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Factors to be Considered in Creating or Assessing Matching-Unit Designs for the MF/HF Spectrum

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This article sets forth a checklist of factors that should be considered by the designer, builder, or purchaser of any matching unit (more commonly referred to as an "antenna tuner") for the MF/HF spectrum. Before using the checklist, though, an initially pivotal question should be addressed. Because so many decisions in designing, building, or purchasing a matching unit turn upon the answer to this question, it was considered important to provide, by way of introduction, some commentary on the topic. Such commentary is presented in the sections that follow.

General Purpose versus Limited Purpose – Two Competing Matching-Unit Philosophies

In every approach to matching-unit design, the first step should be to address a vital question that seems so often to receive inadequate attention in the literature. What is the question? It's whether it makes sense, in the applications contemplated by the designer, builder, or purchaser, to suffer the galaxy of disadvantages inherent in an "all-band" design. Might it not be better to enjoy the very substantial benefits of a "limited-frequency" design? Let's take a look.

Reasons for the Prevalence of General-Purpose Designs

Many hams seem to assume that an all-band design is universally to be preferred. For this purpose, "all-band" means 160 meters through 10 meters or, in many cases, 80 meters through 10 meters. It is easy to understand the origins of an impression that an all-band design is the preferred solution. The great preponderance of commercially manufactured units happen to be of such design. Most construction articles for homebrew units, too, seem to feature an all-band approach.

It is quite understandable that the all-band/all-load format would be the one preferred by manufacturers. Their goal often is to appeal to the broadest possible market. Because the manufacturer will not know the range of applications the purchaser might encounter, the manufacturer who seeks to maximize his market might well choose to create a product that purports to be all things to all matching-unit situations. One will search in vain, however, for a manufacturer who informs the potential purchaser of the scope of significant *negative* attributes of such a "universal" matching unit.

An important additional factor weighs on the all-band side of the scale. Hams tend to be antenna experimenters. Hams might wish, as well, to be able to feed makeshift antennas for portable or field-day use. Hams, therefore, cannot foresee the full range of antennas they might wish try. Why not have a matching unit that will provide a universal solution to unforeseeable antenna-matching problems? Convenience and versatility surely favor the general-purpose approach.

The Case for the Limited-Purpose Approach

Bearing in mind the considerations outlined in the previous section, we might be inclined to adopt a philosophy that matching units necessarily should be general-purpose devices, ones that are not only all-band items but that are intended also to function with a variety of transmission lines and antennas, as well as extremes of impedance and reactance. This, in fact, would be an unfortunate default philosophy.

It is well, therefore, that the ham need not view the world with the myopia of a market-broadening perspective. An all-band solution might indeed be the correct solution for many users. But it might well not be!

Because they seem to receive too little attention, then, let us consider some theoretical and pragmatic benefits of a limited-frequency approach. These technical advantages are so compelling that it is surprising that more emphasis is not given to them in the literature.

What are some examples of a "compelling" advantage of a limited-frequency design? They include

- Reduction, sometimes by an overwhelming margin, in typical points of component failure
- Improved performance, not only in reliability, but also in efficiency of power transfer
- Vast simplification in construction
- Lower cost – sometimes *much* lower – cost of construction
- Improved ease and certainty of tuning

Taken in combination, these benefits can be great enough to tilt the decision toward a homebrew matching unit rather than a commercially manufactured one, even for a relatively inexperienced builder.

To attain a better understanding of the issues, let's look at just one possible limited-frequency homebrew design. Let's consider a high-pass T-match design (series C; shunt L) for a pair or group of adjacent ham bands. Let's assume that the frequency of the top band in the pair or group is no more than approximately double the frequency of the lowest band in the pair or group. This might be a unit for 80 meters and 160 meters. Or it might mean a unit for, say, 20 meters, 30 meters, and 40 meters.

