Jules' Workshop

Standard

Unit 15

TRANSMISSION LINES

ACMA Syllabus February 2024

Contents

Transmission lines 2
Types 2
Coaxial Cable (Coax) 2
Planar Transmission Lines (PCB-based) 2
Parallel Conductor Lines (Balanced Lines) 2
Waveguides 3
Amateur Radio Transmission Lines 3
Looking inside the cable 3
Transmission Lines 4
Schematics 4
Why 50 Ohms? 4
Characteristic impedance (Zo) 4
Transit Time and Velocity Factor 5
How does the transmission line work? 5
Terminations 6
Reflection Coefficient 6
Reflection coefficient and SWR 7
Transmission Line losses or Attenuation 7
Standing-Wave Ratio 8
VSWR 8
Power SWR 8
Comparison Table 9
Connectors 10
Baluns 11
Unun 13
49:1 or 64:1 Unun (End-Fed Half-Wave Antennas - EFHW) 13
Antenna Tuning Unit. 14

 © Jules Workshop 2026

Transmission lines

RF transmission lines (feeders or feedlines) are specialized conductors designed to guide radio frequency (RF) signals between points, such as a transmitter and antenna, with minimal loss.

Types

Coaxial Cable (Coax)

Structure: A central conductor surrounded by a dielectric insulator, a shield (outer conductor), and a protective jacket.

Use: The most common type for RF signalling, providing excellent shielding against electromagnetic interference (EMI).

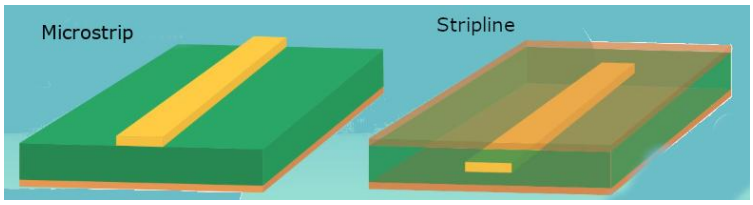
Planar Transmission Lines (PCB-based)

These are typically used on printed circuit boards (PCBs) at higher frequencies (up to 100 GHz+).

Microstrip: A conductor on one side of a dielectric board with a ground plane on the other. It allows easy access for component mounting.

Stripline: A conductor sandwiched between two ground planes, offering better shielding than microstrip.

Coplanar Waveguide: The conductor is on the same surface as the ground planes.



Parallel Conductor Lines (Balanced Lines)

Twin-Lead: Two parallel conductors embedded in plastic, commonly used for television antennas, often at 300 Ohms.

Ladder Line (Open Wire): Two conductors separated by plastic "rungs," minimizing dielectric loss, commonly used in ham radio.

Twisted Pair: Often used in communication, though more common at lower frequencies than high-power RF.

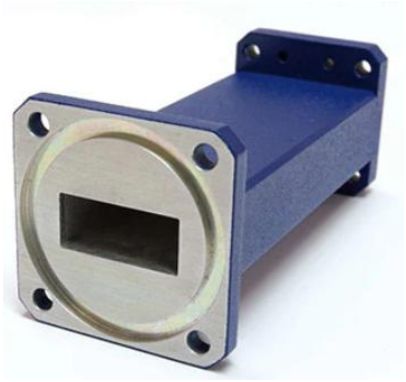
 © Jules Workshop 2026

Waveguides

Structure: A hollow metallic pipe.

Use: Used above 2 GHz, primarily for microwave applications where they provide lower attenuation than coaxial cables.

A waveguide is a special form of transmission line consisting of a hollow metal tube. The tube wall provides distributed inductance, and the empty space between the tube walls provide distributed capacitance. Wave guides conduct microwave energy at lower loss than coaxial cables. A picture of a wave guide is shown below.

