**Newcomers Notebook. An Antenna Tuning Unit does not tune antennas.**

By Jules Perrin VK3JFP

There is one piece of amateur radio equipment that is misunderstood, misnamed, and misused, this is the Antenna Coupler. Also known by names such as antenna tuner, matching network, matchbox, transmatch, antenna tuning unit (ATU), antenna coupler and feedline coupler.

Let us look at this piece of kit and analyse what it does and why it is misunderstood.

## Ideal Setup

In the ideal amateur radio station set up, Figure 1, the transmitter sees a 50 Ohm load at the SWR/Watt meter, low pass filter, transmission line and antenna. The power sent to the antenna is determined by the transmitter (the Forward power), and the power the antenna emits is the Radiated power. A perfect impedance match and the transmitter power is dissipated by the antenna as electromagnetic waves.

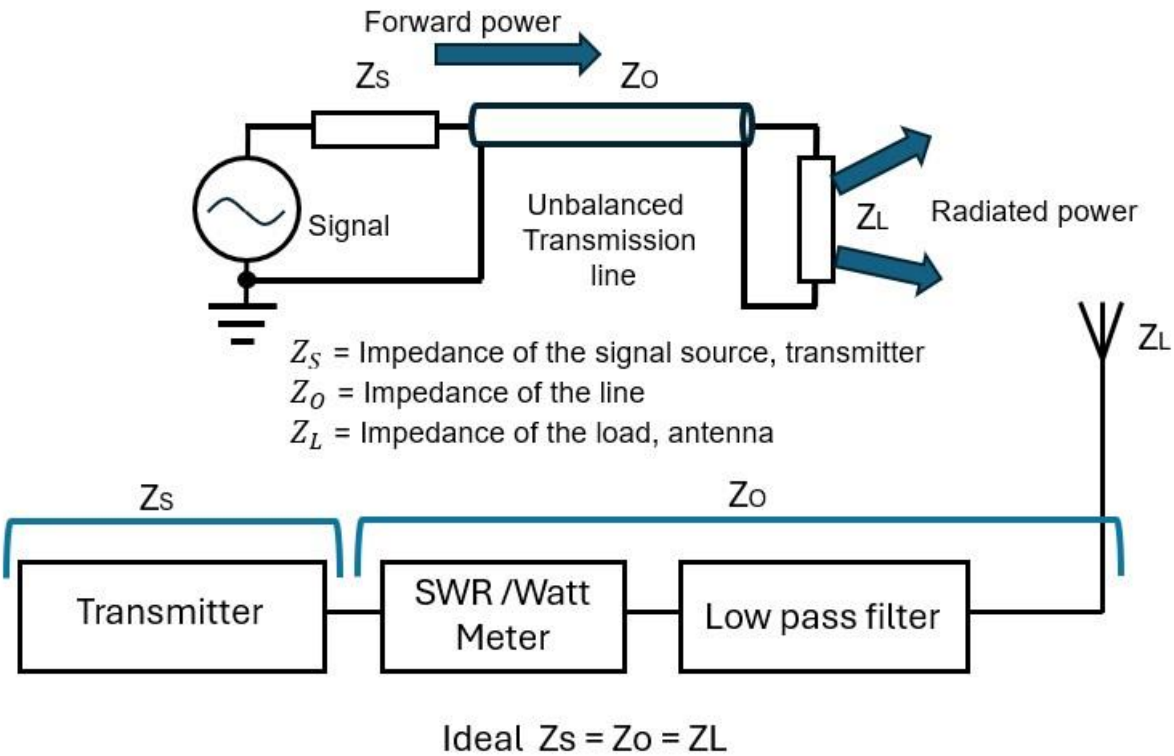


Figure 1 The ideal setup.

The downside is the ideal world is not reality. There are always mismatches, losses and compromises. The result is that a portion of the power sent to the antenna is reflected to the transmitter, called the Reflected power. The Forward signal combines with the reflected signal to present a standing wave and this can be measured as a Standing Wave Ratio (SWR).

## The real set up

If you have a high SWR in your system, assuming you have the correct transmission line, you would tune the antenna to reduce the SWR and match the antenna to the transmitter.

