Brass Tacks

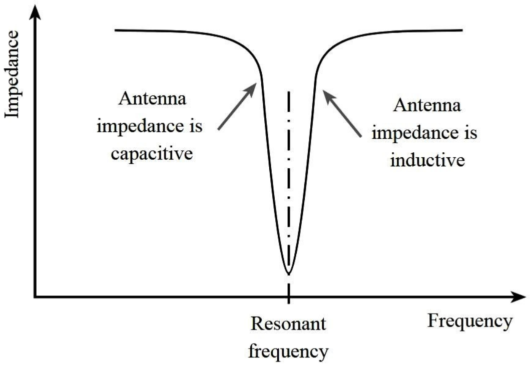
An in-depth look at a radio-related topic

Antenna resonance

By now you know, that to transmit your signal effectively, you need a *resonant antenna*. But what exactly does that mean? To confuse the issue, you also know of people whose antenna is not resonant, and so they rely on a tuner (ATU, or *antenna tuning unit*) to transmit effectively. So, what is antenna resonance, and why should you care? Even so, how do you measure it?

For an antenna to be ***effective*** (perform well according to some set of expectations), it should satisfy (at least these) four criteria: **a)** it should be ***efficient*** (transfer as much power into space as possible), **b)** it should cover an acceptable ***bandwidth*** (work well across the entire spectrum of frequencies you expect it to), **c)** it should be ***resonant*** (appear to be a resistive, rather than reactive, circuit), and **d)** it should have positive ***gain*** (concentrates the signal in a direction.)

a) The complete measure of antenna efficiency includes a discussion about radiation resistance, which I will not cover here. But for the purpose of this article, I'm going to define efficiency as the amount of power the antenna is sending into space, compared with the amount of power that I'm attempting to put into the antenna. According to the *Maximum Power Transfer Theorem*, the most amount of power I can get out of my antenna is that which can only occur if my antenna *impedance* exactly matches that of my transmitter (actually, the complex conjugate, and of the entire system before the antenna.)



Because my system ideally presents an impedance of 50 + j0 ohms, my antenna must therefore ideally also have an impedance of 50 + j0 ohms at the frequency of interest, to transfer the maximum amount of power to my antenna. By the same theorem, however, if my antenna is a little off capacitively, its impedance might be, say, 59 — j14 ohms. In that case, to get the most power out of my antenna, my system before the antenna must present 59 + j14 ohms (the complex conjugate.) But how the heck do I do that? With a tuner or equivalent matching circuit, such as a pi-L match or T match.

b) The bandwidth of an (amateur) antenna is measured by the entire spectrum of frequencies at which its SWR is 2.0:1 or less, known as the *SWR bandwidth*. There are a number of things you can do to improve your bandwidth if, say, your antenna does not span the entire amateur breadth of frequencies in a particular band. One common solution is to increase the diameters of the antenna elements. If you're using a loading coil to shorten your antenna, another is to move the coil to a different location along the radiating element, then re-adjust the lengths of the radiating elements.

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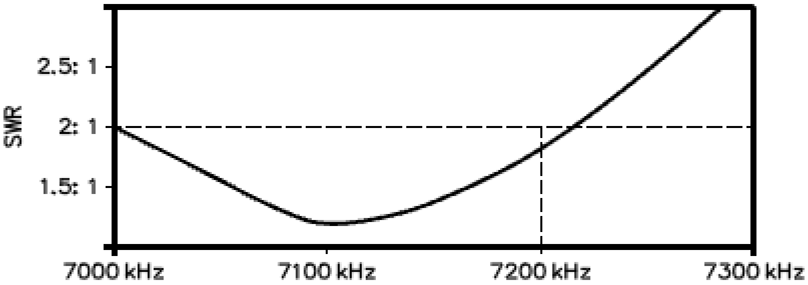

In the antenna analyzer graph to the left, can you tell what the SWR bandwidth is, of this antenna? The dotted horizontal line marks the 2.0:1 SWR boundary, and the solid curve is the actual SWR measured by the analyzer for all the points along the 40-meter band. The graph shows that the solid curve is at 2.0 and below from 7.000 to about 7.215 MHz, so the antenna's SWR bandwidth is about 215 kHz, from 7.000 to 7.215 MHz.

