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.

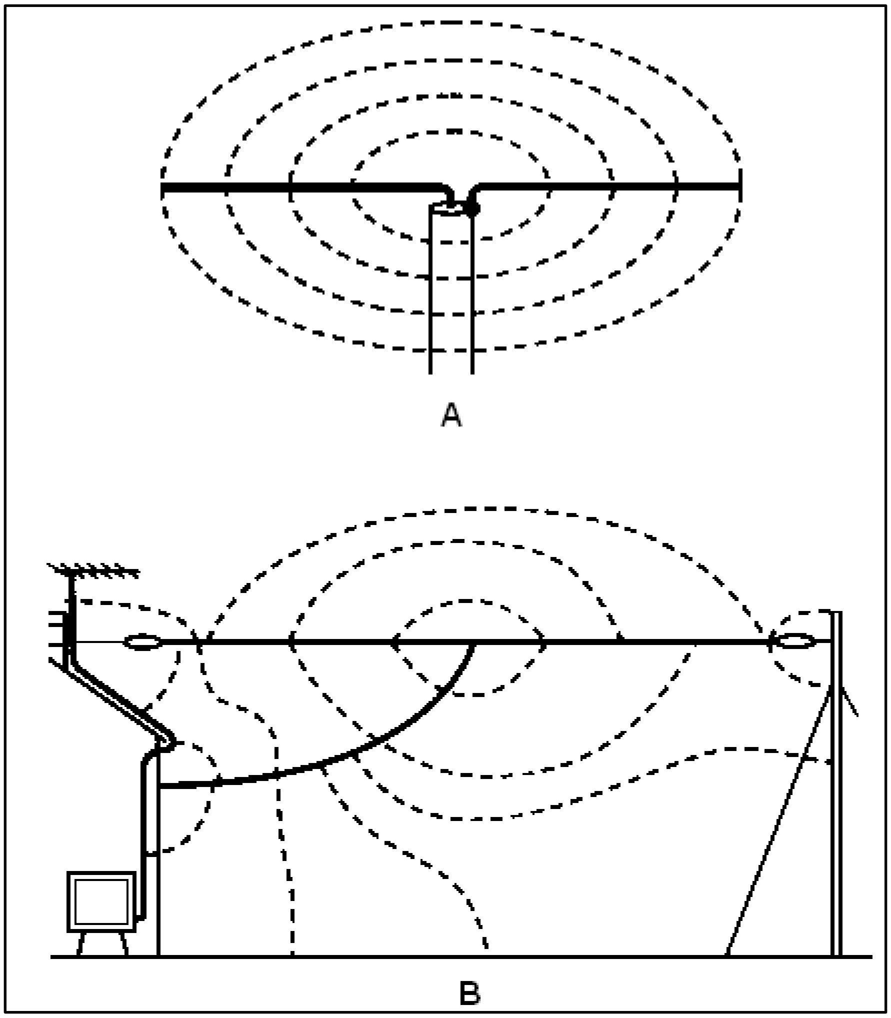


***Figure 1**. (A) Picture with ideal view of the electric fields around a coaxial fed dipole.(B) The typical reality.*

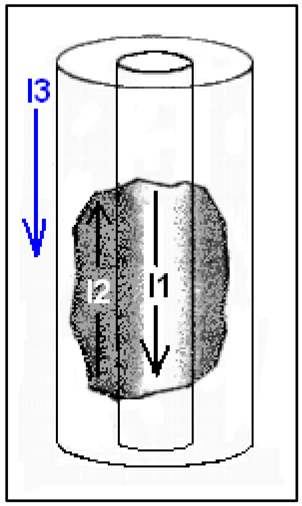


***Figure 2**. Currents on the inside of a coax cable **(I1 and I2)** are equal and in opposite phase. Being **I1** the current on the inner conductor and **I2** the current on the inside of the cable shield due to the skin effect. But curtain conditions may and shall induce or allow a current **(I3)**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

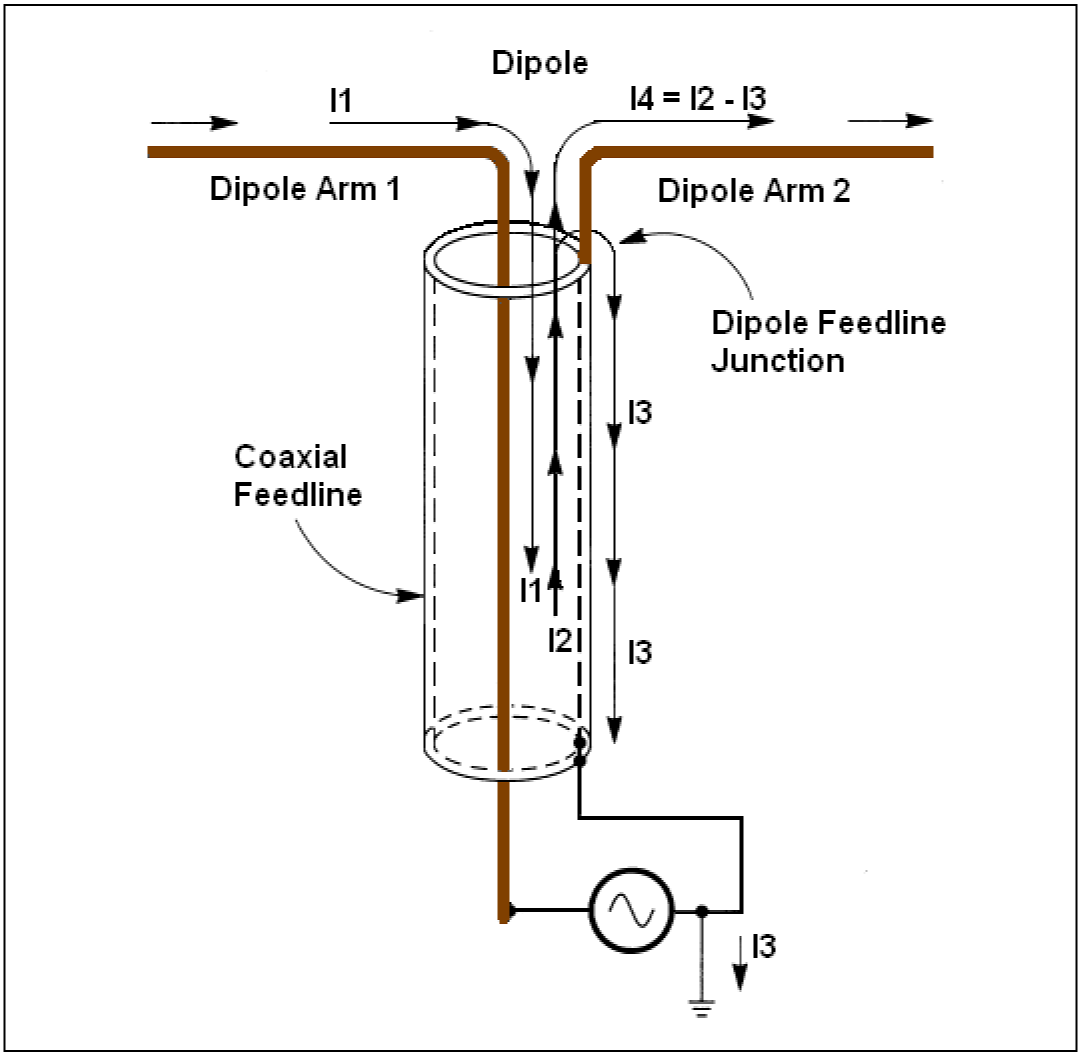
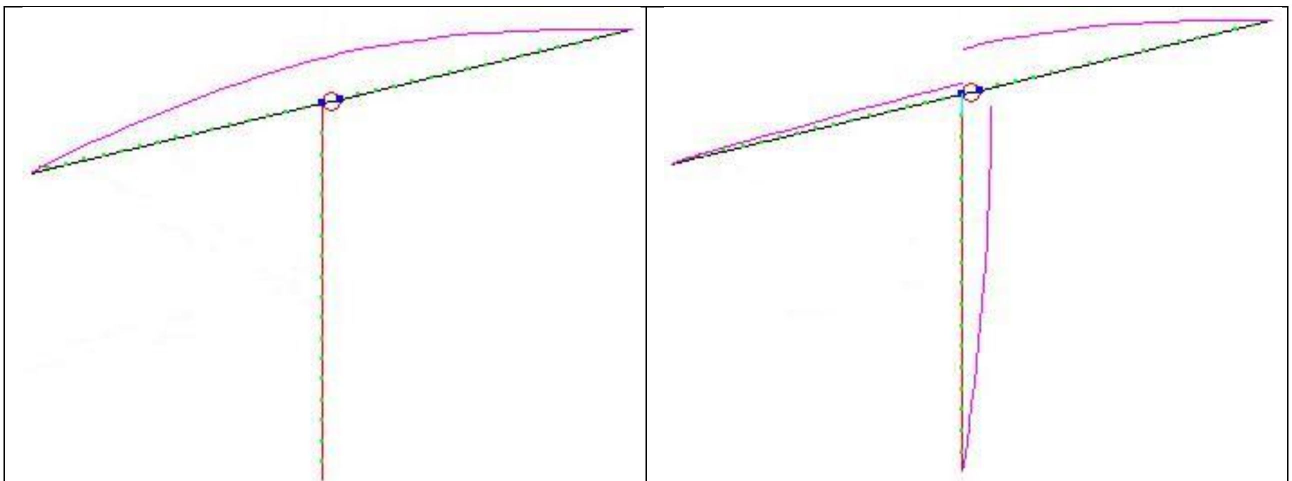