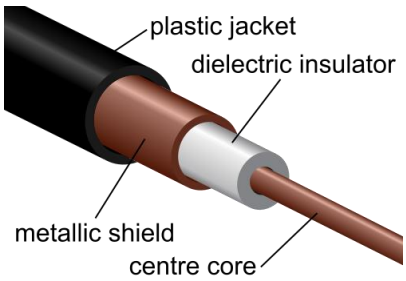


Amateur Radio Transmission Lines

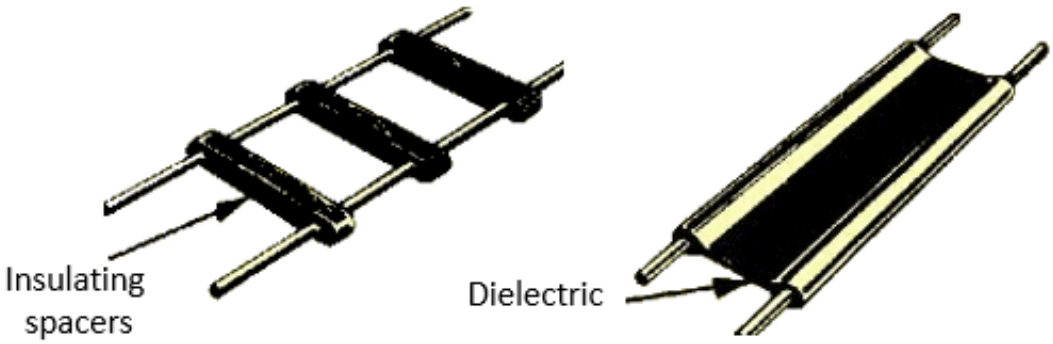
Transmission lines in the Ham world are usually balanced parallel line, such as ladder line or ribbon line or unbalanced coaxial cable.

Looking inside the cable

Coaxial cable (coax) has an inner conductor surrounded by a concentric dielectric then a plastic-coated metallic shield. The common impedance of coax for ham use is 50 ohms. The coax with 75 Ohms characteristic impedance is common in video and TV applications.



Parallel cable or ladder line consists of two parallel conductors separated by an insulator and has a characteristic impedance of 300 Ω, 450 Ω or 600 Ω.



 © Jules Workshop 2026

Transmission Lines

Schematics

Transmission line schematic drawings are shown below.

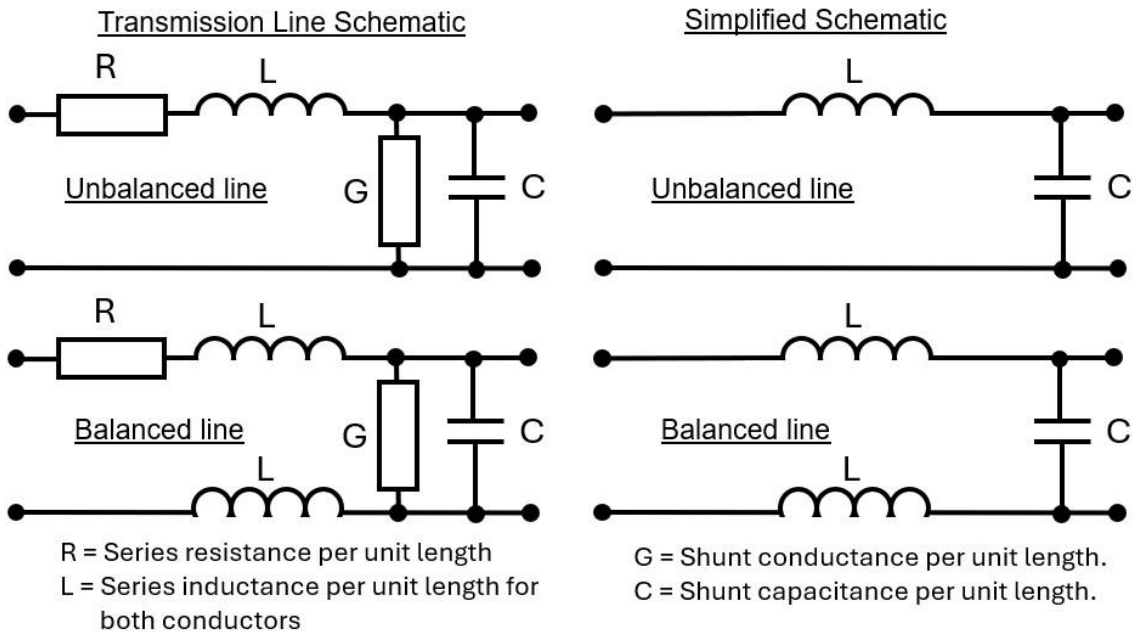


Figure 1 Transmission line model.

