QAntSpotCalc

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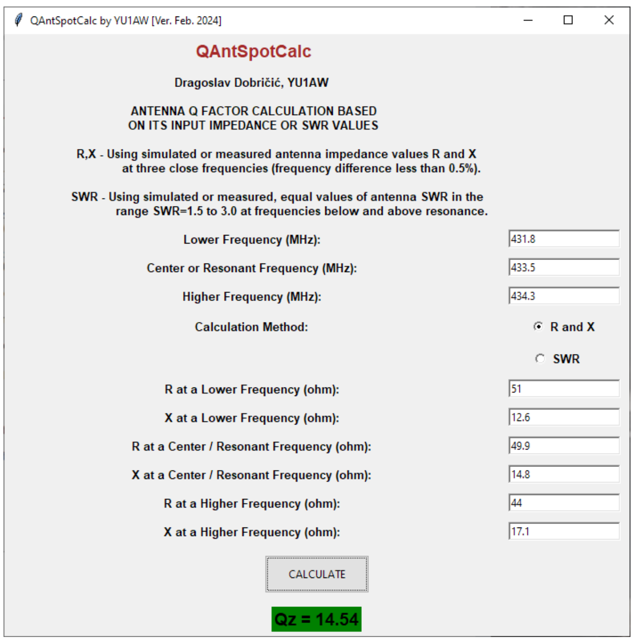
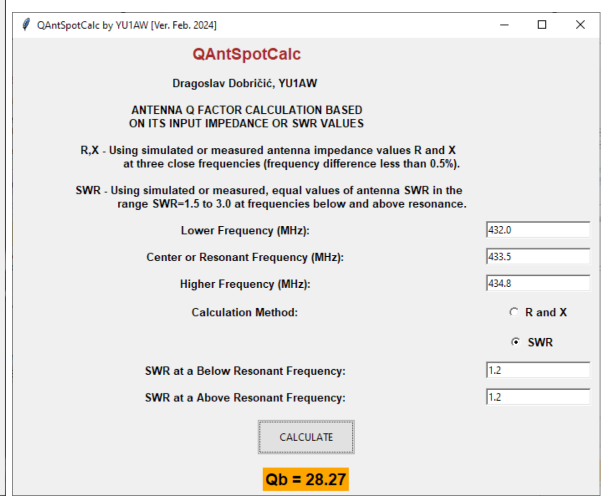
A program to calculate the Q factor of an antenna based on the value of its input impedance or SWR





R and X Method

SWR Method

Importance of antenna Q factor

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 caltered,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 in indicating 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. performance. 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 authors 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.

QAntSpotCalc User Guide

The program calculates the Q factor for one (center or resonant) frequency, but asks to input two other close frequencies at which the input impedance or SWR values will be read, depending on which calculation methodology is chosen.

The correct choice of frequency is very important for the correct use and accuracy of the calculation of the Q factor of the antenna

R and X Method

To calculate the Q factor of the antenna using this method, it is necessary to determine three frequencies. The middle or central frequency is the one at which the Q factor of the antenna is calculated and the adjacent two, one slightly lower and one slightly higher, are needed to calculate the differentials of the change of the real and imaginary part of the input impedance around the central frequency. The frequencies must be relatively close to each other in order to achieve high calculation accuracy. It would be best if the frequencies were just as far apart as necessary in order to read the change of parameters, i.e. a new, different value of the parameters in relation to the central frequency. It would be good if these two frequencies around the central one, if possible, were not more than 1-5 per thousand (0.1-0.5%) away from the central one. If this is not possible, a larger distance can be used with slightly reduced precision.

In fact, the precision of the Q factor calculation at a larger frequency range depends on the behavior of the real and imaginary parts of the impedance in the selected frequency range. If that behavior is such that the value functions are monotonic, i.e. without large and sudden jumps and changes, the accuracy of the calculation will remain high. **The obtained result represents the averaged, average value of the Q factor of the antenna in the selected frequency range. So actually the result always represents the average value of the Q factor of the antenna in the close vicinity around the central frequency.**

The accuracy of the calculation is at best only as good as the accuracy of the device and measurement method that provides the impedance data. In order to improve this as much as possible it is necessary to measure with an accurate and reliable impedance measuring bridge, network analyzer (VNA) or other reliable RF impedance meter.

