HF Balanced Transmitting Systems

A compendium extracted from published material

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Coupling The Transmitter To The Aether

Because the improvised antenna may be of random length, it may not resonate at the operating frequency. Under non-resonant conditions, the antenna will exhibit reactance. Even if the antenna is resonant, it may not present a 50-Ohm load to the transmitter.

The antenna tuner can solve these problems. The type of antenna used for short and medium range HF work is usually an NVIS or inverted-V dipole. Such an antenna requires balanced currents in each leg in order to preserve a good radiation pattern.

For these reasons, a ***system*** can be implemented, composed of a 1:1 balun can be placed between the transmitter and a balanced antenna tuner, and a balanced feedline (ladder line) placed between the tuner and the balanced (dipole) antenna. The balun converts the unbalanced output of the transmitter to a balanced feed for the tuner and the tuner adds the proper reactances to cancel the antenna's reactance and also transforms the 50-Ohm transmitter output impedance to the impedance presented by the antenna.

Baluns:

Ferrite-core baluns are RF transformers or autotransformers designed to convert an unbalanced signal to a balanced one. Within reason, the same ferrite core balun can be used over a wide frequency and impedance range. Unfortunately, wide variations of the impedance can cause problems since the inductance of the windings may become inappropriate for the voltages impressed upon them. FC baluns are best used where the impedance fluctuations over the tuning range are limited.

Feedline chokes ("baluns") are designed to keep common-mode RF current (the unbalanced product of an imperfectly balanced system) from flowing on, and radiating from, the outside of the coaxial cable. In general, they are made by placing a number of ferrite beads on the outside of the coaxial cable. The beads serve as an RF choke. The disadvantage of this scheme is that when the impedance is not well-matched, the beads dissipate large amounts of power due to common-mode currents on the cable. This power is wasted. If the transmitted power is high enough, the beads can become heated to the point of exceeding their temperature rating at which point the magnetic properties are changed.

Coaxial air-core chokes (baluns) are also designed to both provide a balanced signal and keep unwanted RF from flowing on the outside of the feedline. The object is accomplished by the inductance presented by the physical arrangement of the coaxial cable as well as the winding of the cable in such a manner that it resembles a coaxial transformer. In common practice the cable is wound on the outside of a form of 4" to 12" diameter. Anecdotal reports indicate that the number of turns and diameter of the winding is not as important as the length of the cable used in the winding, but a small number of scientific measurements indicate that all of these factors are of some importance. The disadvantage of these devices in HF use is that the voltage could become so great as to break down the insulation in cases of severe mismatch and very high power levels.

Tuners:

Antenna tuners can serve several purposes. First, to cancel out the reactive component of the non-resonant antenna, second, to match the remaining resistive load presented by the antenna to the load the transmitter expects, and thirdly, a proper design can suppress unwanted harmonics.

Many designs exist for tuners, and most commercial tuners have an unbalanced input and an unbalanced output. As a convenience, a ferrite core balun is sometimes included in the tuner to convert the tuner's unbalanced output to a balanced one suitable for driving an open-wire parallel feedline ("ladder line") to which a dipole antenna is connected. This kind of tuner, despite 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

Multi-Turn Coaxial Air-Wound Balun Measurements

Ed Gilbert eyg@hpnjlc.njd.hp.com *Mon, 12 Aug 1996 08:40:24 -0400*
Hi Pete,
My experience is that PVC works fine as a form for high Q RF coils. I've measured Qs of up to 450 on loading coils wound on PVC pipe.
I've appended a paper I wrote on measurements of coaxial baluns wound on
PVC forms.
73,
Ed Gilbert, WA2SRQ
eyg@hpnjlc.njd.hp.com

Having access to a Hewlett-Packard 4193A vector impedance meter at work, I have made measurements on a number of baluns, coaxial and otherwise. For my beams I was particularly interested how many turns and on what diameter are optimum for air core coaxial baluns, and what the effect of bunching the turns was (formless). Using the remote programming capability of the HP4193A along with an instrument controller, I measured the magnitude and phase of each balun's winding impedance at 1 MHz intervals from 1 to 35 MHz. For comparison, I also made measurements on a commercial balun which consists of a number of ferrite beads slipped over a short length of coax. I've appended some of these measurements so you can draw your own conclusions.

PVC pipe was used for coil forms. The 4-1/4 inch diameter baluns were wound on thin-walled PVC labeled "4 inch sewer pipe". This material makes an excellent balun form. It's very light weight and easy to work with, and I obtained a 10 foot length at the local Home Depot for about 3 dollars. The 6-5/8 inch diameter forms are 6 inch schedule 40 PVC pipe which is much thicker, heavier, and more expensive.

Each test choke was close-wound on a form as a single-layer solenoid using RG-213 and taped to hold the turns in place. The lengths of cable were cut so there was about 2 inches excess at each end. This allowed just enough wire at the ends for connections to the HP4193A's probe tip. After data was collected for each single-layer configuration, the PVC form was removed, the turns were bunched together and taped formless, and another set of measurements was taken. I have only included the "bunched" measurements in the table for one of the baluns, but the trend was the same in each case. When compared to the single-layer version of the same diameter and number of turns, the bunched baluns show a large downward shift in parallel self-resonance frequency and poor choking reactance at the higher frequencies.

Interpreting the Measurements

All the baluns start out looking inductive at low frequencies, as indicated by the positive phase angles. As the frequency is increased, a point is reached where the capacitance between the

windings forms a parallel resonance with the coil's inductance. Above this frequency, the winding reactance is reduced by this capacitance. The interwinding capacitance increases with the number of turns and the diameter of the turns, so "more is not always better".

The effects of a large increase in interwinding capacitance is evident in the measurements on the balun with the bunched turns. This is probably a result of the first and last turns of the coil being much closer together than the single-layer coil.

An important requirement of these baluns is that the magnitude of the winding reactance be much greater than the load impedance. In the case of a 50 ohm balanced antenna, the balun's winding impedance is effectively shunted across one half the 50 ohm load impedance, or 25 ohms. A reasonable criteria for the balun's winding impedance for negligible common mode current in the shield is that it be at least 20 times this, or 500 ohms. The measurements show, for example, that 6 turns 4-1/4 inches in diameter meet this criteria from 14 to 35 MHz.

The measurement data also reveals the power loss these baluns will exhibit. Each of the measurement points can be transformed from the polar format of the table to a parallel equivalent real and reactive shunt impedance. The power dissipated in the balun is then the square of the voltage across it divided by the real parallel equivalent shunt impedance. While this calculation can be made for each measurement point, an approximate number can be taken directly from the tables at the parallel resonance points. At 0 degrees phase angle the magnitude numbers are pure resistive. I didn't record the exact resonance points, but it can be seen from the tables that the four single-layer baluns are all above 15K ohms, while the ferrite bead balun read about 1.4K. These baluns see half the load voltage, so at 1500 watts to a 50 ohm load, the power dissipated in the coaxial baluns will be less than 1.3 watts, and the ferrite bead balun will dissipate about 13.4 watts (neglecting possible core saturation and other non-linear effects). These losses are certainly negligible. At 200 ohms load impedance, the losses are under 5 watts for the coaxial baluns and 53.6 watts for the ferrite beads.

Conclusions

- A 1:1 coaxial balun with excellent choking reactance for 10 through 20 meters can be made by winding 6 turns of RG-213 on inexpensive 4 inch PVC sewer pipe.

- For 40 or 30 meters, use 12 turns of RG-213 on 4 inch PVC sewer pipe.

- Don't bunch the turns together. Wind them as a single layer on a form. Bunching the turns kills the choking effect at higher frequencies.

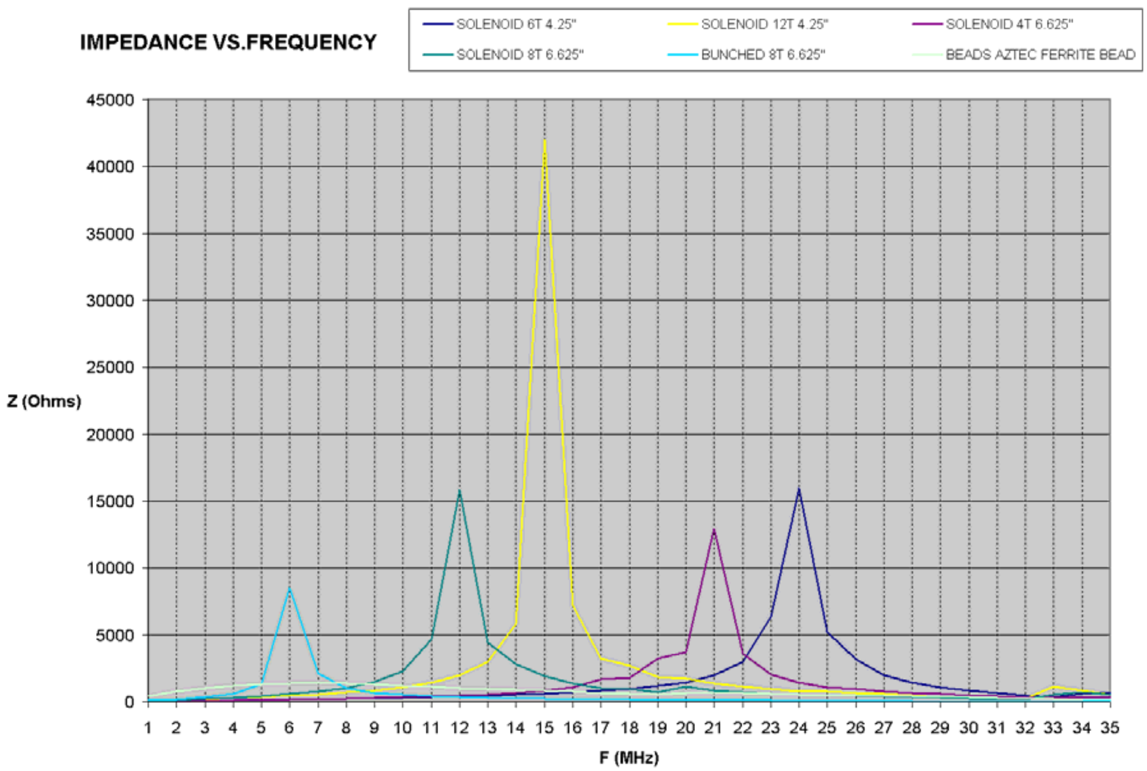
- Don't use too many turns. For example, the HyGain manuals for my 10 and 15 meter Yagis both recommend 12 turns 6 inches in diameter. At the very least this is about 3 times as much coax as is needed, and these dimensions actually give less than the desired choking impedance on 10 and 15 meters.

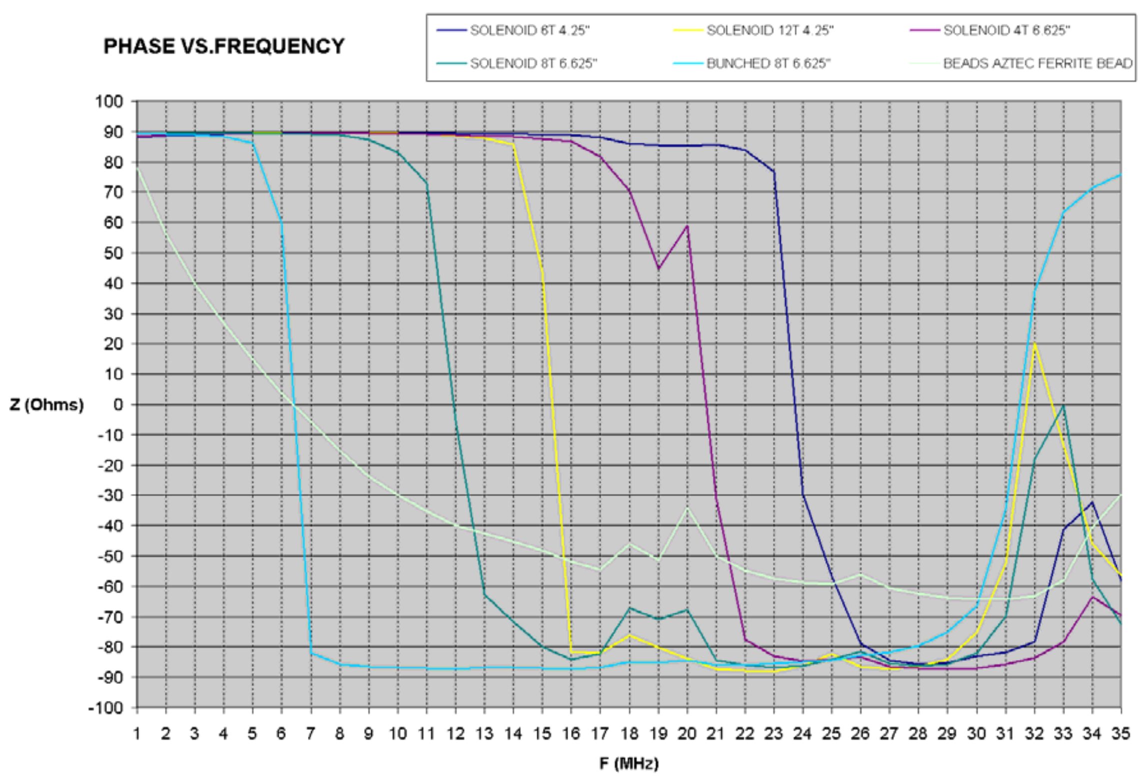
Measurements

Magnitude in ohms, phase angle in degrees, as a function of frequency in Hz, for various baluns.

	6 Turns 4-1/4 in sngl layer		12 Turns 4-1/4 in sngl layer		4 Turns 6-5/8 in sngl layer		8 Turns 6-5/8 in sngl layer		8 Turns 6-5/8 in bunched		Ferrite beads (Aztec)	
Frequency	Mag	Phase	Mag	Phase	Mag	Phase	Mag	Phase	Mag	Phase	Mag	Phase
1.00E+06	26	88.1	65	89.2	26	88.3	74	89.2	94	89.3	416	78.1

2.00E+06	51	88.7	131	89.3	52	88.8	150	89.3	202	89.2	795	56.1
3.00E+06	77	88.9	200	89.4	79	89.1	232	89.3	355	88.9	1046	39.8
4.00E+06	103	89.1	273	89.5	106	89.3	324	89.4	620	88.3	1217	26.6
5.00E+06	131	89.1	356	89.4	136	89.2	436	89.3	1300	86.2	1334	14.7
6.00E+06	160	89.3	451	89.5	167	89.3	576	89.1	8530	59.9	1387	3.6
7.00E+06	190	89.4	561	89.5	201	89.4	759	89.1	2120	-81.9	1404	-5.9
8.00E+06	222	89.4	696	89.6	239	89.4	1033	88.8	1019	-85.7	1369	-15.4
9.00E+06	258	89.4	869	89.5	283	89.4	1514	87.3	681	-86.5	1295	-23.7
1.00E+07	298	89.3	1103	89.3	333	89.2	2300	83.1	518	-86.9	1210	-29.8
1.10E+07	340	89.3	1440	89.1	393	89.2	4700	73.1	418	-87.1	1123	-35.2
1.20E+07	390	89.3	1983	88.7	467	88.9	15840	-5.2	350	-87.2	1043	-39.9
1.30E+07	447	89.2	3010	87.7	556	88.3	4470	-62.6	300	-86.9	954	-42.7
1.40E+07	514	89.3	5850	85.6	675	88.3	2830	-71.6	262	-86.9	901	-45.2
1.50E+07	594	88.9	42000	44.0	834	87.5	1910	-79.9	231	-87.0	847	-48.1
1.60E+07	694	88.8	7210	-81.5	1098	86.9	1375	-84.1	203	-87.2	778	-51.8
1.70E+07	830	88.1	3250	-82.0	1651	81.8	991	-82.4	180	-86.9	684	-54.4
1.80E+07	955	86.0	2720	-76.1	1796	70.3	986	-67.2	164	-84.9	623	-45.9
1.90E+07	1203	85.4	1860	-80.1	3260	44.6	742	-71.0	145	-85.1	568	-51.2
2.00E+07	1419	85.2	1738	-83.8	3710	59.0	1123	-67.7	138	-84.5	654	-34.0
2.10E+07	1955	85.7	1368	-87.2	12940	-31.3	859	-84.3	122	-86.1	696	-49.9
2.20E+07	3010	83.9	1133	-87.8	3620	-77.5	708	-86.1	107	-85.9	631	-54.8
2.30E+07	6380	76.8	955	-88.0	2050	-83.0	613	-86.9	94	-85.5	584	-57.4
2.40E+07	15980	-29.6	807	-86.3	1440	-84.6	535	-86.3	82	-85.0	536	-58.8
2.50E+07	5230	-56.7	754	-82.2	1099	-84.1	466	-84.1	70	-84.3	485	-59.2
2.60E+07	3210	-78.9	682	-86.4	967	-83.4	467	-81.6	60	-82.7	481	-56.2
2.70E+07	2000	-84.4	578	-87.3	809	-86.5	419	-85.5	49	-81.7	463	-60.5
2.80E+07	1426	-85.6	483	-86.5	685	-87.1	364	-86.2	38	-79.6	425	-62.5
2.90E+07	1074	-85.1	383	-84.1	590	-87.3	308	-85.6	28	-75.2	387	-63.8
3.00E+07	840	-83.2	287	-75.0	508	-87.0	244	-82.1	18	-66.3	346	-64.4
3.10E+07	661	-81.7	188	-52.3	442	-85.7	174	-69.9	9	-34.3	305	-64.3
3.20E+07	484	-78.2	258	20.4	385	-83.6	155	-18.0	11	37.2	263	-63.2
3.30E+07	335	-41.4	1162	-13.5	326	-78.2	569	-0.3	21	63.6	212	-58.0
3.40E+07	607	-32.2	839	-45.9	316	-63.4	716	-57.6	32	71.4	183	-40.5
3.50E+07	705	-58.2	564	-56.3	379	-69.5	513	-72.5	46	76.0	235	-29.6


IMPEDANCE VS.FREQUENCY
SOLENOID 6T 4.25"
SOLENOID 12T 4.25"
SOLENOID 4T 6.625"
SOLENOID 8T 6.625"
BUNCHED 8T 6.625"
BEADS AZTEC FERRITE BEAD
Z (Ohms)
F (MHz)


PHASE VS.FREQUENCY
SOLENOID 6T 4.25"
SOLENOID 12T 4.25"
SOLENOID 4T 6.625"
SOLENOID 8T 6.625"
BUNCHED 8T 6.625"
BEADS AZTEC FERRITE BEAD
Z (Ohms)
F (MHz)

K3LR And W0IYH Feedline Chokes Vs Air Baluns

To: <towertalk@contesting.com>
Subject: [TowerTalk] K3LR and W0IYH "choke" baluns in the feedline system
From: W8JI@contesting.com (Tom Rauch)
Date: Fri, 11 Jun 1999 09:18:38 -0400

I've had some telephone line caused server problems, and I'm not sure my post made it to the reflector or anywhere.

>From: "Greg Gobleman" <k9zm@frontiernet.net>
>Subject: Re: [TowerTalk] K3LR and W0IYH "choke" baluns in the feedline system
>Date sent: Thu, 10 Jun 1999 20:02:45 -0500

> I also read W2FMI's book and I would have to agree that something isn't right about the W2DU type Balun. I experienced heating and a rise in SWR when using a KW and an under 2:1 SWR but not flat. It would heat up and the standing wave would rise over 2:1. This is not to say that all bead Baluns are bad. I had heard good things about the Force 12 version. Perhaps it uses a different ferrite material.

Walt's balun is based on good engineering for choking, but if you look at it closely there is no headroom for power. I suspect Walt never caught that because he mostly runs low power.

