adjustable balun for yagi antennas

Complete design and construction details for adjustable balanced-to-unbalanced feedline transformers

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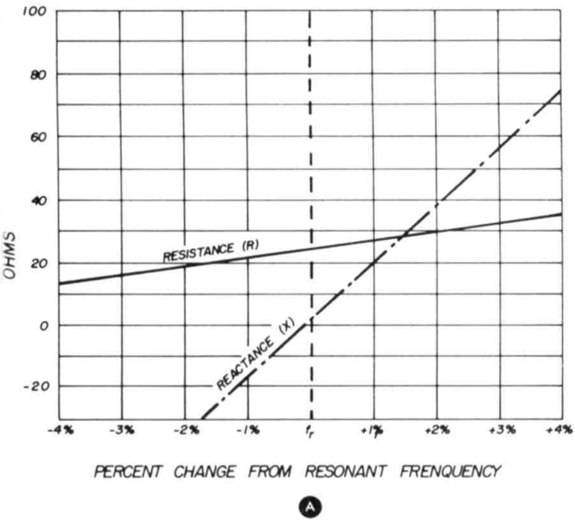
How convenient it would be if all Yagi beams presented a 50-ohm, unbalanced, non-reactive load at the feedpoint! Unfortunately, this is not the case, as most single-band Yagis exhibit a balanced feed-point impedance in the range of 18 to 30 ohms. Off-resonance, the impedance becomes complex, varying in the typical manner shown in **fig. 1A.** Moreover, when using a center-fed dipole the feedpoint impedance is balanced to ground, and an unbalanced coaxial feed system can result in degraded antenna performance. Poor front-to-back ratio, noise pickup and TVI may be some of the problems arising from improper attention to system balance.

A number of interesting matching and balancing systems have been evolved from time to time to solve these problems, and the better solutions work quite well. This article discusses an adjustable transformation linear balun of a type that has seen service in commercial installations over the years. However, its use in amateur circles has been restricted, possibly because of lack of knowledge regarding its operation. The balun will provide *an adjustable step-up impedance match* plus an accurate transformation from an unbalanced to a balanced mode for load values of about 10 to 50 ohms. Best of all, it is easy to adjust. Here's how you design, construct and tune this interesting device.

the L-network

The adjustable balun is derived from the basic L-network shown in **fig. 1B.** By the use of a combination of a series and shunt reactance the low-impedance load may be matched to a high-impedance source. Transformation ratios up to ten or more are common. Two lumped constant L-networks are shown in **fig. 2.** They are conjugate networks, the sign of the series and shunt impedances being reversed between the A and B versions. The A network is rather common in amateur equipment;[1] it may be recognized as the output section of the popular pi-L network circuit.



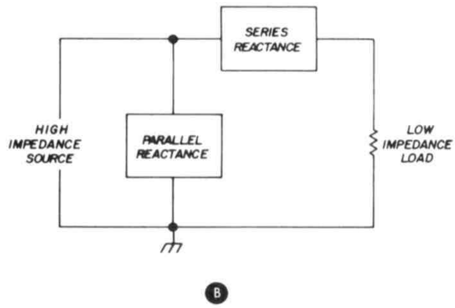
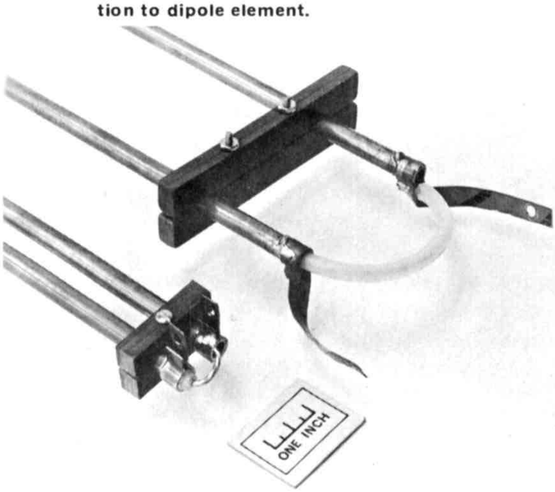


fig. 1. Yagi-beam impedance plot in A is similar to that of a dipole. Resistive component increases with frequency; reactive component is negative below resonant frequency and positive above it. L-network in B consists of series and shunt reactances and may be used to match a Yagi to 50-ohm coaxial line.

