Wideband RF Baluns

A practical guide to the perfect match.

by Carl Markle K8IHQ

Amateurs who have been in the hobby for a few years know that many articles have appeared in various magazines and publications describing balun RF transformers. Much of this material has been written with very little practical applications information. Most articles either contain just enough information to allow the reader to construct (monkey see, monkey do), or go to the other extreme and include involved mathematical and theoretical explanations. Most readers want middle-of-the-road information with appropriate references to answer the more technical or application-type questions.

This article will answer some of the basic questions: What is a balun transformer? When does an application require a balun? How do you construct an efficient balun transformer? Where can you purchase component parts? I will also provide cost, performance, and technical information.

What is a Balun?

The word balun is an acronym describing a transformer. The letters "bal-un" stand for *bal*anced-to-*un*balanced impedance matching. This is to say that either the balanced or unbalanced windings may be used for input or output; the device will match unbalanced-to-balanced or balanced-to-unbalanced devices. Applications might include coax-to-ladder line, antenna arrays, and multiband antenna systems. The ratio required for a given application can be from 1:1 up to 1:16.

When to Use Baluns

The most obvious use is in matching a 50 or 75 ohm coax transmission line to an antenna system. This is especially true if it is a multiband antenna system.

One example is when connecting to a center-fed dipole antenna with a 1:1 ratio balun. Both sides of the dipole will provide equal half-power RF lobes, thus providing an undistorted figure-eight pattern. The second advantage of the unbalanced-to-balanced match in this situation is minimization of the TVI interference caused by the radiation of the coax shield instead of the dipole antenna. You will also notice that the SWR meter will start telling the truth about the actual standing waves present on the coax. Regardless of what is said, a low SWR is desirable because it ensures against high RF voltage breakdown on the coax line. It also gets all the RF power to the radiating antenna system, not allowing the feedline to radiate. In the chapter listing coax cable losses, *The ARRL Antenna Handbook* explains that the foam-type coax cable has very low breakdown voltages, which is not the case with the solid types. Some of these values are as low as 600 volts.

When using baluns at low frequencies, from 1.8 through 7.0 MHz, it is obvious that a coax-type balun would be physically very large and heavy and not practical. The second type of balun to be considered is the air-wound type. Because of the large number of turns required, it too would be a very poor choice. The most practical choice to cover this frequency spectrum is a ferrite or iron core wideband RF transformer. This core could be either a rod or the toroidal type. These types of baluns are the most practical type of matching device for transmitting uses to match the antenna to the transmission line. This is particularly true when multiband, i.e. 160, 80, 40 meter operation, is anticipated. It would be quite difficult, if not impossible, to mount an antenna tuner between the transmission line and the antenna. The remote tuning system would be expensive and very difficult to use because it would require retuning on each band before using. The wideband RF balun transformer is the most practical solution to this problem.

When selecting an appropriate core, consider its A_L factor (the inductance index) since the higher the A_L, the less the number of turns that are required to provide the inductance necessary at 1.8 MHz. Again, the use of a rod or toroidal core is a matter of the builder's choice. I chose the iron toroidal cores over the ferrite rod and toroidal types. The T-200-2 (2" o.d.) type of iron core is a good choice because it has an inductance index (A_L) of 49 and a permeability (μ) of 10.. With 14 turns of AWG14 magnet wire, the center resonant point falls into approximately 3.5 MHz, where 10 turns falls in at about 15 MHz.

The difference between iron and ferrite is usually only two turns, and certainly not a good trade-off in favor of ferrite. I discourage using ferrite because tests have proved that if high SWR occurs, heating of the core will also occur. High power core saturation can also cause heating of the core. If heating

