A Single-Core 4:1 Current Balun of Improved Performance

by

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Introduction

Among the topics of interest to radio amateurs, baluns are of particular interest as they are to be found in balanced amplifiers and antenna matching networks, especially in the case of balanced antennas such as dipoles.

Baluns come in essentially two varieties, the first being voltage and the second being current. The voltage balun derives it's name from the fact that it maintains the voltages at the output terminals (with respect to ground) equal in magnitude and opposite in phase, regardless of the load [1]. The current balun, on the other hand, maintains currents at the output terminals that are equal in magnitude and opposite in phase regardless of the potentials at the output terminals with respect to the ground connection on the unbalanced side [1]. A third type of balun, often referred to as a 180º power divider or hybrid junction, is of little interest to radio amateurs due primarily to their cost but finds wide usage in professional applications.

Misconceptions

There are a number of misconceptions regarding the design and application of balun transformers, amongst which are:

"*...it is impossible to build a 4:1 ratio current balun that uses two 1:1 baluns on a single core* [2]."

"*It's well established (that) any balun made up of series / parallel transmission lines requires different voltages from the start to finish of each transmission line* [3]."

"*It is quite impossible to build a current balun of any ratio other than 1:1 using multiple transmission line transformers on a single core unless flux leakage between transmission lines is terrible* [4]."

"*It (is) impossible to build anything but a 1:1 ratio current balun when multiple transmission line transformers are placed on a single core* [5]."

"*It is physically impossible to build a transmission line current balun other than 1:1 on a single core when the windings have mutual coupling through the core* [6]."

In order to avoid having these and other misconceptions regarding the design and applications of current baluns become widespread, I'll provide here a tutorial on the subject, beginning with a review of the theory and shortcomings of two of the basic forms of baluns (the Guanella 4:1 current balun and the Ruthroff 4:1 voltage balun), and then a discussion of a 4:1 current balun that overcomes the shortcomings of these two basic forms, ending with some test results from a prototype suitable for HF, VHF, and UHF applications.

The Guanella 4:1 Current Balun

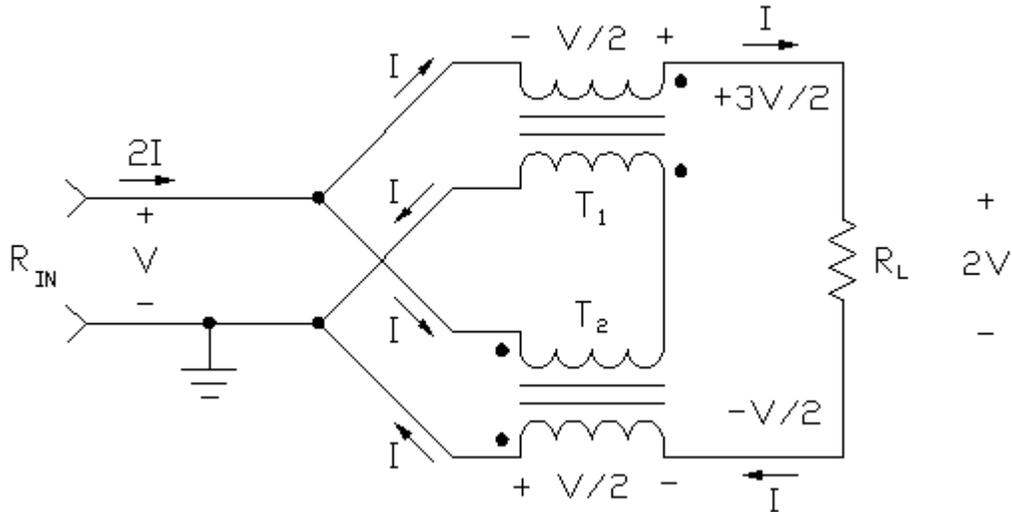Perhaps the single most popular form of 4:1 current balun is that which was origi-

Figure 1 - The Guanella 4:1 Current Balun with Floating Load

nally conceived by Guanella [7], and which is shown in schematic form with a floating load in Fig. 1. Basically, the Guanella 4:1 current balun consists of a pair of 1:1 transformers, connected in such a way as to induce equal and opposite currents at the two balanced output ports, thereby meeting the definition set forth earlier for a current balun [1].

