

CONSTRUCTION AND USE of BROADBAND TRANSFORMERS

Broadband transformers are not difficult to understand. They are commonplace in today's amateur technology. Most broadband transformers are wound on ferrite toroids or rods. Some are wound on powdered-iron cores, while others are formed on pot or cup cores. We will confine our discussion to transformers that are wound on ferrite toroids or balun cores (sometimes called "binocular" cores. Basic information on toroids and how to wind them is available in the Oak Hills Research application note No- T-IA. Therefore, I shall not repeat the fundamental information about toroids in this note.

Basics of Broadband Transformers

A broadband RF transformer is designed to operate over a wide range of frequencies with minimum X_L or X_C occurring at one or more frequencies within the design range of the transformer. This requires that we use high permeability cores with relatively small windings for the MF and HF spectrum. As the operating frequency is increased the core becomes less and less evident to the circuit. Only the winding on the core is effective at the upper range of operation. At the lower end of the frequency range the core is "seen" by the circuit, and it enables the winding to exhibit the necessary inductance for the low-frequency portion of the operating range. Most HF broadband transformers are wound on ferrite cores that have a μ (initial permeability or μ) of 125 or 850. The latter type is the most common for coverage from 1.8 to 30 MHz. The 125 μ cores have the suffix "61" for Amidon or Fair-Rite products. No. 43 material has a μ of 850. No. 63 and 68 material is generally used for VHF broadband transformers ($\mu = 40$ and 20 , respectively).

There are two kinds of broadband transformers. One is known as a "conventional" type, which has separate primary and secondary windings, as do power and audio transformers. The other type is called a "transmission-line" transformer. It is believed that the latter variety is the most efficient of the two. In any event, all transformers must have some loss, however small. W2FMI has developed broadband transformers that have efficiencies in the high 90% range. This is discussed in his ARRL book, Transmission Line Transformers. I recommend this book to those who want to learn more about broadband-transformer design and application.

Transmission-line transformers are wound with twisted or parallel windings and produce specific integers of impedance transformation, such as 4:1, 9:1 and 16:1. Conventional transformers permit you to obtain any transformation ratio you need. The windings on a transmission-line transformer exhibit a characteristic impedance of roughly 25 ohms. Some designers use teflon insulated miniature 25-ohm coaxial cable for the windings. Parallel-wire windings are laid on the core with the wires for a given turn adjacent to one another. Twisted-wire windings generally contain 6 to 8 twists per inch.

A bifilar winding has two parallel wires that are wound on the core at the same time. A trifilar winding has three such wires, and a quadrifilar winding has four wires. Fig. 1 illustrates in schematic form how a conventional and transmission-line transformer compare.

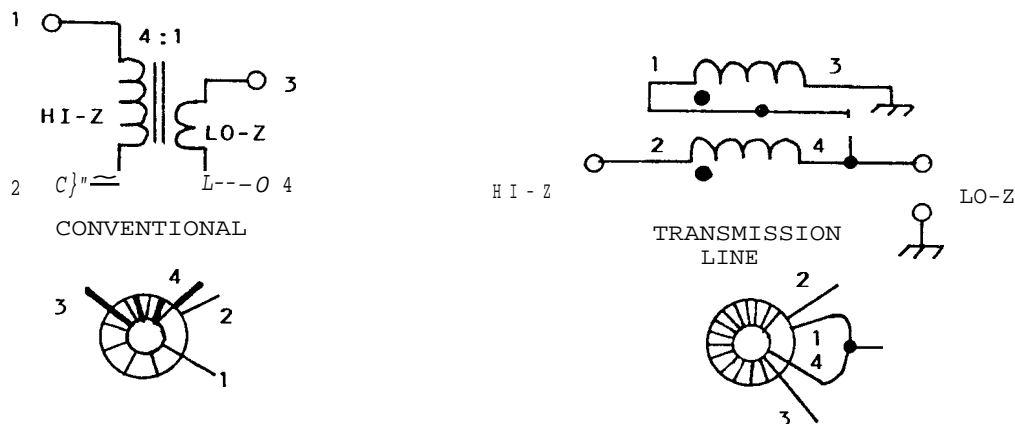


Fig. 1 -- A conventional broadband transformer is shown at the left. The example at the right illustrates a bifilar-wound transmission-line transformer. The pictorial drawings show how the windings relate to the schematic diagrams. The large black dots near leads 1 and 2 of the transmission-line transformer indicate the polarity or phase of the windings.

Determining - the - Minimum - Number - of - Turns

Once we know the required impedance transformation ratio for our circuit we can calculate the turns or voltage ratio of the transformer. The turns ratio is the square root of the impedance ratio. Thus, for a 4:1 Z ratio we have a 2:1 turns ratio. For example, we might have 10 turns of wire for the hi-Z winding, and 5 turns of wire for the low-Z winding. This 2:1 turns ratio equates to a 4:1 Z ratio.

