
Yagi Antenna Design Sensitivity

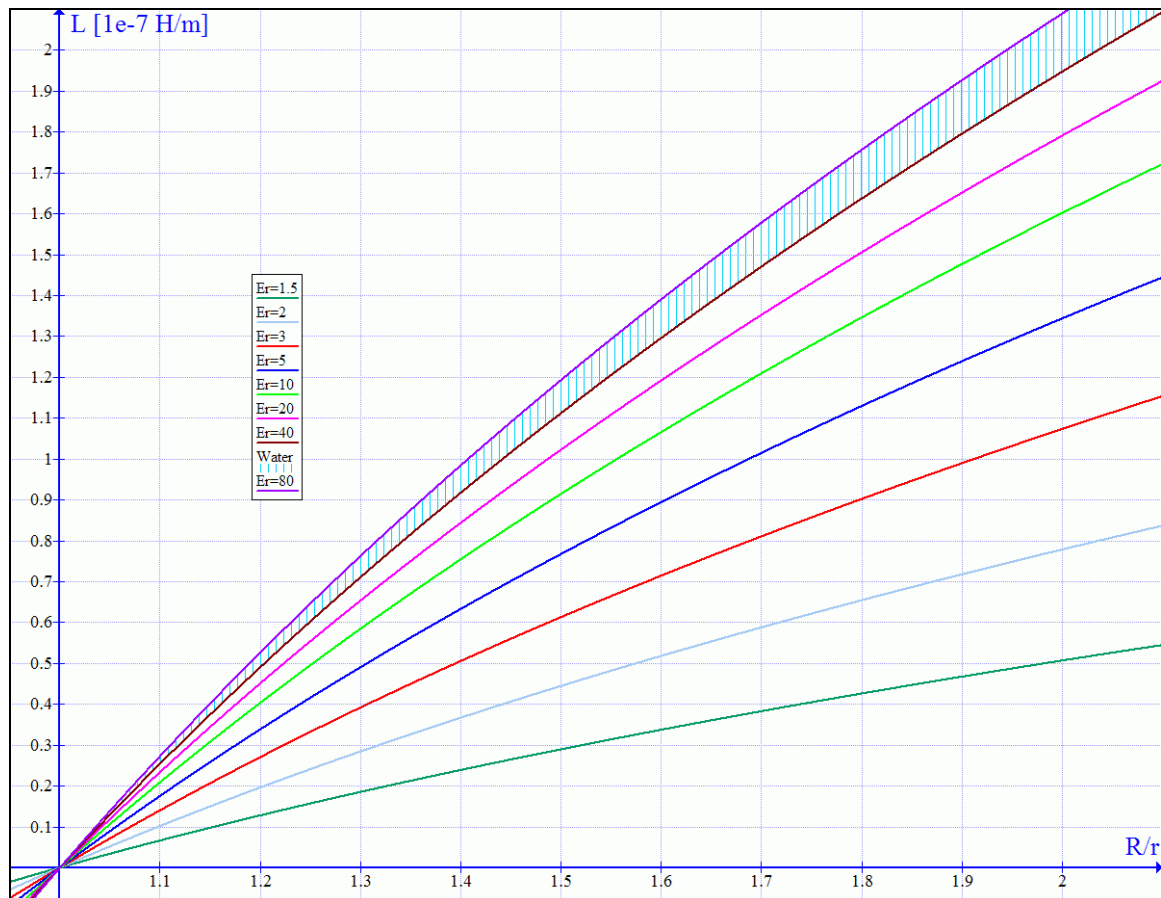
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Introduction

In my previous simulations of wet antennas in articles [2 and 3], I opted for “water foam” thickness on antenna elements in order to improve accuracy of simulation and to ensure fair enough comparison between antennas.

Some difficulties in the right choice arose because of the different of antenna element diameters. The quantity of accumulated water on elements might depend on its diameter. Water on elements produce performance influence that is dependent on R/r , where r is bare wire radius and R overall water covered wire radius. Ratio of these two radiuses R/r is important for the wet antenna performance. This water coating produces the effects of shortening in the element wires, thus lowering the velocity factor which can be expressed as equivalent distributed inductance L .