When constructed on a single core, the Guanella 4:1 current balun will work with floating loads as shown in Fig. 1 and is therefore well suited for most antenna applications, especially dipoles. However, when used with a symmetrical load such as shown in Fig. 2, the

Guanella 4:1 current balun requires that the two 1:1 windings be constructed on separate cores as the voltages across these two windings are now dissimilar. In order to enjoy the best possible bandwidth, the construction of these two separate windings must ensure that the windings are of identical electrical length in order that the propagation delays be the same for both sides, otherwise the frequency range of the balun will be limited by way of phase imbalancing. This places constraints on the selection of the magnetic core material, if any is used, and since permeabilities of both powdered iron and ferrite materials can vary widely from one lot to
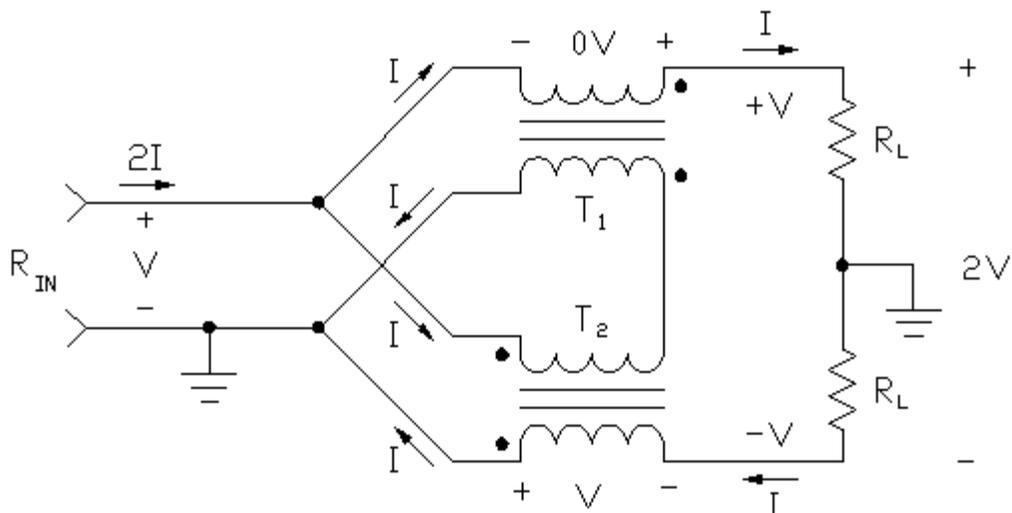

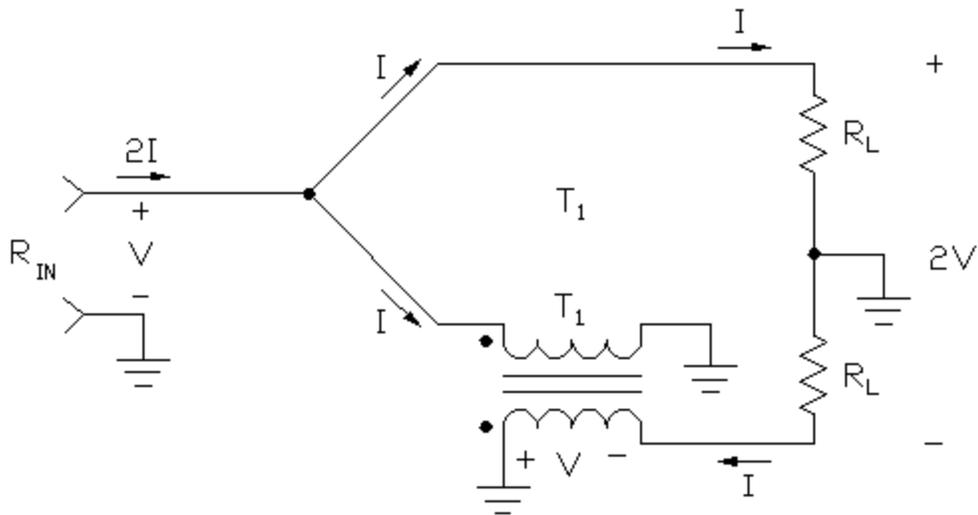Figure 2 - The Guanella 4:1 Current Balun with Symmetrical Load

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Figure 3 - The Ruthroff 4:1 Voltage Balun

another [8, 9], it becomes necessary that the cores be selected in matched pairs in demanding applications, particularly when the application frequency approaches the ferroresonant frequency of the material [8].

Regardless as to whether the Guanella 4:1 current balun is constructed on one or two cores, the losses and parasitics associated with the two windings will cause the output voltages to be unbalanced. For instance, for a balun of this type constructed for a 50Ω system and having just 0.1Ω of loss in each winding, there is a voltage imbalance of 0.035dB. Parasitic reactances, including leakage inductances that result from flux that

is not linked to the core [10, 11, 12] also further limit the performance.