Figure 3*. If the antenna currents on either side of the feedpoint (arm 1 and arm2) are unequal, the difference I1 – I2 = I3 will flow down the outside (outer shield) of the coax cable.*

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.



Balanced Antenna system	**Unbalanced Antenna system**

***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.

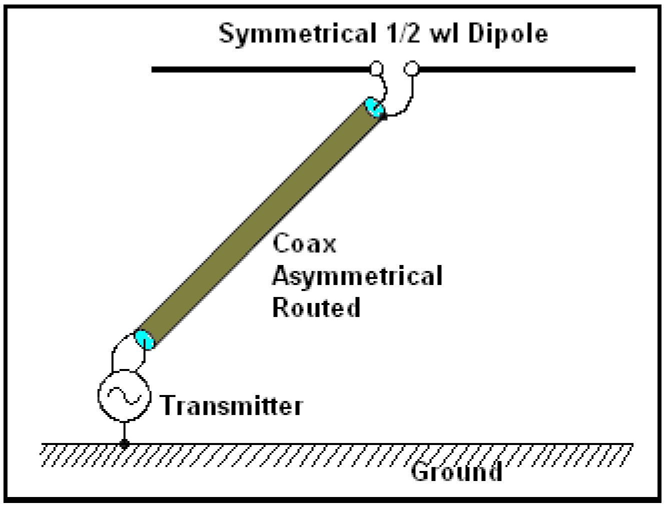


Figure 5.*Coaxial transmission line asymmetrically routed from a symmetrical dipole.*

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.

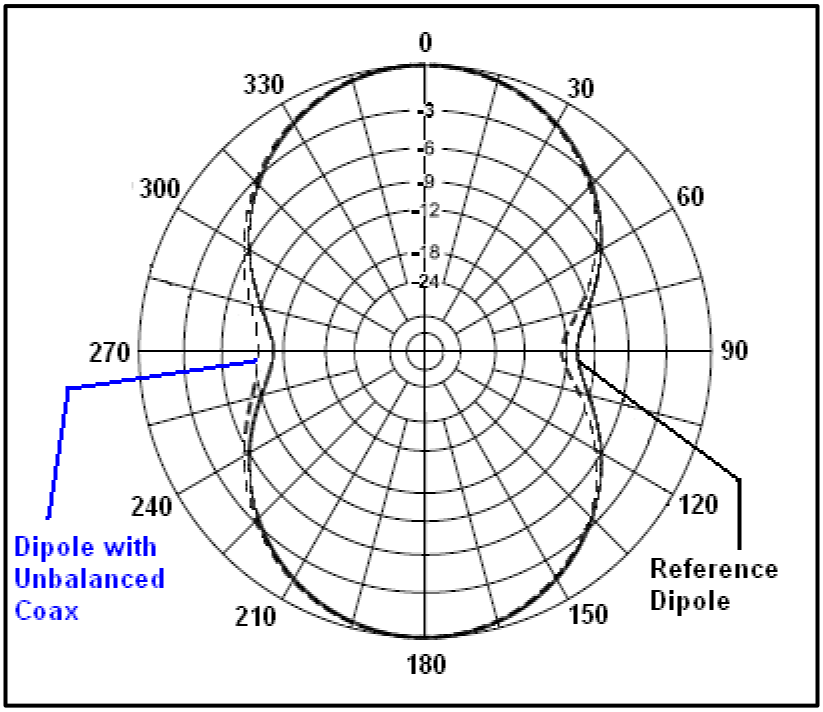


***Figure 6**. Comparison of azimuthal radiating patterns of two λ/2 long 14-MHz dipoles mounted λ/2 over average ground.*

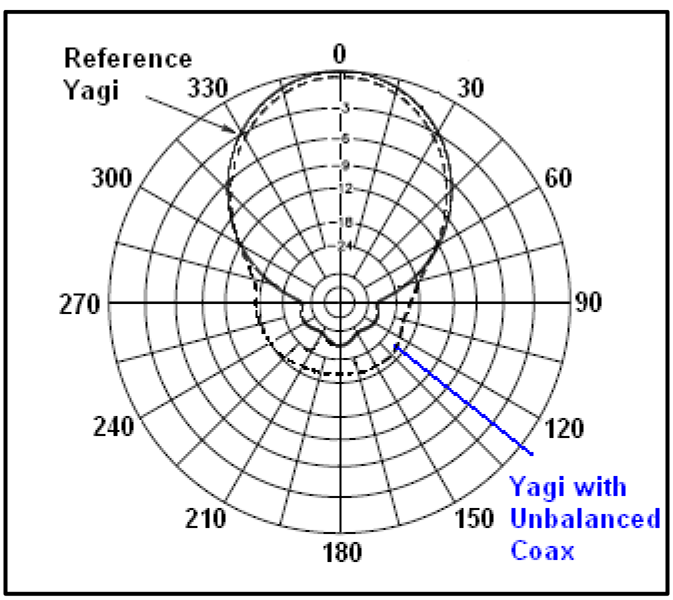


***Figure 7a**. Comparison of azimuthal radiating patterns of two highly directional Yagi's mounted λ/2 over average ground.*

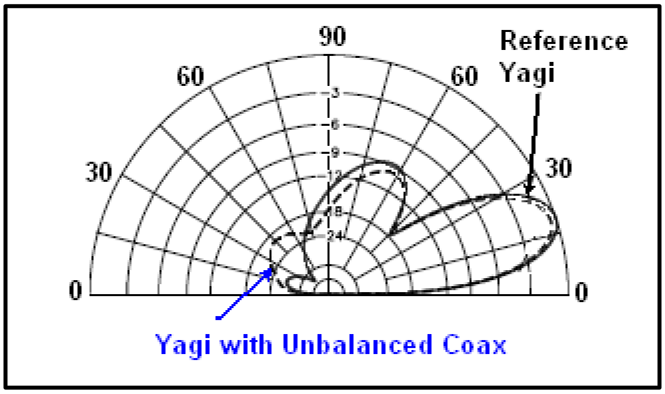


***Figure 7b**. Comparison of elevation radiating patterns of two highly directional Yagi's mounted λ/2 over average ground.*

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.

