QAntFileCalc

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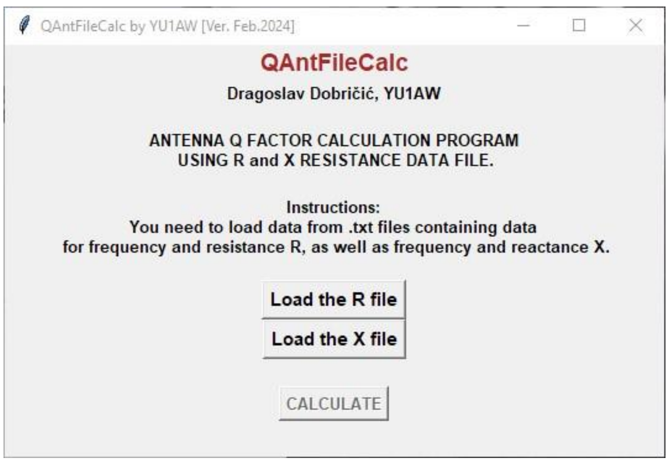
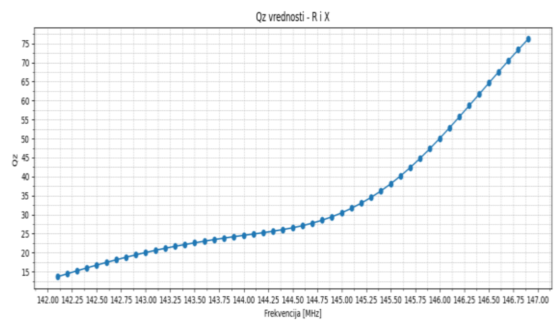
A program to calculate the Q factor of an antenna using input impedance data files





<u>**Importance of antenna Q factor**</u>

The program for calculating the Q factor of antennas was created for the needs of realistic and comprehensive evaluation of antennas based on its Q factor.

Namely, it is known that the Q factor of an oscillatory electromagnetic system, in addition to directly influencing the efficiency, also determines how resistant the system will be to external influences. With the rise of losses in the antenna due to the increased Q factor, the noise temperature of the antenna also increases, which is a caused by losses, that directly transform the physical temperature of the antenna into the noise temperature.

It is easy to show **[Ref. 3, 4, 5]** that possible external influences on the antenna, such as surrounding nearby objects, ultimate height from the ground, presence of mast, supports, coaxial cables, other antennas on the mast, rain, frost, ice, snow, etc. they disrupt the radiation pattern of the antenna and thus affect the gain of the antenna, which is also manifested by a change in the input impedance of the antenna. It has been shown that this parameter, although it can be significantly altered, it does not even reflect the true state of the antenna in terms of noise increase and changes in its diagram and thus gain.

For example, when water is retained on the antenna elements in the rain, there is a change in the resonant frequency, a change in the antenna diagram, the front/back and front/side ratio, which affects the gain. Changing the radiation pattern and resonant frequency, on the other hand, affects the change in input impedance and increased losses in the power cable due to mismatch. Because of this, the losses at the output stage of the transmitter increase, which increases dissipation of the circuit elements and thus by the increased operating temperature of the output stage of the transmitter.

Due to presence of external objects and alterations of electromagnetic properties in the surrounding space around the antenna, it reacts by changing the size and distribution of currents in the conducting elements and thus its Q factor and input impedance. Usually the effect of the changed Q factor on the noise temperature of the antenna is much greater than the effect on the gain and input impedance. Let's say, for many antennas, the presence of the layer of water on the elements caused a change in gain by about 0.5 dB, the input impedance by several ohms, but the noise temperature of the system due to the changed diagram and increased losses increased by more than 100 K.

Having all this in mind, it became obvious that bringing under control the sensitivity of the antenna to environmental influences is of key importance for the control and prediction of the operation of the antenna in modified operatingl conditions. Those conditions are usually neglected (or idealized) when performing deterministic antenna optimization on a computer. However, the question arises as to how to check the antenna on the pole with the instruments and knowledge that the average experienced radio amateur has. It is Difficult!

The gain of the antenna is difficult to measure directly, special polygons are needed for antenna measurements to prevent environmental influences on the measurements, especially the reflection from the ground and other objects. In addition, calibrated antennas and measuring devices are required. The directivity diagram of the antenna is also difficult to measure in real conditions because the huge number of reflected waves from surrounding objects introduces errors and reduces the dynamics and accuracy of the measured diagram.

Input impedance can be measured relatively accurately with an RF bridge or network analyzer (VNA), somewhat less accurately, and often completely inaccurately, with wideband multi-band SWR meters. However, the change in the input impedance of the antenna shows us that the antenna changed due to the influence of the environment, but not how much it affected the change in its performance.

