Antenna Tuners

Keeping Transmitters Happy For Nearly A Century

Doug Hall K4DSP

What We'll Cover

1. Why use a tuner?
2. How they work
3. Antenna tuner building blocks - the L-network
4. T and Pi networks
5. Impedance matching - just a quick overview
6. Examples of tuners using different topologies
7. Adjusting a tuner
8. Antenna tuner downsides
9. Automatic antenna tuners
10. Open wire feedlines
11. Selecting (or building) an antenna tuner
12. Antenna tuner alternatives
13. Wrap up

An antenna tuner, a.k.a. tuner, coupler, ATU, matchbox, transmatch, is a device that provides impedance matching between a transmitter (usually 50 ohms) and an antenna system of different (and sometimes unknown) impedance.

ATUs are commonly used to:

- Allow operation at band edges where SWR may cause the solid state transmitter to fold back
- Allow operation with non-resonant antennas

Understanding How ATUs Work

An antenna system presents a complex impedance consisting of a resistive component and a reactive component. The reactive component may be inductive or capacitive. To your transmitter the antenna system looks like a resistor with some reactance in series. An antenna with a VSWR of 1:1 will have a resistive component of 50 ohms and a reactive component of 0 ohms. As long as the resistive component is close to 50 ohms and the reactive component is close to zero no antenna tuner is generally needed. But once we stray far from these values the impedance mismatch is too far from 50 ohms for most transmitters to operate properly, and some form of impedance matching is necessary. This is where the ATU comes in.

ATU Examples

ATU Building Blocks

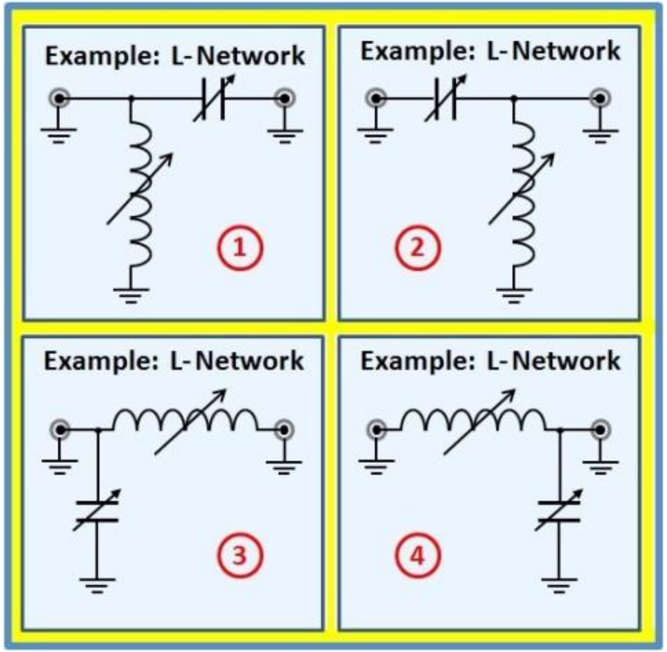
The job of an ATU is to cancel reactance and transform impedance. We do this with capacitors and inductors arranged in a handful of configurations:

1. L-network
2. T-network
3. PI-network

It turns out that you can match nearly any antenna using a simple L-network, but many (most?) antenna tuners sold today are based on the T-network. We'll see why shortly. First let's look at the L-network.

ATU Building Blocks - The L Network

The L-network is named because its schematic looks like an “L”
Basic L network configurations:



1. Highpass, Zout<Zin

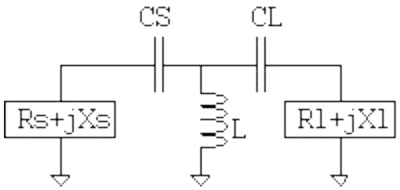
2. Highpass, Zout>Zin

3. Lowpass, Zout<Zin

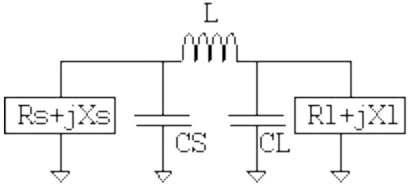
4. Lowpass, Zout>Zin

ATU Building Blocks - The T and Pi Networks

The T and Pi networks are created by combining L networks:



T-Network (Highpass)



Pi-Network (Lowpass)