Figure 1 is a representation of transmission lines. The resistance (R) and conductance (G) are necessarily small otherwise the cable has too much loss. A simplified diagram of transmission lines negating the resistance and conductance, as used in most handbooks, is also shown in Figure 1. This diagram shows the series inductor (L) and the parallel capacitor (C).

Looking at the data sheet for coaxial cable RG58, we can see the real values for the series capacitance is 85.3 pF/M and the inductance is 0.254uH/m.

Why 50 Ohms?

In the 1930s, engineers developed transmission cables for very high power (kilowatts) radio stations. They found that 50 Ohms provided the best compromise between minimum losses, maximum power transfer and maximum voltage handling.

Characteristic impedance (Zo)

Characteristic impedance is the main feature of the cable that most hams are concerned about so let's explore what is impedance. Impedance is a complex number showing resistance and reactance. In Figure 2, resistance is the line to the right as we can only have positive resistance. Inductive reactance is the ascending line, and capacitive reactance is the descending line. The impedance number has two parts. The first number is the resistance value and the number starting with j is the reactance part. Positive for inductive reactance and negative for capacitive reactance. We will not be doing complex maths but remember the makeup of this number for later lessons.

 © Jules Workshop 2026

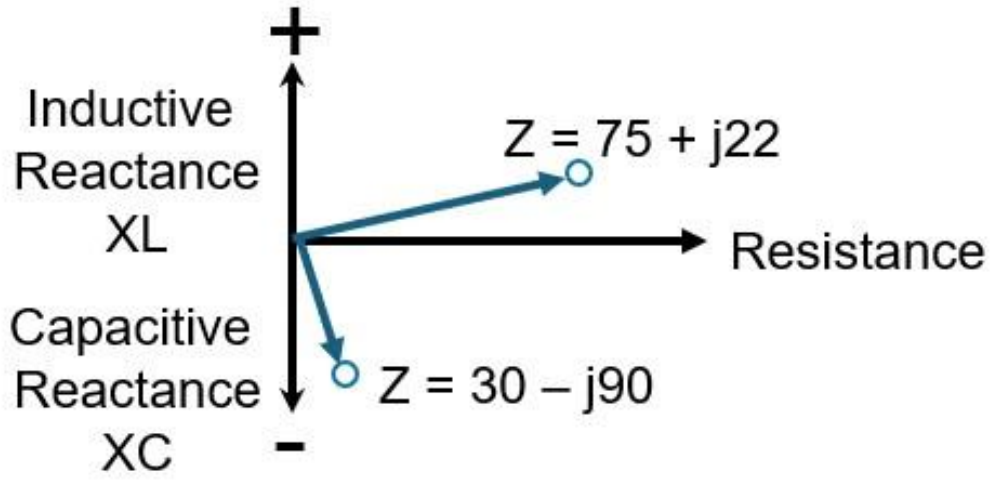


Figure 2 Impedance.

To measure the impedance, use an impedance analyser which measure complex electrical impedance as a function of frequency. Two measurements at a sweep frequency are needed. First measurement is between the centre conductor and shield with the other end of the line open. This results in a value $Z_{OC,}$ the Open Circuit Impedance.

Second measurement is between the centre conductor and shield with the other end of the line shorted between the centre and shield. This results in a value $Z_{SC,}$ the Short Circuit Impedance.

The characteristic impedance, Z_0, of a transmission line is the ratio of voltage and current of a single wave along the line. The wave is travelling in one direction without reflections in the other direction.

Transit Time and Velocity Factor

Radio waves in free space travel at speed of light 299,792,458 metres per second (m / s).

The velocity factor (VF) of a transmission line is the ratio of the signal in the line compared to the speed of light. The speed of radio signals in a vacuum is the speed of light, so the velocity factor is 1.0 (unity). Velocity

In the case of a hundred (100) meters of coax transmission line, the time to cover this length, in a perfect line, would be 333nS.

Cables are not perfect so there will be some reduction in speed.

In the case of the RG58U coax, the signal delay is 5.03nS/m or 503nS for 100 metres.

Total transit time for a signal in hundred metres of RG58U is 333 + 503 = 836nS.

$$333 / 503 = 0.66$$

The RG58U velocity of signal propagation is 66% slower than the free space signal.

Typical velocity factors range from 0.42 to 0.72.

