Baluns for 88–108 MHz

An electromagnetic wave illuminates both an antenna and its feedline. Signal current induced on the outer surface of a coaxial feedline may enter it at the antenna feedpoint. Common-mode signals induced on a parallel transmission line may become differential at the receiver. Either makes the transmission line an unintended part of the antenna structure, which can degrade the directive pattern and forward gain. A current balun, sometimes called a choke balun, can attenuate unwanted coax shield current. A current or voltage balun can reject common-mode signals on parallel line.

Coiled-Coax Balun

You can make a simple current balun by coiling coaxial feedline in a particular way. The coil inductance and distributed capacitance resonate as a parallel trap whose high impedance inhibits unwanted shield current.

To construct the balun, mark RG-6 coax with tape at two spots 27″ apart (26″ for RG-59). Coil the coax into three turns with the marks aligned. At the marks secure the coil with dark, UV-resistant tie wraps overlapped as shown. Tie-wrap the coil across all three turns at two other places so that adjacent turns everywhere touch.

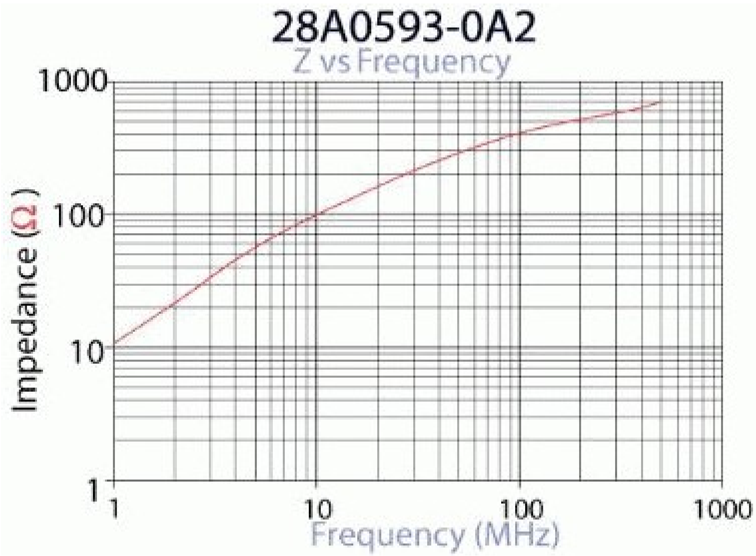
The coil may not meet the cable's minimum bend radius specification. Bending coax too sharply may cause an impedance change, or with certain dielectrics and enough time, an internal short. The spec varies among cables and manufacturers. It is 2½″ for Belden 1505A RG-59. For 1530A RG-6, it is 3″.

Ken Wetzel uses Belden 1855A coax because it is small, easy to bend, and has a very accurate characteristic impedance. He uses three turns with an outside diameter of 223⁄32″. He bonds the turns together with superglue and uses two tie-wraps to secure the exit leads. The minimum bend radius for 1855A is 1½″. Loss is 3.33 dB/100′ at 100 MHz.

The minimum bend radius for Times Microwave LMR-300-75 is ⅞″. Loss is 1.75 dB/100′ at 100 MHz.