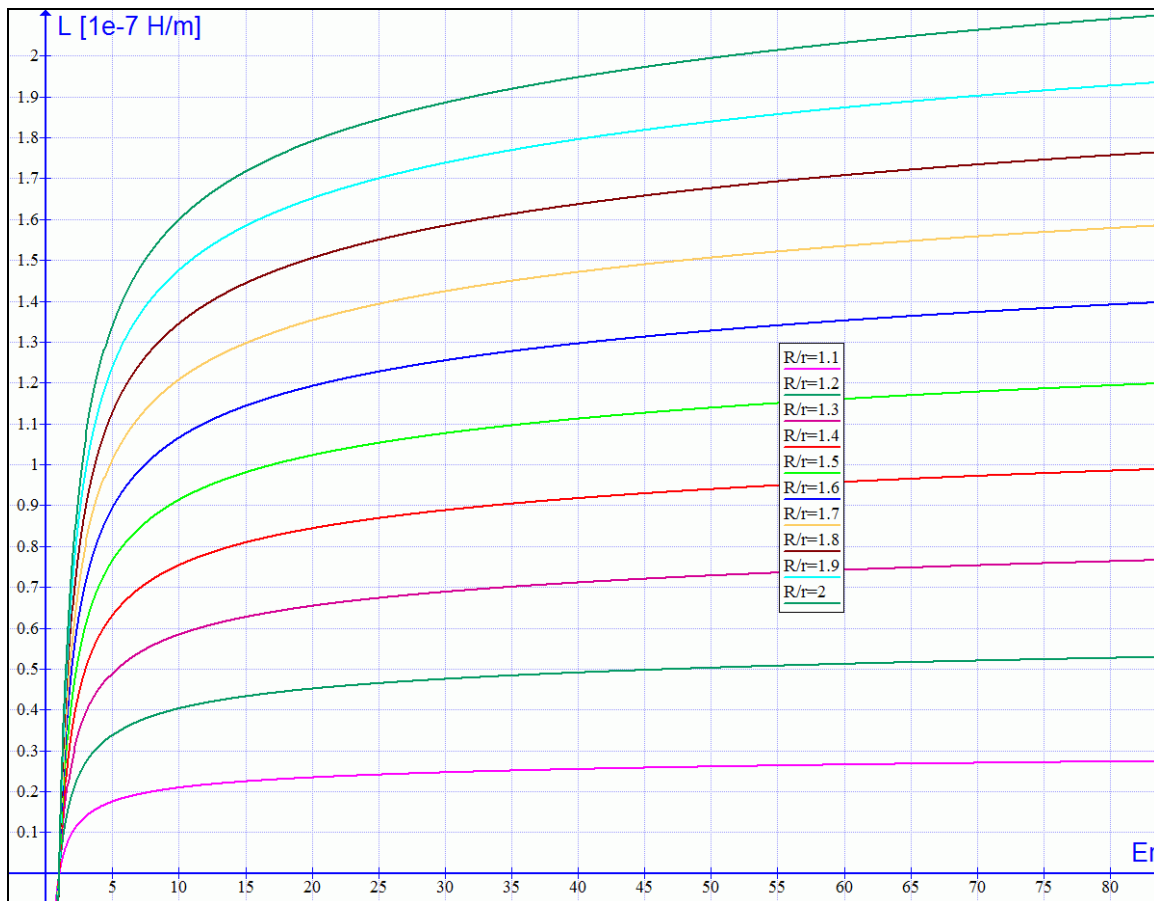


Dependence of the wet antenna elements equivalent distributed inductance L on the wet to dry elements radius and the water relative dielectric permittivity as parameter

Water influence

As can be seen from equation [4] and corresponding diagrams, water influence mainly depends on two factors: water relative permittivity ϵ_r and thickness of water film on the elements.

Another factor that is usually considered is water conductivity. The conductivity of rain, mist or ice is usually very small compared to the metal elements conductivity so we can ignore it. The effects of which the accumulated water produces on antenna performances due to its conductivity is negligible comparing to the effects of water's high relative dielectric permittivity.



Dependence of the wet antenna elements equivalent distributed inductance L on the water relative dielectric permittivity and the wet to dry elements radius as parameter

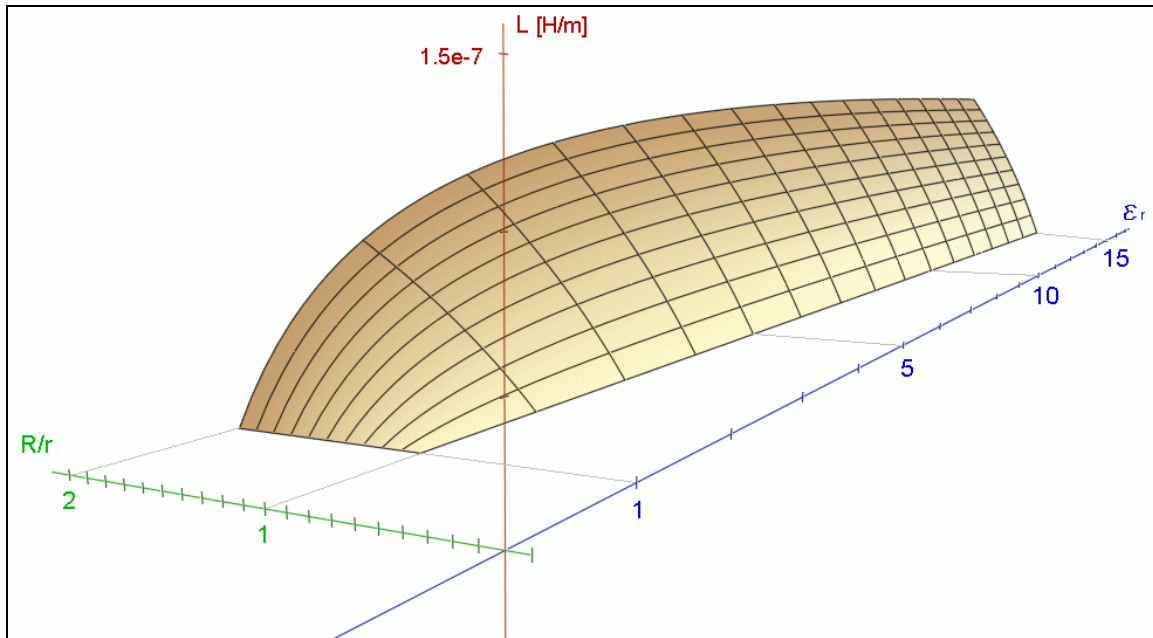
The water relative permittivity ϵ_r can vary in very large range from about 40 to 80. Fortunately this very large variation gives relatively small variation in the equivalent element loading distributed inductance.

As can be seen from the diagrams, very small change in loading distributed inductance happens for the relative dielectric permittivity over about $\epsilon_r=20$.

It is obvious the main factor that determines water influence to the antenna performance is water thickness compared to element radius, or ratio of dry, bare elements and wet, water-covered elements radiuses R/r .

A water “insulation” around a wire acts very much like a distributed inductance along the wire shortening the required physical length of wire for a given electrical length. [4] From the diagram it is visible that there is almost a linear increase of loading distributed inductance with the increasing of relative water film thickness on antenna element for high ϵ_r values.

It means that the antenna with thicker elements for the same water film thickness will have lower R/r value and thus lower equivalent loading distributed inductance than the antenna with thin elements.