Resonance, the point of this discussion

c) Resonance is defined as the state or condition at which a circuit appears to be purely resistive. That circuit could be an antenna, which indeed presents a capacitance, an inductance, and a resistance, and at one particular frequency, its capacitive reactance and inductive reactance will cancel each other, leaving only the resistance. This answers which frequency:

$Z = R + jX$ (impedance)

$X = X_L - X_C$ (reactance, the "X" part of the impedance)

$X_L = 2\pi fL$ and $X_C = 1/2\pi fC$ (inductive reactance and capacitive reactance, respectively)

$Z = R + j0$ (resonance)

therefore, $X = 0 = X_L - X_C$

therefore, $X_L = X_C$, or $2\pi fL = 1/2\pi fC$

and solving for the frequency, $f = 1/[2\pi\sqrt{(LC)}]$

But don't let the math scare you. What this means to us lay folk is that there must be a balance between the capacitance inherent in an antenna and its inductance, for a given frequency. So, whether a particular antenna is resonant is dependent on frequency. But that leaves us with two problems to solve: changing the reactance and changing the resistance, to fit our needs.

Tuning your antenna

Changing the reactance of an antenna might sound difficult, but is actually pretty easy, and I'll show you how, with a halfwave dipole. And because I'm explaining with a dipole, it's fairly straightforward to transfer that same adjustment to many other antenna types, like a folded or fan or end-fed or OCF or Yagi or other beam, because they have dipoles at their centers. So, let's start with a plain wire 40-meter dipole.

First, let's start with the standard calculation, using the quarter-wave "234" method, which is nothing more than the MHz-to-feet conversion. That means, to calculate each quarter-wavelength-long leg (side) for 7.200 MHz, use

234 / 7.200 = 32.5 feet

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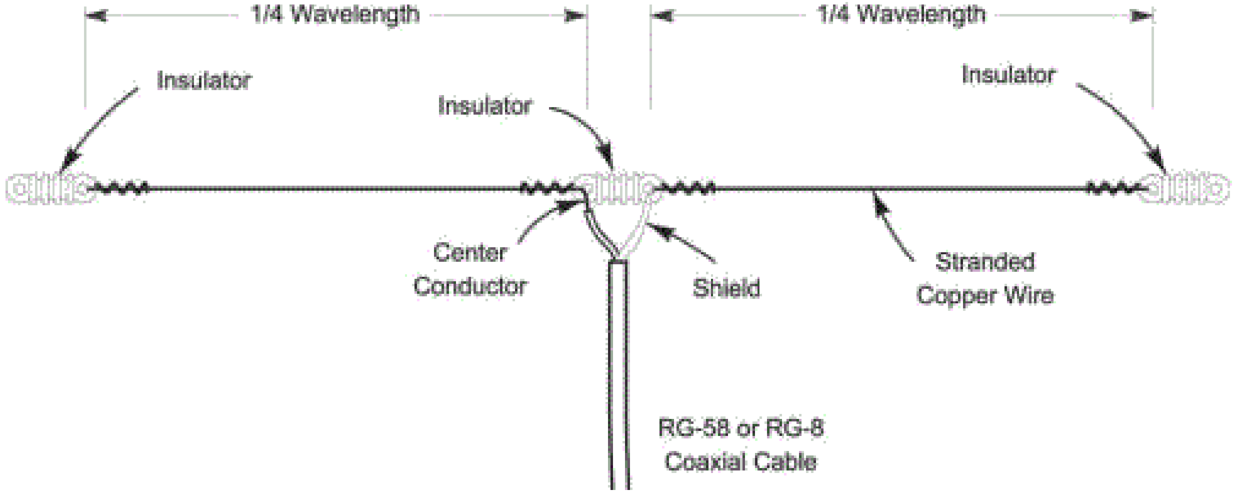
With that calculation, let's cut two 33 ½-foot wires, then tie six inches of each end around a center insulator connected to your coax, and six inches of the other end around a dogbone insulator. For a flat-top configuration, let's hoist the dipole a few feet.