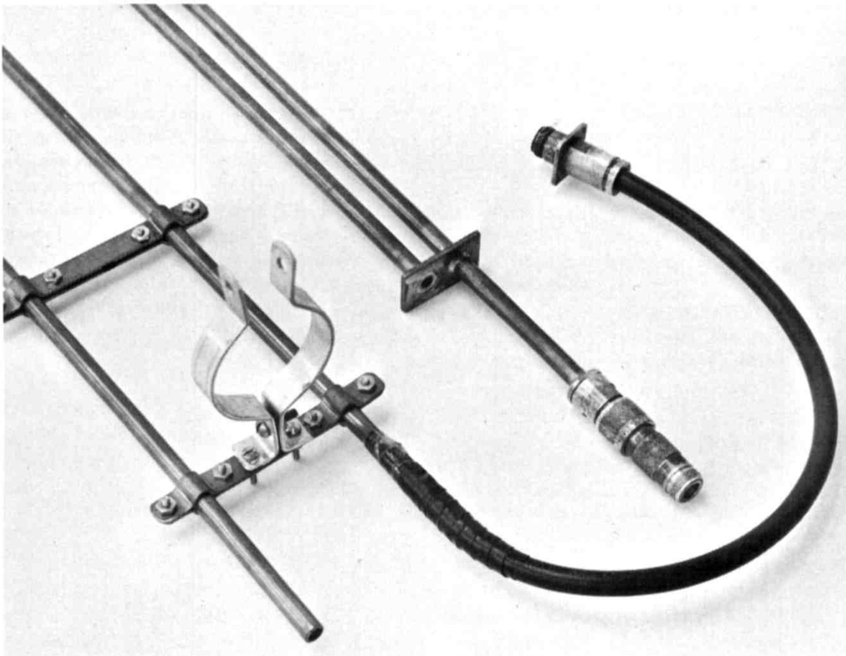
Vhf (left) and hf (right) balun construction. Balun tubes are locked in position by phenolic blocks. Inner conductor of coaxial line crosses over and is soldered to opposite tube. Short lengths of copper ribbon provide easy connection to dipole element.



The configuration in **fig. 2B** is used less often although it performs in the same general fashion as the A network. This second version of the L-network is the one used in the adjustable antenna balun described here.

In both versions, X_L and X_C represent real components, and R represents a resonant antenna load. If the antenna is deliberately made *non-resonant,* however, it may be adjusted to simulate a complex impedance containing the desired value of either X_L or X_C. Specifically, if the dipole antenna element is longer than resonance, it exhibits inductive reactance (X_L) at the center terminals; if it is shorter than resonance, it exhibits capacitive reactance (X_C). Thus, varying the length of the antenna beyond the resonant point eliminates the real components X_L (in network A) and X_C (in network B). The L-network may be reduced to an off-resonant antenna, and either a parallel capacitor or inductor may be used, depending upon the type of network.

may take the form of a shorter-than-resonant dipole. In addition, the lumped inductor X_L may be removed and a shorted segment of transmission line substituted as shown in **fig. 4.**



Base end of hf (left) and vhf (right) baluns. Adjustable shorting bar is visible on hf balun. Extra shorting bar has aluminum boom clamp mounted on it. Coaxial line passes out of balun tube and has female type-N coaxial fitting (UG-23B/U) fitted at end of line. Vhf balun has one adjustable shorting bar (not in photograph) with copper shorting bar sweated to bottom of balun tubes. One tube is a few inches longer than the other and has a modified UG-18B/U coaxial plug soldered to the tube. In the hf balun, the coax braid is soldered to the end of the copper tube and the joint wrapped with vinyl electrical tape. The braid is completely removed in the vhf balun with the inner conductor of the line soldered directly to the coaxial fitting; the inner conductor is passed through the tube to the opposite end.

balanced L-network

There still remains the problem of connecting an unbalanced coaxial transmission line to a balanced antenna element. **Fig. 3** shows the network of **fig. 2B** redrawn for a balanced condition. The ground point is moved to the center of coil X_L, and two capacitors, each double the value of X_C are placed in series with the load. As before, if the load is considered to be an antenna, the series capacitance

The configuration is the mechanical heart of the adjustable balun. A shorted transmission line less than one-quarter wavelength long presents an inductive reactance at its open end. A shorter-than-resonance dipole presents a capacitive reactance at its terminals. If the length of the line segment (or stub) and the length of the dipole are properly chosen, the components of the impedance matching network are reduced to a few lengths of tubing, two of which are the halves of the driven element in the beam antenna.

