Broad-Band Balun Transformers

Compactness and Efficiency Using Ferrite Cores

BY RICHARD TURRIN,* W2IMU

Ferrite cores lend themselves to the construction of wide-band transformers for low-impedance operation. Here's an application that will interest anyone who has the problem of connecting a balanced load to a single-ended source.

The balun transformer is not new and has appeared in a variety of forms, the most popular of which are the bifilar air-wound coils for the low frequencies and the half-wave coaxial-line type. The line-section type is suitable for single-band operation while the air-wound-coil type can be made to cover the lower-frequency amateur bands in the region 3.5 to 30 Mc. However, both are somewhat bulky and awkward to apply.

With the advent of new low-loss high-frequency ferrite materials it is now possible to use the bifilar-coil balun with a toroidal ferrite core. In one stroke the size is reduced, the bandwidth and efficiency are increased, and full kilowatt power-handling capability is easily realized. This form of the balun and other types of broad-band transformers have been described by C. L. Ruthroff.[1]

This article will confine itself to the two basic baluns most widely employed, the 4:1 impedance transformer, balanced to unbalanced, and the 1:1 impedance transformer, balanced to unbalanced. One transformer will perform its design function over a frequency range of 1.8 to 90 Mc. when terminated in 50 ohms on the unbalanced side. Fig. 1 shows the winding method for each transformer. These transformers are transmission-line transformers at the high-frequency ends of their useful ranges, and tightly-coupled coils at the low-frequency ends. In fact, the low frequency response is limited simply by the winding inductance while the high frequency response is limited by transmission-line resonances.

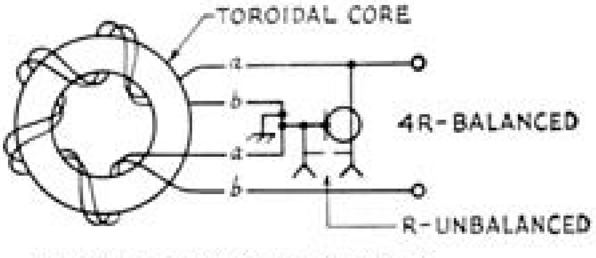
By suitable selection of core material, winding size, and termination impedances it is possible to achieve very broad-band balun transformers. The power-handling capability is difficult to estimate since core flux varies with frequency. At low frequencies the coupled coils transfer most of the energy through their high mutual inductance. At high frequencies almost all the energy is transferred through the transmission line structure.

Core Material

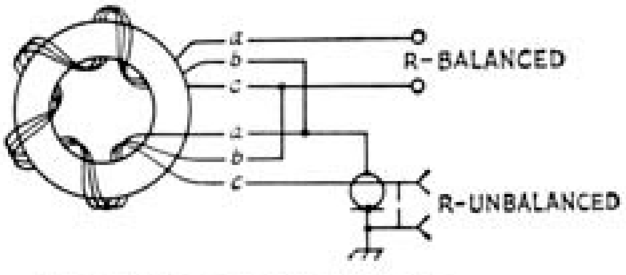
The key component of this transformer is quite obviously the core material. While other sources of useful material may be available, the author has had experience only with a material called Ferramic-Q, manufactured by Indiana General Corporation, Electronics Division, Keasby, New Jersey. Ferramic-Q is available in three high-frequency grades, and a tabulation of two useful properties is given below:

Material	*Permeability*	*Approx. Frequency at which Core Losses Increase by a Factor of 10*
Q-1	125	10 Mc.
Q-2	40	90 Mc.
Q-3	14	200 Mc.

Toroidal cores are available in a wide variety



4:1 BALANCED TO UNBALANCED



1:1 BALANCED TO UNBALANCED

Fig. 1—Broad-band balun transformer schematics. The letters indicate single winding ends. By arranging the windings side-by-side without crossovers the connections can be made as shown.

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[1] C. L. Ruthroff, "Some Broadband Transformers," *Proc. IRE*, Vol. 47, pp 1337–1342, Aug. 1959.

of diameters and cross-sectional areas. Outside diameters ranging from 0.020 to 9.0 inches may be obtained. Typically, the 2½-inch o.d. cores cost about $5.00 each, while the ⅞-inch o.d. cores are about $.60.[2] Q-1 or Q-2 material has been found to be quite satisfactory for 3.5- to 30-Mc. baluns. Little work has been done with Q-3 material at the higher frequencies because for 144 Mc. and higher the standard single-band coaxial-line balun is simple and efficient.