There are certainly many cases where his balun would work OK, but 73 material or ANY material with high loss tangent is the wrong material for QRO or for use where the core is involved in handling any high flux density.

> I built several of the W1JR type of Baluns and have had no problem with heating. I have had a problem finding an inexpensive enclosure. I have tried using 3" PVC caps and plugs and have about $5 in the enclosure. However, I created another problem. Weight of the enclosure and the core/coax with connectors is a bit much for a dipole. An inverted V or mounting on a beam is not a problem.

There is no need for the criss-crossed winding style, a single layer solenoid winding measures nearly the same. Some articles and books tell you any stray C across the balun reduces choking, but the opposite actually happens. You just have to be careful and not use such a large winding that the self-resonant frequency of the balun is lower than 1/2 of the highest operating frequency.

The cheapest balun for a given impedance and power rating is still an air-wound coil of coax on a PVC drainpipe.

> I have also had excellent success with a coil of coax. When you are lighting every florescent tube within a block at 2 AM while on 80m with a flat SWR. This will cure it.

If you use multiple turns through a core, the impedance goes up by the square of the turns increase. If you stick them through a string of beads, the increase in impedance is linear with length and has almost nothing to do with bead thickness. An air wound choke is somewhere 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

160 Meter Air-Wound BALUNS

Subject: Re: Topband: 160 Meter BALUNS
From: Joe Reisert <W1JR@arrl.net>
Date: Mon, 22 Dec 2003 10:24:03 -0500

Hi Tom,

A follow up to my prior Email on a solenoid baluns.

Regardless of whether 50 feet of RG8X wound on a solenoid (tube) is proper to use a balun or not, I'll leave that up to you and W8JI to decide. I guess you some would describe this type of balun as a choke.

Now, here is some more theoretical information and measurements etc. that maybe of interest to some for the engineering types on this reflector. This maybe helpful to design similar types of solenoid baluns at other frequency bands.

50 feet of RG8X coax is a good starting point for a 160 meter solenoid (choke) balun for many reasons. If you close wind the coax on a 4.5" OD (I mistakenly said 4" in my prior Email) standard white PVC tube, you obtain an impedance of about 650 Ohms (as measured on an HP Network analyzer). This means that you are above the 500 Ohms (and well above 250 Ohms) impedance that most experts feel is adequate for a balun impedance.

At 80 meters, the same solenoid balun will have an measured impedance of about 1300 Ohms. However, depending on how tight you make the turns, a resonance will be noted somewhere between 12 and 15 MHz. Hence, 50 feet of coax is probably only good for 160 through 30 meters. Use less turns if only for higher bands (see below). It looks like a 4 or 5:1 ratio of lowest frequency to highest useable frequency is a good rule of thumb.

To carry on further, 50 feet of RG8X will amount to approximately 38 turns on a 4.5" OD former and the winding will be approximately 9.25" long. If you plug these numbers is into most standard equations to calculate inductance, you will calculate an inductance of approximately 60 micro Henries. Using the standard formula for reactance: Xl = 2 pi FL, yields about the same impedance as measured above. Pretty nifty to get such agreement! So, you can see that don't need fancy measuring gear to make a solenoid balun for any band. Just decide on how high an impedance you want (but not too high-see below) and make sure that you don't put on too many turns so resonances will occur above rather than in band!

Some may ask if RG58 is OK for a solenoid balun. Sure it is but for lower power than RG8X. Since it is slightly smaller in diameter, 50 feet have a slightly higher impedance. Since the power handling ability of coax goes down as frequency increases, it maybe safer to use Teflon (RTM) type coax such as RG303 if you are running high power, especially at 80 meters and above. RG8 will also be OK but it is larger in diameter so more coax will be required. You can make your own calculations on this one. I wouldn't recommend foam RG8 coax as it may deform on such a small diameter. However, if you use a larger diameter tube, that will work with RG8 and since the diameter is larger, the impedance will increase accordingly. Use the standard inductance equations.

I made a solenoid balun with 25 feet of RG303 Teflon (RTM), about 20 turns on a 4.5" tube, and the first measured resonance was about 24 MHz. This balun would be great, even at high power, for 80 through 15 meters. Again, about a 5:1 frequency range.

Some purists will say to space the turns, for example, by the diameter of the coax. This maybe less of a problem for flash over if lightning hits. I'll leave that up to you to decide. However, using the info above, this would calculate (using standard inductor equations) to about 33 micro Henries of inductance for space windings (and an impedance of only 375 Ohms), well below that normally suggested for a 160 meter balun. Hence, more coax or a larger diameter tube is required.

Finally, what about laying the balun on the ground. I'd recommend against that simply because that at least may lower the self resonance frequency. This is the old story that you shouldn't place objects near (1-3 diameters away) an inductor (which is what a solenoid balun is on the outside shield).

I hope this info is of interest and help. There will always be the disagreements over whether to use ferrite beads, ferrite toroids or solenoid baluns. No one size fits all! However, for those interested in designing there your own solenoid type baluns, I've hopefully given some info on how to "roll your own."

Happy holidays and best of DX in 2004.

73,

Joe, W1JR

Generalized "ugly balun" construction (Air-Wound)

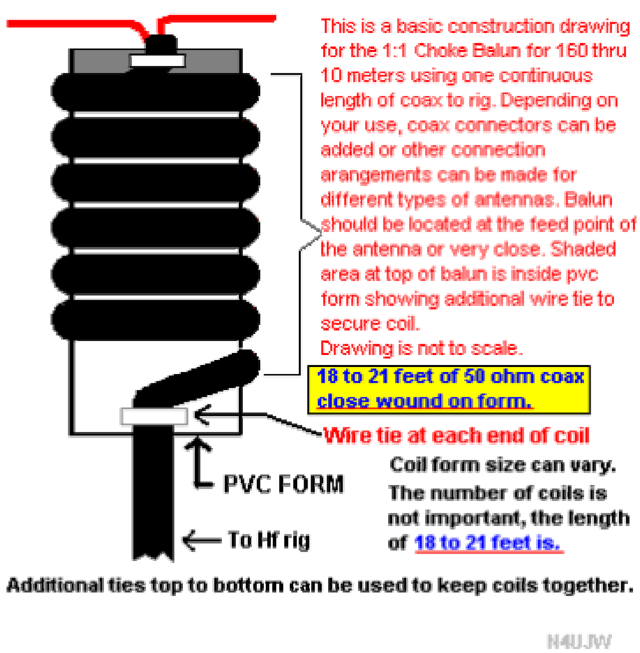
http://www.hamuniverse.com/balun.html

In transmitting antennas, balance is accomplished by presenting a high impedance (resistance), to RF currents flowing outside the coax shield. This forces currents in each side of a driven elements to be equal. This is especially important in beam antennas because it prevents distortion of the beam's pattern caused by unequal currents in the driver(s). In a simple dipole, the balun assures that the dipole, and not the feed line, is doing the radiating!

As the feedline becomes part of the unbalanced antenna system, currents can flow from the line into the mains and on TV cables, metal masts and Yagi booms, causing a variety of EMI problems that can be very difficult to trace. Frequently these problems are simply due to unbalance - and the solution is the humble balun!

If an antenna system is fed at center with a parallel conductor line (provided that correct installation procedures are followed) balance will be maintained, USING A BALUN, with currents in equal and opposite phase canceling each other out.

When the connection is to a coaxial cable, WITHOUT A BALUN, this cannot occur because currents flowing inside the cable from the connection to the inner conductor are separated from those flowing on the outside from the connection to the shield, and the result is unbalance causing feeder radiation. However, if the two electrical circuit elements (antenna and coaxial cable) are coupled using a balun, balance will be maintained.
Enter.....The Ugly Balun!.....N4UJW



An Inexpensive, High-Performance, Ugly 50ohm 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.
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.

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"....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!

4:1 Toroid Balun For Unbalanced Tuners And Resonant Dipoles

By N1HFX
Many modern HF transceivers come fully equipped with built in tuners. While these tuners are great for changing bands, the manufacturers left out a very important accessory; the 4 to 1 balun.

With out a balun the transceiver can only feed an antenna which uses coaxial cable. While this may be satisfactory for some operators, this is a real problem for those of us who prefer the super low loss ladder line. The only other alternative is to buy an external tuner with a built-in balun which is really absurd after spending the additional money to have one built into the radio.

Fortunately, a 4 to 1 balun can be easily home brewed as illustrated in Figures 1 and 2. Figure 1 shows a bifilar winding on a toroid. The toroid should be type 2 (red) material and can be any of the following sizes but the number of bifilar turns should be adjusted accordingly:

TOROID	NUMBER OF TURNS	POWER RATING
T80-2	25	60 Watts
T106-2	16	100 Watts
T130-2	18	150 Watts
T157-2	16	250 Watts
T200-2	17	400 Watts
T200A-2	13	400 Watts
T400-2	14	1000 Watts

The exact number of turns is not critical but the numbers listed in the preceding table should yield optimum results. It is possible to exceed the power ratings listed above but the performance of the balun may be degraded during high SWR causing heating of the core.

Toroids of this type are available from Palomar Engineers, P.O. Box 462222, Escondido, CA 92046 (1-800-883-7020).

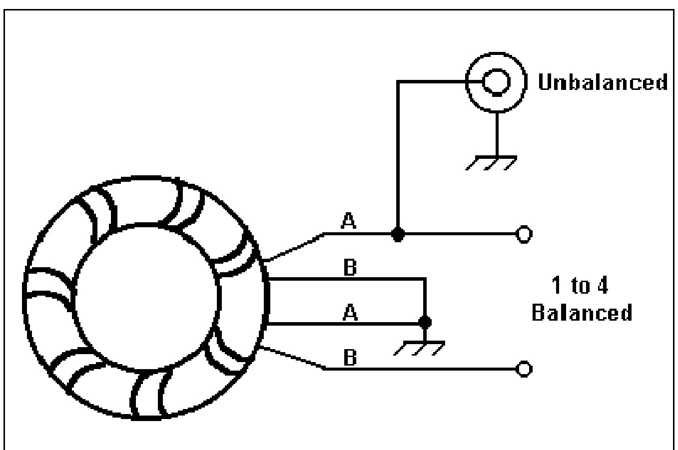


Figure 1

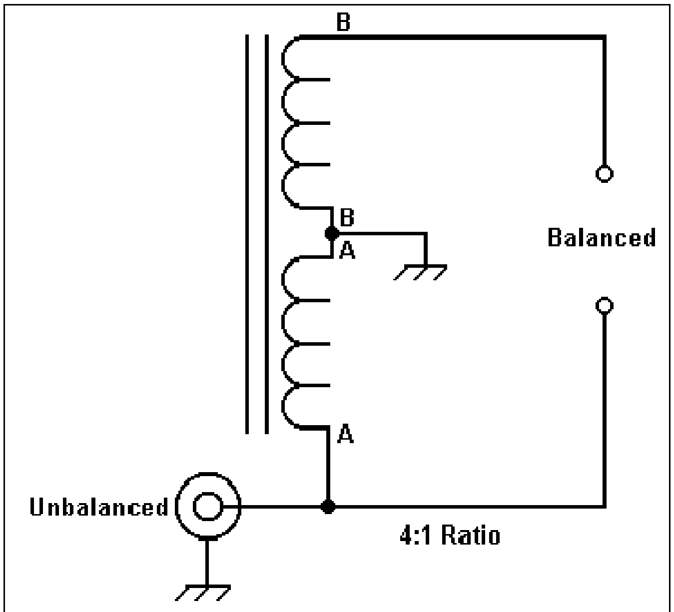


Figure 2

The above article is an example of an unbalanced transmitter directly feeding a built-in unbalanced tuner, which then feeds a balun and the balanced antenna. If the impedance of the antenna is substantially higher than 400 to 1000 ohms due to operation far from resonance, the core-type balun may become very inefficient due to high voltages impressed across its low-inductance windings by the antenna tuner.

When this type of balun is to be used on the output of a tuner, it is best to get the antenna as close as possible to resonance by itself first.

This problem or requirement is also the chief reason for those who wish to be both frequency-agile and efficient to adopt a system wherein a balun is placed before a balanced tuner where the impedance radio is about 1:1 and the impedance is low, and the balanced tuner feeds a balanced feedline and antenna with no intervening balun to cause an inefficiency on an unusual frequency. *--Opcom*

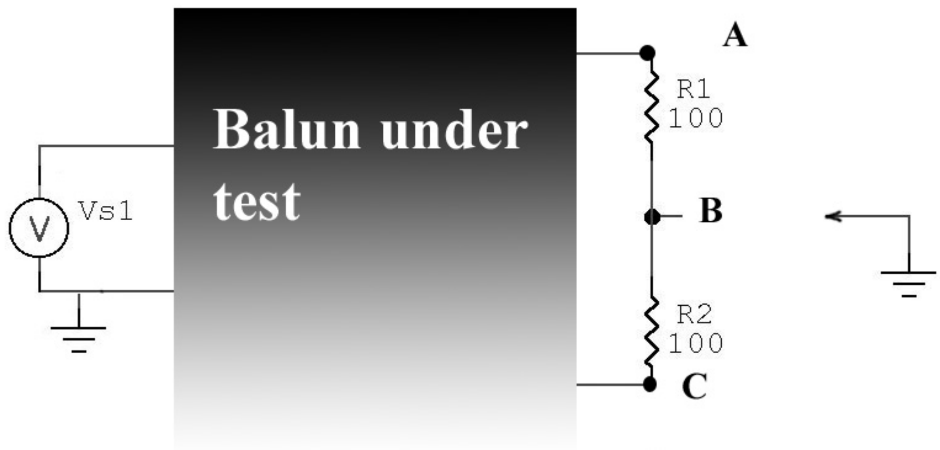
"..The cause of directional radiation by a resonant $^1/_2$ wave dipole antenna is that the radiation intensity is proportional to the square of the current in the antenna, and in the dipole current is maximum at the middle; hence the maximum radiation line passes through the middle of the antenna perpendicularly." *--Vigyan Prasar*

Balun Tests

Balance Quality Test

http://www.w8ji.com/Baluns/balun_test.htm

We can test balance quality of a balun by moving a ground (common with signal source) to points A, B, and C and watching voltages or currents in the load. The best balun would have the least change in input SWR or current through R1 and R2 as the ground is moved.
R1 and R2 should be selected to equal design load impedance.

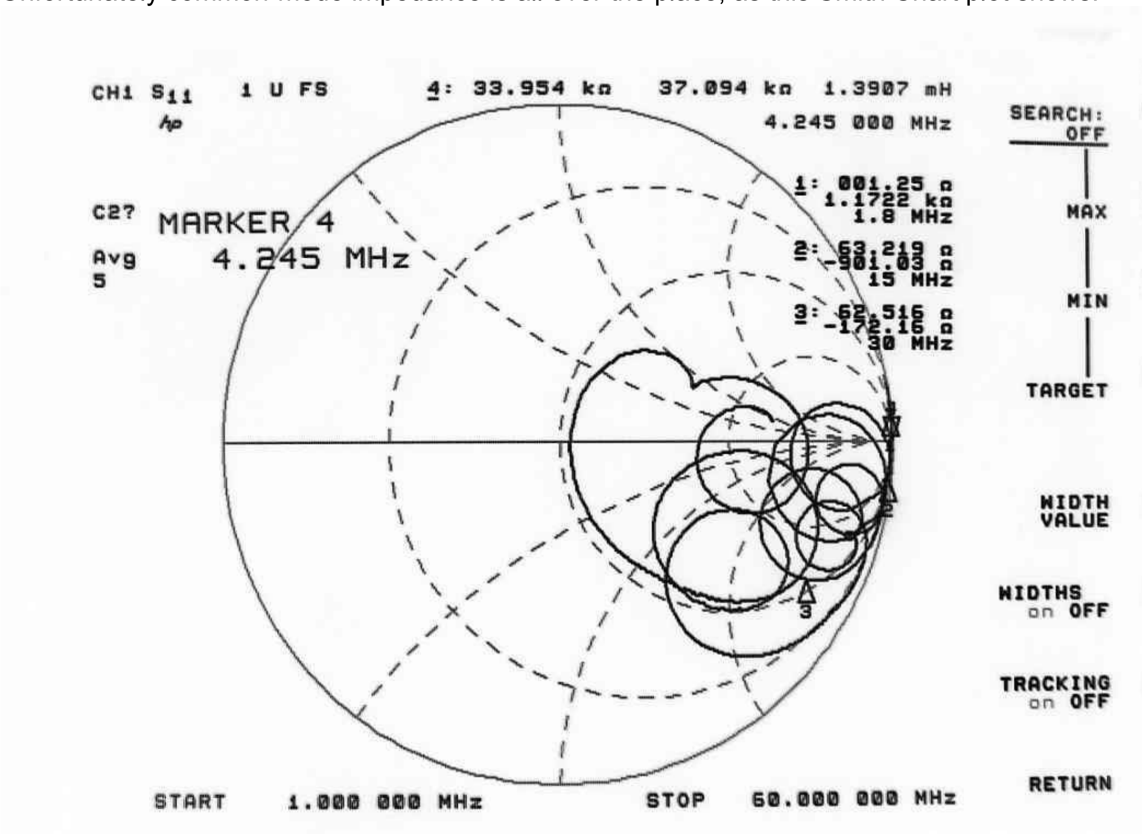


The same test above can be used, at high power, to evaluate the power handling of the balun. The balun should not overheat at full power in a worse case condition for output jumper position. Heating limits in an HF balun, regardless of load impedance, is almost exclusively due to losses in the core. This is true for any type of balun in the real world. Do not confuse heating with flux-saturation of magnetic materials. Flux saturation does not necessarily cause heating, it simply means the core cannot carry any more flux and any additional current causes a reduction in inductance. Virtually all HF cores heat from the loss tangent of the core. The loss tangent causes the core impedance to appear as a complex combination of resistance and reactance. The resistive part represents the dissipative characteristics, while reactance is lossless.

All baluns, even transmission line baluns, will have significant flux in the core with real-world loads. This flux density is the primary loss or heating mechanism in a balun.

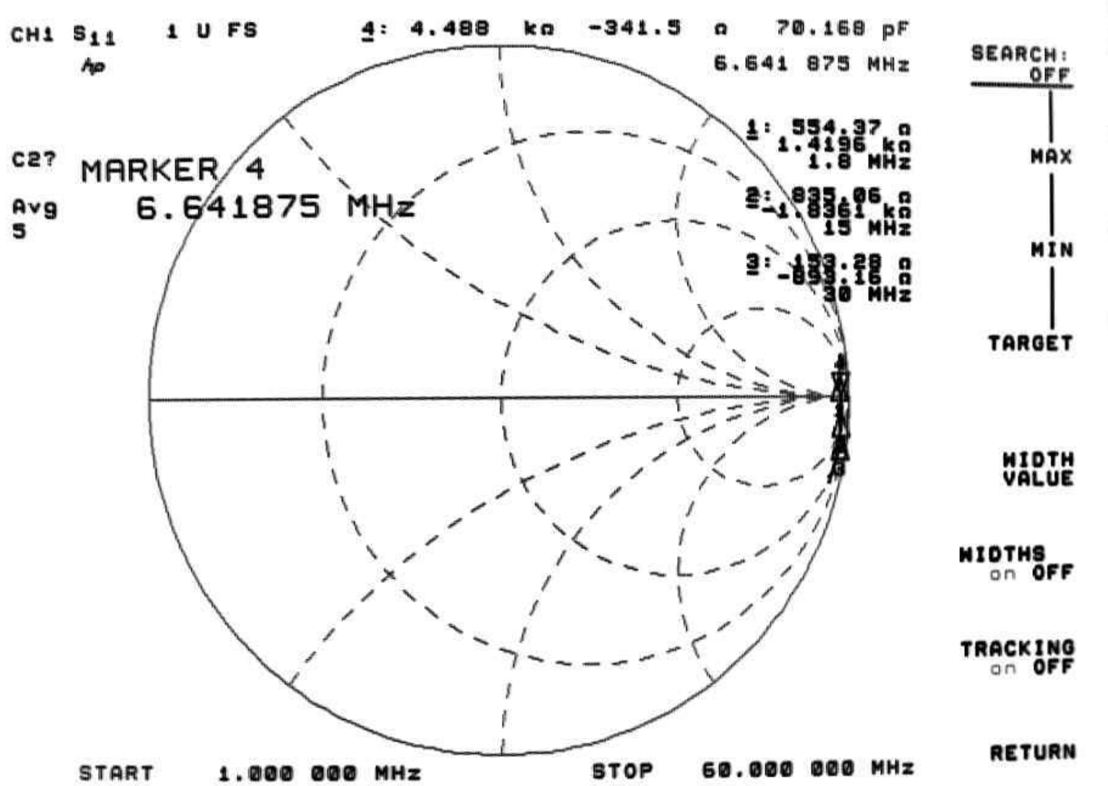
Choke Impedance

This data shows the common mode impedance of the balun. In general, the highest impedance at the operating frequency or over the operating frequency range is desirable. This impedance isolates the antenna from undesired signals on the feedline shield, and prevents antenna terminal voltage from exciting the feedline with unwanted currents. Common mode impedance is directly related to the care in design and construction.
Pay particular attention to the impedance peak in air-core baluns. For narrow-band applications they make excellent baluns.
Unfortunately common-mode impedance is all over the place, as this Smith Chart plot shows:



The air-core balun is good only for a three or four-to-one frequency range, unless you pick a winding style and size that places unwanted series resonances outside desired bands.

