COAXIAL TRANSMISSION LINE
COMMON-MODE CURRENT

Introduction

Coaxial transmission lines are popular for their wide frequency bandwidth and high resistance to electromagnetic interference (EMI). Coax cables are unique because the propagation of RF current flows in both directions within the cable. Coax cables are classified as "unbalanced" because the impedance between its center conductor and shield is unequal.

Common-Mode Current

When RF current migrates to the outer shield surface of the coax cable, this is identified as "common-mode current". By connecting an *unbalanced* cable to a *balanced* antenna, this will cause some level of RF common-mode current. Understanding how the RF energy migrates to the cable's outer shield surface can be confusing. RF (AC) energy (unlike DC energy) travels on the "outer surface" of conductors. This phenomena is called the "skin effect" and plays a major role in how the RF energy travels within the coax cable. The drawing below (Figure 1) shows that the antenna driven element on the left is connected to the coax cable's center conductor. Due to the "skin effect", RF energy connected to the cable shield actually travels between the cable's dielectric material and inner surface of the shield. When the RF energy reaches the cable end, it splits into two paths. Most of the RF energy goes into the element because of its wavelength, but some of the RF goes down the coax outer shield. The RF current on the shield's outer surface is considered "common-mode current". This RF current has no return path and is radiated into the air, so the shield outer surface becomes part of the antenna. At the lower HF frequencies, the antennas operational bandwidth is very narrow and operating out of this range will cause more RF energy to flow on the feedlines outer surface.

