Transforming the Balun

In this *QST* breakthrough, W2DU's peerless 1:1-current-balun design serves as the basis for excellent ferrite-bead-choke current baluns capable of 4:1 and 9:1 impedance transformation.

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Much has been written in recent years on balanced-to-unbalanced RF transformers (*baluns*),[1,2,3,4,5] and they are a popular discussion topic at club meetings and on the air. The over-the-air discussions make for interesting listening. Some amateurs have their preferred balun type. Some do not want to hear about baluns! Many radio amateurs, it seems, do not understand baluns or when they should be used. Manufacturers of antenna products or antenna-system tuning units (ASTUs) advertise the superiority of their balun over the competition's. What are we to believe?

Baluns fall into two basic classes: voltage and current.[6] The *current balun* of the type developed by Walt Maxwell, W2DU,[7]—a balun consisting of ferrite beads slipped over a length of coaxial cable—is the best so far devised. By *current balun* I mean a balun that, with each of its balanced-output ports terminated in unequal resistances, forces essentially equal, opposite-in-phase currents into each resistance. The traditional toroidal balun is a *voltage balun* in that, terminated as just described, it produces equal, opposite-in-phase *voltages* across the two resistances.

For minimal radiation from a balanced transmission line, the currents on both of its conductors must be equal in amplitude and opposite in phase; that is, there must be no current discontinuity on the radiator at the antenna feed point. In other words, the currents driven into each arm of a dipole radiator should be equal. For antennas fed with a coaxial transmission line, the goal to achieve is little or no current on the outside surface of the coax shield. *In general, these requirements cannot be met without a current balun.*

[1]Notes appear on page 33.

Voltage Baluns

We can better judge the performance of current baluns by first taking a look at a typical voltage balun. The standard bifilar toroidal balun[8] is a voltage balun. Two common versions of this balun allow 1:1 and 4:1 impedance transformations. Some voltage-balun implementations perform worse than others, of course; in general, however, the toroidal voltage balun is an efficient device. Fig 1A graphs the input-impedance-versus-frequency performance of a typical 4:1 voltage balun. This balun has a grounded center tap. Terminated with a balanced, non-center-tapped 200-Ω load, as it would be used when connected to a balanced transmission line or an antenna, its input-impedance-versus-frequency response is excellent: It appears as close to 50 Ω across the HF range. Terminated with a center-tapped 200-Ω load (center tap connected to input common [transceiver ground]), the voltage balun does not work quite so well. Its impedance rises with frequency, indicating to me that its output is not quite balanced.

Fig 1B graphs power loss in the 4:1 voltage balun—insignificant for frequencies below 20 MHz, and less than 1 dB at 30 MHz. (I measured the balun's insertion loss by connecting two identical baluns in series, balanced terminals connected to balanced terminals, and terminating the output balun in 50 Ω. I attributed half of the observed total loss to each balun.)

