BALUNS – PART I

Andy Griffith – W4ULD

Recently I was thumbing through my files on baluns and realized that over the years I had collected a wealth of information that could be of use to fellow Hams. So, I decided to write this series of short articles. In this first article I will describe baluns and a little about using them. In later articles I will talk further about how to use baluns, balun construction, balun performance, and power ratings.

The term balun is an acronym for balanced-to-unbalanced. To the Ham this usually means connecting a balanced load such as a dipole antenna to an unbalanced input such as 50 ohm coaxial cable. The shield side of the cable is usually grounded.

The balun belongs to a class of devices known as "transmission line transformers". Transmission line transformers are formed by winding bifilar turns, multifilar turns, coaxial cable, or strip-line cable (two strips of flat conductor with a dielectric material between the strips) on a core having high permeability[1]. Because of the high impedance of the winding, the balanced output terminals are isolated from the unbalanced input terminals.

There are two general classes of baluns: the voltage balun and the current balun. The voltage balun forces equal voltage across the two sides of a balanced load and the current balun forces equal current through the two sides of a balanced load. The 1:1 current balun is usually nothing more than a simple transmission line (e.g. bifilar winding or coaxial cable) wound on the core. Voltage baluns are a little more complicated. They will be discussed in more detail in a later article.

The action of the balun described in the previous paragraph can be most easily pictured by describing the balance test for a balun. Referring to Figure 1, the balun is placed on a conducting plate. The ground side of the input terminals is grounded to the plate. The center of the load resistor is grounded to the same plate. A low level signal at the test frequency is applied from a signal generator, or other source, to the unbalanced input terminals. The voltage from each output terminal to ground is measured with an oscilloscope or RF voltmeter. If the balun is acting as a balun, that is, the output terminals are truly isolated from the input terminals, the voltage across each half of the load resistor will be equal.

Commercial baluns (voltage and current) available for Ham radio use usually have an impedance transformation ratio of 1:1 or 4:1. The 1:1 ratio balun is designed for 50 ohm balanced to 50 ohm unbalanced. The 4:1 ratio balun is designed for 200 ohm balanced to 50 ohm unbalanced. The ratio one should use depends on the magnitude of the balanced load and has nothing to do with the impedance of the transmission line. For example, a dipole antenna will have an input impedance at its fundamental frequency from about 50 to about 85 ohms. One should use a 1:1 balun to feed the antenna with 50 ohm coax. A

folded dipole has an input impedance of about 270 ohms. A 4:1 balun would be best in this case to feed the antenna with 50 ohm coax. In either case an antenna tuner may be required at the transceiver.

Commercial baluns are available with power ratings up to about 5 KW. The ratings depend mostly upon the amount of ferrite in the core. If there is insufficient core, the core may overheat and fracture. High load impedances require more core. It is best to err on the high power side. Unless one knows that the load impedance of his antenna is less than 100 ohms, one should use a 1.5 KW balun for 100 to 200 W and a 5 KW balun for 1500 W.

73, Andy

Notes:

1- Permeability is the ratio of inductance of a winding on a core to the inductance of the same winding in air, which has a permeability of 1, assuming that all of the lines of force around the winding pass through the core material.
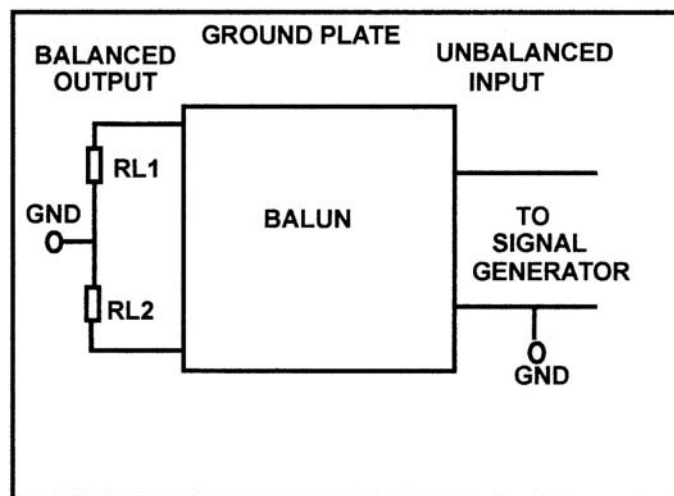

Figure 1

BALUNS-PART II

WHEN AND WHERE TO USE BALUNS

Andy Griffith – W4ULD

Baluns are usually used by Hams to feed dipole antennas with 50 ohm coax and to transpose from ladder line feeding a multi-band antenna to the unbalanced input of an antenna tuner.

The primary reason for using a balun at the feedpoint of a dipole antenna is to prevent RF currents from flowing on the outside of the shield of the coax feeding the antenna. RF current on the outside of the coax shield causes the shield to radiate. This may cause a distortion in the radiation pattern of the antenna and may cause TVI and telephone interference if the coax is passed close to a TV cable or telephone line. If the "hot" shield is brought into the shack, one might encounter the "hot mike" problem where the mike bites one's lips when touched. Let's look at how these things occur and decide whether a balun is needed.

Figure 1 is the classic diagram describing what happens to RF currents at the feed point of a coax fed dipole. This diagram can be found in most books on antennas. The RF current from the transceiver is contained within the coax flowing on the center conductor and the inside of the coax shield. The current on the inside of the shield does not reach the outside because RF currents only flow on the surface of conductors. This is the so called "skin effect". When the RF currents reach the antenna, the current on the center conductor flows into one side of the dipole. The current on the inside of the shield flows into the other half of the dipole and down the outside of the shield of the coax. The amount of current taking each route will depend upon the impedance of each route. For example, if the impedance of the outside of the shield is very high, most of the current will flow into the antenna. However, if the impedance of the shield is low, the current will be divided between the antenna and the outside of the shield. If currents exist on the outside of the coax shield, a 1:1 balun at the feed point will likely correct the problem. A current balun is best for this use[1].

Usually the shield of the coax feed line is grounded somewhere near the input. Preferably, it will be grounded before the coax enters the shack such as at an antenna switch. If the length of the coax is ½ wavelength from the ground point to the antenna feed point, the outside shield will reflect the low ground impedance at the feedpoint and a large amount of current will flow on the shield. Conversely, if the length of the coax is ¼ WL from the ground point to the antenna feedpoint, the shield will present a very high impedance at the feedpoint and most of the RF current will flow into the dipole antenna. Coax lengths that are not a multiple of ¼ or ½ WL will have a current level on the shield somewhere between the two extremes. The velocity factor of the coax is not involved in determining the length in wavelengths. One half wavelength will be approximately 468/frequency in MHz. If the feed line is not grounded outside the shack but is brought to

the transceiver and the transceiver is grounded, the length of the ground wire must be added to the length of the coax plus some allowance for the equivalent length of the transceiver case. In this case one is bringing the radiating coax into the shack which is not good. Also, if the length of the ground wire is ¼ WL, the case of the transceiver and the mike will be very hot. Some Hams have also experienced computer problems because of a high amount of RF.

Now that I have explained what can happen, I must say that I have successfully operated many dipoles fed directly with coax by simply being careful about coax length and grounding. Unless one is operating and inverted vee antenna where there is a center support, hanging a balun in the middle of an antenna without center support can stress the antenna wire and its connections. I recommend not using a balun unless one finds that it is needed.

I have never been able to see a significant effect on the radiation pattern of a dipole because the antenna is unbalanced by feeding it as much as a foot off-center. I did extensive modeling of the situation using EZNEC antenna program. So, I would not recommend using a balun at the feedpoint just to correct small errors in measuring the two legs of a dipole. A distorted pattern can be seen via EZNEC for the Windom antenna which is fed about 1/3 off-center; however, the distortion was not noticed in operating the antenna for several years.