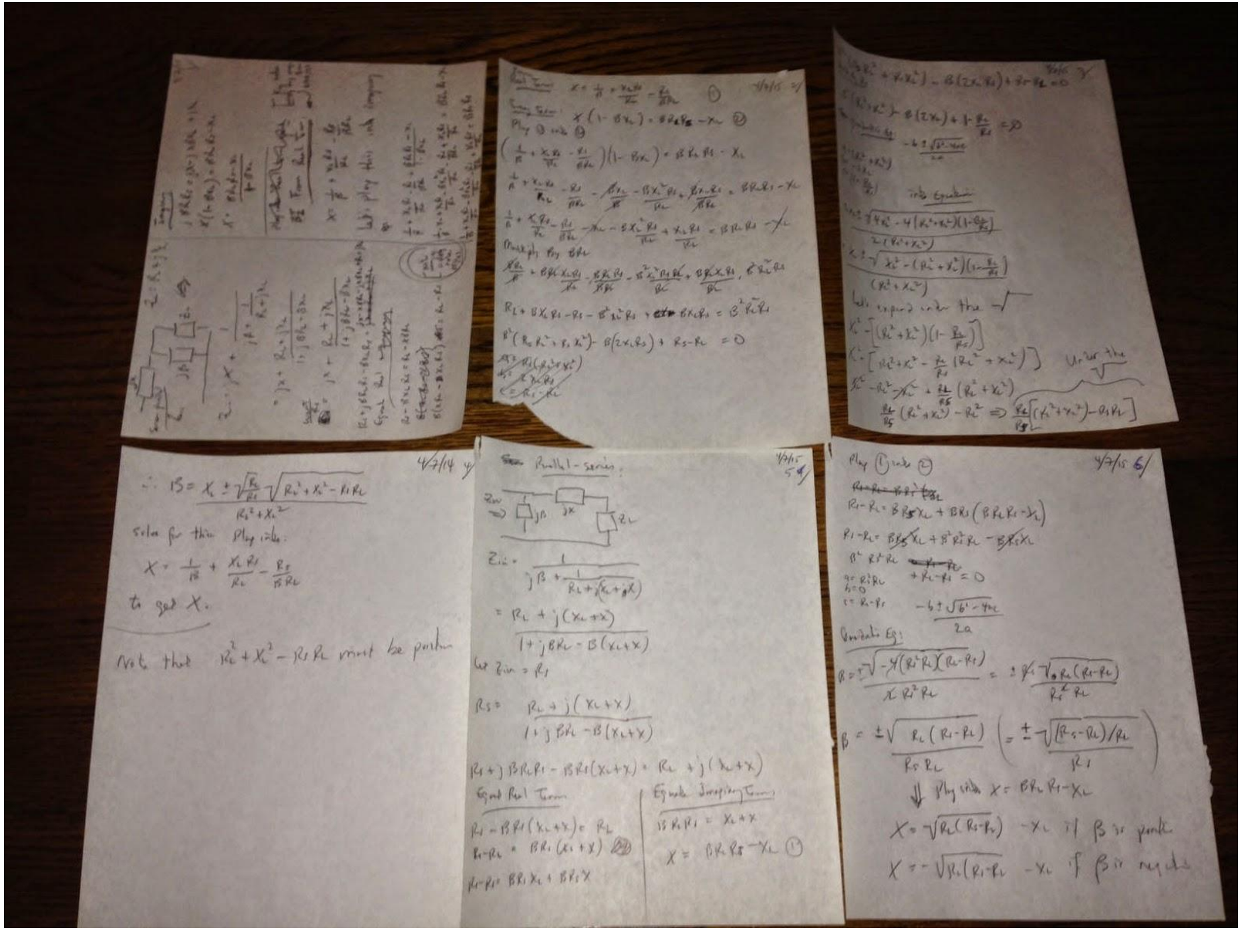
How Do We Determine L network Values?

The job of an ATU is to cancel reactance and transform impedance. We do this with capacitors and inductors arranged in a handful of configurations:

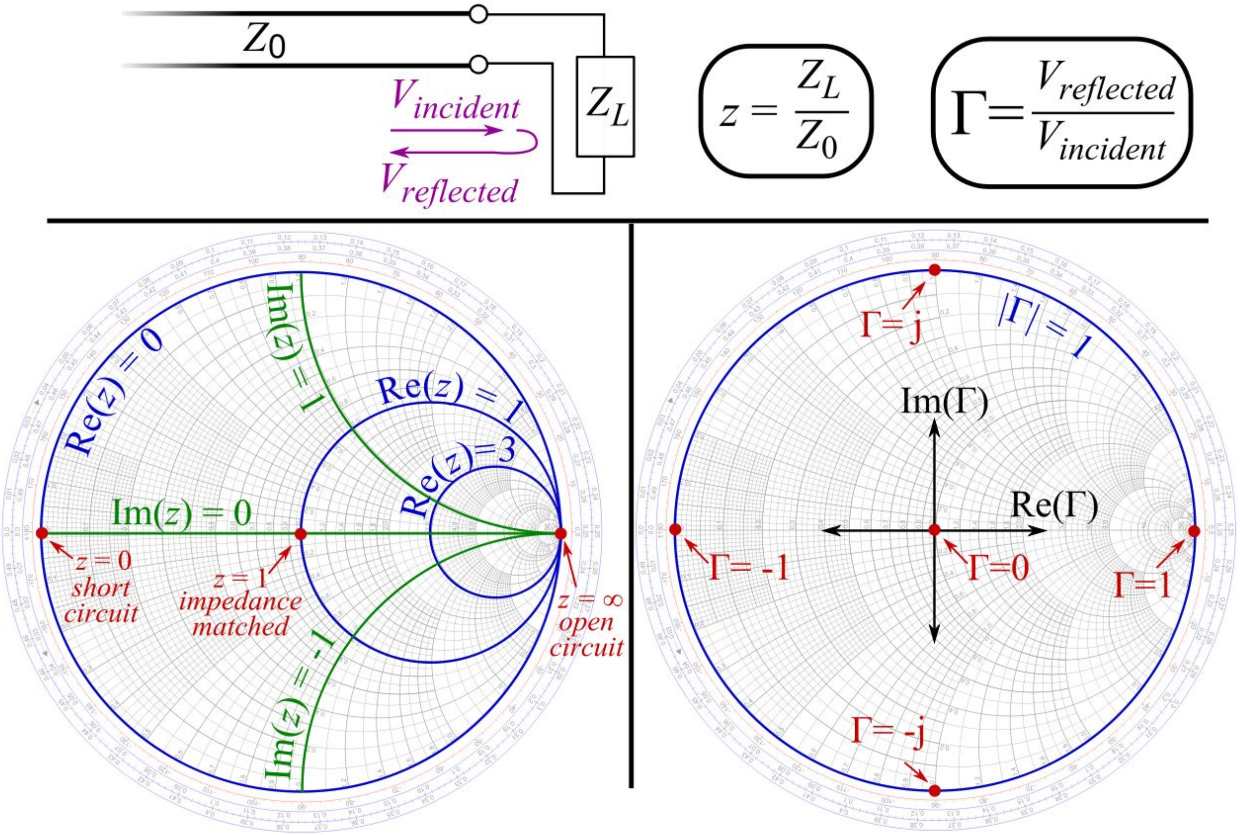
If you know the complex impedance (R+/-jX) that you need to match there are several methods to determine which L-network configuration is needed as well as the the proper component values:

1. Calculate the values based on network theory equations (tedious)
2. Use a Smith Chart (much less tedious)
3. Use a software package (easiest of all)

Why Not Just Calculate The Values?