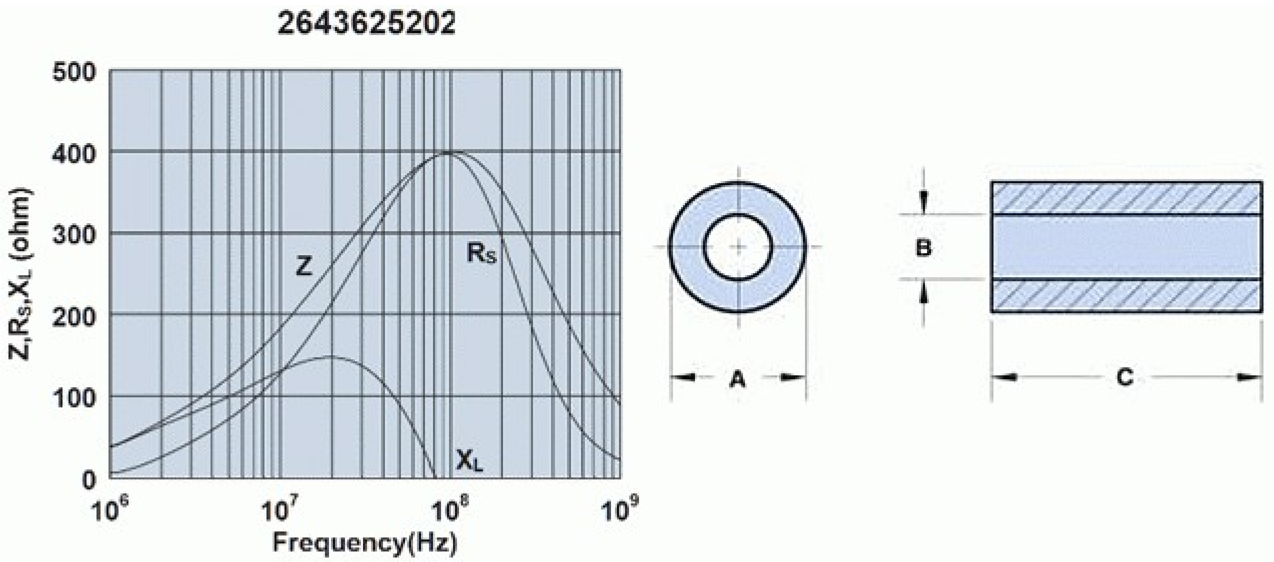
Hans-Peter Dohman, DL9EBA, uses this balun on a 75Ω Yagi. Position the coil away from anything conductive and orient it perpendicular to the elements. The balun is most effective when placed at the feedpoint where shield current is highest. If that's not possible, form the feedline into a second balun a quarter wavelength (30″) away from the first. Spaced baluns are particularly effective at reducing shield current induced by coupling to an asymmetrical feedline, as may occur for vertical polarization.

Ferrite Chokes



Passing coax through ferrite material increases its common-mode impedance without affecting its characteristic impedance. A Laird 28A0593-0A2 snap-on, split-ferrite choke, stocked by Mouser and Digi-Key, is simple to install. The rated impedance at 100 MHz is 407Ω (Ken Wetzel measured 250Ω). It will accomodate 0.258″ coax, which includes RG-59 but not RG-6. The Laird 28A0640-0A2 handles quad-shield RG-6 and provides a rated impedance of 240Ω.

The plastic closures of a split-ferrite choke may become brittle and fail when flexed after long outdoor exposure. Tape or tie-wrap a broken housing to ensure that the ferrite halves remain firmly joined. The ferrite material does not seem to degrade outdoors.



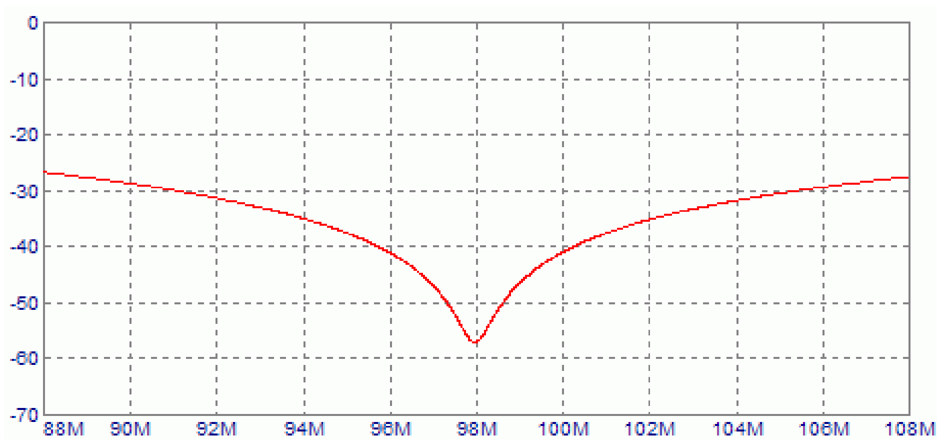
A nonsplit ferrite sleeve, installed before terminating the cable, is inherently more robust than split ferrite. A Fair-Rite 2643625202 choke, available at Mouser, has a rated impedance at 100 MHz of 384Ω (Ken Wetzel measured 330Ω). It has a minimum hole diameter of 0.3″ and will accomodate quad-shield RG-6.

