HF Balanced Transmitting Systems

A compendium extracted from published material

advertised high power levels and other marketing claims, is actually the least expensive to manufacture.

A balanced-balanced tuner, that is, one with a balanced input and output, removes the need for an output balun, and allows the user of common HF radio equipment to place the balun where it belongs - between the transmitter and the tuner -where the impedance ratio is more like 1:1 and the impedance is fairly low so that voltages are for example only about 300 volts at 2000 watts.

At the other end of any tuner, where the feedline and antenna live, the voltage may very well be anywhere from 100 to 7000 volts. Not having to deal with the limitations of a specific balun here is a good thing. One could certainly try an air-wound balun or have two or three purpose-wound ferrite baluns to switch in or out to accomplish the job. But why? -You will never notice the losses in the balun because once you have tuned the tuner up, the SWR seen by your transmitter will be a perfect 1:1!

Transmission Lines:

Either coaxial cable transmission line or parallel-wire transmission line can be used to get the RF from the tuner to the antenna. If the antenna is a dipole, whether horizontal or vertical, it still requires equal drive to each section. A single ended antenna which works against ground may not be as sensitive to balance, but is sensitive to the impedance match to the line.

A transmission line is a perfect impedance match to a wire antenna at only one frequency.

A coaxial cable will drive a dipole, but it will also radiate RF from its shield unless the system is in perfect balance and the impedance of the antenna is matched to the impedance of the line (1:1 SWR). Seldom in real life do we get a SWR of 1:1, and in fact it is not really required to do so, other things being adjusted properly. If the SWR is high, the coaxial cable will suffer localized heating of the dielectric at the voltage nodes, and possibly, heating of the well-insulated center conductor at current nodes. It transforms your power into heat with the operator unaware, even if, on the transmitter's side of the antenna tuner, the SWR meter reads a perfect 1:1.

A parallel-wire transmission line ("Ladder Line") has some advantages over coaxial cables when the line does not match the antenna. In case of the impedance mismatch, the ladder line radiates equally and out of phase from each wire, so that common-mode (unbalanced) radiation is practically eliminated, and it can generally handle the higher voltages because the space between the wires is 1" or more for commonly available line. Dielectric heating is not a real issue because the dielectric is air instead of a plastic substance trapped inside a metal braid. If the mismatch between the ladder line and the antenna is gross enough, it is possible to have current nodes of sufficient amplitude to heat the line at those points. At normal amateur radio power levels, and even somewhat more, this has not proven to be a problem. If an operator is burning up "legal-limit" ladder line, he can build his own from common materials.

Antennas:

Most commonly, a dipole or other balanced antenna will be used for medium range HF. Most of the articles in this compendium therefore pertain to matching dipoles to transmitters. The subject of antennas is so complex and any discussion thereof so laden with digressions that the writer prefers not to comment too much on it! If you want to get started, just loosely adhere to one of the articles on antennas.

W0IYH Feedline Choke Performance

To: <towertalk@contesting.com>
Subject: [TowerTalk] W0IYH Feed line Choke Performance
From: k3lr@k3lr.com (Tim Duffy K3LR)
Date: Mon Aug 18 16:19:16 2003

I posted some of my experience concerning the W2DU type choke performance a few weeks ago. There were several requests for the test data. I retrieved my lab notes taken from my HP Network Analyzer on October 15, 2001.

The W0IYH choke is made from 100 type FB-5622-43 beads on RG-142 with silver plated PL-259's on each end.
The list is test frequency followed by impedance
1.8 MHz 1152 ohms
3.7 MHz 3483 ohms
7.1 MHz 4115 ohms
14.2 MHz 1783 ohms
21.2 MHz 1280 ohms
28.5 MHz 1234 ohms

My tests with the W2DU choke:
1.8 MHz 984 ohms
3.7 MHz 1733 ohms
7.1 MHz 1921 ohms
14.2 MHz 1432 ohms
21.2 MHz 905 ohms
28.5 MHZ 423 ohms

In 100% key down CW tests into a 50 ohm dummy load for 10 minutes I found the W2DU to overheat (individual bead temperature exceeded manufactures ratings) at 500 watts on every band. The W0IYH choke passed the same test at 2000 watts and was well within the temperature specification for each bead. I believe the W0IYH choke has adequate safety factor for 1500 watt stations as long as the VSWR does not exceed 3:1.

There are lots of W2DU chokes in service and as you can see they will work well. The W0IYH design is an improved version. As I indicated in my September 1998 CQ Contest magazine article, I use the W0IYH design at my station. They are on every feed point of every antenna, at the tower mounted stacked antenna RF switch box and at the end of each antenna feed line where it connects to the RF amplifier in the radio room. They keep RF from flowing on the outside shields of the feed lines very well.

If you are interested in ready to go chokes, completed W0IYH chokes are available from Comtek Systems. Please contact them for price and availability.
http://www.comteksystems.com

73,
Tim K3LR
http://www.k3lr.com

between unity ratio and squared impedance as turns are increased, depending on mutual coupling between turns.

A string of 43 material beads 36 inches long has the same common mode impedance as a stack of 43 cores 1 inch tall with 6 turns of coax. The string of beads will handle more power, because it has more surface area exposed directly to cooling air no matter how thick the beads are (beyond a certain limit).

The more stress the balun has, the lower the ui of the core you should use. At the feed point with high power, a low-ui low-loss-tangent core is generally best, like air or a 61 material. This is especially true if the feedline parallels the antenna, or if the element is off balance, or if the element impedance is high.

In a coaxial line connected the normal way near the shack (like in the second chokes K3LR uses), a string of 73 material beads would almost certainly be acceptable no matter what the power level.

The feedline should be grounded to the tower or another ground as soon as possible after the balun, only on the side of the balun closest to the shack if possible.

I use air chokes, or 61 material cores at transmitting antennas. I use 73 or 75 material cores for receiving and in-the-shack or "down the cable a distance" isolation.

73, Tom W8JI
w8ji@contesting.com

An Inexpensive, High-Performance, Ugly 50ohm Air-Wound Balun

Building a no-grief 1.8MHz to 30MHz 50ohm-balun is easy. No costly ferrite-cores are needed, just a short length of 3 to 5 inch size plastic pipe, about 25 feet of 50ohm coax plus some nylon cable ties. Solid-dielectric coax is best for this application because foam-dielectric has a tendency to allow a change in the conductor to conductor spacing over a period of time if it is bent into a tight circle. This can eventually result in voltage breakdown of the internal insulation. The required length of the plastic pipe depends on the diameter and length of the coax used and the diameter of the pipe. For RG-213/U coax, about one foot of 5 inch size pipe is needed for a 1.8MHz to 30MHz balun. For 3.5MHz to 30MHz coverage, about 18 to 20 feet of coax is needed. This length of coax is also adequate for most applications on 1.8MHz. The number of turns is not critical because the inductance depends more on the length of the wire (coax) than on the number of turns, which will vary depending on the diameter of the plastic pipe that is used. The coax is single-layer close-wound on the plastic pipe. The first and last turns of the coax are secured to the plastic pipe with nylon cable ties passed through small holes drilled in the plastic pipe. The coil winding must not be placed against a conductor. The name of this simple but effective device is a choke-balun.

Some people build choke-baluns, without a plastic coil-form, by scramble-winding the coax into a coil and taping it together. The problem with scramble-winding is that the first and last turns of the coax may touch each other. This creates two complications. The distributed-capacitance of the balun is increased and the RF-lossy vinyl jacket of the coax is subjected to a high RF-voltage. The single-layer winding on the plastic coil-form construction method solves these problems since it divides the RF-voltage and capacitance evenly across each turn of the balun.