In contrast a good core-type balun looks like this:



SWR

The lowest SWR is desirable, although any mismatch can often be compensated by adjustment of antenna dimensions. This SWR mainly comes from incorrect wire impedance inside the balun. It may be caused by excessive length of internal leads, or incorrect cable or winding impedance inside the balun. It generally is a construction related problem.

Measured SWR and Choking Impedance

The following data is measured using a currently certified network analyzer with low capacitance test fixture:

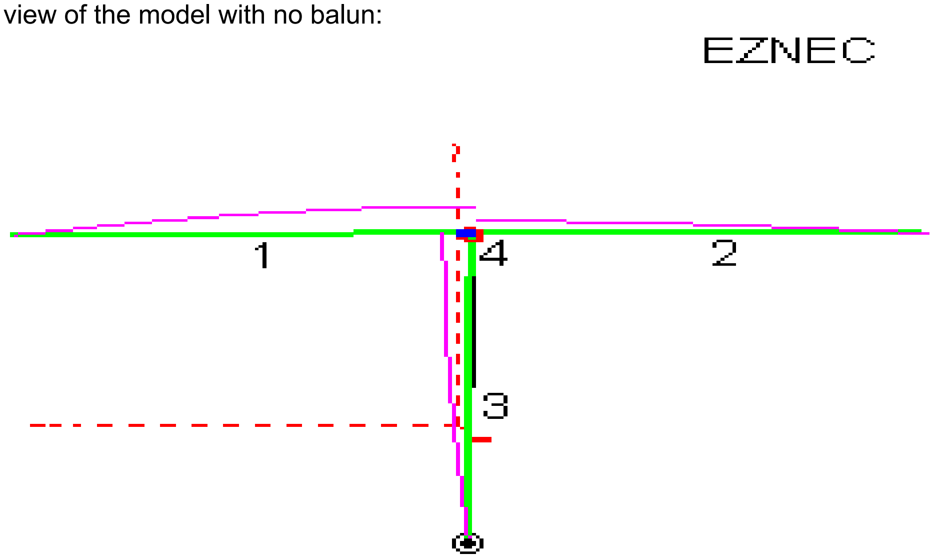
	Centaur	DXE	W2DU(1)	W2DU(2)	Force 12	Scramble	Solenoid	W2AU volt
Choke Impedance								**Note 2**
R+X@1.8	84 129j	554 1.4k j	378 617j	230 325j	169 286j	1.67 245j	1 +1.18k j	.488 5j
R+X@15	3.76 2.7k j	835 -1.84kj	727 -611j	761 -10j	883 -105j	11.97 -850j	62 -895j	1.36 42j
R+X@30	143 -729j	153 -893j	284 -440j	610 -296j	538 -381j	73 162j	68 -168j	8.2 68j
Max Z@F	17 MHz	6.65 MHz	7.16 MHz	15.3 MHz	13.24 MHz	6.42MHz	4.25 MHz	60 MHz
R+X at max Z	5.87k -943j	4.5K -340j	1.3K -13j	770 -20j	914 2.25j	42.7k 0j	34K 37K j	75 286j
Min Z@F						27.68MHz	11.7Mhz	
R+X at min Z						10 -2j	198 -252j	
SWR								
F SWR=1.25	6.8 MHz	65 MHz	21.15 MHz		20.2 MHz	note 1	note 1	20.9 MHz
1.8MHz	1.07	1.02	1.03		1.03			1.43
15MHz	1.58	1.04	1.17		1.18			1.2
30MHz	2.16	1.08	1.37		1.39			1.35

note 1: SWR not measured because construction and cable type affects SWR
note 2: This is a W2AU voltage balun. It is only shown as a example of poor shield isolation offered by voltage baluns if the antenna is not perfectly matched to the balun with the feedline exiting the balun at right angles. This type of balun is unsuitable for non-symmetrical systems such as off-center-fed antennas, verticals, or antennas with the feedline paralleling the antenna (even at a fairly large distance).
The W2DU baluns were manufactured by Unidilla. (1) is a Maxi balun and 2 is a 10-40 meter model.
The DX Engineering balun is the dipole balun type DXE-BAL050-H05-P
The scramble-wound choke was about 20 feet of RG8X in a six-inch diameter "bundle".
The solenoid balun was about 60 feet of RG-8X on a 4" PVC thin wall drain pipe coated with rubberized roofing tar.

Power Dissipation and Feedline Common-mode Current Estimates

Balun power dissipation is estimated using Eznec to simulate a perfectly balanced dipole.

Please be aware I made no special effort to create a "bad antenna" other than I intuitively understand what the worse case condition of feedline length would normally be and I selected that length. I dropped the wire representing the feedline vertically from the center of a perfectly balanced dipole, and made that wire 1/4 wl long.
Here is a view of the model with no balun:



SWR is 1.46:1 power is 1500 watts
Currents at 1500 watts are approximately:
5.65 amperes into wire 1
2.63 amperes into wire 2
3.73 amperes into wire 3 (coaxial cable shield)

Using this model (a 135 foot high 160-meter dipole) we can add each of the balun impedances in the coaxial cable shield and estimate feedline current and power dissipated in the balun:

Centaur	DXE	W2DU(1)	W2DU(2)	Force 12	Scramble	Solenoid	W2AU
0.90 amp	0.12 amp	.25 amp	.47 amps	.57 amps	.87 amps	.16 amp	.4 amps
69 watts	8.5 watts	25 watts	51 watts	55 watts	1.3 watts (26w TL loss)	.03 watt (74w TL loss)	34 watts

From this we can see the following:
Adding more beads is very inefficient. **W2DU(1)** has about twice the beads as **W2DU(2)**, yet it has 53% of the current and 49% of the power dissipation! This does increase power rating by a factor of four, but it is still too low to prevent balun heating.

The **solenoid** has (by far) the lowest choking or balancing power loss, but it is 60-feet of RG-8X wound on a 4" diameter form in a single layer. It adds transmission line loss of 74 watts, but since the area is so large it will not overheat.

The **scramble wound** balun has inadequate impedance since wire length is only 20 feet. It has low loss, but it really isn't acting like a balun (at 6.5 MHz it would be super, having 42K ohms of impedance).

Of the baluns above, only the DXE, scramble wound, and solenoid would not be overheated in normal operation for continuous Morse CW transmissions.

Perspective of Heat

Think about the heating this way. Imagine you had a 60-watt light bulb. Nearly all of the applied power is turned to heat, and the surface area of the bulb and conduction through the base radiates that heat. Would you hold a 60 watt light bulb?

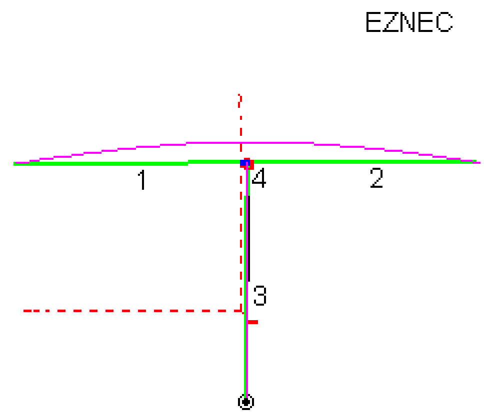
Now picture a balun core with a surface area a fraction of the size of the light bulb. This core area is enclosed in a case that often has poor thermal conductivity.

The large air-core baluns mainly produce heat from transmission line losses.

W2DU and other style baluns mainly have CORE losses. Transmission line losses are negligible since the transmission lines are very short.

Currents

Every ampere of current not going onto the cable shield goes to the dipole's shield-fed leg! The total is not the exact sum, because of phase differences. Here is a view of currents in the dipole with the DXE balun:



Currents are:

```
Wire 1     4.52 amperes
Wire 2     4.52 amperes
Wire 3     .12 ampere
```

Remember power radiated increases by the square of current. The feedline shield current is now .12A compared to 3.73A without a balun! The feedline radiates about .1% of the power it radiated without a balun. While pattern distortion on transmit may not hurt, the feedline radiation probably aggravates RFI and allows noise to couple into the antenna when receiving.

Remember the model is worse case in the NO BALUN condition. This does not mean every system or most systems will be this bad. This example was only intended to show how bad balance can be and how much power baluns (even with a matched load) can dissipate!

A *Balanced* Balanced Antenna Tuner

By Richard L. Measures, AG6K

The published version of this article appeared in the February 1990 issue of *QST* Magazine. This is the pre copy-edited version, updated in May, 2003.

JPG of a remote controlled, balanced L-network tuner built by Mike, WA1SEO.

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.

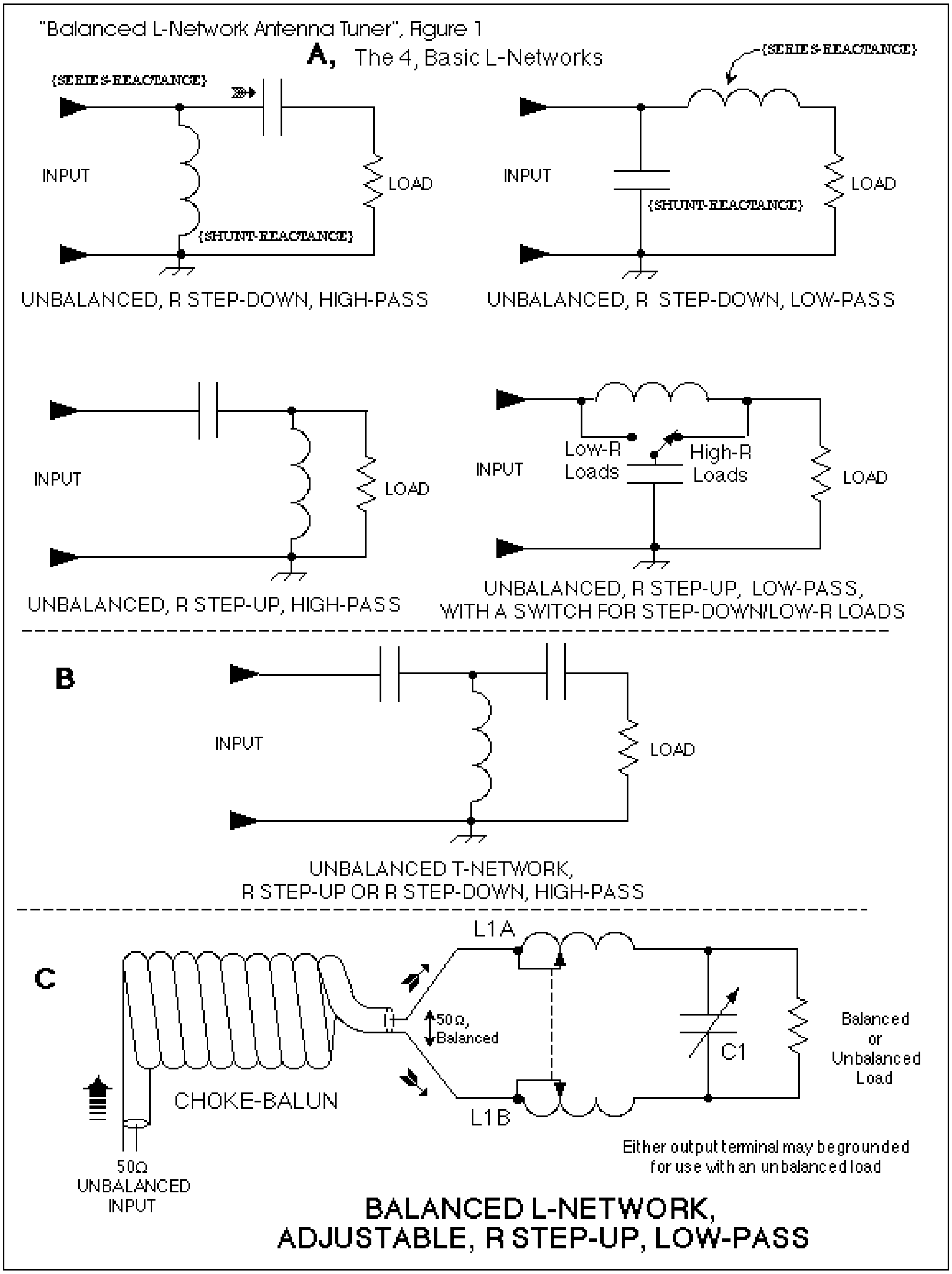

"Balanced L-Network Antenna Tuner", Figure 1
A, The 4, Basic L-Networks
{SERIES-REACTANCE}
INPUT
LOAD
{SHUNT-REACTANCE}
UNBALANCED, R STEP-DOWN, HIGH-PASS
{SERIES-REACTANCE}
INPUT
LOAD
{SHUNT-REACTANCE}
UNBALANCED, R STEP-DOWN, LOW-PASS
INPUT
LOAD
UNBALANCED, R STEP-UP, HIGH-PASS
Low-R Loads
High-R Loads
INPUT
LOAD
UNBALANCED, R STEP-UP, LOW-PASS,
WITH A SWITCH FOR STEP-DOWN/LOW-R LOADS
B
INPUT
LOAD
UNBALANCED T-NETWORK,
R STEP-UP OR R STEP-DOWN, HIGH-PASS
C
L1A
50Ω, Balanced
C1
Balanced or Unbalanced Load
CHOKE-BALUN
L1B
50Ω UNBALANCED INPUT
Either output terminal may be grounded for use with an unbalanced load
BALANCED L-NETWORK,
ADJUSTABLE, R STEP-UP, LOW-PASS

Figure 1

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.

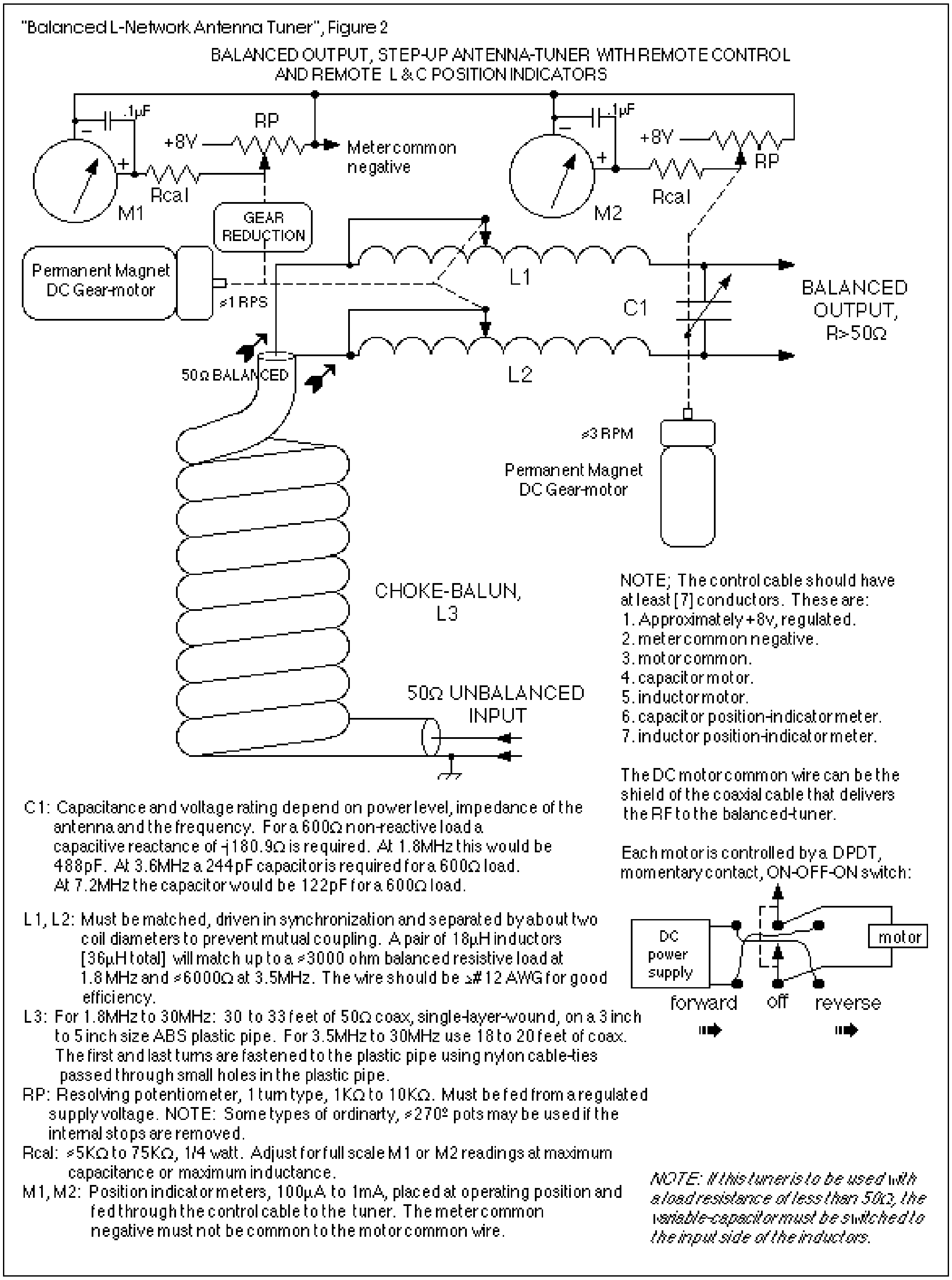
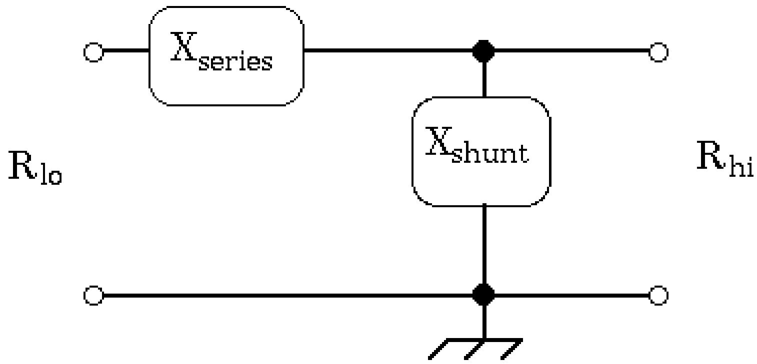

"Balanced L-Network Antenna Tuner", Figure 2
BALANCED OUTPUT, STEP-UP ANTENNA-TUNER WITH REMOTE CONTROL AND REMOTE L & C POSITION INDICATORS
.1µF
RP
+8V
Meter common negative
M1
Rcal
GEAR REDUCTION
.1µF
+8V
RP
M2
Rcal
Permanent Magnet DC Gear-motor
≤1 RPS
L1
C1
BALANCED OUTPUT, R>50Ω
50Ω BALANCED
L2
≤3 RPM
Permanent Magnet DC Gear-motor
CHOKE-BALUN, L3
50Ω UNBALANCED INPUT
NOTE; The control cable should have at least [7] conductors. These are:
1. Approximately +8v, regulated.
2. meter common negative.
3. motor common.
4. capacitor motor.
5. inductor motor.
6. capacitor position-indicator meter.
7. inductor position-indicator meter.
The DC motor common wire can be the shield of the coaxial cable that delivers the RF to the balanced-tuner.
Each motor is controlled by a DPDT, momentary contact, ON-OFF-ON switch:
DC power supply
motor
forward
off
reverse
C1: Capacitance and voltage rating depend on power level, impedance of the antenna and the frequency. For a 600Ω non-reactive load a capacitive reactance of -j180.9Ω is required. At 1.8MHz this would be 488pF. At 3.6MHz a 244pF capacitor is required for a 600Ω load. At 7.2MHz the capacitor would be 122pF for a 600Ω load.
L1, L2: Must be matched, driven in synchronization and separated by about two coil diameters to prevent mutual coupling. A pair of 18µH inductors [36µH total] will match up to a ≈3000 ohm balanced resistive load at 1.8MHz and ≈6000Ω at 3.5MHz. The wire should be ≥#12 AWG for good efficiency.
L3: For 1.8MHz to 30MHz: 30 to 33 feet of 50Ω coax, single-layer-wound, on a 3 inch to 5 inch size ABS plastic pipe. For 3.5MHz to 30MHz use 18 to 20 feet of coax. The first and last turns are fastened to the plastic pipe using nylon cable-ties passed through small holes in the plastic pipe.
RP: Resolving potentiometer, 1 turn type, 1KΩ to 10KΩ. Must be fed from a regulated supply voltage. NOTE: Some types of ordinarty, ≈270º pots may be used if the internal stops are removed.
Rcal: ≈5KΩ to 75KΩ, 1/4 watt. Adjust for full scale M1 or M2 readings at maximum capacitance or maximum inductance.
M1, M2: Position indicator meters, 100µA to 1mA, placed at operating position and fed through the control cable to the tuner. The meter common negative must not be common to the motor common wire.
NOTE: If this tuner is to be used with a load resistance of less than 50Ω, the variable-capacitor must be switched to the input side of the inductors.