The 135 ft. center-fed Zepp (dipole) fed with "450 ohm" ladder line to a 1:1 balun and an antenna tuner is a popular all band antenna and highly recommended for those unable to have a multi-band beam. The ladder line may be any length although some lengths on some bands may present an impedance to the tuner that is outside of its tuning range. In this case adding or subtracting a couple of feet to or from the feed line will usually correct the problem. Most Hams using the center-fed Zepp mount the balun just outside the shack and run a short length of 50 ohm coax into the shack to the antenna tuner. The coax should be six feet or less in length to prevent a high loss. The balun input on some bands may be over 1000 ohms or 20:1 SWR. However, the system will work as long as the impedance at the tuner is within its tuning range. Because of the possible high impedance and potentially high voltages, one should use a 1KW balun for 100 –200 watts and a 5 KW balun for 1500 W. I recommend a 1:1 balun (voltage or current: I have used both) because some input impedances will be less than 50 ohms. A 4:1 balun would convert this to a very low impedance where tuner losses may become excessive. The tuner should have the same power rating as the balun. The inexpensive 300 W tuners will arc over in this service. Some operators bring the ladder line into the shack and connect it to the balance output terminals of the tuner. Most modern tuners use a 1:1 current balun. This procedure is OK as long as one can tolerate the extra RF in the shack.

73, Andy

Notes:

1- Roy Lewallen, W7EL, ARRL Antenna Compendium-Vol.1, pg. 157.
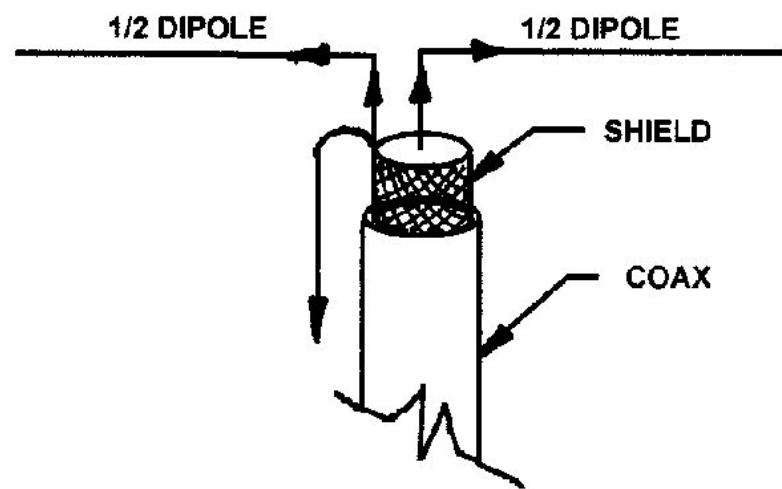
Figure 1

BALUN PART III
BALUN DESIGN

Andy Griffith – W4ULD

Balun design is not an exact science. There are several rules of thumb for guidance. The first rule is that to maintain balance at the lowest operating frequency the reactance of the winding must be twice the highest ohmic value of the load expected. Thus if one expects the maximum load for a 1:1 balun to be 200 ohms, the inductive reactance of the winding on the core must be approximately 400 ohms.

Since the winding on the core is a transmission line, the load of a 1:1 balun will be transitioned to a difference impedance depending on the characteristic impedance (Z0) and the length of the line wound on the core. Thus the second rule is that one should use the shortest possible length of wire in the winding. The effect of line length will be most noticed at the higher frequencies.

The third rule of thumb is that the characteristic impedance (Z0) of the winding on the core should equal the average load impedance expected for the 1:1 balun.

Let's design a 1:1 voltage balun for 3.5 MHz. to 29 MHz. which will maintain balance for a maximum load of 200 ohms. We will use an Amidon FT-240 toroid core to insure adequate power capability (more on this later). We should select a core having a broadband impedance range within the frequency range of interest. Based on Amidon data type 61 material is good for .2 to 10 MHz. for resonant circuits and 10 to 200 MHz. for wide band circuits. Thus we would expect this material to provide an inductive reactance to a winding between 1.8 MHz. and 29 MHz.

Thus we have chosen an Amidon FT-240-61 toroid core. Amidon has derived A_L values for their cores to calculate inductance. The A_L value for this core is 173. The turns required for a given inductance is $T = 1000\sqrt{U/AL}$ where *T = turns, U = required inductance in millihenrys, and AL = 173*. If we design our balun to maintain balance at 200 ohms load impedance at 3.5 Mhz. the inductive reactance needed is about 2 X 200 = 400 ohms. The inductance required a 3.5 MHz. is $L(uH) = \dfrac{400}{2\pi \times 3.5} = 18.2$

microhenry or .0182 millihenry. Then the turns required $= 1000\sqrt{\dfrac{.0182}{173}} = 10$. Ten turns on this core will require about 1.875 ft.of wire which is .055 WL at 10 meters. This is a little high for good operation on 10 meters so we will compromise on 9 turns. Nine turns will give us 307 ohms reactance at 3.5 MHz. which may be enough.

The 1:1 voltage balun is shown schematically in Figure 1. The additional non bifilar winding is called a balancing winding and is necessary to "complete the path for the magnetizing current"[1].

In Baluns Part IV we will construct and test the balun we just designed.

73, Andy – W4ULD

INPUT   OUTPUT

BIFILAR
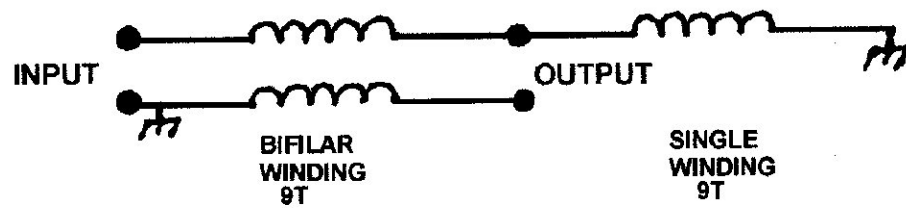WINDING
9T

SINGLE
WINDING
9T

FIGURE 1

BALUNS PART IV
CONSTRUCTION AND TESTING

Andy Griffith, W4ULD

In Part III we designed a 1:1 voltage balun that should maintain balance with loads as high as 200 ohms from 3.5 MHz. to 29.0 MHz. We chose an Amidon Associates FT-240-61 toroid core. This core is 2.4 ins. OD x 1.4 ins. ID x .5 in. high and is constructed of Type 61 material ferrite which has a permeability of 125. Each turn of wire on this core is approximately 2.25 ins. long.

The balun was constructed by first wrapping the core with black electrical tape. The ferrite core is conductive and must be insulated from the winding. For the winding two 24 inch lengths of #14 enameled wire were paralleled and held together with glass electrical tape about each two inches.. This parallel winding was wound on one-half of the core. The third non-bifilar winding was added on the second half of the core. This winding is essentially an extension of the ungrounded half of the main bifilar winding. The finished balun is pictured in Figure 1 during balance testing.

Some of the data obtained during an evaluation of the balun are shown in Table 1. The impedance readings were made with an Autek Model VA1 analyzer. This is a good instrument but sometimes the algorithm that detects sign of reactance gets confused. Loads were ¼ W resistors. It appears that the optimum impedance of the winding is about 67 ohms. Thus, a load impedance of 67 ohms will transpose to an input impedance of about 67 ohms with little reactance in the input impedance over a broad range of frequencies..

At loads below and above 67 ohms the Z0 of the winding follows the general rules for transmission lines. That is, if the load is below the Z0 of the line, the input resistance will be greater than the load resistance and a positive reactance will be evident. If the load impedance is greater than the Z0 of the line the input resistance will be less than the load resistance and a negative or capacitive reactance will be evident.

The balance test was described in Baluns Part I and is shown in Table 2. It appears that balanced was maintained for resistances of 20 through 200 ohms load from 1.8 MHz .through 29 MHz..For 300 ohm load resistance (2 x 150) balance was fairly good from 1.8 MHz. through about 7 MHz. but fell apart at higher frequencies. Thus, the balun will work well on 160 M.