A more compact, less ugly, 1 to 1 impedance-ratio, 50ohm trifilar-wound (with wire) ferrite-core balun could also be used but there would be some tradeoffs. Ferrite cores are not cheap. Also, the air-core of the coax-balun can't saturate like the ferrite-core and, unlike ferrite-core wire-wound baluns, single-layer wound coax-baluns almost never have an insulation breakdown problem. Also, a trifilar-wound balun does not like to work into anything but a perfectly balanced load. With an imperfectly balanced load, the coax-balun will not, as does the trifilar balun, generate a differential, third RF-current on the outside of the coax that brings the RF to the input of the tuner. The choke-balun is not fussy. It will work as well into a less than perfectly balanced load as it will into a perfectly balanced load, and do so without the possibility of creating a differential RF-current on the station ground and fricasseeing the operator's fingers.

C-31XR Feedline Choke

Subject: C-31XR Balun ...
Author: John Petrich <petrich@u.washington.edu>
Date: 13-Jan-2001 20:39:50

Hi Greg,

Thanks for the reply and comments about baluns. It is good to share ideas with people who make observations and have ideas.

Yes, I am familiar with the W1JR balun and have used it in some applications. It was good 30 years ago, it is still good today. The only reason that it is not as popular as it once was, is that the bead baluns are easier to construct and harder to goof up on. There may be a small advantage in terms of bandwidth for the bead baluns. In some applications, bandwidth is very important. In other applications, bandwidth is really not important at all.

I know what you mean about unrecognized balun heating. So many baluns are located up at the antenna feed point and the heating is only discovered after the balun has failed. Antennas can be properly constructed yet it is of major importance to pair the balun, the antenna and the band of operation correctly to avoid balun heating and unwanted feedline radiation. Feedline radiation isn't always a problem. Wanted feedline radiation can make for a useful antenna i.e. G5RV.

Balun heating is the result of common mode currents flowing on the outside of the coax shield. These currents are then dissipated in the real component of the complex common mode impedance characteristic for that balun. There is no other source for heating for the ferrite beads. This heating problem occurs just the same way and for the same reason with all ferrite baluns, whether they are constructed with ferrite toroids or ferrite beads. The phenomenon is the same. It is interesting, if you carefully examine an overheating bead balun, the beads closest to the high impedance connections are the warmest. The beads closest to the low impedance connections are the coolest. It is as if each little bead functions as an individual little attenuator element. The entire stack of ferrites does not act like a resistor. The power from the common mode current is not dissipated uniformly as it would along a purely resistive element.

There are two independent factors that contribute to common mode current flow and the resultant risk of balun heating:

1) INSUFFICIENT COMMON MODE IMPEDANCE TO CHOKE OFF COMMON MODE CURRENT FLOW: Anytime, repeat "anytime", one of these 800 ohm common mode impedance bead baluns is connected across a high impedance load, such as a 80 meter doublet excited on 40 meters, there is the risk of severe balun overheating. The same goes for trying to operate a old style tribander on 17 or 24 meters with a ferrite balun. Low power operation won't heat the balun, BUT, the common mode current is still flowing, and the system could be operating at a disadvantage. This limitation from the balun's common mode impedance in a high impedance environment is BY FAR THE MOST SIGNIFICANT FACTOR that contributes to bead balun overheating. High power makes the heating problem easier to recognize. Low power doesn't cause as much heating but the system may not be functioning in an ideal manner. But, "everything works." A better solution for a balun in a high impedance environment is to use one of those coiled coax or "Badger", baluns. This particular style of balun is capable of exhibiting extremely high common mode impedance values if properly constructed and tested for the frequency of use. Just like an old antenna tuner of years gone by.

2) FERRITE MIX: Yes, ferrite mix can make a difference, but don't get overly excited on this one. Any importance that ferrite mix has on balun heating is not because one mix is "better" than

another, or one mix is "worse" than another. The reason that ferrite mix can contribute to balun overheating problems is because of #1 above- Insufficient Common Mode Impedance. The Force-12 balun, I'm guessing, acts like a string of #43 mix ferrite beads. The Maxwell, W2DU, bead balun uses a string of #77 mix ferrite beads. The Force -12 balun has a good peak common mode impedance from 40 meters to 10 meters. The Maxwell bead balun has a useful peak common mode impedance from 160 through 15 meters. There is substantial overlap for both and both are good. The Maxwell balun might not have enough common mode impedance on 10 meters and overheat in some 10 meter applications. The Force 12 balun might not have enough common mode impedance for a 160 meter installation and overheat in some applications on that band. I haven't actually tested each balun side by side in the antenna situations I have referred to but I am extrapolating from their common mode impedance curves.

The key to reducing balun overheating probably lies with pairing up the antenna (and it's feed point impedance), and band of operation, with a balun having sufficient common mode impedance to choke off common mode current flow. The standard of comparison between "current mode" baluns is their measured common mode impedance at the frequency of use. Some "current mode" baluns have low common mode impedance compared to other baluns. I have only tested the Force-12 and Maxwell baluns and they exhibit common mode impedances of about 800 ohms. Unfortunately, the various manufacturers never publish the common mode impedance characteristics of their baluns. I think that it is very hard to get common mode impedance values greater than 800 to 1000 ohms using low Q type #43 and #77 ferrites. Maybe I don't know enough, so take that statement with a grain of salt. One can get relatively high common mode impedance by coiling coax on a higher Q #61 ferrite toroid. The air coiled coax, "Badger, balun or an old fashioned antenna tuner will give the highest common mode impedance values that I know of.

Let me know your thoughts, Greg.

John Petrich, W7HQJ

"No costly ferrite-cores are needed, just a short length of 3 to 5 inch size plastic pipe, about 25 feet of 50ohm coax plus some nylon cable ties.

Solid-dielectric coax is best for this application because foam-dielectric has a tendency to allow a change in the conductor to conductor spacing over a period of time if it is bent into a tight circle. This can eventually result in voltage breakdown of the internal insulation.

The required length of the plastic pipe depends on the diameter and length of the coax used and the diameter of the pipe. For RG-213/U coax, about one foot of 5 inch size pipe is needed for a 1.8MHz to 30MHz balun. For 3.5MHz to 30MHz coverage, about 18 to 20 feet of coax is needed. This length of coax is also adequate for most applications on 1.8MHz.
18 to 21 feet should cover all of 160 through 10 meters.

The number of turns is not critical because the inductance depends more on the length of the wire (coax) than on the number of turns, which will vary depending on the diameter of the plastic pipe that is used. The coax is single-layer **close-wound** on the plastic pipe.
The first and last turns of the coax are secured to the plastic pipe with nylon cable ties passed through small holes drilled in the plastic pipe.
The coil winding must not be placed against a conductor.
The name of this simple but effective device is a choke-balun.

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The problem with scramble-winding is that the first and last turns of the coax may touch each other. This creates two complications. The distributed-capacitance of the balun is increased and the RF-lossy vinyl jacket of the coax is subjected to a high RF-voltage. The single-layer winding on the plastic coil-form construction method solves these problems since it divides the RF-voltage and capacitance evenly across each turn of the balun"....AG6K

Credit for this article goes to **AG6K, Rick Measures** and was edited from a Pre-copy version of another article titled
"A BALANCED - BALANCED ANTENNA TUNER" published in QST,February,1990

Related opinion:
"For 6m (50MHz), use a PVC pipe approx. 3" diameter with 5 turns of RG-213 co-ax cable. "

For The G5RV Antenna

From the MFJ manual:

BALUN REQUIREMENT

The G5RV is a balanced antenna fed with a balanced 450 ohm line that terminates in a SO-239 connector. When feeding this antenna with an unbalanced line (such as coaxial cable), it is a good idea to use a 1:1 choke BALUN at the coax to feed point connection. The balun will reduce or eliminate parallel currents on the outside of the coax shield. This will prevent or reduce RFI, RF feedback, RF burns, and other effects of excessive RF in the station.

The best balun for this antenna is an **air-core choke balun**. Avoid using other types of baluns, such as ferrite sleeve or transformer type baluns. This antenna has a high reactive component at the feed point SWR of more than 2:1. The high SWR increases loss in ferrites and may cause excessive core heating, core
saturation, or arcing in the windings.

