Balun CONCEPTS – VK5AJL

VOLTAGE AND CURRENT BALUNS - DIRECT COMPARRISON

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| 1:1 transformer balun |  | A simple current balun |
| Simple 1:1 voltage balun |  | Simple 1:1 current balun |
| A voltage transformer type balun uses magnetic transfer (transfomer action) to produce a balanced signal at the output. The 1:1 impedance transformation is achieved by making the impedance of each winding the same. If changing the number of turns on one (or more) winding changes the the voltage, it is a voltage balun. |  | A 1:1 current balun controls currents. There is NO transformer action. Equal and opposite (balanced) currents cancel each other out and present a low impedance. Common mode currents produce a mutually inductive magnetic field that presents a high impedance to these, unwanted, signals. If the number of turns on one winding is made different to the other, the action will remain the same except that there will now be a small impedance associated with balanced currents but still a much higher impedance for to common mode currents. If changing the number of turns on one (or more) winding changes the the current, it is a current balun. |

Working currents travel (are induced through the core) in the same sense in the voltage balun but are in an opposite sense (are not induced through the core) in a current balun.

To quote from ARRL (2008 21.16-17):-

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|  | *Choke or current baluns force equal and opposite currents to flow. The result is that currents radiated back onto the transmission line by the antenna are effectively reduced, or "choked off," even if the antenna is not perfectly balanced.**If winding inductive reactance becomes marginal at lower frequencies, the balun’s ability to eliminate antenna currents is reduced, but (for the 1:1 balun) no winding impedance appears across the line.*Although this wording is a little confusing, this is entirely consistent with this page.

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| 1) | This does not mean something that forces equal and opposite currents to flow is a current balun. In fact [Kirchoff's current law](http://vk5ajl.com/projects/baluns.php#basics_laws_kirch1) says the 1:1 voltage balun shown above (unreferenced to ground) does just that but it is still a voltage balun. |
| 2) | At the same time, the 1:1 current balun shown above doesn't quite balance the line. Although there is a high impedance presented to common mode currents, this impedance is still finite and so some common mode currents can still flow. |
| 3) | There is NO CHOKING action in any sort of voltage balun including the guanella. |
| 4) | In some ways it is unfortunate the words "(for the 1:1 balun)" were included. This may lead people to think there is allowed to be winding impedance in the 4:1 balun but there is no 4:1 balun shown. It is labelled a "current transformer", not a balun. These words were obviously included so readers would not think there is no winding impedance in the 4:1 transformer. Here is the major problem I have with the wording. There is NO difference between a "voltage", "current" or "impedance" transformer. |

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WHICH TYPE OF BALUN TO USE - BANDWIDTH

The type of balun used depends on what you want to achieve and what bands you are working. If you are going for maximum coverage of bandwidth, you will not have an antenna as good on one particular frequency but a wide bandwidth balun is best. If you are looking for maximum signal using a Narrow Mode such as CW or SSB, it is pointless using a wideband antenna (ergo balun) in which case a narrow bandwidth balun is best.

WHICH TYPE OF BALUN TO USE - VOLTAGE OR CURRENT

The best balun to use is the one that does the job with the least loss, of course.

On 6m and above, most generally use a dedicated antenna. A ½ wave loop made of RG-214 has an insertion loss of roughly 0.03db and so is the lowest loss balun I could find. This is a voltage balun. A common mode choke (ugly balun), a type of current balun, wound with RG-58 using the recommended lengths has a loss of roughly 1.2db. In addition, some sort of impedance matching may be needed so a voltage balun is the only real alternative.

On HF, a wide bandwidth is desirable. Voltage baluns are either too big or too inefficient. If you use a tuner, that does all the impedance matching necessary so a simple current balun after an unbalanced tuner has the lowest insertion loss. In this situation a current balun is best.

If a wound balun with impedance matching is needed, the auto-transformer types are generally more efficient.

FERRITE V POWDERED IRON

Both ferrite and powdered iron cores are ceramic materials. They consist of small particles of either iron (for powdered iron obviously) or mixtures of iron oxides mixed with binding substances and are fired in a kiln like pottery. Both are more efficent than solid iron.

There are advantages and disadvantages to using both. Ferrite saturates (fills up with a magnetic field) at a lower level than powdered iron. After any core saturates, it behaves like just a piece of wire and not like a coil anymore. You must also remember that the relationship between magnetic field strength and ampere turns is not linear so, the closer you are working to the saturation point of any core, the more harmonics (mostly odd harmonics) you produce.