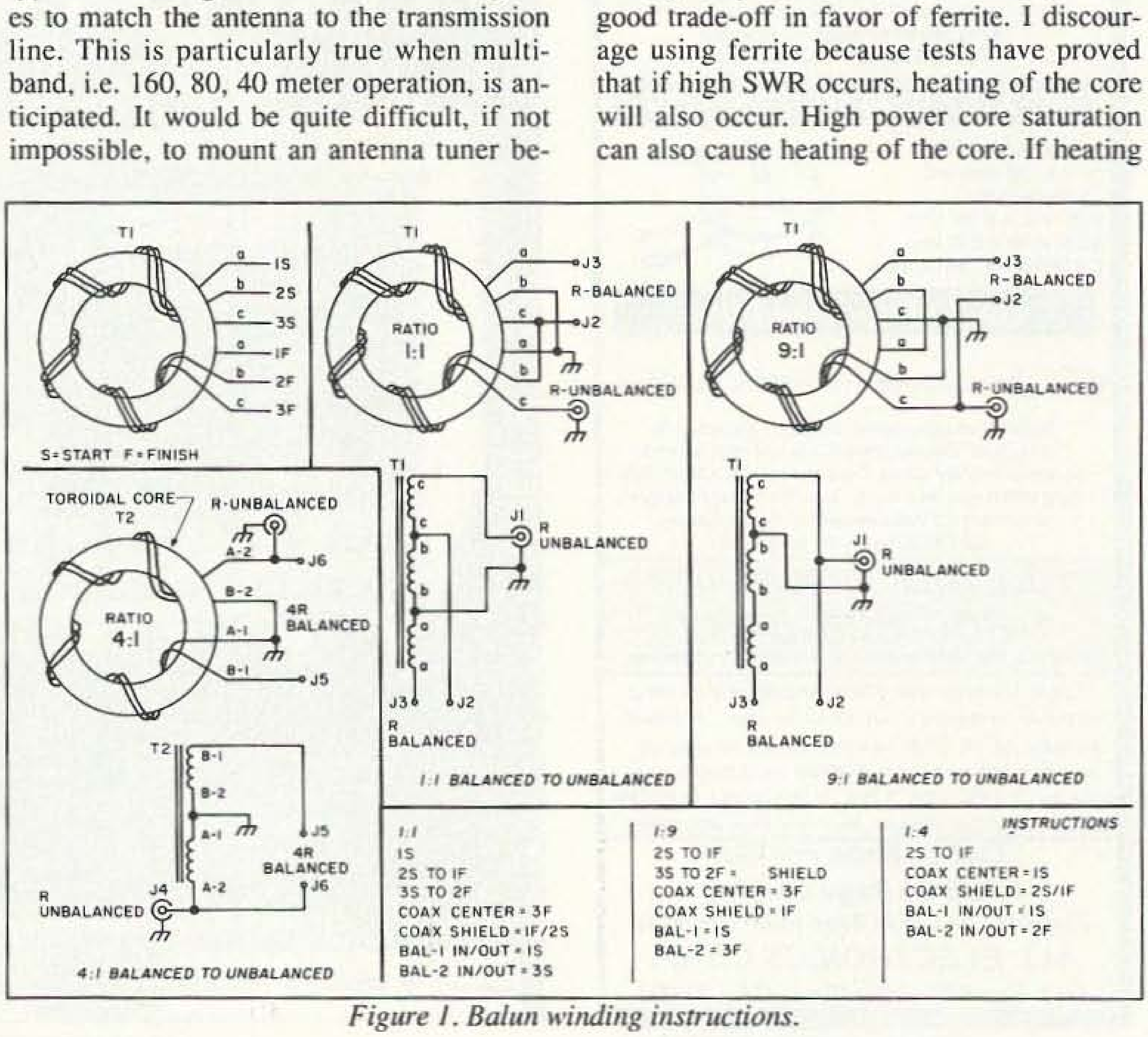

Figure 1. Balun winding instructions.