Most transmission lines would be shorter than 100 metres so transit times for HF signals is not a concern. Most transmission lines would be shorter than 100 metres so transit times for HF signals is not a concern.

How does the transmission line work?

Looking at Figure 1, this represents the whole line. If we break the transmission line into smaller segments, as in Figure 4, and analyse how each segment works.

 © Jules Workshop 2026

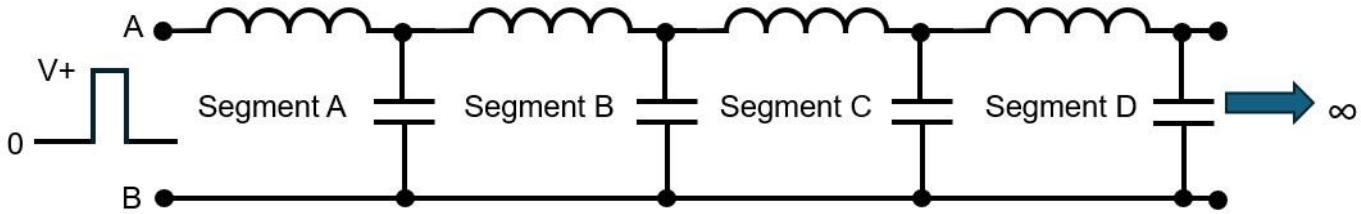


Figure 4 Line segments.

A pulse enters at point A and B on a transmission line of infinite length. Once the capacitor in segment A is charged the pulse moves down the line to charge the next capacitor and so on. The pulse is propagated along the line in this method. This charging of capacitors has a finite time, and this is where the delay of 5nS per metre, for the RG58U, originates.

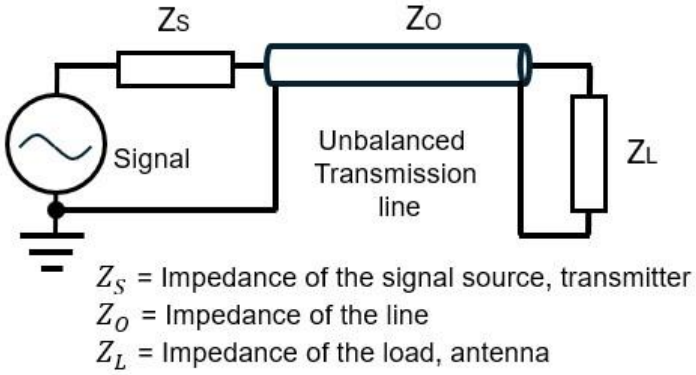


Figure 5 Load resistances.

Terminations

In Figure 5, the same transmission line is shown with source and load resistances.

- If Zs = Zo = ZL then all the power from the source will be radiated through the load.
- If Zs = Zo and ZL is open circuit (infinite resistance) then all the transmitted signal will be reflected to the source as a positive signal.
- If Zs = Zo and ZL is short circuit (0 resistance) then all the transmitted signal will be reflected to the source as a negative signal.

Examples: Zs = Zo = 50 Ohms and ZL is between 51 Ohms and infinity, the reflected signal will be positive.

Zs = Zo = 50 Ohms and ZL is between 49 Ohms and 0, the reflected signal will be negative.

Reflection Coefficient

The reflection coefficient (τ Tau) describes how much of a wave is reflected by an impedance discontinuity in the transmission line.

The reflection coefficient is equal to the ratio of the amplitude of the reflected wave to the incident wave, with each expressed as phasors.

In an electrical transmission line, to calculate how much of the electromagnetic wave is reflected by an impedance discontinuity. The reflection coefficient is closely related to the transmission coefficient.

 © Jules Workshop 2026

If a reflection coefficient is calculated that 20% of the wave's energy is reflected while 80% is transmitted. Since the reflection coefficient is positive, the phase of the reflected wave remains unchanged.

Reflection coefficient and SWR

The reflection coefficient describes how much of a signal wave is reflected by a mismatch in the transmission line.

Hang on, isn't that the SWR?

Yes, they are related.

The reflection coefficient and Standing Wave Ratio (SWR or VSWR) both quantify impedance mismatch on a transmission line.

The reflection coefficient is the complex ratio of reflected voltage to forward voltage, while SWR is the simple ratio of maximum-to-minimum voltage, ranging from 1 to infinity.