Baluns
Part 2

It is usually advisable to limit or cancel as much as possible, the common mode current on the antenna feedline. A device called a balun can be used to eliminate common mode currents. As mentioned in the preceding episode, baluns come in a variety of forms which we will explore in this section and in the next episode. The term balun applies to any device that transfers differential mode signals between a balanced system and an unbalanced system while maintaining symmetrical energy distributed at the terminals of the balanced system. The term applies only to the function of energy transfer and not to how the devise is constructed. The balanced-unbalanced transition can be done in different ways: through symmetrical transmission line structures, flux-coupled transformers or simply by blocking the unbalanced current flow.

Baluns are often described as *current balun* or *voltage balun*. A current balun forces symmetrical current at the balanced terminals, regardless of voltage. This is of particular importance when feeding antennas, since antenna current determine the antenna radiation pattern. A voltage balun forces symmetrical voltages at the balanced terminals, regardless of current. Voltage baluns are less effective in causing equal currents at their balanced terminals, such as at the antenna feedpoint.

There are also impedance transformers which may or may not perform the balun function. Impedance transformation which is changing the ratio of voltage and current is not a requirement of a balun nor it is prohibited. Therefore, multiple devices are often combined in a single package called a balun. For example: a 4:1 balun can be a 1:1 current balun in series with a 4:1 impedance transformer.

Choke or Current Baluns

Coaxial Choke Baluns

The choke balun aims to prevent **I3** (common mode current) from flowing by placing a large series impedance on the outside of the feedline. As a result, the antenna currents can only flow on the inside of the feedline and the properties of the coaxial cable force the antenna currents at either side of the feedpoint (arms) to be equal and in antiphase or balanced. Choking off the difference in current will adjust the antenna currents themselves to become more symmetrical. By using an appropriate type of balun at the antenna feedpoint, one can effectively prevent stray surface current on the feedline.

The simplest baluns are the ones that prevent surface currents from flowing by forming the cable into an RF choke at the antenna feedpoint, **Figure 1A.** The currents flowing inside the cable are quite unaware that the cable has been coiled up. In its very simplest form, a choke balun can be just a few turns in a loop of diameter 300 to 600 mm (6'' to 12'') and in some circumstances this may be all you need. Such a coiled coax choke balun is rather narrow banded. Therefore, in my preference, they should be used for single-band antennas. However, some multiband coverage is possible. For construction data see **Table 1a** and **1b**.

MHz	Meters	Feet	Turns	Meters	Feet	Turns
3.5	6.7	22	8	6	20	6 – 8
7	6.7	22	10	4.5	15	6
10	3.65	12	10	3	10	7
14	3	10	4	2.4	8	8
21	2.4	8	6 – 8	1.8	6	8
28	1.8	6	6 – 8	1.2	4	6 – 8

Table 1a. *Data for coiled-coax feeding chokes for single-band application. Yellow shade values are for RG213 and green shaded for RG58 coaxes.*

MHz	Meters	Feet	Turns
3.5 – 10	5.5	18	9 – 10
14 - 30	2.4	8	6 – 7

Table 1b. *Data for coiled-coax feeding chokes for a good compromise in multiband application.*

The RF choke or air-wound type can also be constructed by winding the cable as a single-layer solenoid around a section of plastic pipe or any other suitable cylinder, **Figure 1B**. The coil form may be removed if desired, **Figure 1C.** For both types of coiled coaxial chokes, use cable with solid insulation. It's better not to use the foamed insulation type to minimize migration of the center conductor through the insulation toward the outer shield. The diameter of the coil should also be at least ten times the cable diameter to avoid mechanically stressing the cable.

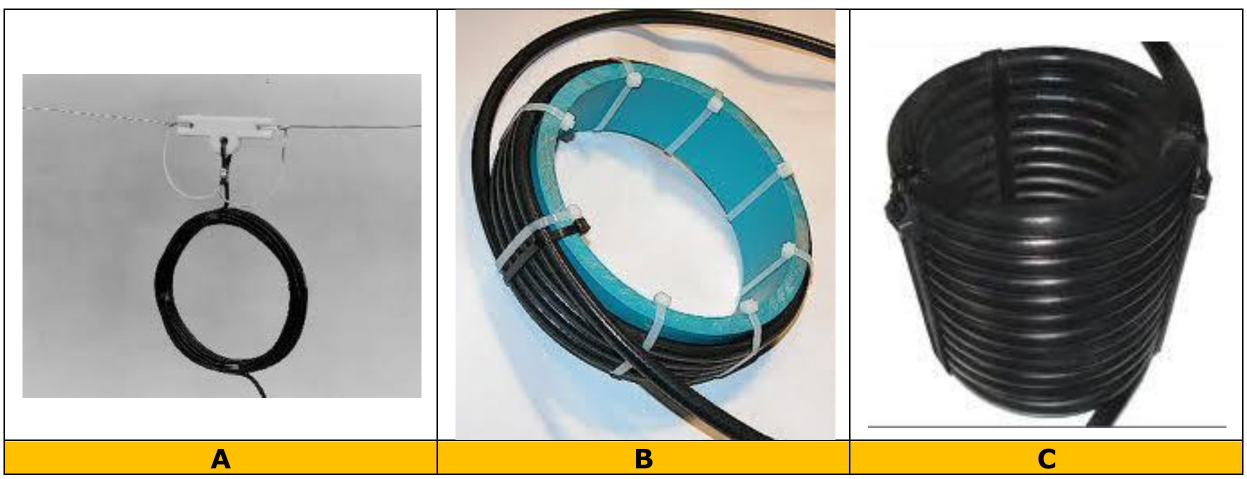


Figure 1. *Coaxial choke baluns*

Ferrite-core Choke Baluns

A ferrite choke is simply a very low-Q parallel-resonant circuit tuned to the frequency where the choke should be effective. By choosing a suitable core material, size and shape, and by adding multiple turns and varying their spacing, the choke can be optimized for the required frequency range.

When we use an inline RF choke to suppress unwanted RF current, we are inserting some additional impedance between two impedances that are already present in the system, (Z1 and Z2), **Figure 2. T**his illustration captures the essential features of almost every common-mode current suppression and EMC situations in a highly simplified manner, (**E**lectro **M**agnetic **C**ompatibility. Looking upstream of where you are going to insert the choke, the unwanted common-mode current has some kind of source which we can represent as V1 with an impedance of Z1. Looking downstream, that current is almost certainly trying to find earth along a pathway that has a series impedance Z2. The only thing that changes between one case an another are the values of V1, Z1, Z2 and of course the unwanted common-mode current, $\mathbf{I_{cm}}$.

The aim of the RF choke is to reduce $\mathbf{I_{cm}}$ to some much lower level that the affected equipment can tolerate. To achieve this, Ohm's Law tells us the impedance of the RF choke will need to be much higher than Z1 and Z2 combined. How much higher does $\mathbf{Z_{choke}}$ need to be in order to be certain it will dominate the situation? Experience tells us we must look for dependable solutions to a wide range of practical EMC problems. Therefore, the RF choke need to have an impedance of at least a few thousand ohms maintained across a wide bandwidth. Commonly suggested criterion for common-mode chokes is 500 ohms and based on unsound theory and isn't high enough to work dependably in practice either. More recent work and studies tends to aim for at least 1000 ohms and preferable higher.

