Brass Tacks

An in-depth look at a radio-related topic

Tuners

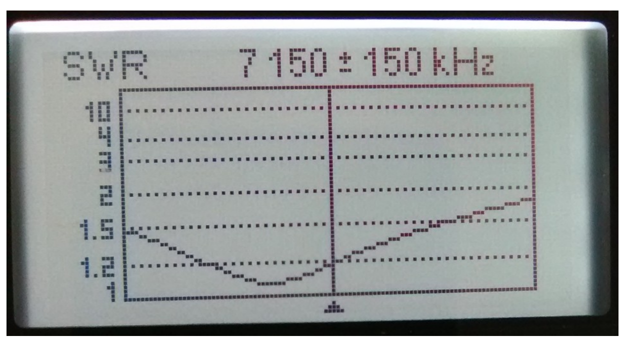
Many who get into amateur radio will never get involved with HF (high frequency, or about 1.8 to 30 MHz), and that's simply a matter of personal preference. Those who do, however, find a whole new world of challenges awaiting them, mostly technical. One of these challenges is getting their HF radios to work favorably with their antennas, whether they purchase the antennas from stores or they build them at home.

Whether you're working with HF, VHF (very high frequency, or about 30 to 300 MHz), or UHF (ultra high frequency, or about 300 to 3000 MHz), antenna construction allows for quite a lot of assembly-time tolerances. In other words, they don't all arrive at your doorstep set with the exact right dimensions or adjustments required for proper operation on your desired frequencies. Because of that, you're often required to *tune* your antenna for the best possible performance on the band(s) of interest.

Still, even after all the cutting, bolting, and modifying you make on an antenna, its best-performing frequency range might not be close enough to your target for satisfactory operation, as determined by your *analyzer*. For this situation, you can purchase a *tuner*, if one isn't already built into your transceiver. So, just what does a tuner tune, and how does it work? Rather than quote a bunch of theory, I thought this is better explained by a few examples.

The matched case

Your transceiver is connected by 100 feet of 50-ohm RG-8X coax to a *near-perfectly tuned* 40-meter antenna, meaning its SWR is very close to 1.0:1 within that band. You set your transceiver to transmit at 100 watts, and key up, screaming into your mic (no audio means no power out, and loudest audio means full power out.) The 100 feet of RG-8X will attenuate (reduce) your 40-meter signal by 1.0 dB, or about 20 %, meaning about 80 watts will reach the antenna. And because the antenna impedance (50 ohms) matches that of the coax (transmission line), all 80 watts of the remaining signal will be sent into the air, the best possible outcome.



Not quite a perfect match, but pretty good

The mismatched case

Your transceiver is connected by 100 feet of 50-ohm RG-8X coax to a *poorly tuned* 40-meter antenna, such that its SWR is about 5.4:1 within that band. You set your transceiver to transmit at 100 watts, and key up, again screaming into your mic. The 100 feet of RG-8X will attenuate your 40-meter signal by 1.0 dB, so about 80 watts will reach the antenna. However, because your antenna is not perfectly matched to the transmission line, part of the power (energy per unit time) is *reflected* back from the antenna, and part of it is sent into the air. So, just how much of that power is reflected, and how much is sent into the air? The equation that

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relates the reflected power to the forward power, due to SWR, is as follows:

$$\frac{P_r}{P_f} = \left(\frac{SWR-1}{SWR+1}\right)^2$$

$$P_r = (80 \text{ watts})[(5.4 - 1)/(5.4 + 1)]^2 = 38 \text{ watts}$$

That 38 watts will be sent back in the coax to your transceiver, meaning 80 watts — 38 watts = 42 watts will be radiated into space. The coax will again attenuate the 38-watt signal by 1.0 dB, making about 30 watts that will return to your transceiver. Your transceiver will therefore momentarily experience 100 watts + 30 watts = 130 watts in signal strength, and if your transceiver was manufactured with a final (final output transistor or circuitry) that was designed to handle up to 120 watts, that will likely spell the end of its life.

Then again, most modern transceivers are designed with what's known as a *fold-back* circuit, which causes the transmitter to reduce its output signal strength to something around 5 watts, if it detects a return wattage that exceeds a predefined threshold. If the fold-back circuitry responds fast enough, it'll reduce the transmitter power before any serious damage is done to your finals. But relying on the speed of the circuit can be an expensive chance to take, so it's probably better to reduce the reflected power to your transceiver instead.