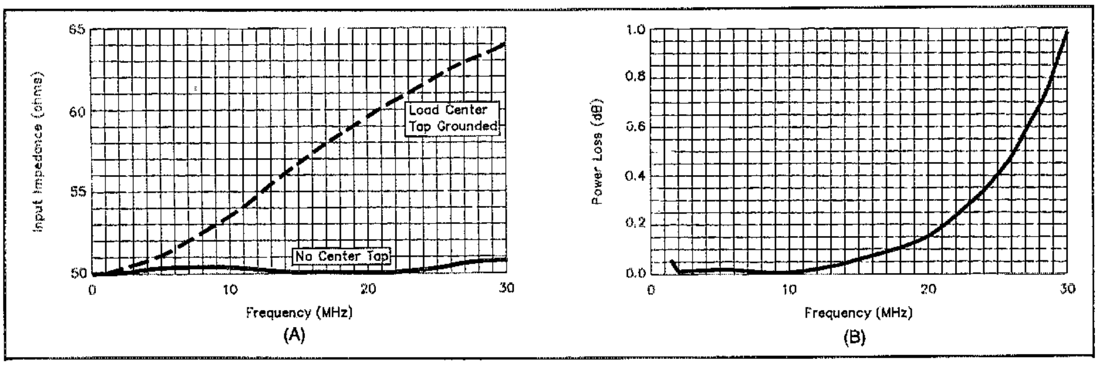


Fig 1—At A, input impedance for a typical 4:1 voltage balun terminated with a balanced 200-Ω load with no center tap (solid curve) and a center-tapped 200-Ω load with its center tap connected to input common (dashed curve). The solid curve indicates excellent HF-range performance (relatively constant impedance-versus-frequency response) with a balanced, no-center-tap load. The dashed curve indicates that a 4:1 voltage balun exhibits an undesirable transformation-ratio shift across the same range when driving a balanced, grounded-center-tap load. The balun consisted of 11 bifilar turns of no. 18 wire wound on two stacked cores of Q1 ferrite. B shows the balun's power-loss-versus-frequency characteristic.

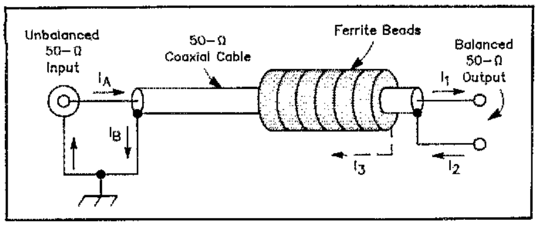


Fig 2—The W2DU 1:1 balun consists of a length of coaxial cable and ferrite beads (50; see text and the article cited at note 9 for material) that choke RF-current flow on the outside of the cable shield. The arrows associated with conductors show the relative direction of RF-current flow at one instant during the signal cycle—input currents I_A (center conductor) and I_B (shield), balanced output currents I_1 and I_2, and outside-of-shield output current I_3 (shown by a dotted arrow because it is choked off by the ferrite beads). Result: A *current* balun that exhibits a good input impedance-versus-frequency characteristic (see Fig 3). Although the drawing shows a 50-Ω balun made from 50-Ω coax, you can use 75-Ω coax to construct an equivalent 75-Ω balun.

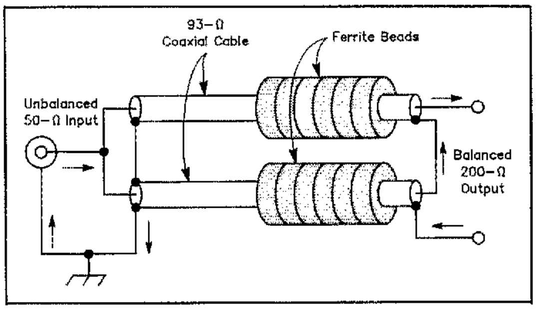
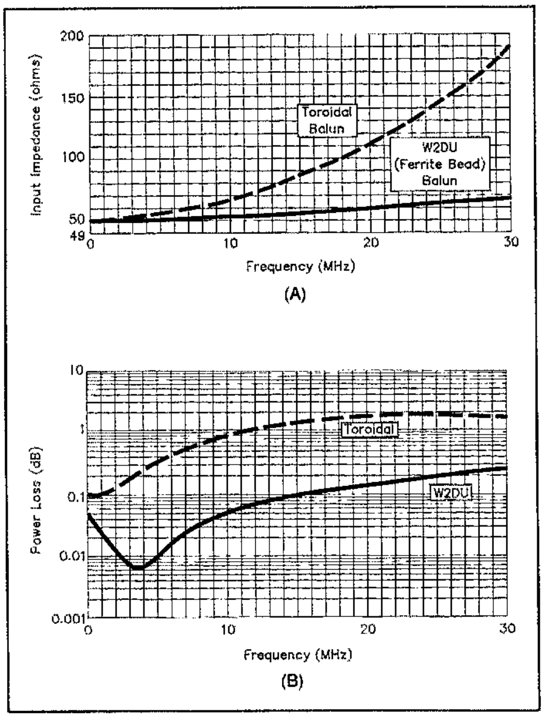


Fig 4—A 4:1 current balun based on two ferrite-bead coax-shield chokes. Each choke consists of a length of 93-Ω coax (RG-62A for powers on the order of 100 W, and RG-133A for the 1-kW level) and 50 beads (see text and the article cited at note 9 for material). The arrows associated with conductors show the relative direction of RF-current flow at one instant during the signal cycle. Fig 5 shows an RG-62A version.