The Smith Chart - A (Somewhat) Easier Way



Smithchart Tutorial:

W2AEW Alan Wolke - "Basics of Smith Charts"

Highly recommended!

Impedance Matching Software

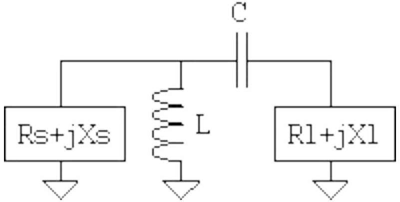
One example:

http://f5len.org/tools/matching/index.htm

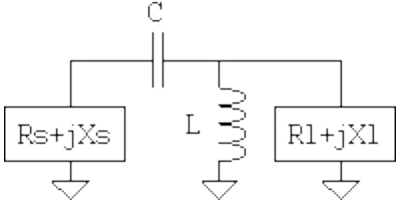
This webpage contains an easy-to-use impedance matching utility. If you know the complex impedance you want to match it will calculate the L, T, or Pi network values.

ATU Building Blocks - The L Network

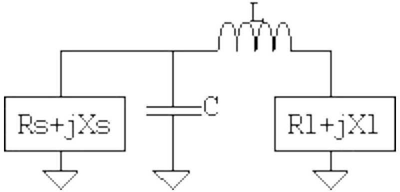
The L-network is named because its schematic looks like an “L”
Basic L network configurations:



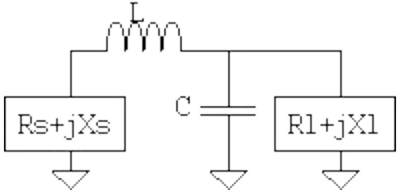
1. Highpass, Zout<Zin



2. Highpass, Zout>Zin

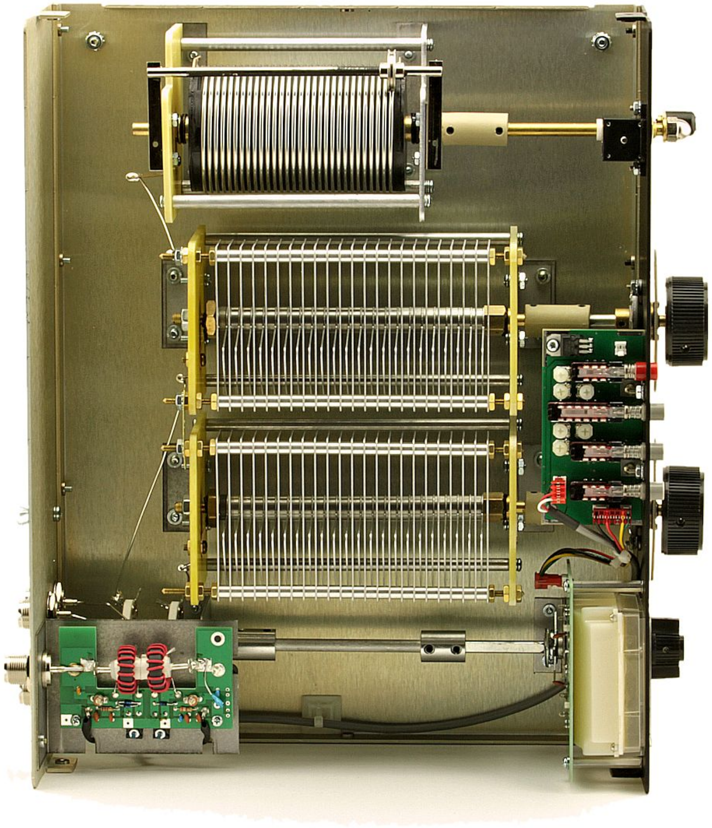


3. Lowpass, Zout<Zin



4. Lowpass, Zout>Zin

Examples

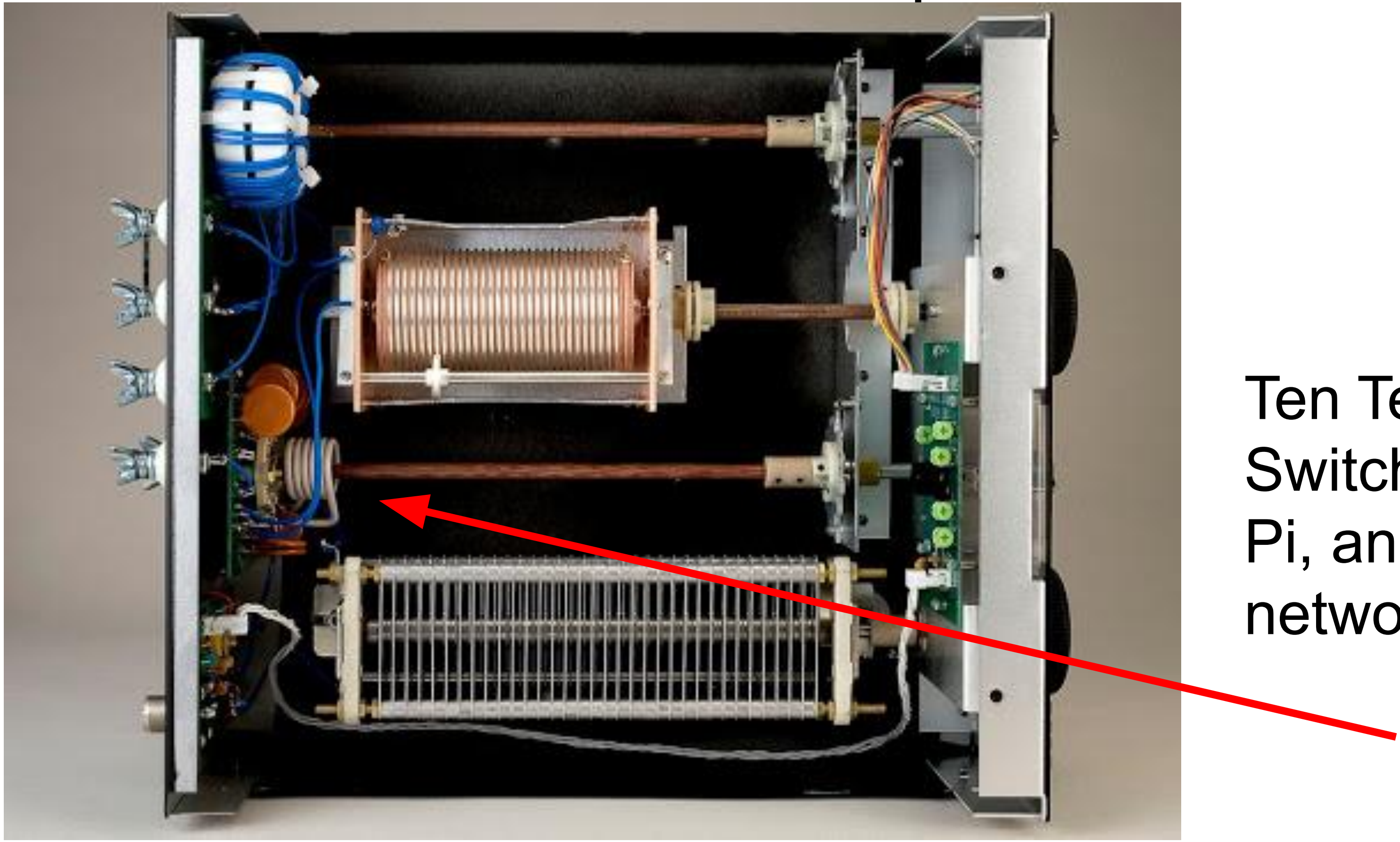


T-Network tuner

Examples

L-Network tuner

Examples



Ten Tec 238
Switchable T,
Pi, and L
network!

Ten Tec multi-configuration tuner (cont)

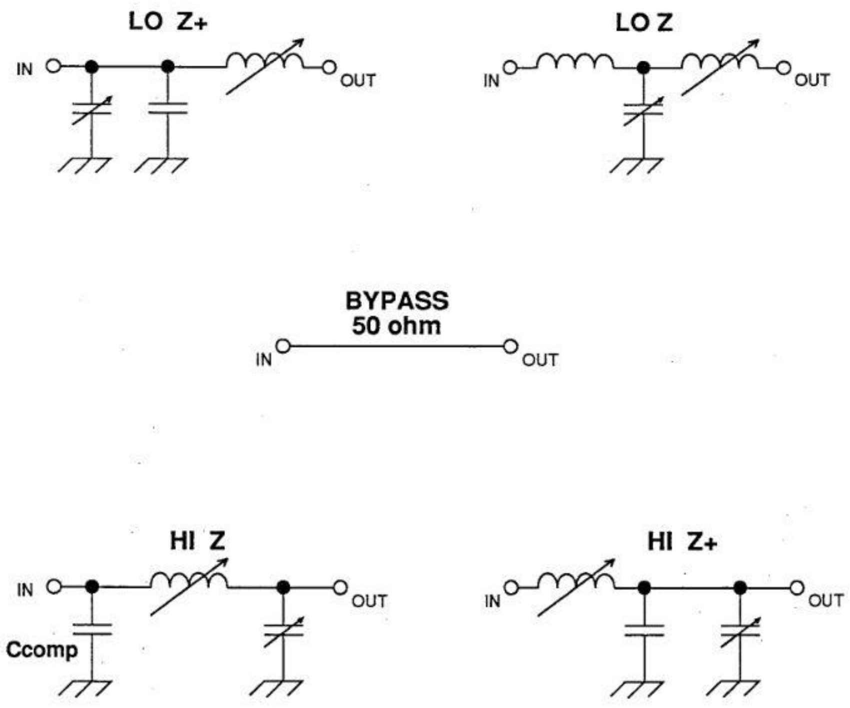


FIGURE 3-6. MODEL 238 TUNER CONFIGURATION DIAGRAMS

Adjusting a T-Network ATU

(Courtesy of Tom, W8JI)

Unlike the L network which has only one setting for a given load impedance, a T network can provide a match at multiple settings. And many tuners use the T-network. How do we find the best setting?

We want the lowest inductance setting with the maximum capacitor setting that provides a match. If you always set your capacitors at mid-scale to start (as is often recommended) and adjust the inductor for a dip in SWR you run the risk of obtaining a match with higher loss. Recommended capacitor settings to begin are:

1. 160/80M - max (fully meshed)
2. 60 - 20M - ¾ meshed
3. 15 - 10M - ½ meshed

Finally, when putting a new tuner in service (or when changing your antenna system) check for inductor heating and capacitor arcing.