The Ruthroff 4:1 Voltage Balun

The Ruthroff 4:1 voltage balun of Fig. 3 [13] is a very convenient 4:1 voltage balun that can be constructed on a single core, and which has become very popular by way of the efforts of Jerry Sevick, W2FMI [14], and it can be used with both floating and symmetrical loads without modification. But it does have limitations more serious than those mentioned earlier for the Gaunella 4:1 current balun. Specifically, the losses and delays of the two output terminals are not equal, and therefore
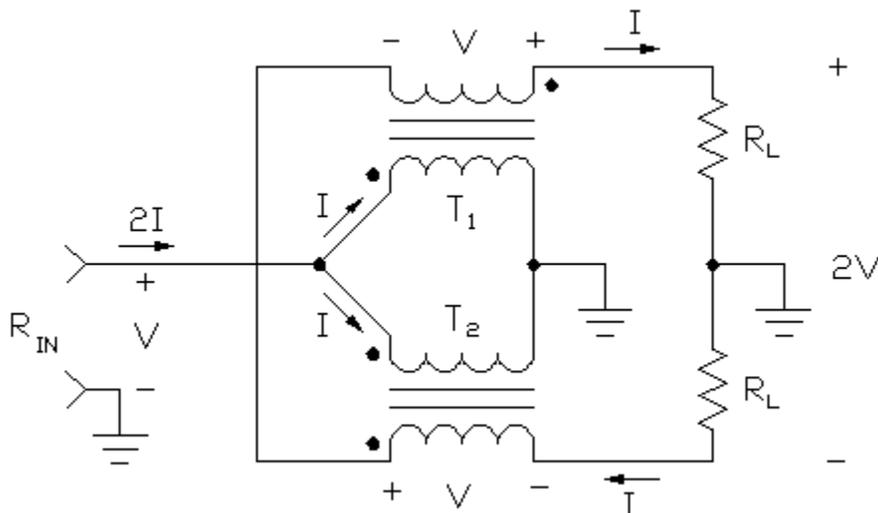
Figure 4 - Improved 4:1 Current Balun

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the frequency performace drops off more rapidly than for a Guanella balun made with the same materials

An Improved 4:1 Current Balun Using a Single Core

The shortcomings of the Guanella and Ruthroff 4:1 baluns gave rise to speculation of the possibilities of devising a 4:1 current balun comprised of a pair of 1:1 current baluns on the same core that can be used with floating, symmetrical, or even asymmetrical loads. In a very short period of time, the 4:1 current balun of Fig. 4 was devised, modeled, prototyped, and tested. It was found to fulfill the definition set forth earlier by McLeary [1], and can be constructed on a single core or with no core at all, if desired.

Theory of operation is simple and straightforward. The first transformer T_1 receives a current I from an input voltage source V across the primary winding. By way of transformer coupling, an equal current I and voltage V are induced in the secondary winding (make note of the polarity reversal of transformer T_1). At the same time, the second transformer T_2 receives a current I from the input voltage source V across the primary winding. And also by way of transformer coupling, an equal current I and voltage V are induced in the secondary winding. Since neither of the transformers have a reference to ground on the secondary side, they each constitute a 1:1 current balun.

With the primary sides of transformers T_1 and T_2 being in parallel, the secondary voltages are equal and therefore the output voltage is 2V. At the same time, since the secondary sides of the two transformers are in series, the currents through the balanced loads are equal. Since there is no connection to ground on the secondary side of the balun (excluding that of the load), the balun will deliver equal and opposite currents at the output terminals regardless of any imbalance in the load impedances, thus fulfilling the definition set forth earlier by McLeary [1]. By grounding the common connection between the two secondaries, this 4:1 current balun can be readily used as a 4:1 voltage balun.

PSpice modeling showed that with ideal transformers the balun performed as required, and the input impedance did not vary regardless of whether a ground was connected to the first output terminal (+V), the centre of the balanced load, or the second output terminal (-V), indicating that the balun would work equally well with floating, symmetrical, and asymmetrical loads.

Adding small resistors to the transformer windings to simulate losses showed that the balun retains it's balance and insensitivity to output grounding. The same was true when small inductors simulating leakage inductances were added.

Small parasitic capacitors were then added between the three terminals, and as expected these resulted in some minor output voltage imbalance and sensitivity to grounding of the second (-V) output terminal at higher frequencies, which is typical for a balun transformer or for any transformer having a single input and a balanced output.

Experimental Results

To verify that the concept is valid, a prototype was constructed using a single Fair-Rite 2843010302 binocular core and two 3-inch long pieces of RG-316 coaxial cable, which is a bit short for HF applications but which is sufficient for this testing and which is consistent with the design of transmission line transformers for HF and VHF applications.