Transmission Line losses or Attenuation

The loss of power in a transmission line is specified in decibels per length and depends on the frequency of the signal. The cable manufacturer often supplies a chart showing the loss in dB/m at a range of frequencies. A loss of 3 dB corresponds to approximately halving the power.

This is the attenuation for RG58U cable. This is in dB per 100 metres.

Attenuation @ 20°c

Frequency (MHz)	Attenuation (dB/100m)	Frequency (MHz)	Attenuation (dB/100m)	Frequency (MHz)	Attenuation (dB/100m)
5	2.7	400	30.0	1000	51.8
10	4.1	500	34.2	1350	61.2
50	9.7	600	37.9	1500	65.6
100	13.9	800	45.1	1750	71.6
200	20.4				

 © Jules Workshop 2026

Standing-Wave Ratio

VSWR

VSWR stands for Voltage Standing Wave Ratio (VSWR), also referred to as Standing Wave Ratio (SWR), describes the ratio of signal voltage reflected from the antenna.

Any impedance mismatches in a transmission line result in standing waves along the transmission line. SWR is the ratio of the maximum to minimum voltage on a transmission line. SWR is measured using a dedicated SWR meter.

If $Z_S = Z_O = Z_L$ and you looked at the antenna signal with an oscilloscope, you would see a perfect sine wave. All the power is transmitted to the antenna. This is a matched condition.

Now if there is a mismatch and the forward voltage is 100 V and the reflected voltage is 50 V, this is an SWR of 2:1. The reflected signal of 50 V adds and subtracts from the original signal as the waves go in and out of phase. Measuring voltages along the line, the voltages would vary from 50 V to 150 V. So, now the reflected signal of 50 V is third or 33% of the maximum voltage on the line.

Power SWR

The power of the forward and reflected waves are proportional to the square of the voltage due to each wave, SWR can be expressed in terms of forward and reflected power.

The SWR is a measure of how much power is delivered to an antenna but does not mean that the antenna radiates all the power. A low SWR means the antenna is well-matched but does not indicate that the power delivered to the antenna is also radiated.

 © Jules Workshop 2026

Comparison Table

VSWR	Voltage Refected %	Power Reflected %
1.0 : 1	0	0
1.1 : 1	5	0.2
1.2 : 1	9	0.8
1.3 : 1	13	1.7
1.4 : 1	17	2.8
1.5 : 1	20	4
1.6 : 1	23	5.3
1.7 : 1	26	6.7
1.8 : 1	29	8.2
1.9 : 1	31	9.6
2.0 : 1	33	11
2.5 : 1	43	18.4
3.0 : 1	50	25
4.0 : 1	56	36
5.0 : 1	67	44.4
10.0 : 1	82	67

 © Jules Workshop 2026

Connectors

Choice and use of the correct connector for the cable is important.

Picture from the ACMA.

N Type - The N connector is used to join coaxial cables capable of carrying microwave-frequency signals up to 11 GHz.

PL259 and SO-259 – These are the most common type of RF connector. The name "UHF" is a source of confusion as the connectors were named when UHF when "UHF" meant frequencies over 30 MHz.

BNC - The BNC connector is a quick twist-to-lock design, where two lugs on the female connector engage slots in the shell of the male connector. BNC connectors are available in 50-ohm and 75-ohm versions and is suitable for signals up to about 2 gigahertz and 500 volts.

SMA – SMA (Sub Miniature version A) connectors are RF connectors with a screw-type coupling mechanism with a 50 Ω impedance. SMA connectors are most commonly used in microwave systems, hand-held radio and mobile telephone antennas and Wi-Fi.