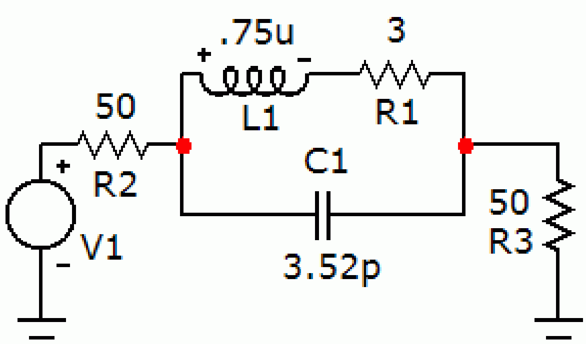
Ferrite choke impedances are much lower than those a coiled-coax balun provides. But coil resonance varies with jacket material and construction, and verification requires instrumentation. Ferrite chokes provide moderate, noncritical, broadband attenuation in a compact package. To increase the impedance, use more than one choke.

Balun Model

With the AO 8.50 Antenna Optimizer I modeled a highly directive narrowband Yagi in free space. Due to its extremely small backlobes, this antenna is very sensitive to stray signal pickup. I added a conductor to one side of the feedpoint to represent the coax shield. In practice, the shield surge impedance and resulting current depend on the length of the coax, what it couples to, and what it connects to. Since these parameters are unknown, I modeled a traveling wave on the shield as a general, nonresonant example. As you lengthen any conductor, it develops a traveling wave as the incident power gradually radiates away. I created a traveling wave on a relatively short wire by placing a 350Ω load a quarter wavelength from the far end. I adjusted the load impedance and position for the most uniform wire current.

This is the model geometry. The red dot is the feedpoint and the green dot is the traveling-wave termination. The yellow traces represent current magnitude. A traveling wave on a vertical wire radiates mostly downward. To examine a worse case, I bent the shield wire horizontal 6′ below the Yagi. The horizontal section is 20′ long. It is centered on the elements and does not couple to them. Note the discontinuous driven-element current and the nonsinusoidal shield current.





With a circuit analysis program I modeled a coiled-coax balun as a parallel trap in a 50Ω system. I adjusted the component values to obtain the response I had measured for the test balun. Then I used the values for an RLC load in AO. Analysis at 88.1 MHz tests the worst-case shield-current suppression of a coiled-coax balun resonated at midband.

To try a resonant shield, I removed the termination and adjusted the horizontal wire length to maximize its current, which occurred at 231″. For a traveling wave and no balun, shield current at the feedpoint was 6.8% of maximum model current. For the resonant shield, it is 19%. Forward gain with no balun is 6.02 dBd.