Figure 2

"Balanced L-Network Antenna Tuner", Figure 3

L-Network Formulas For Resistive Loads



The series and shunt reactances must have opposite signs for non-reactive [resistive] loads. In other words, one capacitor and one inductor must be used.

X_{series} = the reactance of the series component in ±Ohms.

Note: For a balanced L-network, the series reactance must be divided into two equal parts and the shunt reactance must be completely insulated from ground.

X_{shunt} = the reactance of the shunt component in ±Ohms.

$$X_{series} = \pm\sqrt{\left[\left(R_{lo}\ R_{hi}\right) - R_{lo}^{2}\right]}\quad \Omega$$

$$X_{shunt} = \pm\frac{R_{lo}\ R_{hi}}{X_{series}}\quad \Omega$$

To convert X into a capacitance in farads or an inductance in henrys for a specific frequency, F, in Hertz (Hz):

$L = X_L \div (2\pi F)$ $\quad C = 1 \div [X_C\ (2\pi F)]$

Figure 3

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.

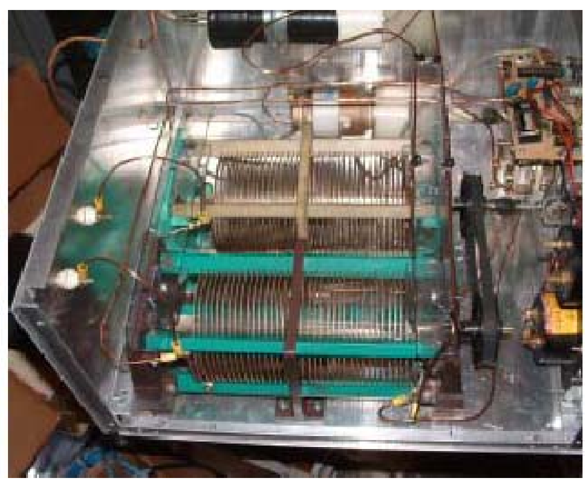
The price of an 18" belt is $5.50 in my old Catalogue #10. The price of 40-t pulleys is under $7.00 each. The price of 30-t pulleys is under $6.00 each. I assume that the prices have probably increased.

Home Brew Balanced Antenna Tuner

I have homebrewed a balanced line antenna tuner that I just started using and it works really great. Back about 3 years ago I started collecting parts and pieces for a t-match tuner which I started and then changed mind to build a balanced-balanced tuner before I started cutting my face plate. The tuner was based on a tuner "Richard Measures AG6K" has on his website http://www.somis.org/bbat.html

The one that I built has a switch to swap from input side of the roller inductors to the output side. The materials that I used were (2) 10,000 watt Gates roller inductors that are paralleled with two 4" fiber cogged pulleys and driven with a Barker & Williamson turns counter, 10,000 volt Jennings vacuum 5-500uH variable capacitor that used to swap in the capacitance from the input to the output, my switch for the capacitor came from a Gates 10,000 watt transmitter, 5000 watt 1 to 1 balun which is placed on the input side to give a true 1-1 match again on the input side, the guts a Heathkit HM-2140A SWR-Power meter. I just use the forward and reflected functions of the meter. I used about 20 feet of the center conductor of some 9913 coax. It weighs about 48 pounds and built like a M1A Tank. The power meters were home brewed by "Joe Kane, KF4TOH".

Everything is accurate or close to accurate as I could get. It will only tune 450 ladder line which is all I use now. used to get some RF into my TV and computer monitor, but now. I used to have computer interference on certain bands, but now I don't. I don't want to talk about cost to make the tuner but logged about 140 hours in building the tuner. I tried to use the best components that I could use but you can use less costly parts if you preferred. I wanted a tuner that I could keep and last for a long time. My next project is basically the same tuner but with stepper motors to turn the roller inductors and capacitor. I'll have the case finished and ready to start looking for more parts.
73 Philip KB4I



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

A New Generation of Balanced Antenna Tuners

Joel R. Hallas, W1ZR
Assistant Technical Editor, QST

Paul Danzer's article[1] in the April 2004 issue of *QST* brought to paper concern many of us have had for some time—the use of baluns at the output of antenna tuners. As noted in his article, the balanced load is near the balun's design impedance (typically 200 . for the usual 4:1 balun) all is well. Unfortunately, the typical random sized centerfed antenna with random length ladder line feed has an impedance at the feed point that varies dramatically with frequency. The result can be heating and loss and occasional damage) at the balun. These effects were well documented in series of *QST* articles by Frank Witt[2] and later in a performance evaluation of unbalanced tuners with both balanced and unbalanced loads.[3]

So How Do We Fix the Problem?

As Danzer noted, the classic solution has been the use of an inherently balanced tuner. The commercially manufactured E.F. Johnson Matchbox tuners of the '50s worked reasonably well in their day, and over the bands that they covered (we didn't have the 60, 30, 17 and 12 meter bands back then).

Now at least three manufacturers have begun offering balanced antennas tuners of a different configuration. For this review we selected the MFJ-974H and the Palstar AT1500BAL and AT4K. Interestingly, each of the three uses a different architecture, and each different from the design of the old Matchbox! In addition to those units, SGC has announced a low power selfcontained auto-tuner, the SG-211, which shares the design concept of the AT4K and will be the subject of an upcoming Short Takes column. We thought it would good to evaluate the performance of the medium and high-power units and provide a comparison to the old Johnson tuner.

What's in the New Tuners?

Glad you asked! As noted, each of the tuners uses a different design configuration. Each can be directly compared to some of the common unbalanced configurations. Note that the power ratings and price of the Palstar tuners put them in a different category from the MFJ units and thus, direct comparisons may not be appropriate. Both the MFJ and the Palstar AT1500BAL are fully balanced tuners— the MFJ a dual T section design with shunt L, and the Palstar a dual L section with shunt C. The Palstar AT4K tuner takes a completely different approach. It uses the insulated unbalanced scheme suggested in Paul's article and described in detail in *The ARRL Antenna Book*.[4] The relationship of the designs to their more commonly encountered unbalanced configurations are shown in simplified schematics in Figures 1 through 3. The other differences between the units are in their ratings. The MFJ tuner covers 160 through 6 meters, while the Palstar tuners top out at 10 meters. Both Palstar tuners are rated at 1500 W or greater (the AT4K has a reduced rating below a 25 . load) while the MFJ tuner is rated at 300 W PEP, 150 W CW. The ratings of the Johnson Matchboxes were established in a day when amateur power levels were specified based on average dc power input, rather than the current PEP RF output power. A "275 W" Johnson matchbox was thus rated to work with transmitters running 275 W dc input, or about 200 W average output. This was in the day of plate modulated AM service, so that rating further translates to 800 W PEP under today's rules. Similarly, a "kW Matchbox" would likely be rated today as a 3 kW PEP tuner.

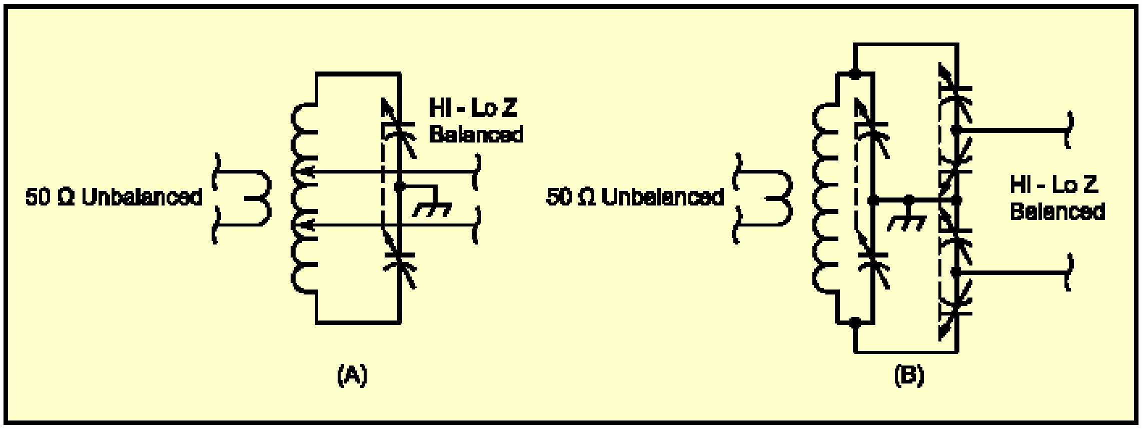


Figure 1—At A, the traditional balanced antenna tuner. At B, the Johnson Matchbox antenna tuner. Simplified view without bandswitching.

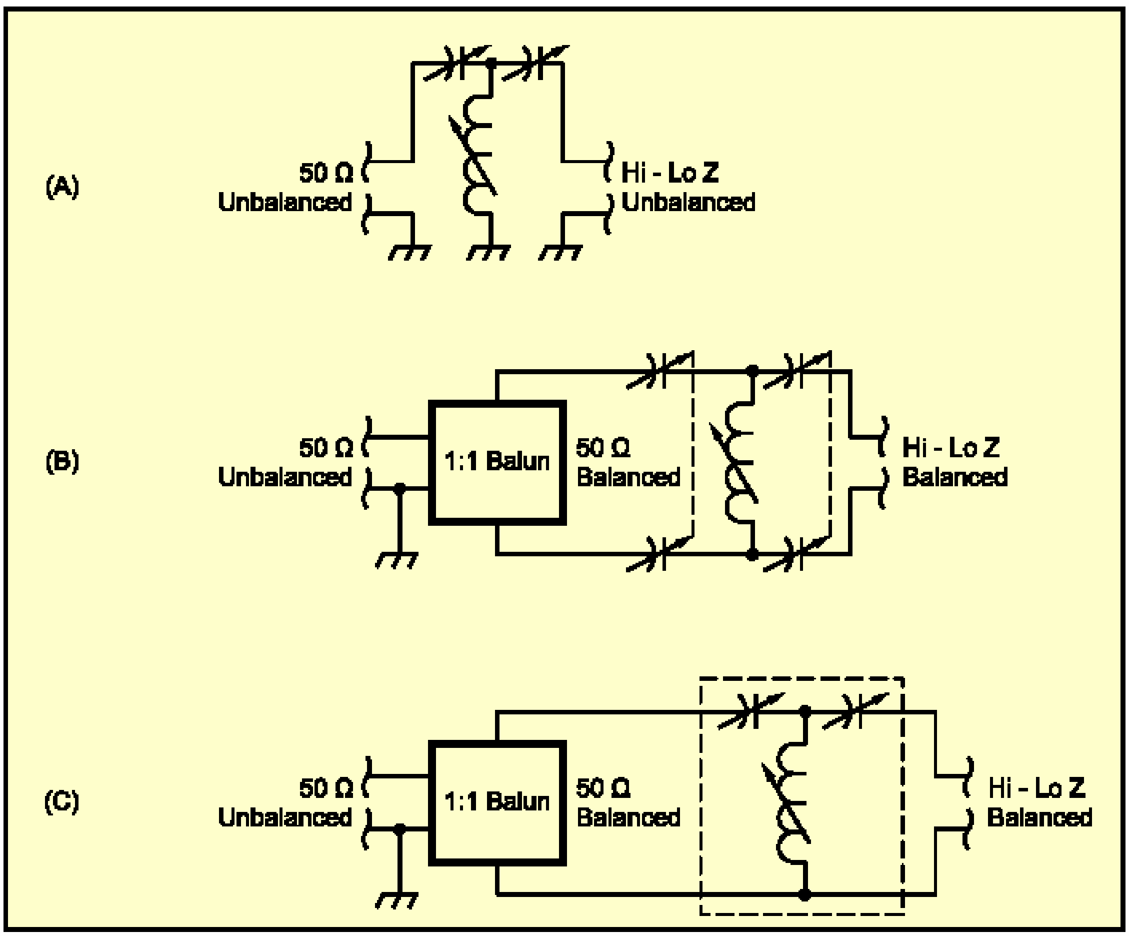


Figure 2—At A, an unbalanced T-network tuner. At B, a balanced T-network tuner. At C, an unbalanced T-network tuner for balanced loads.

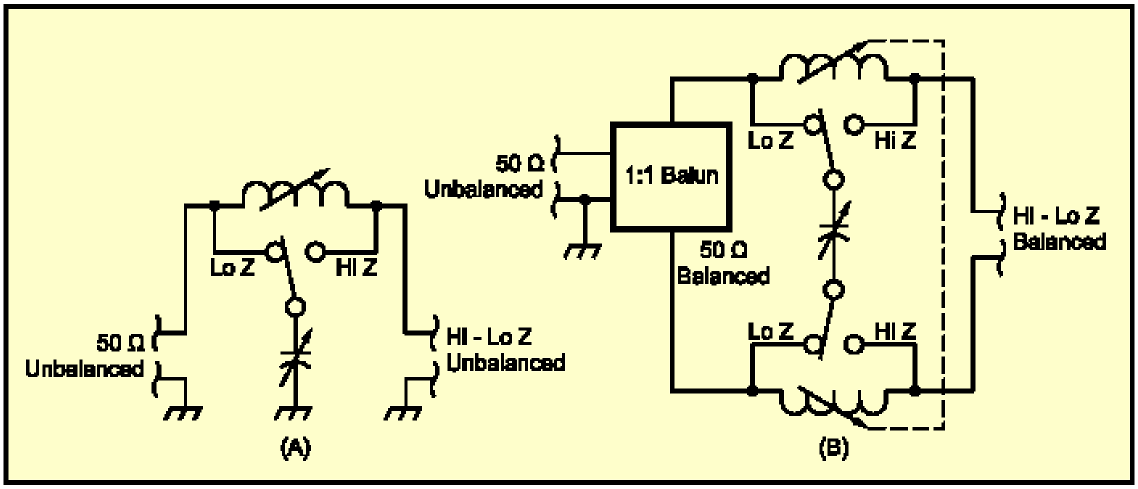


Figure 3—At A, an unbalanced L-network tuner with switched capacitor. At B, a balanced L-network tuner with switched capacitor.

Bottom Line

A new breed of antenna tuner available in different flavors from multiple manufacturers addresses concerns about using baluns with high SWR to feed balanced antenna systems.

[1] P. Danzer, N1II, “Open Wire Feed Line—A Second Look,” QST, Apr 2004, pp 34-36.
[2] F. Witt, AI1H, “How to Evaluate Your Antenna Tuner—Parts 1 and 2,” QST, Apr 1995, pp 30-34 and May 1995, pp 33-37.
[3] R. Lindquist, N1RL, “Product Review— QST Compares: Four High-Power Antenna Tuners,” QST, Mar 1997, pp 73-77.
[4] The ARRL Antenna Book, 20th edition, Chapter 25, pp 15-18,

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.

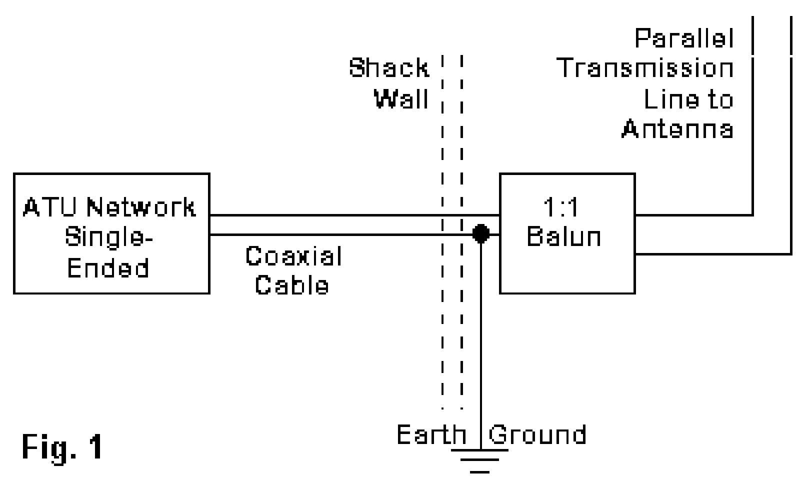
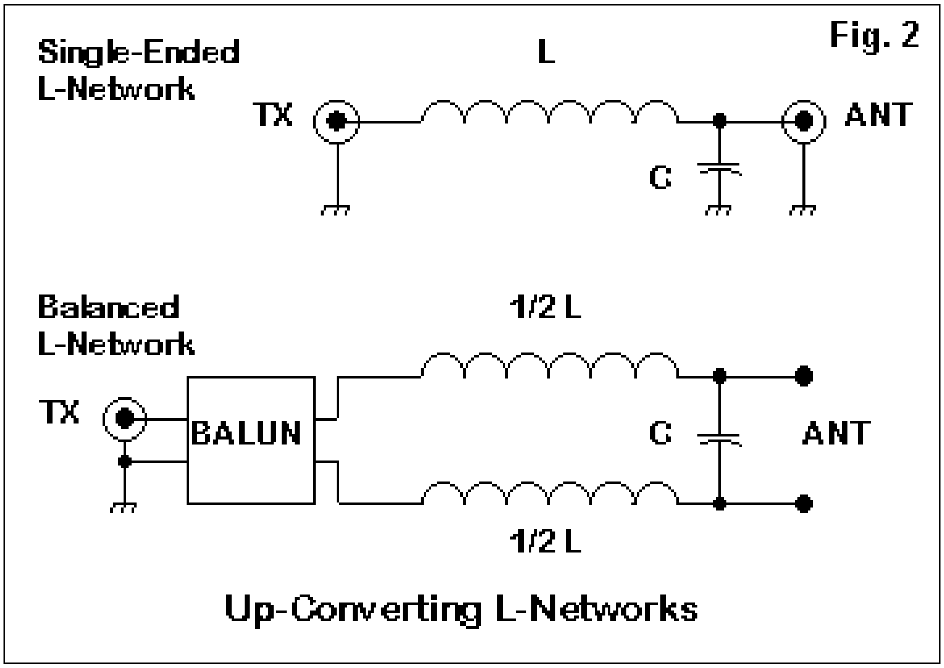


Fig. 1

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.