The question now arises concerning the required inductance of the transformer windings. Most industrial designers follow a rule that dictates the X_L (inductive reactance) of the smallest winding must be X_4 or greater the load impedance of the winding. Therefore, if the smaller winding looks into a 50-ohm load, the X_L of that winding must be 200 ohms or greater. I use the X_4 rule for all of my design work. The inductance of the winding may now be found from $L(\mu H) = X_L / (6.28 \times f(\text{MHz}))$. We can now look up the A_L for the toroid core we plan to use and learn how many turns are needed to obtain the required inductance. Once we learn the number of turns for the small winding we will be able to wind the larger winding in accordance with the already determined turns ratio.

If there is too little inductance in the transformer winding we will experience losses and SWR problems because of the to-Z transformer winding placing a low value X_L in parallel with the resistive load.

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Transformers on Balun Cores

Many designers prefer to use balun or binocular cores for broadband transformers that must accommodate RF power. For the most part, these transformers are of the conventional type shown in Fig. 1. Balun cores are made from ferrite. The permeability of the core material is 850 to 900 for applications from 1.8 to 30 MHz.

You may create your own balun cores by using two rows of ferrite toroids, side by side. For example, you want to build a 50-W broadband RF amplifier. You can use two rows of 6 each FT-50-43 ferrite toroids. The cores are glued together by means of quick-setting epoxy cement to form two separate tubes of toroids. When the glue has dried, cement the two rows together (side by side) with epoxy. This results in a binocular type of core assembly. Additional toroids can be added to the two rows if higher power is anticipated. Fig. 2 shows an example of a **one-piece balun core** and one that has been fashioned from two rows of toroids.

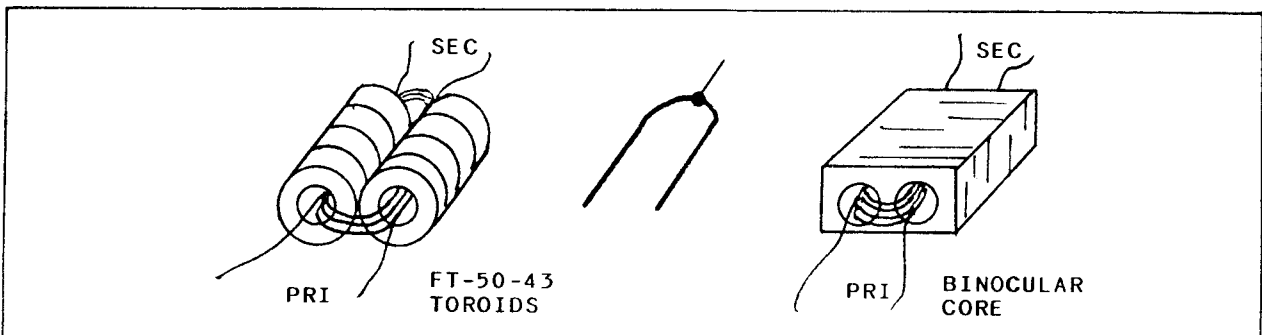


Fig. 2 -- Examples of broadband RF power transformers. Two rows of toroid cores (ferrite) are formed by gluing the toroids to one another. The two rows of cores are then glued together, side by side. A balun core is shown at the right. It can be an Amidon Associates BN-43-7501 or similar unit. The low-Z winding is generally a single, U-shaped turn of wire. The larger winding has as many turns as are needed to provide the desired impedance transformation. The BN-43-7501 has an A_L factor of 6000.

The transformers in Fig. 2 are configured for unbalanced circuits. If a push-pull amplifier is used, merely place a center tap on the U-shaped, one-turn winding. Locate it at the center of the U bend of the winding, as shown above. The 1-turn primary winding should be made from heavy-gauge wire or small copper or brass tubing since it must carry considerable dc and RF current for the transistor or transistors in the power amplifier. The larger winding, which feeds the harmonic filter, may be fashioned from smaller wire. Use the largest wire gauge practicable, consistent with fitting the winding in the holes of the core. The larger the wire diameter the lower the losses.

Broadband Balun Transformers

Balun (balanced to unbalanced) transformers are used in test equipment, mixers, receivers, transmitters and antenna circuits. **Circuits and wiring information concerning baluns is available in The ARRL Electronics Data Book and The Radio**

Amateur's Handbook, plus the W1FB book, Ferromagnetic Core Design & Applications Handbook (1). Therefore, that information will not be repeated here.