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Yagi/Balun Model                        ; use 27 segments/halfwave
Free Space
88.1 MHz
9 6063-T832 wires, inches
x1 = 0                                  ; element positions
x2 = 21.9375
x3 = 37.25
x4 = 76.8125
y1 = 67.375/2                           ; element half-lengths
y2 = 67.1875/2
y3 = 61.6875/2
y4 = 53.6875/2
a = -2                                  ; position of balun below antenna
b = -72                                 ; position of shield bend
c = x2 - 209.5                          ; position of traveling-wave termination
d = c - 30.5                            ; position of shield endpoint
1   x1 -y1  0   x1  y1  0    0.375      ; reflector
1   x2 -y2  0   x2   0  0    0.375      ; one side of driven element
1   x2  y2  0   x2   0  0    0.375      ; other side
1   x3 -y3  0   x3  y3  0    0.375      ; first director
1   x4 -y4  0   x4  y4  0    0.375      ; second director
1   x2   0  0   x2   0  a    0.15       ; dipole to balun
1   x2   0  a   x2   0  b    0.15       ; balun to bend
1   x2   0  b    c   0  b    0.15       ; horizontal run to termination
1    c   0  b    d   0  b    0.15       ; beyond termination
1 source
Wire 2, end2 1 0 39 pF                  ; shunt capacitor for 75-ohm match
2 loads
Wire 7, end1 .75 uH 3.52 pF 3 ohms      ; RLC balun model resonant at 98 MHz
Wire 9, end1 350 ohms                   ; termination to create traveling wave
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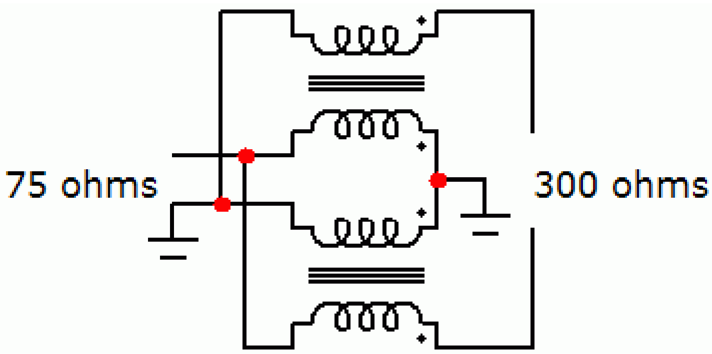
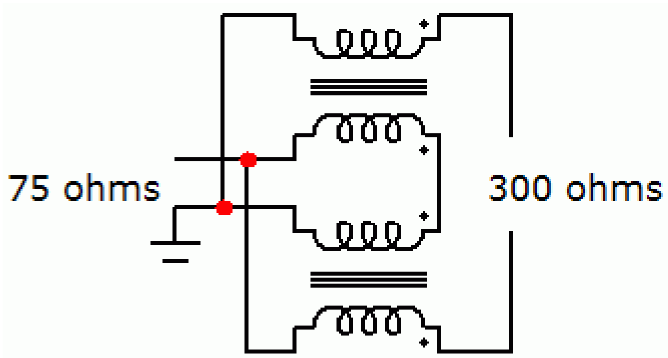
In a different simulation, I fed a shorted folded dipole against a vertical conductor to model the common-mode impedance of a typical Yagi driven element and coax shield. For shield lengths between 15′ and 30′, worst-case 75Ω mismatch loss was only 6.3 dB. Since the impedance is high at mismatch loss peaks, any feedline coupling to lossy material should lower this value. The small mismatch loss values mean that you can't count on a nonresonant feedline length to inhibit unwanted common-mode signals. The Yagi pattern for minimum shield current and no balun illustrates this result.