Many types of cable chokes fail to meet these more demanding but realistic criteria. So, there are some cases where they will fail to work properly. To get the higher choke impedance, we will need ferrite material (see below for ferrite properties). However, air-wound chokes and ferrite loaded chokes have different weaknesses.

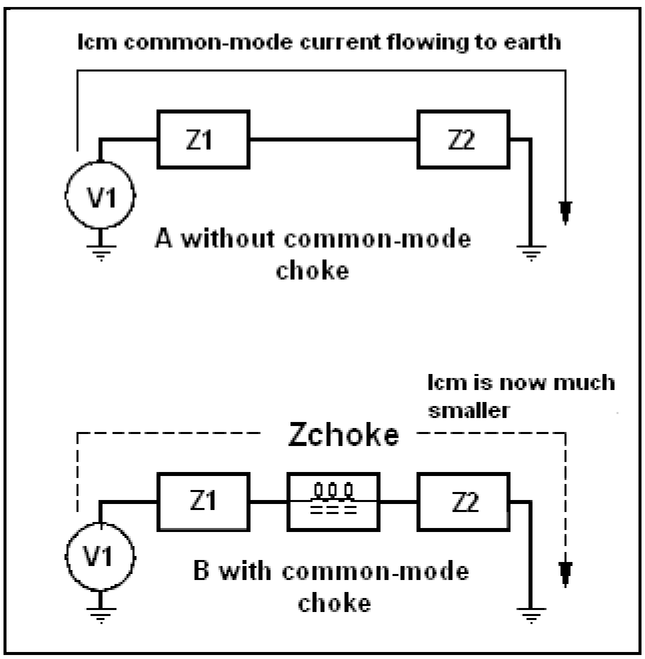


Figure 2. *An effective common-mode choke must dominate the up and downstream impedances, Z1 and Z2.*

As described above, air-wound chokes are simple coils of coax cable, usually the coax feedline itself. We tend to think of these coils as inductors, but their high-frequency performance is actually dominated by the distributed capacitance between the turns. So, instead of an inductor we really have a high-Q parallel resonant circuit formed by the coil inductance and the capacitance formed between the turns. Such a parallel resonant circuit does not make a highly dependable RF choke. The impedance is only high around the resonant frequency and much lower elsewhere, **Figure 3.** The resonant frequency is also quite sensitive to small changes affecting the capacitance between the turns, even how tightly the turns are taped together. Because such air-wound chokes have narrow bandwidth they are better only used at the low RF bands, such as monoband dipoles.

To overcome the problem where the reactive impedance sometimes shifts or become too low, the impedance of a dependable RF choke needs to be high and predominantly resistive. The advantages of resistive impedance are that it cannot be cancelled out and it also tends to broaden the useful bandwidth of the choke.

The only way to create high-resistive impedance is to carefully engineer a certain amount of loss into the choke which is why we need the ferrite. Usually loss is something to avoid but resistive loss in an RF choke is a good thing. We just need to make sure it appears as a very high value of **R** in the series impedance, $\mathbf{Z_{choke} = (R \pm jX)}$. The resistive loss (heat) in the choke equals $\mathbf{I_{cm}^2 R}$, where $\mathbf{I_{cm}}$ is the residual level of the common-mode current remaining after the choke has been inserted. If the choke has successfully suppressed the common-mode current, then the residual value of $\mathbf{I_{cm}}$ will be very low and is unlikely significant heating in the ferrite will be noticed. That's why we are aiming for an **R** value of several thousand ohms, rather than a low value like 500 ohms which has proven to be inadequate.

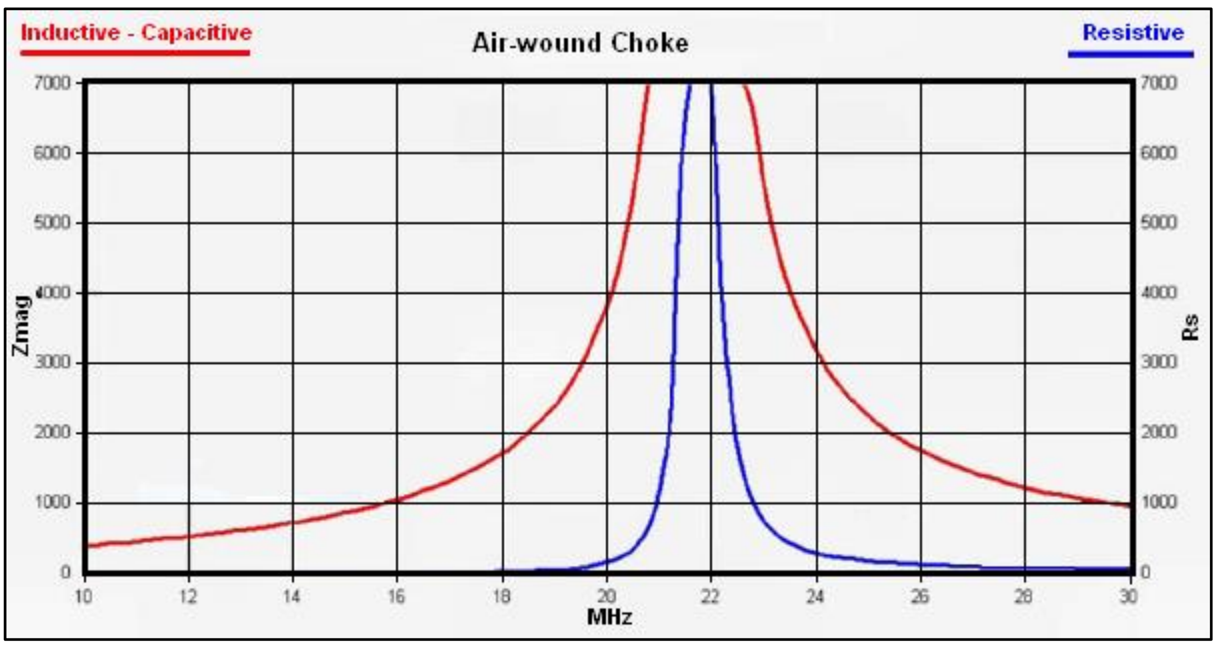


Figure 3. *The inductive, capacitive and resistive characteristics of an air-wound choke. The graph displays they have rather narrow bandwidth. The inductive value curve is shown at the left and the capacitive value curve at the right. The change-over happens where the resistive property is at the highest.*

Ferrite chokes with resistive impedance less than 1000 ohms are a much greater risk of underperforming and overheating. Some commercial chokes only meet the inadequate level of 500 ohms and some also suffer further cost-cutting by using smaller quantities of ferrite content and thus failing to use the correct materials. If a ferrite-loaded choke begins to overheat, the ferrite may reach the Curie temperature at which its magnetic permeability collapses allowing $\mathbf{I_{cm}}$ to increase and causing further overheating. In that case the choke will almost literally crash and burn.

