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Baluns in Matching Units

Robert Neece, KØKR

The information presented in this brief essay is not intended to be a comprehensive treatment of baluns. For more complete information on the subject, the reader is referred to the sections of the *Antenna Book* devoted to baluns. The general purpose of the information below, rather, is to alert the reader to special issues that often arise when baluns are used in conjunction with matching units that are also commonly called "antenna tuners."

A more specific goal of the article is to serve as a companion to the document "Comparison Table - Matching Unit Designs" that is also included on the *Antenna Book* CD-ROM. The need for a balun can be deemed a disadvantage of several of the designs listed in the comparison table. It was considered useful, therefore, to provide a few comments, separate from the table, as to the nature of the disadvantage.

In the context of matching units, a balun is often integrated into the matching unit itself. In the alternative, the balun can be inserted into a transmission-line system somewhere between the matching unit and the antenna. The thoughts expressed below apply with equal force to both of these alternatives.

Evolution of Choices Among Matching-Unit Designs

Historically, many matching units were of an inherently *balanced* design. In this context, the word balanced signifies symmetry, or near symmetry, in circuit architecture, usually with respect to ground. Such designs were intended for use primarily with the symmetrical (or balanced) transmission lines that were in widespread use at the time. In Amateur Radio circles, the most common of the commercially built balanced matching units was the venerable Johnson *Matchbox*.

Balanced matching units, such as the *Matchbox*, have largely been superseded in the ham market, although a few such units (which, however, differ substantially from the Johnson circuit architecture) have emerged in recent times. Why did balanced circuits fall out of favor? There appear to be two primary reasons.

First, the typical contemporary transceiver or other RF generator is intended to deliver power not directly into a balanced transmission line but, rather, into an unbalanced (i.e., asymmetrical) line such as coaxial cable (coax). This and other factors have led to the adoption of coax as the standard form of transmission line for radio amateurs. The preponderance of current matching-unit designs (be they commercial or home-brew) have an unbalanced configuration as their essential circuit architecture because it's assumed that the transmission line to be connected to the unit will be coax.

A second important reason, however, relates to choice of antenna. Antenna choice, in turn, is influenced by two opposing but interrelated factors – lack of space available for antenna installation coupled, ironically, with an increased need for such space.

Why the need for more space? One reason is growth in interest in the 160 meter band. During the heyday of the *Matchbox*, regulatory impediments and interference from other radio services rendered the 160 meter band relatively unpopular territory for hams, one that was considered something of a specialty area. Typical ham rigs (and, indeed, the *Matchbox* itself) did not even provide coverage of the band. Today, though, 160 meters has become more of a mainstream band and the preponderance of recent-vintage HF transceivers cover 160 meters.

The physical scale of efficient, resonant, balanced antennas for 160 meters, however, is so great – both in length and needed height above ground – that few radio amateurs are in a position to erect such antennas. As a result, unbalanced antennas have, of necessity, become the norm for 160 meters. Such unbalanced antennas include electrically short loaded vertical monopoles, and other space-adaptive designs, such as inverted Ls. Modern living patterns, moreover, have reduced available residential space enough that electrically short, unbalanced antennas have grown in popularity for 80 meters and other bands, as well.

The *Matchbox*-class of circuits, however, tends to work at optimum efficiency not with electrically short antennas but, rather, with ones that are of not much shorter than resonant length on the lowest frequency of interest. That is, antennas of a length of approximately 0.4 wavelengths, or longer, on that frequency. It happens that, with electrically short antennas, unbalanced matching circuits, particularly the L network, tend to outperform a *Matchbox* design, both in efficiency of power transfer and in matching range.

The important second reason for the movement away from the *Matchbox* and toward unbalanced designs, then, is an assumption on the part of the designer – based on the modern circumstances described above – that the matching unit will need to work well with antennas of significantly shorter than resonant length. That is, antennas of a length less than and often considerably less than 0.4 wavelengths.

<u>Why use a balun</u>?

Although coax has become the predominant form of transmission line, balanced lines (such as ladder line or open-wire line) continue to offer advantages that are addressed in other sections of the *Antenna Book*. As a result of those perceived advantages, balanced lines remain a popular and attractive choice with a variety of antennas. For this reason, the Johnson *Matchbox*, despite having ceased to be manufactured decades ago, remains a popular item, one that can be found in everyday use by many of today's radio amateurs.

But didn't we just say that *Matchbox*-style circuits are not an ideal solution to the need to transfer power to electrically short, unbalanced antennas? Suppose a ham wishes to have the best of both worlds. Suppose the ham wishes to feed a loaded vertical monopole for 160 meters or, perhaps, 80 meters, but also to feed a horizontally polarized 40 meter dipole, both for 40 meters itself and for the higher bands? Such a desire has become a rather common one.

A convenient, versatile solution is to begin with an unbalanced matching unit. That solves the problem of delivering power efficiently to electrically short, unbalanced antennas.

But matching units of unbalanced configuration are unsuitable for use with balanced transmission lines – which work well with a 40 meter dipole intended for multi-band use – without a supplemental circuit intended to create balance. Multi-band matching units, moreover, require such a supplemental circuit to function over a wide range of frequencies.

