Performances of Wet Yagi Antennas

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Introduction

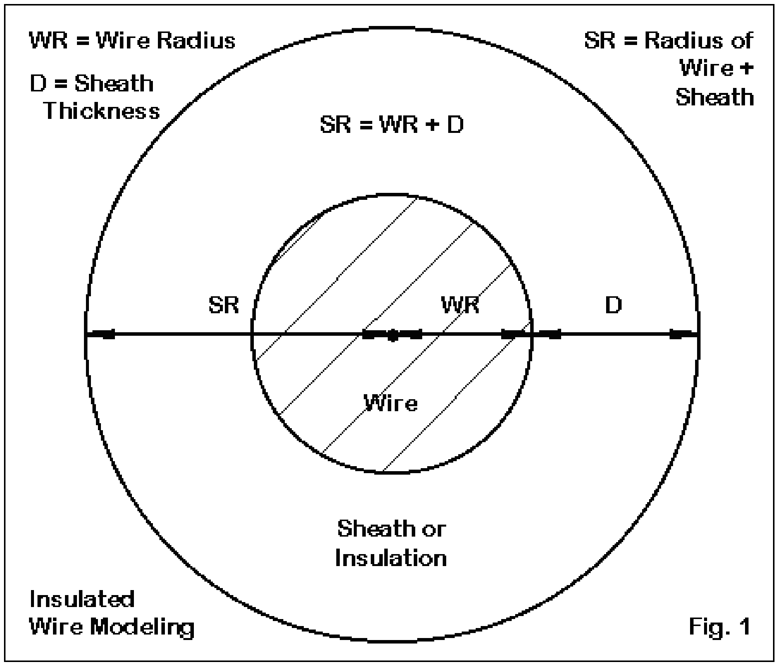
In the referenced article [1], I conducted a small research about performances of antennas when they become wet. The antenna gain and input SWR were two parameters monitored in the antenna simulation while the antenna elements were covered with water coating of different thickness.
This simulation shows that different antennas have very different sensitivity to moisture. Some antennas become completely unusable with very thin water coating on elements, while others are working still very satisfactory with much thicker water coating.
Some correlation between the input resistances, which are for VHF/UHF antennas mainly consisted of the antenna radiation resistances due to very low loss resistances, and sensitivity to moisture were established. The radiation resistance is important in antenna Q factor value determination. Hence, there is dependence of the antenna sensitivity to moisture on the antenna Q factor.
An antenna, as any series RLC circuit, has a Q factor that can be calculated according to the following equation [5], [6]:

$$Q = F / 2R * (dX / dF + |X| / F)$$

F Frequency
X Antenna reactance
R Antenna resistance consisted of radiation and loss resistances.

In my article [2], I show that Q factor of Yagi antennas can change its value in very wide range in the antenna working bandwidth. Some very similar antennas with almost identical gain can have very different value of Q factor.
It was obvious that in antenna simulations, which are usually conducted in almost ideal antenna working conditions, antenna Q factor do not show its impact to overall antenna performances in real environmental conditions.

Because of that, I was curious to find the way, which would give me better insight into antenna sensitivity and performance degradation in practice due to negative environmental effects and antenna Q factor.
One of the easiest ways to check antenna sensitivity to moist working condition is to try to simulate moist conditions during antenna simulations.



Simulation of wet elements
The simulation program, which I used, was 4NEC2 and it has the ability to analyze antenna built from insulated wires [3] and calculate the influence of wire insulations to overall characteristics of antenna using LD7 card. [4]
This insulation produces shortening effects in the wires, thus lowering the velocity factor.
Internally in the program the LD7 card converted to an LD2 card using the below equation [3]:

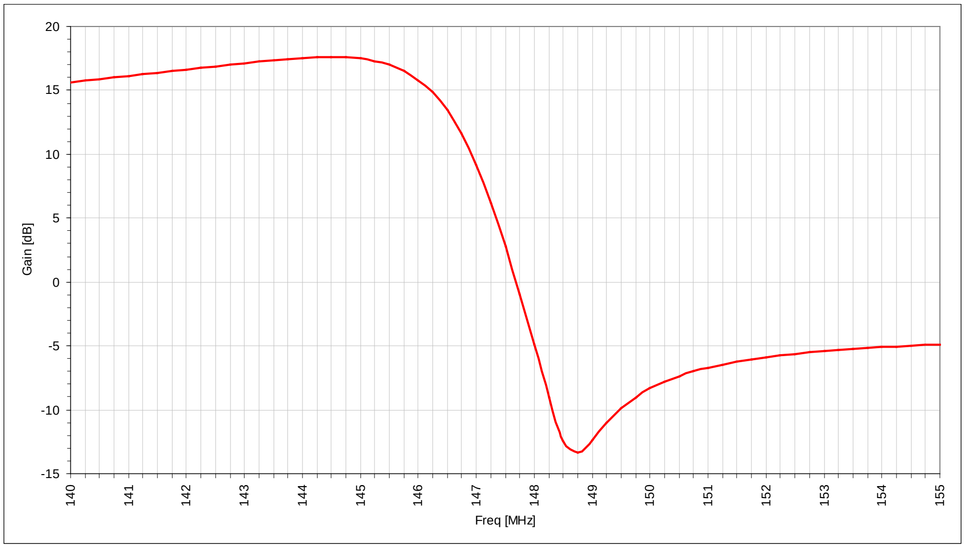
$$L = 2e\text{-}7 * (Er * R/r)^{(1/12)} * (1 - 1/Er) * \ln(R/r)$$

L	Value for distributed inductance in Henry/meter
Er	Dielectric constant (as specified in the LD7 card)
Ln	Natural Logarithm
R	Radius of wire plus insulation (as specified in the LD7 card)
r	Radius of (bare) wire (as specified in the corresponding GW card)