A T-match circuit satisfying these assumptions can work quite efficiently with only a *single value* of inductance. A fixed value of inductance that is optimal for 40 meters will not, of course, be optimal also for 20 meters. But, within broad parameters, an inductor optimized for 30 meters can function in a high-pass T-match at acceptably high efficiencies also on 20 meters and 40 meters. Thus, matching can be achieved with a wide range of load impedances and reactances by varying only the capacitive components in the circuit. That is, one input capacitor and one output capacitor.

Why is this so wonderful? The answers are that a single value of inductance:

- Avoids one of the most troublesome and commonplace component-failure modes in typical units based upon the T-match circuit
- Simplifies construction of the inductive component of the circuit by orders of magnitude, thereby simplifying overall construction, and component placement, in the complete unit
- Renders it substantially easier and less expensive to produce an efficient inductive component that has a high value of Q and a low percentage of power loss
- Reduces the number of variables that must be managed in tuning the unit, thereby rendering the unit easier and faster to use in practice and less susceptible to power-robbing mistuning

Let's take a bit closer look at the issues of component failure and complexity of construction in the inductive component of a T-match circuit. There are two common means of attaining variability in the inductive component: use of a roller inductor, and use of a tapped-and-switched non-roller inductor. In either case, we're talking about the use of moving parts.

Each of these moving-parts approaches involves contact wear and eventual contact failure. The wiper contacts on a roller inductor are not maintenance free, and tend to lose quality of contact with extended use and age. The same is true of switch contacts in a non-roller variable inductor. It is typical, moreover, for the contact points to be a weak link in the chain. These points tend to have lower power-handling and voltage-handling capacities than does the coil portion of the inductor.

In addition, the Q of a variable inductor tends to suffer at the extremes of the range of inductance. Few, if any, roller inductors maintain a good value of Q at the low end of their inductance range. Similarly, a tapped-and-switched coil will, with each tap, have a different aspect ratio among its windings and, therefore, a somewhat different Q.

Variable inductors, then, can be troublesome – both electrically and mechanically – in ways that do not apply to a single, fixed, un-switched inductor. Plus, the cost and mechanical complexity of variable inductors of either variety is vastly greater than that of a single, fixed inductor. A single-value inductor of excellent electrical quality can be fashioned quite simply and cheaply from ordinary hardware-store copper tubing.

Issues of inductor performance, summarized above, are given merely by way of example. There are many other problems that afflict all-band designs. These tend to become most evident at the frequency limits of the unit. Components having sufficient inductance and capacitance to match a range of impedances on 160 meters tend also to have too much minimum inductance and too much minimum capacitance to permit optimum performance on 10 meters. A unit having such components might well be capable of achieving a *match* on 10 meters, but the match might be made using circuit values that result in very low efficiency of power transfer.

Conversely, components having low enough inductance and capacitance to match a range of impedances on 10 meters with high efficiency tend also to have too little inductance and too little capacitance to permit optimum performance on 160 meters. A unit having such components might be able to achieve a *match* on 160 meters, but the match might be achieved with circuit values that result in very low efficiency of power transfer on that band.

One might then ask: why not switch among different components, some optimized for 160 meters and others optimized for 10 meters? One answer is that the switching system tends to introduce so much stray capacitance and stray inductance that the desired goal is defeated. Another answer is that such an array of components and component values imparts an unwieldy complexity to the unit, and causes costs to balloon beyond practical boundaries.

All of this shows that the trade-offs in moving from a general-purpose T-match to a limited-purpose one should be weighed with care. Similar trade-offs apply to most other circuits. The T-match was chosen merely as one example. Where matching unit circuits of any flavor are concerned, versatility and optimum performance can be very nearly mutually exclusive goals. Versatility tends to equate to compromise, sometimes over-compromise.