Dependence of the wet antenna elements equivalent distributed inductance L on the water relative dielectric permittivity and the wet to dry elements radius

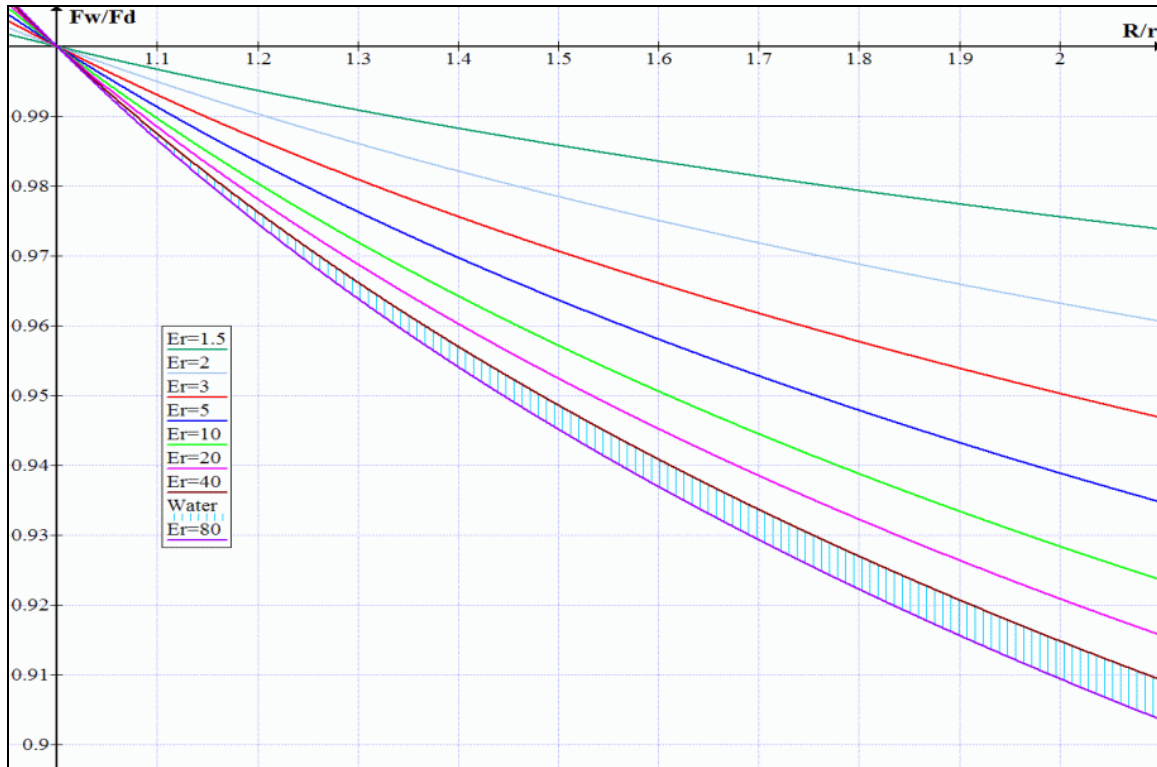
An entire new question arises now: whether the thicker elements during rain collect the same water thickness on its surface as the thinner ones?

No big difference between water film thickness collected on Yagi antenna elements and on antenna boom is noticeable in practice even though they have different dimensions. It seems that water thickness depends mostly on the water to metal adhesion force as opposition to the effective gravitational force. The former one depends on metal surface conditions and the latter one on surface geometry and its slope relative to ground.

The wind’s blowing force can also change amount of collected water on elements in very large extent.

We can say that the difference in water film thickness which is collected on thin and on thick elements is not too significant compared to elements dimensions and can be ignored for our purpose.

The wet antenna performance frequency shift is given as ratio of wet to dry antenna frequencies F_w/F_d where some of the noticeable performances characteristics occurred. Because the wet and dry frequency ratio is proportional to $1/\sqrt{1+L}$ it is possible to draw a diagram of expected F_w/F_d dependence on wire wet to dry radius R/r .