Baluns are transmission-line transformers. The greatest common misuse of balun transformers is when they are used in antenna systems. A balun is designed to interface between specific impedances. It cannot accommodate a wide range of impedances, irrespective of its transformation ratio. For example, a 4:1 balun transformer is normally used between a 50-ohm unbalanced line and a 200-ohm balanced line or termination. It may be used also for joining a 75-ohm unbalanced line to a 300-ohm balanced one. The importance of balun design and application is clearly explained in the W2FMI book, Transmission Line Transformers (ARRL). Broadband transformers are not effective at impedances above approximately 600 ohms. Therefore, when they are included in the circuit of an Transmatch (antenna tuner) for use with "any impedance," they can't perform properly -- especially at high impedances. The phase becomes questionable and they can saturate and burn up easily under certain conditions. An ideal environment for a balun is one that presents input and output impedances that are suitable for the transformer design. These impedances should remain constant over the operating-frequency range of the balun. A worst-case example of a balun in an improper environment is one that is used at the feed point of a dipole that is meant for multiband use. If sufficient RF power is fed through the balun, it will saturate or burn up on some frequencies. This is because the antenna impedance may be several thousands of ohms at some frequencies. This results in extremely high RF voltages within the balun. Core saturation is dependent upon the cross-sectional area of **the core, the number** of turns on the windings and the current (ac and dc) flowing through the windings. Add to this the peak-peak voltage in the windings. High values of RF voltage can also cause arcing between the windings and the transformer core. A situation of this type is common also when a balun is used at the feed point of a single-band dipole, where the SWR is low at the design frequency, but high above and below the design frequency. **Should you attempt to use the antenna at** a frequency where the SWR is high (1.5:1 or greater), the balun finds itself in a very hostile environment. Not only is there a mismatched condition at the balun, but high RF voltage will be present at the feed point. Evidence of core saturation is noted when the transformer becomes hot to the touch. This assumes that the wire used for the windings is large enough to prevent heating of the windings. Core saturation also causes the generation of square waves, and these are rich in harmonic energy. Therefore, a saturated core can cause TVI and RFI. Equations for calculating the core size versus saturation are given in the books listed at the end of page 3 and the start of this page.

Practical Examples of Broadband-Transformer Use

Fig. 3 shows examples of some common uses for broadband transformers. Circuit A illustrates the use of a broadband transformer at the output of an active mixer. The resistor bridged across the transformer primary helps to establish a constant impedance. This makes it less difficult to calculate the turns ratio when the load impedance is known. Another advantage of R1 is that it helps to improve the IMD characteristic of the mixer. Typical R1 values are from 4700 to 12,000 ohms for IMD improvement.

Fig. 3B shows how you can use a broadband transformer for matching a 50-ohm antenna to a grounded gate RF amplifier in a receiver or converter. The input impedance (source) of the JFET is on the order of 200 ohms, which calls for

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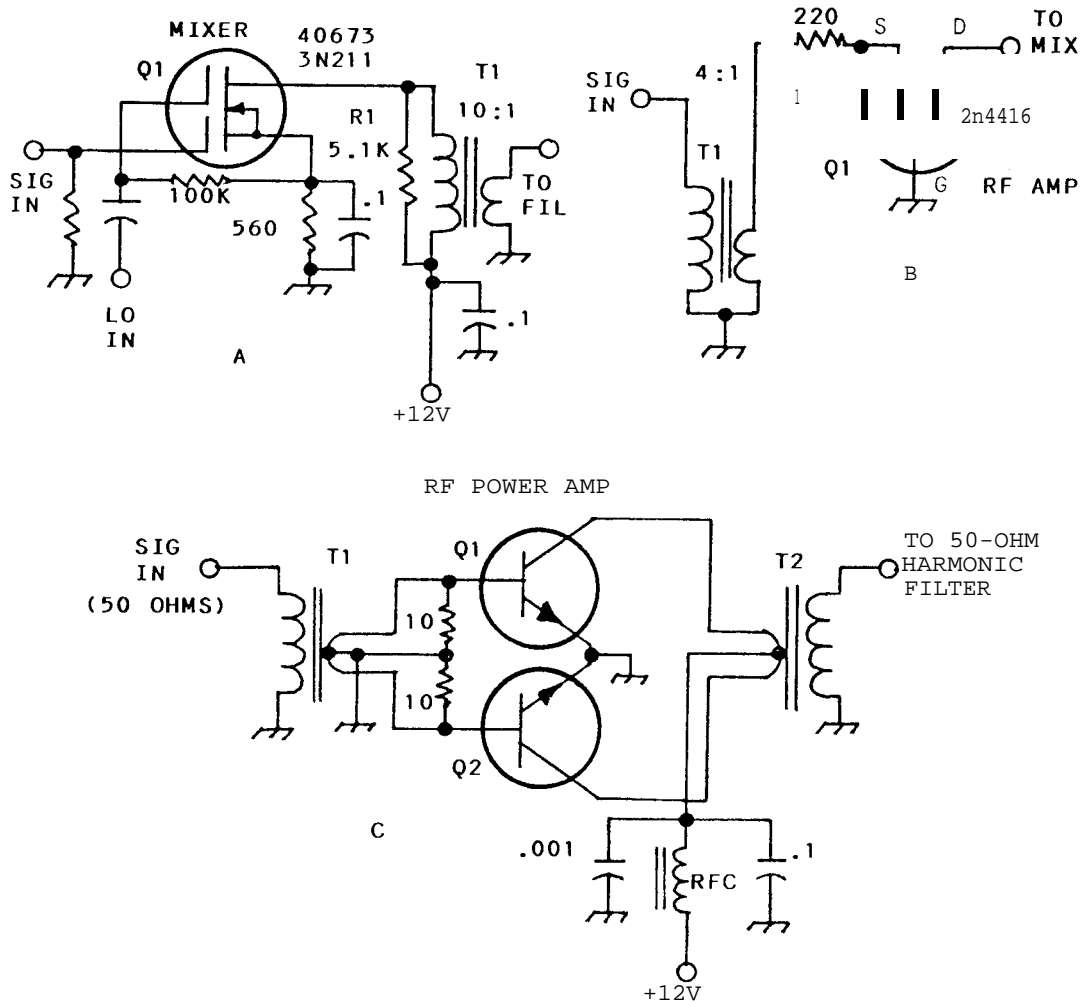