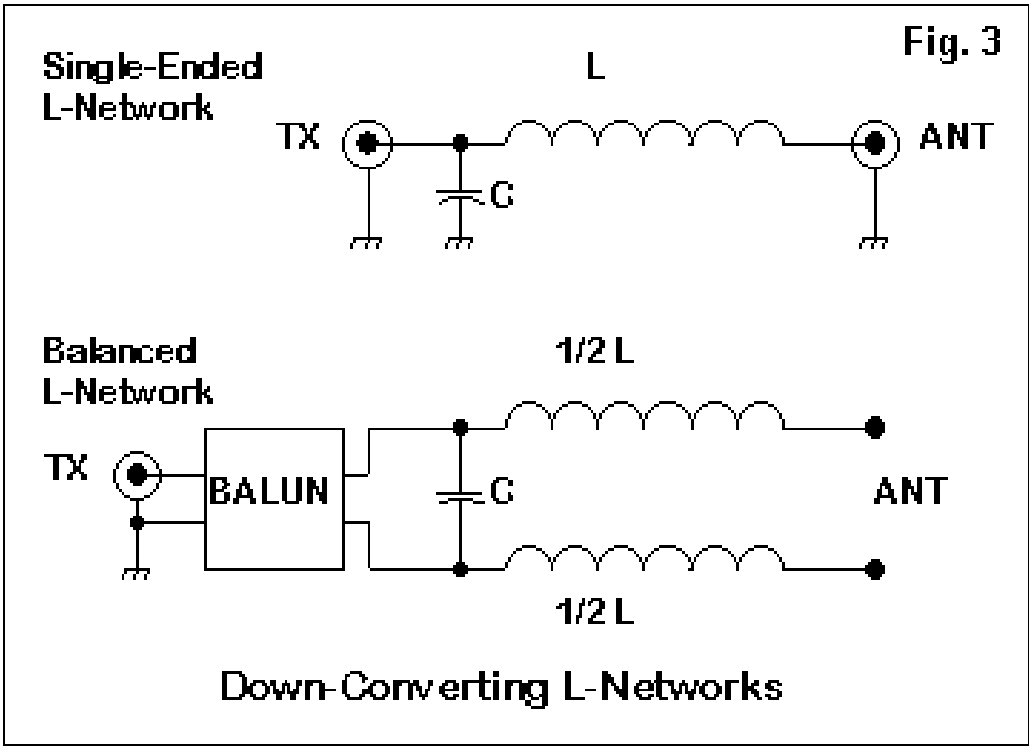
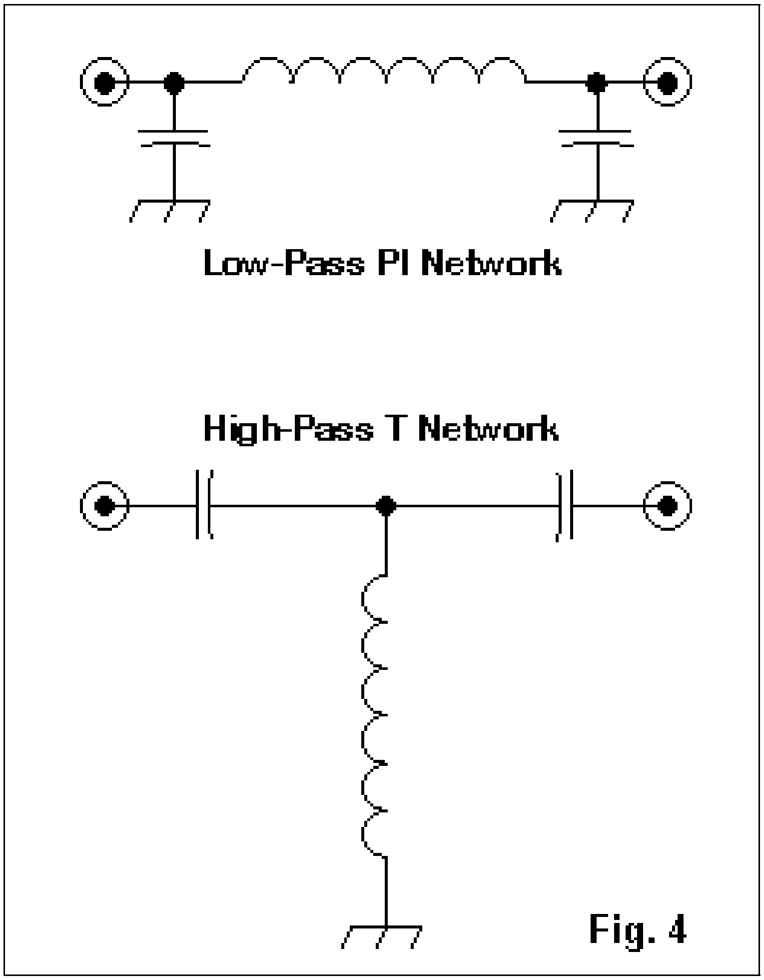


Fig. 3 shows the balanced L-network--and its single-ended counterpart--set up as a down converter using a low-pass configuration. If we had used a high-pass configuration, with series capacitors and a parallel or shunt inductor, we would achieve a circuit identical to that of the beta or hairpin match. 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.

The calculations of delta for PI and T tuner networks are more complex. The general outcome is this: for any matching conditions within the range of both an L-network and a PI or a T network, the L-network sill show lower losses (assuming that the components in all cases have the same unloaded Q values).

However, the L-network, whether single-ended or balanced has a second inconvenience besides the requirement for switching the shunt component when going from up-conversion to down-conversion and back. The component values required to effect a match for impedances within a ratio of about 1.5:1 (or .67:1 for down conversion) relative to the input impedance tend to be impractical in a wide-band antenna tuner. Hence, for matching impedance above 35 Ohms but below about 75 Ohms, one must simply omit the L-network and feed the antenna directly (accounting for the shift from unbalanced coax to a balanced line, of course).

Commercial implementations of the balanced network tuners tend to opt for the L- network because it achieves economy. Anyone who has priced high-voltage variable capacitors of either standard or vacuum design will easily note the saving accrued by eliminating one from the circuit. A patch panel, switch, or relay tends to be far less expensive. While this economy also affects ATU home- builders, the lower losses of the 2-component network may also be appealing, while the inconvenience of switching network ends with the shunt component may be accepted as the appropriate trade-off.

Balanced L-Network Component Values

The next question concerning a balanced L-network concerns the components that we must use to effect a match with various loads. Using calculation methods developed by Brian Egan, ZL1LE, and available on recent version of HAMCALC from VE3ERP, we can survey those values from 160 to 10 meters. **Table 1** provides calculated data for some up- and down-conversion loads that are purely resistive.

. . . .

Table 1. Calculated Values for L-Network matching to various Resistive loads from 15 to 2500 Ohms. All inductance values (L) in uH, all capacitance values (C) in pF. Loads are in Ohms.

Up-Conversion	Load = 100		Load = 250		Load = 500		Load = 1000		Load = 2500	
Freq.	L	C	L	C	L	C	L	C	L	C
1.8	4.4	884	8.8	707	13.3	531	19.3	385	30.9	248
3.75	2.1	424	4.2	340	6.4	255	9.3	185	14.9	119
7.15	1.1	223	2.2	178	3.3	134	4.9	97	7.8	62
10.125	.79	157	1.6	126	2.4	94	3.4	69	5.5	44
14.175	.56	112	1.1	90	1.7	67	2.4	49	3.9	31
18.118	.44	88	.88	70	1.3	53	1.9	38	3.1	25
21.225	.38	75	.75	60	1.1	45	1.6	33	2.6	21
24.94	.32	64	.64	51	.96	38	1.4	28	2.2	18
29.0	.27	55	.55	44	.82	33	1.2	24	1.9	15

Down-Conversion	Load = 35		Load = 25		Load = 15	
Freq.	L	C	L	C	L	C
1.8	2.0	1158	2.2	1768	2.0	2701
3.75	.97	556	1.1	849	.97	1296
7.15	.51	291	.56	445	.51	680
10.125	.36	206	.39	314	.36	480
14.175	.36	147	.28	225	.26	343
18.118	.20	115	.22	176	.20	268
21.225	.17	98	.19	150	.17	229
24.94	.15	84	.16	128	.15	195
29.0	.13	72	.14	110	.13	168

The table uses amateur-band center frequencies for all but the limiting bands, where we use a low frequency for 160 meters and a high (but not the highest) frequency on 10 meters.

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.

Table 2. Calculated Values for L-Network matching to various Resistive +/- Reactive loads from 100 to 2500 Ohms. All inductance values (L) in uH, all capacitance values (C) in pF. Loads are in Ohms.

Up-Conversion	R = 100		R = 100		R = 2500		R = 2500	
	X = j100		X = -j100		X = j2500		X = -j2500	
Freq.	L	C	L	C	L	C	L	C
1.8	7.7	1208	7.7	324	44.0	194	44.0	158
3.75	3.7	580	3.7	155	21.1	93	21.1	76
29.0	.48	75	.48	20	2.7	12	2.7	10

Down-Conversion	R = 35		R = 35		R = 15		R = 15	
	X = j35		X = -j35		X = j15		X = -j15	
Freq.	L	C	L	C	L	C		
1.8	2.8	2062*	5.1	1158	0.7	2701	3.4	2701
3.75	1.3	990*	2.5	556	.34	1297	1.6	1297
29.0	.17	128*	.32	72	.04	168	.21	168

....

The starred entries in the down-conversion portion of the table indicate that the required configuration of the balanced L-network is for up-conversion, that is, with a shunt output capacitor. Note the high values of capacitance required for both 160 and 80 meters. such values will likely fall outside the range of what we build into either a 160-10-meter or an 80-10-meter ATU.

At the highest frequency for which I calculated values, down conversion requires the smallest inductance values. 0.2 uH will be difficult enough to attain with the best components; 0.04 uH is outside of practical reality in a multi-band tuner.

Why 160 or 80 Meters Through 10 Meters?

I once designed an SPC single-ended network tuner for 20-10 meters due to the relatively poor performance on my C-L-C single-ended T-network tune on the highest bands (12, 10). No single cause attended the weakness in the 80-10-meter ATU, but the component minimum values and a tight-fitting metal case all contributed to 10-meter problems with a 100' doublet. The SPC unit used Johnson 4.5 kV air variables (a 50 pg single unit and a 50-50 pF split stator), and the rotary inductor had a maximum inductance of 6 uH. The case was no deeper than the original, although the components were considerably shorter. My case was both wider and higher than the commercial case. These measures doubled--at least--the range of matchable impedances, and the component Q was sustained at least through 30 MHz.

Similar thinking is applicable to a balanced L-network. Although we tend to think of an 80-10-meter ATU as some sort of standard, only our demand for convenience has created that standard. Neither commercial nor handbook designs covering those bands tend to address either the range of matchable impedances as it changes with frequency or the loss of component Q with increasing frequency due to strays.

Consequently, it is up to the individual ATU builder to design a unit to meet his or her needs and having the highest component Q available. If attaining a wide tuning range on the upper HF bands requires one to reduce the coverage to 20-10 meters to achieve this goal, then perhaps this is the route to go. In many cases, we shall have to suffer with the shortcomings of a wide-band unit, since it is difficult to carry individual ATUs for each band to a DXpedition on a remote island. Nevertheless, we are not under such restrictions at the home station. As well, it is often easier to find rotary coils with low values at good prices, since they are in far less demand then units with a maximum inductance ranging from 10 to 30 uH.

These notes certainly do not cover every aspect of balanced L-networks. However, they may serve to alert you to both the potentials and the limitations of these substitutes for the link-coupled tuner.

Wiring The Tuner To The Antenna

Balanced transmission line should be used whenever possible between the tuner and the antenna. Using coaxial line in this application invites unpredictable performance and high losses. Commercial transmission line, called "ladder line" because it looks like a continuous ladder, the insulated or bare wires being the 'uprights' and the insulating plastic between them being the 'steps', can be bought easily. Hand-made line, however, can provide superior performance at very low cost. Here is how to make your own if you wish.

Low-Loss "Ladder Line"

By - ray heindl

When I bought my first (and so far only) house, one of the things I was looking forward to was having room to put up antennas for my amateur radio station. Living in an apartment, I had been limited to VHF operation because of the much smaller antennas required (and a lack of HF equipment). With my own yard I would be able to put up one or two modest HF antennas.
My first attempt was a dipole fed with 50-ohm RG-58 coax. It was cut to resonate on 40 meters (7 MHz), so it was about 60 feet long. I would have preferred a longer antenna cut for 80 meters, but my yard is pretty small and the trees aren't ideally located. The dipole worked OK on 40 meters, but not too well on other bands where it was not resonant. It balanced out, though: I couldn't hear anybody, and nobody could hear me. I wanted to use frequencies from 3.5 to 28 MHz, which is a fairly wide range for a single antenna to cover.

The problem is that coax is lossy; that is, part of the signal goes into heating the coax rather than being radiated. For instance, at 3.5 MHz, RG-58 has a loss of about 0.8 dB per 100 feet. This doesn't sound like much -- unless the coax is very long -- but the losses increase dramatically when the antenna and coax impedances are mismatched. I won't get into the details here, but there's a very good discussion of the topic in the *ARRL Handbook for Radio Amateurs* (Chapter 19 in the 1999 edition).

A local ham, K8MT, suggested that I use open-wire line instead of coax. Open-wire line consists of two parallel conductors separated by a dielectric, similar to the 300-ohm flat cable that was once used on TV antennas. The advantage of open-wire line is that it is much less lossy than coax, which is especially important with a mismatch between the antenna and the feedline. An example quoted in the *Handbook*, with a non-resonant antenna, shows a loss of 5.8 dB in 100 feet of high-grade coax, versus 0.3 dB in open wire line -- a huge difference. Open-wire line is less lossy than coax because most of the electric field passes through air, a very efficient dielectric, rather than a solid insulator as is used in coax.

Naturally, the low loss of open-wire line comes at a cost: it must be kept away from other conductors. In coaxial cable the field is contained within the cable, so being near other conductors isn't a problem. But with open-wire line the field surrounds the parallel wires, so other conductors will distort the field. According to *The ARRL Antenna Book*, the line should be kept away from other conductors by two to three times the wire spacing.

That means you can't just drill a hole through your aluminum siding to bring the cable through. If you route the cable through a wall, you also need to be sure there are no foil vapor barriers inside the wall. In addition, the two parallel wires should be equally spaced from any nearby conductors to avoid unbalancing the current in the two wires. You'll need an antenna tuner with a balanced-line output to match the open-wire line to a transmitter. Finally, for safety's sake the cable should be routed where no one can touch it while you're transmitting.

When I decided to switch from coax to open-wire line, I needed to find a source. Unfortunately, all I could find at the time (late '80s) was molded twin-wire type cable, similar to 300-ohm TV cable only bigger. I wanted something with wider spacing and less dielectric between the conductors, to minimize losses due to dielectric between the wires, as well as water or dirt deposits on the cable surface. Since I couldn't find anything commercially available, I decided to make my own.

What I made is known as ladder line. It consists of two wires held parallel by nonconductive spacers. The spacers look like the rungs of a ladder; hence the name. I needed to find a good material for the spacers, and a way to attach the spacers to the wires.

Rooting around in my basement, I came up with some cheesy-looking molded plastic coat hangers. They were shaped like the metal dry-cleaning kind, but made from 1/4" diameter plastic rod. The rod material wasn't particularly round or uniform, but that didn't matter. Each coat hanger would yield two 8.5" and one 15.5" piece of straight rod. I've seen this type in discount stores, in various colors, but I just used up all the ones I found in the basement. Not being married, I can do things like that.

The plastic felt somewhat slippery like polyethylene, although I don't know that it was. The key thing was that it had a low melting point. My plan was to heat a wire and let it melt its way into the plastic.

Before proceeding, I needed to decide on the dimensions of my feedline. According to *The ARRL Antenna Book*, the impedance of a parallel-conductor (open-wire) transmission line is given by:
$Z = 276 \log(b/a)$
where **Z** is the line impedance in ohms, **b** is the center-to-center spacing of the conductors, and **a** is the radius of the conductors, in the same units as **b**. Because I didn't need to match a specific impedance, I could pick convenient dimensions. I chose #16 (0.051" diameter) wire, with a spacing of 2 inches. This combination gives an impedance around 450 ohms, which used to be a standard impedance for commercially-made ladder line. Other standard impedances are 300 and 600 ohms.

I arbitrarily picked 12 inches as the distance between spacers. More spacers would improve the mechanical robustness, but increase the electrical losses -- and the construction effort!
For the wire, I used tinned copper bus-bar. Because it was uninsulated I could make electrical connection to it for heating. The heating device is dead simple - two hefty alligator clips attached to a soldering gun (with the soldering tip removed). I also built a simple jig to hold a spacer and ensure that the wires and spacers were the correct distances apart.

I used an electric jigsaw to cut the hangers into 2.5" lengths. Wire cutters would also work, but the cut ends wouldn't look as nice. The 2.5" length allowed for 2" conductor spacing, with a quarter inch overhang at each end of the spacer to hold the wire.

Assembly was straightforward. I stretched two parallel lengths of straightened bus-bar wire across the length of my basement, held 2" apart at each end. The jig sat on a small table which I slid along under the parallel wires as I attached the spacers. I straightened the wire by simply pulling on it; because it was soft copper this did the job.

To attach a spacer, I first put the 2.5" length of plastic rod into the slot in the jig, then placed it under the parallel wires. A reference mark on the jig, 12" from the slot, ensured that the spacers were evenly spaced, so to speak.

To embed a wire in the plastic, I clipped the alligator clips to the wire on either side of the spacer. With the soldering gun turned on, the wire quickly got hot enough to melt the plastic. I pressed the

wire horizontally against the end of the slot, and vertically down against the rod. When the wire had melted about halfway through the plastic, I turned off the soldering gun and allowed the wire to cool before removing the clips. Repeating the procedure on the other wire, at the other end of the spacer rod, completed the attachment.
Once I had completed enough ladder-line to reach my antenna, I had to run it along the outside of the house.

I used TV antenna cable standoffs from Radio Shack to space the feedline from the house. The standoffs are metal, which is not ideal, but as long as they're centered between the parallel wires they shouldn't be a big problem. Where the line crossed the metal edge of the roof I used a wooden post attached to the side of the house to hold it away from the edge.

Not wanting to drive standoffs through the roof, I suspended the feedline between two supports. Between the supports I put a gradual half-twist in the line, to try to equalize any current imbalances caused by the two conductors not being equal distances from the roof. The two over-the-roof supports have a pair of plastic plates with shallow grooves; the wires are clamped between the plates and held in the grooves by friction. I couldn't rely on holding one of the plastic spacers because the wire can slip through the plastic if you pull it hard enough.

