Antenna Tuner

(Gary Wescom – N0GW – 10/23/16)

Antenna tuners are common items in modern ham stations. How and why they are used is confusing for beginners. This article will attempt to reduce that confusion. First we should talk about why they are often necessary in a ham's station. Then we can get into how they work.

Also, this discussion is about manually adjusted antenna tuners, not automatic antenna tuners. Knowing the internals of an automatic antenna tuner can be interesting. Operation, though, is normally a matter of pushing a button and letting its microprocessor do the hard work.

Using a manual antenna tuner can be made easier if you have some knowledge of what is going on inside the box. This article should help with that.

Why?

Before getting into what an antenna tuner is and how to use it, let's first look at the problem they are intended to solve. Essentially all modern ham transceivers (and transmitters) are designed to be used with a 50 Ohm resistive load. That is to say they work best when hooked to a 50 Ohm resistor. Of course that resistor must have sufficient power rating to handle all the RF produced by the transceiver. In fact many hams do have appropriate 50 Ohm resistors for testing their transceivers and amplifiers. They are called Dummy Loads. As you might imagine, though your transceiver is happy transmitting into a Dummy Load, being heard by other hams is not likely since all your RF power is being used to heat a resistor. Connecting your transceiver to an antenna is much more conducive to effective radio communications.

Obviously your goal should be to have your transceiver's or amplifier's RF power output efficiently transferred to your station antennas. We do that by using a special cable type, called a Transmission Line. These cables are specifically designed for RF use. There are many types of these cables but for this discussion we will stick with the kinds most commonly used by hams. One is the coaxial cable which is round with an insulated center wire conductor and an outer braided wire shield. Coaxial cable is the most common RF cable used by hams. The second kind is called Open Wire or TwinLead which is like a bigger version of the 300 Ohm twinlead that used to be run from TV antennas to TV sets.

Real world ham antenna systems seldom act like a perfect 50 Ohm resistor. That is just the nature of antenna physics. Obviously transceiver designers know this so allow for some degree of variation from a pure 50 Ohm resistive load. That variation is typically listed as a Standing Wave Ratio (SWR) of 1.5 to 1 or better. In terms of pure resistance, that would be a range of 33 Ohms to 75 Ohms. Of course, antenna system load values are seldom pure resistance. Usually the load will appear as if a capacitor or inductor is in series with a resistance value. This combination of capacitive and inductive reactance and pure resistance is called a complex load. (Both technically and mathematically)

A Real World Example:

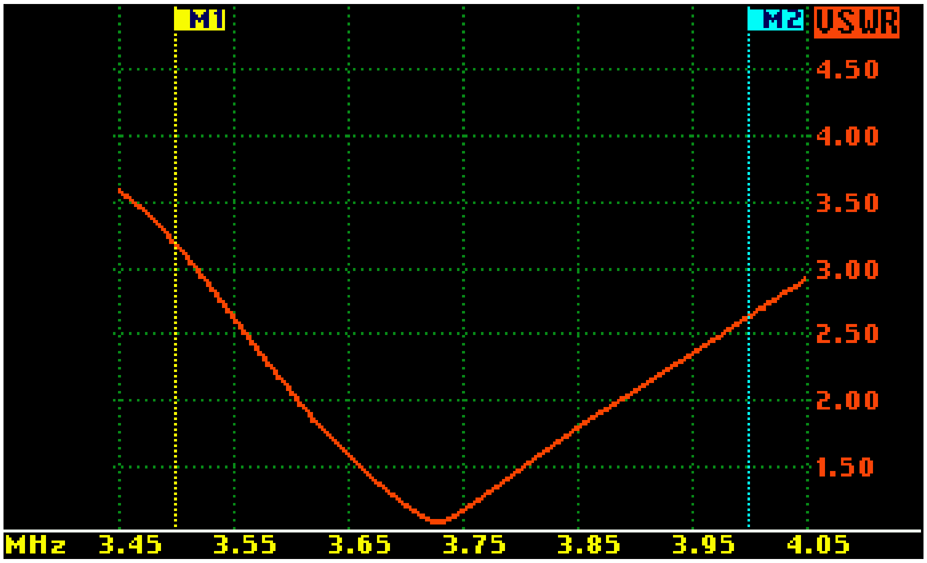

Figure 1: My 80 Meter dipole antenna as measured at the ham shack end of the coax

Figure 1 above shows a SWR plot of my 80 Meter dipole antenna as measured at the ham shack end of my coax feedline. Notice that the SWR line approaches the bottom 1.0 to 1 line at about 3.73 MHz. At that frequency the load presented to my transceiver is very close to a pure 50 ohm resistance. That is really great if all I ever operate on is 3.73 MHz. As you can see on the plot, I could operate on any frequency between about 3.65 MHz and 3.8 MHz and be within the 1.5 to 1 SWR design range of the transmitter section of my transceiver.