When measuring, you should use the shortest and highest quality cable because long and bad cables will show better values than the real ones due to their own losses. Therefore, place the meter as close as possible to the antenna and connect it via a quality cable, as short as possible, with as few losses as possible. When using the VNA, calibration should be performed on the plane of the antenna connection. When measuring with an RF bridge, if it is not possible to connect the bridge directly to the antenna, it is necessary to use a high-quality cable that is an integer multiple of half the wave with an included shortening factor in order for the measurement to be accurate, because the transformation of the impedance through the cable changes the result of the calculated Q factor. If the losses in the cable are not negligible, they should be included in the obtained antenna impedance value.

When using the simulation results or when measuring when the impedance meter is connected directly to the antenna connection, or the electrical length of the cable is an integer multiple of a half wave, there is no impedance transformation over the cable and the results of the Q factor calculation are accurate within the accuracy limits of the method.

Read the values for X and R as precisely as possible and enter them in the corresponding field in the program for each of the selected frequencies.

SWR Method

For the SWR method, it is also necessary to use a high-quality and reliable SWR meter. SWR meters are known as one of the least reliable devices because of the way they work. Namely, directional couplers used to measure standing waves on a cable have very limited directivity in a wider frequency range. Unfortunately, wideband versions of SWR meters are often very inaccurate at the edge bands. In addition, SWR meters can be very sensitive to currents flowing on the outside of the cable due to asymmetry in the antenna power supply, the so-called Common Mode Currents (CMC).

A quick, partial reliability check can be done by measuring the SWR of the antenna with two slightly different lengths of cable and if the results differ then the SWR has a problem with CMC currents or is unreliable on that frequency range. It is best to measure the SWR with a short length of low loss cable and then add a piece of cable between a quarter and half wave length multiplied by the cable shortening factor**. A good and reliable SWR meter should not show different readings for both cases, because the SWR of the antenna is constant over the entire length of the cable.**

The coaxial cable in the SWR method only introduces additional attenuation and it would be good to take it into account if it is not negligible. Since the SWR is on an ideal cable, or a cable with low total loss, at every point on the cable the same measured SWR must be the same with any length of cable.

The choice of frequencies for this method is also essential for the accurate calculation of the Q factor.

First, it is necessary to choose a resonant frequency or one close to it where R and X are the same or very close values as in resonance. Resonance is the frequency at which **the reactance value is X=0**. The SWR meter will not tell us that frequency, but the assumption is that the antenna is well constructed and has a resonant frequency in the middle of the frequency range for which it was designed to operate. Usually, the authors try to ensure that the resonance of the antenna has a good SWR, often the best, so it is a logical choice, although it must be noted that **the resonant frequency and the frequency of the minimum SWR are not the same thing!** However, the error due to this will be relatively small, so choosing the minimum SWR frequency will usually not greatly affect the accuracy of the Q factor calculation. From the resonant frequency to the lower and higher one should choose one frequency at which the SWR is identical. The magnitude of the SWR at those frequencies can range between 1.5 and 3. Lower values can also be used but are usually less accurate due to the influence of various factors, primarily cable losses, diode nonlinearities, etc. which introduce error into the measurement. Too large values, on the other hand, are also usable, but in some meters, they can lead the RF signal detection diodes to saturation or to the non-linear part of the characteristic and thus introduce an additional error into the measurement.