My conclusion is that this balun surpassed the design criteria. This balun should be good for at least 1 KW power. We will talk about power ratings later.
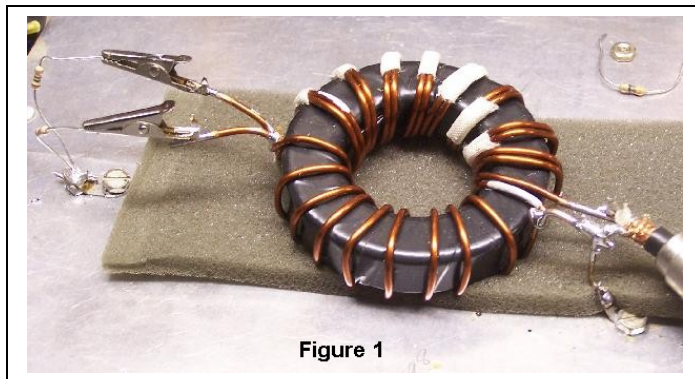
73, Andy, W4ULD

Figure 1

Table 1

Load R Ohms	Freq. MHz.	Input Impedance R +/- jX	SWR
27.2 SWR=1.84	1.8	30 + j4	1.70
	3.5	30 + j6	1.66
	7.0	30 + j11	1.75
	14.0	34 + j19	1.77
	21.0	28 + j40	3.2
	29.0	38 + j39	2.42
67.2 SWR=1.34	1.8	69 + j8	1.40
	3.5	70 + j4	1.40
	7.0	69 – j0	1.40
	14.0	69 + j2	1.38
	21.0	67 + j2	1.30
	29.0	62 + j11	1.31
80.8 SWR=1.62	1.8	82 + j11	1.66
	3.5	83 + j3	1.65
	7.0	84+ j0	1.62
	14.0	76 + j8	1.54
	21.0	69 + j5	1.38
	29.0	60 + j17	1.41
99.5 SWR=1.99	1.8	101 +j14	2.03
	3.5	102 + j4	2.04
	7.0	97 – j7	1.94
	14.0	86 – j7	1.74
	21.0	73 – j10	1.51
	29.0	60 ? j16	1.38
219 SWR=4.38	1.8	204 + j52	4.30
	3.5	217 – j23	4.30
	7.0	175 – j79	4.2
	14.0	108 – j88	3.73
	21.0	63 – j84	3.99
	29.0	59 – j45	2.25

Table 2
BALANCE TEST

Load R Ohms	Freq. MHz.	V1/V2	Balanced Y/N
2 x 10= 20	1.8	4.6/4.6	Y
	3.5	3.5/3.5	Y
	21.0	2.4/2.2	Y
	29.0	2.2/2.2	Y
2 x 27= 54	1.8	2.2/2.2	Y
	29.0	2.6/2.6	Y
2 x 100= 200	1.8	5.0/5.0	Y
	29.0	2.0/2.0	Y
2 x 150+ 300	1.8	2.6/2.6	Y
	3.5	4.6/4.5	Y
	7.0	6.2/6.4	Y?
	14.0	3.6/4.0	?
	21.0	3.0/2.8	?
	29.0	2.7/2.0	N

W4ULD, 1-9-07

The power rating of a balun depends on many factors and cannot be readily calculated. Most baluns will fail from overheating and the limits on temperature rise for powdered iron and ferrites have been fairly well established. It is reported that the core of a balun will shatter when subjected to over power and thus over temperature. I have never had a core shatter but also I have never subjected a FT-240-61 core to more than 800W.

The only way I know to get accurate measurements of temperature rise is to place the balun in a calorimeter under various loads and powers. I don't know of any Hams with a fancy calorimeter.

Amidon Associates gives the following formula to calculate the flux in a core:

$$B\max = \frac{Epk \times 100}{4.44 \times Ae \times N \times F} \; Gauss$$

$Epk = Applied \; RMS \; volts \; across \; winding$
$Ae \; = \; Crossection \; area \; of \; core, \; sq. \; cm.$
$N = Number \; of \; wire \; turns$
$F = Frequency, \; MHz.$

Amidon also gives the allowable flux for the HF bands as seen in Figure 1. The equation for the curve in Figure 1 is:

$$LogB = -0.48299\,LogF + 2.17609$$

$B = Flux \; in \; Gauss$
$F = Frequency, \; MHz.$

The above information is great for designing chokes and conventional transformers where the entire voltage across the windings creates flux in the core. In the case of a well balanced balun the theoretical net voltage across the winding is zero so a small core will take a lot of power. We cannot depend on operating with perfect balance so what level of unbalance should we use for design. I have found that 1.5/1 is about right: that is, if the total voltage is say 1000 V, the voltage across the two halves of the load will be 400V and 600V with a net unbalance voltage across the winding of 200V.

As an example, The allowed flux at 7 MHz. is 57 Gauss. The FT-240-61 toroid core has a crossectional area of 1.57 sq. cm. The bifilar winding on the core is 9 turns. By rearranging the above equation we obtain the allowed *Epk*.

$$Epk = \frac{57 \times 4.44 \times Ae \times N \times F}{100} = \frac{57 \times 4.44 \times 1.57 \times 9 \times 7}{100} = 248V \text{ allowed across}$$

the winding. This translates to a total of 1240V across the output terminals. Then for a 1000 ohm load (20:1 SWR is about maximum for most situations) the power is

$$P = \frac{E^2}{R} = \frac{1240^2}{1000} = 1538W$$

Two stacked FT-240 cores with 13T are used in the MFJ-986 tuner rated for 3000W SSB and 1500 W AM.

A 1:1 balun having six bifilar turns on a FT-140-43 core (1.4 in. OD) calculated out to be good for 181W into a 1000 ohm load. I evaluated this core with 100W for one minute into a 50 ohm load and about 300 ohm load at 3.9 MHz. and 7.2 MHz. With a 50 ohm load I could not detect any increase in temperature. With the 300 ohm load at 3.9 MHz. the balun warmed just enough to detect by hand. At 7.2 MHz. no increase in temperature could be detected. This is consistent with the allowable flux at the two frequencies. I concluded that the 181W rating was pretty close.
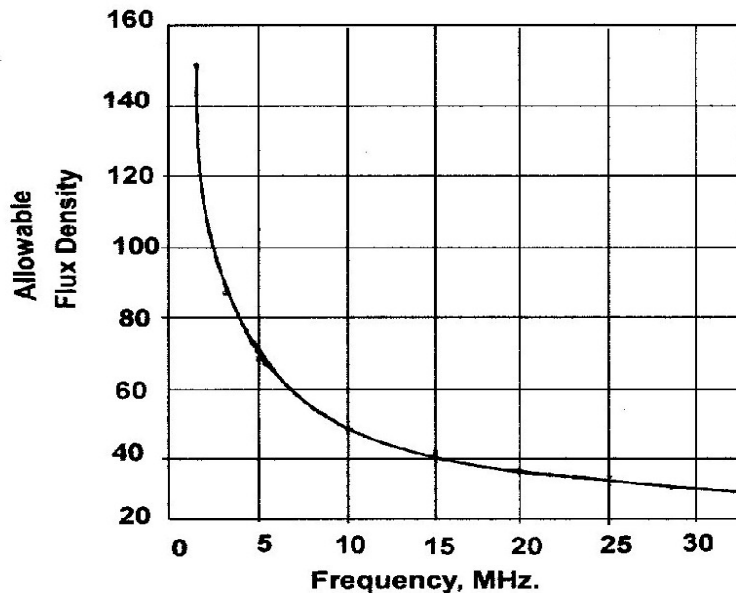

Figure 1

Andy Griffith, W4ULD

Determining power loss in a balun is another area where expensive equipment is required for direct measurement. Mainly, non-inductive resistors up to about 1000 ohms with ratings up to at least 100W. I worried about loss for a long time until I realized that the loss under most circumstances is much less than 1 dB. There is more loss in common T-network antenna tuners than in a balun. The reason for this is that the transmission line wound on a balun is quite short.