Measuring it with an analyzer, you might find that the resonant frequency is probably close to 6.90 MHz, meaning our elements are too long. What it means is that the actual antenna impedance might be something close to 21 –j13 ohms, according to the analyzer. Assuming your transmitting system (radio, coax, etc.) presents an impedance of exactly 50 + j0 ohms, you now know why it's off-frequency.

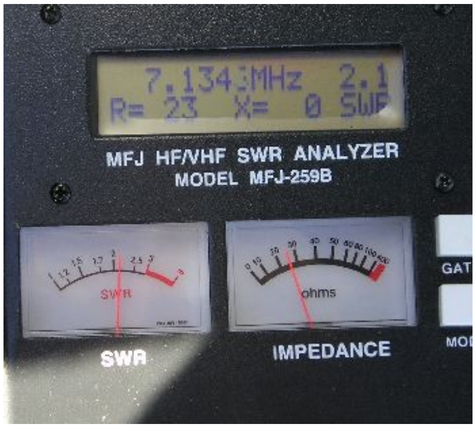
You reason that, because 21 — j13 ohms is capacitive (due to the negative sign), all you need to do is add an inductor across the center insulator to counteract its capacitance. In fact, you calculate that the inductor must present a reactance of +13 ohms by

$$X_L = 2\pi f L$$

therefore, $L = X_L/2\pi f = 13 \text{ ohms}/2\pi(7.20 \text{ MHz}) = 0.287\ \mu\text{H}$

So, you create an air coil of about 0.3 μH, connect it across the center insulator, then re-measure. You've now reached your goal of 7.20 MHz for a resonant frequency, meaning that you've removed or canceled the capacitive reactance of -13 ohms from the picture. But wait, there's more.

Yes, even though the antenna is now resonant at 7.20 MHz, there is one remaining problem: its impedance is 21 ohms, which is a clear mismatch for your 50-ohm system. Your resonant antenna will have an SWR of 50 / 21 = 2.38:1, not good. Now what, after all that work?



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A halfwave dipole antenna is capacitive by nature, because it has very little inductive coupling between the two widely separated elements, but both sides have to transfer energy to each other, so the elements are connected through capacitive coupling. That means that you should have noticed a drop in capacitive reactance, had you simply cut some lengths off each dipole leg.

But by so doing, you'll also notice an increase in pure resistance, and that's the effect you want. In the end, you might well see the analyzer display an impedance of 35 + j0 ohms for your halfwave dipole antenna, whose resulting SWR will be 50 / 35 = 1.43:1, which is much more acceptable.

So, you can have a resonant antenna that has an unacceptably high SWR. But what's so bad about high SWR? Well, besides prospective harm to your transmitter, that's where efficiency comes in, and in order to maximize the amount of power you're sending out of your antenna, its impedance needs to match that of the rest of your system, which in the amateur world is 50 + j0 ohms. And if your antenna presents a 50-ohm impedance, its SWR will be 50 / 50 = 1.0:1, a perfect match, allowing all of the power from your transmitter system to get sent out through your antenna.

d) Finally, gain is a widely misunderstood topic I'm going to save for another article in another issue.

e) By the way, people also cite other parameters, such as cost, quality (durability and reliability), ease of installation, and wind load, as being worthwhile, valid, and relevant considerations for an effective antenna. What do *you* think?

Conclusion

An effective antenna requires efficiency, sufficient bandwidth, resonance, and gain at the very least. Resonance is the presentation of the antenna impedance as a purely resistive load at a particular frequency. A resonant antenna is therefore one whose reactance components have been canceled, a process we commonly refer to as *tuning*, but it's still possible to have a resonant antenna that has high SWR. In the end, to satisfy both the resonant requirement and the SWR requirement might take a small juggling act, but it IS possible, and you can do it.

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