300Ω Ferrite Baluns



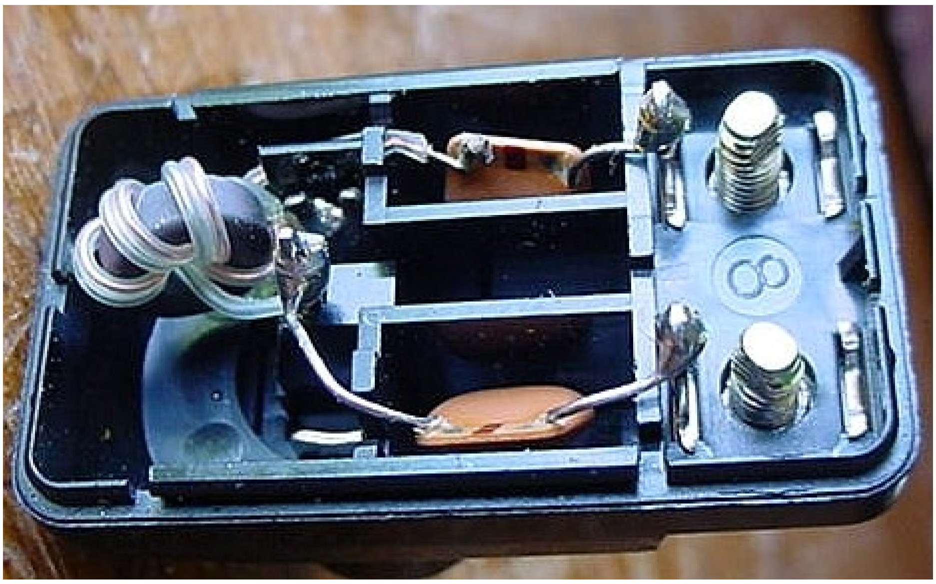
Most 300Ω ferrite baluns use two transmission-line transformers interconnected as shown. These baluns produce equal voltages of opposite phase at the 300Ω terminals when driven at the 75Ω terminals. Conversely, voltages common to the 300Ω terminals cancel at the 75Ω terminals. With both ports shorted the common-mode impedance typically is less than 20Ω.

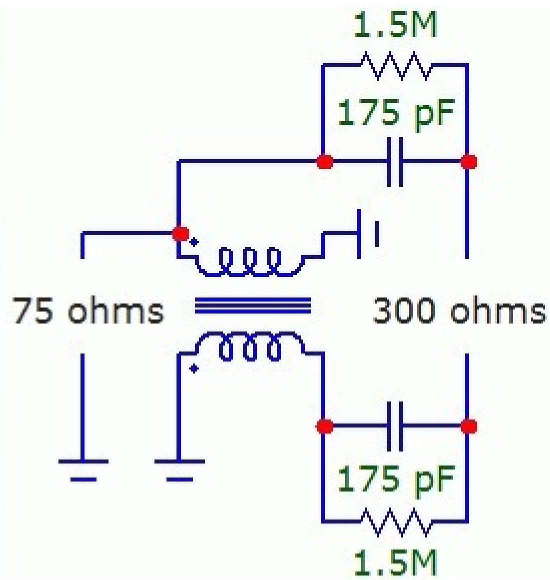
Inside a typical balun you'll find a two-hole ferrite core that accomodates both transformers without adverse coupling.



Some baluns unground the transformer interconnecting lead. These baluns tend to equalize currents rather than voltages at the 300Ω terminals. This promotes signal cancellation when the parallel-line impedances differ, as when one line is closer to a conductor than the other. The common-mode impedance typically is 250Ω.

A wire at the center of the core and two leads instead of four to the coax shield identify this as a current balun.





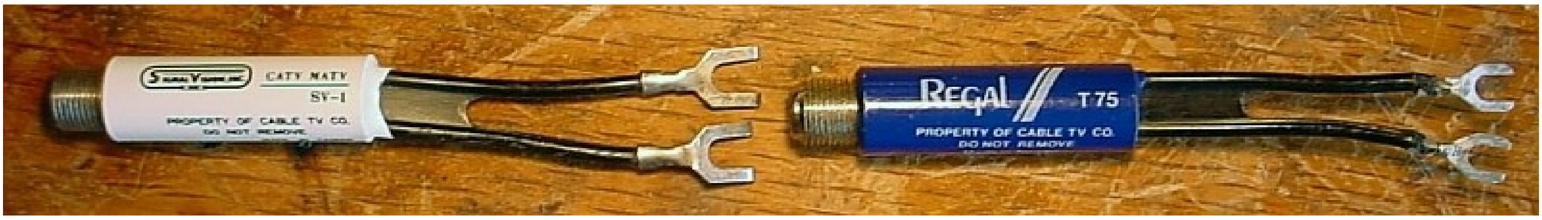
Some voltage baluns use a single toroidal transformer as a phase inverter. What look like series capacitors actually are integrated RC networks. Not all single-transformer baluns have these networks and they can be found in other kinds of baluns as well. The capacitance improves the low-frequency balance and the resistance drains any static charge.