Fig 3—At A, input impedance versus frequency for a W2DU ferrite-bead-choke, 1:1 current balun (solid curve) and a bifilar, toroidal 1:1 current balun (dashed curve). (The W2DU balun is from Antennas Etc, PO Box 4215, Andover, MA 01810, tel 508-475-7831, fax 508-474-8949. The bifilar-choke current balun is the type used by MFJ [MFJ Enterprises, Box 494, Mississippi State, MS 39762, tel 601-323-5869, fax 601-323-6551] in their differential-T tuner Model MFJ-986.) The W2DU balun exhibits a superior impedance-versus-frequency response. Both baluns were terminated with balanced 50-Ω loads. Graph B shows power-loss-versus-frequency curves for the same baluns (solid curve = W2DU balun, dashed curve = toroidal balun) under the same conditions.



A 1:1 Current Balun

A W2DU ferrite-bead-choke balun—a *current* balun—consists of a length of coaxial cable (of the required impedance) with ferrite beads around its shield. See Fig 2. (Remove the cable's outer jacket so the beads fit tightly around the shield as shown in Fig 2.) W2DU used 50 beads of no. 73 ferrite (for example, Amidon no. FB-73-2401) on about 12 inches of Teflon-dielectric cable to make a practical balun for the 1.8 to 30 MHz.[9]

The ferrite beads choke RF-current flow on the outer braid surface, thus forcing RF current to flow on the *inner* braid surface. Because this low-loss path parallels the high-loss, bead-choked outer-surface path, most of the current flows on the inner braid surface and the beads dissipate little power. The output currents (I_1 and I_2) are equal in amplitude and opposite in phase—just what's necessary to feed a balanced line. The input RF currents flow on the coaxial cable's center conductor and inner braid surface. This device is a balun, even though at first sight it may not look like one because I_3 is very much less than I_1 or I_2.

Advantages of this balun:

- It forces nearly equal currents into each leg of a balanced transmission line, *even in cases where the antenna itself is unbalanced,* such as an off-center-fed dipole;[10]
- Its excellent power-loss- and impedance-versus-frequency characteristics are much superior to those of a bifilar current balun wound on a ferrite toroid (see Fig 3);
- It has excellent power-handling capability, and can function quite satisfactorily when working into highly reactive loads. This is so because the magnetic flux produced by currents flowing on this balun's wires cannot saturate its ferrite beads.

The windings of toroidal baluns produce magnetic flux that can saturate their core material. This harms balun performance and causes heating that may destroy the balun. Core saturation is not a consideration with ferrite-bead-choke baluns. You need only take care to choose coaxial cable of the appropriate impedance and power/voltage rating, and ferrite beads (of a material suitable for the operating frequency) that fit snugly over the coaxial shield.

Disadvantages of this balun:

- The beads are lossy at HF, and under some circumstances can get extremely hot. The beads nearest the balun's balanced output heat the most. Tests indicate that heating is not a concern at a transmitter power of 125 watts. For high power (1 kW CW), however, you must use a design intended for higher power.[11]
- An *apparent* disadvantage is that only 1:1 ferrite-bead-choke baluns are available,