Let's put these trade-offs into context. Hams often do not need an all-band matching unit, especially for fixed locations. Hams who have at home a rotatable multi-band beam antenna for, say, 20 meters through 10 meters, might need a matching unit only for, say, a horizontal wire antenna to be used both on 80 meters and 40 meters. Or a ham might have a vertical antenna for 40 meters, but wish to use a horizontal wire antenna for 20 meters through 10 meters. A matching unit might be unnecessary with the former antenna, but indispensable with the latter one. In any of these circumstances, why accept the substantial (sometimes overwhelming) negatives involved in a matching unit of all-band design? Especially since the negatives can often be avoided without practical sacrifice?

As noted above, commercial producers of matching units, owing to marketing considerations, tend to avoid limited-purpose designs. The home designer, however, is not subject to any such business restraint, and should and can – in many situations – seek to avoid the expense and performance issues that afflict "universal" matching units. It's easy to design and build a world-class two-band matching unit. It's not feasible to design and build an affordable world-class unit that not only can cover 160 meters through 10 meters, but also take on all impedances (load Z) and all ratios of reactance (load X) to resistance (load R).

What could be better? Outdo costly commercial units with ease, with economy, and with superior performance!

The ultimate in no-compromise performance, of course, is delivered by single-band matching units. This is especially true of designs fine-tuned for a particular load, that is, to a particular transmission-line-and-antenna combination. A desirable feature of a unit dedicated to a single band is relative freedom from a need for readjustment, except in circumstances of large frequency excursions within the band.

When the operator changes bands, a minimum of attention -- perhaps none at all -- is needed to the tuning controls of a matching-unit dedicated to a single band. This characteristic is of particular benefit to contest operators. Contest-oriented stations often have separate antennas for each band. A matching unit could be expected, then, to remain tuned for a single band. All-band coverage would confer little, if any, benefit. Contest operators, moreover, wish to have the ability to change bands as quickly as practicable. A single-band matching unit adds little, if any, time to the procedure to change bands. In such applications, the performance benefits of a single-band design rise to a predominant status.

A single-band matching unit, though, does suffer from the lowest marks on the versatility scale.

<u>Checklist of Issues -- Matching-unit Design and Construction</u>

Other than those outlined in the previous sections, what factors should the prudent and performance-oriented designer or purchaser consider? See the items on the checklist below.

1. Tuning range of the circuit

    a. in Ω of impedance

        This should take into consideration the high ratios of X to R presented by particular loads at the high and low regions of the Z range.

    b. in f

    In assessing tuning range, it must be recognized that f and Z ranges cannot be determined in isolation but, rather, must be determined in the context of the particular R, X, and Z attributes of the particular load that is presented to the circuit. As a result, a list of strategically chosen examples -- ones that can or cannot be matched -- is apt to be especially useful information in evaluating a tuner's range limits.

2. Suitability of the circuit to various antenna-and-transmission-line combinations

    a. electrically short antennas (as affected by length of transmission line)

    b. resonant antennas (as affected by length of transmission line)

    c. electrically long antennas (as affected by length of transmission line)

    d. appropriateness to

        (1) balanced transmission line

            (a) without a "broadband" balun

                i) degree of balance achievable

(b) with a "broadband" balun

i) degree of balance achievable

ii) susceptibility to common-mode currents

a) degree of choking efficacy as a function of frequency

(See the companion article, “Baluns in Matching Units” on the CD-ROM included with the *Antenna Book*.)

(2) unbalanced transmission line

3. Problem matches for the circuit, e.g.,

a. low-impedance loads, especially ones with high ratio of X to R

b. high-impedance loads, especially ones with high ratio of X to R

c. bands at limits of HF/MF spectrum

d. at or near a 1:1 transformation ratio (e.g., with an L network)

4. Efficiency of power transfer

5. Simplicity/complexity of circuit

6. Simplicity/complexity of construction

7. Cost

a. of components

b. of construction

8. Ease of tuning

a. initially

b. after initial values have been determined

9. Certainty of correct tuning

    a. for 1:1 SWR

    b. for maximum power transfer/efficiency

        (1) with RF current/voltage metering on transmission line

        (2) without RF current/voltage metering on transmission line

10. Issues with components -- needed value ranges; problem areas with particular components; availability

    a. required component value ranges

        (1) for a 10 meters through 160 meters design

        (2) for designs specific to narrower frequency ranges

    b. problem areas with particular components

        (1) does a variable capacitor with sufficient maximum C for the contemplated f or Z range have too much minimum C for the range?

