Baluns
Part 1

Many times the use of a balun is recommended for proper performance of an antenna system. Within the amateur radio community baluns have three main functions.

- First, they convert an antenna feedpoint or a parallel transmission line from a balanced circuit to a single-ended unbalanced configuration. The single-ended unbalanced configuration is necessary for cables and equipment using coaxial connectors in which the outer conductor is connected to ground somewhere in the system.

- Second, often we employ baluns to attenuate or avoid common-mode currents to keep them out of equipment and off the surface of coaxial cable sheaths.

- Third, we employ some baluns to transform load impedance values to an alternative value. There are many designs for baluns capable for various impedance ratios from 1:1 upward, whereas the most usual impedance ratio is 4:1. But depending on the need and circumstances, other transformation ratios are available such as 6:1 and 9:1.

More than often baluns are also described as a choke, current or voltage type. Some explanation is needed here to see the forest from the trees. First of all, what is a balun? The name balun is short for **Balanced** to **Unbalanced** and each part is pronounced the same way as in the separated words and not as "*balloon*" more than often heard**.** A balun is a device which somehow connects a balanced load to an unbalanced transmission line.

Balanced – Unbalanced

When is an antenna system balanced or unbalanced and what is then balanced or unbalanced? In real live an antenna system is practically never balanced. Antenna handbooks show us as example: a simple dipole, fed at the exact center, with electric field lines neatly connecting the opposite halves and magnetic flux lines looping around the wires. **Figure 1(A)** is a picture of a perfected version to show only the electrical field lines for clarity. Everything is symmetrical and the system is said to be "*balanced*" with respect to ground.

The reality of a typical antenna installation is very different as seen at **Figure 1(B).** The electric field lines connect not only with the opposite half of the dipole, but also with the feedline, the ground and any other nearby object. The magnetic field (not shown) may be less disturbed, but its overall picture is in no way symmetrical. The electromagnetic coupling between the opposite halves of a horizontal dipole makes the antenna balanced in theory. But the coupling has to compete with the distorting effects of the asymmetrical surroundings. As a result, practical antennas can be very susceptible to the way they are installed and are hardly well-balanced. By being unbalanced the currents on both halves will be different.

In contrast with the messy environment of the antenna the story is different inside a coax cable, **Figure 2.** The currents on the center conductor and the inside of the shield are equal and opposite (180° out of phase). The two conductors are closely coupled along the entire length, so the equal and opposite current relationship is strongly enforced. What is going on inside the cable is totally independent of the situation outside. The skin effect causes HF currents to flow only close to the surfaces of the conductors. The inner and outer surfaces of the coaxial shield behave as two entirely independent conductors. The cable may be taped to a tower or even buried while the currents and voltages inside the cable remain exactly the same.