I've been using this line for over ten years now, with only one problem. Between the last support on the roof and the connection to the antenna (a wire dipole), about 20 feet of the line is suspended. When the antenna moves in the wind the feedline flexes at the last support. After a few years of Lake Erie winds, the soft copper wire broke at the support. I replaced a couple feet of the copper wire, on either side of the support, with Copperweld copper-clad steel wire, and haven't had a problem since.

The antenna at the end of the ladder line is another 40-meter dipole. Using an antenna tuner, I can get a good match with low loss on all the bands from 80 to 10 meters (3.5 to 28 MHz). With the new antenna and feedline, I can hear plenty of people, and most of them can hear me.

For more information, *The ARRL Antenna Book* has a good discussion of open-wire transmission lines. *The ARRL Handbook* is also a good source.

Putting a Balun and a Tuner Together

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Introduction

Commercial antenna tuners use unbalanced circuits such a Pi-, T-, or L-network to match unbalanced loads to 50 ohms for our transmitters. A simple way to include the capability to handle balanced loads is to include a balun somewhere in the circuit. Johnson Matchbox tuners, which are no longer produced, but can sometimes be found at hamfests, have a balanced output circuit and a link coupled input to make the transformation from the unbalanced input to a balanced output. Some hams still build tuners this way too.

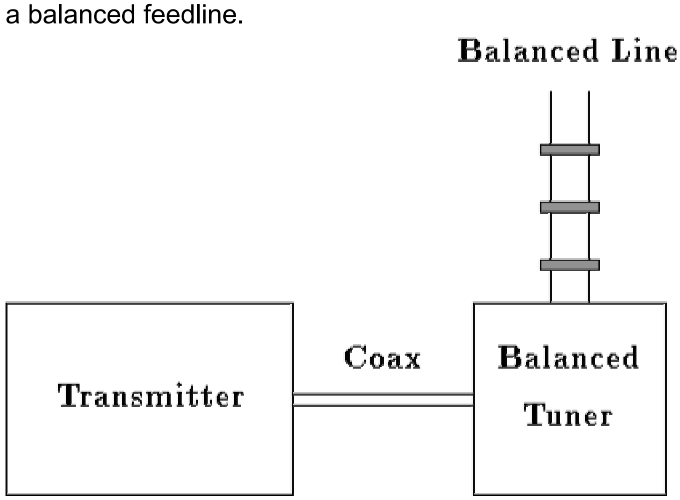
Since a simple multiband antenna is a center fed wire fed with twinlead or windowline to an antenna tuner, a beginning ham (and even some old timers) can wonder what is the best or at least a good way of handling the two jobs of impedance matching and changing from twinlead or windowline from the antenna to coax at the transmitter.

Typical solutions are summarized as:
Use a balun to connect from the twinlead to an unbalanced tuner. That is use a balun on the output of an unbalanced tuner as shown in figure 1.

Connect a balun to the input of an unbalanced tuner and ``float'' the tuner. The output of the tuner is connected to the twinlead; one side of the twinlead goes to the center conductor of the unbalanced output connector and the other to the case of the tuner. That is, use a balun at the input of an unbalanced tuner as shown in figure 2.

Use a balanced tuner configuration to convert the twinlead impedance to 50 ohms balanced and then use a 1:1 balun to convert to 50 ohms unbalanced. That is, use a balun on the input of a balanced tuner as shown in figure 3.

Figure 1: A transmitter connected to an unbalanced tuner with a balun on its output connecting to a balanced feedline.



In all of the following, I will assume that the balun is a 1:1 choke or current type. Examples are the ferrite bead balun described by Walter Maxwell, W2DU[1], coiled up coax, and coax or a bifilar winding through a toroidal core. A nonradiating balanced transmission line requires that the current in the two conductors be the same. If, for example, the balanced line is poorly routed, the currents in the two wires can become different because of unequal coupling to their surroundings. Even so, to minimize transmission line radiation near the transmitter (and operator) the currents in the two wires should still be equalized at the transmitter. Again, this tells us that the best choice will be a choke or current balun.

Figure 2: A transmitter connected to a balun to an unbalanced tuner to a balanced feedline.

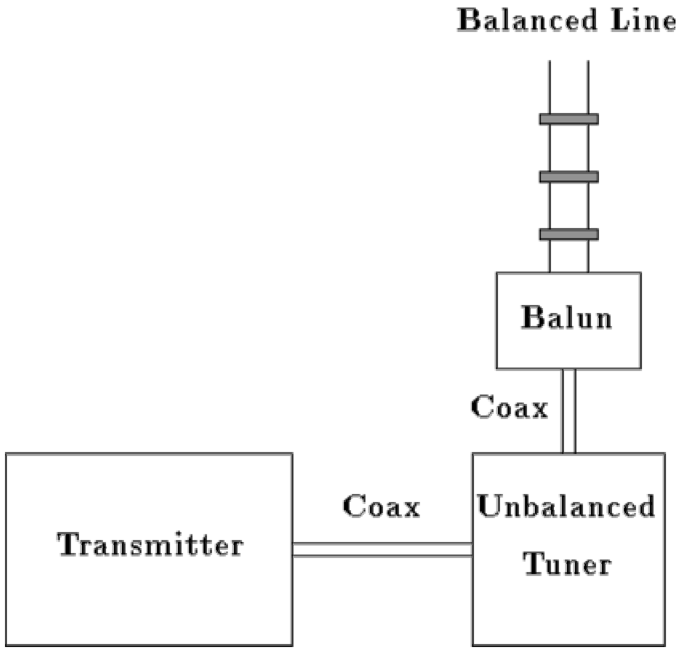
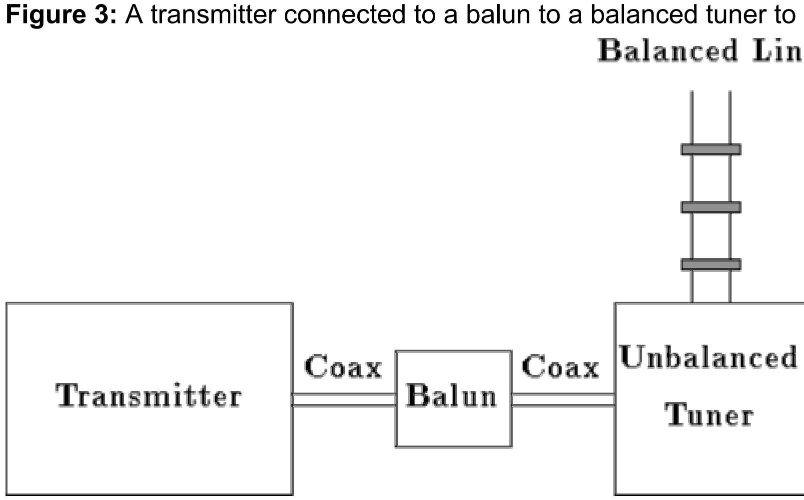


Figure 3: A transmitter connected to a balun to a balanced tuner to a balanced feedline.

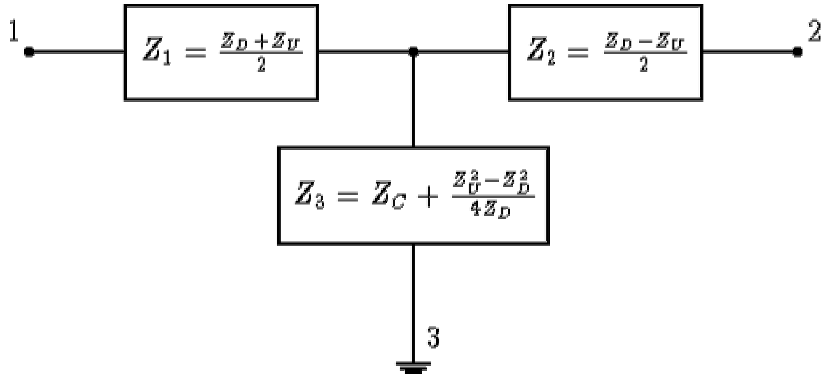


A two wire transmission line as a three terminal Device

Commercial transmitters have unbalanced outputs. That is the output is taken between the output connectors center conductor and the transmitter case. I will call the transmitter case ground. That is, whenever an impedance is measured between a point in the circuit and ground, it means that the point is close to the transmitter case, and the impedance is measured between that point and the transmitter case.

The two wires of our balanced transmission line are two connections with some impedance across them from the antenna. In addition, the lines will have an impedance to ground. For example a quarter wave length of twinlead, both wires connected together and driven against ground will would look like a quarter wave monopole. If the antenna is not well balanced or if one of the transmission line wires runs close to another conductor, the line can be unbalanced to some extent. That means that the impedance measured between one of the lines and ground is not the same as between the other line and ground. A general two-wire transmission line ending up near our transmitter can be represented as a T equivalent circuit as shown in figure 4. If I put a current into one wire of the transmission line and remove it from the other, this is the differential mode of the line. The resulting impedance I will call Z_D or the differential mode impedance. If I connect both wires together, and drive them against ground, I call the resulting impedance the common mode impedance Z_C . Finally, if the impedance from each wire to ground is not the same, this is unbalance which I'll represent as Z_U . The labeling in figure 4 shows how these impedances relate to the three impedances of the T equivalent circuit. Notice if the twinlead is well balanced that $Z_U = 0$,

Figure 4: The two wires of a balanced transmission line are labeled connections 1 and 2, and the case of the transmitter is labeled as connection 3. The impedances between these three points when they are close together can be represented in a T-equivalent circuit by three impedances: a differential mode impedance Z_D , a common mode impedance Z_C and an unbalancing impedance Z_U .



These impedances can be measured with inexpensive equipment. One of my antennas is a ``dipole'' about 60 feet on a leg running around the outside of my 1 story house. It is fed by about 30 feet of 300 ohm TV twinlead. The legs of the ``dipole'' are not straight, and it isn't symmetric about the feedpoint since the shack is at a corner of the house. I have measured Z_D , Z_U , and Z_C , at 3.52 MHz to be:

$Z_D = 158 + j\,533\ \Omega$
$Z_U = 224 + j\,182\ \Omega$
$Z_C = 887 + j\,622\ \Omega$.

As you can see the system is not well balanced at all The method of measuring these impedances is described in the appendix. I highly recommend making some measurements to better determine the best solution to match the feedline impedance.

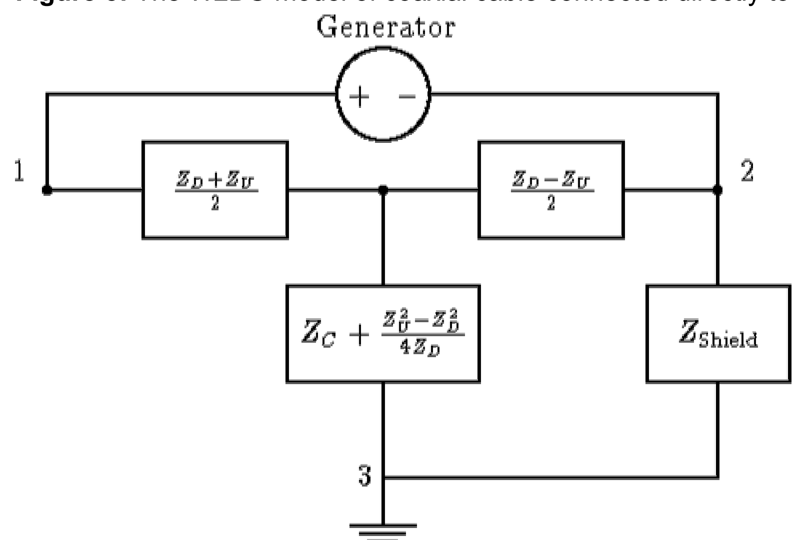
The W2DU and W7EL models of a choke balun

I now have a circuit equivalent of our antenna and transmission line. Since the circuit for tuners is well known, this leaves only the equivalent circuit for a choke balun to allow us to analyze our tuner-balun-antenna sytem using standard circuit theory.

Two useful and equivalent models of a choke balun are those described by Walter Maxwell, W2DU and Roy Lewallen, W7EL. In Maxwell's model, of a choke balun, he uses the fact that the coax shield is many skin depths thick so that it shields the outside from fields on the inside of the coax. The only place the fields can escape is therefore at the end where the coax is connected to a balun or to some other load. A well shielded transmitter driving one end of the coax therefore can only produce external fields at the other end of the coax. You can think of the transmitter as producing a voltage across the points where the center conductor and the shield of the coax attach. At this point, the internal fields escape, and can cause currents to flow on the outside of the outer conductor of the coax.

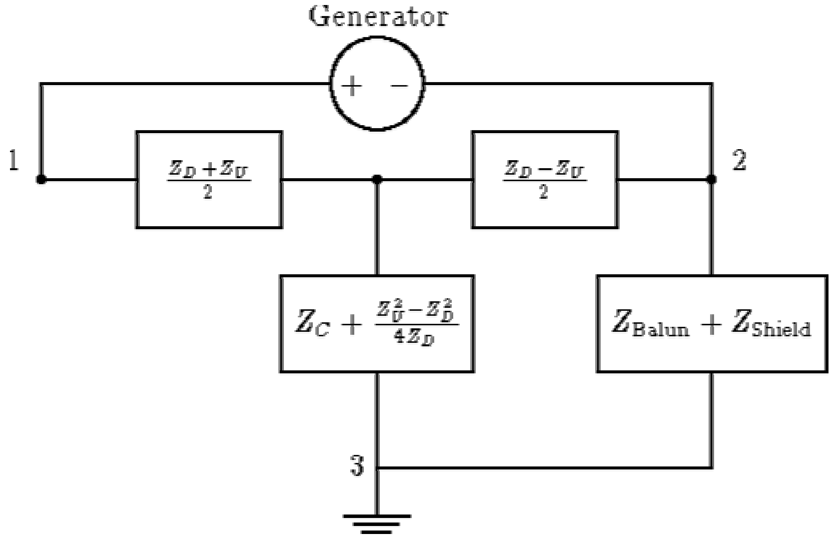
The equivalent setup is is shown in figure 5. The transmitter applies a voltage between the inner and outer conductors of the coax, and the outside of the outer conductor of the coax is then another part of the system. If I use no balun, and simply connect our coax to the twinlead, center conductor to terminal 1 and shield to terminal 2, the transmitter applies a voltage across terminals 1 and 2 in figure 4. The outside of the outer conductor presents an impedance Z_{Shield} back to the case of the transmitter which I have taken to be terminal 3. That means that this impedance is placed from terminal 2 to 3 as shown in figure 5.

Figure 5: The W2DU model of coaxial cable connected directly to a balanced line.



A choke balun made by coiling up coax would change the impedance of the outside of the coax shield to the inductive reactance of the coil. A choke balun made from ferrite beads slipped over the outside of the coax will also increase this impedance. In his July 1983 QST article Maxwell gave measurements of about 15.6 + *j*13.1 ohms per bead at 4 MHz for #73 beads. (However, I recently bought a bead balun kit at a hamfest which claimed to be 50 #73 beads. My balun measured 660 + *j*438 ohms or 13 + *j*9 ohms per bead 4 MHz. Apparently, all beads are not created equal, and it is prudent to make a few measurements to see how many beads are needed to make a good balun with your materials.) Adding this impedance in series with Z_{Shield} gives the balun common mode impedance Z_{Balun} and the circuit shown in figure 6. Since there is only a single connection to ground, I have dropped this connection to simplify the circuit diagram. Notice that Z_{Balun} is connected in series with Z_C so it effectively just increases Z_C .

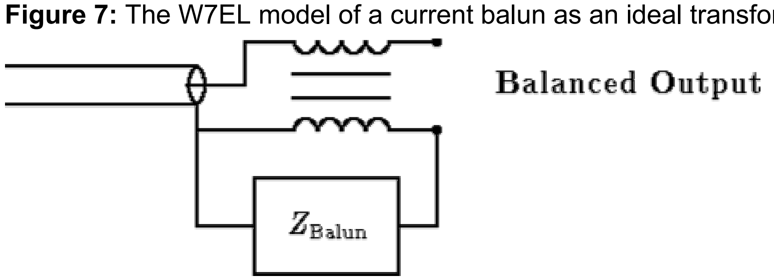
Figure 6: The W2DU model of a coaxial cable choke balun driving a balanced transmission line.



Maxwell's analysis gives a simple rule for understanding a choke balun connected to the three terminal network given by our twinlead fed antenna. Simply connect the balun common mode impedance from the terminal 2 to 3, and drive the antenna across terminals 1 and 2. If the current through terminal 3 is made small enough by the balun impedance, then the drive current is balanced between terminals 1 and 2.

Roy Lewallen, W7EL, has given model of a choke balun by using an ideal transformer as shown in figure 7. The connection shown is schematically the same as that normally drawn for a bifilar wound choke balun. A real balun is not an ideal transformer (nothing is), so the impedance Z_{Balun} is added. The ideal transformer performs exactly the same task as the independent generator in the W2DU model. The W7EL model is equivalent to W2DU's model. The advantage is that you can write down a complete equivalent circuit for the tuner, balun, and antenna immediately without applying Maxwell's rules.

Figure 7: The W7EL model of a current balun as an ideal transformer and an extra impedance



Baluns on the input and output of unbalanced tuners

Roy, W7EL, worked out the math for moving a current balun from output to input of an unbalanced tuner using his model of a choke balun and found that essentially nothing changed.[2] I'll look at a particular case later, but it is easy to see this result using the W2DU model of a choke balun.

Assume a transmitter is connected with a short length of coax to a well shielded unbalanced tuner which is connected to another short piece of coax to our twinlead. Also assume that while the transmitter may be grounded, that the rest of this does not have additional connections.

Since the shield is continuous from the transmitter around the tuner to the end of the output coax, I can apply the same analysis as Walter Maxwell did and what happens inside the tuner and coax is immaterial for what happens outside. Changing the tuner adjustment will change the impedance the transmitter sees, but it does nothing else. In any case, assume that the tuner is always adjusted so the transmitter sees a 50 ohm load.

Now replace the output coax jumper with a 1:1 current balun at the output of the tuner. W2DU's model tells us to replace the inner conductor with a generator across the balun output, and an additional impedance from the choke in series with the shield impedance back to the transmitter. Move the balun to the coax at the input to the tuner, and analyze the system. In this case, because the tuner is also shielded, the generator that W2DU tells us should be at the tuner input can be moved (with a different source impedance) to the tuner output. In that case all that has changed is the position of the choke.

The only difference between these situations is that we have moved the choke balun to a slightly different point on a feedline. If you built a tuner so that it was a cylinder a foot long with the same outside diameter as RG-8, with the input on one end and the output on the other, you could move the balun from input to output by simply sliding the your ferrite beads along the "feedline" by a foot or so. If you use a air wound coil, you would simply move the coil one foot along the feedline. This really can't do anything useful unless the tuner is poorly constructed. In that case fixing the tuner would be more useful. The one difference that you might see in the two cases would be if the tuner case itself had substantial self capacitance or if it had capacitance back to the transmitter case. In the latter case, a balun at the input of the tuner could be ``short-circuited'' by the tuner-transmitter case capacitance. This might happen if both rested close to a large metal desk or shelves. The tuner case self capacitance is easily estimated. A rough estimate is to take the largest dimension of the case in centimeters, divide this by 2 and you have a rough estimate of the self capacitance of the cabinet in picofarads. For a cabinet of 30 cm on a side this would give 15 pF, or about 3000 ohms at 80 meters - probably not low enough to worry too much about, but the most sensible place to put a balun is on an <u>unbalanced</u> tuner's output, like it is on nearly all commercial tuners, and not on its input.

Notice that the above says nothing about the effectiveness or lack of effectiveness of the balun. It simply says it is essentially equally effective or ineffective on the input and output sides of an unbalanced tuner.