Fig. 3 -- Examples of how to use broadband RF transformers. An untuned mixer output circuit (T1) is seen at A. R1 improves the IMD performance and helps establish the T1 primary load impedance. The 10:1 Z ratio permits the use of a 500-ohm IF filter. A typical transformer for the mixer might have a primary with 25 turns of no. 28 enam. wire on an FT-50-43 toroid. A 10 turn secondary would be used for a 500-ohm load. Circuit B shows a common-gate JFET RF amplifier. T1 provides a match between a 50-ohm antenna and the 200-ohm input Z of Q1. Amplifier C is a push-pull Class C type for RF power service. T1 matches the 50-ohm input line to the bases of Q1 and Q2. Balun cores of the type in Fig. 2 may be used at T1 and T2 of this circuit. T2 matches the collector impedance to a 50-ohm harmonic filter.

a T1 impedance ratio of 4:1. Fig. 3C shows a push-pull RF power amplifier that uses two broadband transformers of the type in Fig. 2. T1 matches 50 ohms to the Q1/Q2 base impedance (generally less than 10 ohms). T2 is wound to transform the Q1/Q2 collector impedance to a 50-ohm harmonic filter. The center tapped windings of T1 and T2 are shown at the center of Fig. 2. Numerous practical examples of broadband transformers and associated circuits are found in The WIFB QRP Notebook, The ARRL Handbook and Solid State Design for the Radio Amateur.

Toroidal transformers may be used in place of T1 and T2 in Fig. 3C. The major disadvantage of using a toroidal transformer in a push-pull circuit is that it is difficult to provide a precise electrical center for the tapped winding.

Physical and electrical symmetry are important for any balanced circuit. The transformers in Fig. 2 lend themselves more readily to effective balance.

Bits and Pieces of Information

Check your December annual indices in QST for articles about toroids. A number of good articles on the subject have been published in QST during the past 20 years.

Use caution when winding ferrite cores. They break easily if dropped on a hard surface. Also, many ferrite cores have not been tumbled to provide smooth edges. These sharp surfaces can easily strip the enamel insulation from the wire used for the windings. This can cause shorted turns that ruin the transformer performance. It is wise to wrap large ferrite cores with 3M glass tape or plumber's Teflon tape before applying the windings. This helps to protect the wire from abrasion.

A broken ferrite core may be repaired and used again if the halves are glued firmly together with epoxy cement. I once shattered a huge 20-kW toroid (used as a balun core for commercial broadcast) by applying too much power in a situation of high RF voltage. It broke into flour pieces. It was glued and used successfully in a high-power application.

In order to avoid confusion when building transformers with multifilar windings you can spray paint the wires with different colors before putting the winding on the core. Also, be on the lookout for magnet wire with different colors of enamel insulation (green red, brown and gold, which are standard colors).

Ferrite is not a perfect insulator. Rather, it is a semiconductor type of ceramic. Bare wire should not, therefore, be used on an untaped ferrite core.

If you have ferrite or powdered-iron cores of unknown characteristics you may learn the A factor by winding a few turns on the core, measuring the winding inductance and applying this equation: $AL = (L(\mu h)) \times 10^4 / N^2$ where N is the number of turns on the core.