Suppose you have a powdered iron core and a ferrite core of the same size. Suppose the powdered iron core saturates at 12 watts and the ferrite core at 10 watts. If you put 5 watts through them, the ferrite, being more efficient, will transfer more power. If, on the other hand, you put 9 watts through it, although the powdered iron is less efficient, less power is lost in the harmonics. The power transfer at the desired frequency will now be the about the same for both and you won't be disturbing the neighbours TV anymore.

WINDING DETAILS

The number of turns will depend on the core material. Since there are so many types, exact figures can't be quoted here. For an HF transformer and a powdered iron core, about nine or ten turns per winding is a good place to start. Since a current balun is a type of common mode choke, the more turns the better.

There are several ways of testing it but none of them really easy. If 10 turns works OK, leave it. If you really must be sure, one way to test it is to put power through it at increasing levels and run it into a dummy load. Wind a 1:1 BALUN with extra turns using the desired material connecting the primary to an RF source and ground and the secondary to a dummy load (50Ω). You will need a big dummy load.

DOT NOTATION

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| DOT notation - demonstration coil only. | Dot notation is used to simply indicate the starting point of windings which should all be made in the same sense as shown at left. NOTE ON THE WINDINGS: Having the windings spaced as shown is not important but it is probably better to have them evenly spaced as shown. Some authors insist they should be close because they are transmission lines. They are transmission lines only when the telegrapher's equations can be applied. This is true of current baluns but NOT transformer baluns. Dot notation can be verified at <http://www.minicircuits.com/pages/pdfs/tran14-2.pdf> |

WINDING COILS WITH COAX

There are situations where [winding coils with coax](http://vk5ajl.com/projects/baluns.php#current_ugly) is useful but there are some strange misconceptions. The centre conductor is surrounded by a good conductor that contains any magnetic or electrical fields it (centre) produces. The inner conductor therefore produces no magnetic effect whatever in the coil or any former it is wound on unless it is by currents it induces in the outer.

Coils of coax around a former do not constitute a transformer. They form a choke on the outer conductor only.

VOLTAGE BALUNS

½ WAVE LENGTH COAX BALUN
Highly recommended where it can be used (usually impractical on HF). This is a very low loss balun.

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| ½ wave loop balun.½ wave loop balun on 2m folded dipole. | This balun works on the same principle as transformer baluns, in fact, it is a transformer balun. One side of the signal is transmitted as is and the other side is produced by delaying the signal by half a wave length. This inverts the signal to produce the opposing one. These baluns work well enough but have the disadvantage of being restricted to a very narrow band of frequencies. They are the best if a narrow bandwidth is what you want. The length of the half wave loop is calculated from both the wavelength and the velocity factor of the cable. RG213 typically has a velocity factor of 66% so for 144.4 MHz the wave length is 299.8/144.4 (2.076 metres) divided by 2 (1.038m) multiplied by velocity factor giving 685 mm. To be sure, consult the technical specifications of the coax you are using.It is important use the best coax you can for the balun even if you use lousy coax for the feedline. Using heliax is a little impractical because it doesn't bend so easily but something like Benelec LMR400 is ideal. A balun made from this cable will have an insertion loss of about .05db. One side will be driven harder than the other by this amount. It also has a velocity factor of 85% meaning it needs to be longer. The losses will be the nearly the same regardless of frequency. At higher frequencies the loss per metre is higher but you need less of it. Since the electrical fields in both halves of the dipole will affect the other, the average insertion loss will be less than 0.05db, probably about 0.03 but who's counting. |

SINGLE SIDED TRANSFORMER BALUN (4:1 impedance match)
Less than ideal and not recommended.

When winding this balun cheap speaker wire works fine. Keep the windings together. Do not put the primary on one side of the toroid and the secondary on the other. Performance will degrade more rapidly with frequency. SEE WINDING THE DOUBLE SIDED CORE BELOW and [DOT NOTATION ABOVE.](http://vk5ajl.com/projects/baluns.php#basics_concepts_dot)

DOUBLE SIDED TRANSFORMER BALUN (4:1 or anything:1 impedance match)
Use only if other than 4:1 matching is also required. Not recommended.

NOTE:- The diagramtic representation shown for transformers, tends to show two ends to each winding. These baluns are wound on toroids so there is no real end. It is a continuous circle. The ends and dots simply show the feed point.