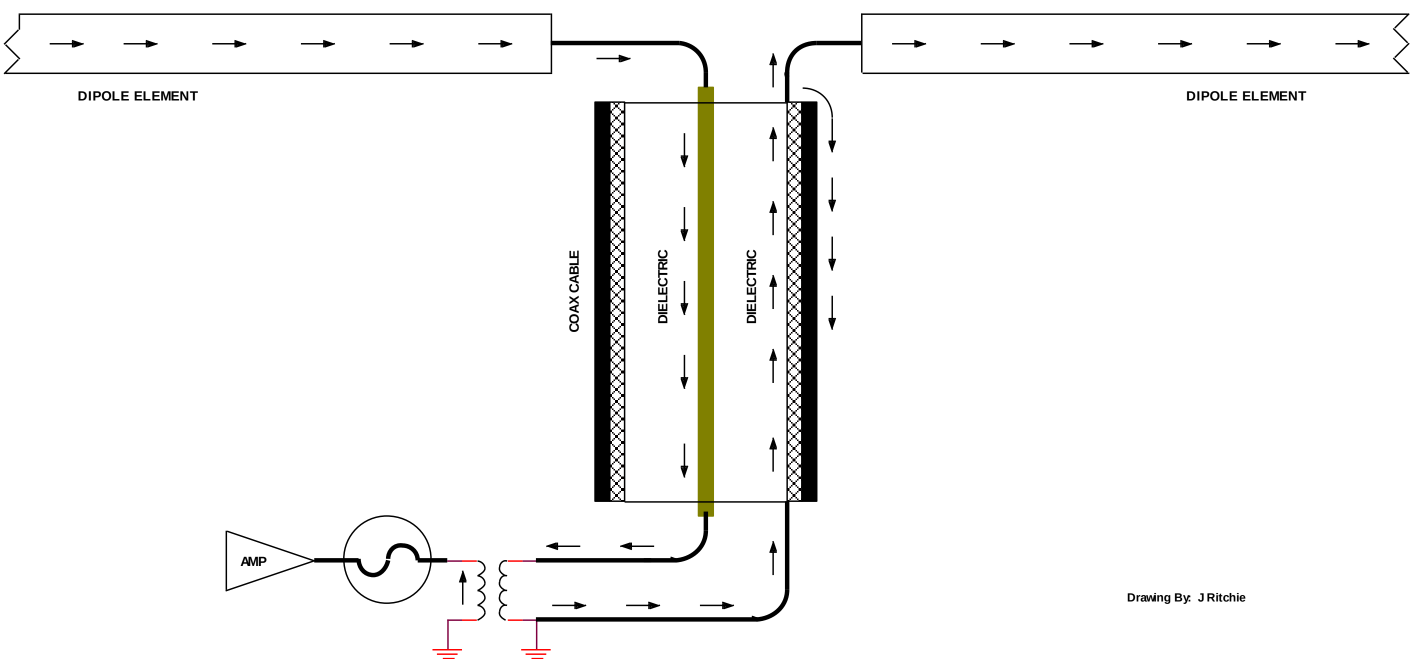


Figure 1

Problems Caused by Common-mode Current

Noise interference is the most common problem encountered when the antenna's outer shield acts as part of your antenna system. Noise is usually vertically polarized and the vertical path of your coax cable provides an excellent antenna to pick up this noise. At HF frequencies, noise interference can override weak signals and most of this noise is vertically polarized. Many amateur operators have reported a significant reduction in their receive noise levels when the common-mode current was eliminated. If you search the Internet for "antenna common-mode current noise", you will find numerous articles related to this problem. Radio frequency interference (RFI) at your QTH and to your neighbors has also been reported. Some antenna tuners have problems when common-mode currents are present. The antenna's radiation pattern is also modified by common-mode current. Dipole antennas are notorious for having common-mode current problems, but vertical antennas can experience the same problem. If the vertical antenna's counterpoise (ground-plane) provides a poor current path, the feedline outer shield will become part of the antenna. Common-mode current on a mobile antenna's coax cable can cause interference to a vehicles electronic systems.

Measuring Common-Mode Current

Measuring the level of common-mode current is a non-scientific process. RF radiation levels on the coax cable's outer shield is very high near the antennas feed point, but it dissipates as it travels down the coax. Measuring the RF current at the transmitters cable end can be deceiving. SWR meters, VNA's and antenna analyzers cannot be used to measure RF common-mode current levels. I have a MFJ-984 RF current meter which uses a clamp-on transformer that snaps around the coax cable. It has a current range of 3 mA to 3 Amps, but its maximum frequency range is only 30 MHz. For frequencies above 30 MHz, this would require an instrument that will detect RF energy above this frequency. Using a field strength meter (e.g. MFJ-801) that covers these VHF/UHF frequencies would work by winding two turns of wire around the coax cable and attaching it to the FS meter.

Baluns

If you are interested in obtaining the most efficiency from your antenna by reducing or eliminating common-mode current, this can be achieved by installing a balun at the antenna's feed point. There's a large selection of baluns being sold on the amateur radio market, but choosing the correct type for your antenna system can be confusing. There are two types of baluns available, voltage or current, with coupling ratios of 1:1, 4:1, 6:1 and 9:1. For most amateur applications, the 50Ω to 50Ω (1:1) ratio current balun will be used.

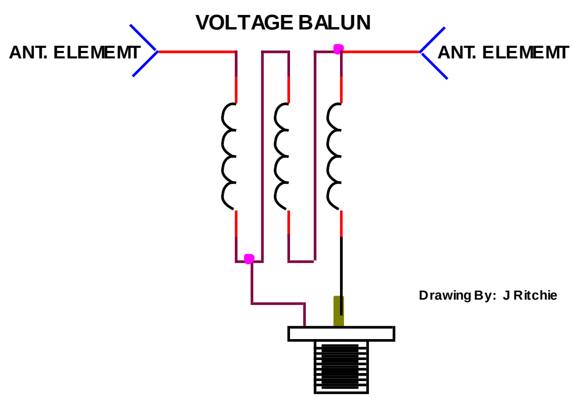
- **Voltage** baluns convert the coax cable unbalanced termination to a balanced termination. They also do not provide common-mode isolation. Voltage baluns were the first designs to appear on the amateur radio market.

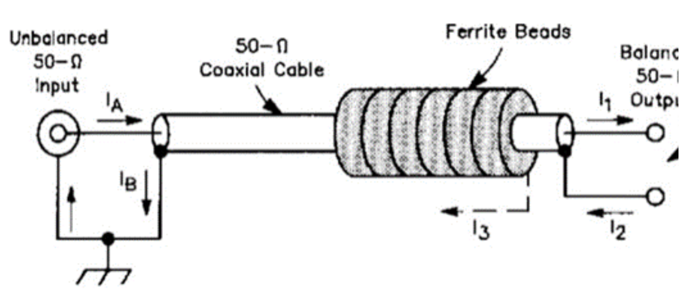
- **Current** baluns, rather than voltage baluns, should be used whenever possible. Current baluns provide better balance and often have lower loss. Current baluns, especially 1:1 ratio baluns, tolerate load impedance and balance variations much better than voltage baluns. These baluns act as a RF choke to common-mode current.