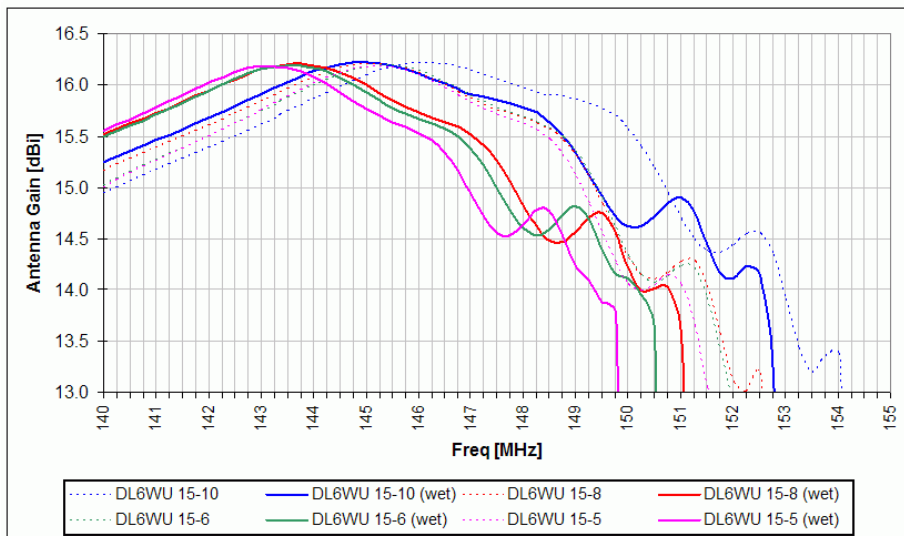
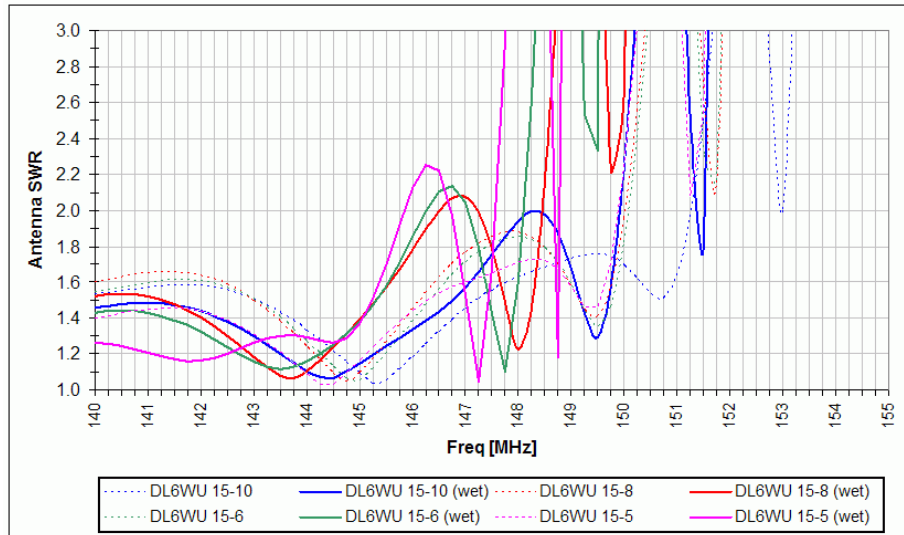
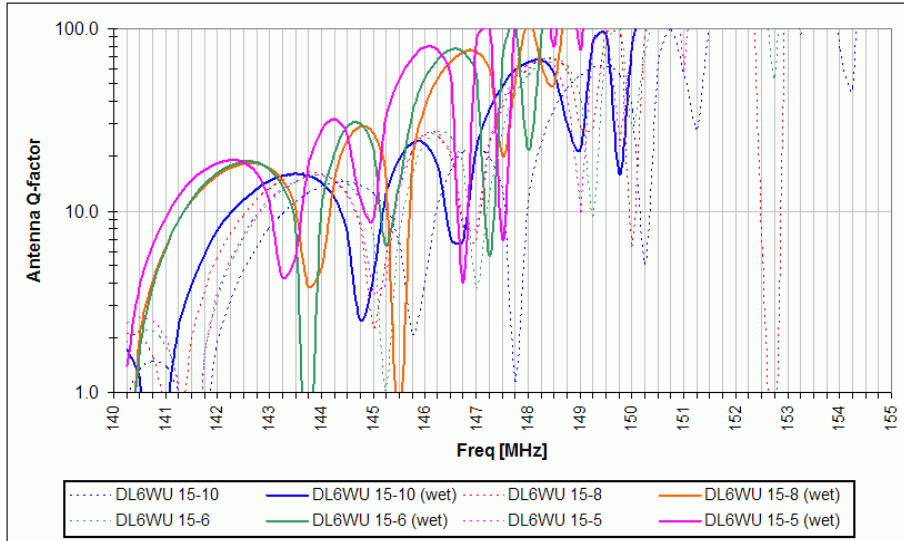
The expected wet antenna frequency shift F_w/F_d dependence on the wire wet to dry radius R/r

The comparison of antennas with various element diameters

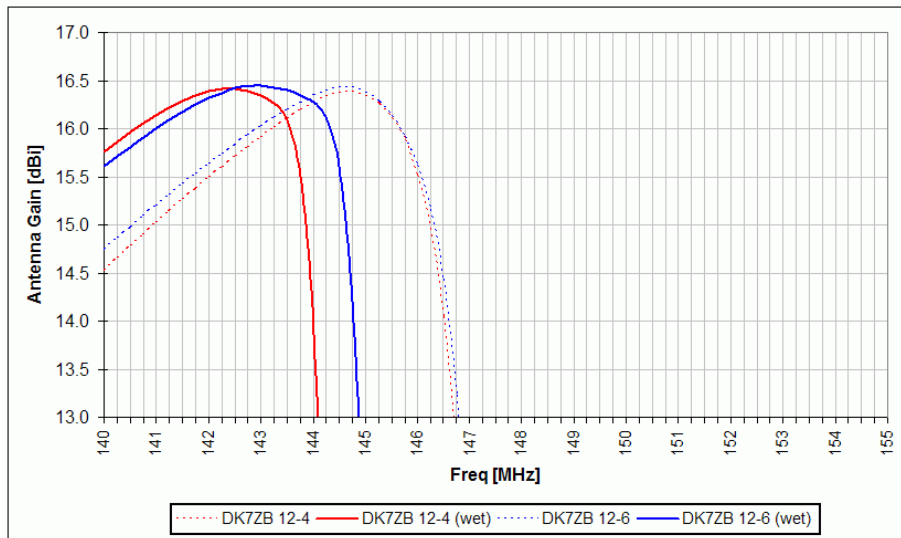
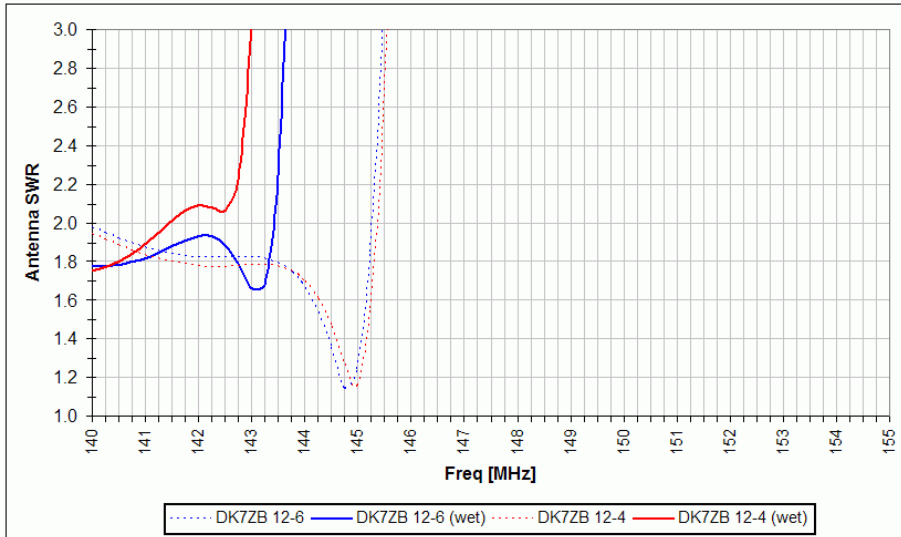
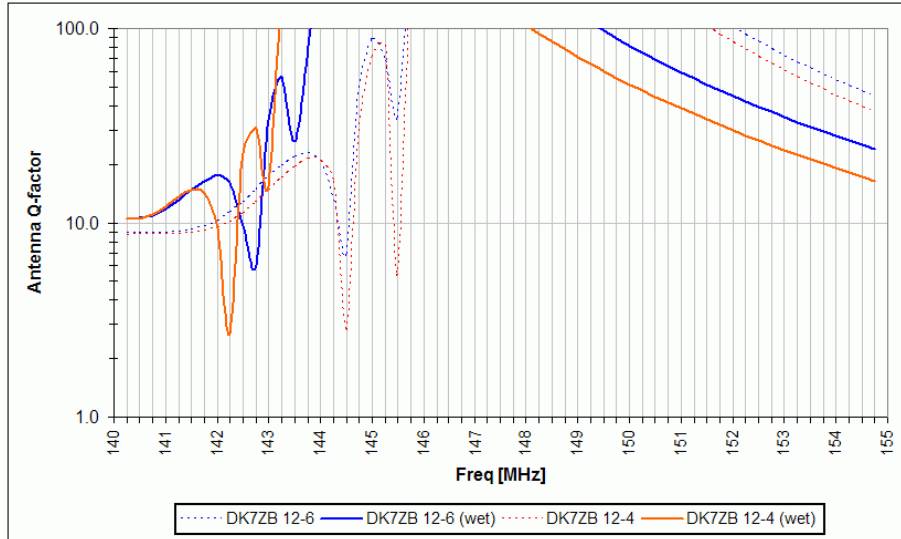
From diagrams in my previous article [2] it is easy to conclude that same antenna types with thicker elements experience less performance frequency shifting than with thin elements.