Actually, what I just wrote is not quite true. My transceiver has a built in antenna tuner which allows operation over the full width of the band with this antenna. However, the transceiver's built in antenna tuner is designed to cover mismatches up to about 3 to 1 SWR. I do have a solid state amplifier that does not have an internal antenna tuner. An external antenna tuner is therefore a necessary part of my station.

The V shaped SWR plot above is typical of 80 meter dipole antennas. If I chose, I could adjust the length of my dipole to shift the bottom of the V left or right on frequency scale. However, my antenna is 50 feet in the air and 250 feet from my ham shack. I am much too lazy to do that on a regular basis.

Actually, ham antennas seldom provide a pure 1.0 to 1 SWR on even one frequency. Many very good antennas don't provide a SWR below 1.5 to 1, even when properly adjusted. I was lucky with my 80 meter dipole that it does have a nice low SWR point very close to 1.0 to 1. This does raise the question as to how can I use this antenna on frequencies above or below its 1.5 to 1 SWR slot if your equipment does not have an internal antenna tuner?

It's not always a problem:

Actually, SWR values shown in the plot above are not always a problem. While our solid state transceiver transmitter sections and solid state amplifiers are sensitive to feedline SWR, most tube transmitters and amplifiers are not. Tube transmitter output stages normally have Plate Tune and Load adjustment knobs. These controls must be correctly adjusted, per the transmitter's instruction manual, for each operating frequency and antenna used.

Having to make a series of adjustments on tube gear before being able to transmit is a little bit of hassle, but not much. The advantage, though, is that these controls not only allow you to match the output tubes impedance to a 50 Ohm load, they generally allow adjustment to match loads with SWR values up to and sometimes past 3.0 to 1. Back in the days when most ham transmitters and transceivers had tube final amplifiers, most of us did not worry much about SWR. As long as the Tune and Load controls had sufficient adjustment range for us to get the correct tuning indication, we figured that was good enough. Even now, tube type linear amplifiers are still typically specified to handle SWR values up to 3.0 to 1.

Once solid state transmitters and transceivers became more common, hams began paying more attention to SWR values. Instruments for measuring SWR and RF power became common in ham shacks. Most modern transceivers even include SWR measuring and display features.

Solving the SWR problem:

The solution to the SWR problem was to use devices with controls equivalent to the Plate and Load controls in tube transmitters to correct for high antenna/feedline SWR and provide a 50 Ohm resistive load our solid state transceivers. Actually, these devices have been around almost since the beginning of radio. Many well performing antenna and feedline configurations present very high impedances to the transmitter feed point. Combinations of coils and capacitors were used to transform these high impedances into the range usable by transmitters. These devices were given the name "Antenna Tuner" even though they don't tune antennas. They match the feedline to the transmitter.

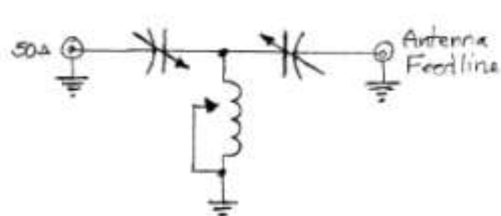

Figure 2: Simplified T-Network

There is a large variety of configurations of coils (inductors), capacitors, and switches that are used in antenna tuners. In recent years, the majority of tuners use either a capacitor-inductor-capacitor Tee configuration (**Figure 2**) or a capacitor-inductor L configuration (**Figure 3**). Both configuration use wide adjustment range components to handle the widest possible SWR correction range.

Of course, commercially made antenna tuners have multiple switches, connectors, and meters not shown in the simplified T-Network and L-Network sketches. Those extra components simply add convenience features such as allowing you to have more than one antenna cable connect to your tuner and select between them. Electronically speaking though, the components shown in the simplified sketches are the working parts of antenna tuners. They are what transform complex feedline impedances to 50 Ohms resistive.