AIR WOUND BALUN CONSTRUCTION

The air wound balun required for this antenna can be constructed by winding the coaxial feed line cable in a single layer solenoid coil with at least 10 turns of 4 to 6 inch diameter. The turns can be taped or secured by nylon cable ties. The balun can be wound on PVC pipe or any other non-metallic form. Place the balun immediately at the feed point connection. The feed line shield should not be grounded on the antenna side of the balun.

WARNING: The balun should be kept away from any conductive material!

Antenna tuners are like shovels. It takes more than one kind of shovel to be able to efficiently perform a variety of jobs. For example, a snow shovel isn't suitable for digging holes in hard ground. A tiling spade could be used to shovel snow, but it wouldn't be very efficient. Similarly, no single antenna tuner circuit can do everything extremely well.

A balanced load tuner should be designed, from the ground up, for the job that it is intended to perform. This article describes a circuit that does a good job of feeding an open-wire transmission line [ladderline]. It is not intended to be used for unbalanced loads such as a coaxial transmission line or for end-fed, Marconi or Hertz antennas - although it seems to be capable of doing so. Now that we have nine amateur radio bands below 30MHz, an open-wire transmission line, center-fed wire, all-band antenna system looks even more attractive than it did when it first came into popular use in in the 1930s. In those days, we had only five bands below 30MHz. Taking advantage of this versatile antenna system requires a box that will interface the 50ohm unbalanced output of today's transceivers to the highly variable impedance [Z] of the balanced feed points of the all-band antenna .

Contemporary antenna tuner circuits claim to be able to operate into an unbalanced load or a balanced load such as ladderline. In actual use, most of the contemporary "matches everything, balanced or unbalanced" antenna tuner circuits produce a semi-balanced output when used with a balanced load. Although the antenna will radiate in this situation, a semi-balanced output is like having a semi-balanced checking account. It is less than wonderful.

A look at the diagram for the contemporary "matches everything" antenna tuner circuits reveals that they are usually unbalanced, high-pass filter characteristic, T-Network circuits with an add-on balancing device hooked to the output of the unbalanced tuner circuit. This is a compromise design which, not surprisingly, also has compromise performance when used with a balanced load.

The imbalance in these "balanced" tuners can be easily confirmed with a RF voltmeter or RF amperemeter(s). When the actual current or voltage is measured at each output terminal, the observed imbalance gets progressively worse above about 7MHz. At 28MHz, it is not uncommon to have 50 more current or voltage in one of the legs than in the other leg.

Some may ask: "why not use the balanced tuner design that was in vogue in the 1930s?" As many of you old-timers know, the 1930s-era balanced tuner consisted of a resonant or near-resonant, center link-coupled, tank-circuit with movable-clip taps on the secondary. For each band change, the clip taps had to be moved and re-optimized, the total inductance changed and the tuning capacitor re-tuned. Changing bands was a labor intensive job. These ancient tuners were seldom built in enclosures because near constant access to the clip taps and the inductor(s) was a necessity for changing frequency. It was a common practice to build these tuners on a breadboard for maximum accessibility. Hence the name breadboarding.

In the 1950s, the E. F. Johnson Company came out with their Matchbox® series of balanced antenna tuners. These tuners used the same center link coupling arrangement as the earlier tuners, but they eliminated the movable clip arrangement by using a double-differential capacitive voltage divider across the tank inductor. A differential capacitor is the RF-equivalent of a potentiometer / DC voltage-divider. This allowed the operator to electrically increase and decrease the voltage fed to the antenna, without changing taps. The Johnson circuit worked, but the Z-matching range was severely limited. Frequently, the SWR could not be reduced to a satisfactorily low level.

The balanced tuner that is described in this article has two, front panel adjustments, one optional, hi-Z / low-Z switch, and no clips. It uses the rarely seen, balanced version of the familiar, unbalanced, L-network. Changing bands is a piece of cake with this balanced tuner and the matching range can be made very wide by using enough L and C to handle the job.

The Trouble With Baluns

On paper, an unbalanced tuner, feeding a balun, connected to a ladder-line fed antenna should work well. In practice, it does not work well. The reason for this lies in the balun.

As a rule of thumb, a balun should have about 4 times as many reactive ohms as the resistive ohms of the load. This means that for use with a 600ohm balanced load, the balun should have a secondary winding reactance of about 2400ohm. For 80 meter operation, this works out to be more than 100µH of balun inductance! To create this much inductance on an appropriate MF/HF-rated [µ=40] ferrite core, an impracticably large number of turns of wire would be required.
The use of a balun, in a high-impedance circuit, inevitably creates two, very sticky problems: More turns means more ampere-turns of magnetic flux in the balun's core, and high magnetic flux densities can cause the ferrite-core to saturate. This distorts the RF waveform and creates harmonics. These harmonics extend well into the UHF TV band. The remaining problem with using many turns of wire is that doing so increases the winding-capacitance of the balun. The high capacitance of the winding creates unwanted reactance and/or balun imbalance. This is especially true with the commonly used 4 to 1 bifilar-wound balun, which does not have an evenly distributed winding capacitance like the trifilar-wound balun. When enough turns are placed on the 4 to 1, bifilar balun for satisfactory 80 meter operation, the inherent capacitive imbalance in the balun causes a progressively greater imbalance in the output voltage of the balun as the operating frequency increases. This imbalance causes a differential RF-current to flow through the ground wire on the tuner. The name "4 to 1 balun" is a misnomer. They are much better suited for broadband, unbalanced-to-unbalanced 4 to 1 transformer service such as would be needed in the input circuit for a grid-driven Class-AB1 amplifier, whose grid terminating resistance was 200ohm.

There is a problem with a substantial current flowing in the ground wire on any tuner: Since ALL conductors, no matter how wide, have inductive reactance, the RF current that flows through the ground wire or strap can develop a large RF-voltage on the tuner-end of the ground wire. With 1000W on 21MHz, 24MHz or 28MHz, the RF voltage on the "matches everything" tuner chassis can brilliantly light a neon-lamp, make sparks with a graphite pencil and burn fingers.
The 1 to 1, trifilar-wound balun solves the capacitive imbalance problem of the 4 to 1 balun. Unfortunately, it does not solve the problem of high capacitance in the windings themselves. And, more importantly, it does not solve the problem of core saturation due to the high magnetic flux-density created by the large number of turns required for any high-impedance balun.
The bottom-line is: high-impedance baluns are a very likely source of GRIEF no matter how carefully they are engineered and constructed.

All of these problems are easily avoided. The solution is simple: don't put the balun in the highest-impedance part of the circuit. Instead, put the balun in the lowest-impedance part of the circuit, and build a balanced L-network tuner for the balanced output of the low-impedance balun. So, why have we been putting the balun in the wrong part of the circuit for these many years? Good question. In most cases, the lowest-impedance part of the circuit is the 50ohm coax input to the antenna-tuner.

The Versatile L-Network

The L-network is THE basic RF-resistance or reactance plus resistance (impedance) [*Z*] transformation tool. It is also used to build high-pass, low-pass and band-pass filters. The imbalanced L-network forms the basis for all of the antenna tuners that are currently being sold. All contemporary amplifiers use two, or more, L-networks in series to match the high, anode (plate)-resistance of the amplifier-tube to the low-resistance of the coaxial output. Most amplifiers use (2) L-networks in series, which is more commonly known as a Pi (Pi)-network. A few amplifiers use (3) L-networks in series, which is called a Pi -L-network. "No tune-up/broadband" amplifiers may use 5 (or more) fixed L-networks in series for each bandswitch position. More L-networks means more harmonic-suppression in the output of the amplifier. The complex-appearing Butterworth and Chebyshev filters are nothing more than a series of basic L-networks.

When used for matching resistive loads, an L-network consists of one capacitor and one inductor. When the L-network is used for matching loads that contain both resistance and reactance (Rohm +/- jXohm = Z), the reactance of the load may partially or sometimes completely replace one of the reactances in the L-network. Thus, in rare cases, it is possible to build an L-network with only one component, but only for a specific frequency and load Z. In some situations, cancelling the load reactance will require the use of a larger reactive component in the L-network. In more extreme situations, the load may be so reactive that the L-network must be made from two capacitors or two inductors!