For the purpose of easier comparison, I sorted out few very similar antennas with different element thickness. I was limited to antenna types which are designed for different element diameters. I compared DL6WU, DK7ZB and YU7EF antennas with boom lengths of 2.5 and 4 wavelengths and with various element diameters from 4 to 14 mm.

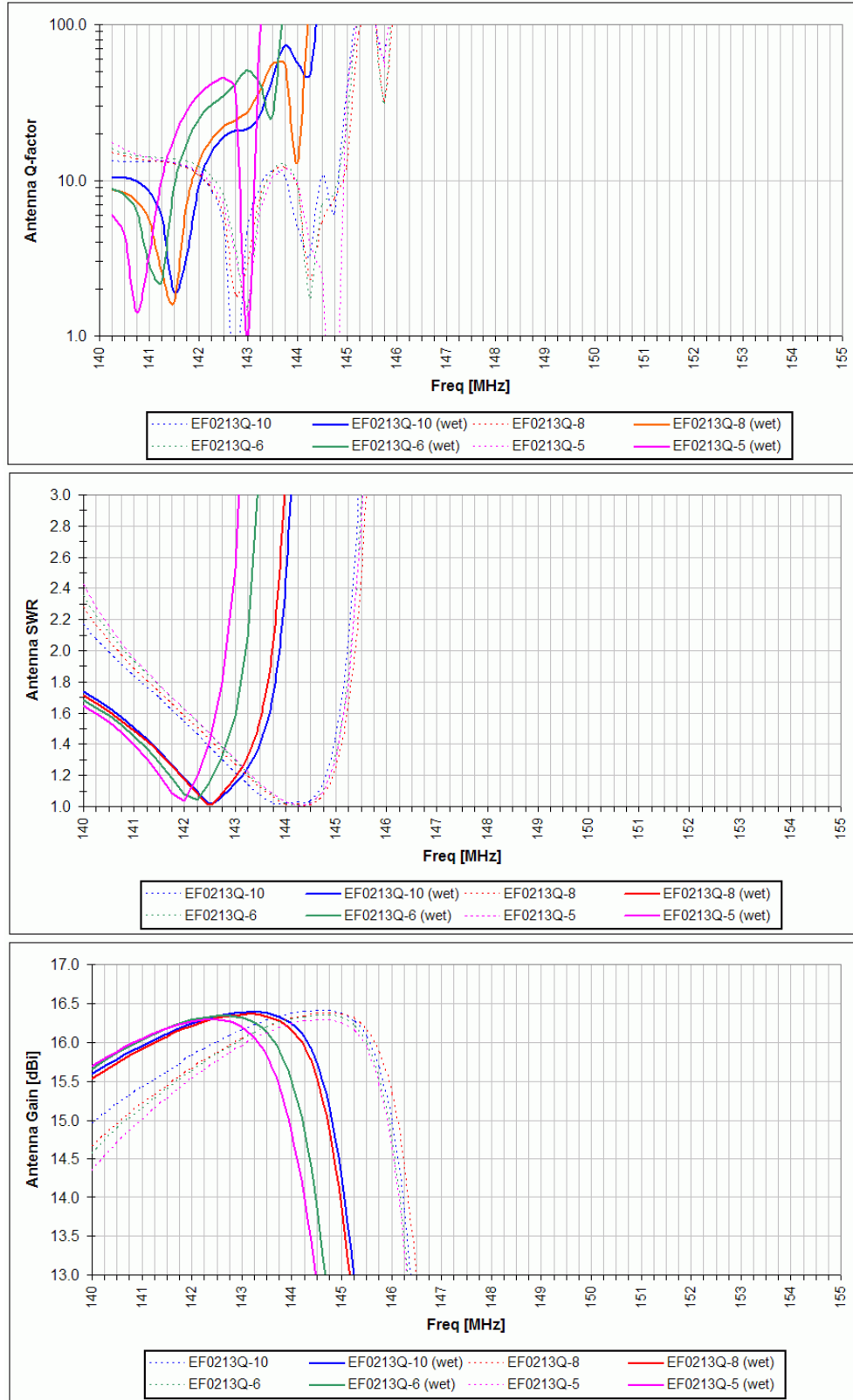
First I compared antennas from the same experimenter to see how the elements diameter influenced to the wet antenna performance shift on the same antenna design. From the diagrams it is seen that for thicker antenna elements, the frequency shift of performances is less than for thinner elements, as expected. It is noticeable good correlation between true and expected antenna performances frequency shift versus elements R/r ratio as it is predicted on the diagram.