My previous simulations of wet antennas [1] were not very realistic because I presumed that water coverage of the elements is a uniform water cylinder of the same thickness all over the surface of the elements that is not very likely to happen in practice. I decided to improve this model in order to get simulations that are more accurate.
First, I noticed that very rarely the whole element surface could be covered with the same thickness of water. Usually, it is covered with big number of water blobs (drops) of

different size, which are separated by air. Blobs size cannot be very large due to gravitation force, which pulls the largest ones to drop down on ground.
Because the dimension of the blobs are very small compared to antenna working wavelength, with air between them, we can assume that moisture on an antenna element is made of "water foam", which can be electrically modeled similarly as the plastic foam insulator in coaxial cable.
The foam dielectric permittivity is determined by dielectric permittivity of the materials used to make the foam and its specific volume ratio.
In this case, we have water with relative dielectric permittivity of about 70-80 and air with much less value of about one. Looking at wet antenna elements, it is easy to conclude that specific volume ratio of water and air in moisture coverage can change significantly depending on the elements' material, surface filth, wind, geometry, dimensions, etc.
It is noticeable that if we take into account just the very thin layer of the "water foam" near the element's surface we can see that the water much more densely moistens the element's surface than if we take into account some thicker moisture layer. This is because the element's surface is usually moistened with very thin water film which covers the majority of element surface. Over that basic thin film larger water blobs are commonly formed that are spread over entire surface in a seemingly random fashion.
All this led me to conclude that if we take into account the thinner water foam layer then the water to air ratio is higher and thus higher is the water foam effective dielectric permittivity. However, if we take the thicker foam layer, the water to air contribution ratio is less and so is the effective dielectric permittivity. From an electrical standpoint, both situations give similar results because both the effective dielectric permittivity of material and its thickness tend to give similar results.
Contribution ratio of water and air in its foam coverage can vary considerably because of the many different antenna materials and moisture conditions.
For our research, we can choose one volume ratio that is very probable in practice and use the same for all antennas investigated. Because all antennas are simulated with identical moisture foam electrical parameters, the results are valid enough for fair comparisons.
After some trials, I found that water to air volume ratio in water foam could be about 1:10. That is considerably less than usual heavy rain condition and little more than usual moist condensation. It gives effective dielectric permittivity of about Er=8.
Thickness of the water foam of 0.5 mm as an expected increase of the element radius is found to be a very probable and acceptable factor. This thickness is much less than water thickness under heavy rain conditions but on the other hand, it is more than a tiny moisture condensation like morning dew.
So, all antennas are simulated in two different environmental conditions: dry and wet.
Dry conditions are absolutely the same as how antennas are given in publications or in program results.
Wet conditions are as they are described. All elements are "insulated" with 0.5 mm thick "water foam" coating. It means that the overall radius of "insulated" wire or tube element (metal wire plus water foam coating) is increased by 0.5mm. Such foam has an effective dielectric permittivity Er=8.

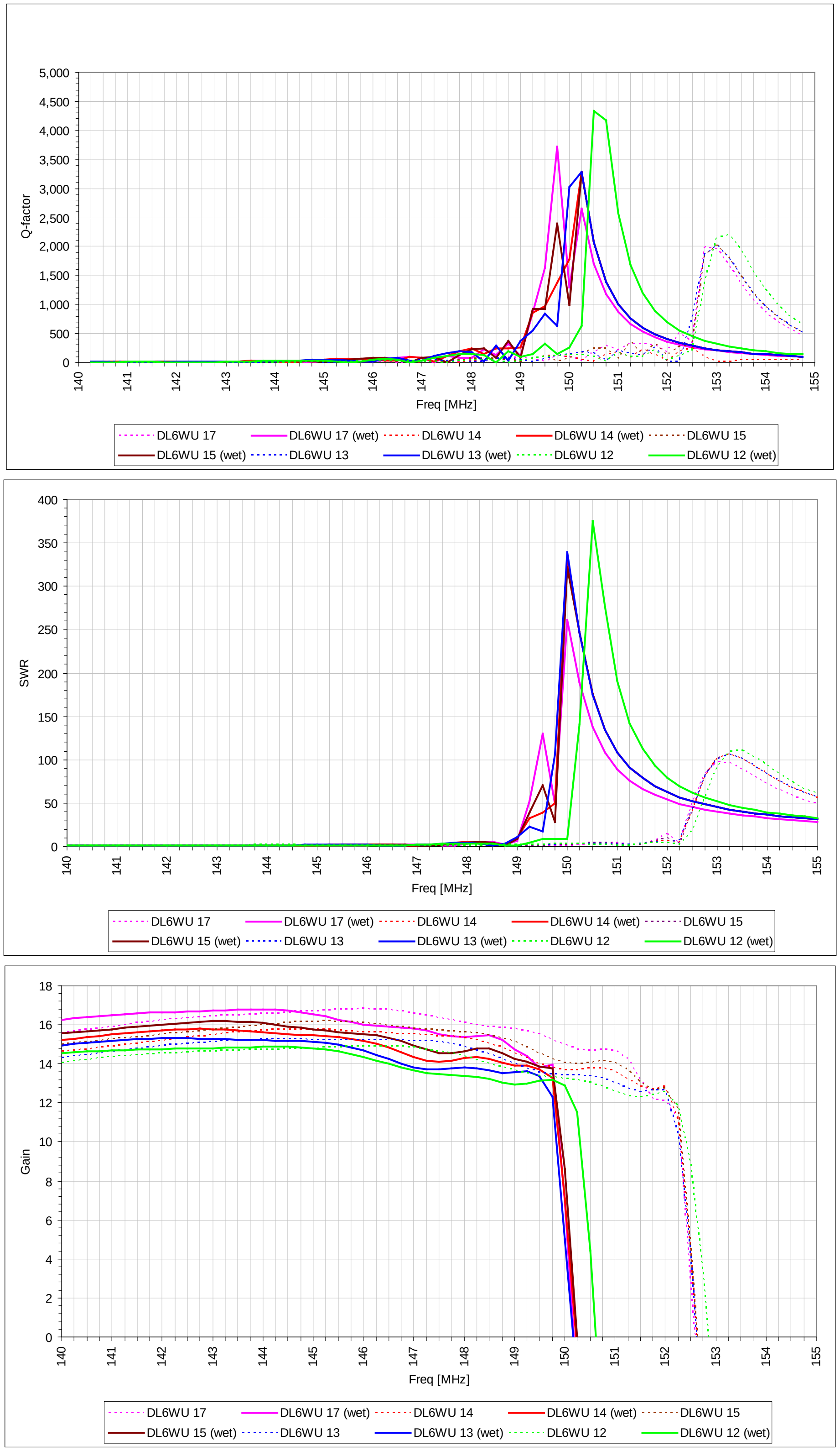
I have to say that it seems to me that, according to real world moisture condition observations, chosen conditions of Er=8 and radius increase of 0.5 mm are pretty light conditions because, in many situations during rainy or icy weather conditions, effects are much more severe.
From a statistical stand of point, this is correct choice because antennas are very often used under dry conditions too.