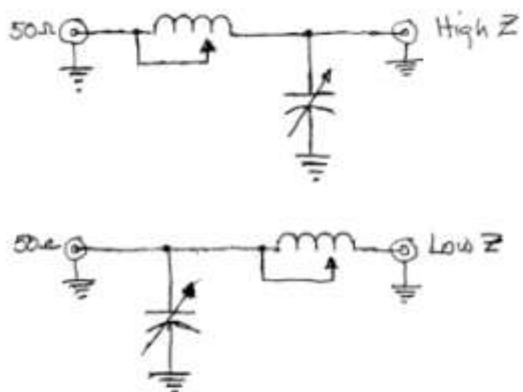

Figure 3: Simplified L-Network configurations

A specific example

Let's look at my 80 meter antenna/feedline from an antenna tuner's perspective.

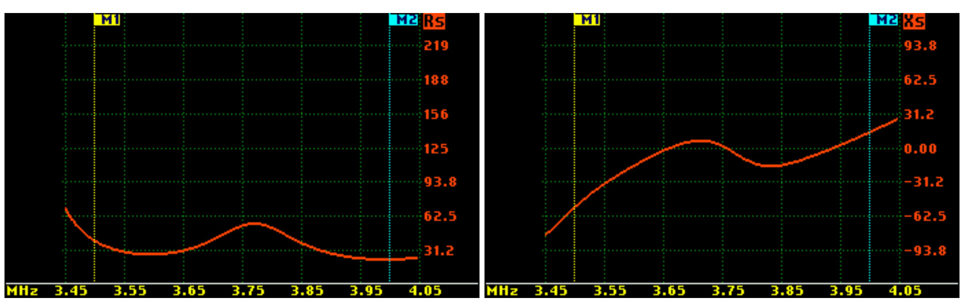

Figure 4: Resistance and reactance at 80 meter feed point.

The left plot in **Figure 4** is resistance and the plot on the right is reactance (+ is inductive, - is capacitive). My antenna tuner does not care about SWR values or forward and reflected RF power. It just sees the complex impedance at its end of the feedline. At any given frequency in the band there is a specific resistance and reactance value. It must transform those specific values to appear to be 50 Ohms resistive to my amplifier.

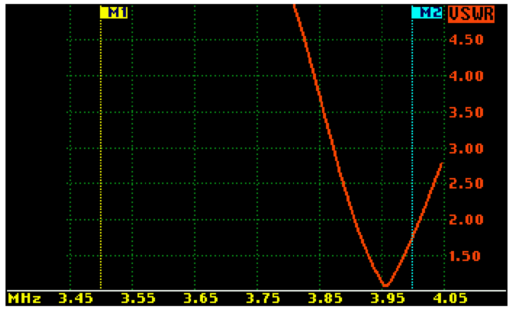

Figure 5: Antenna tuner adjusted to 3.963 MHz

The **Figure 5** plot above shows the SWR at the amplifier side of my antenna tuner when adjusted for lowest SWR at the Missouri Traffic Net frequency of 3.963 MHz. Notice that SWR rises rapidly above and below 3.963 MHz. This is a characteristic of this specific antenna tuner. Others may not produce as sharp an SWR notch. An ideal antenna tuner would not produce such a sharp SWR notch thus allowing you to change frequency farther without retuning.

It should be obvious that if I want to operate on some other frequency, such as 3.598 MHz for the Missouri digital network, the antenna tuner will need to be re-tuned. Knowing that I would want to operate on a variety of frequencies on the 80 meter band, I took the time to create a table of tuner settings. I can preset the tuner and then do a little fine tuning, taking only seconds to be ready to transmit on a new frequency.