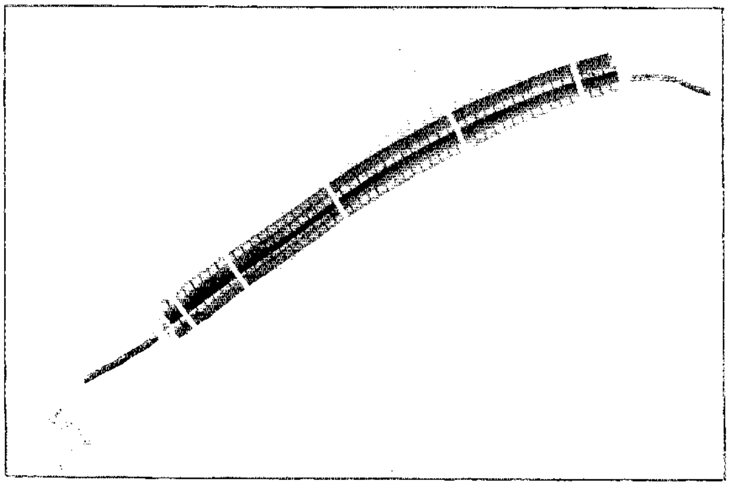


Fig 5—Nylon wire ties hold this RG-62A-based 4:1 current balun together. This version requires only weatherproofing to ready it for outdoor use.

whereas a 4:1 transformer would be useful in many applications.

A 4:1 Ferrite-Bead-Choke Current Balun

I have devised a 4:1 ferrite-bead-choke current balun (Figs 4 and 5) based on two equal lengths of 93-Ω coaxial cable (RG-62A at power levels near 100 W; RG-133A should suffice at the 1-kW level[12]), each fitted with 50 ferrite beads. Connecting these line sections' inputs in parallel and their outputs in series results in output-current polarities correct for a 4:1 balun, in a configuration that has a center tap. Fig 6A shows that this new 4:1 balun design exhibits all of the excellent characteristics of the W2DU 1:1 balun.

This balun should ideally be constructed with 100-Ω coaxial cable, but because the balun is physically short with respect to the wavelength, 50-Ω coax might work just as well. Experimentation confirms this expectation, as Fig 6B reflects. Both versions work as 4:1 transformers. The 93-Ω-coax version introduces less reactance, as comparison of the Θ curves in Figs 6A and 6B reveals.

The off-center-fed antenna system Peter Bouliane and I were investigating[13] when we devised the 4:1 current balun was, in effect, center tapped because we fed it via two equal lengths of 93-Ω (RG-62A) coaxial cable configured as a balanced 186-Ω transmission line. What's the best way to connect such a balanced, coaxial-cable transmission line to a 4:1 ferrite-bead-choke current balun? The line's center conductors connect to the balun's balanced output terminals, of course. For the line braid—that is, both of the line's coax-section braids connected together—two possibilities exist: (1) Connect the braid to the balun center tap at the balun output terminals, or (2) connect the braid to the ASTU (or transceiver) ground. Connecting the braid to the ASTU/transceiver ground is by far the better arrangement. Doing so balances the transmission-line currents (that is, the currents flowing on the center conductors of the feeder's two coaxial lines). Connecting the braid to the ASTU/transceiver, *with no RF connection between the balun center tap and equipment ground,* also minimizes the braid current.[14] So much for the concept of virtual ground![15] This type of transmission line operates best when a real wire path connects its braid to the chassis of the transmitter/ASTU that feeds it.

A 9:1 Ferrite-Bead-Choke Current Balun

A 9:1 version can be fabricated by appropriately connecting *three* ferrite-bead-