Caution: Some balun manufacturers advertise their voltage baluns as being current baluns. It's easy to identify these baluns with an ohm meter by measuring the resistance between the connector center pin and connector ground. If the resistance is zero (short), it's a voltage balun. If your balun is already in your antenna system, just measure the resistance feedline end.

Balun Drawings and Photos

The drawings and photos on this page show the electrical and mechanical construction of baluns that are available on the amateur market. The first illustration is a voltage balun which is housed in the same enclosure as a current balun. These enclosures are normally sealed and can't be taken apart, but you can measure the difference with an ohmmeter.





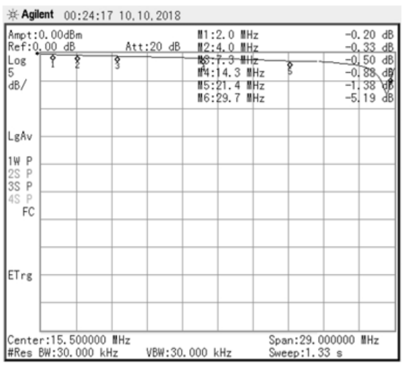
CURRENT-MODE BALUN

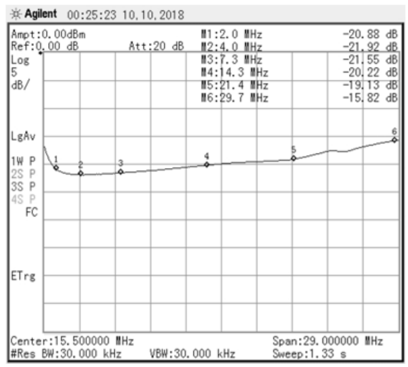
This article would not be complete without mentioning the "Ugly Balun" as seen below, which is technically a RF choke. For this type of balun to be effective on the 80 – 10 meter bands, you need at least 20 feet of close wound coax with a diameter of 4 to 6 inches. The 3 turn choke was designed for 10 meters.

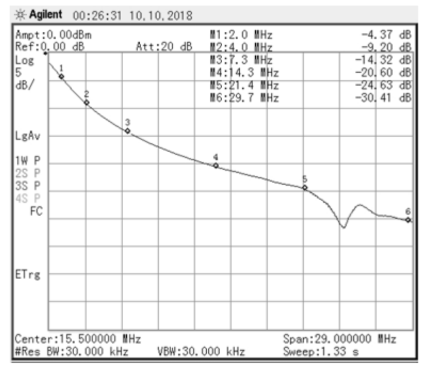
Balun Performance Tests

Measuring a balun's design performance on a test bench can be a challenge and manufacturers seldom provide any performance specifications. Each type of balun show in this article was tested for common-mode current rejection, insertion loss, return loss and SWR.

Common-mode Current Rejection:

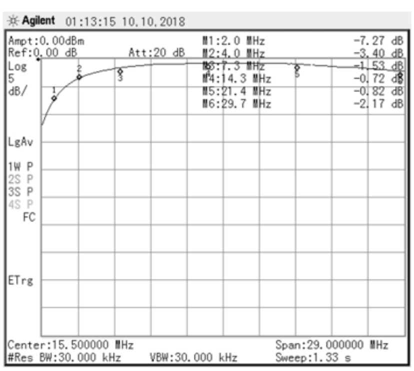

Voltage

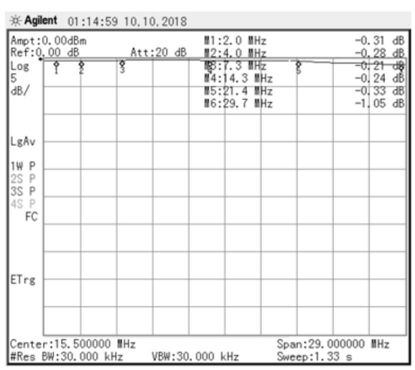

Current

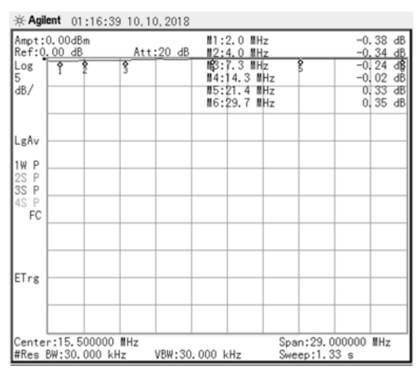

Ugly

Voltage baluns are not designed to reject common-mode current. The Current balun provided the best common-mode rejection. The Ugly balun fail short on the HF low frequency end because it had only 17 feet of coaxial cable on a 4" diameter PVC pipe. You need 20 feet or more of coax cable for good performance on the 80 and 160 meter bands. My benchmark for common-mode current rejection is more than 15 dB.