The typical curve of Yagi antenna gain vs. frequency

Q factor, SWR and gain of wet Yagi antennas

After heavy and tedious work on simulations of numerous antennas, I generated diagrams, which show very similar behavior tendency of all simulated Yagi antennas.
Because of increase of dielectric permittivity near the element's surface, RF propagation velocity in elements decreases and all antennas behave as they work at a higher frequency than they were projected. Usually, all antenna performances changed and shifted down for about 2-3 MHz on the 2m band.
Every particular antenna shows slightly different behavior and overall performances under wet conditions.
How good or bad performances are at moist conditions depend on the design, mechanical construction and optimization method of every particular type of the antenna.
Some of the antennas are still good performers under moist conditions, but some others are very poor and practically useless.
Why is it so?
The typical curve of Yagi antenna gain is a line which monotonously increases with increasing of frequency until the point where frequency becomes so high (wavelength becomes so short) that the current phase in the passive antenna elements changed abruptly and this sudden change completely ruins antenna performances.

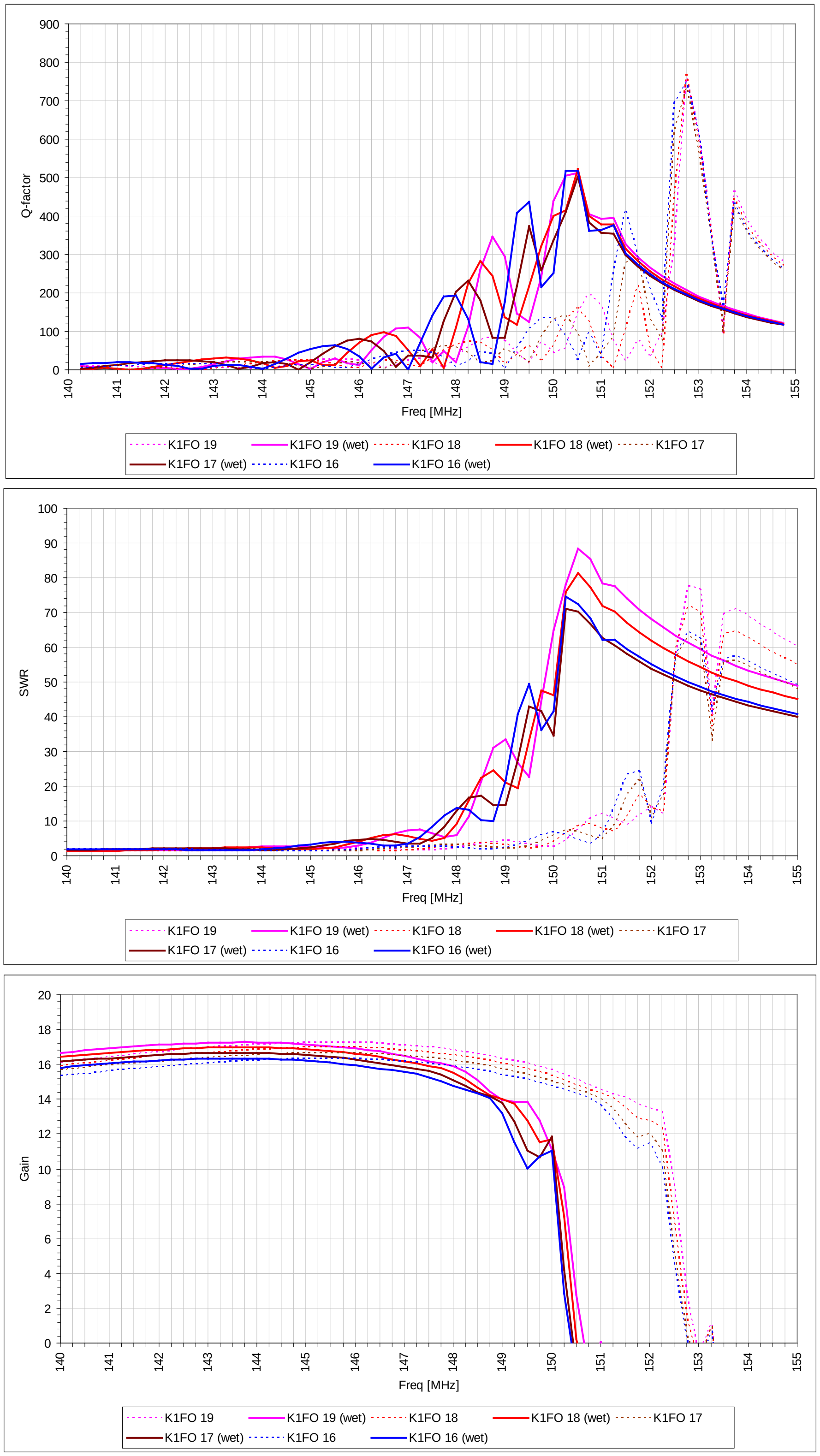


Q-factors, SWR and gain of dry and wet
DL6WU Yagi antennas with various boom lengths