The linear L-network is easily converted to a practical balun transformer as shown in **fig. 5.** Points A and B of the balun are balanced to ground and present the correct impedance to match the shortened dipole. The unbalanced coaxial line may be brought into the balun through one of the balun tubes, with the center conductor of the coaxial line crossing over at the end of the device to contact the opposite balun tube, as shown in the illustration. Of course, the impedance of the coaxial line must be held to the original value as it passes through the balun tube. By adjusting both the shorting bar on the balun and the length of the dipole this simple device will provide excellent balance and transformer action.

Balance is achieved by permitting the outer shield of the coaxial line to assume the potential of the balun tube as it passes from the grounded end (C) to the terminal end (B). Cross-connecting the center conductor to the opposite balun leg insures 180° phase reversal is maintained.

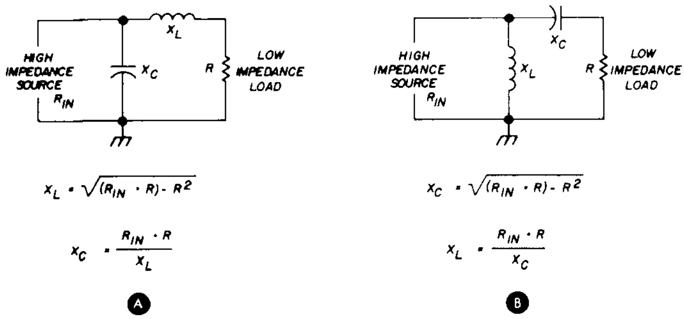


fig. 2. Conjugate L-networks. Network A is preferred when load reactance may be negative. Network B is preferred when load reactance is positive. For reactance ranges common to Yagi antennas, either network may be used.

network transformation

The reason the L-network is able to transform one impedance value to another is that, for any series circuit consisting of a series reactance and resistance, an equivalent parallel network which possesses the same impedance characteristic can be found.[2] The general case for determining the values required for any two impedances to be matched by the L-networks of **fig. 2** are summarized by the following equations:

$$\frac{R_{in}}{R} = Q^2 + 1 \qquad (1)$$

$$Q = \frac{X_s}{R} \qquad (2)$$

$$Q = \frac{R_{in}}{X_p} \qquad (3)$$

Where R_{in} = the input impedance, R = the load impedance, X_s = the series reactance, X_p = the parallel reactance, Q = the circuit Q, and the series and shunt reactances are of opposite sign.

For easier usage with 50-ohm lines, these formulas may be reduced to the ones shown in **fig. 2** with the relationship

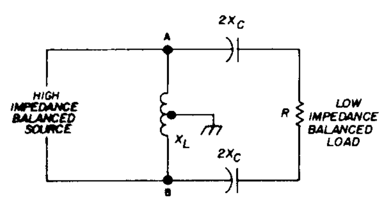


fig. 3. The L-network of fig. 2B redrawn for a balanced source and load. Points A and B are at equal and opposite potential to ground.

between X_s, X_p, R_{in} and R given in **fig. 6.** The reactance values are in ohms and may be translated to picofarads and microhenries with the aid of a reactance chart.*

balun design

Once the transformation ratio and the values of series and parallel reactance have been established, the physical balun may be designed from transmission-line formulas. The fact that a shorted, two-conductor transmission line of the proper length exhibits inductive reactance at the terminals makes it possible to substitute such a line for the inductor in an L network. The amount of reactance shown by the line segment is determined by the characteristic impedance and the electrical length of the two-conductor line. The inductive reactance of a shorted lossless balun line, less than a quarter-wavelength long, constructed in this fashion, is:

$$X_L = Z_0 \tan l$$

where X_L = inductive reactance in ohms, Z_0 = characteristic impedance of the balun line, and l = length of the balun line in electrical degrees.

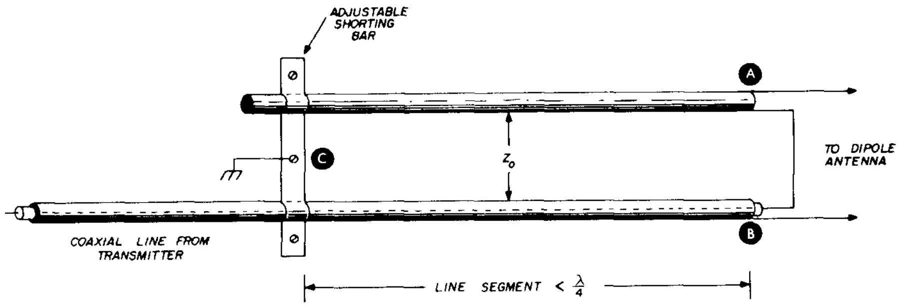


fig. 5. Linear transformer of fig. 4 is modified into balun by passing coaxial line down one leg. Points A and B are balanced to ground. Inner conductor of coaxial line is cross-connected to opposite balun leg. The impedance transformation is adjusted by varying length of the balun and length of driven element of antenna.