There are four ways to connect the capacitor and the inductor in an L-network. See Figure 1A. When inductance is used for the series-reactance and capacitance is used for the shunt-reactance, the L-network acts as a low-pass filter as well as a resistance matching device. When capacitance is used for the series-reactance and inductance is used for the shunt-reactance, the L-network acts as a high-pass filter and a resistance-transformation device.
The resistance-matching range of the L-network is remarkably wide. It can match 50ohm to a 1ohm or to a 10Kohm load with ease and good efficiency provided that a reasonably high-Q inductor is used.

When the L-network is used for stepping up the input R, the shunt-reactance is placed across the load. For stepping down the input R, the shunt-reactance is placed across the input of the L-network. Another way to look at it is: The shunt-reactance is always connected across the highest-resistance side of the L-network. This means that, for a 50ohm input, wide-range tuner, which will match loads of more than 50ohm and less of than 50ohm, a step-up/step-down [Z] switch must be provided so that the shunt-reactance can be switched to the input side for <50ohm loads and to the output side for >50ohm loads. The same result could be accomplished by reversing the input and output connections. The switch saves time.

The T-network eliminates the need for the step-up/step-down switch by using a clever tool from AC circuit-analysis. This tool is based on the fact that, for every R-X series circuit, an equivalent R-X parallel-circuit may be calculated and substituted for the series-circuit. The equivalent circuit will act exactly the same as the original circuit. This also works in reverse.

See Figure 1, B. An additional capacitor or inductor is placed in series with the load of a resistance step-up L-network which will not normally match a load resistance that is lower than the input resistance (usually 50ohm). If the added series capacitor or inductor is adjusted so that it has a sufficiently high reactance, the resistive component of the R-X series load's parallel-equivalent circuit will be above 50ohm and the step-up L-network will be able to match the load. For example: Given: a Z step-up, series-L / shunt-C {low-pass filter characteristic}, L-network, that will only match load resistances that are greater than 50ohms, is connected to a 1ohm load.

Problem: Obtain a Z-match.

One solution is to add a +j10ohm (inductive) reactance in series with the 1ohm load { Z = 1ohm + j10ohm} This series RX circuit is electrically equivalent to a parallel-circuit of R=101ohm in parallel with an inductor whose reactance is plus j10.1ohm. Since a load resistance of 101ohm is above 50ohm, a match could be achieved if minus j10.1ohm is added to the L-network's shunt capacitor in order to cancel the parallel equivalent circuit's +j10.1ohm.
Adding more capacitive reactance to a variable capacitor is easy: simply adjust the capacitance to a lower value. This is clearly a case where less [C] gives more [ohms]!
The Balanced L-Network

The L-networks shown in figures 1A and 1B is designed to work with an unbalanced input and an unbalanced load. The balanced L-network is similar to an unbalanced L-network. The difference is that the balanced L-network's series-reactance is divided into two equal parts and both ends of the shunt-reactance must be well insulated from ground instead of one end being grounded. See Figure 1, C. The balanced L-network must be fed from a balanced source. The same formulas are used for either network.

Mechanical Considerations For Balanced L-Networks:

The tuning shafts of the variable-inductors and the variable-capacitor are hot with RF voltage and must be insulated from each other and from the outside world. Also, the insulated frame of the variable-capacitor should be kept well away from any grounded surface. This requirement is much easier to meet if the balanced tuner is built in a polyurethane-varnished plywood-box, instead of in a metal box. The (RF-hot) frame of a single-section variable capacitor should be elevated on standoff-insulators. This helps to keep the circuit capacitively balanced.

If a split-stator variable capacitor is used, it won't be necessary to insulate its tuning shaft for high-voltage RF, or to keep the capacitor well away from ground. However, an insulated tuning knob with a well recessed set-screw, instead of an all-metal tuning knob, might prevent an unpleasant surprise to the operator's fingers if the split-stator capacitor proves to be less than perfectly balanced.

The variable-inductors must have equal inductances and be driven in synchronization by one tuning-shaft. It is possible to end to end-couple the two variable-inductors with an insulated coupling that can handle minor, axial, shaft misalignment, but this does not result in good electrical symmetry or optimum inductive de-coupling between the two variable-inductors unless a shaft extension is used. Good symmetry is probably a moot point for 80 meter operation but it is a consideration on the higher-frequency bands. If you decide to use end-to-end coupling, there is a material, which is available in stores that carry drip-irrigation materials, which is ideal for end-coupling RF-components. The material is called clear (actually translucent) 1/4 inch size,polyethylene drip-tubing. It is semi-rigid and solves the axial shaft alignment problem and RF insulation problems nicely. It is a very-tight fit over 1/4 inch shafts. It can be held in place with 5/16 inch size flat spring-clamps.

Another method of coupling the variable-inductors is to use a 3/8-inch plastic timing-belt and two plastic timing-belt pulleys like the type used on xerographic copiers. This allows the variable-inductors to be placed side-by-side which results in better layout symmetry. One single-flange timing-pulley and one double-flange timing-pulley should be used so that the belt can not slip off. Small flats can be ground into the variable-inductor's tuning shafts so that the pulley set-screws will stay put.

The ends of variable-inductors that have a coil-end contact that is electrically connected to their tuning-shafts should be connected to the lower-voltage, input side, of the balanced tuner. This minimizes the RF-voltage stress on the insulated parts that synchronize and drive the variable-inductors. The roller-contact must be shorted, across the un-used turns of the inductor, to the low-voltage end of a variable-inductor. This is done to stop the Tesla-coil transformer-effect which can cause spectacular HV RF-arcing at some L settings. The courser-turns-pitch ends of variable-turns-pitch variable-inductors is placed at the (higher voltage) output side, of the tuner.
Sometimes it is more convenient to put the balanced L-network antenna tuner in a remote location so that the ladderline does not need to be brought through the wall of the house. A simplified diagram of a remote-controlled, permanent-magnet {reversible}, DC motor-driven tuner is shown in Figure 2. This simplified diagram does not show the detailed wiring of the control cable and the remote indicator/control-box/power supply.

Limitations

The balanced L-network that is illustrated is designed to work with balanced or semi-balanced loads that have a resistance greater than 50ohm. The vast majority of open-wire transmission-line fed antennas fit into this category. Rarely, it is possible to have a situation where an open-wire transmission-line fed antenna would have a resistance of less than 50ohm. This would be the case with a half-wavelength dipole, less than one-quarter wavelength above ground, that is fed with a transmission line that contains an even-number of quarter-wavelengths.
If a load resistance of less than 50ohm is to be successfully matched, the variable-capacitor must be switched to the input side of the variable-inductors, or, as in a T-network, a matched-pair of appropriate reactances can be inserted in series with the load to obtain a match.

Since the actual feedpoint Z at the bottom of a ladder-line fed, multi-band antenna, can be almost anything imaginable, it is probably prudent to include a DPDT Z-step-up / Z-step-down switch in the design of a balanced L-network antenna tuner.

Calculating The Series And Shunt Reactances

The formulas for calculating the total series-reactance [Xser] {in +/- j ohms} and the shunt-reactance [Xsh] {in +/- j ohms} are shown in Figure 3. These ohmic values can be converted into actual values of capacitance and inductance for a specific frequency by using the two formulas at the bottom of Figure 3. Since most hams do not have access to an RF Z-Bridge, the formulas are not widely used.

The reactance formulas give exact values only for non-reactive, purely-resistive loads. If the reactances of the L-network are adjustable, a wide range of load reactances can be cancelled by adjusting the L-network to create an equal and opposite reactance. This is accomplished by tuning the L-network for zero reflected power while using a minimum power level.
The shunt and series-reactances, in ohms, that are found with the formulas can be either inductive or capacitive, but they must always be opposites for resistive loads. If a high-pass filter characteristic is desired, as is frequently the case on 160 meters where a strong, local, broadcast-station would otherwise cause receiver overload problems, the series-reactance is capacitive and the shunt-reactance is inductive.