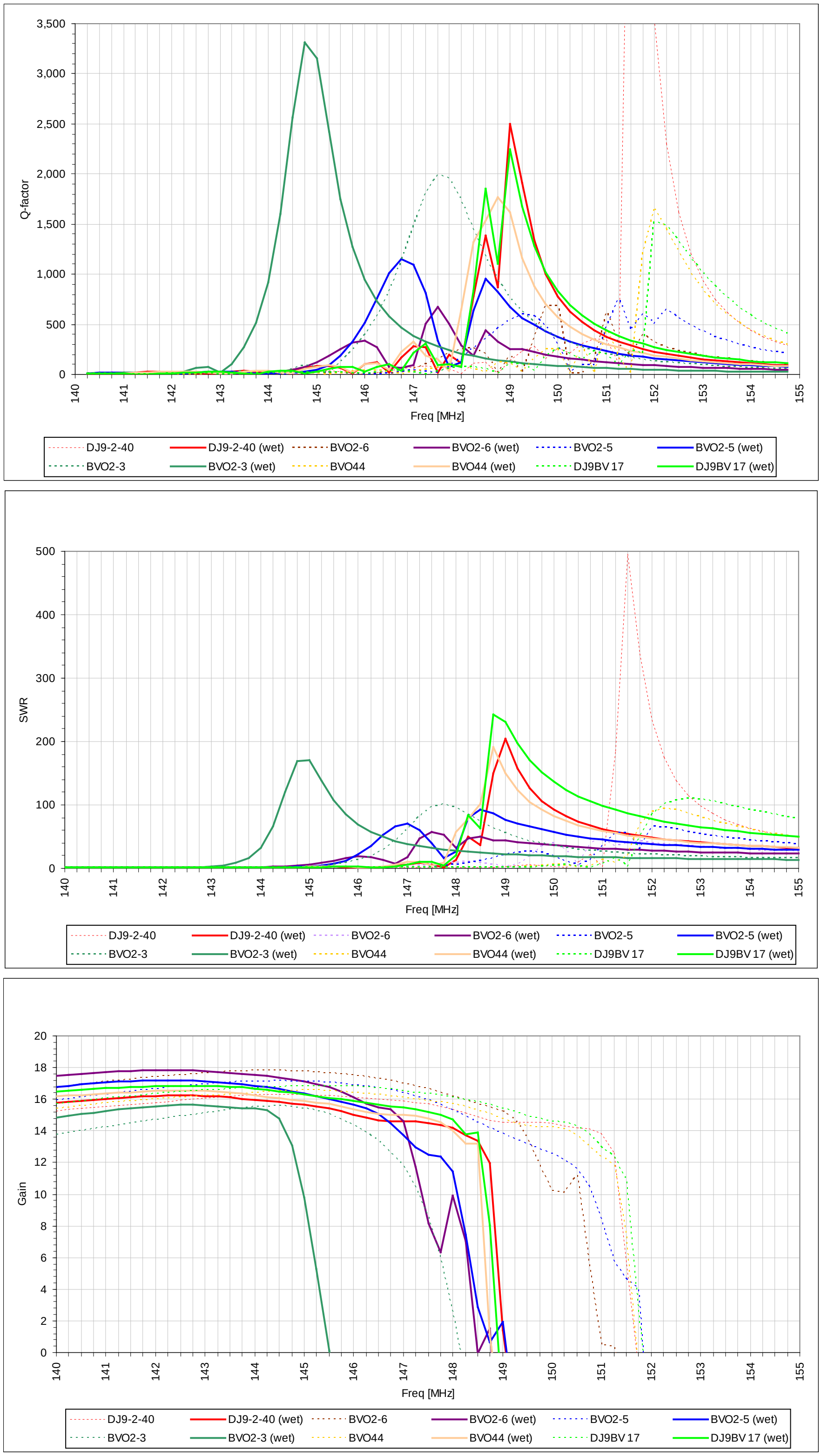
During the performance optimization process of a Yagi antenna computer program, it tunes length and spacing of passive elements to achieve performances which best satisfy optimized conditions as determined by the user.
Under the usual optimization conditions, in which the maximum gain and minimal SWR in the very limited working bandwidth dominate with high weighting factors values, the program results are as can be seen on diagrams of some newer types of antennas.
In the working bandwidth, which is usually only a small part of the overall amateur band, the SWR and the Q factors are minimal and the antenna gain is maximal. On the upper part of the amateur band, values slowly change and just above the upper band limit, performances become just the opposite: Q factor and SWR become very high and gain drop to very low value.
Such antennas can be good performers if they are working in such environmental conditions that are very similar to conditions under which antennas are optimized.
These conditions are usually dry, ideal Yagi antena alone in free space.
In practice, wet antenna in companion with many other close spaced antennas on the mast, with ground, roofs and other objects in its vicinity may have completely different performances as can be seen from the diagrams.
All these environmental influences to the antenna have similar effect and they shift performances and important antenna electromagnetic parameters down in frequency.
This shift in frequency domain produces similar effects as the antenna is working on much higher frequency than it is optimized for.
High SWR and Q factor together with low antenna gain are being shifted from upper frequencies down to the antenna working band and the antenna does not have the same performance as it is expected to have according to optimization results.

It is obvious from the diagrams that earlier designers did not make the same compromises and did not choose same optimization conditions for their antennas as the more recent ones.
Comparing diagrams of wet DL6WU antennas, calculated with various programs which all are using original Gunter Hoch’s algorithm for Yagi antenna dimensions, despite of small modifications and dissimilarities between them, always give very good results.
In my referenced article [2] antennas named as “DL6WU antennas” and “G3SEK antennas” have very similar performances. This is because “G3SEK antennas” in my article are in fact DL6WU antennas but only calculated with the aid of a small DOS program written by Ian White, G3SEK many years ago.