I made a direct measurement once by constructing two identical 4:1 voltage baluns and placing them back to back with their balanced terminals connected together. The input (umbalanced) terminal of one was connected to a 600 watt dummy load and the input of the other was connected to an antenna tuner. Thus the baluns were operating at 4:1 and 1:4 ratios. A Bird 43 wattmeter was placed between the transmitter and the tuner and at the dummy load. The tuner was tuned for 1:1 SWR. Thus the power was measured under 1:1 SWR conditions where the accuracy of the measurements was the greatest. Measurements were taken with and without the baluns in place so the loss through the tuner could be measured and subtracted from the total loss to get the loss through the baluns. Between 3.9 MHz. and 28.7 MHz. I measured losses in each balun between 0 and 0.193 dB. Of course, these values will be higher for loads below and above the design loads.

One can also use the formula for loss in a transmission line based on input and output SWR. The SWR's must be based on the characteristic impedance (Z_0) of the line wound on the balun. This is seldom known with high accuracy. The formula is:

$$Loss(dB) = 10\log\frac{C(A^2-1)}{A(1-C^2)}$$

$$A = \frac{SI+1}{SI-1} \qquad\qquad C = \frac{SL-1}{SL+1}$$

SI = Input SWR based on line impedance on the balun (Z_0)
SL = Load SWR based on Z_0

Using the 1:1 balun we designed in Part IV and 67 ohms for Z_0, SL = 3.27, and SI = 2.03, we calculate .08 dB loss at 29 MHz.

73, Andy – W4ULD

BALUN PART VII
THE 4:1 VOLTAGE BALUN

Andy Griffith-W4ULD

In Part III we designed a 1:1 voltage balun and described its performance in Part IV. We
have mentioned the 4:1 balun. In this part we will describe the performance of the 4:1
balun.

The 4:1 voltage or Ruthroff balun is shown schematically in Figure 1. In this case the
winding on a toroid core covers the entire core rather than half the core as with the 1:1
balun. Generally the same rules apply with respect to the number of turns on the core. Of
course one must use more turns because the average load inpedance is now about 200
ohms. Also, the approximate impedance of the winding on the core must now be
$Z_0 = \sqrt{R_L} \times \sqrt{R_I}$ where R_L is the design load impedance and R_I is the input impedance.
Thus for a 200/50 ohm balun, the bifilar line should be approximately 100 ohms. This
value is obtained by slightly increasing the spacing of the two wires making up the
bifilar winding usually by insulating one or both of the wires.

I have built many 4:1 baluns on the FT-240-61 core for 200/50 ohms using 11 to 15 turns
of insulated house wire stripped from 14-2 w/ground cable. The insulated wires were
held tightly together with glass tape. The ferrite core does not have to be insulated
because the winding is insulated. All of these baluns exhibited good performance near the
design load of 200 ohms but balance suffered at loads much above 200 ohms.

I measured the impedance and velocity factor of a tight pair of insulated #14 wires as 122
ohms and 0.76. The relatively low VF of 0.76 indicates a fair amount of loss. I suspect
that line loss contributes to unbalance since the 4:1 balun I describe below showed good
balance up to about 600 ohms load.

The best 4:1 balun I ever built was constructed on a FT-240-61 core which had been
wrapped with Teflon tape. The bifilar winding consisted of two #14 enameled wires
which were each covered with a Teflon sleeve. The loss in the Teflon insulated winding
should be quite low. The OD of each insulated wire was about 0.1 in. Looking at the data
for 224 ohm load in Table 1, it appears that the impedance of the winding was about right
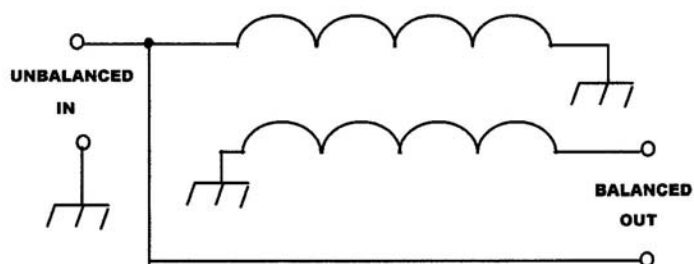for a 200/50 ohm balun. Balance data are shown in Table 2.

Figure 1

4:1 Voltage Balun

Table 2

4:1 Balun Balance Test

R_L, Ohms	F, MHz.	V_1	V_2
2 x 150	1.8	4.4	4.4
	7.0	4.2	4.2
	21.0	5.7	5.7
	30.0	5.4	5.4
2 x 220	1.8	2.8	2.7
	30.0	3.5	3.5
2 x 330	1.8	3.1	3.1
	30.0	4.0	4.5
2 x 466	1.8	4.0	3.8
	30.0	5.6	6.0

Table 1

Performance of 4:1 Voltage Balun

Load R_L, Ohms	F, MHz.	Input Imped. R	X	Z
100	1.8	27	6	28
	3.5	28	6	29
	7.0	28	7	29
	14.0	28	12	30
	21.0	27	22	35
	30.0	29	25	26
153	1.8	39	10	40
	3.5	40	9	41
	7.0	41	6	41
	14.0	41	10	42
	21.0	43	4	43
	30.0	43	14	45
224	1.8	51	20	55
	3.5	57	14	59
	7.0	59	5	59
	14.0	58	1	58
	21.0	53	0	53
	30.0	49	8	50
330	1.8	67	36	76
	3.5	80	26	84
	7.0	87	5	87
	14.0	77	0	77
	21.0	65	-3	65
	30.0	62	-11	63
561	1.8	77	74	107
	3.5	127	50	136
	7.0	145	6	145
	14.0	112	-24	115
	21.0	83	-32	90
	30.0	80	-10	81

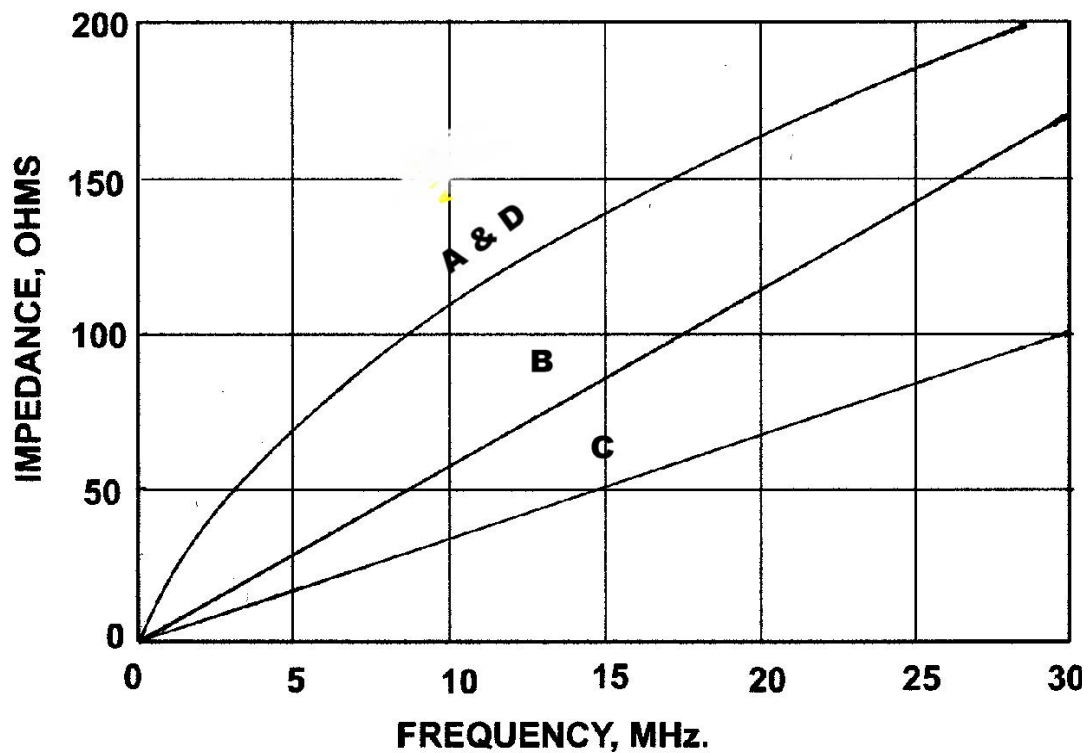BALUNS PART VIII
THE BEAD BALUN

Andy Griffith, W4ULD

Ferrite beads hsve been used by Hams for quite a few years to "knock" the RF off of computer cables and other lines. Ferrite beads over coax also make an effective 1:1 current balun by preventing the flow of RF currents along the outside of the coax shield. The bead balun amounts to one turn on the core. One advantage of the bead balun installed over coax is that the impedance of the line is not changed..