        (2) does a variable inductor with sufficient maximum L for the contemplated f or Z range have too much minimum L for the range?

        (3) if the variable inductor is a roller inductor, does it suffer from inadequate Q at the bottom end of its L range?

        (4) if the variable inductor is a roller inductor, does its frame (and other aspects of its physical package) introduce too much stray C or L for the contemplated f or Z range?

        (5) balun problem areas

            (a) core saturation, heating, power loss, and thermal break down

            (b) voltage break down

                i) between windings themselves

                ii) between windings and core

iii) between windings and ground

(See companion article, "Baluns in Matching Units" on the CD-ROM included with the *Antenna Book*)

c. component availability

(1) are the needed components available in ready-made form, or must they be custom fabricated?

11. Component voltage and current ratings required by the circuit; relative ease of determining ratings

a. if the circuit operates in a resonant condition

This should take into particular consideration the voltage rise that occurs at resonance. At resonance, the voltage across each reactive component in a parallel-resonant circuit equals the product of (i) the applied voltage; and (ii) the loaded Q of the circuit.

b. if the circuit (such as an L network) operates in a non-resonant condition

c. how simple or complex are the calculations to determine the voltage and current ratings needed for various components in the circuit, over an assumed range of loads?

12. Bandwidth of matching, a.k.a "QSY bandwidth"

13. Filter effect (low-pass, high-pass, or band-pass)

14. Concern (or lack of it) over

a. coupling

b. co-efficient of coupling

(These concerns are specific to inductively coupled designs, such as the Johnson Matchbox, and do not apply to the currently predominant network-based designs, such as the L-section, the T-match, or the Pi-network. See companion article, "Comparison Table – Matching-Unit Designs" on the CD-ROM included with the *Antenna Book.*)

15. Need for band switching

16. Need to plug in supplemental L or C, or to change coil sets

17. Degree of change in operating Q with change in load impedance

18. DC issues

    a. isolation (or lack of it) between transmitter and load

    b. static discharge path to ground to protect equipment from buildup of voltage on antenna and transmission line

19. Amenability to auto-tuner applications

    This should take into consideration the need to switch fixed-value components, rather than to adjust continuously variable components. In switching fixed-value components, an infinite SWR can be presented to the source during the switching interval. This SWR condition might occur too fast to permit a response from SWR-protection circuitry in the source, thus exposing the output devices in the source to damage or destruction.

20. Location issues

    a. on-site station use

    b. remote station use

21. Physical-package issues

    a. cabinet size

        (1) Many manufacturers (and, for that matter, many hams) appear perfectly willing to sacrifice performance on the altar of compactness.

        (2) Is a given matching unit roomy enough to comply with F. Terman's rule of thumb that each inductor needs to be spaced at least one-half the coil radius from any other conductors and farther still from cabinet or enclosure walls? (See Terman's *Radio Engineering*)

        (3) Is the inductor, rather, so close to other conductors or to enclosure walls as to cause one or more of (i) substantial diminution in the value of available inductance; (ii) substantial undesirable capacitance; or (iii) excess unintended coupling to other circuit elements? In an inductively coupled balanced design, in particular, circuit balance can be undermined by undue (and, especially, asymmetrical) proximity of the coil pair to enclosure panels. This might tend to explain the relative roominess of the Johnson KW *Matchbox*.

b. weight

(1) Low-loss, high-power roller inductors tend to be heavy, bulky items. This is especially true if the coil-following connection is to be capable of maintaining ultra-low-impedance and reliable contact (able to handle substantial current) over many cycles of rotation. To save weight, bulk, and cost, many manufacturers seem to prefer light-weight (and flimsy) roller inductors.