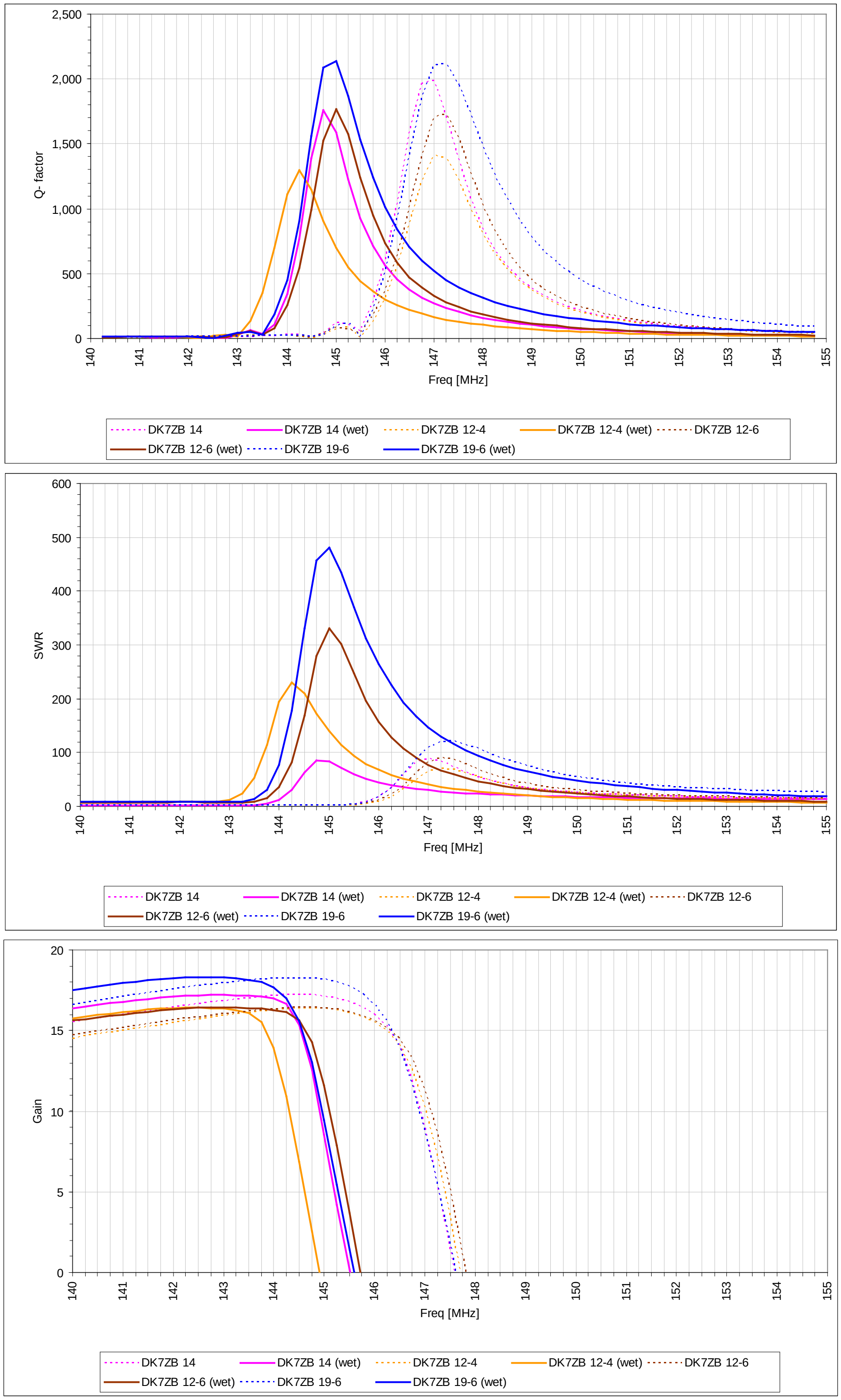
If a Yagi antenna is constructed in such way that when it is dry it works at the very edge (end) of increasing gain curve and thus provides maximum possible gain, then in wet weather conditions such antenna can behave very badly. This is because of frequency shifting of its performance and a fall off over the edge of maximum gain to a very low value.
When an antenna becomes wet, SWR and Q factor high values, which are located just above the upper working bandwidth edge, are shifted down in the working bandwidth and the antenna performs very poorly.
It is obvious from diagrams that the antenna Q factor, SWR and Gain are so closely related that change of one parameter strongly influenced and changes the other two.



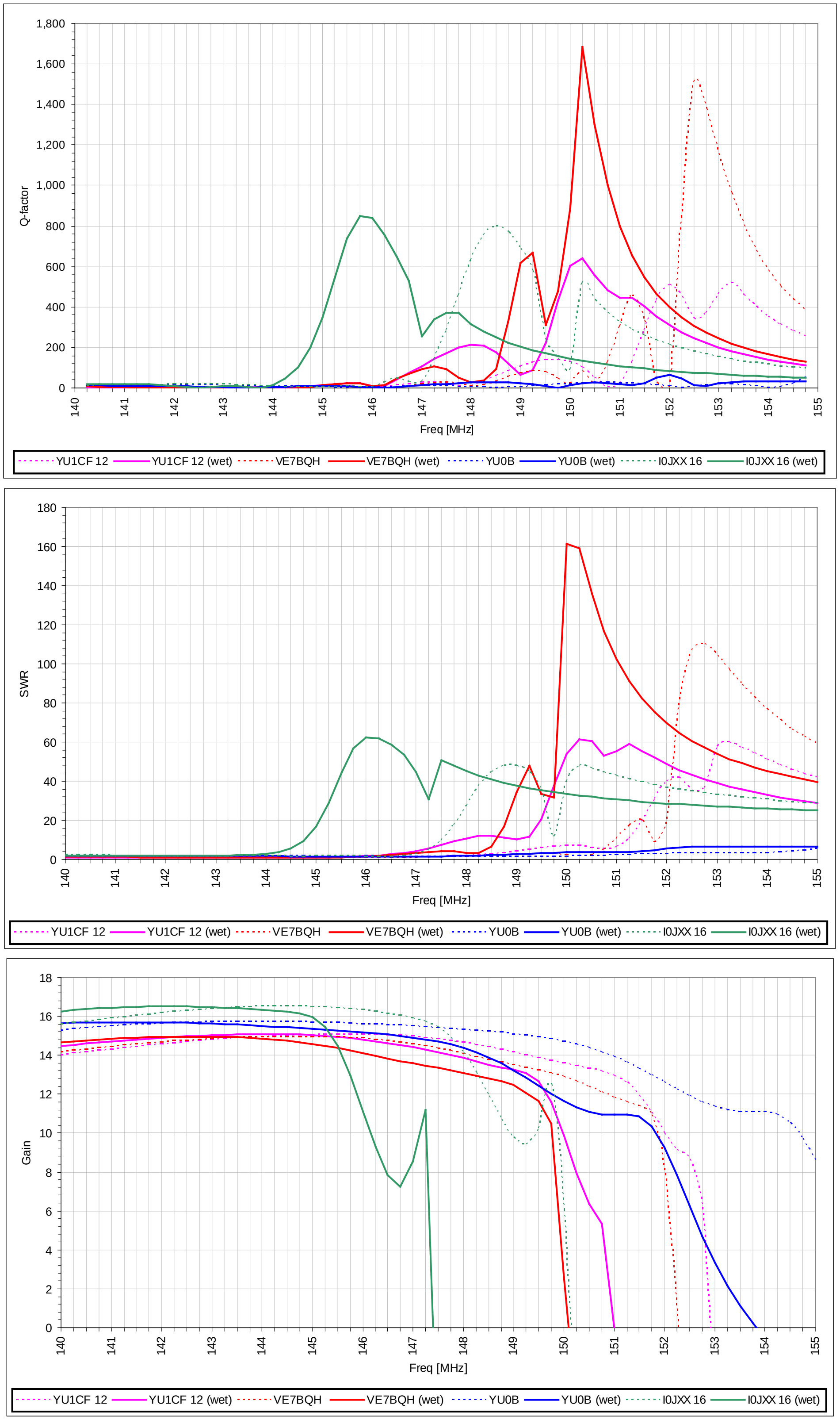
Q-factors, SWR and gain of dry and wet K1FO Yagi antennas with various boom lengths