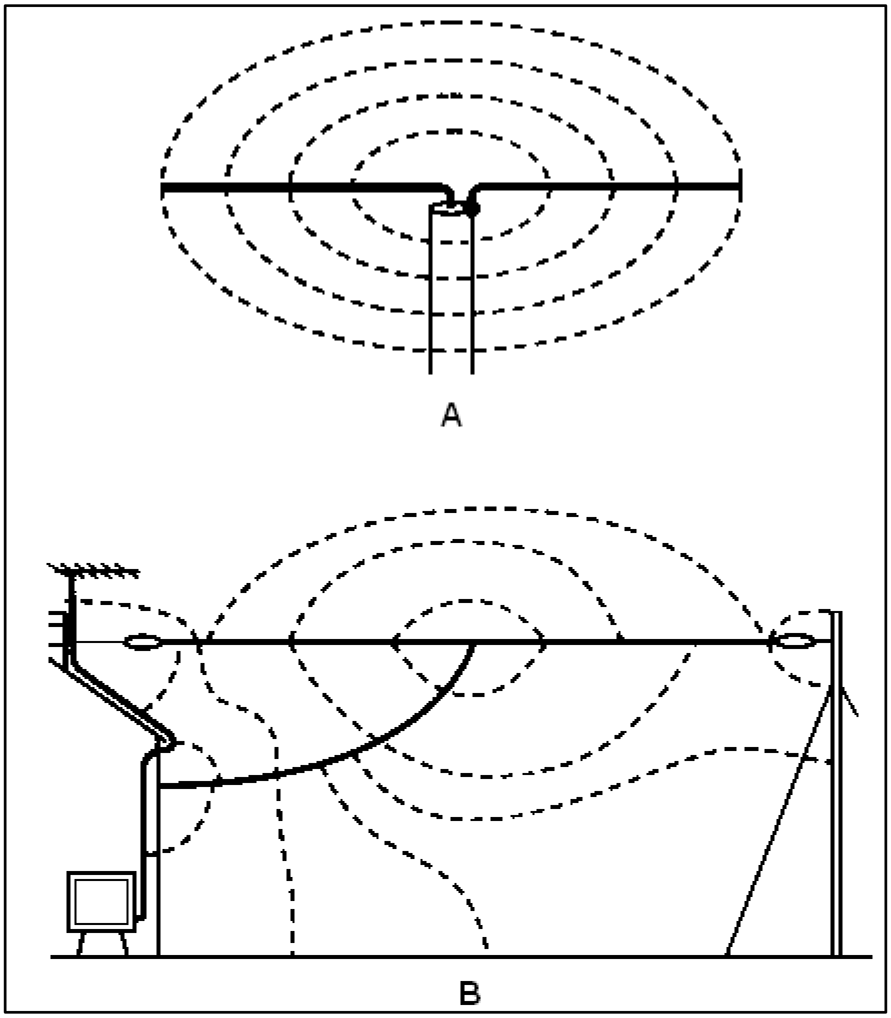

Figure 1. *(A) Picture with ideal view of the electric fields around a coaxial fed dipole.(B) The typical reality.*

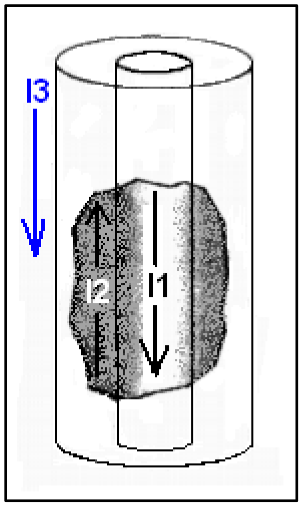

***Figure 2**. Currents on the inside of a coax cable **(I1 and I2)** are equal and in opposite phase. Being **I1** the current on the inner conductor and **I2** the current on the inside of the cable shield due to the skin effect. But curtain conditions may and shall induce or allow a current **(I3)** to flow on the outside of the coax cable shield.*

The problem arises when connecting a coaxial cable to an antenna. If the antenna is in any way unbalanced, which it will be in any practical situation, a difference will appear between the currents flowing in the antenna at either side of the feedpoint, **Figure 3.** Current **I1** and **I2** from the transmitter flow on the inside of the coax. **I1** flows on the outer surface of the coax's inner conductor and displayed as the current flowing in the dipole arm 1. However, the situation is different for the other dipole arm 2. **I2** flows on the inner surface of the coax shield. Once the current **I2** reaches the end of the coax, it splits into two components. **I4** is going directly into dipole arm 2 and **I3** is flowing down on the outer surface of the coax shield. Here also, because of skin effect, **I3** is separate and distinct from the current **I2** on the inner surface. Therefore, the current in dipole arm 2 is equal to the difference between I**2** and **I3**.