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| Double sided transformer balun. | This balun works in much the same way as the first but, in this case, both signals are passed through the transformer. There are some additional transformer losses in transforming both signals but both signals suffer the same loss and are therefore more properly BALANCED. |

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| Double sided transformer balun. | AN INTERESTING POINT. At left is a 4:1 balun published in a similar form elsewhere on the web as an improvement to the Guanella balun. This is a good idea but it can be further improved. It uses two parallel windings for the primary and keeps two groups of windings, one for each side of the balanced output. This is unnecessary. Magnetisation of the core is proportional to the number of turns multiplied by the current (almost). There are twice as many turns but half the (resistive) current in each side. Magnetisation of the core can be achieved in an even better fashion with only one primary winding as shown below. In addition, the inductive current is larger with this double winding. It has been stated many times that the inductive impedance should be as high as possible. Using only one wire instead of two achieves this. |

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| Double sided transformer balun. | This winding method uses a single winding for the primary, therefore twice the resistive current and also double the inductive current, as the one shown above and therefore the same magnetisation of the core. In addition, because there is only one triple winding, coupling is as balanced as you can get. This was only done for illustration purposes. |

GUANELLA BALUN
This doesn't really balance anything. Not recommended.

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| 4:1 transformer/Guanella balun. | Contrary to some belief, the ARRL handbook does not describe a Guanella balun. It describes something which looks like one but properly labels it as a 4:1 balanced impedance matching transformer. (Chapt 21 page 16 of 2008 edition.) Various authors have changed it into a balun by connecting one side to ground. This is a voltage balun because it does nothing to limit common mode currents and allow working currents other than matching impedances.At the extreme left, two sets of dots are shown on the bottom set of windings. The pink dots are those as published. Whether it is wound on a single core or two separate cores makes no difference, the transformer action is exactly the same. Since there are two sets of separate windings, the dots (winding start) of each set of windings is entirely arbitrary. On separate cores, the action and performance of this balun is exactly the same no matter which end of the core you start winding so the blue dots can just as easily be used without changing the action of this device in any way. |

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| Guanella transformer/balun. | Viewed in this light, the Guanella balun is two, crossed over, series, auto-transformers. Another way to look at it is stretched out as shown at left. The magnetic circuits are shown in yellow. It uses transformer action to induce currents in the top and bottom windings. It transforms a voltage so it is a voltage balun NOT a current balun.

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| Shown at right are the voltages of the input and output with respect to ground. The currents in both legs of the output are still the same but they are working from different impedances. This does NOT mean the currents are balanced but the voltages aren't. This is only voltage with respect to ground but balanced signals do NOT have to be referenced to ground and often aren't. Provided the whole system is isolated from ground, 100,000 volts (with respect to ground) can be connected to a single point ANYWHERE in this system and the action is exactly the same. This is how birds can perch on power lines without getting electricuted. |

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1:1 TRANSFORMER BALUNS
The third example can be adjusted for other than 4:1 and recommended over the first two.

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| 1:1 transformer baluns1:1 transformer baluns | Here are three interpretations of a 1:1 voltage balun. A 1:1 balun transformer can be made by simply winding the same number of turns on each side of a transformer and connecting as shown or, as in the third example, making the impedances of the input and output the same.The first example has the advantage that, no matter what the impedance of each half of the the antenna itself, there MUST be equal currents in both legs. ([Kirchoff's current law](http://vk5ajl.com/projects/baluns.php%22%20%5Cl%20%22basics_laws_kirch1) applied between both ends of the antenna). It uses transformer action and could be used to match impedances, using different turns ratios, and is a voltage balun. It has the disadvantages of high losses, especially on the higher bands and there is no direct DC path to ground to discharge static.Static discharge can be accounted for by winding with a centre tap as shown in the second example. This negates the advantage of ensuring equal currents if the impedances of each half of the balanced antenna are different, such as one end being near an iron roof. This can be accomplished by placing a nominal resistor in the centre tap ground, say 1k or 4k7. This is enough to discharge static but is bigger than any radiating resistance.Another method of winding a 1:1 voltage balun is the third example. All signals are referenced to ground. Some have called this a current balun, probably because it has a 1:1 voltage transformation but it is nothing more than an autotransformer. Currents in a secondary (lowest winding) are induced by currents in the primary (upper two windings).This system is not as balanced as it looks. Using an autotransformer to divide the input voltage is more efficient, and therefore stronger, than inducing currents in the lower winding. In addition, because ALL signals are referenced to ground, there can be different currents in each leg of the antenna if the load impedances are different. |
| Single winding transformer balun. | The simple transformer balun here relies on one side of the signal being transmitted as it is and producing the opposing signal using a transformer. It can be wound on a toroidal core of the necessary frequency characteristics. There are so many types, listing all here and suppliers is a waste of time. There are only a few turns on an RF transformer anyway so its easy to wind another one if the toroidal core you find in an old power supply works or it doesn't. I have used speaker wire from an old car to wind one which worked fine. These baluns have the advantage anyway that they can be used over quite a wide frequency band eg. all of HF. |

There are only two currents of interest. Common mode currents are equal currents in both phase (which implies direction) and magnitude in two parallel conductors. Working currents are those driving the load. These are equal and opposite (Π/2 out of phase), that is, if there is no way back, nothing will leave. Ground used in circuits is a special case. It is an almost limitless source of charge carriers (electrons or a lack of them) and an almost bottomless pit to absorb them. It can therefore be considered as a zero impedance connection (although that isn't quite correct).