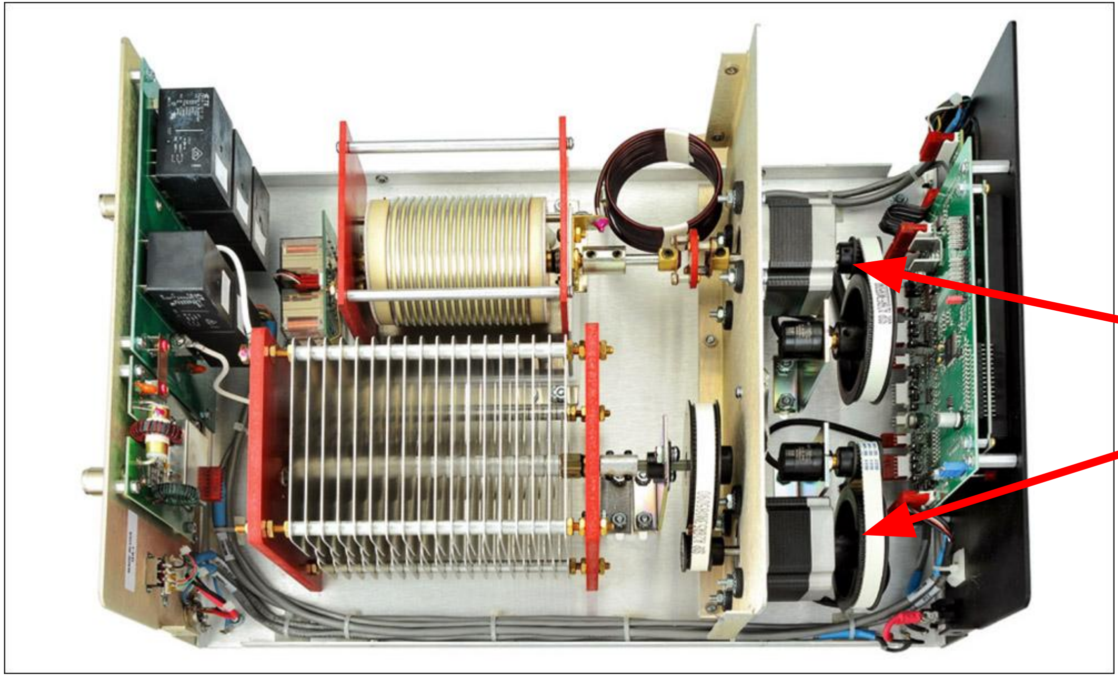
A Perfect Match, But At What Cost?

There are a couple of downsides to using an ATU, especially where coaxial cable is used to feed the antenna.

1. There is loss in the inductor, especially on the lower frequencies. That's why inductors in ATUs sometimes get hot, or even burn up.
2. The higher the antenna SWR the more loss in the coaxial feedline. This can result in some extremely high voltages or currents on the feedline or in the tuner, especially if you run high power. Worst case scenario - melted coax or arced components. This can be largely eliminated (where practical) by using open wire feedline or ladder line. Generally SWR values of even 10:1 or less will not result in extremely high losses (which is why the G5RV gets away with it) but trying to use a coax-fed 20M dipole on 40M with a tuner could easily lose 10+ dB in the coax and another few dB in the tuner. That doesn't mean it won't work. But you're throwing away a lot of signal. On TX *and* RX.

Automatic Antenna Tuners - How Do They Work?

Traditionally ATUs are built with variable capacitors and variable (or tapped) inductors. Early autotuners simply used motors to adjust these components, but that was slow and sometimes problematic.



Stepper Motors

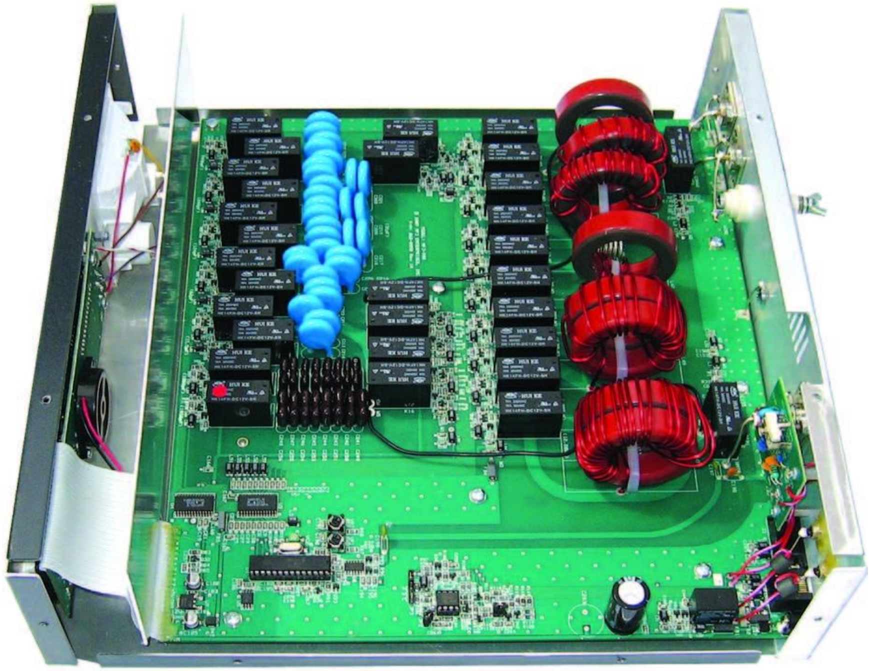
Automatic Antenna Tuner Nostalgia - Made in Raleigh

Motorized Antenna Tuners & Parts

MacKay Auto Tuner
1.6 - 30.0 MHz

Automatic Antenna Tuners - Ditching The Motors

There is a better way. If we use relays to switch in binary banks of capacitors and inductors we can approximate a variable capacitor and inductor. We can also use relays to reconfigure the L-network, eliminating the need for a T-network. Nearly all modern auto-ATUs work this way.