DL6WU wet antenna performances frequency shift with various elements diameter

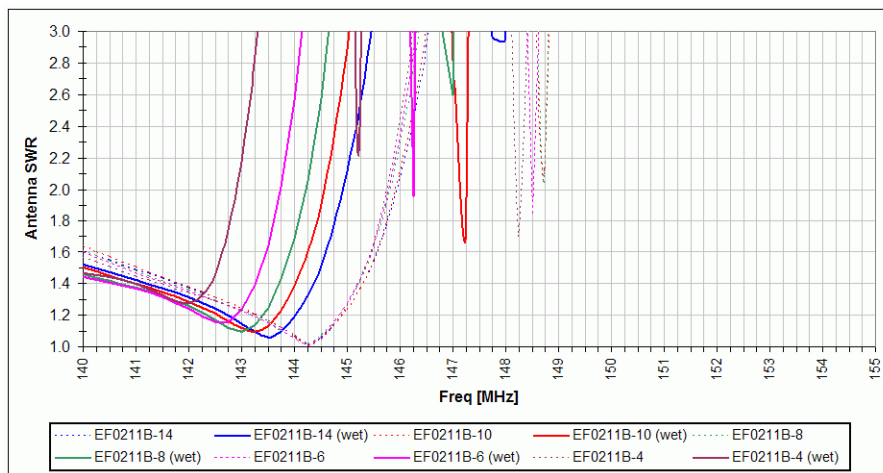


DK7ZB wet antenna performances frequency shift with various elements diameter



YU7EF wet antenna performances frequency shift with various elements diameter

From the diagrams we can see that, for wet antennas, the SWR frequency shift is most difficult problem. It is obvious from the diagram of EF0211B antennas, which have very similar SWR curve for all elements diameter from 4 to 14 mm, that when the elements become wet SWR curves for particular antennas are very differently shifted down in frequency. The antenna with the thinnest elements of 4 mm in diameter is shifted about three times more (i.e. 3 MHz) down in frequency then the antenna with the thickest elements of 14mm in diameter which is shifted down only about 1 MHz.



EF0211B antenna SWR frequency shift with various elements diameter from 4 to 14 mm

A similar problem is with the wet antenna maximum gain frequency shift. This can be illustrated with EF0213Q antennas which have an almost identical gain curve with various element diameters. When the antennas become wet, the antenna gain maximums shift down according to the elements diameter because of different wet/dry elements radius ratio R/r .

