not optimize antenna performance over wider statistical distribution of antenna dimensions and various environmental effects. Lack of statistical or yield analysis of today's popular antenna simulation and optimization programs emphasizes this problem. As a result we usually get more narrow and critical specific antenna designs.
4. Sacrificing antenna sensitivity or other performance in order to improve antenna noise temperature on VHF does not have any justification due to high noise temperature of the sky on VHF frequencies. This is clearly shown in my article [6] where from presented calculations and diagrams it is obvious that increasing in signal to noise ratio S/N for antennas of the same length (and gain) but with "lower" noise temperature on VHF does not give anything more than marginal improvement in S/N ratio, and it is true even if the antenna location is very quiet! Even for 2m EME work this lower antenna noise temperature does not produce a

very big difference in S/N ratio even though antennas are situated in rural, quiet locations. It can be said that on VHF bands there are no “Low Noise Antennas” due to the impossibility of the realization of low receiving noise because of high noise temperature of the ground and sky on these frequencies. This is clearly visible from sky noise maps which are presented in this article. By easy calculation of sky area where the antenna beam commonly spreads over the sky, it can be shown that average sky noise temperature that the antenna “sees” is usually much higher than ground noise temperature. So, an elevated antenna usually does not have lower noise temperature than one not elevated! **In the conditions where the sky and the ground noise temperatures are very similar the antenna radiation (and receiving) diagram does not influence antenna noise temperature very much because the antenna noise temperature is much more characteristic of the environment than of the antenna itself.** Taking the absolute minimum of the sky noise (which is available from only one very small part of the sky) as the average sky noise which the antenna always will see when it is randomly pointed anywhere in the sky gives only the illusion that we will get lower noise contribution in received S/N ratio and thus improve receiving performances. The “Low Noise Antennas” have its full meaning only at the frequencies where the average sky noise is much less then ground noise. For instance, on the 23cm band, the sky noise is only a few percent of ground and urban noise and here the low noise antenna can give its full contribution to higher S/N ratio! **-30-**

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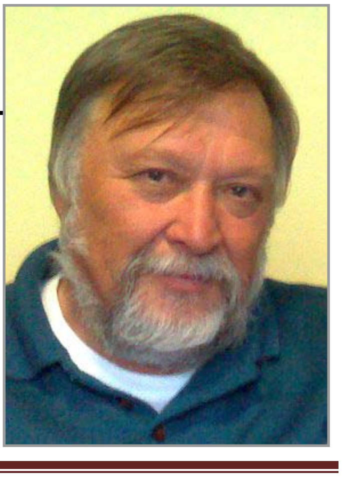

BRIEF BIOGRAPHY OF THE AUTHOR

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 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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