Like toroid cores, beads come in many sizes and material values. Probably the best material for HF through UHF is equivalent to Amidon material 43. Fortunately, all of the beads I have purchased at Hamfests or ordered from surplus houses have been very similar to material 43. The impedance of a single solid bead over coax starts relatively low at 1.8 MHz. but climbs rapidly with frequency (See Figure 1, A & D). Amidon shows 43 material peaking in impedance at about 200 MHz. and still having relatively high impedance as high as 1000 MHz. Thus, we can use 43 material beads for RF suppression and baluns throught the amateur radio spectrum.

Two beads available at Hamfests and surplus houses are shown as A & D in Figure 1. My reliable impedance measurements are limited to about 30 MHz.. D in Figure 1 is for a common bead which is .251 in. ID x .563 in OD x 1.125 in. long. This bead fits nicely over RG-8X coax. A in Figure 1 refers to a larger bead which will fit over RG-213 type coax. Ten of these or the smaller beads stacked in series on coax shows good balance in the HF spectrum from 1.8 to 30 MHz. I have compared bead baluns with other !:1 bsaluns in operating situations and find no difference among them.

Split beads which can be opened to "snap" over the coax are also available at Hamfests and on the surplus market. While these are convenient, their effectiveness is less than half that of the solid beads for a given ID and volume of ferrite in the HF bands as can be seen from B and C in Figure 1. Large bead B had about 1-1/2 times the ferrite of solid bead A. Some of you may remember the 2 M/440 antenna project that CCARS sponsored a few years ago. In this case a single "snap on" bead like B in Figure 1 was an adequate balun for 144 and 445 MHz. Note that in the HF spectrum the split beads follow a straight line relationship between impedance and frequency. It appears that the split beads become more efficient at frequencies above HF.

While not related to baluns, split beads are most useful for Hams using HF mobile rigs. Beads placed over battery cables and coax to the antenna can prevent RF in the cab from interfering with operation of the transceiver and the auto's computer. Usually such problems are a result of an inadequate RF ground to the chassis of the vehicle. This problem should be tackled first.

Legend:
> A = Hamfest .51" ID x 1.014" OD x 1.125" LG
> B = Hamfest, split bead, .535" ID x 1.012" Sq
>   x 1.125" Lg
> C= Hosfelt, split bead, .41" ID x .739" Sq
>   x .748" Lg
> D= Hamfest, .251" ID x .563"OD x 1.125" Lg

Figure 1

BALUNS PART IX
THE 1:1 CURRENT BALUN

Andy Griffith – W4ULD

As described earlier, the 1:1 current balun is simply a transmission line like a bifilar line wound on a core. It is shown schematically in Figure 1.

I wanted a broadband 1:1 balun for average load impedance of about 80 ohms; so I wrapped about three layers of Scotch plastic masking tape around one of the #14 wires in the bifilar pair to increase the distance between the wires and thus increase the characteristic impedance of the winding. The balun then consisted of 13 turns on about 80% of the circumference of the FT-240-61 toroid core. By winding on only 80% of the core circumference, the inductance of the winding was increased somewhat over the normal winding over 100% of the circumference.

As can be seen from Table 1, the balun performed best with a 78 ohm load as desired. Balance was maintained from 2.3 MHz. to 28.5 MHz. with a 54 ohm load (2 x 27). Balance was also maintained with an 11.2 ohm load (2 x 5.6) at 3.5 MHz. and 7.0 MHz. This low load level is often experienced with short dipoles. Other frequencies were not evaluated at 11.2 ohms. With 200 ohms load (2 x 100) unbalance was noted at 3.5 MHz. and 29.0 MHz. At 1020 ohms (2 x 510) severe unbalance was noted from 3.5 MHz. to 30 MHz.

Table 1

1:1 CURRENT BALUN PERFORMANCE

Load R	F, MHz.	Input Impedance R + j X	Balance V_1/V_2
2 x 5.6=	3.5	Out of Range	4.4/4.4
11.2	7.0	27.3 + 22	5.7/5.7
2 x 27=	2.3	52.2 + 5.1	5.2/5.2
54	3.5	51.9 + 5.4	4.3/4.3
	7.0	54.7 + 9.3	6.7/6.7
	14.0	60.8 + 18.8	7.0/7.0
	21.0	73.0 + 26.8	4.0/4.0
	28.5	64.9 + 50.7	3.2/3.4
2 x 39=	3.5	79.0 + 0.5	3.3/3.3
78	7.0	80.2 + 1.4	7.0/6.8
	14.0	86.1 - 1.2	5.8/5.9
	21.0	87.2 + 2.7	4.5/4.7
	29.0	62.7 + 28.2	3.9/3.4
2 x 100=	3.5	210 - 49	4.2/4.0
200	7.0	152 - 108	7.8/7.6
	14.0	70 - 108	4.9/4.8
	21.0	28 - 70	5.3/5.0
	29.0	10 - 53	5.7/5.4
2 x 510=	3.5	249 - 421	5.5/4.7
1020	10.0	12 - 126	7.8/6.8
	30.0	Out of range	3.9/3.0

BALUNS PART X
THE TAPPED BALUN FOR GREATER THAN 4:1 RATIO

Andy Griffith – W4ULD

About 1990 a Canadian outfit called Garant (I'm sure they are no longer in business) resurrected the Windom antenna and fed it with 50 ohm coax through a balun that had a ratio of about 5:1. The Windom antenna is an off-center-fed arrangement. It is ½ WL at the lowest operating frequency and is fed approximately 1/3 of it's length from one end. The input impedance at the fundamental frequency is about 225 ohms and is about the same on its even harmonics. Thus, if designed for 80 M, the antenna will show about 225 ohms input impedance on 80 M, 40 M, 20 M, and 10 M. Garant's innovation was feeding the antenna with coax through a balun. Earlier models were fed with single wire feed and TV 300 ohm twin lead.

The Garant antenna was 136.16 ft. long and was fed at 45.275 ft. from one end. Garant made the antenna work on 15 M and improved performance on 10 M by adding a 15.338 ft. element and a 30.776 ft element attached to the feed point of the main element. These elements were about 40 degrees from the main element.

I reproduced this antenna and designed a tapped balun to feed it. My balun consisted of 14 turns #14 insulated house wire on a FT-240-61 ferrite core. The input was tapped at 13 turns as shown in Figure 1. It was housed in a PVC pipe cap. The 13 turns were established by SWR measurements at the rig. The theoretical impedance ratio was 4.6:1.