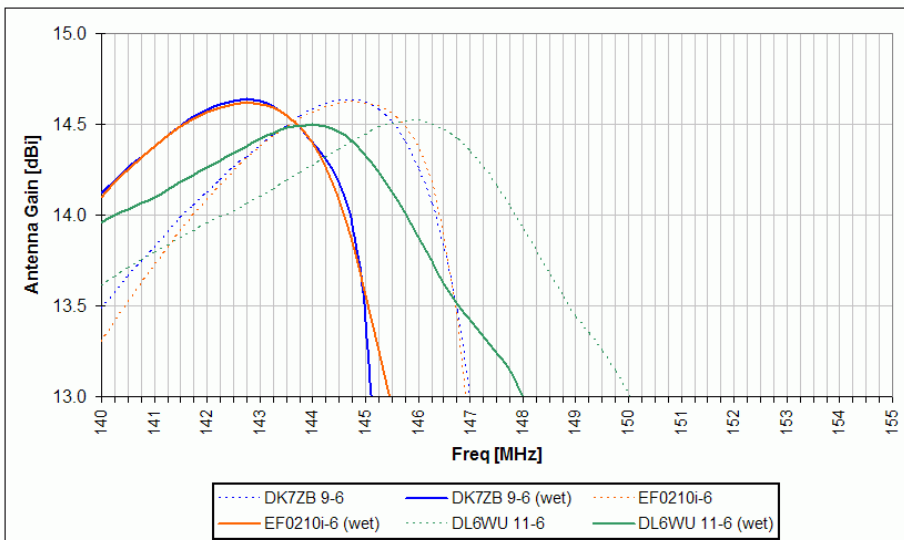
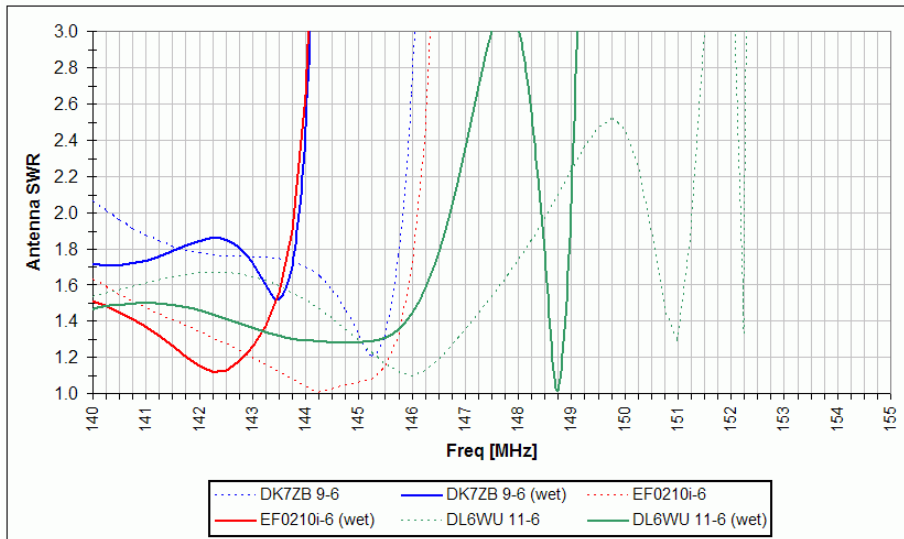
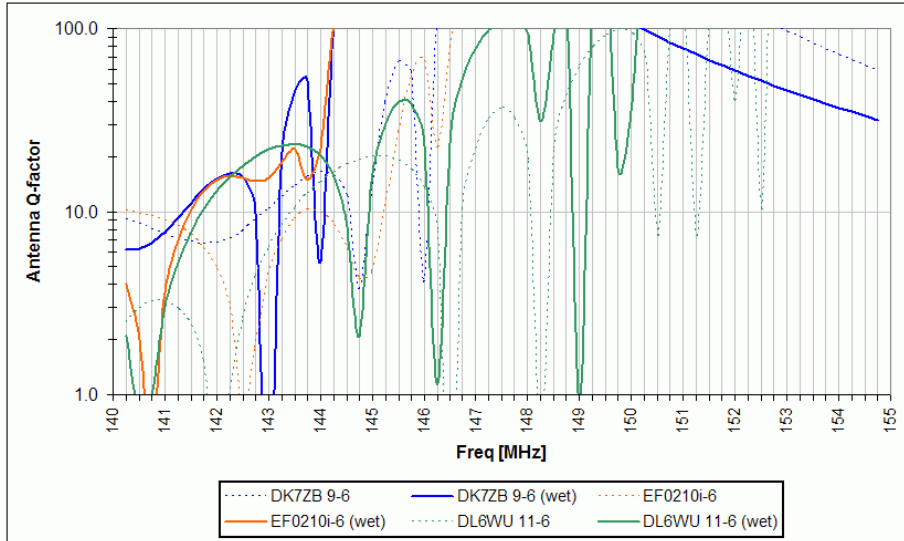
From presented diagrams the two different antenna designs are obvious.

One design with a too narrow antenna gain peak that usually shifts down on the very edge, or even below band, due to wet elements becomes a poor performer.

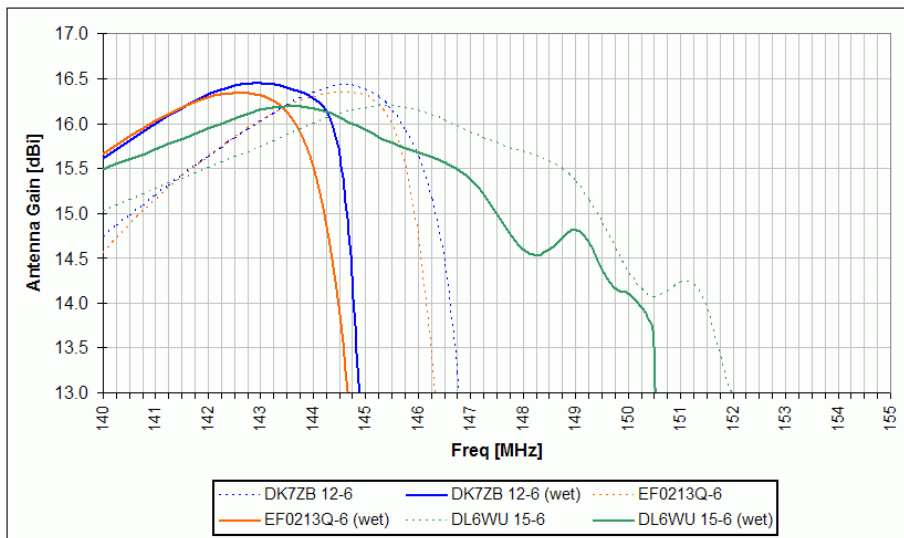
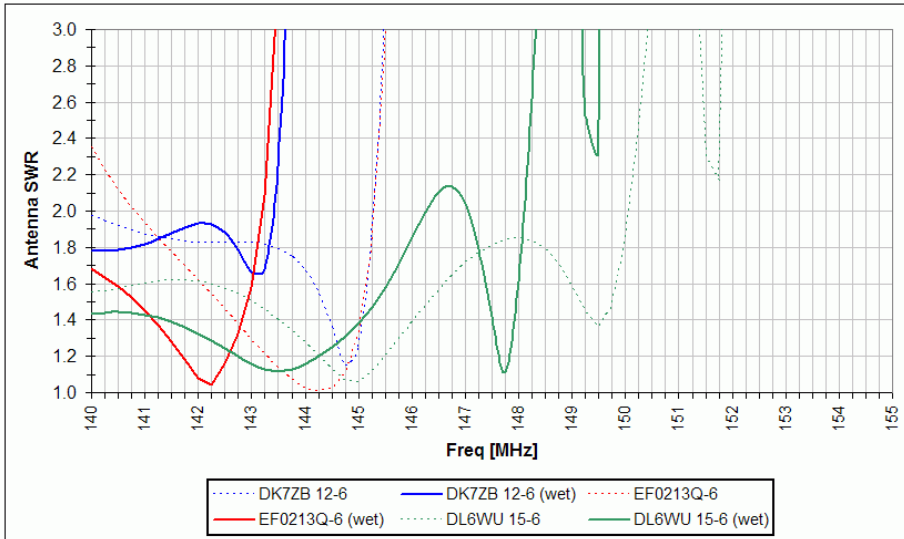
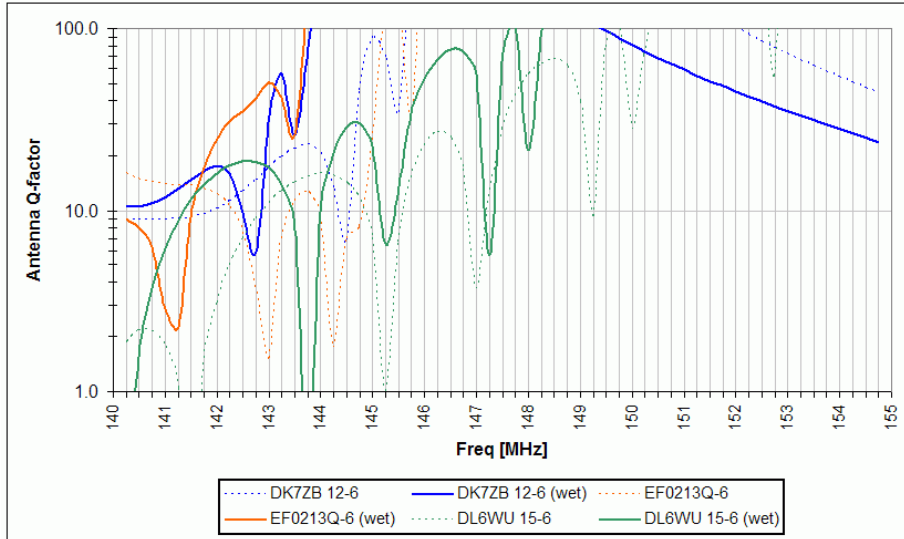
Another design with broad antenna gain peak, that in spite of the similar frequency shift, still has almost unchanged antenna gain. But this attribute has to be paid with about 0.5 dB of gain.