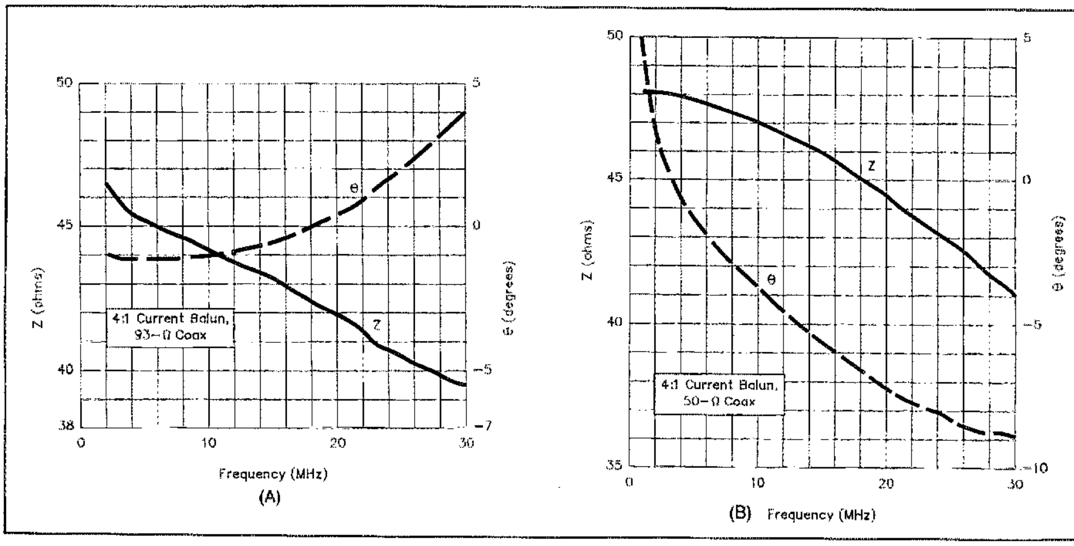


Fig 6—Input impedance (Z, solid curves) and phase angle (Θ, dashed curves) versus frequency for two 4:1, ferrite-bead-choke current baluns (A, based on 93-Ω coax; B, based on 50-Ω coax; both with center tap connected to input/transceiver ground). Negative Θ values indicate capacitive reactance; positive Θ values indicate inductive reactance. The 50-Ω-coax version is classed as "more reactive" because its input phase angle strays farther from 0 degrees—purely resistive impedance—than the input phase angle of its 93-Ω-coax counterpart. Both baluns are usable, however.

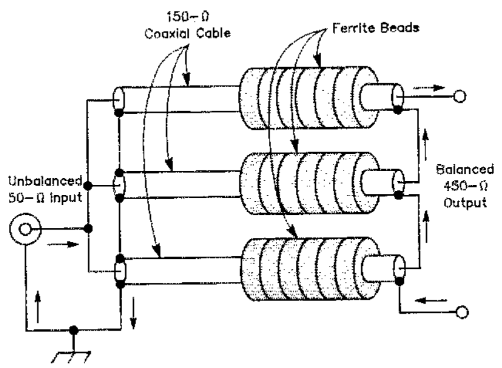


Fig 7—Three ferrite-bead-choke baluns can be combined as shown here for a 9:1 impedance transformation. Each choke consists of a length of 150-Ω coax and 50 beads (see text and the article cited at note 9 for material). The arrows associated with conductors indicate the relative direction of RF-current flow at one instant during the signal cycle.

choke coaxial baluns (each constructed from 150-Ω coax) as shown in Fig 7—that is, with the inputs in parallel and the outputs in series.[16]

Conclusion

If your MF/HF antenna system presently includes a voltage balun *and works well*, the modest performance improvement you may achieve by replacing that balun with a ferrite-bead-choke current balun probably isn't worth the time and effort involved. If, however, you're installing a new antenna system or reworking an old one, *you cannot go wrong* if you use a ferrite-bead-choke current balun where a balun is required. If the feeder of which the balun is part operates at a high SWR, you *must* use a current balun—and a ferrite-bead-choke current balun is best.

With some antennas—antennas that are not symmetrical with respect to their feed lines, for example, or antennas that, with respect to their feed, are asymmetrical with the ground (for example, off-center-fed dipoles, full-wave delta loops installed apex-up with lower-corner feed, and sloping dipoles)—a current balun *must* be used for best results. Whenever your MF/HF application calls for a current balun, a *ferrite-bead-choke* current balun—a type capable of 4:1 and 9:1 impedance transformation as well as the 1:1 ratio afforded by Walter Maxwell's original design—will work best.

Notes on Evaluating Baluns

A *1:1 toroidal, bifilar current balun* has no center tap to ground. In effect, its two windings act as chokes in each side of the line connecting a balanced load to an unbalanced input. Although such baluns are not very effective devices (see the dashed curves in Fig 3), they are used by hams and are available commercially.

Toroidal 4:1 and 6:1 current baluns are available commercially. Those I have seen consist of two cascaded baluns: a standard 4:1 or 6:1 voltage balun at the input, and a choke (current) balun at the output. I have not tested these devices.