Since the transformer depends less on the core material at the high frequency end of its useful range it is easy to see that the fact that Q-1 material has poor intrinsic *Q* above 20 Mc. does not degrade the transformer operation at 30 Mc. Q-2 material, having lower permeability, requires more turns to operate at the lower frequencies.

All three grades of material are essentially nonconductive and are hard and brittle like ceramic. Any flaws or cracks in the toroidal cores will seriously impair the transformer. In general, the cross-section should be square and the outside diameter-to-thickness ratio around 4 or 5 to 1.

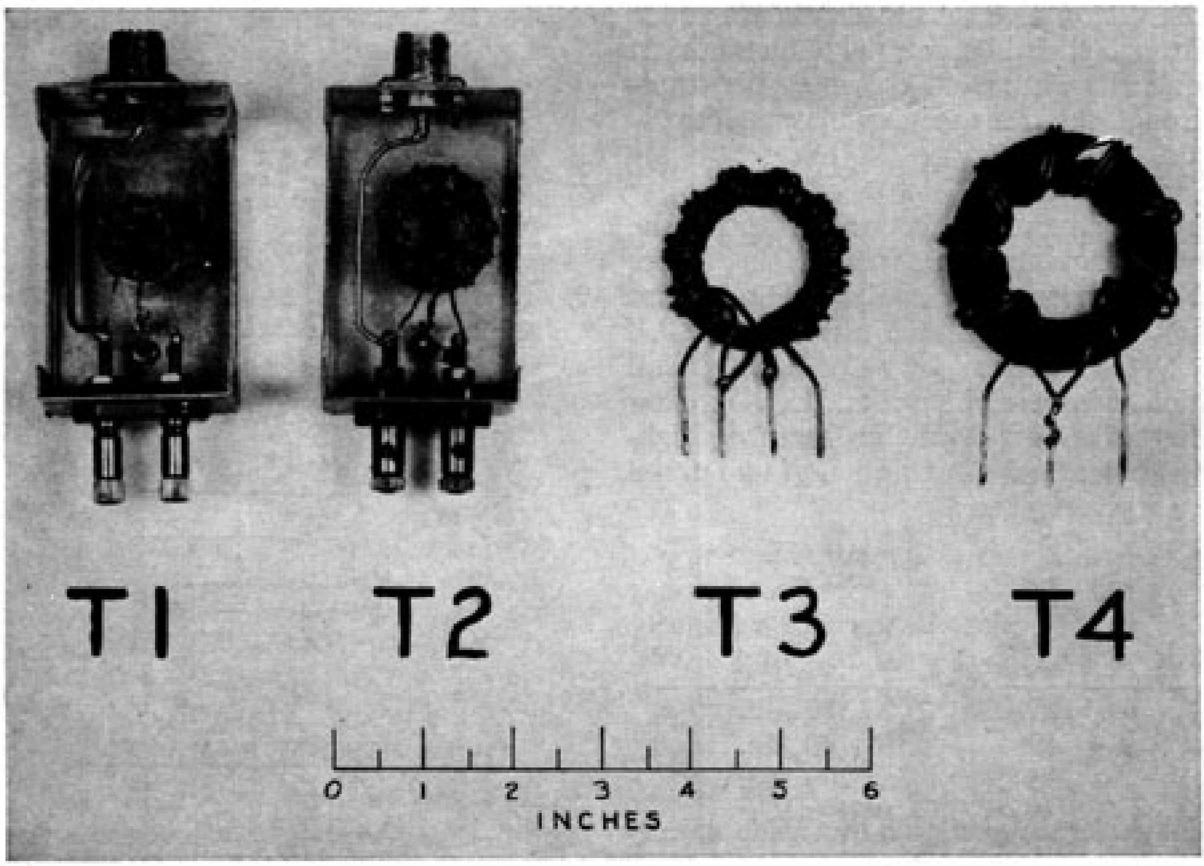
Winding may be done with Formex or Formvar copper wire directly on the core. The sharp edges of the core should be removed with care, using emery paper. Since the material is magnetostrictive, rough abrasion such as filing or grinding may alter the permeability and *Q*. Cores with rounded edges may be obtained by specifying tumbled cores. Since moisture affects the material *Q*, a small sealed enclosure is suggested for weather proofing.