An antenna is a specialized device that converts electric current into electromagnetic (EM) waves or vice versa. But simple antennas, like the dipole, do not present a low SWR across all frequencies. The antenna has one centre frequency ($f_c$) and an upper and lower frequency where the SWR is still acceptable. This is the antenna bandwidth.

When the antenna is used outside its bandwidth, the SWR increases beyond the acceptable limits for the output of the signal source, the transmitter. (Receiver performance is equally affected.)

The transmitter is usually the most expensive and vulnerable device in the transmission chain. This device needs protection from high standing waves causing damage to the output stage of the transmitter. The difference between the transmitter's output impedance and the antenna's input impedance is called a mismatch. This is where the antenna coupler can be of use. I know newer transmitters have built in protection that reduces output power in high SWR situations, but for this exercise, assume it does not.

## Enter the antenna coupler

The antenna coupler is placed in the chain after the low pass filter as shown in Figure 2.

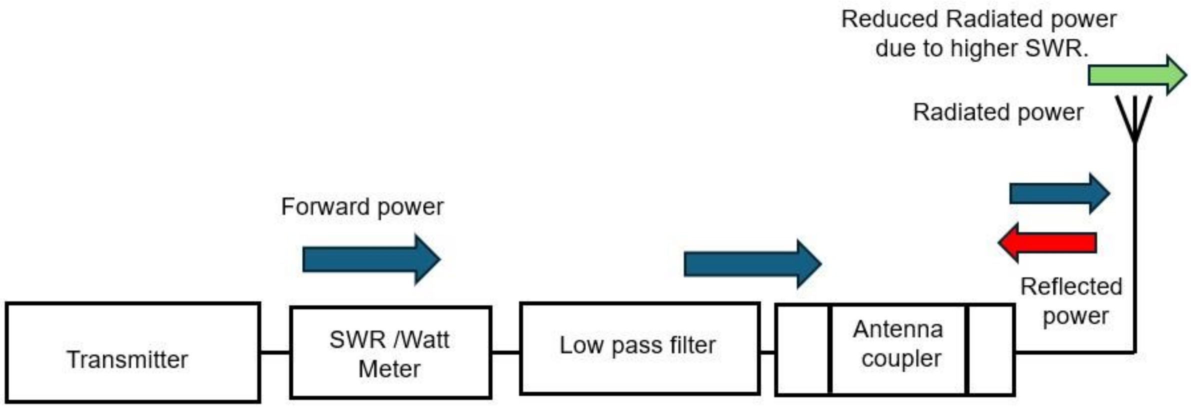


Figure 2 The real setup.

The antenna coupler's role is twofold.

- Match the output impedance of the transmitter to the input impedance of the antenna coupler. This ensures maximum power transfer from the transmitter to the antenna coupler.

- Match the output impedance of the antenna coupler to the input impedance of the antenna system.

What the antenna coupler cannot do.

- Tune the antenna.
- Alter the antenna systems feed point impedance ($Z_o$ + $Z_L$) or SWR.
- Alter the antenna's impedance ($Z_L$)
- Improve the efficiency of the antenna.
- Increase the power to the antenna beyond the transmitter power output. (The coupler is not an amplifier.)

**Coupler Types**

There are four common antenna coupler configurations (Figure 3).

1. The PI Network can produce resonance at more than one set of component values. The PI network can match a wide range of impedances and simple to implement.

2. The L-Network is a very popular configuration and can be found in many production antenna couplers. The L network depicted is not symmetric so best utilized in coax-to-coax antenna couplers.

3. The T network is widely used by the Amateur Radio community and is very simple. The design provides easier matching to the 50 Ohm load on the input side as well as wide range matching on the load side. The configuration in Figure 3 is unbalanced and used for coax-to-coax implementation.

4. The Balanced PI Network, shown in Figure 3, is the most complicated configuration and is required when a balanced output is called for when using Open Wire Feeder. The construction layout of this network requires the matching section floated above signal earth. Stray capacitance can impact the coupler's performance. NB: The BALUN at the input side, which is preferable to using a ferrite transformer on the output side where saturation and commensurate losses can be an issue.