My evaluation of the balun as shown in Table 1 confirmed the ratio of about 4.6:1 as seen from the 220 ohm load data. Balance of the tapped balun is another story. As one lowers the tap point to 12 turns and below, the balance suffers significantly. I thoroughly evaluated balance at 13 turns and have tried to present the data in Figure 2. In Figure 2 I plotted the ratio of the voltages across the two load resistors to ground (standard balance test described in Part I). The load resistance is shown next to each curve. It is clear that balance was not achieved with a 54 ohm load and became worse as the frequency increased. At 94 ohms unbalance peaked at about 21 MHz. and improved significantly at 30 MHz. Near the design load of about 200 ohms the balun performed fairly well with a peak unbalance of about 1.22 at 14 MHz. At the higher loads of 440 ohms and 940 ohms the balun worked well at 7 MHz. and below but was unbalanced above 7 MHz. So my conclusion is: the tapped balun does a good job of transposing 225 ohms to 50 ohms but balance is not all that great. However, I used this antenna successfully for about two years until the stranded copper weld wire rusted apart. The antenna performed well and I did not have problems of RF on the outside of the coax or notice a distortion of the antenna pattern.
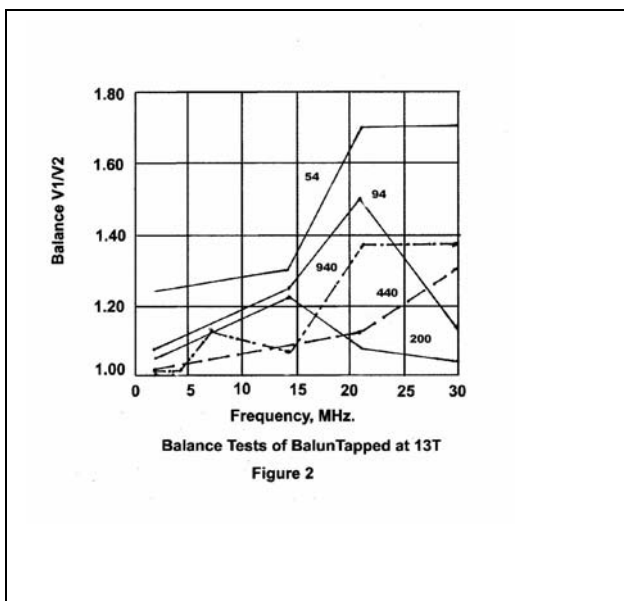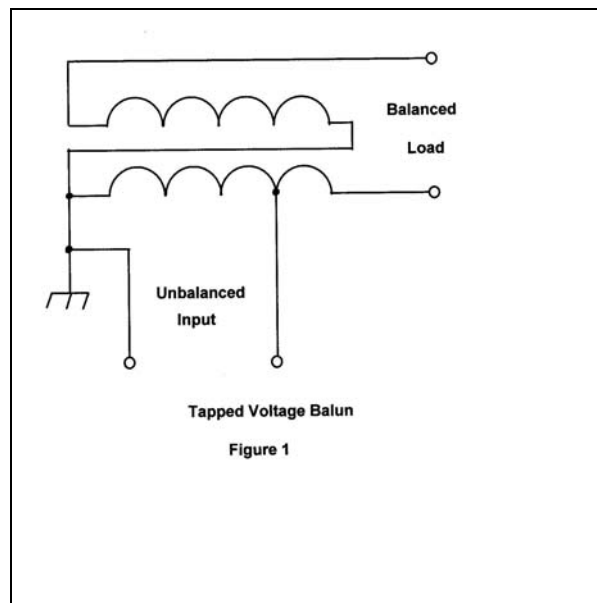
Tapped Voltage Balun

Figure 1

Balance Tests of BalunTapped at 13T

Figure 2

Table !

4:6:1 Tapped Balun
Tapped at 13 of 14 Turns

R_L, ohms	F, MHz.	Input Impedance R +/- jX
47	1.8	11 – 5
	3.5	12 + 6
	7.0	13 + 1
	14.0	12 + 29
	21.0	12 + 41
	30.0	40 + 44
100	1.8	23 – 7
	3.5	25 + 7
	7.0	24 + 14
	14.0	28 + 25
	21.0	19 + 42
	30.0	51 + 35
220	1.8	49 + 9
	3.5	50 + 8
	7.0	51 + 8
	14.0	50 + 13
	21.0	54 + 17
	30.0	62 + 17
330	1.8	71 + 14
	3.5	73 + 8
	7.0	71 – 0
	14.0	66 + 1
	21.0	63 + 2
	30.0	60 + 2
560	1.8	13 + 34
	3.5	123 + 10
	7.0	113 – 12
	14.0	83 – 19
	21.0	66 – 16
	30.0	43 + 3

BALUNS PART XI
OTHER CORES THAN FERRITE

Andy Griffith – W4ULD

A ferrite core for a balun is by far the most effective core. However, early baluns were air wound and wound on powdered iron cores.

In the early 1950's B & W, who manufactured high Q air wound coils for Hams and experimenters, used their coil technology to produce an air wound 4:1 balun. This balun consisted of two bifilar wound coils mounted side by side. The coils were about three inches in diameter and about 12 inches long. The spacing between the wires was about 1/8 in. There must have been 50 or more bifilar turns in each coil. I think the balun was configured as a Guanella type shown schematically in Figure 1.

At the time the Windom antenna fed with 300 ohm TV twin lead was very popular as a multi-band antenna. As explained earlier, the Windom was ½ WL at the fundamental frequency and fed 1/3 its length from one end. A resistive impedance appeared at the feed point on the fundamental frequency and near its even harmonics. The 15 M band had just been authorized and the WARP bands were not yet conceived. Few people operated 15 M because of interference through the 21 MHz. IF used in TV sets at the time. So an antenna for 80 M, 40 M, 20 M, and 10 M was all one really needed. The feed impedance of the Windom averaged about 225 ohms. The B & W balun was a popular transposition between the twin lead and the wide range pi network in the output of tube rigs. The pi network took care of the gross excursions of impedance presented to the rig. I can only guess that balance was pretty good since the inductive reactance of the coils at 3.5 MHz. must have been close to 900 ohms. However, because of the very long bifilar line excursion of impedance and loss must have been quite high. The B & W balun is pictured in the 1974 *The ARRL Antenna Book,* pg. 102.

In their 1982 *The ARRL Antenna Book*, pg. 4-6 ARRL shows a "no core" 1:1 balun for use with their SPC transmatch tuner. The balun consists of 12 turns # 12 trifilar 1 in. OD phenolic or PVC tubing according to Figure 2.. It is suppose to cover the HF bands. I never evaluated this balun, but I am sure it worked for ARRL.

About 1990 a commercial 1:1 balun without a core was sold by a manufacturer that is still in business. I understand that he now uses a ferrite core. The "no core" balun consisted of 9 trifilar turns on thin wall ¾ in. PVC pipe in the Figure 3 configuration. I only evaluated balance at 54 ohm load. The unbalance was not too bad but higher than I like at V_1/V_2 of 1.14 to 1.16 from 3.5 MHz. to 30 MHz. I am sure that the newer model with a ferrite core is far superior.

A 1:1 voltage balun that was considered "standard" for many years consisted of 13 turns bifilar plus balance winding (standard 1:1 voltage configuration) on a powdered iron Amidon T-200-2 toroid. This balun was used by Hams for 1000W. I suspect that 1000W refers to CW (about 50% duty cycle) or 1000W PEP SSB (about 25% duty cycle). This

core is 2.0 ins. OD x 1.25 ins. ID x .550 in. high. The permeability is only 10 so it should not be much better than an air wound balun. Table 1 shows some balance data on this balun. It does not have sufficient reactance for really good balance below 7.0 MHz. even with a 54 ohm load. And does not show good balance at 20 ohms load and 94 ohms load.