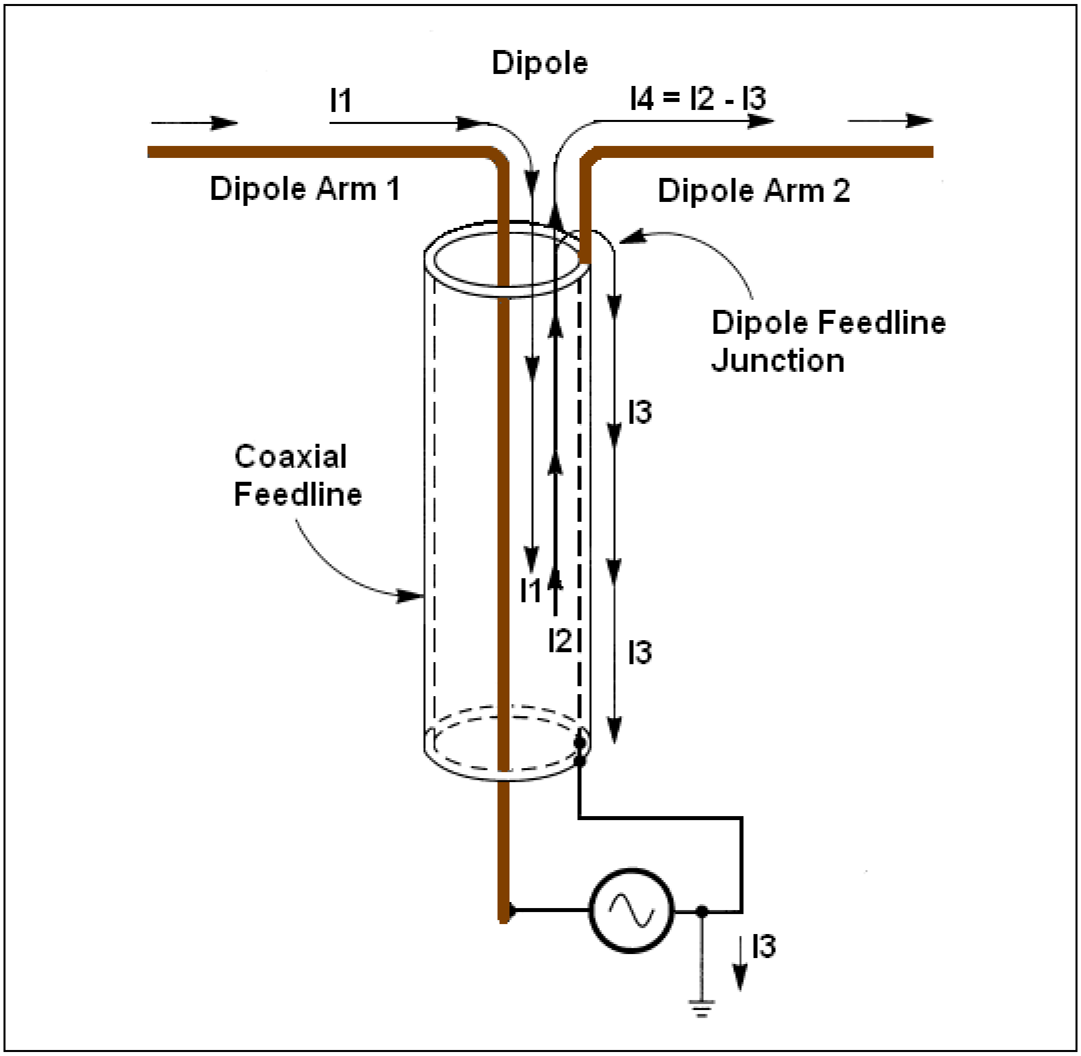

***Figure 3**. If the antenna currents on either side of the feedpoint (arm 1 and arm2) are unequal, the difference I1 – I2 = I3 will flow down the outside (outer shield) of the coax cable.*

I3 causes not only an imbalance in the amount of current flowing in each arm of the otherwise symmetrical dipole it will also force the coax to radiate by itself. This radiation due to the current **I3** would be mainly vertically polarized since the coax feedline is mainly vertically installed. The feedline radiation causes distortion of the radiation pattern, RF current on metal masts and Yagi booms plus problems with stray RF in the shack. Even worse, the RF currents may flow in the mains and on TV cables leading to all sorts of EMC problems. This **I3** current is named the *common-mode current*. The antenna arm which is connected to the coax shield where the **I3** current might flow and the outer coax shield itself form, in fact, a second antenna and will also produce an impedance. This impedance, seen looking down the outside surface of the coax outer shield to ground, is called the *common-mode impedance*. How the current is distributed on the dipole either feed balanced or an unbalanced is illustrated in **Figure 4.**

The common mode impedance will depend on the coax length toward the transmitter and the length of the path from the transmitter chassis to the RF ground. The path from the transmitter chassis to ground may go through the station grounding bus, the transmitter power cord, the house wiring and even the power line’s service ground. In other words, the overall length of the coaxial outer surface and the other parts making up the ground can actually be quite different from what you might expect or want.