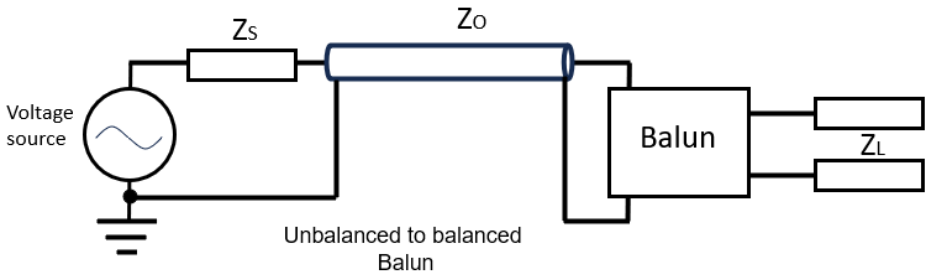
 © Jules Workshop 2026

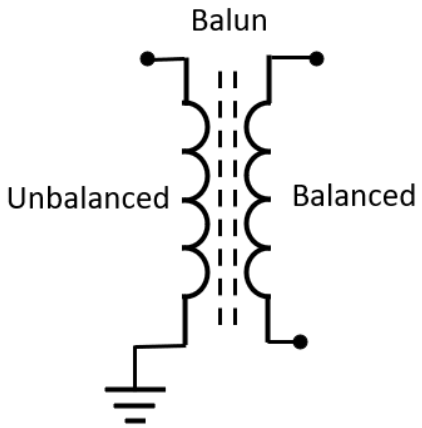
Baluns

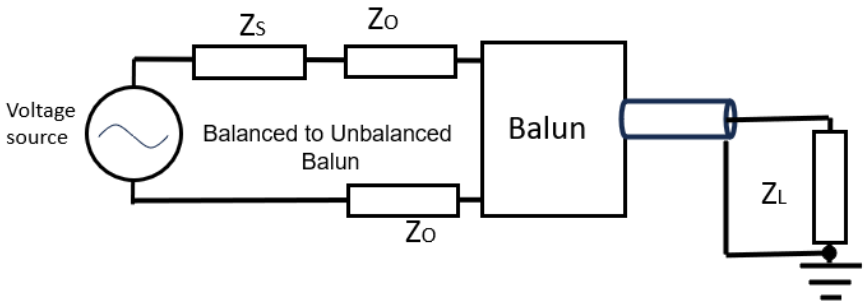
A balun, derived from the mix of the words balanced to unbalance. A balun is a device that allows balanced and unbalanced lines to be connected without disturbing the impedance of either line.

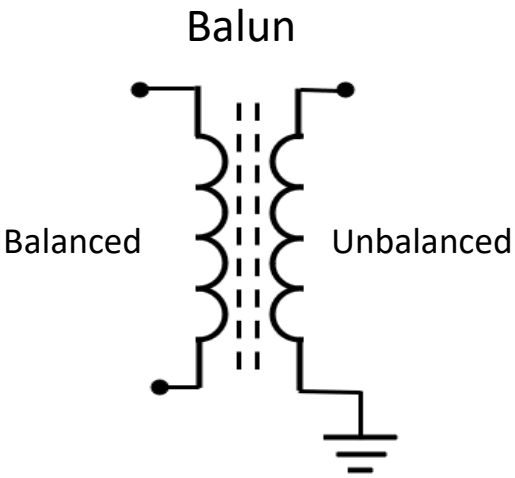
In amateur circles there are many types and configurations of baluns. We will only focus on the transformer type balun.

A balun can work both ways. Transforming an unbalanced line to a balanced line or transforming a balanced line to unbalanced.

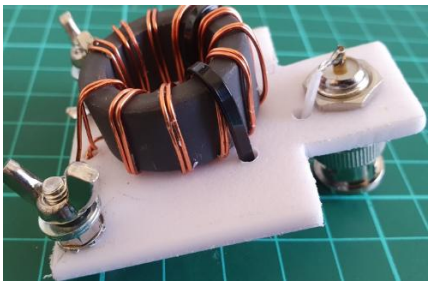








 © Jules Workshop 2026



)

Unun

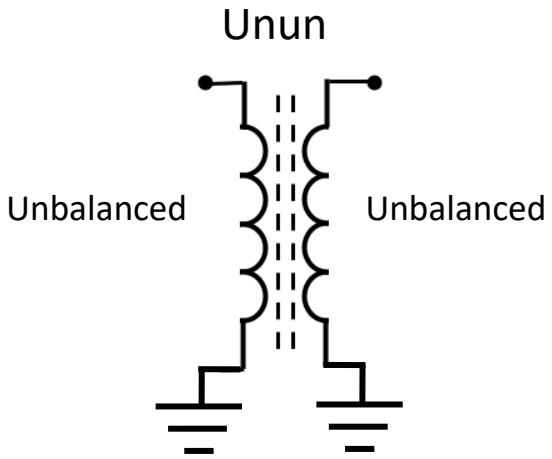
An Unun is a device that matches an unbalanced line to another unbalanced line. Ununs are often used if an unbalanced feedline is driving an unbalanced antenna. A whip antenna with a low input impedance would benefit from an impedance transforming Unun to efficiently couple a 50Ω feedline with the antenna.