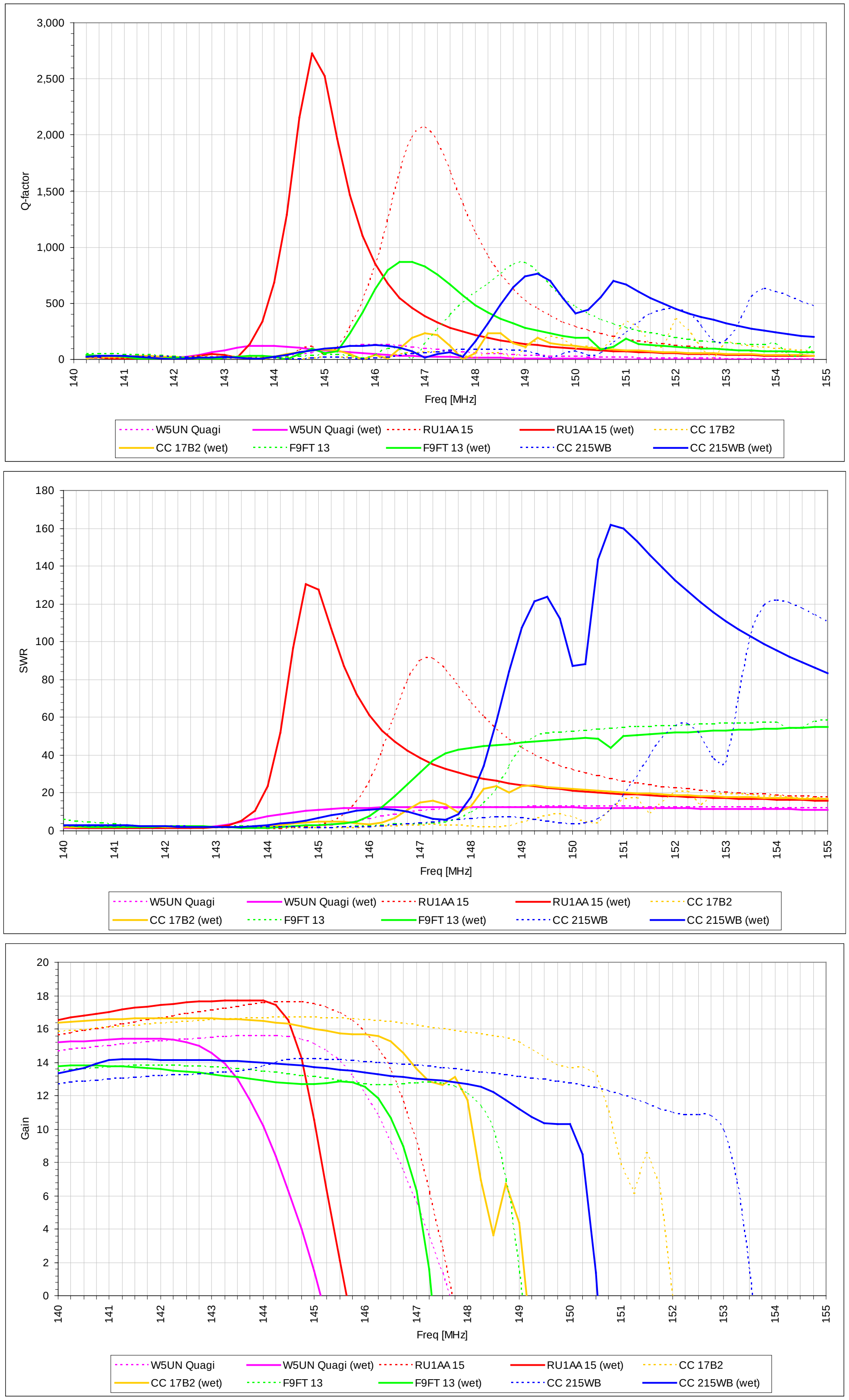
Q-factors, SWR and gain of dry and wet DJ9BV Yagi antennas with various boom lengths



Q-factors, SWR and gain of dry and wet DK7ZB Yagi antennas with various boom lengths



Q-factors, SWR and gain of dry and wet Yagi antennas of various experimenters



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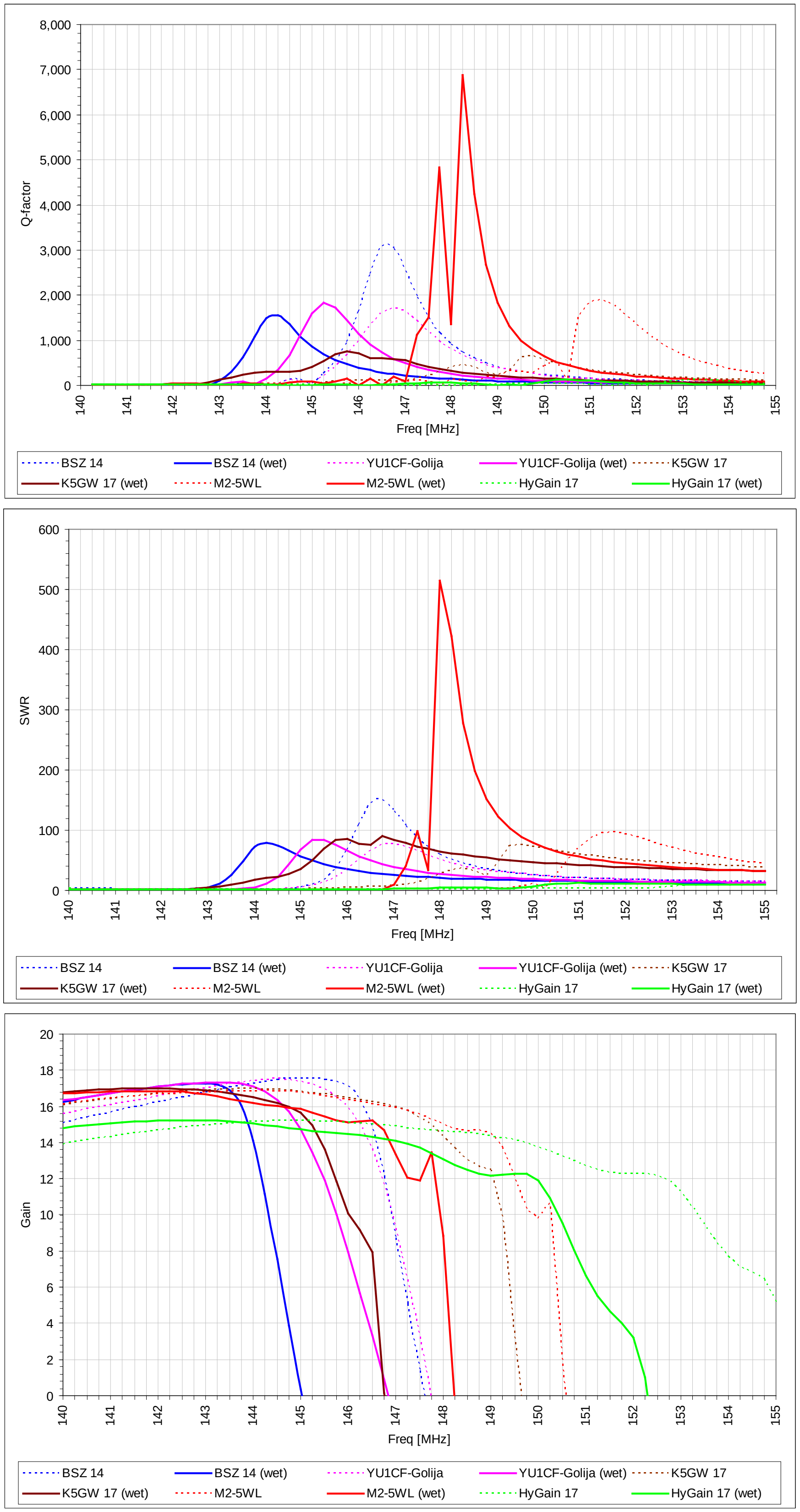