A worst case common mode impedance will occur when the effective path to ground is an odd multiple length of λ/2, making this path a half-wavelength resonant. In this case, we have a sort of transmission line transformer that practically short circuits the antenna arm that is connected to the coax shield and resulting in a very low impedance at the antenna feedpoint. **I3** will be a most significant part of I**2,** and as such, little current will flow in one half of the dipole antenna. Another extreme situation that might occur is when the overall effective length of the coaxial feedline to ground is an odd multiple length of λ/4. The common mode impedance transformed to the feedpoint is then high in comparison to the dipole’s natural feedpoint impedance. In this case, **I3** will be small in comparison to I2 meaning that the radiation by **I3** itself and the imbalance between the two dipole arms (I1 and I4) will be minimal. Between these two extreme cases of imbalance (odd multiple length of λ/2 or λ/4), other lengths will create common mode impedances between extreme low or extreme high. That is why and the reason that the SWR measured at the bottom end of the coax transmission line shall change (increasing or decreasing) when shortening or lengthening the coax line. So, a varying SWR measurement with varying coax cable length is always an indication of common mode current flowing on the outside shield and the fact that the antenna is unbalanced.

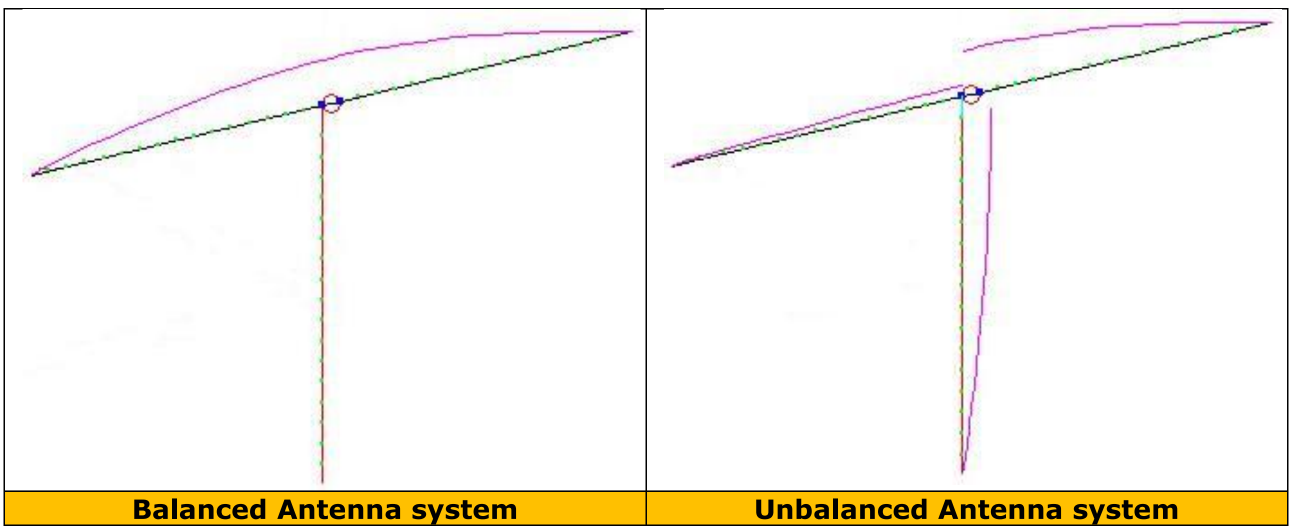

Figure 4*. The currents on two dipoles: one with a balanced feed the other with an unbalanced feed. As can be noticed is that the current on one arm of the unbalanced system is significantly reduced, and instead, now a part of the current now on the transmission line itself. As a result the unbalanced antenna system will have worse radiation properties.*

Asymmetrical routing of the feedline

In **Figure 5** a symmetrical located coax cable is considered showing one that drops vertically at a 90° angle directly below the feed point of a symmetrical dipole. That situation is seldom met and mostly the coax cable will be in a slanted position or asymmetrically routed toward the shack.

Such a situation is illustrated in **Figure 5.30** where the feedline is routed toward the transmitter at a 45° angle from the dipole. Here one side of the dipole can radiate more strongly onto the feedline than can the other half. Thus, the currents radiated onto the feedline from each half of the symmetrical dipole will not cancel each other. So, the antenna itself radiates a common mode current onto the coaxial outer shield. The inner surface of the coax shield and the inner conductor are shielded from such radiation by the outer braid. This is a different form of common mode current from what was discussed above but have similar effects. The outer surface of the braid carries common mode current radiated from the antenna and then subsequently reradiated by the feedline. Also, as explained earlier, the antenna and its environment are not perfectly symmetrical in all respects and there will also be some degree of common mode current generated on the transmission line.