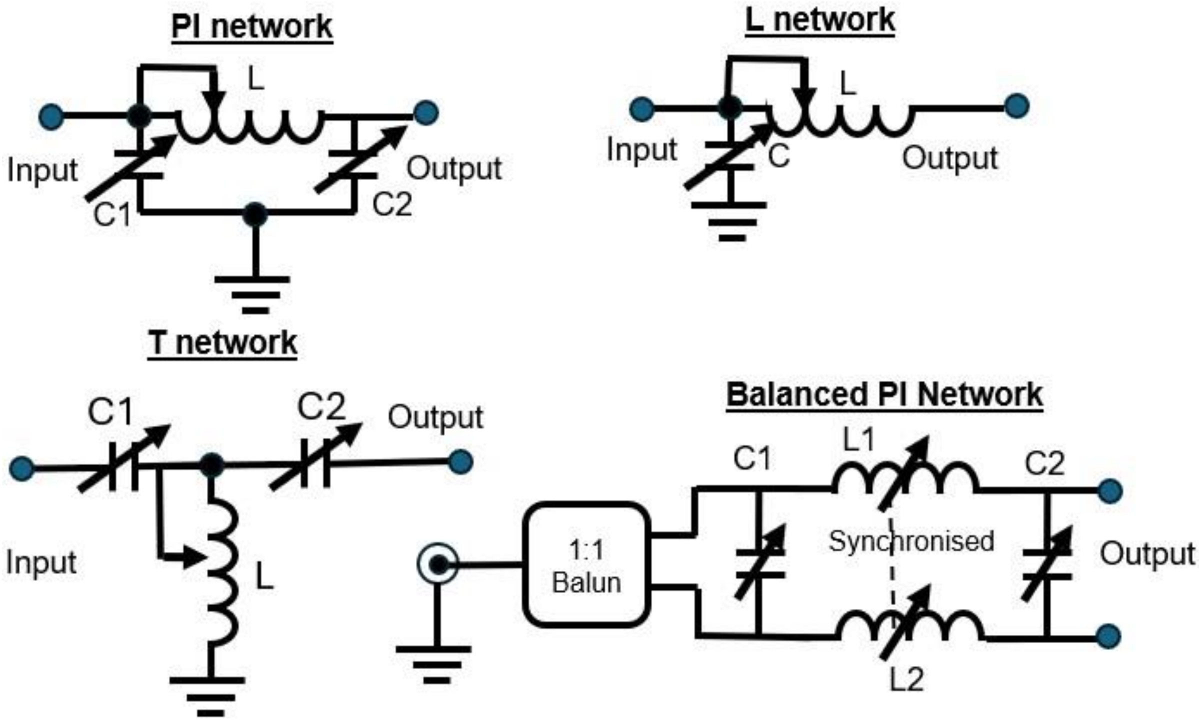

Figure 3 Antenna coupler configurations.

Figure 4 shows the internals of my antenna coupler, MFJ 945D, which uses the common T network configuration.