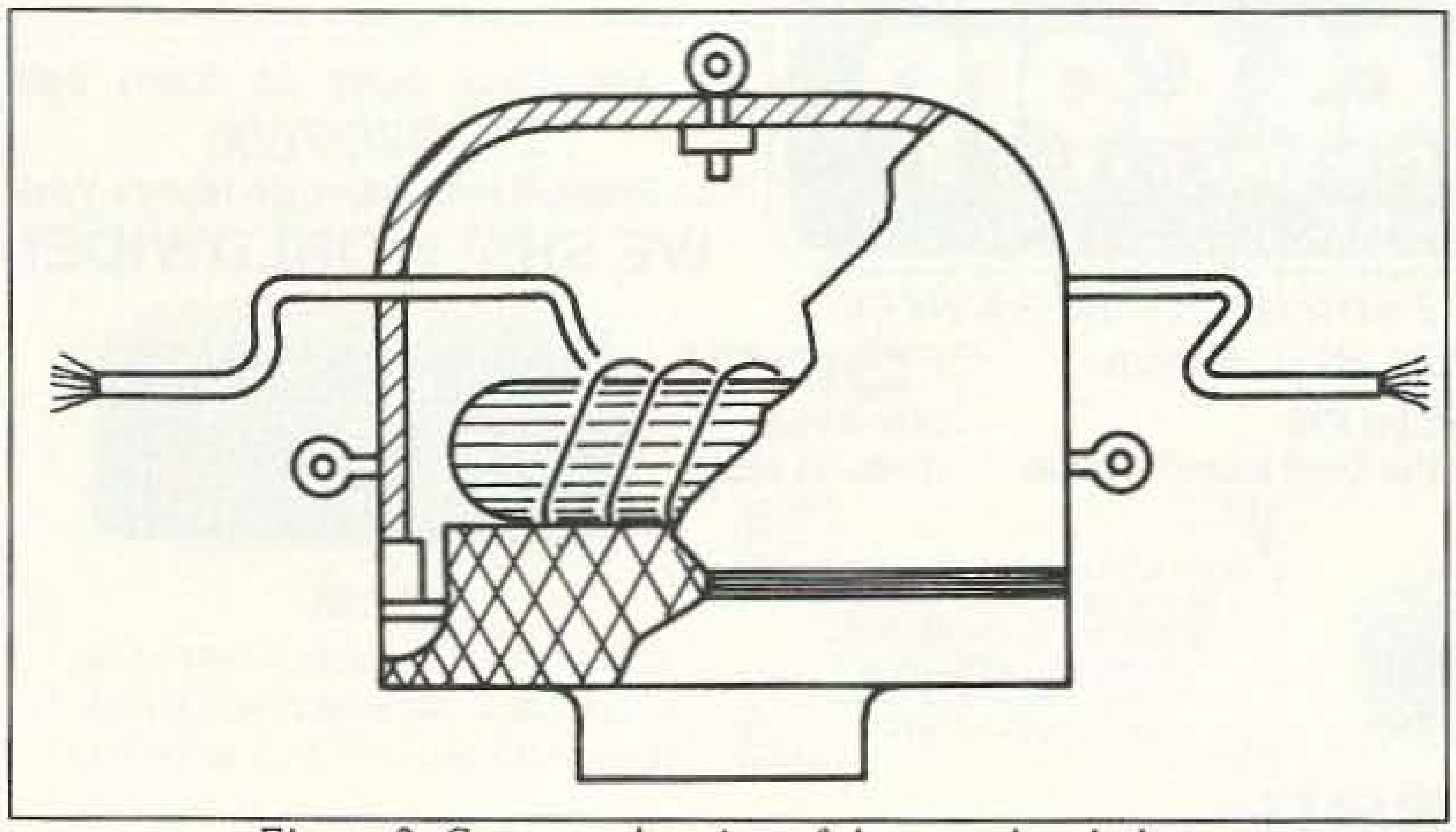

Figure 2. Cutaway drawing of the complete balun.

occurs on an iron powder core, the core will recover after cooling, whereas the ferrite will change $A_L(\mu)$ and not ever recover. Another consideration is that ferrite is very fragile and is prone to break if physically stressed (dropped to the ground during installation or damaged by a storm). Even water build-up can damage or fracture the core if it freezes in cold weather. Hairline cracks, visually hard to detect, can cause considerable performance problems. Also, note that ferrite is electrically a nonlinear material, very unlike the linear powdered iron cores. In general, I feel that ferrite should not be used for outdoor or transmitting applications.

Again, when to use baluns depends on the application. Practical winding ratios are 1:1, 1:2, 1:4, 1:6 and 1:9. If a ratio of 1:16 is needed, two 1:4 devices should be used. Table 1 lists some situations where baluns are necessary.

I highly recommend using these balun transformers to match line-to-load impedance differences (high SWR) over the 1:1 through 1:9 range if you expect maximum efficiency and power transfer. The second consideration is that unbalanced lines/loads can be matched to balanced lines/loads over a broad frequency range without tuning out the impedance differences which usually exist over a broad frequency range in a high Q situation. Since the balun is a low Q broadband device, there will be no large impedance differences caused by the change of frequency. This subject has been covered in many ham magazine articles.