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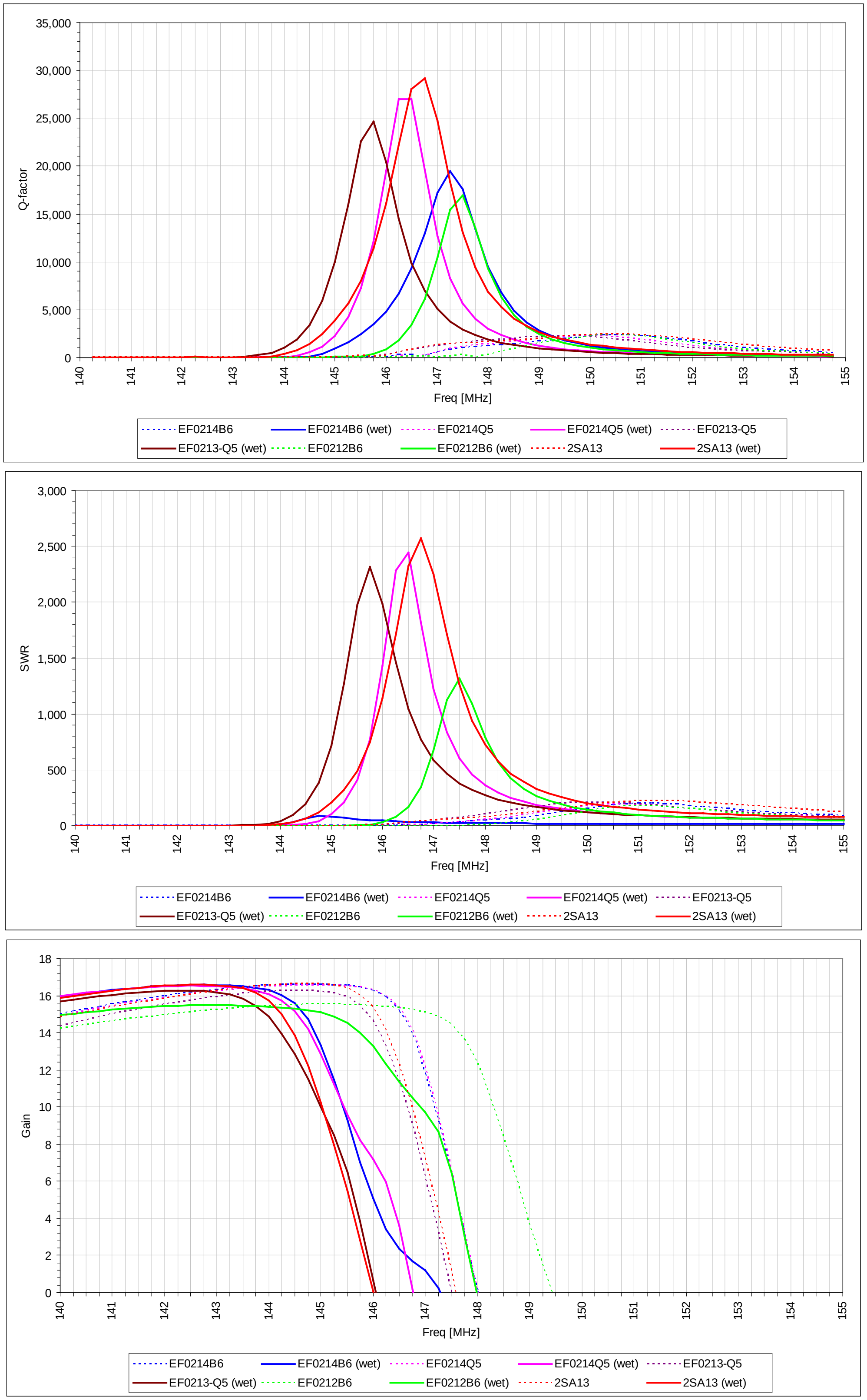
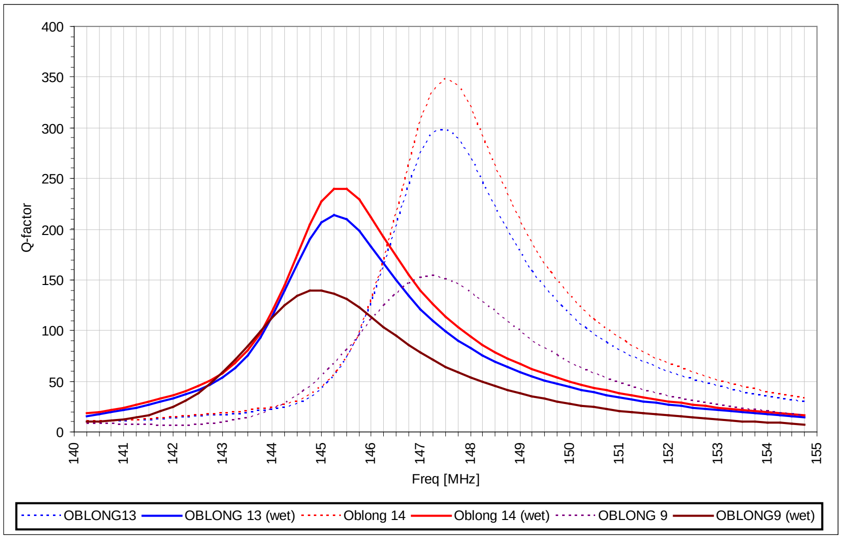
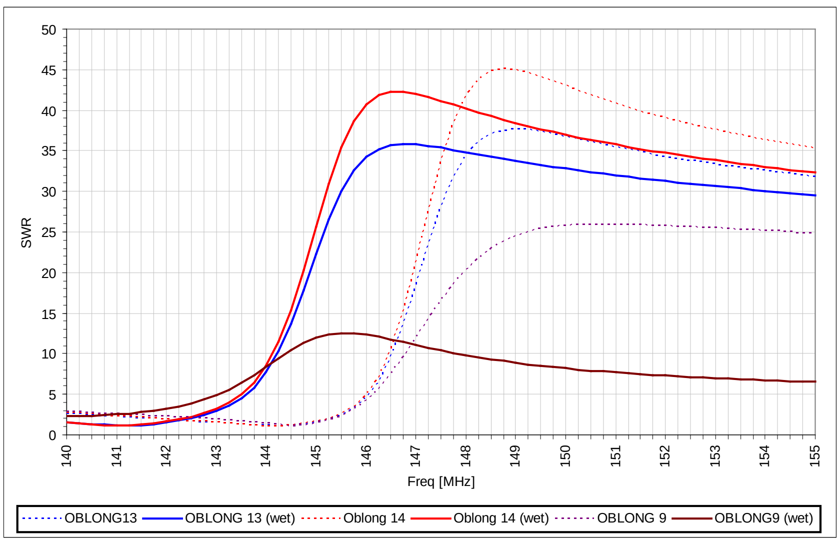
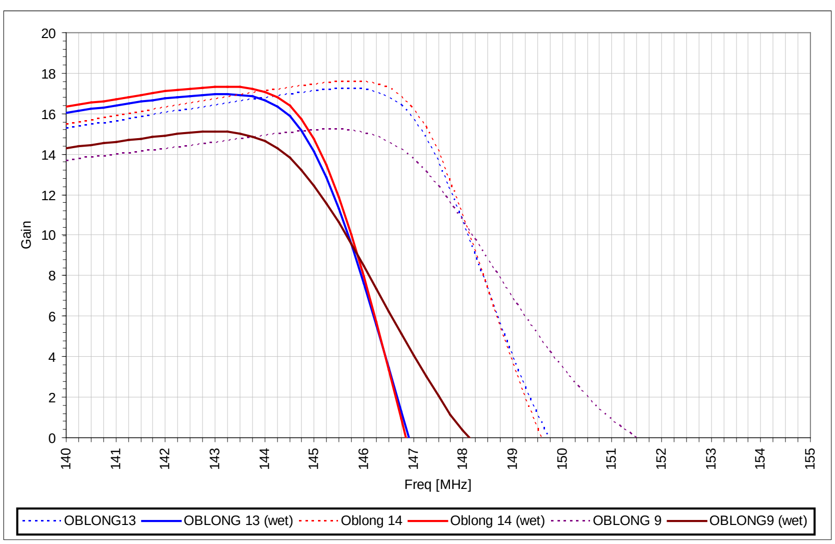