Automatic Antenna Tuners (cont)

The key to modern automatic antenna tuners is the use of a microcontroller to:

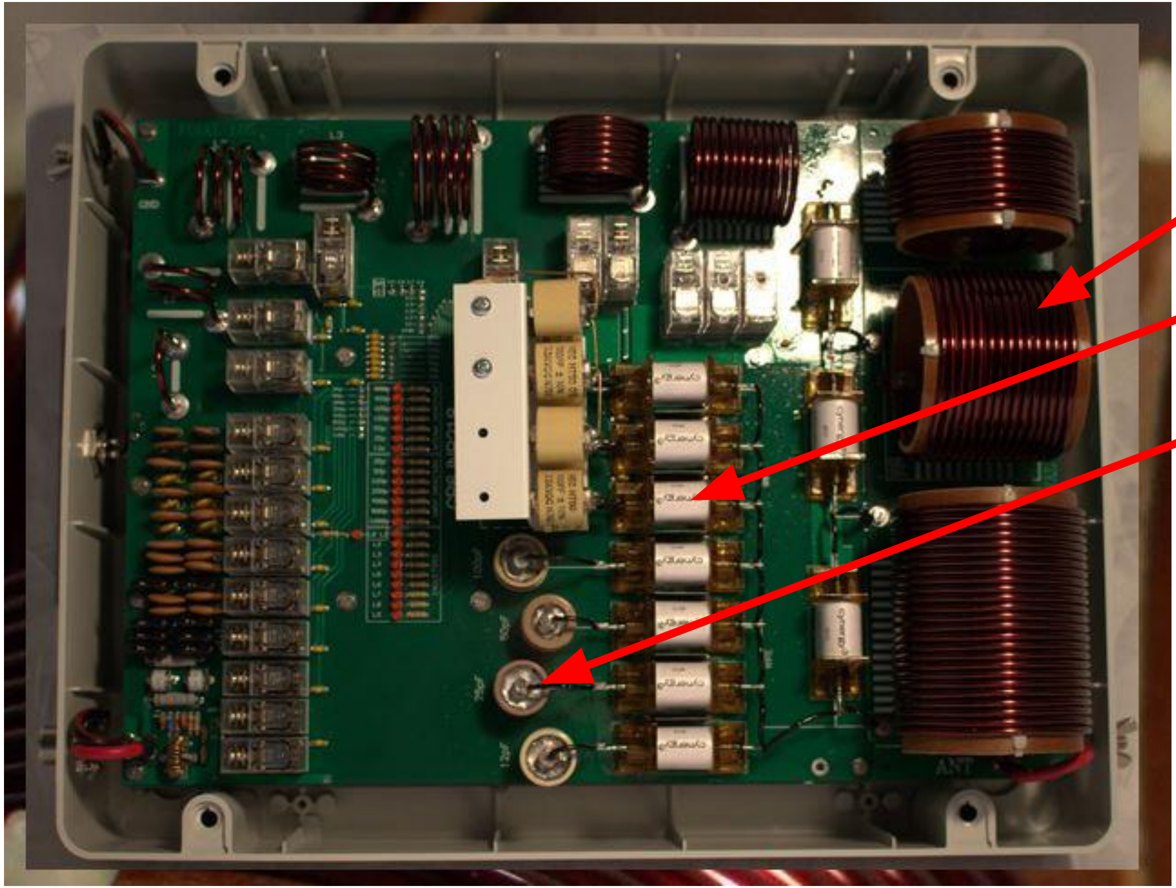
1. Read forward and reverse power and sometimes frequency. Ideally we'd just measure impedance but accurate impedance measurement adds more cost and complexity.
2. Make some initial circuit adjustments to determine which L network configuration is needed
3. Select L and C values based on a tuning algorithm to achieve a match
4. (Optionally) Save the settings for that frequency in memory for fast recall next time.

This method can yield tune times of a few seconds, and even less if the ATU has previously been tuned on that frequency/antenna.

Automatic ATU Downsides

1. Making a really high power auto ATU is expensive. A 4000W auto-ATU with vacuum relays sells for approx. $3800.
2. Auto ATUs are software-controlled, which brings the good and the bad.
3. It’s harder to “roll your own” automatic tuner than it is to build a manual tuner. At least for most people.
4. Excessive power while tuning can damage relays
5. Momentary spikes in SWR can cause some tuners to retune in the middle of a transmission which is annoying.
6. There aren’t many true “legal limit” automatic ATUs available. If you’re running “on the hot side” you may want to opt for a manual tuner.

4KW Auto ATU



Air-wound inductors

Vacuum relays

HV doorknob capacitors

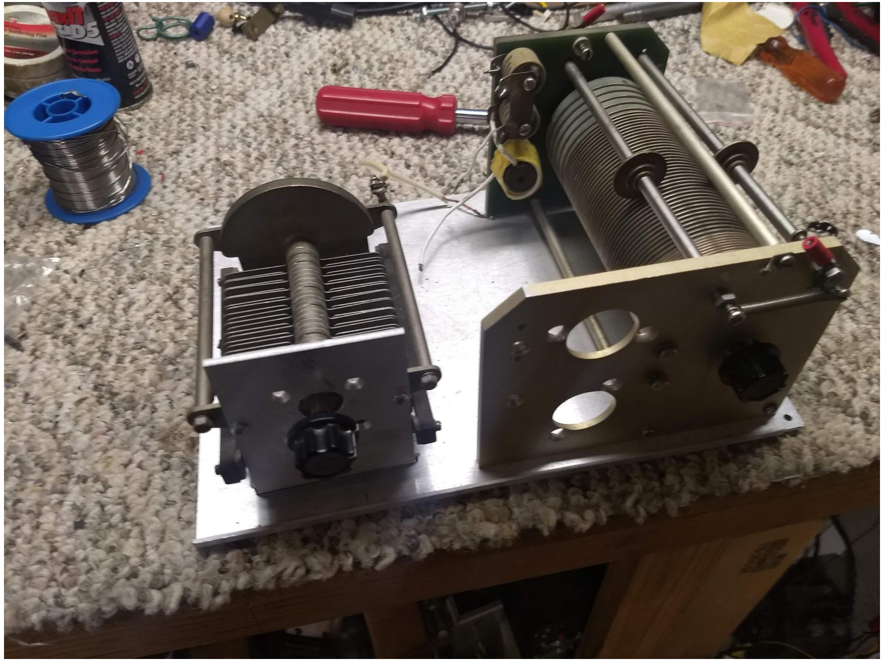
What About Open Wire or Ladder Line Feedlines?