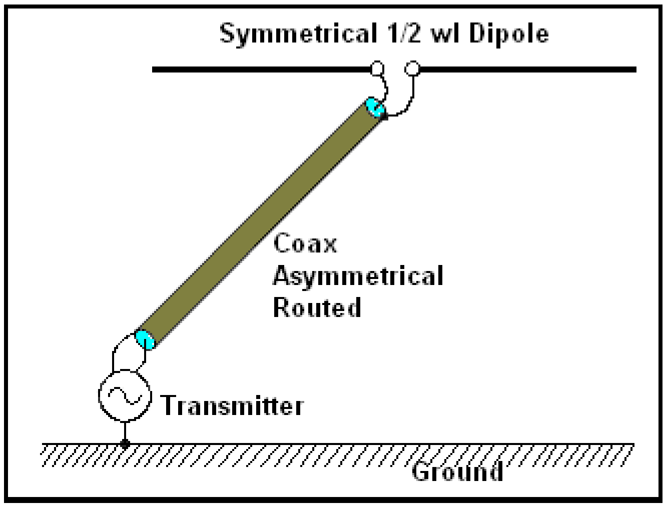

Figure 5*.Coaxial transmission line asymmetrically routed from a symmetrical dipole.*

What is the impact when common mode current exists? **Figure 6** shows the azimuthal radiation patterns of either a dipole without feedline common mode current as the transmitter should been located right at the feedpoint, (the solid line) and the pattern for the same dipole as affected by common mode current (the dashed line) on its feedline due to the use of unbalanced coax feeding a balanced antenna. The patterns are for a 20-meter band dipole installed at a λ/2 height above average ground. The reference dipole displays a classic figure-8 pattern. Both side nulls dip symmetrically as is typical for a 20-meter dipole at a half wavelength above ground.

Many amateurs will suggest that the unbalanced pattern asymmetry does not look very significant or important and they would be right. Even more, most dipole antennas used by amateurs are for the low HF bands (80 and 40 meters) and the azimuthal pattern of such a dipole will show practically equal radiation all around. The figure-8 pattern will be for those bands hard to achieve because it's very difficult to install the dipole at least at a λ/2 height. No doubt around the world is many thousands of coax-fed dipoles in use where no effort has been made to negate the common mode current or being unbalanced.

But the story is completely different for antennas that are specifically designed to be highly directional, such as a Yagi or a quad. Much care is usually taken during design of such directional antennas to tune each element in the system for the best compromise between directional pattern, gain and bandwidth. What would be the result should we feed such a well-designed directional antenna in a fashion that creates common mode feedline currents? Here the pattern deterioration resulting from common mode currents will be significant and not to be ignored, **Figure 7a, 7b.** The solid line represents the reference Yagi, where it is assumed that the transmitter is located right at the balanced driven element. The dashed line represents the Yagi fed with a unbalanced coaxial line routed to ground directly under the balanced driven element's feedpoint.

The minor pattern skewing evident in the case of the dipole now deteriorates in the rearward and sideward directions of the otherwise superb pattern of the referenced Yagi. In other words, the front to back and side to side ratio is much worse. Here is clearly seen the pattern that is supposed to be from a highly directional antenna can be seriously degraded by the presence of common mode currents on the coax feedline.