Any subjective observations and evaluations of antenna performance can be very wrong or at best incomplete and are of little use in assessing the extent to which the antenna's performance has degraded due to environmental influences.

From all that has been said, it is clear that operation of antenna optimized in one environment and set to work in another, often far less favorable, remains a complete unknown and eludes any objective evaluation of its characteristics in new operating conditions.

The only antenna parameter that comprehensively shows the antenna's possible behavior under changed operating conditions is its Q factor. Since its value is a result of all electromagnetic processes in the antenna, it represents a unique tool for controlling and evaluating the changes that occurred when the operating conditions of the antenna change. Its great sensitivity to relatively small differences in the change of those processes makes it a excellent sensor, just what we need to be able to know if the antenna is still the same as it was on the computer. Its sensitivity, which greatly exceeds the sensitivity og other indicators, such as the change in input impedance and gain, gives us a sensitive and precise tool with which we can obtain information about the behavior of the antenna and also ensures that the antenna will be resilient to altered conditions in future operation. To achieve this goal, a low antenna Q factor should be an important goal in the antenna design process.

Targeted design of low values of the Q factor of the antenna ensures that the antenna will be less sensitive to changed operating conditions in future operation.

Therefore, the Q factor is **the only** tool we can use to accurately compare changes in operation, and a low Q factor is the **only guarantee** that the antenna will be less sensitive to the environment and poor operating conditions, and that it will preserve its original characteristics to a greater extent. In this way, established misconceptions that antennas work the same in idealized environments of computer simulations and in practice will be at least partially reduced.

There remains the problem of measuring and calculating the Q factor of antennas. This program was written precisely to overcome that problem by accurately calculating the Q factor of the antenna at the new location based on the input impedance measurement or adjustment and compare it to the one in the computer or at the previous location.

The program will also help the designers of new antennas to precisely check their antennas in operation on a computer according to the obtained input impedance parameters at certain frequencies of interest. On the other hand, the users and builders of those antennas will be able, by measuring the new parameters of the input impedance at a real location and comparing them with what was published by the author for a given antenna, and obtained by computer simulation, to assess how much things have changed and whether the antenna has remained , as much as possible, within the limits of the expected performance.

A legitimate question arises, how precise and justified is this method of calculation from the point of view of electromagnetism and other natural laws? Elaboration of this would require much more space and a much more serious knowledge of electromagnetics than the average majority of those interested have. Therefore, I will refer all those who are interested in the theoretical approach and the applied mathematical formalism as well as the complete verification by laboratory measurements to the article listed in **[Ref. 1]** from 2005, as well as another article **[Ref. 2]** related to this topic, given below in the list of References. Also on the Internet you can find many articles and works on this topic so that those who are interested can get complete information.

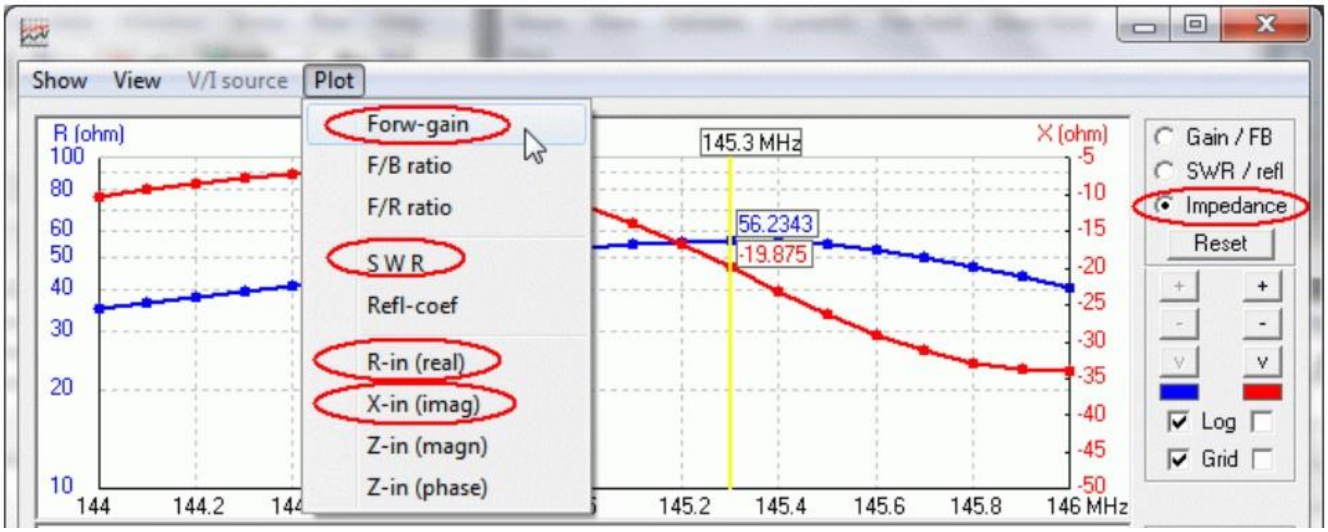
Finally, in order to ensure the best and correct use of this program and achieve the most accurate result values, some basic instructions and important notes will be given.