If an L-network is to be used on just one band, only one of the two reactances usually needs to be variable in order to obtain a low-SWR over the entire band. A good use for this technique is with a half-wave antenna for the 160 meter or 80 meter band. This antenna would otherwise have a low-SWR at the middle of the band and a 5 to 1 SWR at the band edges. With a single variable component L-network tuner, the SWR will usually be less than 1.1 to 1 at the band edges. Of course, if both components are made variable, the SWR will not exceed 1 to 1.
If a band-pass filter characteristic is needed for a specific single-band operation, a high-pass L-network can be coupled to a low-pass L-network with each network contributing about 1/2 of the total resistance transformation. When this is done, only one of the 2-stage L-network's four reactances usually needs to made variable to allow covering the entire band with a low-SWR. I use this circuit in a 160m tuner. It keeps the local broadcast stations from overloading my receiver, and it attenuates the second harmonic, on 80m, to -63db.

Selecting a Suitable Peak Voltage-Rating For The Capacitor:

The RF-peak-voltage that appears across the capacitor varies widely depending on the feed-line Z and the power level used. The voltage can be calculated if the impedance and power at the feed-point are known. The formula for calculating this is $E= [P \times Z]^{0.5}$. Since P is measured in RMS-watts, the AC voltage (E) result will be in RMS-volts which can be converted to peak-volts (e) by multiplying the result by $2^{0.5}$. For example, if Z=600ohm and P=1500W, $e= [1500W \times 600ohm] *2^{0.5}$ =1341v peak.

When using a vacuum variable-capacitor, it is important to realize that the maximum RF peak-voltage rating at 30MHz is usually 60% of the rated DC / 60Hz peak-voltage rating. Thus, a "5000V" rating translates to a 3000 peak RF-volt rating.
Used or new-surplus vacuum-variable capacitors should be tested before use because they may have developed a small air-leak that renders them useless.
Constructing Ladder-Line:

Commercial open-wire transmission-lines seem to use #18 gauge copper wire exclusively. Although #18 gauge copper wire is completely satisfactory for use in transmission-lines that do not carry a high SWR, it is not adequate for the combination of high-power and very high-SWR that is the norm for multi-band-use antenna systems.
Number 14 gauge solid-copper wire is better suited for this application. High-quality, #14 gauge, 2-wire transmission-line does not seem to be commercially available so it must be constructed by the user.

For use in an open-wire transmission-line, solid-wire is better than stranded-wire because it will not twist as easily as stranded-wire and short-out. The exception is the top few inches of the transmission-line, at the center-insulator, which should be fine-stranded for flexibility. Copper-weld wire is not only dangerous to eyes when it is being handled and cut, it is too springy and unruly for use in a transmission-line. It also prematurely becomes brittle due to normal wind movement. Number 14 gauge, TW, single-conductor solid-copper house wire is commonly available in 500 foot rolls where building materials are sold. It affords a good compromise between strength and stiffness. The insulation can be removed by fastening one end of the wire to a stationary object and horizontally pulling a sharp knife between the copper and the insulation

of the stretched out wire. TW wire can also be used for the antenna itself if some support is provided to hold up the center-insulator and transmission-line of the antenna.

High RF-quality, lightweight, long-lived, inexpensive and easy to fasten feedline insulators can be made from ABS thermoplastic. If you can find it, 3/8-inch ABS rod-stock or, as a second choice, 3/8 inch ABS square-stock works well. Rod-stock has the advantage of having less wind resistance. These materials can be found or at some of the larger plastic-supply houses. If you have a color choice, black is usually the most UV-resistant color. If you can't find the rod or square stock, the insulators can also be made from commonly available ABS plumbing pipe. ABS-pipe must first be heated and flattened. This is how: Cut the ABS pipe length-ways into halves or thirds with a table-saw. The lengths should be about the same as the width of a Teflon-coated cookie-sheet that will fit into your oven. Since ABS is a thermoplastic that melts at 150ºC, the oven temperature should be set to 180ºC [350ºF]. The 1/2 or 1/3 round sections of the pipe are baked, concave-side down, on the cookie-sheet until they begin to soften. The oven is opened and a sheet of plywood, weighted with a brick, is placed on top of the pipe sections. When the ABS is flat, it is set aside to cool-down.

ABS sheet is cut, on a table-saw, into strips about 3/8-inch wide and 3 inches to 6 inches long. Or, the rod-stock is cut into appropriate lengths. The ends of these insulators are notched to a depth of 1/4 inch with a hack-saw or band-saw whose saw-cut width is less than the width of the #14 gauge solid copper wire. The lengths of the insulators is not at all critical since the characteristic Z of the ladder-line will change only slightly between 3 inches and 6 inches spacing. The main consideration is that the wires do not short out.

The space between insulators is normally about 5 to 10 times their length. For example, 6 inch length insulators would normally be spaced about 30 to 60 inches apart. No more insulators need to be used than are necessary to prevent feedline twisting and shorting-out.

The ABS insulators can be securely fastened to the bare copper wires thusly: Clamp both parallel wires, spaced appropriately, into a vise. Stretch the wires out straight and fasten the other end of the wires to a post. With a flame from a propane-torch, heat the wire at the place where an ABS-insulator is to be fastened. When the wire is hot enough to melt the ABS, press the wire into the notch on the insulator. The heated wire will melt its way to the bottom of the notch in the ABS. The wire should be held in this position for about 15 seconds while the thermoplastic cools-down and re-hardens, which traps the wire. A damp rag can be used to speed up the cool-down time. Notes: This operation can be done with two hands but it is much easier and faster with four hands. The wire must not be too hot or it will cause the thermoplastic to decompose and/or ignite. The useful life of ladder-line in windy areas can be extended if a Dacron-cord or braided Dacron fishing line tether {or tethers} is fastened to an insulator about half-way up the ladder-line. The tether is pulled sideways to form an angle of 45º and fastened to a stationary object. The tether prevents the feedline from whipping around in the wind which would otherwise eventually cause the wires to break. Two or three tethers, fastened to the same feedline insulator, spread about 120º apart work better than one.

Parts

A source of variable-capacitors and variable-inductors is Cardwell-Multronics Corp. (631) 957-7200
"http://www.cardwellcondenser.com/index.html"http://www.cardwellcondenser.com/index.html
They manufacture the old, E. F. Johnson line of 5 ampere [229 series] and 10 ampere [226 series] variable-inductors. Their P/N for an 18µH, 5a, variable-inductor is 229-0202-1. The 28µH version's P/N is 229-0203-1. These P/Ns are the same as E. F. Johnson's old P/Ns.
Another source for variable-inductors is occasionally Fair Radio Sales, 419 227 6573. Fair Radio also has a few sizes of variable capacitors and a ceramic, HV, RF-switch that is capable of switching the variable-capacitor on the balanced L-network between the output of the variable-inductors, for high-resistance loads, and the input of the variable-inductors, for low-resistance loads. The P/N of this switch is 3Z9626 and the price is $2.50.

Maintenance Note

Variable-inductor roller-bars and other sliding RF-contact surfaces should be routinely wiped clean with a lint-free cloth and re-lubricated about once a year. A suitable lubricant is GC Electronics Tunerlub, "high-frequency lubricant", Catalog #26-01. This material must be applied thinly with a lint-free cloth. More is not better.
Source of cogged belts and pulleys: Small Parts, Inc.,13980 NW 58 Court, Miami Lakes, FL 33014, telephone [305] 751 0856

The part numbers [p/n] for the 40-tooth pulleys are TBPN - 40S [single flange] and TBPN - 40/D.[double flange]. At least one of the two pulleys should be double flanged to prevent the belt from slipping off during use. The outside diameter of 40-t pulleys is 2.78". For 30-tooth pulleys, change the number after the dash from '40' to '30'. The outside diameter of a 30-t pulley is 2.14". Either 30-t or 40-t pulleys may be used but the belt does not have to bend as sharply on 40-t tooth pulleys.