To compare the common-mode rejection of various baluns, I cut a 31″ piece of 300Ω twin-lead. This is a quarter wavelength at the low end of the FM broadcast band. Fed against a surface, a conductor of this length makes an effective antenna. I terminated the twin-lead with a 300Ω resistor at one end and with spade lugs at the other. I connected it to several baluns that I plugged directly into my Wavetek SAM RF-level meter, which I tuned to a local FM signal. Keeping the orientation of the twin-lead constant, I swapped baluns and compared signal levels. Except for a tiny residual, any signal was due to unwanted common-mode balun response.

After connecting the twin-lead directly to the SAM as a reference, I measured the following relative signal levels in dB for several baluns:

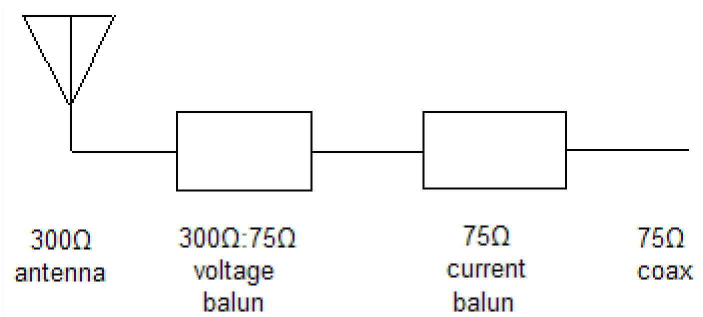
Voltage baluns,	two transformers	<-40	<-40	-35	-29	-27	-26
	one transformer	-18	-18				
Current baluns		-20	-19				

The single-transformer baluns had the worst common-mode rejection. The current baluns were almost as bad even though their common-mode impedance was much higher. I had created one of the current baluns by ungrounding the transformer interconnecting lead in a voltage balun. When I grounded it with an insulated tool while watching the meter, the unwanted signal dropped about 10 dB.



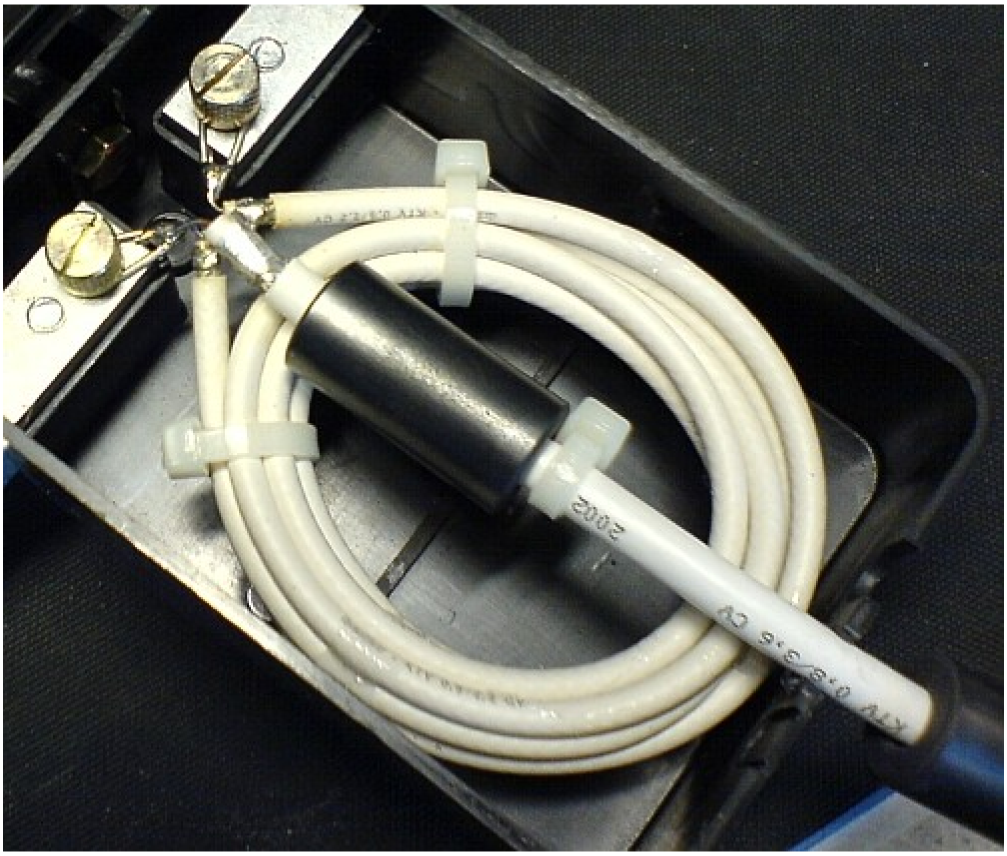
These are the two <-40 baluns. I assume they have two transformers inside. I did not compensate for the extra lead length. In addition to having the best common-mode rejection, these baluns had the lowest transmission loss, 0.5 dB. The other baluns were the push-on type with screw terminals, with a typical loss of 0.75 dB.