The *1:1 ferrite-bead-choke current baluns* tested were terminated in a balanced, center-tapped 50-Ω load with its center tap connected to input common (transceiver ground). This balun design must be tested in this way, since it otherwise appears as merely a short piece of 50-Ω coax terminated in 50 Ω.

Terminating it in a balanced, center-tap-to-common 50-Ω load forces it to function as a balun. The 4:1 and 9:1 current baluns described in the text make the basic 1:1 ferrite-bead-choke balun more versatile.—*VE2CV*

Notes

[1] W. Maxwell, "Some Aspects of the Balun Problem," *QST*, Mar 1983, pp 38-40.
[2] R. Lewallen, "Baluns: What They Do and How They Do It," *The ARRL Antenna Compendium*, Vol 1 (Newington: ARRL, 1985), pp 157-164.
[3] A. Roehm, "Some Additional Aspects of the Balun Problem," *The ARRL Antenna Compendium*, Vol 2 (Newington: ARRL, 1989), pp 172-174.
[4] I. White, "Balanced to Unbalanced Transformers," *Radio Communication*, Dec 1989, pp 39-42.
[5] R. Measures, "A *Balanced* Balanced Antenna Tuner," *QST*, Jan 1990, pp 28-32.
[6] See note 2.
[7] See note 1.
[8] A description of these baluns first appeared in *QST* in R. Turrin, "Broad-Band Balun Transformers," *QST*, Aug 1964, pp 33-35, which was based on C. Ruthroff, "Some Broadband Transformers," *Proc IRE*, Vol 47, Jul 1959, pp 1337-1342. Responding to the availability of new ferrite materials, Turrin revisited the subject in "Application of Broad-band Balun Transformers," *QST*, Apr 1969, pp 42-43 (also see Feedback, *QST*, Nov 1969, p 73).
The ARRL *Handbook* first described toroidal 1:1 and 4:1 baluns—apparently a distillation of Turrin's 1964 article—in the Transmission Lines chapter of its 1968 edition. This treatment remained relatively unchanged until the 1991 *ARRL Handbook* expanded its balun coverage—still in the Transmission Lines chapter—to differentiate between voltage and current types.
The ARRL Antenna Book first covered toroidal baluns in the Transmission Lines chapter of its 13th edition (1974); this material appears to distill Turrin's 1969 article.—*Ed.*
[9] *The ARRL Handbook* indicates that the balun works well when the coax jacket is left in place, and when other ferrite materials are used. See L. Wolfgang and C. Hutchinson, eds, "The W2DU Balun," *The ARRL Handbook for Radio Amateurs*, 1991 ed (Newington: ARRL, 1990), pp 16-9 and 16-10.—*Ed.*
[10] J. Belrose and P. Bouliane, "The Off-Center-Fed Dipole Revisited: A Broadband, Multiband Antenna," *QST*, Aug 1990, pp 28-34.
[11] See note 3.
[12] This type of coax is uncommon, and may not be available in small quantities.
[13] See note 10.
[14] Measured, in the braid-to-balun-center-tap case, on the wire connected to the balun center tap, and in the braid-to-transceiver/ASTU case, on the wire connected to equipment ground.
[15] J. Belrose, "Tuning and Constructing Balanced Lines," Technical Correspondence, *QST*, May 1981, p 43.
[16] The 150-Ω coax required (RG-125, for example) is difficult to obtain. As discussed in the text associated with Fig 6, coaxial cable of other impedances may be used, however. The effect will be to introduce more reactance, which, in any case, can be readily tuned out. [Another solution would be to build your own 150-Ω-line sections from wire, insulating spacers and copper or brass tubing.—*Ed.*]

Strays

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☐ anyone who has operating instructions for a Palomar Electronics Corp model FC 40 solid-state frequency counter. This is not the same manufacturer as Palomar Engineers, which advertises in *QST*. George Nixon Jr, N9EJS, 2021 S Wolf Rd, Apt 203, Hillside, IL 60162-2155.

☐ anyone using a Racal RA-71 (not an RA-17) amateur receiver. Wayne Steiner, NØTE, Rt 1, Box 114, Burlington, KS 66839-9633.