4:1 Balun Transformer

As shown by Fig. 1, the transformer winding consists of a bifilar coil wound on the toroidal core. A bifilar coil consists of two side-by-side windings of equal numbers of turns. The wire size is determined by the maximum current at the low-impedance end of the transformer. No. 14 A.W.G. is sufficient for maximum legal power at a 50-ohm unbalanced impedance level. The number of turns is not critical unless the widest possible bandwidth is desired. Q-1 material requires between 5 and 10 turns per winding for 3.5- to 30-Mc. coverage. Q-2 material requires about two or three times as many turns for low-frequency coverage.

Operation of this type transformer at higher resistance levels or with reactive loads will rapidly reduce the bandwidth. For impedance levels above 1000 ohms single-band or, at best, two-band operation is all that can be expected. At higher impedance levels the transformer behaves like a low-*Q* resonant transformer and may be tuned for single-band operation by altering the number of turns. The photograph shows several 4:1 (200:50 ohm) baluns which were constructed and measured. Table I gives the pertinent data on these transformers.

The most common applications of the 4:1 balun are in feeding a folded dipole with coax or in matching an unbalanced transmitter output to a 300-ohm transmission line. In the first application the balun must be placed at the antenna terminals, which necessitates weather proofing. In particular, these transformers should be very useful in broadband high-power amplifiers. Other applications are too numerous to list here, and the reader with some ingenuity may find an application which will suit his particular problem.



Four broad-band balun transformers constructed by the author, using ferrite cores. Construction and performance data are given in Table 1 and Fig. 1.

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[2] Inquiries regarding Ferramic parts and materials should be directed to Mr. Joseph C. Venerus, Product Engineer, Indiana General Corporation, Electronics Division, Keasby, New Jersey.

TABLE I

Trans.	Z Ratio	Core Material	Core Size, Inches	Turns	Wire Size	R.F. Power Capacity, Watts	Frequency Range, Mc.
T_1	4:1	Q-1	3/32 x 3/32 x 3/32 O. D. (two cores stacked)	7	20	150	3.5-30
T_2	4:1	Q-1	¼ x ¼ x 1¼ O. D. (two cores stacked)	11	18	350	3.5-30
T_3	1:1	Q-2	¼ x ¼ x 1⅞ O. D.	10	16	750	1.8-90
T_4	4:1	Q-1	½ x ½ x 2½ O. D.	8	14	1000	1.8-30

Those who are interested in further applications are urged to consult the reference cited earlier.

1:1 Balun Transformer

This type of balun is also shown by Fig. 1, and requires an additional single winding in order to complete the magnetizing-current path. The key to all these transformers is to arrange one winding so it does not include the load but closes on the generator. This winding is necessary for proper magnetization of the core. The 1:1 balun consists of a trifilar coil with appropriate connections as shown by the figure.

This particular balun is well suited to the problem of feeding a dipole with coax, especially the driven element of a tri-band beam antenna. Since the impedance levels encountered at the center of the driven element of a parasitic beam may be quite low, the wire and core size should be increased accordingly. T_3 in the photograph is a 1:1 50-ohm balun capable of handling 750 watts over the frequency range of 1.8 to 90 Mc.

An exhaustive study of these transformers has not been made, and the values in the table are not necessarily optimum. The maximum power-handling capacity was measured at 14 Mc. and represents an estimate over the frequency ranges indicated in the table. Transformers T_1, T_2 and T_3 showed a slight rise in temperature after several minutes of continuous operation at the power level indicated. T_4 showed no increase in temperature at full power. The pass-band characteristics of each transformer were observed on a wide-band swept basis, and the useful operating range is a measure of the frequency range over which the insertion loss was less than one db. For full legal power transformers of either impedance ratio wound on a core similar to T_4 are recommended, especially for the tri-band beam application.

The two balun transformers described are broad-band, small in size, efficient and inexpensive. In addition, the r.f. field is confined to the core-wire space, and coupling to other circuits may be kept to a minimum. The problem of connecting balanced to unbalanced devices is apparently not fully appreciated, but does represent poor engineering practice when accomplished without a balun. Perhaps these transformers will help solve some of your feed-line, antenna matching or circuit problems. QST