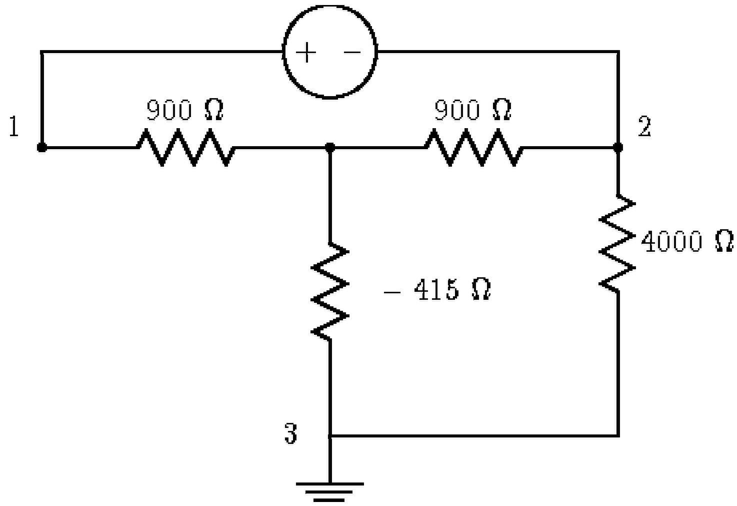
The effectiveness of a balun

Let me analyze a simple case of a perfect quarter wave balanced line with a 300 ohm characteristic impedance terminated in a 50 ohm resistor. The line goes vertically straight up and the ground is assumed perfectly conducting. The reason for all of these assumptions is so I can make simple estimates of what the impedances are. The situation I am modeling is the case where the input to the feedline has a small common mode impedance, and a large differential mode impedance.

$Z_D = 300^2/50$ or 1800 ohms resistive. Z_C will be the impedance of a quarter wave vertical driven against ground or about 35 ohms resistive. $Z_1 = Z_2 = 900$ ohms, $Z_3 = -415$ ohms, where the labeling is given in figure 4.

Now lets hook up our ferrite bead balun by connecting the shield of the coax to terminal 2 and the center conductor to 1. A large ferrite bead balun will introduce an impedance of around $|Z_{Bal}| =$ 6000 ohms from point 2 to ground. (Walter Maxwell's March 1983 QST article gives these values, he measured about 6000 ohms with both R and X around 4000 at 4MHz for a bead balun made from 300 #73 beads). Again, to simplify things I'll just assume the balun is resistive and has a resistance of 4000 ohms. The circuit looks like a driving voltage across $Z_1 + (Z_2 \ || \ (Z_{Balun} + Z_3))$, where || means take the parallel combination. This is shown in figure 8.

Figure 8: The W2DU model of a unbalanced line and current balun driving a balanced line with differential mode resistance of 1800 ohms and common mode resistance of 35 ohms.



The impedance is $Z_D/2 + (Z_{Balun} + Z_C - Z_D/4)Z_D/(2(Z_{Balun} + Z_C + Z_D/4))$. For the balun to work well the second term should also contribute $Z_D/2$, so I want $(Z_{Balun} + Z_C - Z_D/4)/(Z_{Balun} + Z_C + Z_D/4)$ to be close to one. That is I want $Z_{Balun} + Z_C$ to be much larger than $Z_D/2$. Checking this case, $Z_{Balun} + Z_C$ is about 4000 ohms, and $Z_D/2$ is 900 ohms, so the second term is about 80 percent of the first. That means for 1 volt across the terminals, there will be approximately 1/2 volt across the ferrite. The relative dissipation in the balun is therefore 1800/(4 x 4000) or 11 percent. At 1500 watts output that's about 170 watts dissipated in the balun which may be more than it can take. A smaller balun with only a 1000 ohm impedance will be worse.

Another example is to simply take an 1800 ohm 1/2 watt resistor and hook it to your balun. Since the resistor has a very large common mode impedance, you would have $Z_1 = Z_2 = 900$ and Z_3 a very large value. The balun is now in series with Z_3 , and since Z_3 is very large, even though the differential mode impedance is identical, there is no problem, in fact in this case, you don't even need a balun since shorting 2 to ground still doesn't allow any substantial common mode current flow.

Now let's see what happens if a balanced tuner is added to the first case. Picking a balanced L network to transform to 50 ohms I can use a parallel capacitor of 304 ohms across terminals 1 and 2 as in figure 9 which has the equivalent circuit shown in figure 10.

Figure 9: The equivalent circuit of the balanced feedline of figure 8 with a 304 ohm capacitor across the feedline terminals.

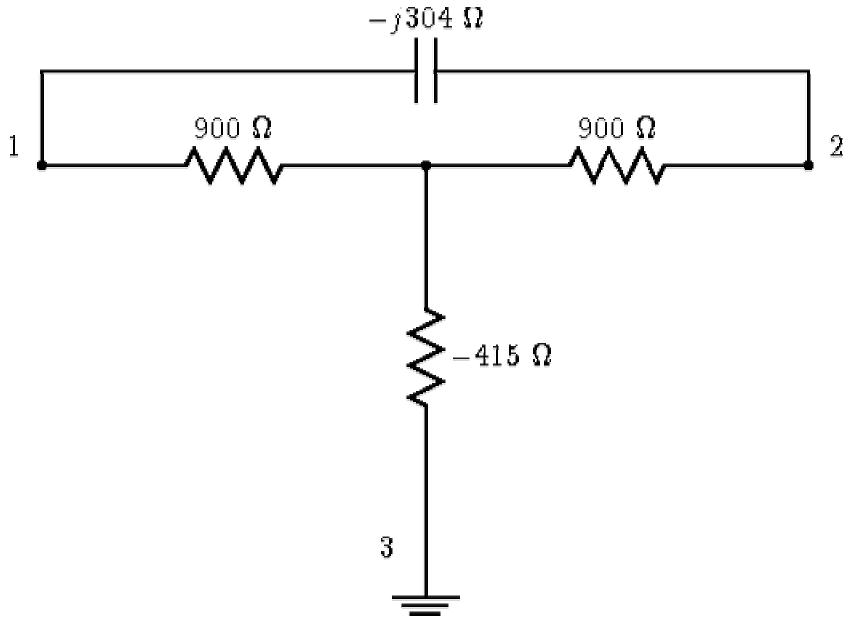
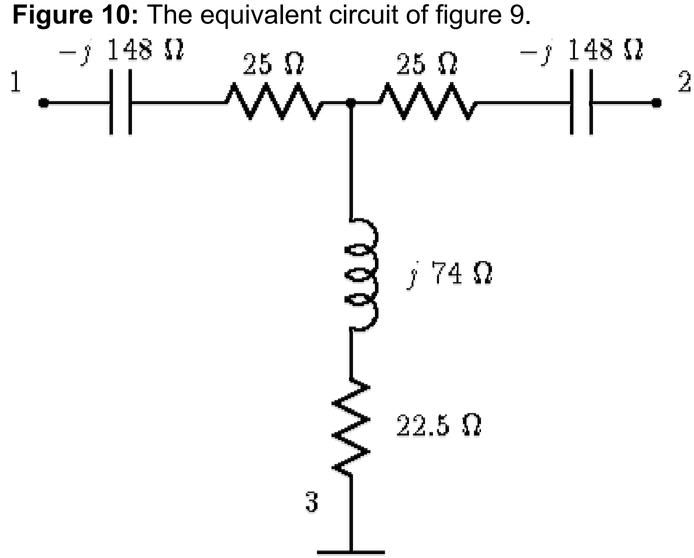
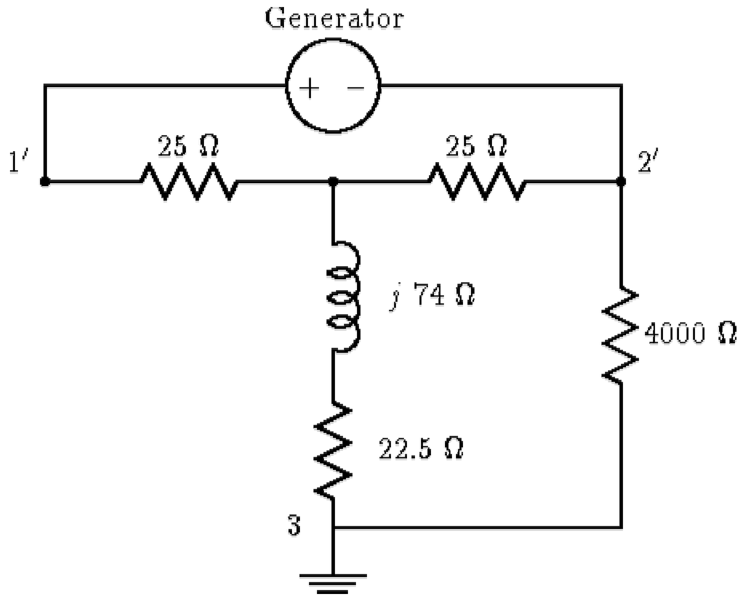


Figure 10: The equivalent circuit of figure 9.



A pair of series inductors of 148 ohms from terminal 1 to a new terminal 1' and from 2 to a new terminal 2' will cancel the differential mode capacitive reactance and when the W2DU balun is attached the equivalent circuit is shown in figure 11.

Figure 11: The complete equivalent circuit of the example of figure 8 with a balanced L-network transforming the differential mode impedance to 50 ohms.

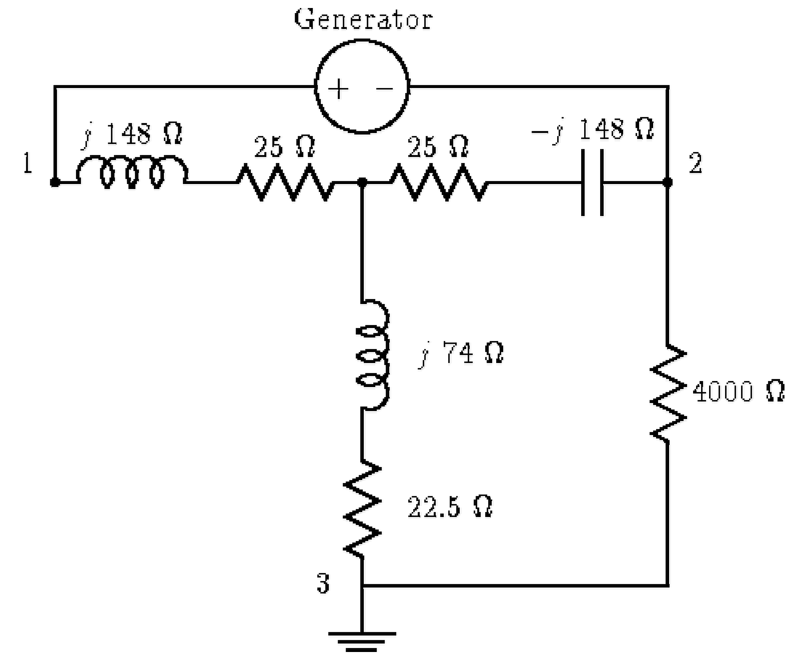


The new differential mode impedance is 50 ohms. The new common mode impedance is the old value plus the impedance of the two parallel inductors = 35 +j 74 ohms.

Clearly the balun will work exceptionally well now. For a voltage V across 1' and 2', the power into the load will be approximately $|V|^2/50$. The power into our balun will be roughly $|V|^2/(4Z_{Balun})$. The ratio is $12.5/Z_{Balun}$ or about 1 percent of the of the power for a 1000 ohm balun and 4 times less for the 4000 ohm balun. 1500 watts input gives 5 to 20 watts dissipated which I think a bead balun can easily stand. So changing from an unbalanced tuner with a balun on either the input or output to a balanced tuner with the balun on the input can really help. An advantage a substantially resistive balun like a ferrite balun is that there is no danger of cancellation in the $Z_{Balun} + Z_C$ term since the resistive parts of both must be positive.

The idea that an unbalanced tuner will transform the differential mode impedance to 50 ohms is correct. Why is it that it doesn't help in reducing the common mode currents? I have already shown that moving the balun to the input can't help matters. Let's see what happens to the equivalent circuit when an unbalanced tuner is added. An unbalanced L network would include a single series inductor rather than the two that I used above. Adding this single series inductor to the circuit of figure 11 gives the circuit shown in figure 12.

Figure 12: The equivalent circuit of the balun on the input of an unbalance tuner.



Notice that for the differential mode impedance is 50 ohms, but there is now a 148 ohm reactance that must be included in the unbalancing impedance Z_U of figure 4. The balun impedance must also be much larger than this impedance to be effective. An unbalanced tuner trades the large differential mode impedance for a large unbalanced impedance making the balun's job unchanged. I can calculate the approximate dissipation in our balun of figure 12. If I (correctly) assume that the balun current is low compared to the current through the 25 ohm load resistors, the power dissipated in the resistors will be $|I|^2 50$ where I is the current through the resistors.

Since the balun impedance is large, I can ignore the 74 ohm inductive reactance and the 22.5 ohm resistance. The magnitude of the voltage across the balun in then approximately $|I| \sqrt{25^2 + 148^2}$, and the power dissipated in the balun divided by the power dissipated in the load is $(25^2 + 148^2)/(50 \times 4000)$ or 11 percent just as before I added the tuner. Notice that $4(25^2 + 148^2)/50 = 1800$; this is simply the design equation used to calculate the L-network that transforms an 1800 ohm resistance to 50 ohms.

Conclusion

The results described here are simple.
As noted by Roy Lewallen, W7EL,[2] putting a choke balun on the input of an unbalanced tuner to drive a balanced line is useless. It introduces a ``hot'' tuner case which must be isolated with no benefit over putting the balun on the output.

Well balanced loads with a high differential mode impedance and a low common mode impedance can stress a balun connected to the output of an unbalanced tuner.
Methods that lower the differential mode impedance without upsetting the balance of the load make the balun's job easier.

Richard Measures, AG6K, described a balanced tuner with a balun on its input in February 1990 QST[3]. Since the balanced tuner transforms the differential mode impedance to 50 ohms, the tuner and balun combination will work well. The extra cost of the balanced tuner is the main disadvantage.

For cases where a balun on the output of an unbalanced tuner is stressed, a brute force solution would be to use a bigger balun. In some cases this may be the most convenient and least expensive solution. Doubling the size of a bead balun should double its impedance which will cut the dissipation in half and doubling the physical size of the balun makes it better able to dissipate heat.

Another possibility is to change the balanced feedline length. Cecil Moore, W6RCA, has advocated the use of this technique, and has developed methods to switch in extra feedline to tune balanced loads. His methods are described in detail on his Web page http://people.delphi.com/CecilMoore/index.html . One method is to add feedline so that a current maximum is located at the balun connection. The differential mode feedpoint impedance is resistive there and has a value of Z_0/SWR where Z_0 is the characteristic impedance of the line, for example 300 ohms, and SWR is the standing wave ratio on the line. Since this cannot be greater than Z_0 , the balun will perform well.

Appendix: Measuring Z_D , Z_C , and Z_U

To measure the differential Z_D , common mode Z_C , and unbalanced Z_U impedances, you need an rf impedance measuring instrument like an impedance bridge, noise bridge, vector voltmeter, or network analyzer. For high frequency work I use an old General Radio GR821A twin-T admittance measuring circuit. The main disadvantage of using an old piece of gear like this is that it is slow. The main advantage is that they can be found for very little money, and they measure impedance from 0.4 to 40 MHz. For these measurements, the case of the GR821A is the ``ground.'' I normally set it on the operating desk with a strap to the same safety ground point that the transmitter connects to. The GR821A measures admittance, and requires corrections to the measured values as described in its manual. The GR821A easily measures high impedances, but low impedance values are often outside its range and require the use of a series capacitor to bring the impedance into range. The impedance of the capacitor can then be subtracted off. The inclusion of the corrections, and conversion from admittance to impedance is conveniently done using a programmable calculator or the shack computer. I have written a web based applet that does this. It is available at http://fermi.la.asu.edu/w9cf , and will run within any Java activated web browser. Many hams have noise bridges, and these can be used if they are fairly accurate. To measure high impedances, they will generally require the addition of a shunt capacitor to bring the impedance into the range of the bridge. Again a programmable calculator or computer is handy to do the needed calculations to get the correct impedance.

I measure Z_C by connecting both leads of the twinlead together and measuring the impedance to ground. Next I connect wire 2 to ground and measure the impedance between wire 1 and ground and call this Z_a . Reversing the connections, by grounding wire 1 and measuring between wire 2 and ground gives Z_b .
A straightforward application of circuit theory gives the equations:

$$Z_D = \frac{4Z_a^2 Z_b^2 Z_C}{S}$$

$$Z_U = \frac{4Z_C^2 Z_a Z_b (Z_a - Z_b)}{S} \qquad (1)$$

where S stands for the expression

$$S = Z_a Z_C(2Z_b^2 - Z_a Z_C) + Z_a Z_b(2Z_C^2 - Z_a Z_b) + Z_b Z_C(2Z_a^2 - Z_b Z_C). \qquad (2)$$

If $Z_a = Z_b$, the system is balanced and Z_U is zero. In that case, the expression for the differential mode impedance also simplifies to

$$Z_D = \frac{4 Z_a Z_C}{4 Z_C - Z_a} \quad \textit{only when} \quad Z_a = Z_b \tag{3}$$

Obviously, the calculations above are tedious unless a programmable calculator or a computer program are used.

References

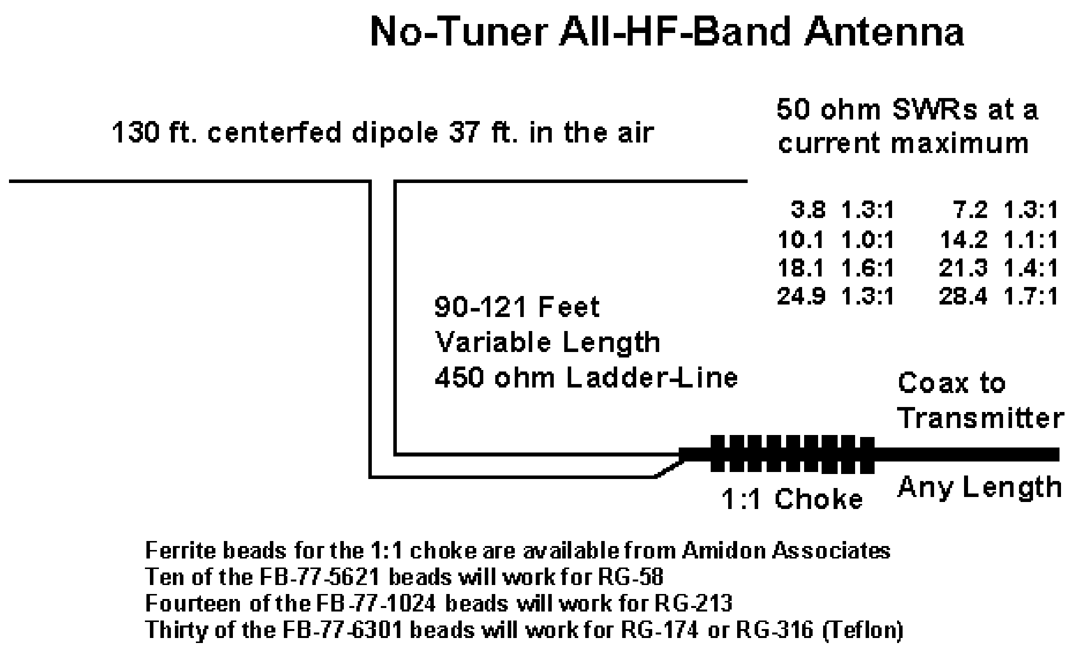
1
Walter Maxwell, W2DU, ``Some Aspects of the Balun Problem,'' QST, March 1983, p. 38.

2
Roy Lewallen, W7EL, ``The 1:1 Current Balun,'' 1995. Available via the internet in the file ftp://www.teleport.com/~w7el/ibalun.txt.