1. A balun is generally needed on the output of an antenna tuner to assure equal currents in each wire of a balanced feedline.
2. Some tuners have a balun built in
3. Outboard baluns can be purchased (or built) for tuners lacking them. They can be installed inside the tuner or (more easily) attached with a short piece of coax. (Longer runs of coax may cause problems depending on the antenna system, but you might get away with it.)
4. A current balun is preferred to a voltage balun for balanced feeders.
5. Many built-in baluns are 4:1, but there are some arguments (see VK1OD, DJ0IP, W8JI) for using a 1:1 balun for some multiband antennas. With my ladder-line-fed inverted vee (140 ft long) I find a 1:1 balun works best for 80 through 30 meter operation.

So What Should You Buy?

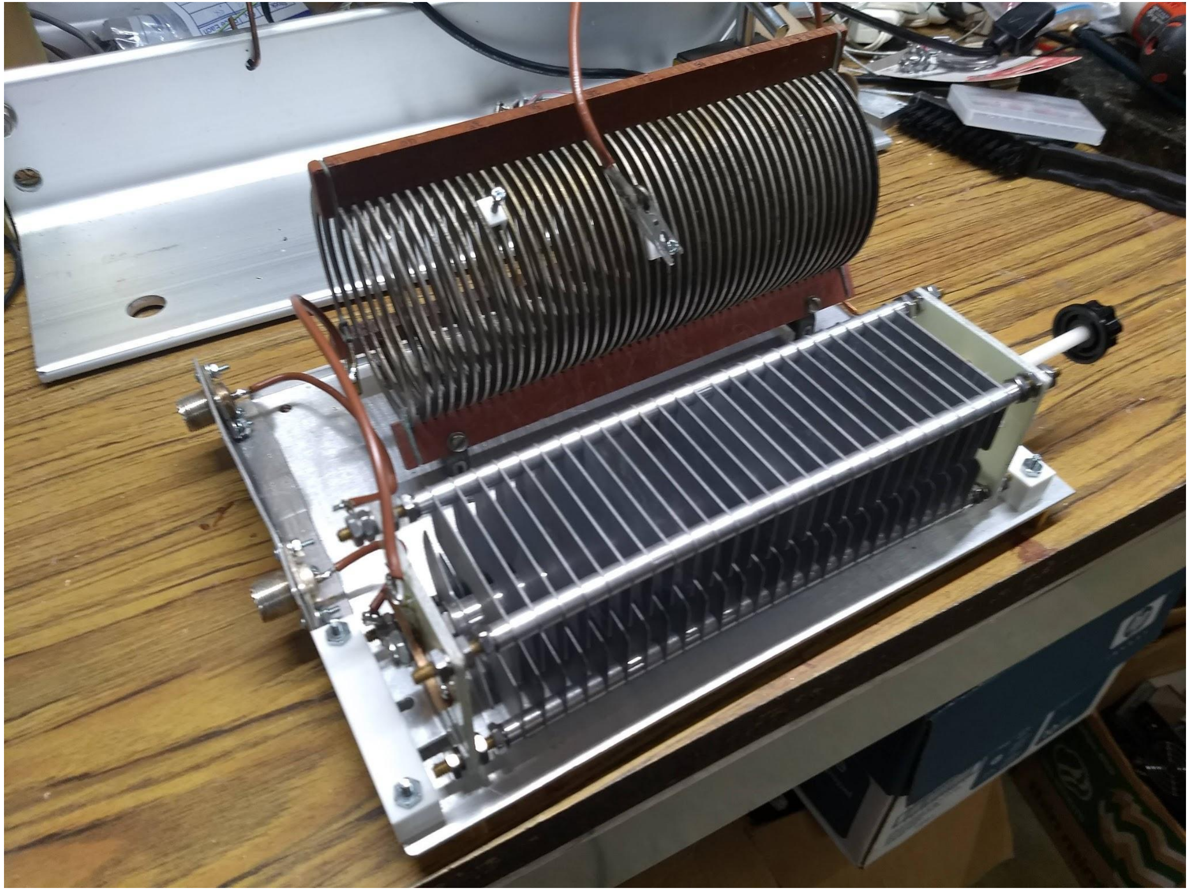
1. If you have an amplifier, or think you might buy one your choices are more limited. Consider not only the power of your amplifier, but what modes you tend to operate. SSB has the lowest duty cycle. Digital modes will find an inadequate tuner very quickly.
2. If you're a contester or rapid-fire DXer an automatic tuner saves time changing bands/frequencies. If you're not in a hurry a manual tuner may be all you need.
3. If balanced feedline is in your future find out what kind of balun is in the tuner. You might be better off building or buying an outboard balun. A good quality current balun is worth the time or money.
4. Finally, consider building a tuner. Of all the HF station components the antenna tuner is one of the easiest to build….

Building an Antenna Tuner



Variable capacitors and inductors can be purchased new, but you can find them at hamfests as well. All of the components above cost me less than $75, and would make two L-network tuners capable of handling a kilowatt.

Building an Antenna Tuner



Why Aren’t There VHF/UHF ATUs?

1. It’s much easier to build full size resonant antennas at VHF and UHF.
2. It’s difficult to manage stray capacitance and inductance at VHF/UHF.
3. Due to extreme feedline loss at the higher frequencies it’s much better to match at the antenna instead of at the transmitter.