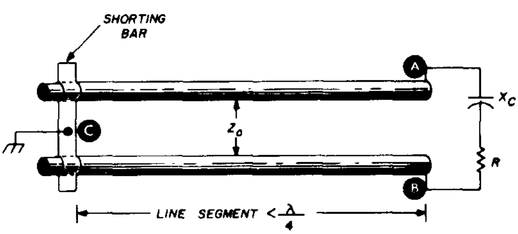


fig. 4. The inductor X_L in fig. 3 may be replaced with a segment of shorted transmission line. Points A and B are at equal and opposite potential to ground, C.

Fig. 7 is a plot of balun line length (l) in electrical degrees as a function of the ratio of load impedance to balun impedance (σ). A plot of the ratio σ in terms of line length in feet for the 20-meter band is given in **fig. 8.** These charts provide sufficient information to build your own linear balun.

practical balun transformer

A balun transformer built along these principles is shown in the photographs. For convenience the balun is made of 3/8-inch diameter hard-drawn copper tubing. The feedline, RG-8A/U cable, will just pass through the tubing when the braid and the vinyl jacket are removed from the line. Using a center-to-center spacing of 3 inches, the balun line will have a characteristic impedance (Z_0) of about 325 ohms.

*The Smith chart may also be used for impedance transformation. See P. H. Smith's book, "Electronic Applications of the Smith Chart," published by McGraw-Hill.

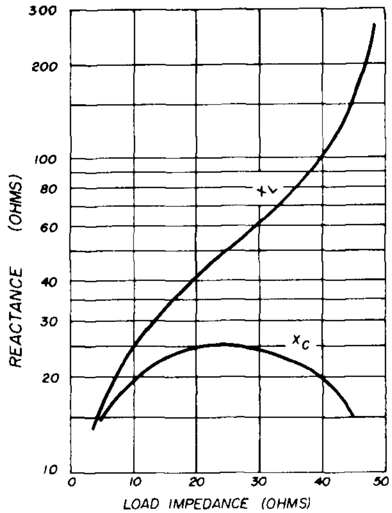


fig. 6. X_L and X_C values for antenna load R. This chart may be used for determining balun reactance values when a 50-ohm transmission line is used. For example, if the load impedance (antenna impedance at resonance) is 25 ohms, the capacitive element (X_C) of the balun of fig. 2B is 25 ohms, and the inductive element (X_L) is 50 ohms. The chart may be used with the balun of fig. 2A if the nomenclature of the curves is reversed (X_L becoming X_C and X_C becoming X_L).

Assume the impedance of the transmission line is 50 ohms and the antenna load is 20 ohms. Using **fig. 6,** the value of X_C is found to be −24.5 ohms, and the value of X_L is +41.5 ohms. Turning to **fig. 7,** the ratio of X_L to balun characteristic impedance (σ) is 41.5/325 ≈ 0.127 as noted on the y-axis. The value for l, as found on the x-axis is about 7.5 electrical degrees.

To get the answer directly in feet, **fig. 8** may be used for the 20-meter band. In this example for $\sigma = 0.127$ (read as 0.125 on y-axis) the balun length is about 1.4 feet, or 16 inches.

The chart of **fig. 6** has indicated that the series reactance (X_C) for this example is −24.5 ohms. This reactance takes the form of a shorter-than-resonance driven element. The amount of shortening required is a function of the length to diameter of the element and the feedpoint impedance at resonance of the element.* The amount of shortening may be computed easily for a single dipole element, but no information exists (that I am aware of) that permits this computation to be made for a multi-element Yagi beam. Consequently, the shortening necessary to bring the driven element to the proper reactance value is best determined by the heuristic method — cut and try! For a three-element 20-meter beam, shortening the driven element about three to six inches each side seems to bring things into the ball-park.