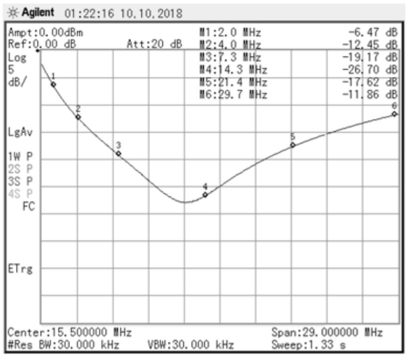
Insertion Loss:


Voltage

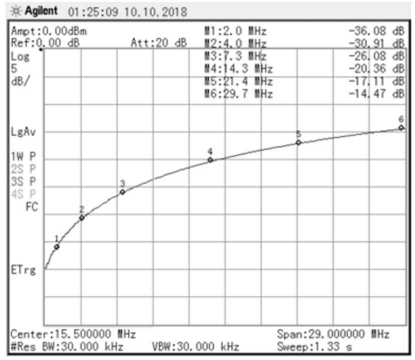

Current


Ugly

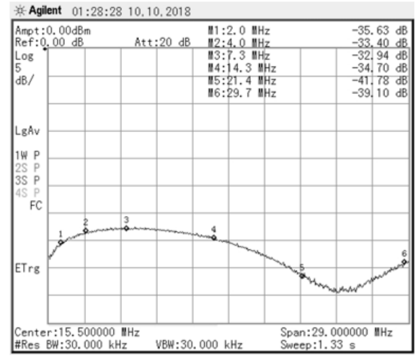
The insertion loss should be less than 1 dB for a well-designed balun. The Voltage balun failed to meet this specification across most of the HF frequency band. The Ugly balun had the best results because its insertion loss depends on the length and type of coax cable.



Voltage



Current



Ugly

Band	Return Loss	SWR
160M	-6.47	2.80:1
80M	-12.45	1.62:1
40M	-19.17	1.24:1
20M	-26.70	1.10:1
15M	-17.62	1.30:1
10M	-11.86	1.68:1

Band	Return Loss	SWR
160M	-36.08	1.03:1
80M	-30.91	1.06:1
40M	-26.08	1.11:1
20M	-20.36	1.22:1
15M	-17.11	1.32:1
10M	-14.47	1.47:1

Band	Return Loss	SWR
160M	-35.63	1.03:1
80M	-33.40	1.04:1
40M	-32.94	1.04:1
20M	-34.70	1.03:1
15M	-41.78	1.01:1
10M	-39.10	1.02:1

Each balun was terminated with a non-reactive 50Ω load during the RL/SWR test. Most baluns will not function properly when the antenna SWR is above 3:1 even when antenna tuner is being used. Antenna tuners only provide a good impedance match between coxa cable and radio, the mismatch between antenna and balun unchanged. Baluns do not perform well with antennas that operate in a harmonic mode.

Summary

When the RF current reaches antenna, it will choose the path of least resistance. If you operate outside the frequency range of your antenna, the path of least resistance might be the outer surface of the coax cable. Using a poorly designed balun can cause more problems than it cures. Although voltage baluns are simple and cheap to build, they are not designed to eliminate common-mode currents. If you purchase a TV antenna, they are usually supplied with 300Ω/75Ω (4:1) voltage balun. When you purchase an amateur radio antenna, it seldom includes a balun. The Voltage balun used in this document was purchased at a ham fest and the manufacturer is unknown. The Current balun was a MJF-918 and the Ugly balun I built several years ago. Since balun manufacturer's specifications only include a baluns power rating and ratio, the buying decision can be difficult. Plus, some baluns being advertised as a Current balun, may actually be Voltage balun.

Jerry Ritchie
WA5OKO