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.

A B C

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.

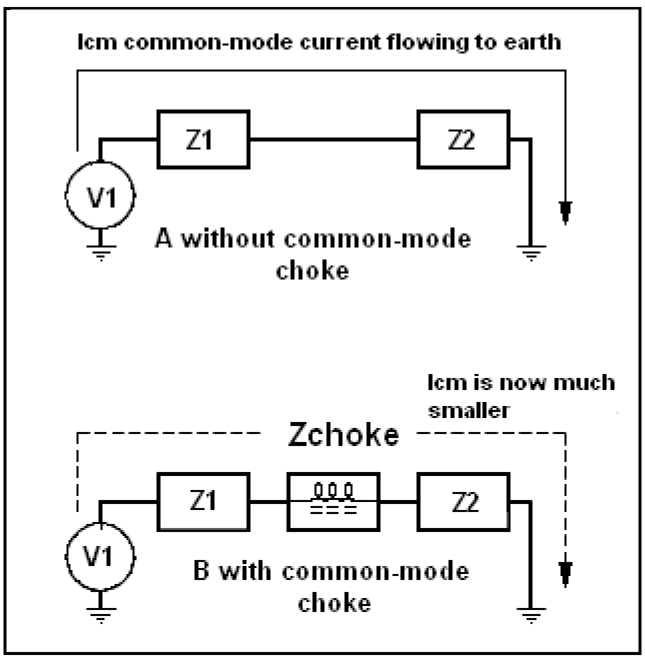

Figure 2. *An effective common-mode choke must dominate the up and downstream impedances, Z1 and Z2.*

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.

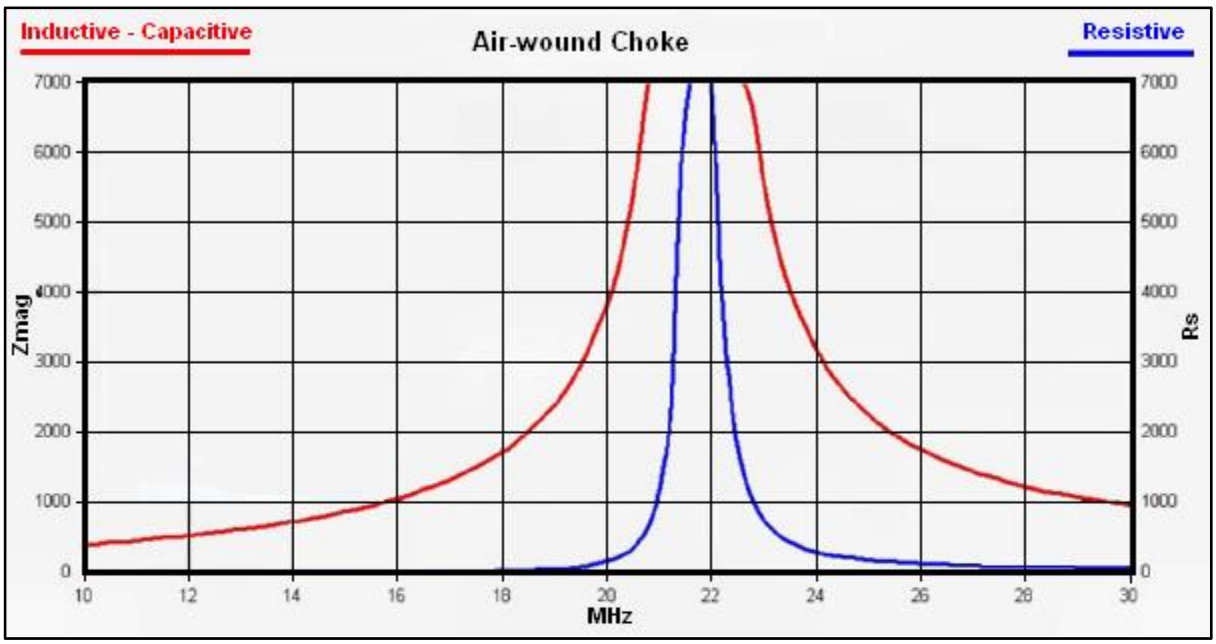

Figure 3. *The inductive, capacitive and resistive characteristics of an air-wound choke. The graph displays they have rather narrow bandwidth. The inductive value curve is shown at the left and the capacitive value curve at the right. The change-over happens where the resistive property is at the highest.*