The mismatched case, but with a tuner

Your transceiver is connected by two feet of 50-ohm RG-8X coax to a tuner. The other end of the tuner is connected by 100 feet of the same model coax to a *poorly tuned* 40-meter antenna, such that its SWR is about 5.4:1 within that band. You activate your tuner, and match your antenna to your feed line, so that the tuner presents the transceiver with an impedance of 50 ohms, resulting in an SWR of close to 1.0:1, and presents your antenna with an impedance that's a *complex conjugate* of that presented by your antenna.

Manual tuner

You set your transceiver to transmit at 100 watts, and key up, again screaming into your mic. The two feet of RG-8X will not attenuate your 40-meter signal much, so nearly all 100 watts will reach the tuner. And because the tuner presents the transceiver with a 50-ohm impedance, there will be *no signal reflected by the tuner back to the transceiver*, but will be completely passed to the antenna side of the tuner. The 100 feet of RG-8X will attenuate your 40-meter signal by 1.0 dB, so about 80 watts will reach the antenna. However, because your antenna is not perfectly matched to the transmission line, part of the power is reflected back from the antenna, and part of it is sent into the air. Once again, 38 watts will be reflected by the antenna, of which 30 watts will return to your tuner and 42 watts will be radiated.

Now for the interesting part. When the 30 watts reaches the tuner, the 5.4:1 SWR still exists between the transmission line and the tuner, the tuner will normally reflect 14 watts back to the antenna, and absorb the 30 watts — 14 watts = 16 watts not reflected. However, the alternating frequency of the reflecting signal between the tuner and the antenna will actually cause

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the transmission line (coax) to transform its own impedance to that of the two end points; that is, the antenna and the tuner! The result is that, instead of the signal reflecting off the antenna, because the transmission line now matches the antenna, the remaining 80 watts will now be radiated from the antenna. This means that if the transmission line had no loss, all 100 watts would be transmitted out of the antenna. This is why many have used *ladder-line* for a feedline in the past: it has probably the lowest loss of all feedline types, close to 0 dB.

If the tuner had absorbed any of the power (indeed, it cannot, because it has no resistive components, except its wires), it would become warm, but tuners remain fairly cool, even during long contests on mismatched bands. And because all of the transmitter power (of a continuous signal, not just a pulse) is eventually emitted from the antenna, the tuner won't receive any net reflected power from the antenna in the first place.

Due to the signal interaction between the tuner and the antenna, however, the signal will suffer excessive loss if the tuner is located a significant distance from the antenna by coaxial cable. This is why you should *install your tuner as close to your antenna as possible*.

What a tuner tunes

So, why do we call a tuner a *tuner*? What exactly does it *tune*? Imagine an antenna that you've purchased or built. Also imagine that your antenna requires some sort of matching section, such as a gamma match or a hairpin match or toroidal 4:1 balun, or window line in the case of a G5RV antenna. The purpose of that matching section is to make your 200-ohm or 450-ohm antenna appear to the transceiver like it's a 50-ohm antenna.

Automatic ("auto") tuner

What's the difference between that matching section and a tuner? Nothing, except that most tuners are adjustable, and even some matching sections are too. The purpose is the same: they *tune your antenna*, or in other words, they make your antenna impedance appear close to the feedline (coax) characteristic impedance, allowing for *maximum power transfer* from your rig to the antenna.

Some are concerned about a tuner's insertion loss, or the power lost as a result of the device being inserted into your antenna system. For many tuners, the insertion loss is fairly small, around 0.5 dB or less, which amounts to less than 11 %. And if you're using coaxial cable for your feedline, you're typically going to experience a lot more loss by your cable than by your tuner.

References

For further study and much greater technical depth on the role of tuners, I refer you to the website *The Myth of Reflected Power* by Davide Achilli IZ2UUF and to the website *How Does a Tuner…Tune?* by Davide Achilli IZ2UUF and to the book *Another Look at Reflections* by M. Walter Maxwell W2DU. Davide's material used with permission. I also recommend the Wikipedia reference on tuners.

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