In **Figure 5** we find the impedance and resistance plot of a ferrite choke which performs much better than an air-wound choke. The amount of turns and the diameter of the coil are the same as the one used in **Figure 4**, the only difference is that the coax cable now runs parallel through 3 ferrite cores, **Figure 5.36.**

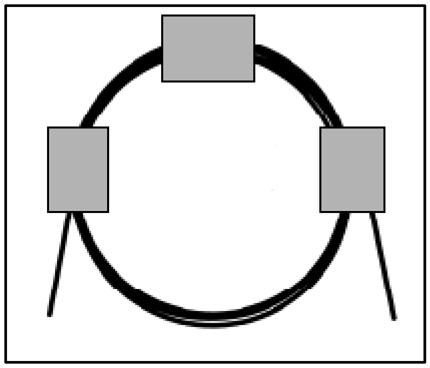


Figure 4. *The turns of coax cable forming the choke are now running parallel through three cores.*

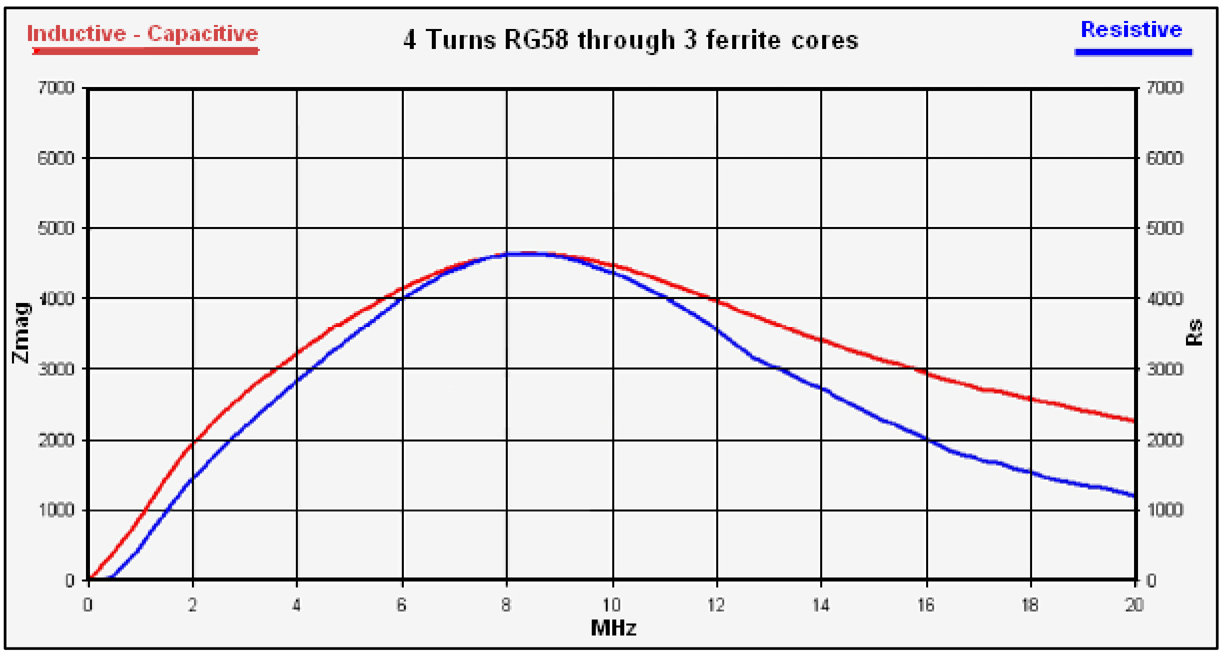


Figure 5. *The performance of a choke formed by 4 turns RG58 coax cable through 3 ferrite cores. Notice here the broad bandwidth with high resistance and impedance.*

The Ferrite

Ferrite is a class of ceramic material with useful electromagnetic properties. Ferrite is rigid and brittle. Like other ceramics, ferrite can chip and break if handled roughly but luckily it is not as fragile as porcelain. Ferrite colors vary from silver gray to black. The electromagnetic properties of ferrite materials can be affected by operating conditions such as temperature, pressure, field strength, frequency and time. There are basically two varieties of ferrite: soft and hard. This is not a tactile quality but rather a magnetic characteristic. 'Soft ferrite' does not retain significant magnetization whereas 'hard ferrite' magnetization is considered permanent. For the current baluns the ferrite materials must be of the 'soft' variety. Ferrite has a cubic crystalline structure with the chemical formula

MO.Fe2O3 where Fe2O3 is iron oxide and MO refers to a combination of two or more divalent metal (zinc, nickel, manganese and copper) oxides. The additions of such divalent metal oxides in various amounts allow the creation of many different materials whose properties can be tailored for a variety of uses.

Because ferrite contains iron and other ferromagnetic elements in oxidation and crystallographic states, the ferrite has high magnetic permeability (μ). If a cable is surrounded by ferrite, then the magnetic field encircling the cable due to common-mode current at the cable magnetizes the ferrite. Because the magnetic permeability of ferrite is very much greater than that of air, the amount of energy stored magnetically in the ferrite is substantial. Thus, the inductance per unit length of cable surrounded by ferrite is very high.

Ferrite is manufactured in different mixes, permeability's, sizes and forms, whereas two kinds: toroidal and bead will be used mostly for constructing radio ham use baluns, **Figure 6**. The permeability is important to the frequencies used. For the HF bands Mix number 43 or 31 is the best choice whereas mix 43 is most commonly used. The reason why many mixes are made is that ferrites are imperfect materials. Some work best at UHF, others at VHF, others at HF, others at MF, and so on down through the spectrum, through audio to DC.

Ferrite can lose its ferromagnetism property when overheated above its so-called Curie temperature. This is very important parameter when constructing common-mode current chokes. Care must be taken to not overheat the ferrite.

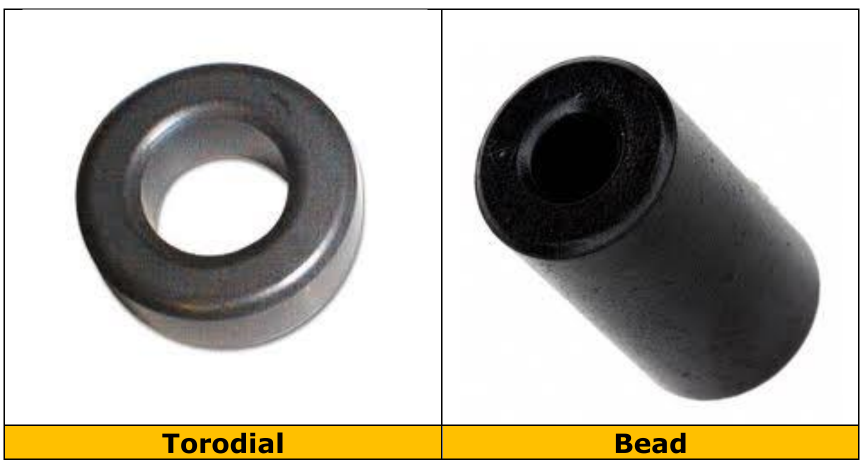


Figure 6. *Most used forms in radio amateur balun constructions.*

In next coming part3 more about ferrite chokes and baluns and how to construct them.

Baluns

Part 3

In part 2 we learned by routing the coax feedline through ferrite toroids gave a high resistance to the common mode current flowing on the outside of the coax shield. Some examples of such baluns are seen in **Figure 1.** The two top ones are for QRO power while the bottom one is more for the regular 100 watt.

Figure 1. *Common mode current chokes by leading the coax feedline through ferrite toroids cores.*

The W2DU Current Balun

It is not always necessary to route the coax several times through ferrite cores. Walt Maxwell, W2DU, decided to place several ferrite beads along and around a short length of coaxial feedline, **Figure 2.** Building such a current balun is not a hard task and the required beads are not hard to find. You can order them from various sources.

The W2DU balun increases dramatically both the resistance and reactance for the common mode current. By adding resistance to the reactance improves the operational bandwidth of the balun with no increase in loss. While the two inner conductors of the coaxial cable remain unaffected, the beads introduce a high impedance in series with the outer surface of the braid. This configuration effectively isolates the external output terminal of the feedline from that at the input end.