Frequency	Input	Band	Output
3.500	55	3.5	33
3.550	58	3.5	42
3.600	59	3.5	38
3.650	24	4	11
3.700	19	4	14
3.750	20	4	10
3.800	29	4	10
3.850	36	4	16
3.900	42	4	21
3.950	43	4	30
4.000	42	4	38

Figure 6: My 80 meter tuning table

Figure 6 above is my 80 meter tuning table. The Input column is for the “Input” tuning capacitor setting. The Output column is for the “Output” tuning capacitor setting. The Band column is the inductor switch setting. This particular antenna tuner labels inductor switch settings with operating frequency hints. Of course, the actual switch setting will depend upon the specific antenna and cable connected to the unit. The frequency ‘hint’ gives the user a starting position. A step or two in one direction or another may be necessary to tune a specific antenna. For my antenna on 80 meters, the labels were surprisingly accurate. For other bands, this was not always the case. For instance, 20 meter (14 MHz) operation was best with the inductor switch set to 15 Meters (21 MHz).

Figure 7: My antenna tuner
The DU 1500 T from HA8DU

I'd like to emphasize at this point that the antenna tuner has not changed my 80 meter dipole or my feedline. Well, except that my amplifier can operate at full power. The impedance at the coax cable feed point is exactly the same as before the antenna tuner was put into operation. The SWR has not changed. Only my amplifier sees any difference. It sees a nice 50 Ohm load to drive its power into.

What's inside the box?

OK, you might be curious what is inside the antenna tuner that allows it to transform my 80 meter feedline impedance into 50 Ohms that my amplifier needs.

Figure 8: My tuner's innards

The photo in **Figure 8** above is of the insides of my tuner. It is rated to handle 1.5 KW all day. As you can see, the components are both large and heavy duty. The air space inside is necessary for cooling. This is typical of high power antenna tuners.

As mentioned above, this antenna tuner uses switch selected inductor taps to chose tuning inductance. **Figure 9** below shows the internals of a tuner with the more common rotary adjustable inductor. The rotary inductor is infinitely adjustable over its entire range. Both switched and rotary inductors have their advantages. The rotary inductor allows more precise tuning while the switch selected inductor makes it quicker to return to a previously logged setting.

Figure 9: Inside a Palstar AT2K 2 KW tuner

What an antenna tuner doesn't do

Now that my antenna tuner has provided me with a nice nearly 1.0 to 1 SWR on 3.963MHz, I'm ready to check into the net. That is great but let's looks at what the tuner does not do. Remember that the antenna tuner does not change the SWR or resistive/reactive load presented at the ham shack end of the coax leading to my 80 meter dipole. All the tuner has done is transform that load into something optimum for my equipment to operate into.

An antenna tuner is not a magic bullet for RF problems. A tuner's internal components are potentially carrying high RF voltages and currents. That means some of my transceiver's transmit power is lost inside the tuner itself. Next, the feedline to the antenna is not lossless. Some power is lost in the cable on the way out to the antenna. Feedline loss increases with increased SWR.

Since the SWR at the shack end of my 80 meter coax is relatively low, the necessary settings in my antenna tuner are likely such that very little power is lost heating its components. No more than a very few percent is lost to internal heating. The primary concern for heating is the tuner's inductor. After all, it is coil of wire with RF current flowing in it.

Another problem that can occur with tuners is that some settings may create very high RF voltages in the tuner components. This can potentially cause arcs and burns, especially on the variable capacitors. Fortunately, a well designed antenna tuner will be able to handle the voltages and currents produced matching a wide range of complex loads.

For the case of my 80 meter dipole and my expensive low loss coaxial cable feeding it, there is little power lost there. That is certainly not true for every antenna and cable combination hams use. High antenna SWR increases power loss in the feedline. It is common for the SWR present on a G5RV type antenna when used on 17 meters to produce 90% power loss in the antenna's coax cable feedline.

We cannot do very much about feedline power loss unless we make adjustments out at the antenna to reduce its SWR or upgrading to a lower loss feedline. For antenna tuner power loss we can choose settings that minimize internal voltages and currents. I'll discuss how to do that later.

How do you hook an antenna tuner into a ham station?

By now, where an antenna tuner is hooked into a radio system should be becoming fairly obvious. It is connected in line with the feedline coming in from your antenna. Beyond that, only some common sense is necessary.

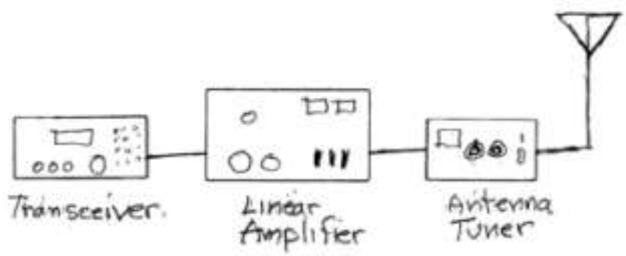

Figure 10: Station sketch with antenna tuner

How do you tune your antenna tuner?