<u>QAntFileCalc User Guide</u>

The program calculates the Q factor and draws a plot of the dependence of the Q factor on the frequency. The data files are **.txt** files in which there are two data in each line: frequency and resistance

R, that is, frequency and reactance **X**. The first two lines are not read because they contain data about the antenna and the names of the quantities that are in the table.

The files can be generated by antenna analysis and optimization programs such as 4nec2, Eznec and similar. In that case, it is only necessary that the file format meets the given conditions.



Example of making R and X files in the 4nec2 program

```
#12elDL6WU 144: R-in (real)
#Freq [MHz] R-in (real) [ohm]
140   64.503
140.1 64.6519
140.2 64.7333
140.3 64.7452
140.4 64.6859
140.5 64.5547
140.6 64.3515
140.7 64.0775
140.8 63.7342
```

```
#12elDL6WU 144: X-in (imag)
#Freq [MHz] X-in (imag) [ohm]
140   -5.29459
140.1 -5.99824
140.2 -6.71617
140.3 -7.44163
140.4 -8.1688
140.5 -8.88999
140.6 -9.59854
140.7 -10.2877
```

Correct R and X file format

It is possible to generate data from the VNA used to measure the antenna. In that case, the calibration of the VNA should be performed on the plane of the antenna connection to prevent the influence of the cable on the result.

The correct selection of the frequency range in which the Q factor is calculated is very important for the correct use of the calculated Q factor and the valorization of the antenna.

Too narrow a frequency range can give a false picture of the overall Q factor of the antenna. The Q factor of an antenna changes with frequency and can have quite large variations. For an objective evaluation, it is necessary to calculate the Q factors of the antenna on a significantly wider frequency range than the intended operating range of the antenna. This gives a complete picture of the possible behavior of the antenna in real environmental conditions and influences. Various influences on the antenna act so that it changes its performance: resonant frequency, radiation pattern, gain, input impedance, efficiency, noise temperature and Q factor. This means that, due to unfavorable influences and changes in the resonant frequency, it will change the resonant frequency, usually to a lower one, causes increase of the Q-factor and its curve to shift down in frequency, so it is very important what the Q-factor curve looks like at frequencies above the operating range. The behavior of the Q factor below the operating range is also important when evaluating the overall stability of the antenna to possible external influences. Antennas that in one part of their operating range have a low Q factor, but in other parts of the operating range or immediately above and below the operating range have a high Q factor are unstable antennas that react in different environmental conditions by changing their characteristics. For the overall assessment of the quality of an antenna, it is of great importance to consider the complete behavior of the Q factor in a wider frequency range than the intended operating range of the antenna. This is precisely why the presentation of a wider frequency range is important, as it avoids making a wrong assessment based on a small part of the frequency range without insight into the overall behavior of the antenna and its Q factor over a wider range.

Results

The calculated Q factor of the antenna for the selected frequency range is given as a diagram of the change of the Q factor per frequency. The acceptability of the magnitude of the Q factor may vary to some extent depending on the antenna type, frequency, purpose, geometry, application conditions, etc. but indicative, empirically chosen, values for common antennas are:

If the Q factor is below 15 over a wide range of frequencies above and below the operating band, these are very good stable antennas.

Q factors between 15 and 30 over a wide range of frequencies above and below the operating range represent acceptable values for slightly less stable antennas.

Q factors between 30 and 50 indicate that they are relatively unstable antennas, although often in some narrow part of the range they can have a lower Q factor.

Q factors over 50, regardless of the possible narrow parts of the lower Q band, represent extremely unstable antennas.

The program is written in Python and complex formulas are used that are accurate enough when calculating the Q factor at anti-resonant frequencies, which can sometimes be useful when calculating a multiplexer for working with multiple antennas on multiple frequency bands in a harmonic relationship. A comparison of the results of various calculation methods is given in the diagram in the Appendix.

Due to limitations of the Python compiler, the program unfortunately only works on Win 10+ and 64 bit computers.

Also, when drawing a plot with a large frequency range or Q factor in a small window, overlapping grid lines and an illegible plot can occur. In that case, the part of the diagram of interest should be cut using the tool marked with the image of a magnifying glass in the lower left part of the window.

The program can be downloaded for free from my website at the link: http://www.qsl.net/yu1aw/Misc/QAntSpotCalc.zip in the 'Software' section and can be freely shared without restrictions in its integral form and without modifications.