Although the voltages are different with respect to ground, there is no problem. Working currents in each side of the balanced line are working against each other, not against ground. Common mode currents induced into the balanced feedline are a different story. They are also working into different impedances and will result in a similar voltage pattern in the transformer **BUT** common mode currents are working against ground. Those in the upper conductor are also working through the source impedance of the unbalanced side of the line. Those in the bottom are also working into this same impedance but with the addition of transformer losses.

CURRENT BALUNS

**CORE TYPE CURRENT BALUN**
Highly recommended. This is a very low loss balun and ideal for use with a tuner.

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| Simple current balunSimple current balun on powdered iron former | This balun works by controlling currents. THERE IS NO TRANSFORMER ACTION. The two windings must be in the same sense (dots at the same end). The magnetic fields of opposing balanced working currents will cancel each other out and so present very little impedance (other than the resistance of the wires) to these currents. On the other hand, common mode currents will produce a mutually inductive magnetic field and face a high impedance.This means the more turns the better, up to a point. In this case, the windings are a transmission line that has losses but these are much lower than the losses transfering energy from one winding to another through a core.Design considerations are really very minimal. Since the losses of balanced lines are low compared to coax, you aren't losing much except for the resistance of the wires which is very low compared to radiating resistance anyway.The current balun shown here, wound around a steel bolt, is probably a little crude but why not? Steel or iron is not normally used for RF because there are too many eddys making it too inefficient for transformers. In this application, since there is no magnetic effect for the desired currents, it doesn't matter. For common mode currents on the other hand, inefficiency is an advantage. Not only is a high impedance presented to common mode currents, the energy from them is absorbed by the bolt.Simple current balun wound around a steel bolt |

I tried but was unable to measure any insertion loss associated with either the bolt or the toroid former (powdered iron) for working currents. There was some but the meter needle was so close to the same value in and out I really could not say what the loss is. As soon as I have the time, I will measure the impedance to common mode currents with various formers.

**COMMON MODE CHOKE OR UGLY BALUN**
Not recommended. There are better ways of achieving the same effect.

Before we start, COMMON MODE CURRENTS ARE EQUAL CURRENTS IN PHASE AND MAGNITUDE IN TWO PARALLEL CONDUCTORS. (Phase also implies direction.) Volts (potential difference) produces an electrical field while amps (current) produces a magnetic one. Fluctuations in an electrical field can induce currents the same as orthogonal magnetic ones can. With coax, there are at least two influences on currents in the outer conductor, one induced by the electrical field fluctuations and the other by magnetic fluctuations orthogonal to it. Since there are orthogonal electric and magnetic fields between the inner and outer conductors, coax can be considered a wave guide. Things are more complex than described here.

This type of balun is one of the easiest to make but more difficult to explain. It would be easiest to build up a picture. Consider first, the following situations.



Figure (a) shows the situation where the outer conductor is not connected to anything. It doesn't matter what happens with the inner conductor, there can be no current at point A because it isn't connected. Current must have at least some place to flow. Where a single radiator is present like this, the electric field on the inner tries to work against the coax outer and produces common mode currents that simply heat the coax.

Figure (b) shows the situation where the outer conductor is now connected to a radiator. In this situation, there are still commom mode currents. The coax shield is a pseudo ground and isn't trying to push any current anywhere. With unbalanced line it is only the inner that is driven. The coax shield only conducts working currents because they are pushed by the inner. The electrical field created along the radiator connected to coax centre is partly working against the coax.



Figure (c) shows the situation where the coaxial cable is wound into a choke. A choke is nothing more than a **BIG** inductance. An inductance resists a change in current both magnitude and direction. As frequency increases, the impedance increases. At Radio Frequency the impedance is so big, neither induced current can pass through it except for the working currents on the inside of the shield. Point A can have currents induced by the electrical field in the radiators but this current can't pass through the choke and to ground.

I have called called it a ½ common mode choke instead of an ugly balun because it affects the outer conductor only. Because both the magnetic and electrical fields generated by the inner conductor are contained within the coax, they are unaffected and thus the currents in the inner conductor are unaffected.

ANOTHER WAY TO DO IT



More ferrite is usually required than two pieces but you should get the idea.