Enter the *broadband balun*. A *properly designed and constructed* balun circuit permits an unbalanced matching unit to deliver power efficiently into a balanced transmission line. Under modern design practice, the balun tends to be inserted on the output side of the tuner network.

At this point, it is worth noting that, for some years, there has been a vigorous debate as to possible advantages of positioning the balun on the *input* side of the matching unit. See, for example, "A Balanced Balanced Antenna Tuner," by Measures (AG6K), *QST* (Feb. 1990), and "A Balanced, Everyday Approach to All-Band Bliss," by Kleinschmidt (NTØZ), *QST* (April 2002). This article does not undertake to join that debate. Instead, the comments here are intended to alert the reader to balun problems that are apt to arise, to one degree or another, irrespective of where the balun is positioned in the circuit.

The ongoing popularity of coupling an unbalanced matching unit with a balun to satisfy the desire for transmission-line versatility has caused the balun to become a near-universal companion to modern matching units, commercial or otherwise.

Balun Problem Areas

For the reasons described above, baluns are needed. Experience has taught, however, that baluns suffer from a number of persistence frailties. What a conundrum: needed but vulnerable. The existence of this conundrum requires the user to be on alert when purchasing or designing a matching unit that includes a balun.

What are some of the balun's dreaded vulnerabilities? Baluns have proved over time to have the potential to be the weakest link in the overall RF-power-transmission chain. A balun *doesn't have to be* a weak link but, with some loads, the typical balun *tends to be* a weak link. As a result, issues pertaining to balun performance deserve to be considered separately from the particular impedance-matching circuit with which they are used.

Many baluns – especially the compact, toroidal, 4:1 broadband baluns that are often integrated into unbalanced tuners manufactured for the ham market – are apt to suffer from one or more of the maladies listed below. What are some of the circumstances that reveal the frailties in these devices? They include the extremes of the tuner's frequency range, or when the balun is inserted on the output side of the tuner network, or when the balun looks into a particularly high or low load impedance (load Z) – especially impedances with a high ratio of reactance (load X) to resistance (load R). Experience has taught that one or more of the calamities listed below is all too likely to occur in these situations.

1. Voltage breakdown

2. Core saturation – leading to heating, with consequent power loss and possible thermal breakdown

3. Failure to achieve adequate balance

4. Failure to achieve adequate suppression of common-mode currents, with consequent feed line radiation, and related impairment of the radiation and reception pattern of the antenna system with which the tuner is used

5. Failure of so-called broadband baluns to function properly as baluns over a sufficiently broad range of frequencies

<u>Avoiding Problems</u>

To circumvent difficulties with baluns, the careful purchaser or designer would, in an ideal world, seek to perform the tests and measurements listed below. Such evaluations would be made (i) at the maximum power throughput the balun will be expected to handle; (ii) over the full range of frequencies to be covered by the associated matching unit; and (iii) into the range of complex impedances that might be expected to appear at the input of the transmission line to be used.

a. Quantify (i) balun common-mode current, as a function of frequency and the nature of the load; and (ii) balun choking effect as a function of frequency.

b. Assess (i) at what points a balun is vulnerable to voltage break down (e.g., between conductors; between conductor and core; and between conductor and ground); (ii) the conditions under which the break down is apt to occur; and (iii) what might be done to increase the balun's resistance to voltage breakdown.

c. Measure core temperature rise, as a function of transmitting time, and evaluate the effect of that rise in terms not only of the ability of the components to withstand the rise, but also in regard to loss of efficiency of power transfer to the transmission line.

d. Assess (i) the benefits of using two or more – possibly switchable – baluns (e.g., one optimized for 160 meters through 40 meters and another optimized for 30 meters through 10 meters) to increase the overall efficacy of the circuit for balanced loads; and (ii) the degree to which such an approach would be less complex and expensive than resorting to an inherently balanced matching network.

Following the described evaluations, remedies can be adopted accordingly. Remedies might include:

1) Increasing the voltage rating of the insulation on the conductors used in the balun.

2) Increasing the mass, or altering the composition, of the core material used in toroid-wound baluns.

3) Moving from a compact, toroidal design to a larger, air-wound configuration.

4) Moving to multiple baluns, as suggested above, to avoid the vulnerabilities of so-called broadband baluns that are not truly capable of sufficiently broadband performance.

Each of these remedies has one or more negative aspects. Those include increases in manufacturing cost, complexity, unit size, and unit weight. Because the balun has so often proved to be the weak link, however – especially in manufactured matching units – such negatives demand to be weighed against the associated risks that can be avoided or minimized by means of such negative aspects.

It seems, though, that few if any manufacturers or designers proceed with the empirical rigor suggested above. As a result, it behooves the radio amateur to adopt an attitude of wariness and skepticism as to balun performance.

For additional insight into the issues identified above, see "Putting a Balun and a Tuner Together," Schmidt (W9CF), fermi.la.asu.edu/w9cf.