Note

An Excel program I wrote earlier to calculate the Q factor via the X and R input impedance of the antenna, which is published on my website, (http://www.qsl.net/yu1aw/Misc/YagiQ.zip) uses the same formula where use the complete impedance Z for the calculation. Realizing the Q factor calculation in Excel was more convenient and easier. The Excel program gives the same results as this program in cases where the Q factor of the antenna at anti-resonant frequencies is calculated. At resonant frequencies, at which antennas, except in very rare cases, always work, the accuracy is identical, because both programs use the same formulas and calculation procedures.

References

1. **Impedance, Bandwidth, and Q of Antennas**; Arthur D. Yaghjian, Fellow, IEEE, and Steven R. Best, Senior Member, IEEE; IEEE Transactions on Antennas and Propagation, Vol. 53, No. 4, April 2005, pp. 1298-1324.

2. Jacques Audet, VE2AZX, **Q Calculations of L-C Circuits and Transmission Lines: A Unified Approach**, QEX magazine Sep/Oct 2006.

3. **Effect of coaxial cable on Yagi Antenna - Part 2**, Dragoslav Dobričić, YU1AW, https://www.qsl.net/yu1aw/Misc/Coax_Infl_yagi_2.pdf

4. **The influence of coaxial cable on a system of four Yagi antennas**, Dragoslav Dobričić, YU1AW, https://www.qsl.net/yu1aw/Misc/Cable_inf_on_ant_array.pdf

5. **The influence of coaxial cable on the noise temperature of Yagi antenna systems**, Dragoslav Dobričić, YU1AW, https://www.qsl.net/yu1aw/Misc/coax_influ_noise_temp.pdf

Appendix

Qb and Qz factors in the program were calculated according to the following formulas **[Ref.1.]:**

$$Q_B(\omega_0) \equiv \frac{2\sqrt{\beta}}{\mathrm{FBW}_V(\omega_0)}, \quad \sqrt{\beta} = \frac{s-1}{2\sqrt{s}}.$$

$$\begin{aligned} Q_Z(\omega_0) &= \frac{\omega_0}{2R_0(\omega_0)}\left|Z_0'(\omega_0)\right| \\ &= \frac{\omega_0}{2R(\omega_0)}\sqrt{[R'(\omega_0)]^2 + [X'(\omega_0) + |X(\omega_0)|/\omega_0]^2} \end{aligned}$$

The exact value of the Q factor for comparison and validation was calculated according to **[Ref.1.]:**

$$Q(\omega_0) = \left| \frac{\omega_0}{2R_0(\omega_0)} X_0'(\omega_0) - \frac{2\omega_0}{|I_0|^2 R_0(\omega_0)} [W_{\mathcal{L}}(\omega_0) + W_{\mathcal{R}}(\omega_0)] \right|.$$

Accuracy check and comparison of the results of calculated Q factors using different methods for a three-element Yagi antenna designed for the 140-150 MHz band **[Ref.1.]:**

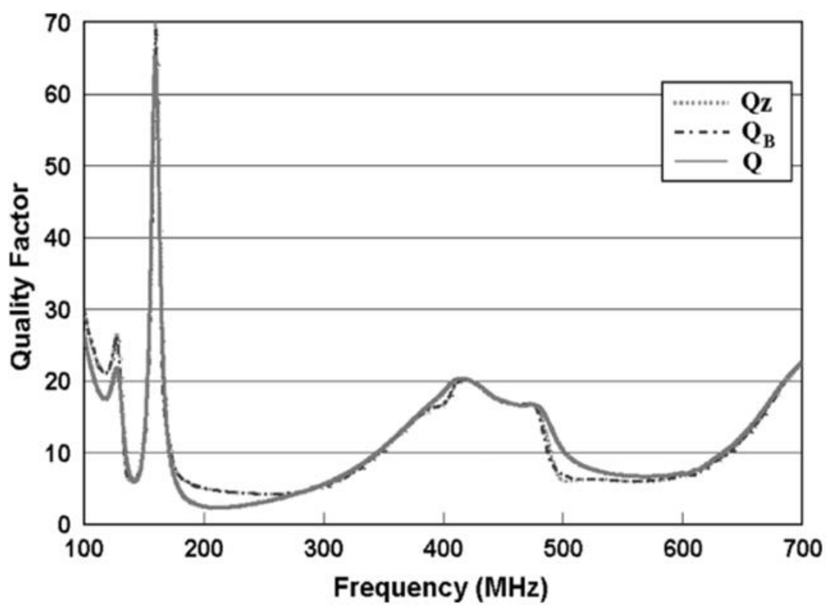


Fig. 17. Comparison of the Q, Q_Z, and Q_B (1.5:1 matched VSWR bandwidth) for the tuned, lossless, 3-element Yagi antenna with the coordinate origin placed at the center of the driven element, but with the exact Q at each frequency determined by interpolating between its values at the natural resonant and antiresonant frequencies.