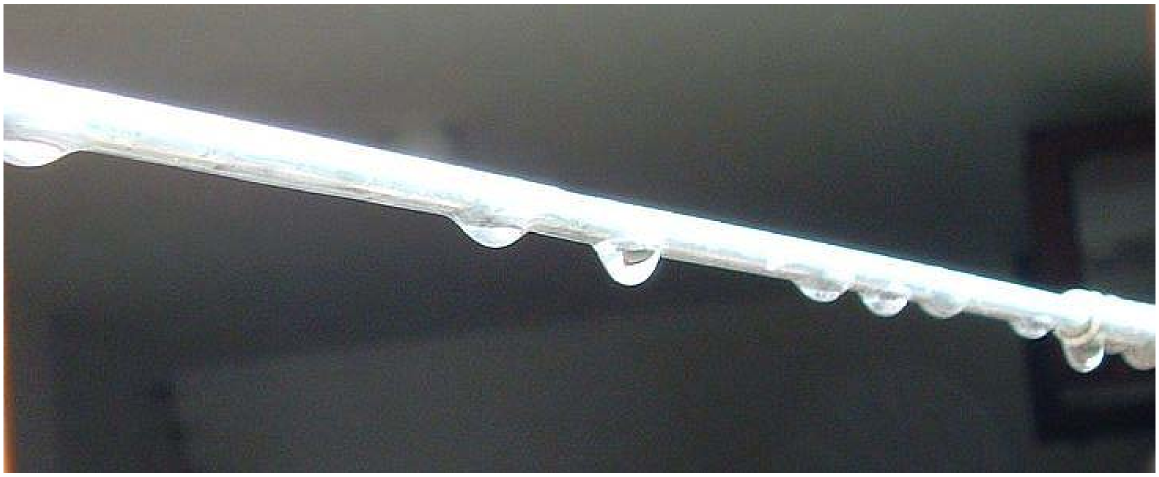
Q-factors, SWR and gain of dry and wet Yagi antennas of various experimenters







Q-factors, SWR and gain of dry and wet YU1QT Oblong antennas with various boom lengths



Conclusion
On the basis of material presented in this paper, I show that Yagi antennas, which are optimized in such way that antenna gain is maximized and the working bandwidth is minimized to the highest possible extent, usually suffers of poor work under less than ideal practical working conditions where antennas are not alone in free space and they are not dry.
Looking at the presented diagrams, we can see that when the antenna's working frequency approaches a critical frequency at which rapid gain decrease starts, due to improper currents phasing in antenna passive elements, consequently increasing Q factor of antenna and input SWR also starts.
An antenna that is working in real world conditions suffers from different environmental influences, such as interaction with mast, other closely-spaced antennas and physical objects, ground, roofs, moisture, etc. Almost all of those factors have a tendency to shift parameters of an antenna lower on frequency. Because of that, all critically constructed antennas approach a critical frequency where rapid gain decrease occurs and thus they perform badly.

The diagrams show that some designers found better compromises and better optimization conditions for their antennas than others.

It is obvious that a Yagi antenna's behavior in moist conditions should be one of important parameters to consider during its operation. **-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.