Now we are getting to the difficult part of discussing antenna tuners. Adjusting an antenna tuner is an art. It takes practice. The settings required for achieving 1.0 to 1 are different for every antenna and frequency, and sometimes for different weather conditions. Finding the correct settings can be a tedious process. However, once those settings are found AND WRITTEN DOWN, returning to a previous working control configuration is quick and easy.

First, let's talk about the difference in how L-network and T-Network antenna tuners are tuned. L-Network tuners have only two adjustable controls and a switch to select between high impedance and low impedance configurations. There will be only one combination of those controls that will provide 1.0 to 1 SWR for your transceiver and amplifier. Start with either the high or low impedance configuration and adjust the capacitance and inductance. If no low SWR position of the knobs can be found, switch to the opposite configuration and try again. One or the other of the high/low impedance configurations should work. Just be forewarned that an L-Network has a somewhat limited tuning range though that range usually includes typical ham antennas.

T-Network tuners, which are the most common type of manual antenna tuners, are somewhat more difficult to adjust than L-Network tuners. The three adjustable controls interact with each other. One of the more confusing parts of adjusting a T-Network antenna tuner is that there typically is more than one setting that will provide a 1.0 to 1 SWR for your station.

If you are new to antenna tuner operation, don't worry. T-Network configuration antenna tuners have been successfully used for many years by many, many hams. Properly adjusting one is not rocket surgery. It just takes patience finding the correct settings (which you will write down won't you?) The concern with the T-Network antenna tuner is minimizing heating in the tuner. A higher than necessary value of inductance in the tuner will increase the heating in the inductor. This may not see immediately obvious but it is a matter of circuit Q. The lower the inductance, the lower the circuit Q which lowers inductor heating. Plus, lowering the circuit Q broadens the low SWR bandwidth, reducing the need to readjust the antenna tuner with small frequency changes.

My procedure when starting from scratch:

1. Check the SWR with the antenna tuner capacitors and inductors bypassed. This is typically labeled as "Direct" on the tuner's selector switch. If the SWR is less than 1.2 to 1, leave the selector switch in Direct and operate. If SWR is between 1.2 to 1 and 1.5 to 1, you can leave the tuner in Direct or not as you choose.
2. For 160 through 40 meters, preset the capacitors to about 50% of range. Preset the inductor to minimum inductance. On 20 through 10 meters, preset the capacitors to about 25% of fully meshed. With most tuners that would be at about 75% of scale on the capacitor's dials.
3. While listening to band noise on your transceiver, increase the inductance until a noise peak is heard. On 160 meters, you can stop before a full peak is detected. The 160 meter peak will be broad. On 15 through 10 meters, band noise may be too low to allow a peak to be noticed. If no peak is detected, return the inductor to the minimum inductance setting.
4. Make sure your linear amplifier, if you have one, is turned off. Set your transceiver to its lowest transmit power setting. Switch your transceiver to a mode that can provide a continuous RF carrier for tuning purposes.

Now the tuning starts:

5. Transmit a low power carrier with your transceiver. Adjust the power level to provide an adequate SWR or forward/reflected power indications to begin tuning.
6. Slowly adjust the inductor for a minimum SWR indication. Increase you transceiver's output power as necessary to maintain a visible SWR indication.
7. Alternately adjust the two capacitors for minimum SWR. This can be a bit tricky since the two adjustments interact. It is common to find a point where 1.0 to 1 is not reached but neither capacitor's adjustment will improve the SWR. There is actually a trick to this step. That is to turn the capacitors very slightly past a SWR dip when adjusting it. Alternate this tuning slightly past the SWR with each adjustment. That will usually bring the SWR right on down to 1.0 to 1. (Remember – I said this is an art! It does take a little practice to learn the process.)
8. Reduce inductance by a quarter or third of a roller inductor turn.

9. Repeat steps 7 and 8 looking for the lowest inductance value that will allow you to achieve 1.0 to 1 SWR. WRITE DOWN THE FREQUENCY, CAPACTOR, AND INDUCTOR SETTINGS.