I return to my earlier conclusion. A proper ferrite core is needed for a versatile balun for the HF spectrum.
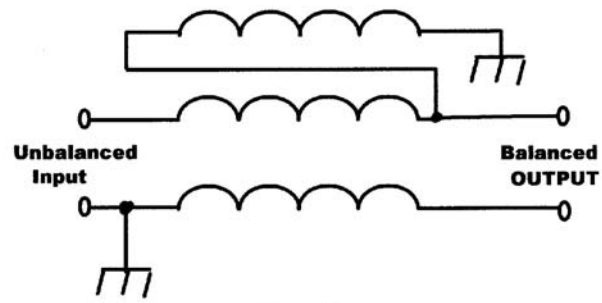

Figure 1

Guanella 4:1 Arrangement

Figure 2

"No core" balun for SPC transmatch
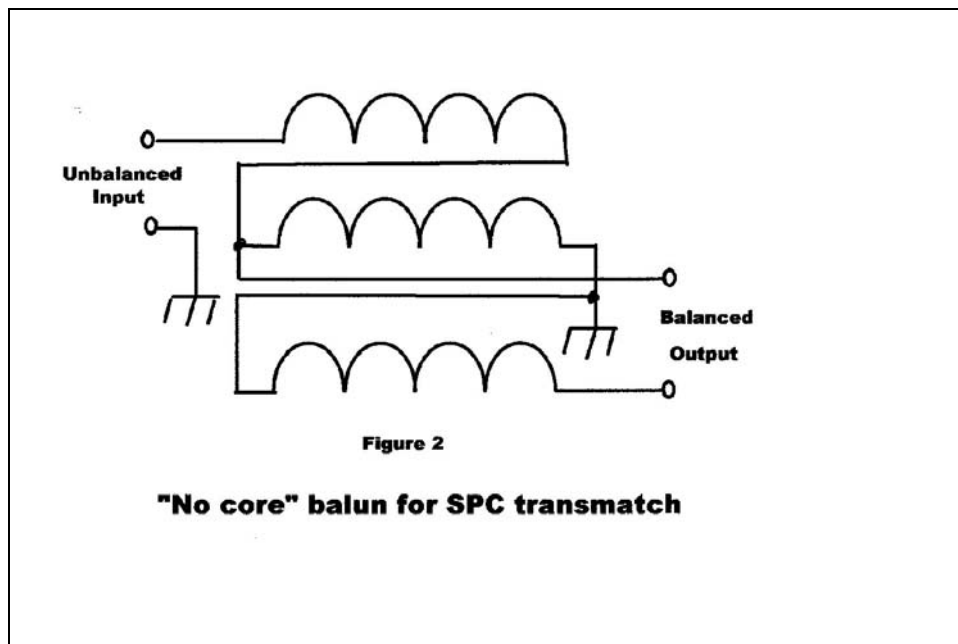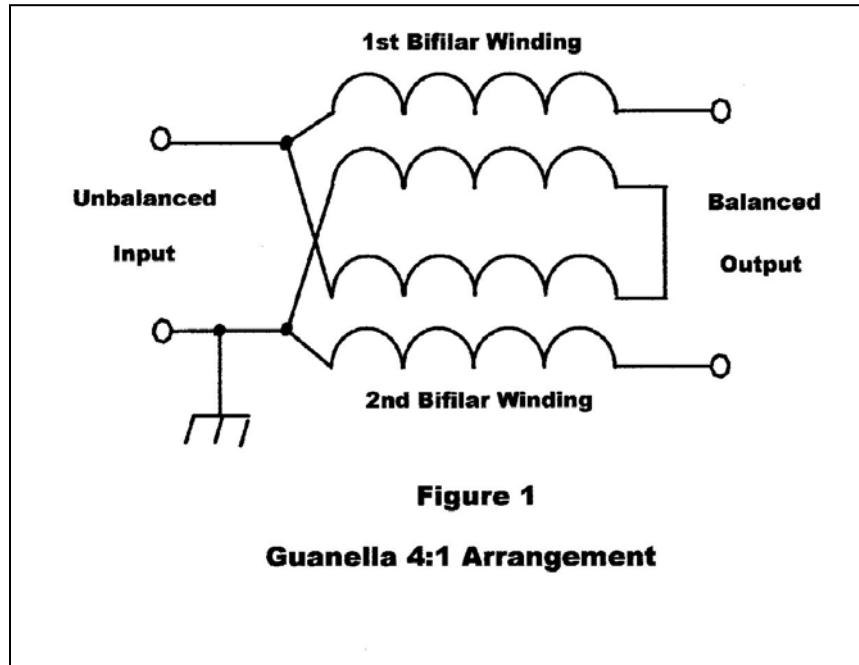
Figure 3

1;1 BALUN CONFIGURATION ON CYLINDRICAL CORE

BALUNS PART XII
THE 22 OHM TO 50 OHM BALUN

Andy Griffith – W4ULD

There are many ways to approach a balun project. This Part describes a successful approach to building a 50 ohm:22 ohm unit by combining a current balun with a 2.25:1 unun.

I was asked to design an extended double Zepp for the 10 MHz. band for a local Ham. The antenna was fed with "450" ohm ladder line. The length of the ladder line was that necessary to create a resistive impedance at its input. This resistance turned out to be about 26 ohms. A balun was needed to convert the balanced ladder line to unbalanced 50 ohm coax. So I built a 1:2.25 balun as described below. This balun should also be suited for feeding HF Yagi type beams which may have 24 – 26 ohms input impedance.

The balun was wound on a ½ in.O D x 7-1/2 ins. Lg. Ferrite rod made of 61 material. As shown in Figure 1 the balun consisted of a 1:1 current balun and a 2.25:1 unun (unbalanced to unbalanced) wound on the same rod. To achieve a low impedance winding for the balun portion 6-1/2 turns of stripline was used. The stripline consisted of 1/8 in. wide aluminum strips of flashing aluminum separated with .004 in.thick plastic Scotch electrical tape. The unun consisted of 13-1/2 trifilar turns #14 enameled wire tight wound adjacent to the stripline. The balun was mounted in PVC pipe with a cap on each end for weather protection.

The evaluation of the balun is shown in Table 1. With a 24 ohm load the input impedance was close to 50 ohms with little reactance from 2.94 MHz. through 15 MHz. Balance was maintained over this same frequency range. Balance was reasonable up through 20 MHz. but fell apart at 25 MHz.
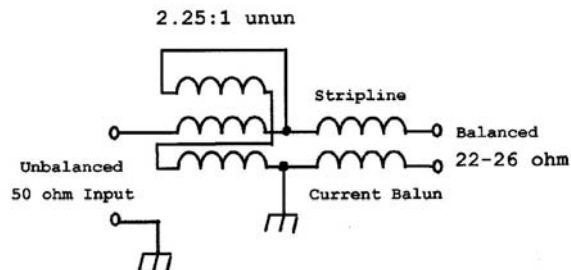

2.25:1 unun
Stripline
Unbalanced
50 ohm Input
Current Balun
Balanced
22-26 ohm

Figure 1
22 ohm to 50 ohm Balun

Table 1
Performance of 26:50 ohm Balun

F, MHz.	R Load, ohms	R +/- jX	V_1/V_2
2.94	2 x 12=	53.1 + 7.6	1.00
4.0	24	53.9 + 4.8	1.00
5.0		54.7 + 5.1	1.00
10.0		57.1 + 0.5	1.00
15.0		60.8 - 4.6	1.00
20.0		64.8 - 14.7	1.04
25.0		76.7 – 43.8	1.05
30.0		Out of range	1.10

Measurements made with accurate General Radio bridge

BALUNS PART XIII
A 1:1 BALUN ON 43 MATERIAL CORE

Andy Griffith – W4ULD

All of the baluns I have seen and tested were wound on material similar to 61 material (125 permeability) or K material (250 permeability). However, as covered earlier, ten beads of 43 material (850 permeability) (.25 in. ID x .562 in. OD x 1.125 ins. LG or .5 in. ID x 1.0 in. OD x 1.112 ins. LG) over coax make a good balun for 3.5 MHz. to 30 MHz. A couple of beads will make a balun for 146 MHz. and 440 MHz. bands. So I became interested in whether a bifilar winding on a FT-240-43 core would make a good HF balun. The answer is "yes" and a very good balun that retains balance over a remarkably broad range of loads.