Even with perfect common-mode balun rejection, nonzero transmission line spacing causes a residual differential signal. Simulation of the terminated twin-lead oriented vertically above an infinite ground plane gave a peak differential signal 44 dB below the peak common-mode signal.

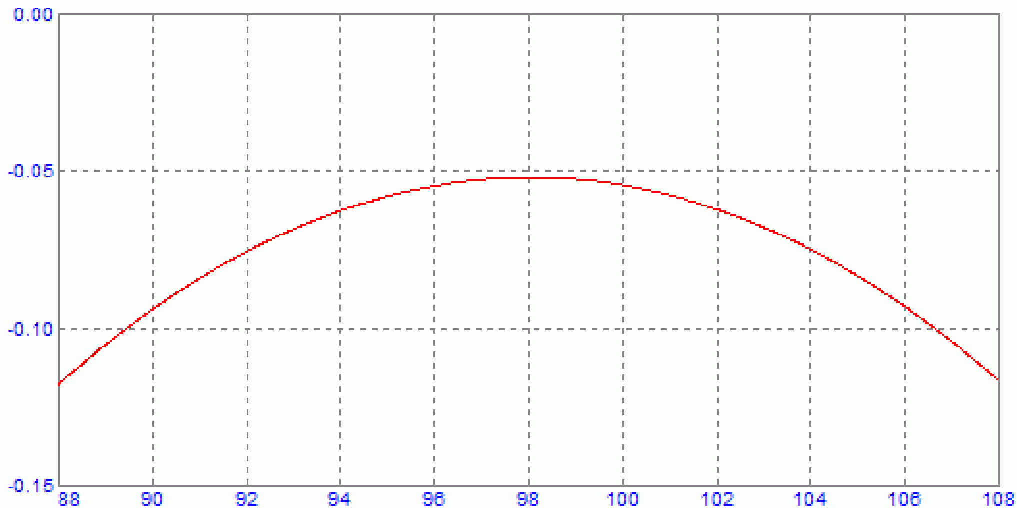


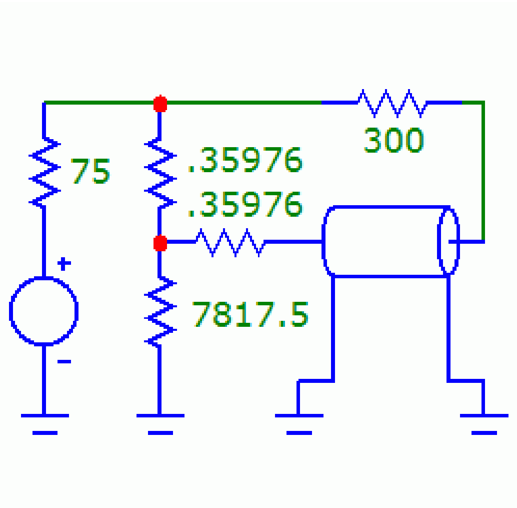
You can increase common-mode rejection by following a 300Ω voltage balun with a 75Ω current balun. Since the common-mode impedance of a voltage balun is low, the cascaded common-mode rejection should be that of the voltage balun plus the common-mode attenuation of the current balun.

300Ω Halfwave Balun

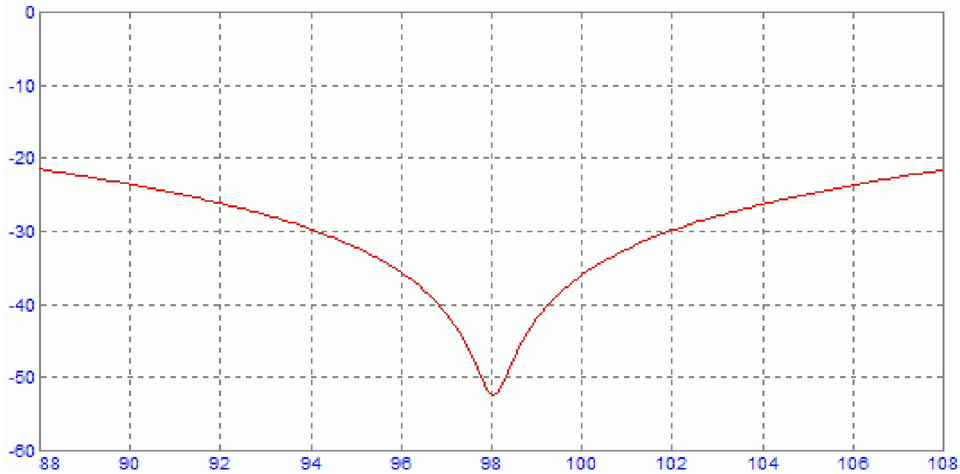


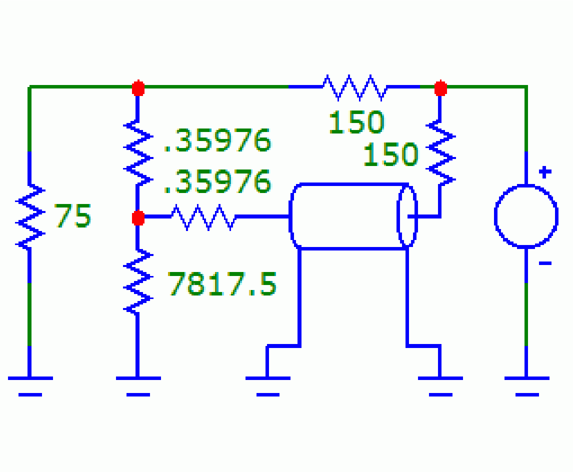
A halfwave coaxial line that inverts the signal makes a low-loss 300Ω voltage balun. Peter Körner used small-diameter coax to save space. Two ferrite chokes provide further common-mode attenuation. All shields connect. The halfwave-line center conductors go to the two antenna terminals, while the feedline center conductor goes to one of them. Keep all leads as short as possible, as Peter did here.





This circuit models the loss of a halfwave balun. The lossless transmission line has a characteristic impedance of 75Ω and a delay of 5.1 ns. The T-pad models the 0.083-dB loss of a 50″ line, assuming RG-6 at 2 dB/100′ and a velocity factor of 83%.





This circuit models the common-mode rejection.

[88–108 MHz]