Antennas with multiple resonant frequencies

Many antennas with a larger number of elements were designed by the authors to cover a larger frequency range with a special way of distributing currents in the antenna elements. This can be seen by the SWR curve, which in a given frequency range has two or more SWR minima at different parts of the frequency range. Practically, for a precise calculation, the SWR curve depending on the frequency should look like the letter U, and not like the letter W. Mainly for antennas with more resonant frequencies, ie. with a W-shaped SWR curve, when determining frequencies with the same SWR, it is possible to find three or more, so the advice is to choose pairs of frequencies between which there is only one minimum SWR, i.e. part of the U-shaped SWR curve and calculate the Q factor for each of the pairs, choosing the central one, ie. resonant frequency in the local minimum between selected pairs of frequencies. This usually gives a better picture of the behavior of the Q factor over a wider range of frequencies for antennas made wideband in this way. The reason for this is that antennas designed in this way have a wider bandwidth than that determined by the actual Q factor of the antenna and **thus give an inaccurate Q factor calculation**. Since the program is based on calculating the Q factor from the bandwidth for an equivalent RLC antenna circuit at a single resonant frequency, which basically has a U-shaped SWR curve, then this needs to be taken into account, as stated, and used properly. if false results are not desired.

Results

The calculated Q factor of the antenna for the selected center or resonant frequency is given as a result printed on a colored background. The background color for each printout of the Q factor is arbitrarily chosen depending on the size, that is, the acceptability of the given value. Acceptability may vary to some extent depending on antenna type, frequency, purpose, geometry, application conditions, etc. Therefore, these are indicative values for common antennas.

If the Q factor is below 15, the background is green and these are very good stable antennas.

For Q factors between 15 and 30, the background is yellow and these are acceptable values for slightly less stable antennas.

If the Q factor is between 30 and 50, the background is red and these are relatively unstable antennas.

For Q factors above 50, the background is purple and these are 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**.

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.]:**

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

$$Q_Z(\omega_0) = \frac{\omega_0}{2R_0(\omega_0)} |Z_0'(\omega_0)|$$
$$= \frac{\omega_0}{2R(\omega_0)} \sqrt{[R'(\omega_0)]^2 + [X'(\omega_0) + |X(\omega_0)|/\omega_0]^2}$$

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.]:**

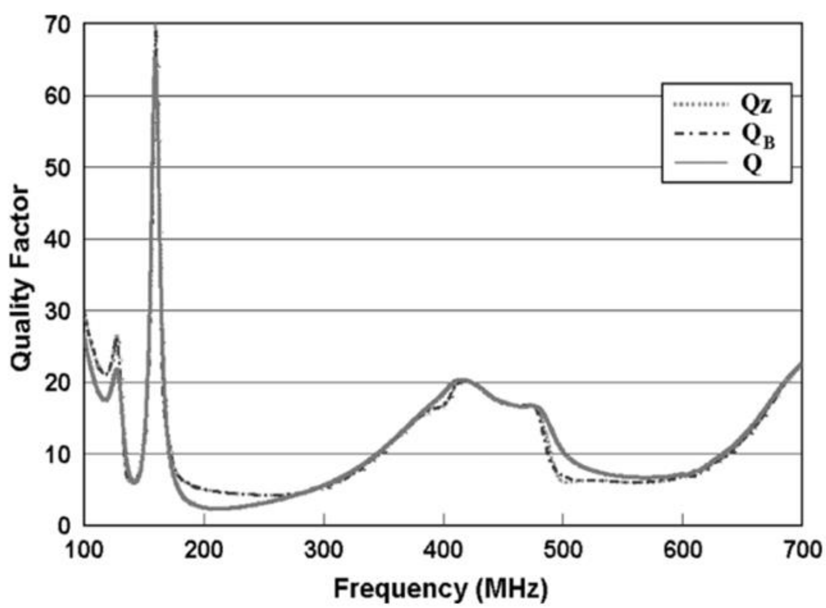


Fig. 17. Comparison of the Q, Q_Z, and Q_B (1.5:1 matched VSWR bandwidth) for the tuned, lossless, 3-element Yagi antenna with the coordinate origin placed at the center of the driven element, but with the exact Q at each frequency determined by interpolating between its values at the natural resonant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