The cables were passed through the holes of the core in a U shape with all the
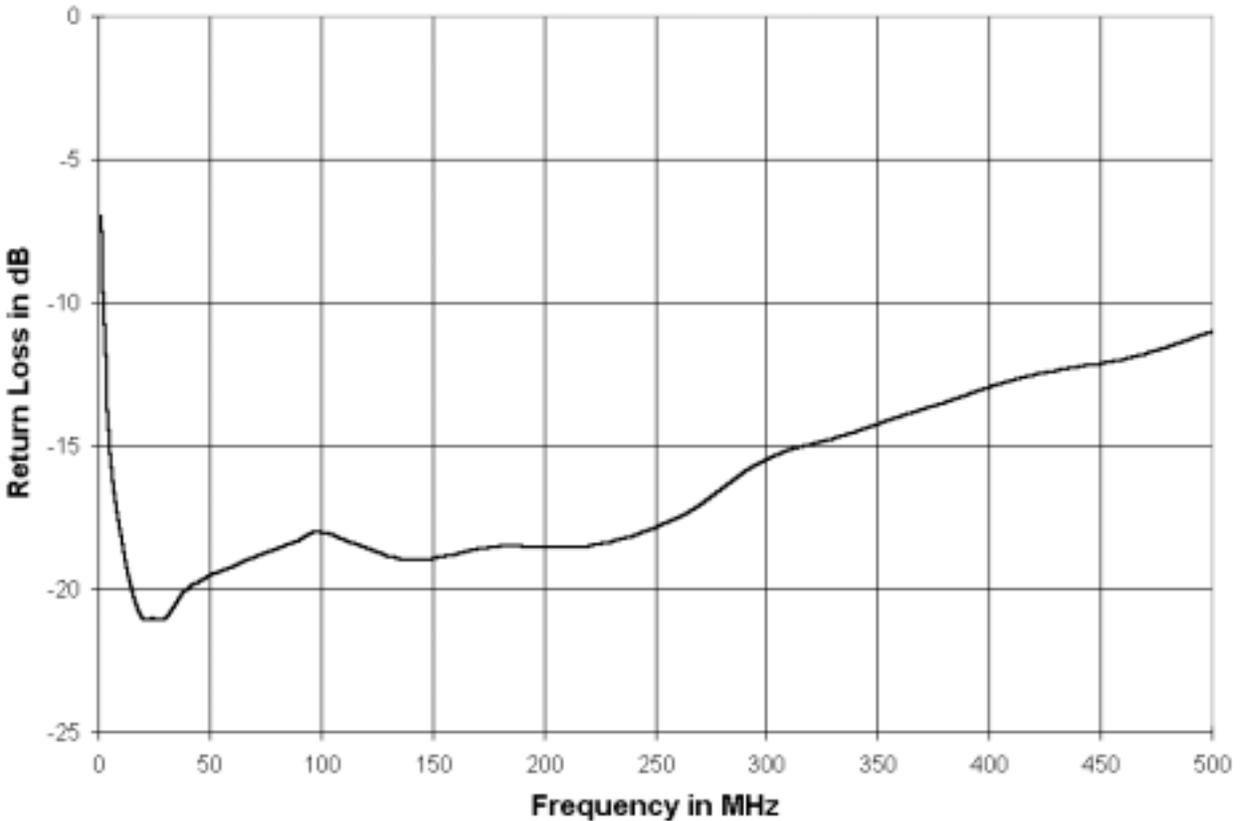
Figure 4 - Improved 4:1 Current Balun Return Loss

ends of the cables projecting from the same end of the core. The outer insulating jacket was left on the cables in order to ensure that the currents through the outer shield of the cables were independent. The balanced load was provided by a pair of 100Ω $\pm2\%$ 1/2W carbon film resistors.

The test results for the measured return loss, shown in Fig. 4, indicates that the improved 4:1 current balun prototype has a return loss of better than -15dB from 5MHz to about 320MHz, which is very good for a transmission line transformer having coupling sections this short. Grounding the common connection of the load resistors resulted in no change in the return loss, nor was any observed when grounding the noninverting output terminal. As expected from the PSpice simulation, grounding the inverting output terminal did result in some minor degredation in the return loss, but only for frequencies above 100MHz, which is beyond the ferroresonant frequency of the Type 43 material of the core. Thus, the prototype demonstrated that this balun will work with floating, symmetrical, and asymmetrical loads.

Closing Remarks

A 4:1 current balun made from a pair of 1:1 current baluns on a single core that overcomes the shortcomings of comparable Guanella and Ruthroff baluns has been devised and modeled, and a fully functioning prototype has been constructed and tested to verify that the concept is valid. This potentially new form of 4:1 current balun design overcomes the minor shortcomings of the Guanella 4:1 current balun that are associated with the losses of the two transformer sections and any dissimilar properties of the two required cores.

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