Repeat the above sequence for each band and antenna you will be using. I find it handy to take the time initially to follow the above procedure for multiple frequencies in each band to create an adjustment table. A beginner might groan at the thought of going through this procedure multiple times. Actually, it is not that bad. First it is a good idea to practice with the tuner to know how to use it effectively. You can think of this as taking notes while you practice. Second, you will become much faster and accurate as you proceed. It usually takes less than an hour for me to make it through all the bands on my antennas. Besides, sometimes it is just fun to play with gear like this.

As an example, I performed the above steps using an MFJ-989C. It has a roller inductor so matches the procedure above a little better than my regular tuner. The settings I worked through for 3.5 MHz are:

C	L	C
6.3	45	4.6
5.9	40	2.9
4.9	35	0.6
4.5	**34**	**0**

Figure 11: Finding the correct settings for 3.5 MHz

The capacitors are marked 0 to 10. I interpolated between marks to provide more precise indication. The capacitors are at maximum capacitance at 0. The inductor read 0 at minimum inductance and 125 at maximum so lower numbers are better. As you can see I tried successively lower inductances until I got 1.0 to 1 SWR with the right side capacitor at maximum capacitance. I usually don't write down these intermediate steps but thought it might be good to show my work. On higher frequency bands, lower capacitances (higher capacitance number settings) were required.

When I change frequency, I look at the table; adjust the knobs to match; and do a quick SWR check. I've found that simply returning to the settings in the table is usually all that is needed to begin operation.

The above procedure is oriented for the more common roller inductor type of antenna tuners. You may use the same steps with a tuner with switch selected inductance values. Obviously the process will be a little quicker since you will have a limited number of inductance steps to work with. The same rule applies though. Use the lowest inductance value that allows you to achieve an adequately low SWR value. That is usually less than 1.5 to 1 though typically 1.0 to 1 SWR is will be achievable.

But what do you do if you just want to do a one time tune up?

Obviously the above procedure is intended for fixed station long term use. What would I do if all I wanted was a quick one time tune up for a temporary antenna? I would do pretty much as described in the procedure but would only make a quick try or two at finding a lower inductance setting. Once you have practiced, it usually takes only a few seconds.

Some points to keep in mind:

1. Your antenna tuner should be rated to handle at least as much power as your station can put out.
2. The earliest commercial antenna tuners were generally rated for the DC input power to the associated transmitter's final amplifier. That was how amateur radio transmitter power was originally specified in FCC rules. Thus, a tuner's RF power rating was only about half or two thirds of the advertised power rating. Some, but not all, antenna tuners today still use that rating method. MFJ's antenna tuners are rated by that old method – advertised 300 watts is really only 150 watts RF. Other manufacturers rate their tuners for actual RF power. Read specifications carefully.
3. Roller inductors in some antenna tuners must be tuned with at least a few watts of RF. That RF voltage and current helps the roller inductor contact wheel break through any thin oxide or film collected on the inductor wires.
4. Sometimes it is difficult to find a control combination that works with a low SWR 50 Ohm load. Fortunately, all that is necessary is to leave the tuner in 'Direct' mode for that kind of load.
5. Achieving 1.0 to 1 SWR with an antenna tuner will not change a crappy antenna into a good antenna. All it does is allow you to transmit at full power.
6. A typical T or L Network tuner is designed to be used with coax transmission line. Using them with open wire or twin lead transmission lines requires a device called a Balun. (This name is a contraction of the term Balanced-to-Unbalanced.) Some antenna tuners have built in baluns. Others require external baluns.
7. There are antenna tuners available specifically designed for tuning open wire or twin lead transmission lines. While a balun on a tuner will work fairly well with these transmission lines, a balanced tuner typically has a wider matching range and potentially lower power loss.

Antenna Tuner Settings Table

1.800			
1.825			
1.850			
1.875			
1.900			
1.925			
1.950			
1.975			
2.000			
3.500			
3.550			
3.600			
3.650			
3.700			
3.750			
3.800			
3.850			
3.900			
3.950			
4.000			
5.300			
5.400			
7.000			
7.100			
7.200			
7.300			

10.125			
14.000			
14.175			
14.350			
18.100			
21.000			
21.225			
21.450			
24.950			
28.000			
28.500			
29.000			
29.500			