Figure 2. *The W2DU current balun*

Two ways of construction are normally used. Once the beads are placed, you can seal the complete length with a heat shrink tube or you can enclose the string in a PVC tube closed with two end-caps, **Figure 3,** and **4.**

Figure 3. *The W2DU current balun: the ferrite beads, the string construction and a waterproof enclosure.*

Figure 4. *A W2DU current 1:1 balun waterproof construction for use at wire dipole feedpoint*

Broadband Baluns

At HF and even at VHF, broadband baluns are generally used nowadays. These can be divided into two distinct categories: voltage baluns and current baluns. Each category might have also an up or down impedance ratio, 1:1 and 4:1 are the most common while the 6:1 and 9:1 are rarely needed. Most of these baluns, either voltage or current types, are mostly constructed on a toroidal ferrite core, **Figure 5.** Two main construction principals are normally used: the **Ruthroff** type and the **Guanella** type both named by their inventors.

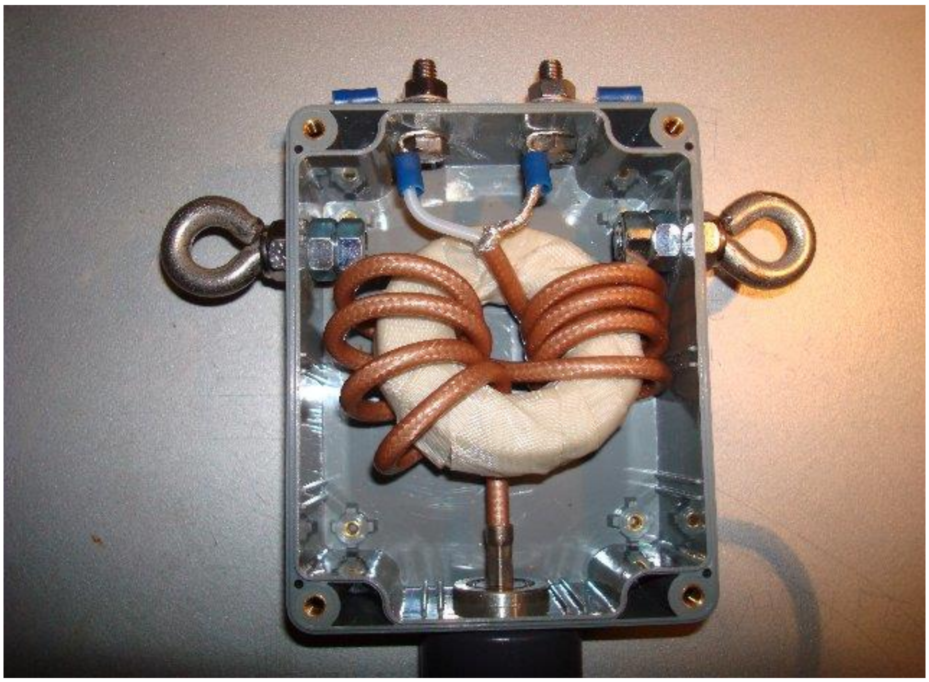


Figure 5. *A broadband current 1:1 balun wounded on a toroids ferrite core.*

The Voltage Balun

The voltage type baluns of **Figure 6** cause equal and opposite voltages to appear at the two output terminals, relative to the voltage at the cold coax cable ground side of the input. If the two antenna halves are perfectly balanced in impedance with respect to ground, the balun will force the voltages to be equal and the current flowing from the balun's output terminals will be also equal and opposite. No common mode current will flow on the feedline and the feedline itself will not radiate. If however the antenna is not perfectly symmetrical, unequal currents will appear at the balun output, despite equal voltage and thus causing common mode current to flow on the feedline, an undesirable condition. Another potential shortcoming of the voltage balun is that the windings appear across the feedline. If the windings have insufficient inductive reactance, the system SWR will degrade, which is a common problem particularly near the lower frequency end range. The 4:1 voltage balun is mostly, but not always used in antenna tuner units for connecting a parallel feedline to the unit.

The Current Balun

The voltage balun does not guarantee equal and opposite currents to flow. Therefore, a current balun is generally recommended to be used at the junction of the antenna and feedline and even elsewhere on the feedline; see later. **Figure 7** displays a 1:1 and 4:1

current balun. These baluns are wound according the Guanella principle and mostly used in amateur radio antenna systems.