After this initial comparative test I decided to make a comparison between similar antennas of different experimenters to see how specific antenna design with the same antenna elements diameter influenced the wet antenna performances shift.

I made two tests: one for short antennas of 2.5 wavelength boom lengths and another for longer boom antennas of 4 wavelengths. Both tests are conducted for the same element diameters and the results are shown by the diagrams.



Performances frequency shift of the 2.5 wavelengths boom length antennas with 6 mm elements diameter



Performances frequency shift of the 4 wavelengths boom length antennas with 6 mm elements diameter

Conclusion

From the presented diagrams it is visible that antennas with thicker elements suffer less influence and performance degradation than with thinner ones under the same working conditions. But it is obvious that even those antennas with the thickest elements suffer from considerable frequency shift of their performances. The SWR usually degrades most severely, making the antenna almost completely unusable.

Summary

From everything presented in this and my previous articles [1, 2, and 3] we can conclude that antennas whose performances are optimized by computer software usually have very narrow and critical design. It is quite obvious the majority of these antennas in wet weather conditions very often suffer from serious performance degradation, so serious that some of them even become almost completely useless. On the other hand, antennas from authors who optimized their antennas by variation of antenna dimensions and measurements in practice obtained much less critical antenna design. These antennas are much more tolerant to wet weather conditions and to other influences of objects which surround the antenna. They preserve their good performances in the working conditions under which the computer optimized antennas very often failed.

What is the reason for such different behavior? How can we explain this weakness of the computer programs to do something that we can do in practice? The computer programs usually do similar things as we do during the manual optimization process. They choose one set of dimensions and calculate gain, input impedance, F/B, etc. and then, step by step, find antenna dimensions which best satisfy our optimization goals.

We do almost the same thing with our manual or “cut and try” optimizations and measurements, don’t we?

But there must be some difference, because the results of both optimization methods differ and both optimized antennas do not behave in similar manner under wet weather conditions in practice.

It seems that manual optimization never gives a very precise antenna because the statistical yield optimization is already incorporated in the optimization process by the influence of the real environment and the experimenter, who is optimizing the antenna using his hands on the antenna. He is moving very close around the antenna and his body and hands become moving factors influencing the antenna work and *de facto* statistically optimize antenna dimensions for best yield and less sensitive design in that single instance.

Only the real difference between computer and manual optimization that one can see is in the lack of statistical or yield optimization in the computer's pure optimization process, because almost all of today’s antenna simulation programs do not have statistical yield analyses and optimizations.

The computer gives results as the unique set of Yagi antenna dimensions which best satisfy optimization goals, but it does not optimize antenna performances over the wider statistical distribution of antenna dimensions. This makes the antenna design very narrow, sensitive and critical.

As the results of two different optimization processes, on the one hand we get from computer program's highly optimized antenna with maximized performances in a narrow band, but very sensitive and critical to any exception of obtained optimum dimensions or of any other influence. These antennas can work as predicted only if all conditions which have been fed to the computer program during the optimization process are also matched to the real-world setup.

That is exactly what we usually get from "new" antenna designs which obtain maximum possible gain on a very limited and narrow frequency band. On the other hand, the manually optimized antennas rarely reach the absolute maximum of gain, but always give much more tolerant design which work better in real environment conditions, because the antenna was already optimized in the very similar real environment conditions.

It seems that it is not possible, or at least not easy to design good, tolerant and insensitive antennas just by comfortably sitting in the armchair in front of computer screen without practical, lengthy and tedious manual changing and moving of antenna elements here and there to "tweak."

The statistical yield analysis and optimization in antenna programs and exact antenna modeling together with correct modeling of expected real antenna working conditions perhaps could partially mitigate the problem.

References

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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



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