*As antenna length decreases, feedpoint impedance decreases, too. The decrease typically runs about 10% to 15% for the range encountered in matching a three-element Yagi beam to a 50-ohm transmission line.

adjusting the balun

The balun transformer may be pre-set and attached to the beam antenna. The

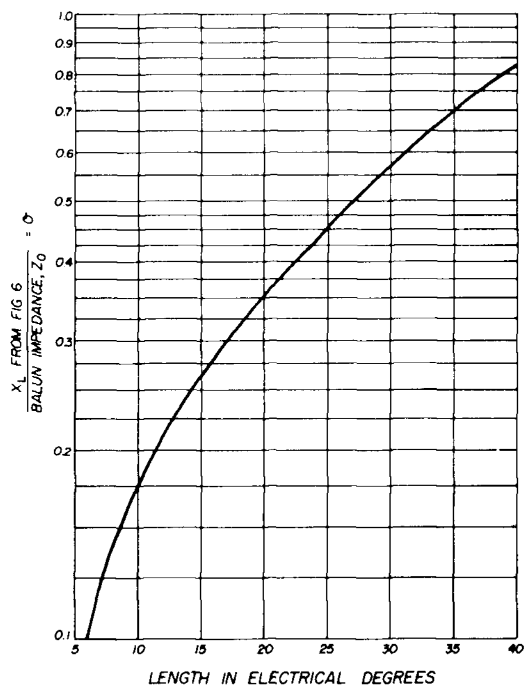
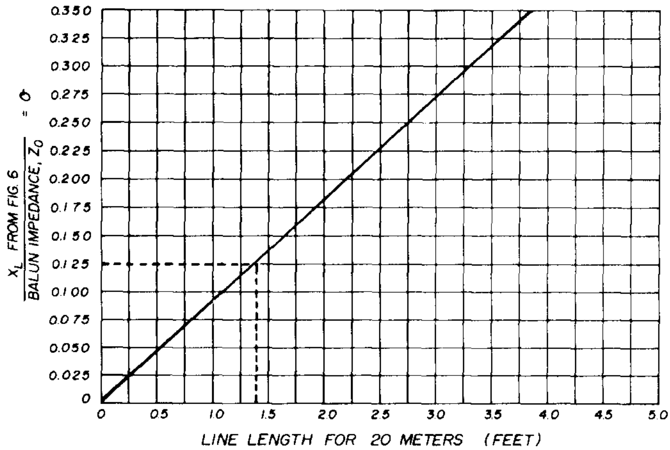


fig. 7. Balun length in electrical degrees as a function of the ratio of the load impedance to the balun impedance (X_L/Z_o).

balun can run parallel to the boom for convenience at a distance of about six inches from the boom. Positioning the balun closer to the boom will necessitate a change in setting. The driven element, for a starter, should be shortened about three inches on each tip (for 20 meters).

The excellence of adjustment is ascertained by running an swr curve across the band, making a measurement every 50 kHz or so. Balun length and driven-element length are then adjusted to drop the swr curve to a 1-to-1 ratio at or near the center of the band. Adjustment is not critical, and if you log your adjustments you will quickly be able to estimate the degree of change necessary to adjust the system "on the nose." Adjustments of balun and dipole length are interlocking, but setting the balun to the length in **fig. 8** for a given value of antenna load and preshortening the driven element a few inches will insure that the starting point is not too far out of line.

fig. 8. Balun conversion chart for 20 meters. Balun length in feet may be determined if resonant antenna load and balun impedance are known. Ratio of these two items is found on y-axis, and balun length is read on x-axis. Chart may be used for other bands (multiply lengths by 2 for 40 meters, divide by 1.5 for 15 meters, divide by 2 for 10 meters, etc.



For convenience the feedpoint impedance of the three-element Yagi beam may be taken as 20 ohms. In fact, it is possible to calibrate balun length versus terminal impedance in the home workshop using a grid-dip oscillator, an antennascope or swr meter and a handful of 1-watt composition resistors of known value. The calibrated transformer balun may then be used backwards, as it were, to determine the feedpoint impedance at resonance of the antenna.

Various adjustable baluns are in use at W6SAI. A permanent one is placed on the beam antenna, and two others are calibrated for use around the shack on experimental antennas. The balun for high frequency work is about five-feet long and has center-to-center spacing of 3 inches. The vhf balun is about the same length (approximately 1½ wavelengths at 144 MHz) with a center-to-center spacing of 1¼ inches. The extra half-wavelength was added to the vhf balun to permit measurements to be made without the operator being in the immediate field of the antenna.

Baluns of this general type may also be used as step-down transformers to match balanced load impedance in the range of 50 to 300 ohms to low-impedance coaxial lines — but that's another story.

references

1. William I. Orr, W6SAI, editor, "Radio Handbook," 18th edition, p. 288, Editors & Engineers, New Augusta, Indiana.
2. Gray and Graham, "Radio Transmitters," Chapter 5, Mc-Graw-Hill, New York,

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