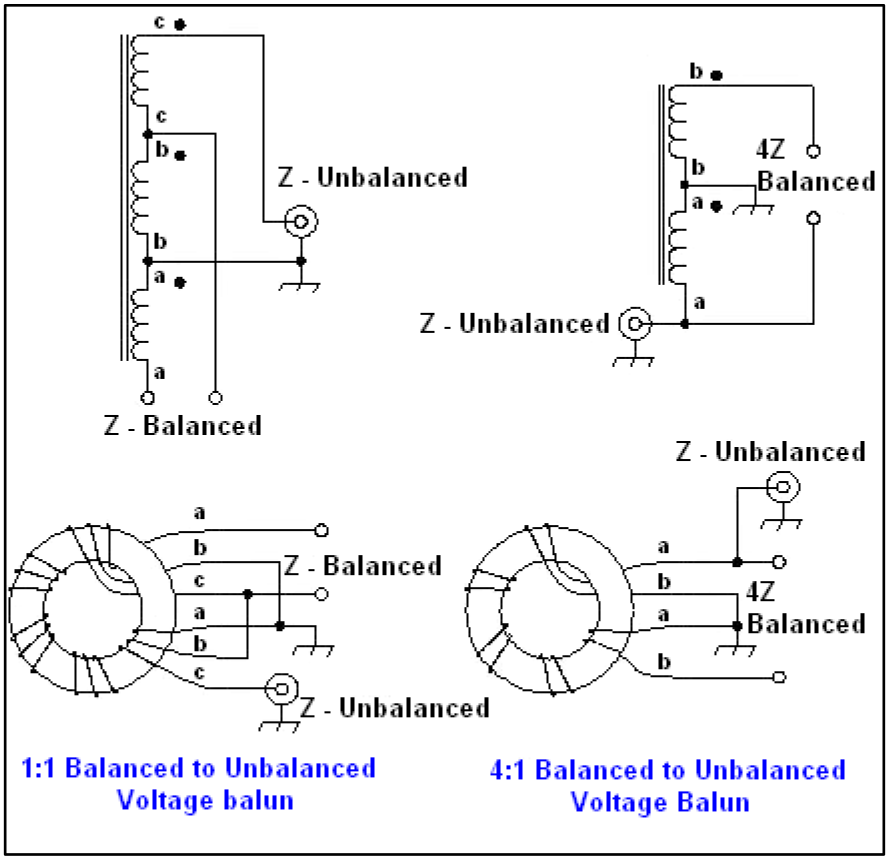


Figure 6. *Voltage balun with impedance ratio 1:1 and 1:4 examples*

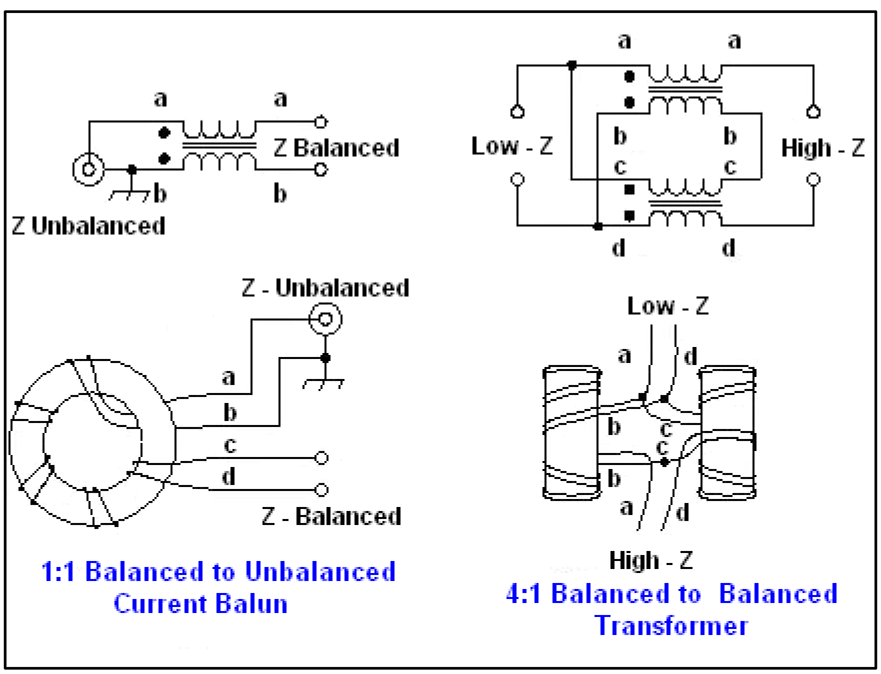


Figure 7. *Current balun with impedance ratio 1:1 and 1:4 examples*

Because the 4:1 voltage balun is not perfect for balanced current flow, a good solution to correct this is by adding a Guanella 1:1 current balun at the low Z side, **Figure 8.**

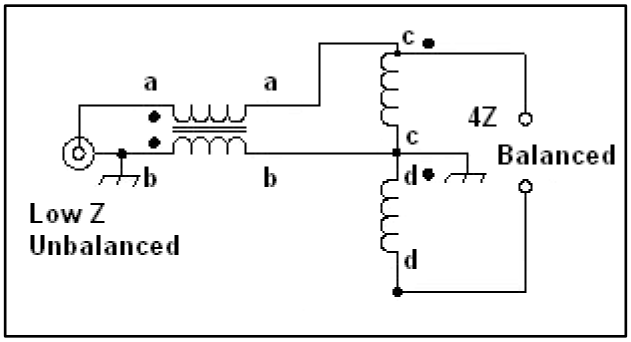


Figure 8. *A better 4:1 voltage balun with an additional 1:1 current balun*

Balun Construction

How to make the toroids? The following instructions are for Guanella current balun construction and are not very difficult to make. First you will need the ferrite toroid core of preferable mix-43 or mix-31. The size depends on the power you want to use but one with an outside diameter of 1.57 inch like I use in the examples below can handle easily a few hundred watts. One with a diameter of 2.4 inch can be used with high power as 1.5 Kw. Two toroids may also been glued together for high power tolerance.

Ferrite toroid cores are indicated as FT-XXX-YY, FT stands for ferrite, with XXX as the OD (outer diameter) in hundredths of an inch and YY the mix. For example, an FT-157-43 core has an OD of 1.57 inch and is made of type 43 material.

1:1 Guanella Balun

To construct a 1:1 Guanella current balun you will need two pieces of 0.5mm to 1mm or AGW #24 to #18 enameled wire. For high power it is preferable to use Teflon insulated wire. With enameled wire, the risk of voltage flash-over is too great. Coaxial cable with Teflon isolation is preferable and can also be used to form the windings and is better for high power. RG-58 is commonly used and with power of 100 watt is fine.

How long do the wires have to be? It all depends on the core size of course. I always use a piece of cord and wind the core with the number of windings in mind or needed, **Figure 9a**. I always add 10 to 15 cm (4 to 6 inches) to the total measured length. For a 1:1 Guanella balun it is not so important to know the specific wire at both ends, but for a ratio of 4:1 and higher, you must know or be able to identify the proper end of the specific wire. You might add a wire number label or color mark at both ends of the wire or make one wire of the two a bit longer; 2 cm or 1 inch longer in total length does the job, **Figure 9b.**

Figure 9a. *How to determine the wire length*

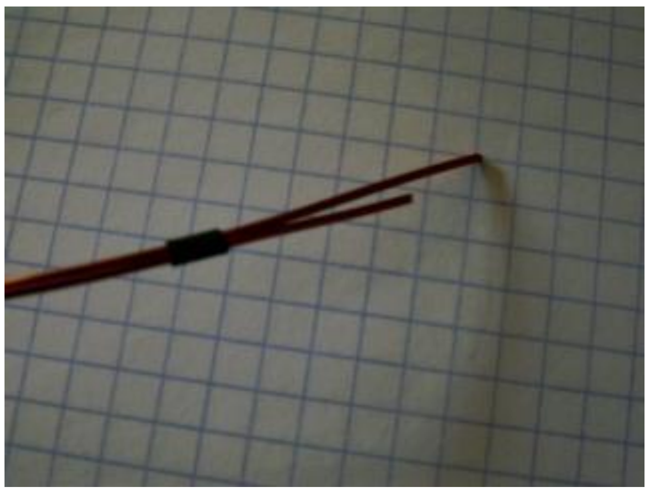


Figure 9b. *A trick to identify the specific wire by making it a bit longer at both ends*

First of all you are **not** winding a transformer! What you will do is to wind a short length of parallel transmission line around a ferrite core. So, the parallel transmission line is formed by the two wires. They have to stay as close as possible to each other; preferably touching each other otherwise the characteristic impedance will alter along the line. The wires also should not overlap. For low power, the wires may be twisted, but I do not recommend this for powers higher than 100W, more danger for voltage flash-over because the enamel isolation may become slightly cracked while twisting them.

The technique I use to construct a decent parallel line is by use of a small short piece of heat-shrink sleeve. Shrinking these short pieces over the two wires at intervals of about 1 inch each will suffice, **Figure 9c**. The heat-shrinking can be done by a heat-gun or above a candle flame.

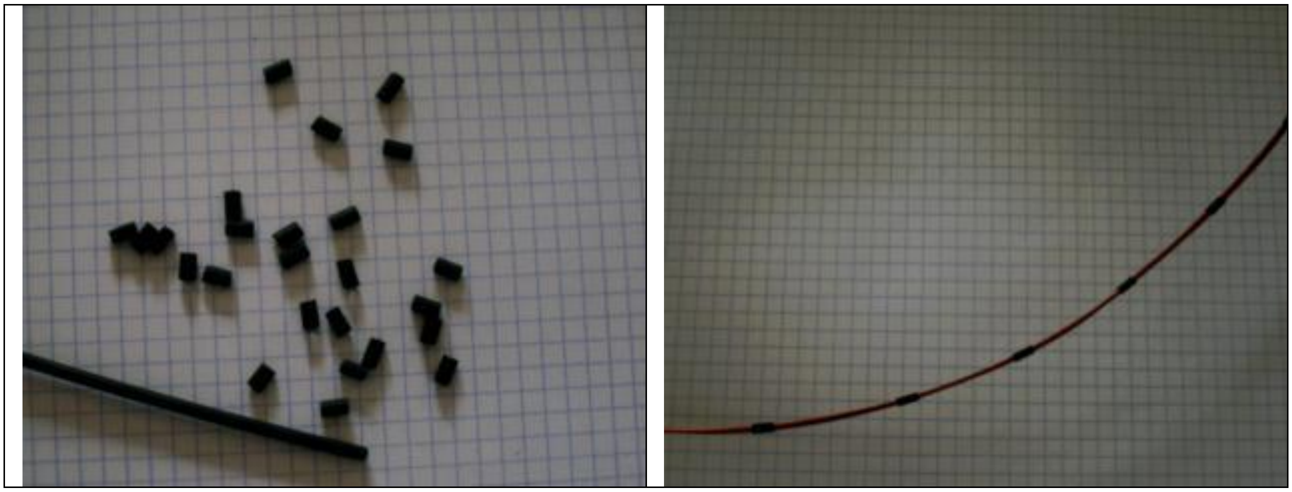


Figure 9c. *Using short pieces of heat-shrink sleeve to construct a parallel feedline*

Winding the balun can be done in three ways: (**Figure 9d)** using only one half of the toroid or using the complete toroid or by the Reisert crossover technique. The complete use of the toroid has only the disadvantage that both the input and output ends are on the same side of the core. This might be more difficult or cumbersome to make the connections for the respective antenna feedpoint terminals and the main coaxial feedline toward the transmitter. Either of the three winding methods give equal characteristics. The method with the cross-over is the most used one. The two ends of the windings are best tightened with nylon cable straps.