In comparing the use of toroidal baluns from 14—50 MHz, the only construction difference is that 10 turns of AWG14 are required, although 14 turns would not be objectionable up to 30 MHz. The 10 turns of AWG14 enameled magnet wire on a T-200-2 (μ=10) core provides a center frequency of approximately 15 MHz. Of course, this is what is desired for 80 through 10 meters, the bands of most interest. This is the ideal balun to be used to match 50/75 coax to a 136'l off-center-fed multiband Windom antenna. Complete coverage on 80, 40, 20, and 10 meters can be used without an antenna tuner. Multiband quad-driven elements can be driven from one balun, thus making only one coax cable necessary to feed the system.

Don't forget that 50-ohm coax is usually fed through a short Q-section of 75-ohm coax to form a single frequency 1:2 balun for quad and delta loop antenna designs. Use of a 1:4 balun to feed all driven loop elements at once will result in no coax balun and a single coax feedline.

Multiband verticals can be made that don't require tuning when using a toroidal balun. Windings can be made to make unbal-unbal configurations useful in feeding verticals with multiband capability built in.

How to Build It

How is always the place where the true amateurs and the appliance operators separate. Most appliance operators will become ham operators sooner or later. The idea is that practical, easy-to-follow instructions, reasonable cost, and readily available materials must be used to encourage construction attempts by inexperienced hams. They must have the fear of failure reduced to a minimum. That is the objective of this article. This project should not take the novice more than a weekend to complete, so it will encourage the amateur to take on more difficult projects.

Schematics and pictorials of the three most popular baluns are provided. There are no critical or tricky items involved. If you just plain follow the instructions, success will follow. Decide on one of the projects and wind the proper ratio for the application.

Parts Sources and Prices

Where to purchase parts? I am sure that there are as many sources of materials as there are varied prices. There are handling/shipping charges, taxes, etc. This type of aggravation has caused many a do-it-yourselfer to just put his hands in the air and give up. I have been tempted many times myself. But, as a very determined person, as well as a ham from the vacuum tube days, I take great pride in displaying home-brew items which perform as well as those expensive imported items.

Costs? The bill for the materials will be the same regardless of what ratio or configuration you choose. It is important to use one of the sources listed below, since all manufacturers do not produce the item in the same physical size. Bargain store or hamfest parts could take all the fun out of the project. A list of sources and relative costs are included in the Parts List.

Testing can be done by connecting a 100W electric light bulb to the balanced output. Connect the transmitter to the balun coax input. Apply less than 100W of RF power at 7.0 MHz and observe the light bulb lighting up. Ensure that the SWR indicates less than 2:1 using 17 feet of coax feedline or less. Two or more of the baluns, regardless of winding ratios, can be connected back-to-back in conjunction with a standard 50 ohm dummy load to check SWR and performance at the 1 kW power level. SWR should read 1.3:1 or less during this test. Always test the feedline connected to the dummy load or 100W light bulb to insure that the line is good and there is an SWR of 1.0:1.

Construction

Always consider the high RF voltages which might occur if the SWR gets greater than about 3:1. This high voltage can break down between windings or short out to the iron core. Follow these steps:

1. Wind the T200-2 core with glass tape. Make sure that all the surface is covered. Overlap the tape slightly to insure that adequate coverage is present.

2. Even though it's not necessary, I always spray the core at this point with polyurethane. Any brand, such as Varathane, may be used.

3. Take all two or three (3 feet each) lengths of #14 AWG magnet wire and simultaneously wind all three wires: 10 turns for a 15 MHz center frequency or 12 turns for a 3.5 MHz center frequency.

4. Configure the windings for the desired ratio as outlined in Figure 1.

5. It's not necessary, but I always spread a little RTV insulating gel between the winding connections. This insures against high voltage breakdown between windings. Additional glass tape could be used instead of the RTV compound.

6. Prepare the S0239 receptacle by soldering two 6" wires to the center and shell of the connector. Place RTV compound freely around the back side of the connector. Place the connector into the 1-1/4" bushing. Allow about one hour for the RTV to set up.

7. Place the S0239 connector/bushing assembly in the 2" reducer. Coat the surface with PVC cement or other adhesive. A thin coat of RTV may also be used for this purpose, although the cure time is quite long.

8. Place this assembly face down and level. Pour the rest of the epoxy into the rear of the assembly. Bring the level up to the lip of the 2" reducer. Now take the prepared balun transformer and place it into the epoxy on top of the 2" reducer assembly. When the epoxy cures the balun will become permanently attached, thus forming an assembly.

9. When the assembly has cured (approximately two hours) you will be able to handle it. Strip and attach the SO239 wires to the correct windings by soldering.