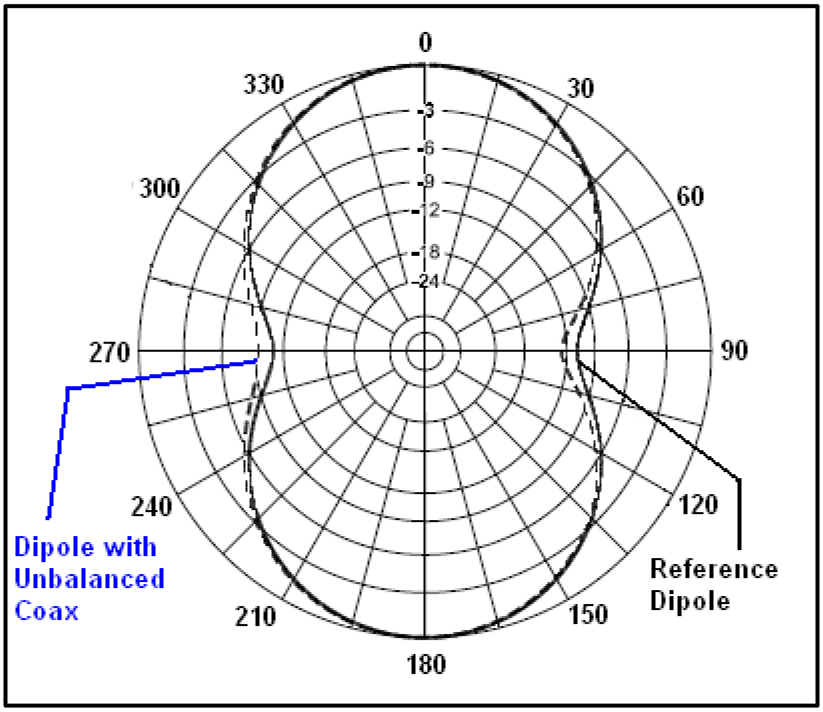

***Figure 6**. Comparison of azimuthal radiating patterns of two λ/2 long 14-MHz dipoles mounted λ/2 over average ground.*

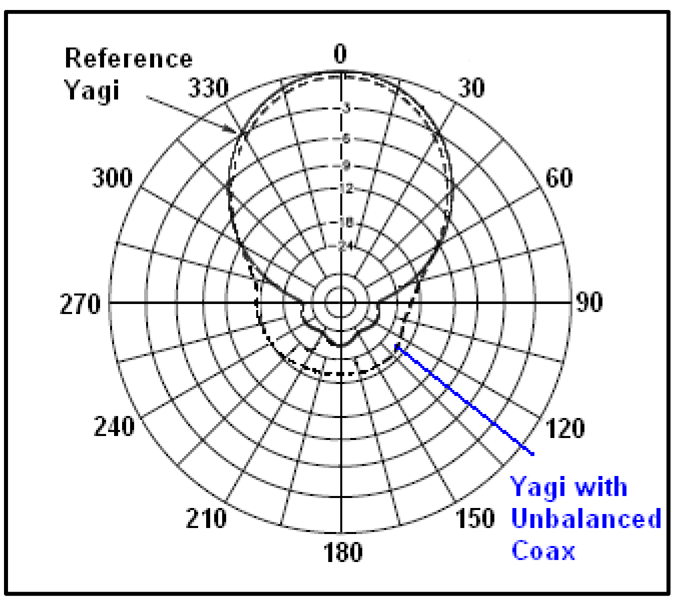

***Figure 7a**. Comparison of azimuthal radiating patterns of two highly directional Yagi's mounted λ/2 over average ground.*

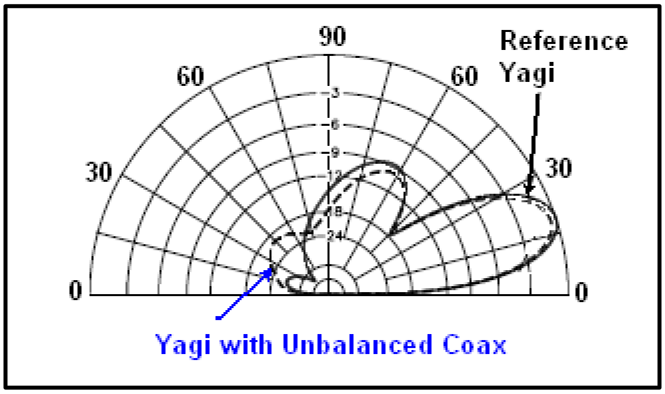

***Figure 7b**. Comparison of elevation radiating patterns of two highly directional Yagi's mounted λ/2 over average ground.*

Common mode currents or unbalancing will practically always exist in particular with a coaxial feedline. However, unbalancing can also exist with symmetrical parallel feedlines as with OCF (Off-Center Fed) antennas. How to prevent or eliminate the common mode current is the next coming subject.