49:1 or 64:1 Unun (End-Fed Half-Wave Antennas - EFHW)

Use Case: End-Fed Half-Wave antennas have very high impedance at their feed point (often 2450–5000 ohms).

Example: A 49:1 unun is used at the base of an EFHW antenna to match that high impedance down to 50 ohms for 40m–10m bands.

Construction: Usually requires a toroidal core, a specific winding ratio, and a capacitor across the output to improve efficiency on higher bands.

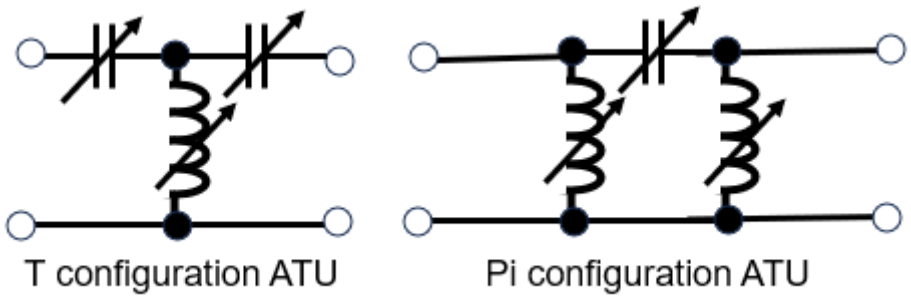


 © Jules Workshop 2026

Antenna Tuning Unit.

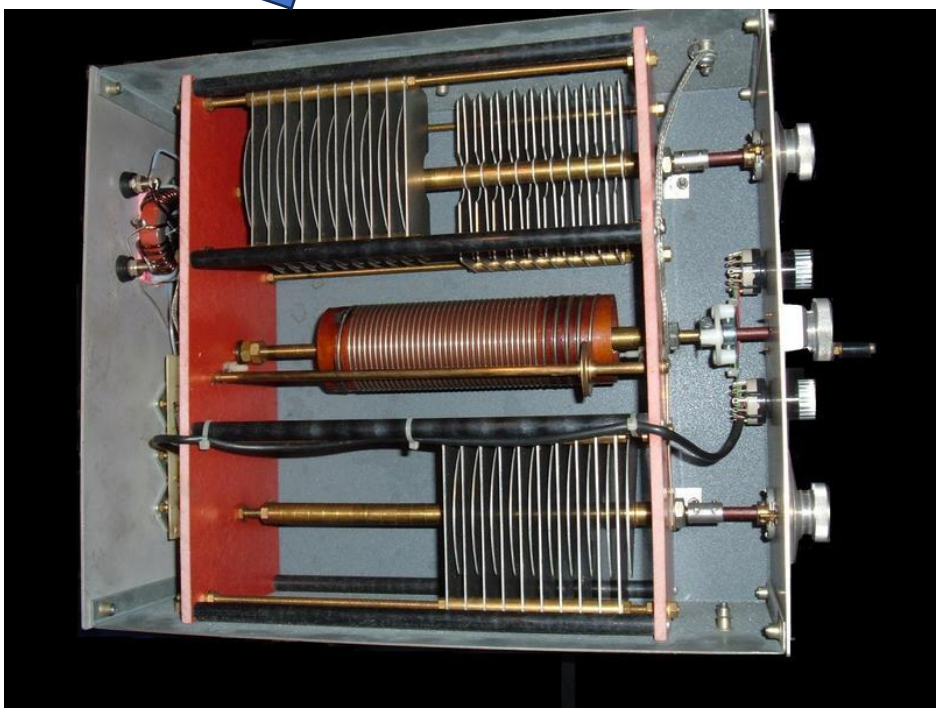
An antenna tuning unit does not change the antenna. This is why the ATU are referred to as Antenna Matching Units (AMU). The ATU or AMU make the transmitter think it is connected to the ideal transmission line (Z_O) and antenna (Z_L). The ATU has variable inductors and capacitors to provide the transmitter with the correct impedance.

Two common configurations are shown below.



T configuration ATU

Pi configuration ATU



Go to Unit 15 questions.

 © Jules Workshop 2026