10. Attach the other two 12" #14 insulated wires to the proper windings again with solder.

11. Drill 1/8" holes at the top of the cap to

Table 1. When to Use Baluns

1:1	Unbal-Bal	Matches 50 or 75 ohm coax to center-fed dipoles and 2-element quads.
1:2	Unbal-Bal	Matches 50 or 75 ohm coax to multi-element quad and yagi antenna systems.
1:4	Unbal-Bal	Matches 75 ohm coax to 300 ohm twin-lead and off-center-fed multiband Windom antennas. Also, they can be used in low frequency antenna stacking arrays.
1:6	Unbal-Bal	As in (3), except for 50 ohm coax.
1:9	Unbal-Bal	Matches 50 ohm coax to 450 ohm open ladder line. Provides an extremely low-loss transmission line for antenna arrays from 15 to 50 MHz. (See Figure 2.)
1:1.5	Unbal-Unbal	Matches 50 ohm coax to vertical antennas.

allow the 12" balanced wire connections to exit the housing.

12. Cut a piece of the #14 AWG insulated wire to fit around the edge of the 2" reducer. This will form a gasket seal when the cap is placed over the balun assembly.

13. After electrically testing the balun for correct operation, place the assembly together. Bring the insulated wires through the cap exit holes. Force the assembly into the cap. Place the insulated wire gasket between the cap and assembly. I recommend using PVC cement to help provide mechanical strength.

14. Place the assembly in a vice, carefully squeezing it together. Finish drilling the 1/8" holes into the assembly, being careful not to drill into the connector. Only epoxy and PVC is removed.

15. Drill one hole at a time, screwing the eye hooks into the housing. This provides a weatherproof assembly. Suspension is generally by way of the antenna system, i.e. dipole wire. The balun acts as a center insulator in this case. The coax (RG58A/RG59A, etc.) will make the assembly hang properly when suspended. The coax connection will then be protected from the weather.

Note: In the case of 1:9 baluns used as 450 ohm ladder line transformers, the ladder line connects to the eye bolts and the coax will provide the required in-line mechanical support.

I recommend that the unit be sprayed with polyurethane to protect it from ultraviolet ray deterioration. This is not necessary, but it is desirable. Unprotected, the housing will last in excess of seven years.

Refer often to the figures and instructions to keep from making a mistake. Mistakes in winding connections can be corrected with less difficulty before final assembly. An ohmmeter should be helpful in determining the beginning and ending of the various windings.

Again, the effort here is on practical construction and not on design information. Pick a project and build a balun or two. Applications include delta loops, quad loops, dipoles, slopers, G5RV(Zep), multiband windom dipoles, low-loss coax to ladder line transformation, etc. 73

Contact Carl Markle K8IHQ at 8385 Locust Dr., Kirtland OH 44094. Please enclose an SASE.

Parts List

Item	Description	Part No.	Qty.	Cost	Source
Toroid core, 2" o.d.	iron powder (μ=10)	T200-2 (1 kW) T200A-2 (2 kW)	1	$3.60 $4.25	Amidon, Palomar
5"-wide electrical tape	glass cloth	Scotch (3M) #27	2'	$4.50	Amidon—66' roll
AWG-14 magnet wire	9' (2kV) thermoleze	wire	9'	$0.90	Amidon
Coax conn.	receptacle	SO239 (flange)	1	$1.29	Radio Shack, Hosfelt, hamfests
Eye hooks	NI-CAD 3/16	none	2	$0.26	local hardware store
AWG-14	PVC strand stranded	insulated machine wire	3'	$2.00	local auto store ($2.00 per spool)
Epoxy	epoxy resin	FHR4	1	$4.95	local auto store Permatex 1-pt.
1.25" x 1.5" bushing	white PVC plastic	Univ. No. 437-167	1	$0.65	local plumbing store; NIBCO or Colonal only
2.0" x 1.5" DWV reducer	white PVC plastic	Univ. No. 4801-2F	1	$0.69	local plumbing store; NIBCO or Colonal only
2" DWV domed cap	white PVC plastic	Colonal 447-020	1	$0.86	local plumbing store; Colonal only

Sources:

Amidon Associates, 12033 Otsego St., Hollywood CA 91607.

Palomar Engineers, P.O. Box 462222, Escondido CA 92046.

Radio Shack/Tandy: Local stores; Part No. 278-201.

Hosfelt Electronics, 2700 Sunset Blvd., Steubenville OH 43952.