The belt length equals the desired distance between the two roller coil drive shafts x 2, plus the circumference of one pulley. The belt-contact-surface circumference of the 40-t pulleys is 40/5=8" and the circumference of the 30t pulleys is 30/5=6". Thus, if the coils will be mounted 5" apart [shaft-shaft] and 40-t pulleys are used, the belt-length needed would be 5" x 2 = 10" plus 8" = 18" [p/n TB6-180]. The belt-length part of the p/n is the 2nd and 3rd digits from the right. Belt lengths from 6" to 26" are available in 1" increments.

The price of an 18" belt is $5.50 in my old Catalogue #10. The price of 40-t pulleys is under $7.00 each. The price of 30-t pulleys is under $6.00 each. I assume that the prices have probably increased.

A Note on Balanced L-Network Tuners

Reference has been made to the AG6K balanced L-network tuner in February, 1990, QST. The scheme, which uses two rotary inductors "belted" together plus a single output capacitor across the line, holds considerable promise as an alternative to single ended networks with a 4:1 antenna-side balun transformer, since it is inherently balanced. A 1:1 balun on the transmitter side effects the required transition to the tuner's balanced circuits.

Unfortunately, the article appeared before the ready availability of calculational programs to see what happens along a transmission line and comparable calculation programs to check the efficiency of various matching network values. Hence, the write-up does not show a full appreciation of a number of factors involved in impedance transformation networks and transmission line impedance transformations--hence, this note.

First, the article refers to the Johnson Matchbox differential capacitor-divider antenna side circuit as a voltage divider. Actually, in the Matchbox, it operates as an impedance transformer, allowing transformation of the line impedance (with compensation for reactance at that point) to the optimal value possible for the secondary parallel tuning circuit. Since the capacitor-divider is continuously tunable, it avoids stepped values inherent in coil taps and allows matches on upper bands where the coil taps would fall under the primary link.

More significantly, the article refers only to antenna impedances, finding most of them to be above the 50-ohm transmitter line value. While this is true, it does not reflect what appears at the antenna terminals of the ATU. Where the antenna impedance is above the 50-ohm mark and there is considerable reactance (as there would be on many multi-band antennas at numerous frequencies of operation), the impedance presented to the ATU is for much of each 180 degrees of feedline very low--often considerably less than 50 ohms. The lengths of lines yielding these values are often the most stable in terms of reactance change per unit of line (and hence less susceptible to variation due to wind, rain, ice, etc.).

It is therefore important that a good balanced network be able to tune low impedances as well as high. Hence, for the tuner shown in the article, it is advisable to be able to change the capacitor position to the 50-ohm side of the line.

However, the plot thickens. For some values of reactance at the ATU terminals, when combined even with a low resistance, one will have to use the normally up-converting mode of placing the capacitor on the output side.

Moreover, some combinations of resistance and reactance yield network values whose delta (loss factor) is greater than 20. What this indicates is that the L-network is not always highly efficient.

An alternative is the PI-network, which is 2 Ls back-to-back, where the two series coils become 1 (and then become 2 again as we make a balanced network from them). However, the required values of capacitance can vary widely, and I recommend that both the input and output sides use a high and low value of C, switchable for each occasion--and able to be switched out to make an L-network with the C at either end. The reason for this move is that sometimes the L-network is the more efficient; sometimes the PI is the more efficient.

How can we tell? The best operational way is with an output indicator of reasonable sensitivity for the power level used. Use the network configuration that both gives a match and yields the highest power output from the ATU.

To get some reasonable idea of when which is better, you can run a series of simulations on the ZL1LE transmatch calculator within the HAMCALC collection from VE3ERP. It will provide network values for virtually any of the major network types (PI, CLC, LCL, L), along with loss-factor (delta) figures. The Transmission Line Performance program will provide tables of values for any input impedance resistance/reactance combination of any kind of line you want to use for every 5 degrees down 180 degrees of line--and you simply find how long your line is in terms of excess length to increments of 180 degrees (1/2 wl) to see what length to check on. Or, you can inspect the tables to see what lengths yield the most stable (slow rate of change of R and X to the next 5-degree mark) values.

Balanced networks with a 1:1 transmitter-side balun are effective in overcoming the problems inherent in single-ended networks with 4:1 output baluns. However, making a match is only half the battle. Making that match one that efficiently transfers power to the load (rather than eating it) is the other half of the battle. If you design a balanced network tuner, design for efficiency as well as a match. Operationally, the power output indicator (relative voltage or relative current) is still a much overlooked but crucial check on our system performance. All too often we assume so much about what happens past the SWR meter when we should be measuring instead.

I hope this proves useful to some.

-73-

LB, W4RNL

The Balanced-L Network

L. B. Cebik, W4RNL

The demise of the link-coupled antenna tuner has left a hole in the array of available antenna tuners. The link-coupled tuner had been the mainstay among tuners for handling antennas that present a wide range of impedance values to parallel transmission line and required--ideally--a balanced coupler to coincide with the transmission line balance. The multi-band doublet, the horizontal or vertical multi-band loop, and a host of phased arrays come to mind as antennas that achieve the greatest efficiency with a balanced antenna tuner. However, as of this writing (12-2002), despite some initial hope, no maker has come forward with a commercial link coupled tuner to replace the long-gone U.S. Johnson MatchBox or the German Annecke ATU.
The single-ended network--including the PI, T, and L--is inherently unsuited to matching the impedances of such antennas, as presented to the ATU terminals, to the standard 50-Ohm unbalanced outputs of current transmitting and receiving equipment. Placing a 4:1 balun at the output terminals of such tuners has always been a source of concern, since the impedance at the terminals may be highly reactive, a condition unsuited to many balun designs. As well, the terminal impedance may also be low as the line transforms the impedance continuously along each half-wavelength, and a 4:1 balun only succeeds in making it lower.

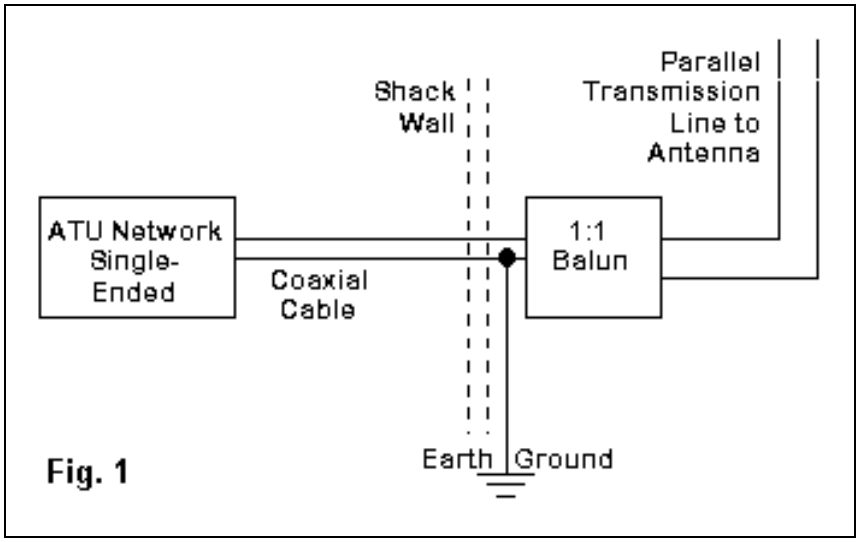
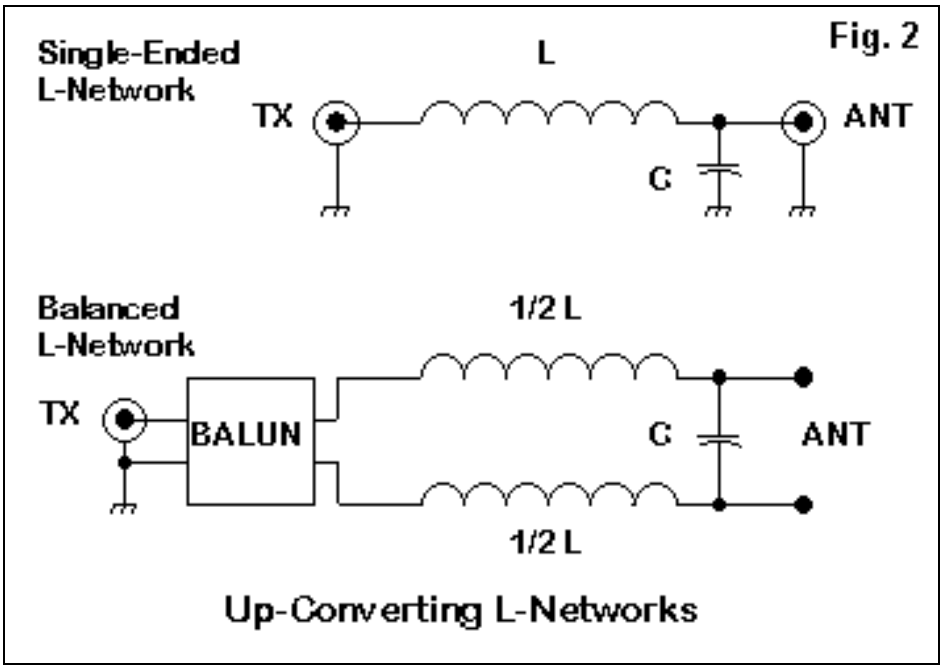