3
Richard Measures, AG6K, ``A Balanced Balanced Antenna Tuner,'' QST, February 1990.

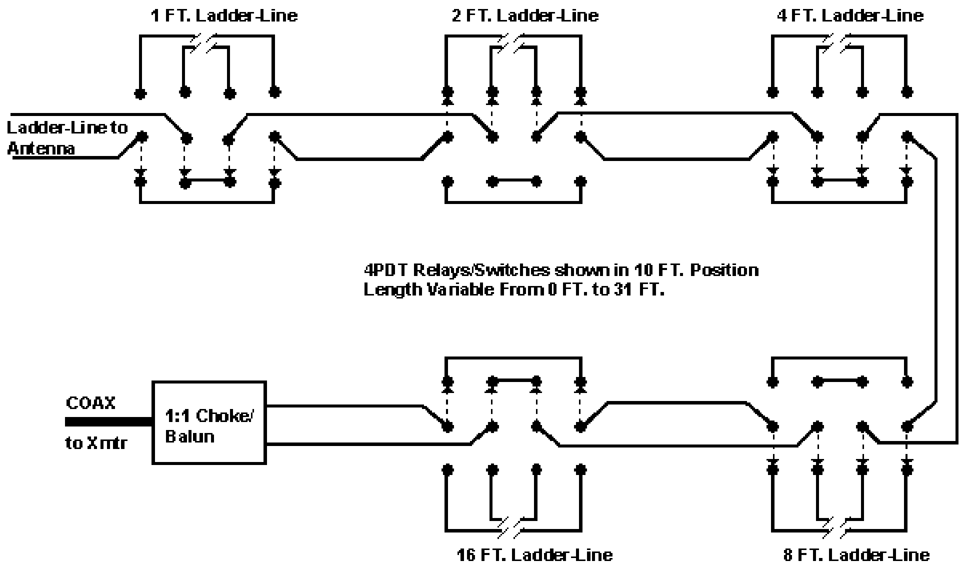
Tuning Specific Bands With A Switched-Length Ladder Line

W5DXP's No-Tuner, All-HF-Band, Horizontal, Center-Fed Antenna



The No-Tuner, All-HF-Band, Horizontal, Center-Fed Antenna is our old friend, the 80 meter halfwave dipole dressed up a bit. By varying the length of the 450 ohm ladder-line feeding the antenna, we can achieve an SWR of less than 2:1 on all frequencies on all HF bands with the exception of the lowest part of 80m. On 75m, we are feeding the antenna with a half-wavelength of ladder-line. On 40m, we are feeding it with 3/4 wavelength of ladder-line.
No antenna pruning required. My transmission line really does tune my antenna system.
Special thanks to Walt Maxwell, W2DU and Jim Bromley, K7JEB.

Ladder-Line Length Selector for Our All-Band Dipole



The length is continuously adjustable in one foot increments from zero to 31 feet.

The Ladder-Line Length Selector actually does tune the antenna system so no conventional "antenna tuner" is needed - no coils and no capacitors. Switches or relays (remote control) can be used for the switching function and should be sized according to the RF power levels involved. W5DXP presently uses ten DPDT Knife switches attached to a piece of plexiglas mounted in the hamshack window. For portable or backpacking use, the length selector function can be performed simply by 1/2/4/8/16 foot pieces of ladder-line with mating connectors on the end. The proper length of ladder-line is selected to cause resonance in the antenna system.

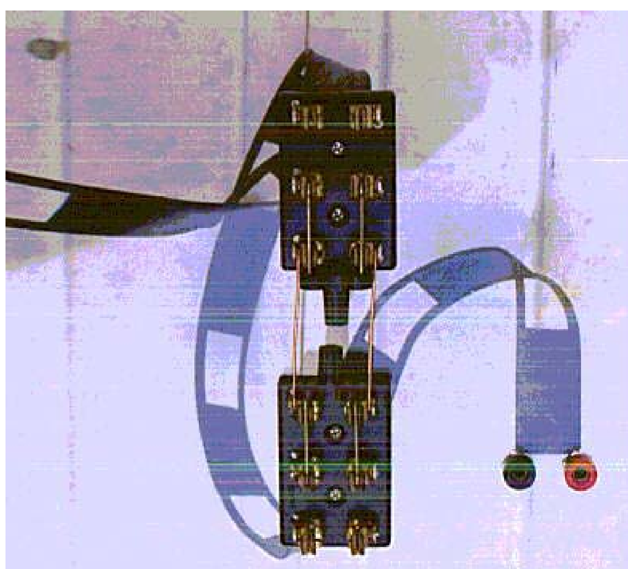
Here's a table that explains it all. The transmission line always consists of a matching section and from zero to six halfwavelengths of ladder-line. The impedance at the antenna is shown along with the 450 ohm SWR and the impedance at the transmitter is shown along with the 50 ohm SWR, i.e. the SWR seen by the transmitter.

..Freq-MHz..	..T-line length = Matching Section + 1/2WL's..	..Impedance at XMTR..	..50 ohm SWR..	..Impedance at Antenna..	..450 ohm SWR..
3.8	109.5' = 109.5' + 0	69 ohms	1.4:1	71+j84	6.6:1
7.2	92.0' = 30.5' + 1x61.5'	40 ohms	1.2:1	4939-j716	11.2:1
10.125	99.4' = 12.0' + 2x43.7'	50 ohms	1.0:1	116-j510	9.1:1
14.2	110.2" = 16.6' + 3x31.2'	53 ohms	1.1:1	2120+j1886	8.5:1
18.14	101.9' = 4.3' + 4x24.4'	81 ohms	1.6:1	111-j267	5.5:1
21.3	94.8' = 11.6' + 4x20.8'	70 ohms	1.4:1	1210+j1378	6.4:1
24.95	94.1' = 5.35' + 5x17.75'	65 ohms	1.3:1	186-j593	6.9:1
28.4	102.8' = 9.2' + 6x15.6'	87 ohms	1.7:1	721+j1009	5.2:1

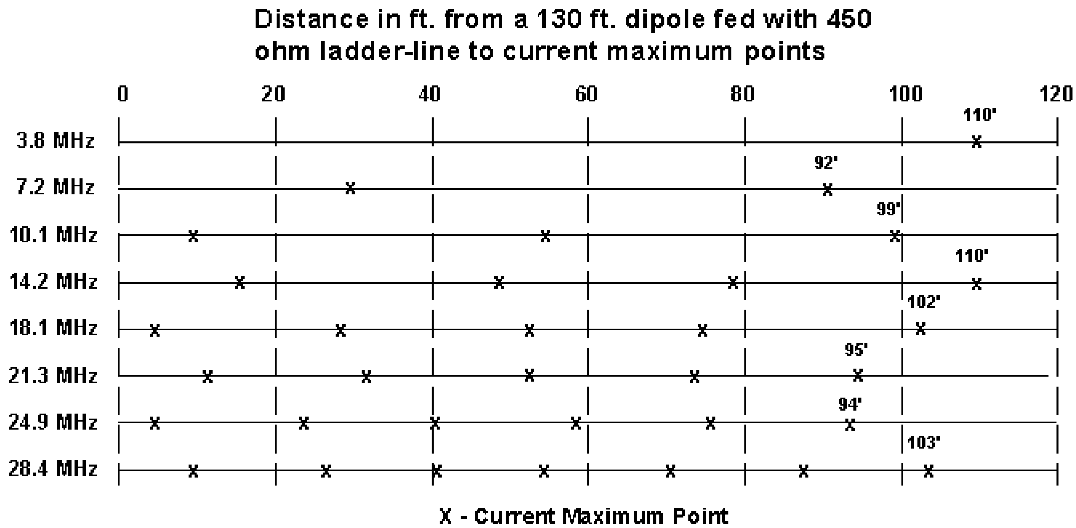
Graphic Data Presentation Using Smith Chart (100k)

75M Graphs	40M Graphs	30M Graphs	20M Graphs	17M Graphs	15M Graphs	12M Graphs	10M Graphs

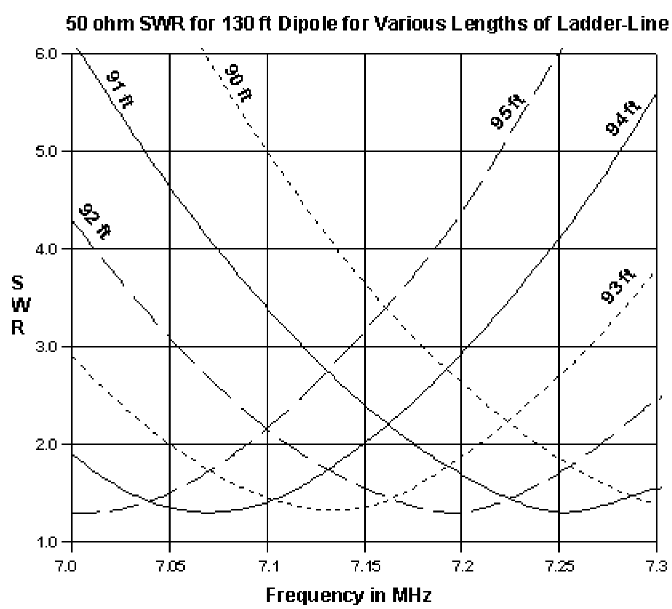
Here are the ten DPDT switches mounted on a piece of plexiglas that mounts in W5DXP's hamshack window. It shows the ten DPDT switches with the one foot, two feet, and four feet loops installed. The eight feet and 16 feet loops are not installed yet in this picture. RF flow is right to left from banana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



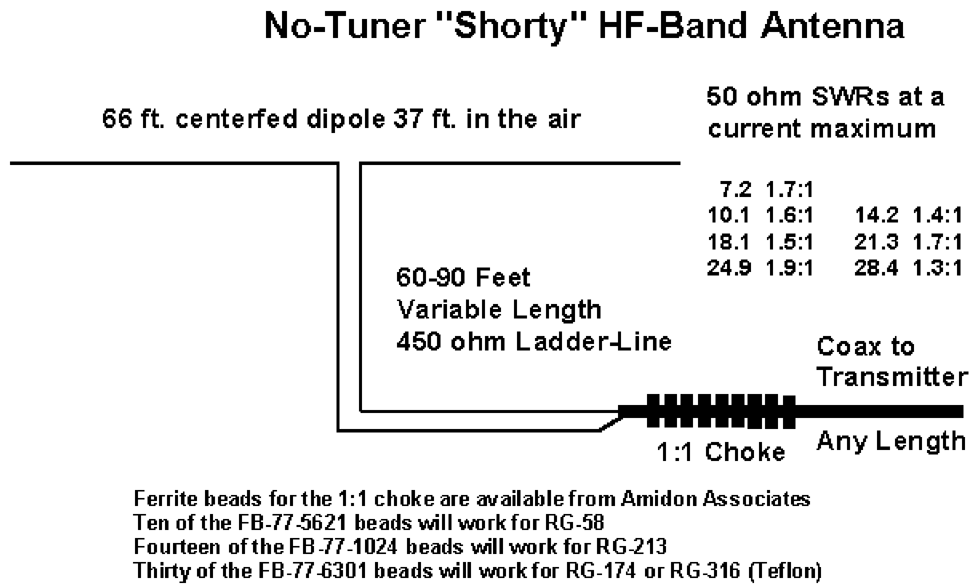
Here's a close up view of the one foot section. The RF flow is right to left into the banana sockets. The switches are shown in the shorted position, i.e. the one foot loop is floating completely out of the circuit to avoid capacitive effects. The bare copper wires in the center are the short. When the 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.



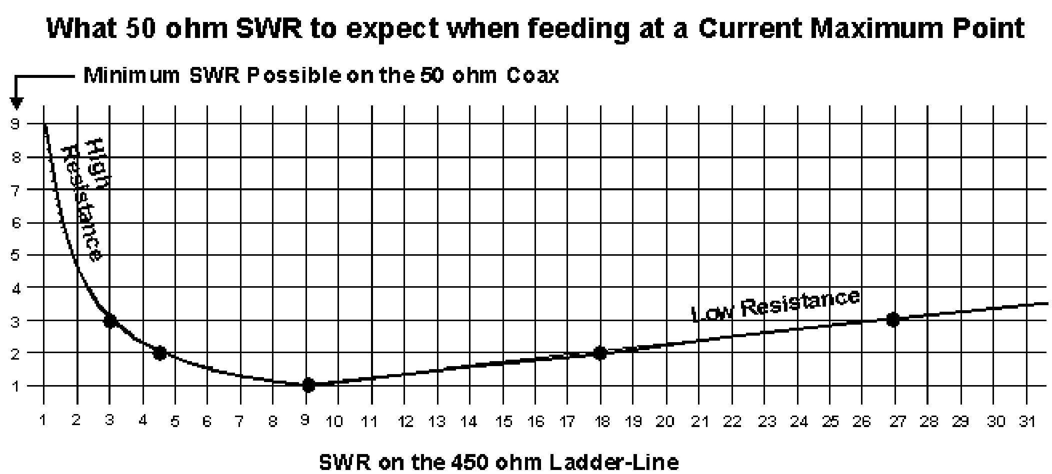
This is a plot of all the current maximum points between the antenna and W5DXP's shack. The transmission line is 90 feet long and the Ladder-Line Length Selector can add in an additional zero to 31 feet for a total of 90 feet to 121 feet. 90 feet matches the antenna on about 7.3 MHz and 121 feet matches the antenna on about 3.6 MHz. The matching points for all the other HF bands lie between these two extremes. Note that if a fixed length of ladder-line needs to be chosen for best results with this antenna, that length should be around 100 ft. which should work with internal autotuners. Caution: Do not expect a similar antenna erected in a different location to exactly match W5DXP's results. The antenna environment has a large effect on the antenna characteristics so W5DXP's results are only approximations when applied to other antenna locations and environments. Mounting this antenna in an inverted-V configuration, for instance, is likely to change the characteristics by an unexpected amount. "450" ohm ladder-line characteristic impedance varies all the way down to 375 ohms for the #14 stranded configuration and velocity factor varies among the different manufacturers and batches of ladder-line.



Who says a full-wave dipole is hard to match? Here's what EZNEC predicts will be the 50 ohm SWR across the 40 meter band for W5DXP's No-Tuner All-HF-Band Antenna given the chart lengths of ladder-line. Similar SWRs occur in similar patterns on the other HF bands.

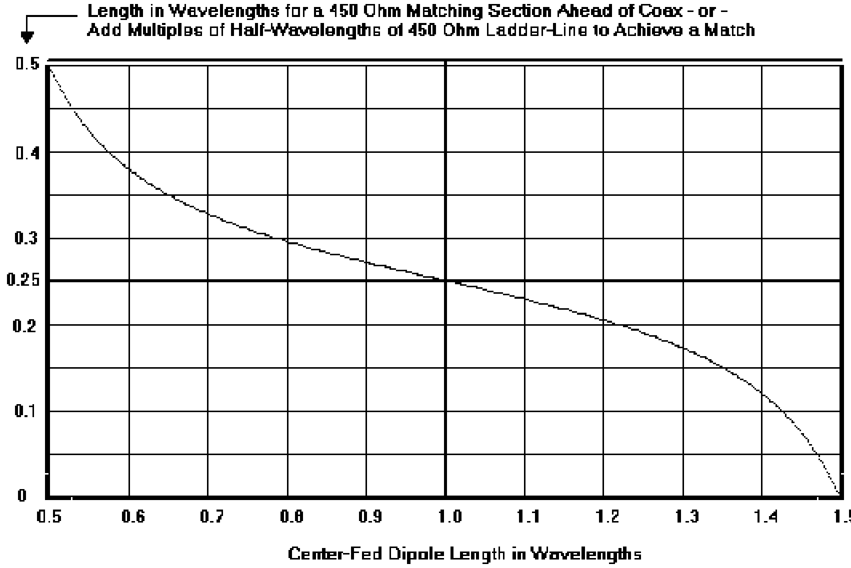


For those who don't have the space for a 130 foot antenna, here's a "Shorty" version designed to work on all HF ham frequencies above 7 MHz. Like the bigger version, the 50 ohm SWRs predicted by EZNEC are below 2:1 for the bands of interest. This antenna will work on 75 meters at reduced efficiency with a matching network or tuner.



Here is the physics that makes it all possible. Any 450 ohm SWR between 4.5:1 and 18:1 will result in a 50 ohm SWR of less than 2:1 IF the antenna system is fed at a current maximum point. *Moral: Make your center-fed HF antenna system at least a half- wavelength long at your lowest operating frequency and feed it at a current maximum point on the ladder-line.*

Optimum Length For A Matching Section



This graph shows the optimum length for a matching section when feeding a center-fed horizontal dipole. The bottom of the chart is normalized to wavelengths so it works for most HF frequencies and most popular lengths of center-fed wire dipoles. The left side of the chart indicates the optimum wavelength for a 450 ohm ladder-line matching section for connection to coax or connection to a multiple of half-wavelengths of 450 ohm ladder-line.

Example: Assume a 102 ft dipole on 7.2 MHz. 102/(936/7.2) equals 0.785 wavelengths on 7.2 MHz. Reading the matching section length from the graph yields 0.3 wavelength. A wavelength of 450 ohm ladder-line on 7.2 MHz is 886/7.2= 123 ft. 0.3 times 123 equals 36.9 ft for the 7.2 MHz matching section. Add 123/2 = 61.5 ft if 36.9 ft is too short for a total of 98.4 ft.

The following BASIC program approximates the optimum feedline lengths given the length of a horizontal dipole and the frequency. It works for both 300 ohm and 450 ohm ladder-line by assuming a velocity factor of 0.8 for the 300 ohm and 0.9 for the 450 ohm. The results are only approximations based on EZNEC and must be fine-tuned to perfection in reality. This program can be cut and pasted to Notepad and stored in the BASIC directory as Imax.bas. Or an unzipped, ready to run, 30kB DOS "imax.exe" file can be downloaded:

Download imax.exe from http://www.qsl.net/w5dxp/imax.exe

Note: This BASIC program only works for *horizontal* dipoles, not for inverted-V's or any other folded antenna.

```
5 CLS
10 PRINT "This program calculates optimum ladder-line"
20 PRINT "lengths given dipole length and frequency"
31 PRINT "for dipoles that are at least 2/5 wavelengths"
32 PRINT "long at the lowest frequency of operation": PRINT
33 PRINT "Enter Break to exit this program at any time.": PRINT
40 INPUT "Enter Frequency in MHz ", freq
50 INPUT "Enter Dipole Length in Feet ", diplenft
51 length = 375 / freq
55 IF length > diplenft THEN
56 PRINT : PRINT "********** Warning! **********": PRINT
57 PRINT "Dipole Length Too Short. For This Frequency"
58 PRINT "It Needs To Be Longer Than"; length; "Feet"
59 PRINT : PRINT
60 GOTO 40
61 END IF
65 INPUT "Enter either 450 or 300 for Z0 ", Z0
70 IF Z0 = 450 THEN LLWL = 886
80 IF Z0 = 300 THEN LLWL = 787
90 dipwl = diplenft / (936 / freq)
100 IF dipwl < .5 THEN dipwl = dipwl + 1
110 IF dipwl < 1.5 THEN GOTO 140
120 IF dipwl > 1.5 THEN dipwl = dipwl - 1
130 GOTO 110
140 fedlinwl = .25 - (TAN(2.5 * (dipwl - 1))) / 12.02
150 fedlinft(0) = (LLWL / freq) * fedlinwl
160 FOR i = 1 TO 7
170 fedlinft(i) = fedlinft(0) + i * ((LLWL / 2) / freq)
180 NEXT i
190 PRINT "Imax points (Current Loops) at"
200 FOR i = 0 TO 7: PRINT fedlinft(i), : NEXT i
210 PRINT : PRINT : GOTO 40
220 END
```