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.**

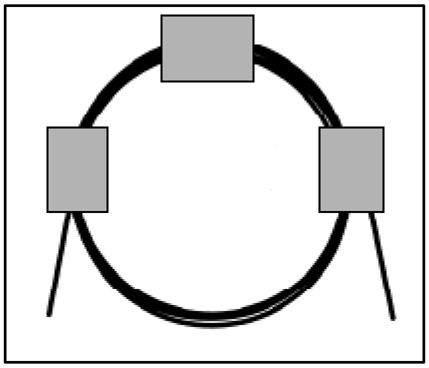

Figure 4. *The turns of coax cable forming the choke are now running parallel through three cores.*

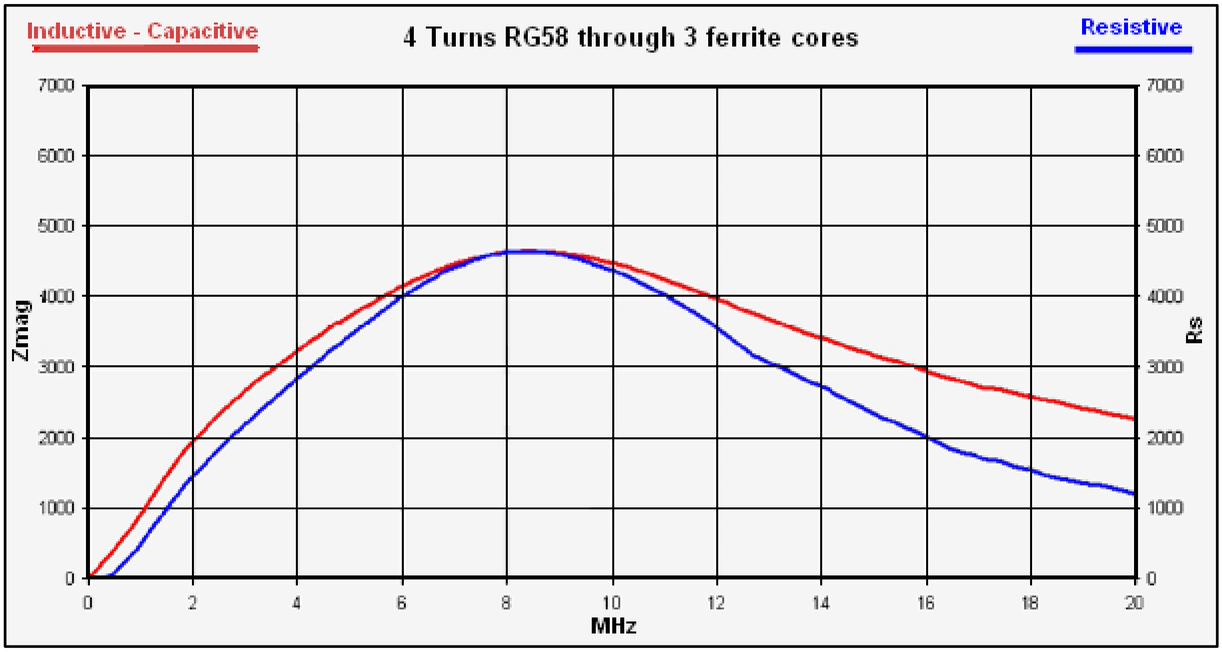

Figure 5. *The performance of a choke formed by 4 turns RG58 coax cable through 3 ferrite cores. Notice here the broad bandwidth with high resistance and impedance.*

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.

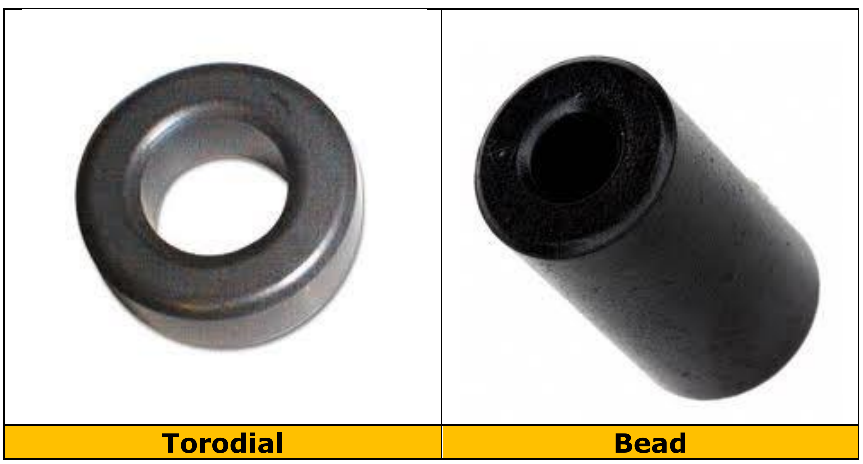

Figure 6. *Most used forms in radio amateur balun constructions.*

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