Fig. 1

A 1:1 choke balun has been used with some success. As **Fig. 1** shows, placing this choke-balun at the shack-entry point can serve two purposes. A. It converts the balanced line input to an unbalanced condition by essentially suppressing currents that would otherwise flow on the outside of the coax braid. B. It permits the installation of a good earth ground at the shack-entry point, which has some advantages for safety and for further isolation of equipment from common-mode currents.

However, the advantages come at a price. The SWR on the coax inside the shack remains in many cases very high. The losses in this line due to SWR increase with both frequency and the length of the line and function as a multiplier on the basic loss per unit length of the coax line selected. The keys to minimal inside line loss are then to use as short as feasible a length of coax from the entry-point to the tuner and to use the lowest-loss coax that one can obtain. Even at

QRP power levels, using a large diameter, low-loss length of coax for this run is extremely advisable.



Recent times have seen the development of balanced network tuners. **Fig. 2** shows a comparison between the single-ended L-network and its balanced counterpart, set up here for up conversion and in a low pass configuration. (A down conversion L-network would place the capacitor at the input side of the network. A high- pass configuration would use series capacitors and shunt or a parallel inductor.) The values required for converting a single-ended network to a balanced network are in the aggregate the same as those for the single-ended network. However, the inductors in the lower part of the figure are in series, so each has 1/2 the value of the required single-ended inductor.

The capacitor, as shown, represents the total capacitance required across the network output to effect a match for a given impedance condition. With a single capacitor, we cannot place an earth ground at the line center as an aid to effecting balance between the two legs of the transmission line. In most, but not all, practical applications, this ground is not necessary. However, should we wish to implement such a line-centered ground, we may change the capacitor to a split-stator type and ground its common. Since the two halves of the capacitor must in series yield the required total capacitance for a match under given output terminal conditions, each half of the capacitor must have twice the capacitance of the single unit shown in the figure. This requirement results in large capacitors, especially where high power and high voltage across the plates might be anticipated. The vastly increased space requirements (or cost requirements for one who purchases such a component) generally has led designers to use single-section capacitors.
The 1:1 balun in the balanced L-network appears at the input side of the network, between the balanced L and the line connector for the transceiving equipment. Except for brief periods during initial tune-up, the balun operates under ideal or close to ideal conditions, that is, with 50 Ohms resistive at its output terminals. Hence, most standard trifilar or bead-choke 1:1 balun designs operate at very high efficiency levels.

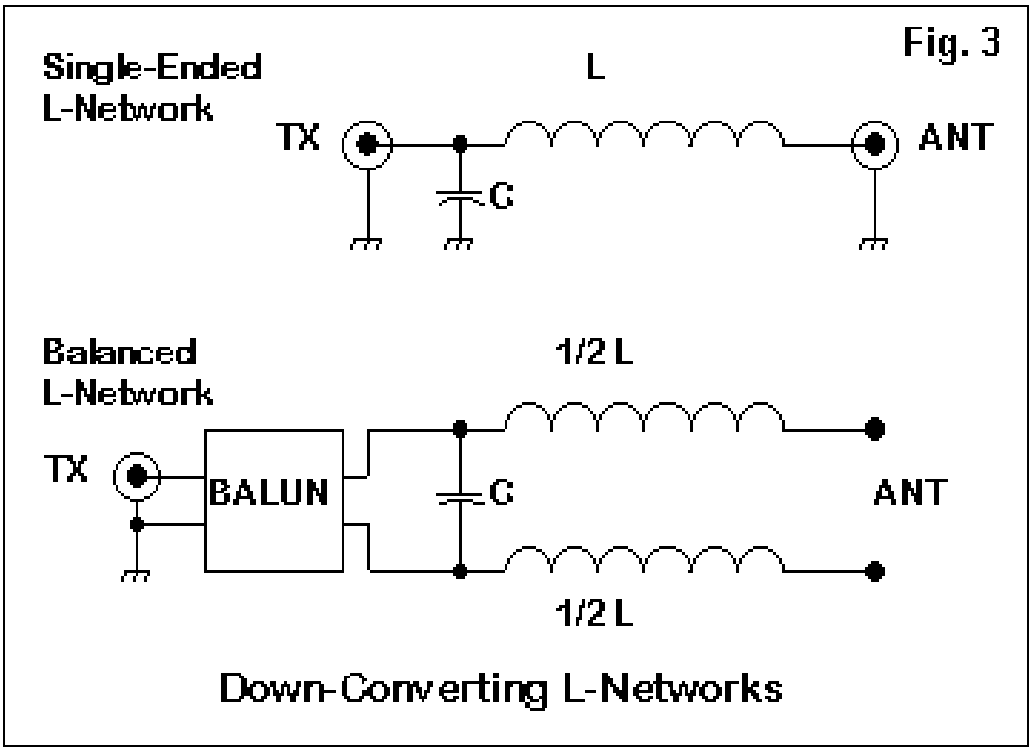
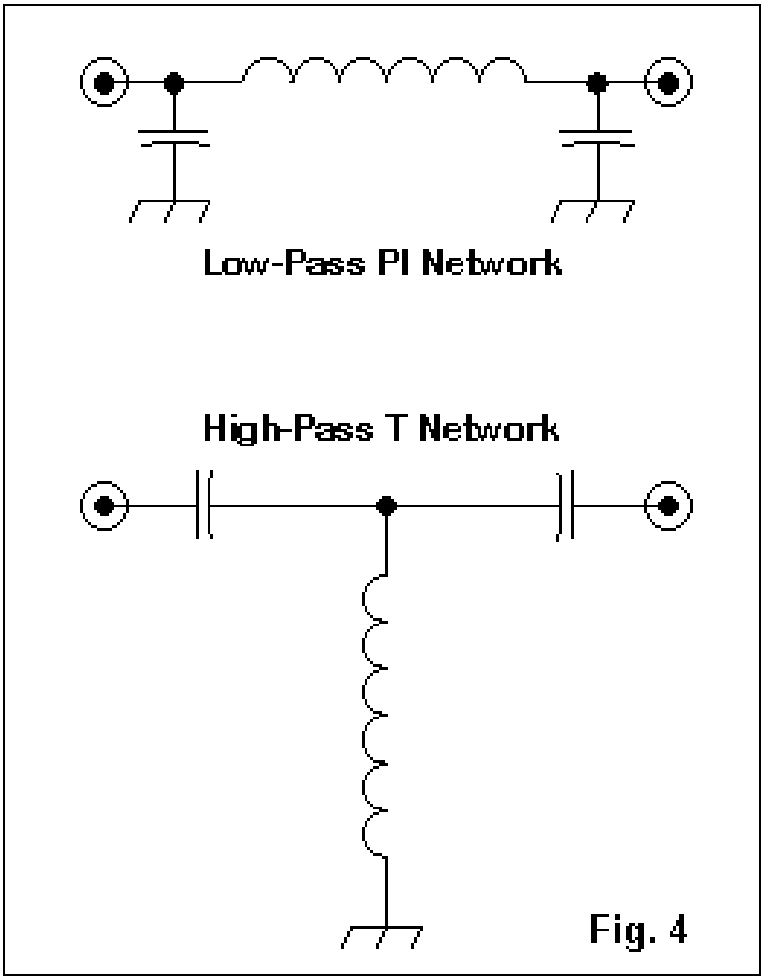