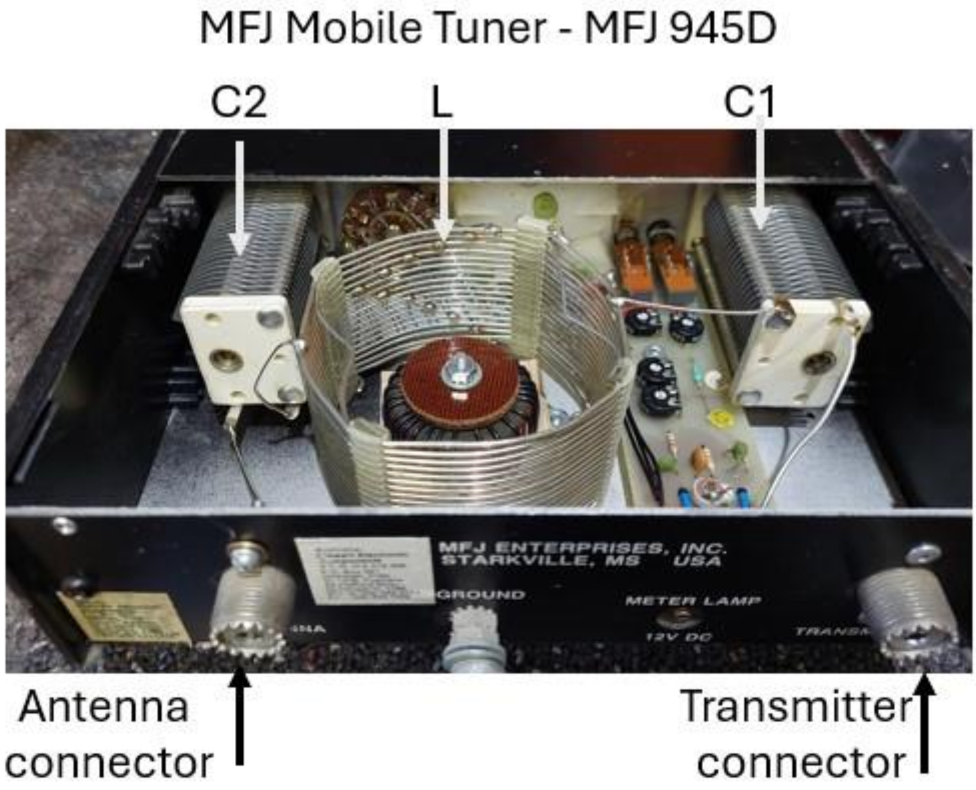

Figure 4 Antenna coupler internals.

**Characteristic impedance ($Z_s$, $Z_o$, and $Z_L$)**

Characteristic impedance can be calculated with the formula below.

$Z = \sqrt{\frac{L}{C}}$ **Example**: L = 0.254 υH and C = 101 pF gives a Z of 50 Ohms.

A complex impedance number has two parts. The first number is the resistance value and the number starting with j is the reactance component. Positive for inductive reactance and negative for capacitive reactance. A complex impedance figure would be shown as Z = 45 + j64. These numbers show there are 45 Ohms of DC resistance and 64 Ohms of inductive reactance as the number is positive.

A complex characteristic impedance is represented as $Z_O$* or $Z_S$*. I will tell you this bit, so the next bit makes sense.

**Conjugate match**

Conjugate matching is where the impedances on one side are opposite and equal to the impedances on another side thus cancelling each other out and allowing the maximum power transfer. A mouthful but read on and this will become clearer.

**How does the antenna coupler work?**

On the antenna coupler there are often three controls. On the input and output sides there is a variable capacitor ($C_1$ and $C_2$) and an inductor (L) control between. See the T network in Figure 3. Some coupler designs have fixed inductors and/or one capacitor.

**Input**

Let's look at the input first. We know the transmitter is looking for a 50-ohm load to transfer its power. By adjusting $C_1$ and L we can get an SWR dip. Say the transmitter has a complex impedance of 50 – j90 and the coupler, through the adjustment of $C_1$ and L, presents a complex impedance of 50 + j90, the complex numbers are opposite and cancel each other leaving 50 Ohms. This is a conjugate match.

**Output**

As the antenna is not operating on its centre frequency, the antenna will present a capacitive reactance ($X_C$) if too short or an inductive reactance ($X_L$) if the antenna is too long.

By adjusting $C_2$ and L on the output side of the coupler, a conjugate match is presented to the antenna.

**Coupler black box**

Looking at the antenna coupler as a black box as in Figure 5, the Transmit box is adjusted so the transmitter sees a pure 50 Ohm load without reactance. Now the Transmit box, through the Linking box, sees a mismatch at the antenna. The Antenna box is adjusted so the antenna sees an impedance equal to the antenna's impedance. The Linking box offers a compromise between the transmitter output resistance and the antenna input resistance. The antenna mismatch still exists and the antenna’s SWR has not changed.