Guanella 1:1 balun wound on one half side of the core. Input and output on opposite side.

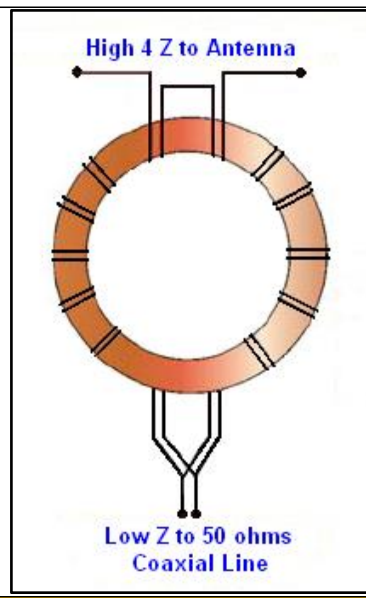
Guanella 1:1 balun using the core entirely. Input and output on the same side.

Guanella 1:1 balun with a Reisert cross-over. Input and output at opposite side.	Guanella 1:1 balun with a Reisert cross-over using RG-58 coax cable whereof the outer jacket is striped

Figure 9d. *Four construction types of a Guanella 1:1 current balun*

4:1 Guanella Balun

The above current baluns are for an impedance ratio of 1:1. Other current balun ratios with the Guanella principles are also possible. In **Figure 7** at the right you find the schematic and construction sketch for a Guanella 4:1 balun. The construction sketch shows the use of two ferrite cores. For rather high power that is advisable but you can also wind a 4:1 Guanella balun on a single core and connect the wires as illustrated at the right side of **Figure 10.** At the high impedance side, which will be the antenna feedpoint (an OCF Off-Center Fed or a folded dipole, as example), the two baluns are connected in series. At the low impedance side (the feedline to the transmitter), the two baluns are connected in parallel.



A Guanella 4:1 balun from two 1:1 baluns wound on one toroid.	How to connect a 4:1 balun from two 1:1 baluns.

Figure 10. *A 4:1 Guanella current balun wound on a single core*

6:1 Guanella Balun

A 6:1 Guanella balun can be constructed from two 4:1 baluns. Take care with the connections of the wires in particular where to make connections in series and where in parallel; good wire labeling is a must here, **Figure 11.** It is obvious here at least two cores are needed.

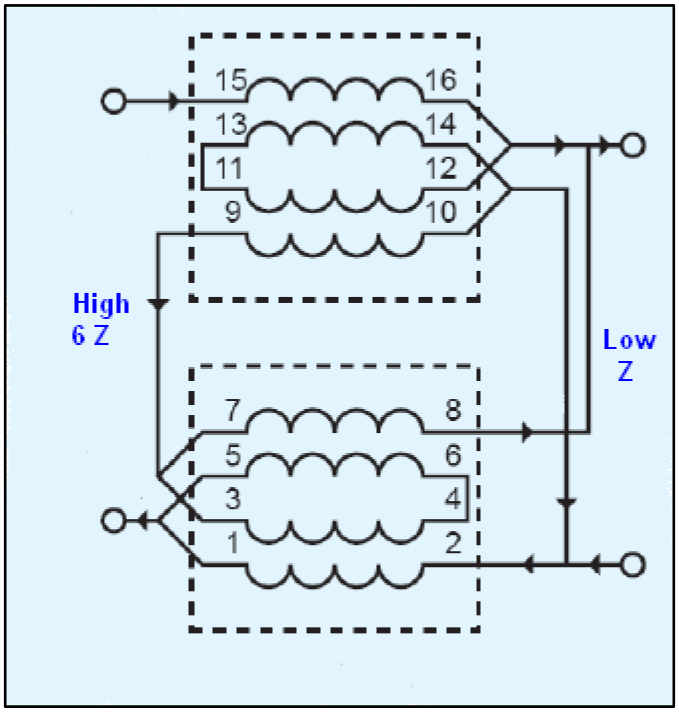


Figure 11. *A 6:1 balun from two 4:1 baluns*

9:1 Guanella Balun

A 9:1 Guanella current baluns can be constructed as seen at **Figure 12.** At least two cores will be necessary; even better is using three. The series connections are at the high Z side. At the low Z side, the connections are in parallel.

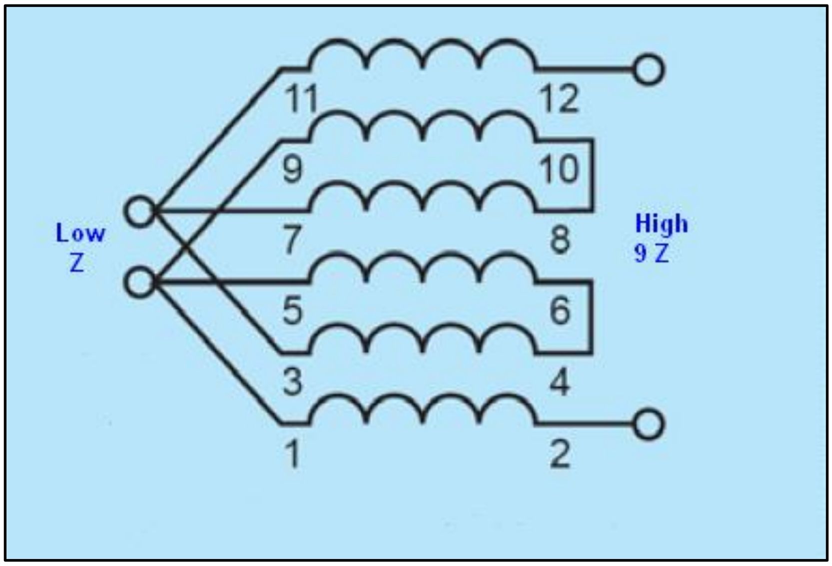


Figure 12. *A Guanella 9:1 balun*

Important Note: In some articles about current baluns, it is mentioned you may use powdered-Iron toroidal cores. This is definitely wrong! Powered-Iron material or mix is completely different in characteristics than ferrite mixes. Powdered-Iron is for sure the right stuff to make coils for tuned circuit low and high pass filters, etc. But for balun constructions it must be avoided as its permeability is far too low.

Feedline Current Chokes

By using a good current balun at the antenna feedpoint, the currents flowing at the antenna and at the feedline is forced be equal and opposite, or at least as much as possible. The current without a balun employed otherwise should flow on the outside of the coaxial outer shield is practically prevented. But at that outer shield of the coaxial feedline, in many circumstances, may also find current to be generated. This may happen if the feedline is in a slanted position (not routed symmetrical at 45° of the antenna halves) or by mutual coupling to surrounding constructions. To prevent this induced current from flowing toward the radio shack is to place an additional current choke. The feedline current choke(s) are placed in between the antenna and the transmitter; the best location being at ¼ wavelength intervals or at least one at the entrance of the feedline into the shack.

The properties and characteristics of current chokes or baluns are also reciprocal. Which means they do also a good job when using the antenna in receiving mode. Manmade noise is also induced at the coaxial feedline outer shield. When employing feedline current chokes, the noise level will be significantly reduced. Using feedline current chokes on HF low band antennas is a must in my opinion.