Fig. 3 shows the balanced L-network--and its single-ended counterpart--set up as a down converter using a low-pass configuration. If we had used a high-pass configuration, with series capacitors and a parallel or shunt inductor, we would achieve a circuit identical to that of the beta or hairpin match. The hairpin match achieves its shunt inductive reactance with a shorted transmission line stub instead of a "lumped" inductor. Otherwise, all of the principles applicable to the up-converting L also apply to the down-converting L, whether single-ended or balanced.
Balanced L-Networks vs. 3-Component Networks

Commercial implementations of the balanced L-network are beginning to appear. In general, they are offered in preference to balanced PI-networks and balanced T-networks. **Fig. 4** shows the general outlines of both of these 3-component networks in single-ended configurations. The PI is a low-pass configuration, while the T is a high-pass configuration.



The 3-component network offers a distinct advantage over the L-network. One may effect a match on a given frequency for any "in-range" impedance without switching a component from the output to the input side of the network (or vice versa). As well, one may even effect a match for a 50-Ohm resistive load at the antenna terminals of the tuner. In most cases, the user does not know what the load impedance is, and the ability to tune any load within the overall tuner range is a convenience.

However, we pay a price for the convenience. For virtually any load impedance, the L-network has lower losses than the T or PI. We may define a factor for any of the networks and call it (following Terman) delta. In recent times, we have come to refer to the factor as the network Q or the working Q of the network. For the L-network,

Delta = SQRT ((Ri/Ro)-1)

where Ri is the network input impedance and Ro is the network output impedance.

By itself, delta is simply a number. However, the network losses are directly related to the ratio of delta to the unloaded Q of the network components. In most--but not all-cases, the limiting component Q is that of the inductor. Maintaining a low loss network of any type requires that we uses network components with the highest possible unload values of Q.

Maximum and Minimum Component Values

For up-conversion, the maximum component values are all feasible, even on 160 meters. However, for down-conversion, the lower the impedance, the greater the chances for requiring a capacitance value that exceeds practical implementation as a standard-construction high-voltage air-variable capacitor. A 3000-pF, 5-kV or higher air-variable is a very large unit, indeed.

The inductor--with respect to maximum required component values--is not a problem. The table lists the total for the 2 series inductors, so each inductor requires only half the total. A pair of inductors, each with a 20 uH maximum value, would easily handle the required load.

The troublesome part of the patterns of required component values concerns minimums. The values given are--in a practical circuit--the sum of the component values and any stray capacitances and inductances within the overall ATU unit. The minimum capacitance available is partly a consequence of capacitor construction. Many capacitors--especially military surplus units found at hamfests--use heavy frames with full size end plates and even bottom plates that cover most of the bottom of the capacitor. Such units may have a minimum capacitance of up to 30 pF for a maximum capacitance of 150-200 pF. In contrast stand the E. F.Johnson (later, Cardwell) high-voltage units that have small trapezoidal end plates and a bar running the length of the unit to connect the end plates and permit mounting. For the same maximum capacitance, the minim is only 12-15 pF. Even better are some current designs that use non-conductive end plates and front-to-rear bracing bars. Their minimum value may be as low as 8-9 pF. Some capacitors also use plate-shaving techniques to further lower the minimum capacitance.

However, minimum capacitance is not solely a function of the capacitor structure. The plates and other components of the network may be at a different potential from each other, from nearby leads, and from the metal ATU case. In all of these instance, we have a level of capacitance that we cannot eliminate with redesign of the circuit and the overall unit. The simplest way to tell if a case is introducing stray capacitance is to remove it and check the ATU settings under very low power and otherwise controlled test conditions.

As the basic table shows, minimum inductance can be a major limitation in down conversion. All is not lost in this regard, even if the minimum inductance that we can obtain is higher than the required component value. Down conversion tends to be very broad-band, and one can obtain usually a match to within less than 1.5:1 50-Ohm SWR, a useful if not perfect value.

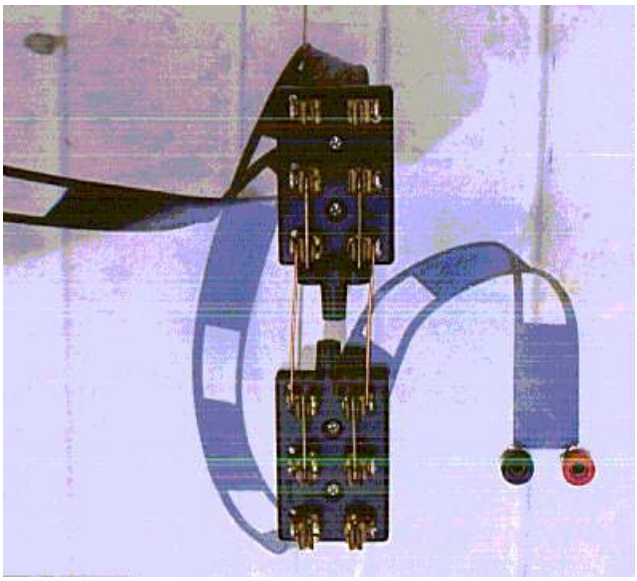
Adding to the series combination (additive) of the two inductors in a balanced L-network is the inductance of the leads. The more complicated the switching-- whether we are switching in a fixed capacitor to achieve a high value or switching the capacitor from the output to the input end of the network--the more likely we are to find stray inductance that raises the minimum value that we may obtain. A secondary problem associated with stray inductance within an ATU is the fact that is usually has a low unloaded Q. Hence, the loss level of the circuit rises.

The appropriate countermeasures, of course, include a detailed inspection of the circuit to see if one can redesign component placement to keep leads as short as feasible. With large components designed for high power duty, we can do only so much in this arena. We can also try replacing the case with a non-conductive case. To a large measure, any radiation from an ATU is a function of linear leads that do nothing to confine the fields that surround them. Hence, it is a bit of a gamble to move to a non-conductive case. However, it is worth a try. If the radiation is too high and eludes efforts to reduce it, then one can simply use a larger case within which we try to center the network components, that is, we try to keep the network components well-spaced from the case walls.

Reactive Loads

We have based our initial survey of the conditions under which a balanced L- network must operate on resistive loads. As a general guide, let's look at some sample cases of reactive loads. In **Table 2**, we shall examine some high- and low- impedance loads, each impedance having a 45-degree phase angle. Hence, we shall match 100 Ohms resistance with +j100 Ohms and with -j100 Ohms. In addition, we shall only look at 160, 80, and 10 meters, the HF frequencies likely to represent the limits of an ATU that we might construct.

Here are the ten DPDT switches mounted on a piece of plexiglas that mounts in W5DXP's hamshack window. It shows the ten DPDT switches with the one foot, two feet, and four feet loops installed. The eight feet and 16 feet loops are not installed yet in this picture. RF flow is right to left from banana socket set to banana socket set. When installed in the hamshack window, the switches are on the inside and the loops of ladder-line are on the outside.



Here's a close up view of the one foot section. The RF flow is right to left into the banana sockets. The switches are shown in the shorted position, i.e. the one foot loop is floating completely out of the circuit to avoid capacitive effects. The bare copper wires in the center are the short. When the switches are thrown into the other position, the one foot loop is inserted into the circuit and the short is completely out of the circuit. This is the cleanest mechanical configuration W5DXP could think of but there might be a better way.