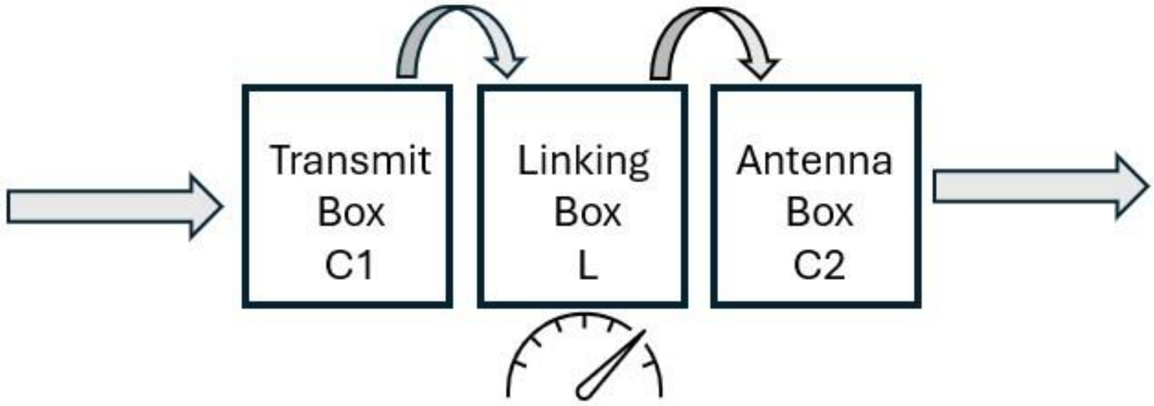


Figure 5 Antenna coupler as a black box.

**Coupler capabilities**

Couplers have varying capabilities. Figure 6 demonstrates the variability of a selection of couplers used to match the transmitter to an antenna.

**Typical HF Autotuners**

| BRAND | MODEL | Matching Range | SWR | Power |
|---|---|---|---|---|
| Elecraft | KAT500 | 5 to 500 Ohms | 10:1 / 10:1 | 600W |
| Elecraft | T-5 | 6 to 500 Ohms | 8:1 / 10:1 | 20W |
| LDG | Z-817 | 6 to 600 Ohms | 8:1 / 12:1 | 20W |
| LDG | Z-100+ | 4 to 800 Ohms | 12:1 / 16:1 | 125W |
| LDG | AT-200 PRO2 | 6 to 1000 Ohms | 8:1 / 20:1 | 250W |
| LDG | AT-600pro II | 6 to 800 Ohms | 8:1 / 16:1 | 600W |
| mAT | mAT-125E | 5 to 1500 Ohms | 10:1 / 30:1 | 120W |
| MFJ | MFJ-929 | 6 to 1600 Ohms | 8:1 / 32:1 | 200W |
| MFJ | MFJ-993B | 6 to 1600 Ohms | 8:1 / 32:1 | 300W |
| | | 6 to 3200 Ohms | 8:1 / 64:1 | 130W |
| MFJ | MFJ-994 | 12 to 800 Ohms | 4:1 to 16:1 | 300W CW |
| | | | | 600W SSB |
| MFJ | MFJ-998 | 12 to 1600 Ohms | 4:1 to 32:1 | 1500W |

Figure 6 Antenna coupler capabilities from Rick Westerman DJ0IP.

## Automatic or Manual

An automatic antenna coupler makes changing frequencies and antennas much easier, but you lose fine control of the adjustments. Automatic tuners integral to a transceiver tend to have relatively narrow impedance matching ranges, whereas external automatic and manual tuners tend to have much wider and useful ranges.

The downside with a manual antenna coupler is that it takes time to readjust the coupler for each change, however regular use overcomes this.

## Hazards

High RF voltages can develop on the transmission line and the antenna side of the coupler due to higher standing waves. Voltages inside the coupler can cause RF burns if operated while the case is open. Also, the high voltages can cause flashover or arcing in the coupler’s antenna stage. Starting on low power when tuning and increasing power gradually until you are confident the coupler will not arc over is the best approach.

## References and further reading.


1. Radio Handbook 16th Edition 1962 Page 450 Antenna Couplers (Orr)
2. Antenna Tuners - For Beginners - | HAM RADIO on Waters and Stanton Channel at www.youtube.com/watch?v=qRlxfzqm2Hk
3. Antenna Matchbox Shootouts. Rick Westerman DJ0IP/NJ0IP/G5BMH. www.dj0ip.com/ant-tun-sh-outs www.dj0ip.de www.dj0ip.com
4. HRN 199: Standing Up for Standing Waves on HamRadioNow - Bill Hays AE4QL's Video at (186) HRN 199: Standing Up for Standing Waves on HamRadioNow - YouTube
5. Z-Match. VK5BR www.qsl.net/vk5br/index.htm


**Have fun and stay safe.**