A Little History

There are more antenna tuners available now than there were 50 years ago, mainly because the need for them is greater. Tube type transmitters had a high impedance plate circuit (sometimes thousands of ohms) which had to be matched to a nominal 50 ohm antenna. To achieve this a PI network was built in. Radios like the Collins S-line, Heath SB and HW lines, Drake R4 lines, and many others could tolerate a 3:1 SWR (and often higher) with no problem. If you look at the schematic for the final amplifier for these radios you'll see a Pi network connected to the plate output circuit. As a result there wasn't as much need for tuners except for non-resonant antennas and antennas fed with open wire feedlines.

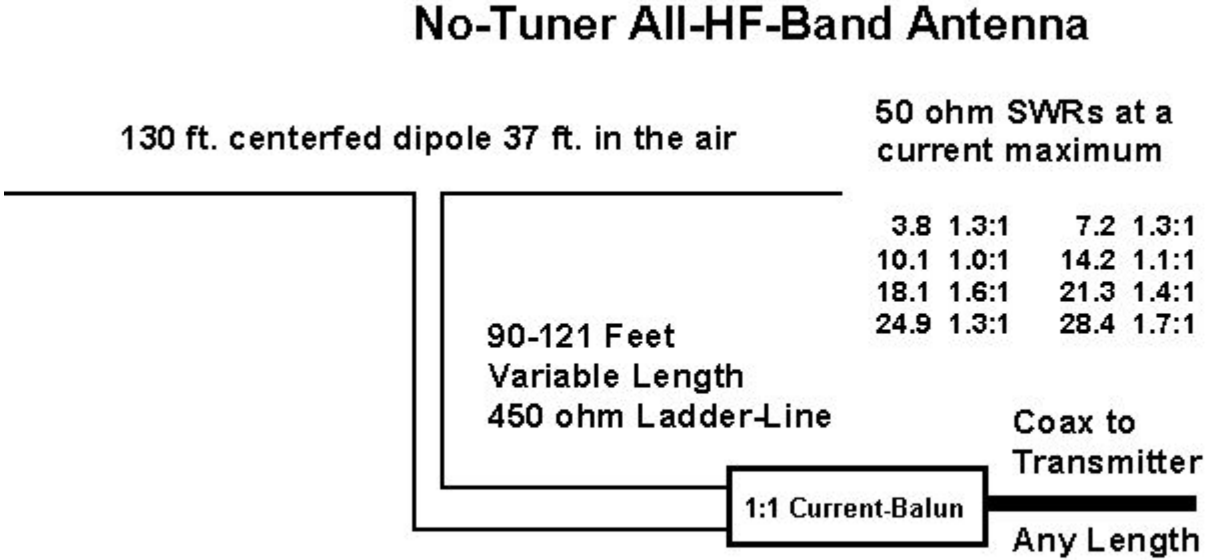
Clearing Up Misconceptions

- ATUs do not change the impedance, efficiency, or radiation pattern of an antenna
- ATUs do not make all antennas efficient multiband antennas. (*There ain't no such thing as a free lunch.*)

The key to successful ATU use is to know their limitations and to know when to use them and when to avoid them.

ATU Alternative

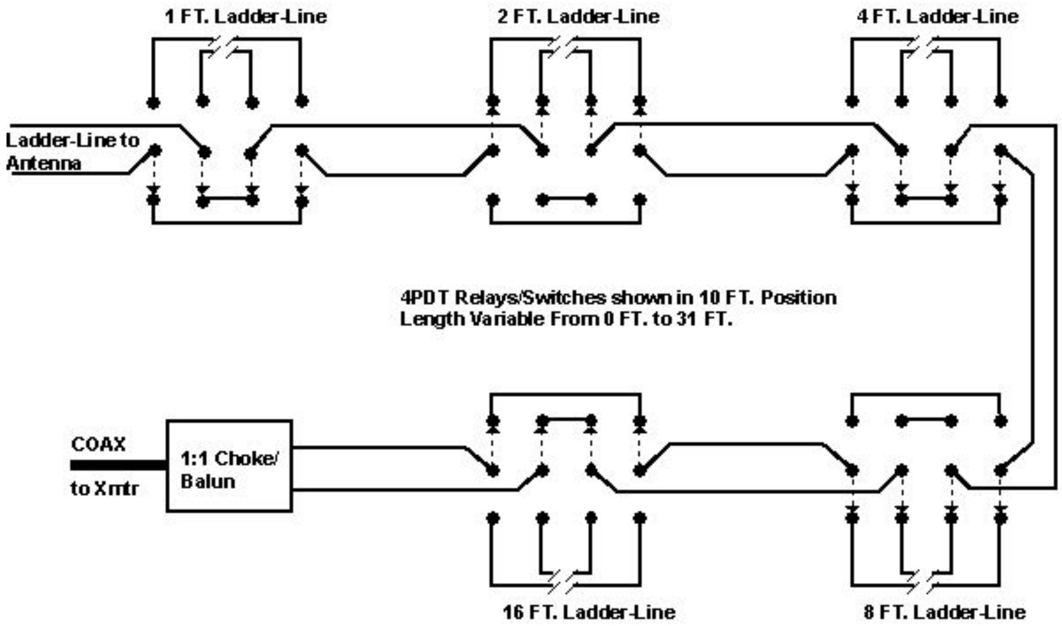
Remember that a length of transmission line (coaxial cable or open wire feedline) can be used as an impedance transformer. W5DXP described an all-band antenna which presents a close match on all HF bands by varying the length of the feedline. See http://www.w5dxp.com/notuner/notuner.HTM for more details.



W5DXP ATU Alternative

How do you vary the length of the feedline?

Ladder-Line Length Selector for Our All-Band Dipole



The length is continuously adjustable in one foot increments from zero to 31 feet.