I first covered the core with glass cloth electrical tape[1] for insulation. I then wound 10 bifilar turns of #14 enamel wire over half of the circumference of the core. This formed a 1:1 current balun. This balun was fairly well balanced from 20 ohms load to 940 ohms over 1.8 MHz. to 30.0 MHz.. So I removed one and then a second turn still covering one-half of the core. Slight unbalance was noted at 1.8 MHz. with 20 ohms load so I decided that 8 turns was about the minimum to cover the entire HF band. This current balun performed nicely over the range of loads (20 to 940 ohms) tested, from 1.8 MHz. to 30.0 MHz.. The optimum load was a little below 68 ohms. It would be a good balun for an all-band center fed Zepp.

Next, I wound an 8 turn balancing winding over the blank half of the core making the balun a 1: 1 voltage balun as shown in Figure 2. The performance of this balun was phenomenal. Essentially perfect balance was maintained at least down to 20 ohms load to at least 2000 ohms load for 1.8 MHz. to 30.0 MHz. The optimum load was about 82 ohms. These results were confirmed with a 6 turn balun on a FT-140-43 core.

Power loss tests were run on the 1:1 FT-240-43 balun (Position A in Figure 1) by connecting the balanced output to the balanced output of another 1:1 balun. The unbalanced input of the second balun (Position B)(9 T #14 bifilar on a FT-240-61 core) was connected to a 50 ohm dummy load. The unbalanced input of the "test" balun was connected to a TS-520S transceiver. Thus, the input SWR to the test balun was about 1:1. A Bird 43 wattmeter was used to measure the power into the balun and into the dummy load (point X). Loss for the two baluns measured .175 dB at 3.5 MHz. to .333 dB at 28.5 MHz. A 4:1 voltage balun was substituted for the 1:1 balun in Position B. Thus, the 1:1 "test" balun was connected to about 200 ohms. The net input power was taken as the forward power minus the reflected power. In this test the power loss in the two baluns was .186 dB at 3.5 MHz. and .258 dB at 28.5 MHz.

To insure that the FT-240-43 core met my criterion of maximum allowed unbalance of 1.5 (See Part V) I connected the balanced output of the balun to the balanced output of a 4:1 balun. The unbalanced input of the 4:1 balun was connected to a 1 KW dummy load.

Thus the 1:1 balun was exposed to about 200 ohms load impedance. Key down 1 KW at about 3.9 MHz. was fed into the baluns for about 10 seconds and 1 KW PEP SSB was fed about 30 seconds. There was no detectable increase in temperature of either balun. Using the 1.5 unbalance calculation described in Part V, the balun should be good for 3.4 KW into a 200 ohm load. At 29 MHz. the allowable power is even higher. I concluded that the balun was easily good for the legal power limit at least for SSB and CW and that my estimate that maximum allowable flux based on 1.5 unbalance is conservative.

Based on the above results, I recommend the 1:1 FT-240-43 balun for all applications including the go-between window line and 50 ohm coax for a center fed Zepp.

1- Available from Amidon Inc., 240 Briggs AVE., Costa Mesa, CA 92626
www.amidoncorp.com

Figure 1

Figure 2
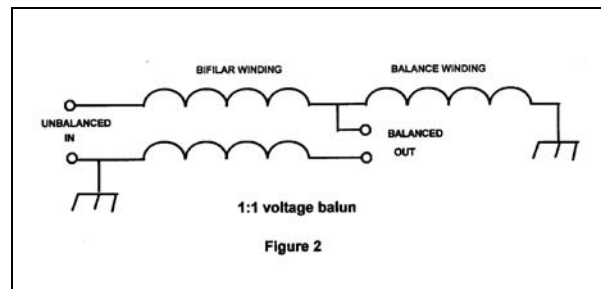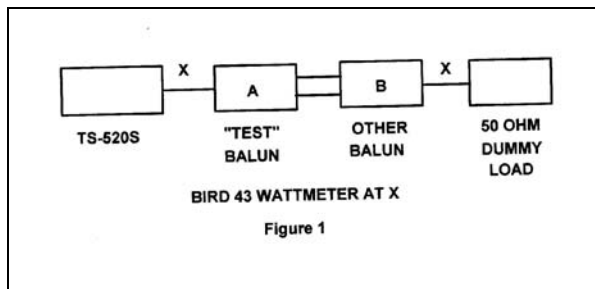
BALUN XIV

EVALUATION OF 1:1 BALUN ON FT-240-43 TOROID
WITH AIM ANALYZER

W4ULD 7-27-07

In BALUN XIII I reported excellent wide range balance for a 1:1 voltage balun
consisting of 8 bifilar turns on a FT-240-43 core. Since that time I have been using this
balun on my 1/3 WL all band dipole with good results.

I have recently purchased a new toy- an AIM4170 antenna analyzer. This device is
described in the August 2007 issue of QST on page 68. QST reports that at least to 200
ohms load resistance the instrument approaches the accuracy of an expensive impedance
bridge. At 1000 ohms load resistance the AIM fell apart. I have not yet compared the
AIM to my manual General Radio bridge which is quite accurate but very time
consuming to use since each load at a given frequency must be manually balanced using
two controls. I will accept ARRL's assessment of accuracy.

The AIM is primarily a bench instrument since it depends upon a computer for readout. It
can be fitted to a battery pack and a laptop computer for measurements away from the
bench but is nowhere near as convenient as a MFJ-259, for example. The AIM provides a
graph of R +/- jX, SWR, and several other interesting parameters vs. frequency for a user
selected frequency range. It also correctly predicts the mathematical sign of reactance (X)
and the phase angle. This is one area where the popular hand held instruments fall down.
Thus the AIM is very useful for evaluating the input impedance of baluns over the HF
range at various load resistances as well as measuring the input SWR and impedance of
an antenna.. Of course the AIM cannot detect the balance provided by a balun so its
readout is the effect of the transmission line wound on the balun core.

I have found that most 1:1 baluns wound with #16 or #14 bifilar windings on any toroid
core will show a characteristic impedance (Z0) in the range of 60 to 100 ohms. Thus any
load less than the Z0 will be correct at low frequency but will increase in Z +/- jX as the
frequency is increased. The AIM4170 graphs this very well.

The lesson is that the balance afforded by a balun depends on the amount of ferrite in the
core and its permeability, but the input impedance is a function of the characteristic
impedance of the bifilar winding on the core. I don't know of any 1:1 baluns that have a
Z0 of exactly 50 ohms. Exactly 50 ohms is hard to obtain with a bifilar winding because
it is difficult to maintain close contact between the wires of the winding. Jerry Sevick[1]
reports that a bifilar winding of #14 wire should have a Z0 of about 25 ohms. I find this
very difficult to achieve.

In Figures 1 and 2 I have shown an AIM printout for the 1:1 balun on the FT-240-43 core
from 2 to 32 MHz. The Z0 of the winding is also between 60 and 100 ohms. In the
figures the red line is SWR as read from the left hand axis. The top yellow line is

resistance (R) and the second dirty yellow line is reactance both referred to the right hand axis. In Figure 1 the load is 50 ohms. Both the R and the X increase with frequency because the Z0 of the winding is greater than 50 ohms. Note that the SWR (red line) is almost 1.6:1 at 30 MHz. but still within the range of most rigs without an antenna tuner.

Figure 2 shows a scan for a 100 ohm load. Since the Z0 of the bifilar line is less than 100 ohms the trace for resistance (yellow line) decreases with frequency.

This concludes my series of articles on baluns. I hope the readers have learned a little. If you have any questions direct them to my email address agriffith003@ec.rr.com.

Notes:
1- "Transmission Line Transformers ", Jerry Sevick, 1987, pg. 3-2

Figure 1

Figure 2