Bal-Uns, Un-Uns, Chokes, etc.

INTRODUCTION

A "**BalUn**" is bi-directional adapter between a **bal**anced device and an **un**balanced device. Twin-lead feedlines and dipoles are "balanced" (two signal conductors, with equal-but-opposite current: symmetrical). Coax cables, and the antenna port of a typical sold-state transceiver, are "unbalanced": one signal conductor that is referenced to ground (a.k.a. "single-ended"). Baluns other than those with a 1:1 transformation ratio, also act as impedance transformer.

There are two basic types: voltage baluns and current baluns:

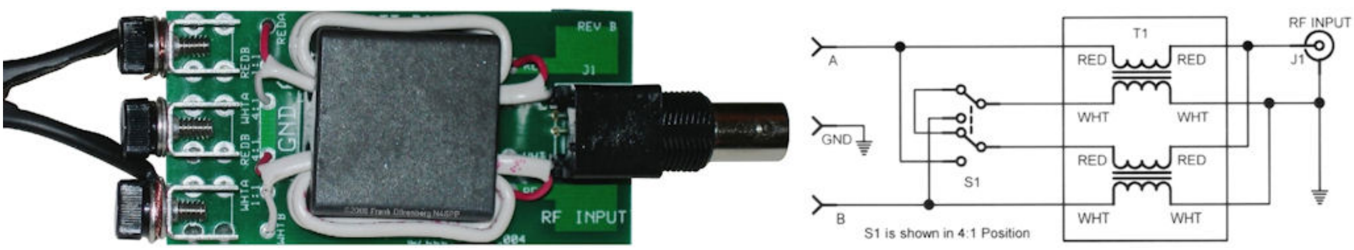
- **Voltage baluns** comprise a transformer with at least two sets of windings; they may be interconnected like an auto-transformer. If the input and output section of the transformer has the same number of turns (ratio = 1), than the balun has the same voltage and impedance at its input and output. The impedance transformation ratio is the square of the turns ratio.
- **Current baluns** typically consist of ferrite beads on a section of 2-conductor transmission line such as a coax, or conversely, coax wound multiple times through a ferrite ring, or tight-wound coil of coax turns (air core). Its purpose is to provide high impedance to common-mode current on the transmission line: it "chokes" that current. There is no impedance transformation. When placed between a balanced device such as a symmetrical antenna (ignoring stray capacitances etc. from surrounding objects that may actually make the antenna a-symmetrical), and a coax (unbalanced transmission line), the current balun rejects the common-mode and passes the dif ferential voltage.

As the name suggests, an " **UnUn**" is bi-directional adapter between two **un**balanced devices.

I am not a expert (real or self-anointed) of baluns, impedance transformers, transmission lines, transmission line transformers, etc. Far from it. So, rather than writing here what my interpretation is of what they are, how they work, how to build a good one, etc., I refer to the extensive list of references.

1:1 AND 4:1 BALUN TRANSFORMERS THAT I USE

My 1:1 and 4:1 baluns are BL1 and BL2 kits from Elecraft (ref. 2I/J). The BL1 uses a two-hole "binocular" ferrite core (a.k.a. "pig nose") of type BN43-7051, and has two sets of thermostat wire windings. It can be wired as 1:1 or 4:1. The balun is rated for 150 watt (when connected to a 200 Ω load). The BL2 uses two stacked ferrite cores of the same type, for increased power handling capability (250 W). It includes a DPDT slide-switch for changing between 1:1 and 4:1.



My BL1 4:1 balun and the schematic (incl. 1:1 to 4:1 reconfiguration)

This type of ferrite core has an advantage compared to an equivalent "single hole" ferrite ring (toroid) or a ferrite rod: about half of the winding wire is inside the "tunnels" through the ferrite block. This reduces stray capacitance and required wire length (= loss resistance). Broadband transformers in transmitter power stages often use such cores, or two cylindrical cores side-by-side.

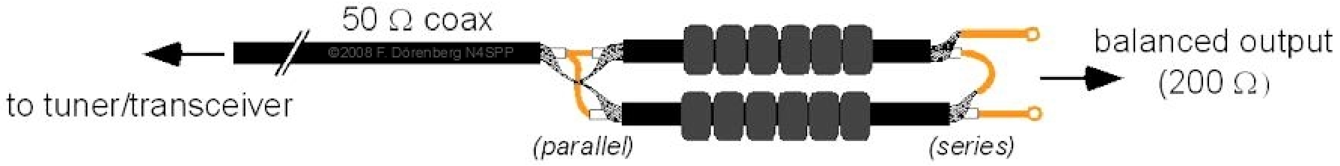
There are many different ferrite material mixes. Most commonly used in transformers are Amidon / Fair-Rite / Micro Metals mixes nr. 31, 43, and 61 (or equivalents from another manufacturer). Important parameters from the data sheets (ref. 6) are "Initial Permeability and Loss Factor vs. Frequency" and "Core Loss vs. AC Flux Density" curves. Note that the permeability of ferrites varies with the magnetic flux level. Hence inductance of a coil or transformer made of such material will change with the power level. Power handling limited by core losses. These core losses (primarily hysteresis loss and eddy-current loss) roughly increase with the square of the flux density in the core, at any frequency. Ferrite RF transformers must be operated at a core flux-density level that is commensurate with the volume and cross-sectional area of the ferrite. Conversely, the core dimensions should be adequate for the power level.

The maximum flux level is driven by the loss tangent (dissipation hysteresis loss factor) of the ferrite mix. If that flux density limit is exceeded, a runaway effect causes the core temperature to rise very quickly and ultimately (and possibly violently) destroy the core! Note that mix 61 has a Curie temperature (above which the ferrite properties are destroyed) that is much higher than that of type 43: 350 °C (660 °F) vs. 150 °C (300 °F).

Cores can be stacked to increase power handling capability. However, stacking cores also increases the total inductance of a transformer. Furthermore, a larger core also results in larger inductance, compared to a smaller core of the same material. The permeability of ferrite material changes significantly when flux is increased. This may lead to unpredictable behavior when higher power levels are involved, and saturation sets in (which happens at much lower levels then in iron dust cores, but those have much lower permeability). This may also explain observed differences in behavior when exciting a circuit with an antenna analyzer that outputs no more than several mW, compared to full power of a transmitter.

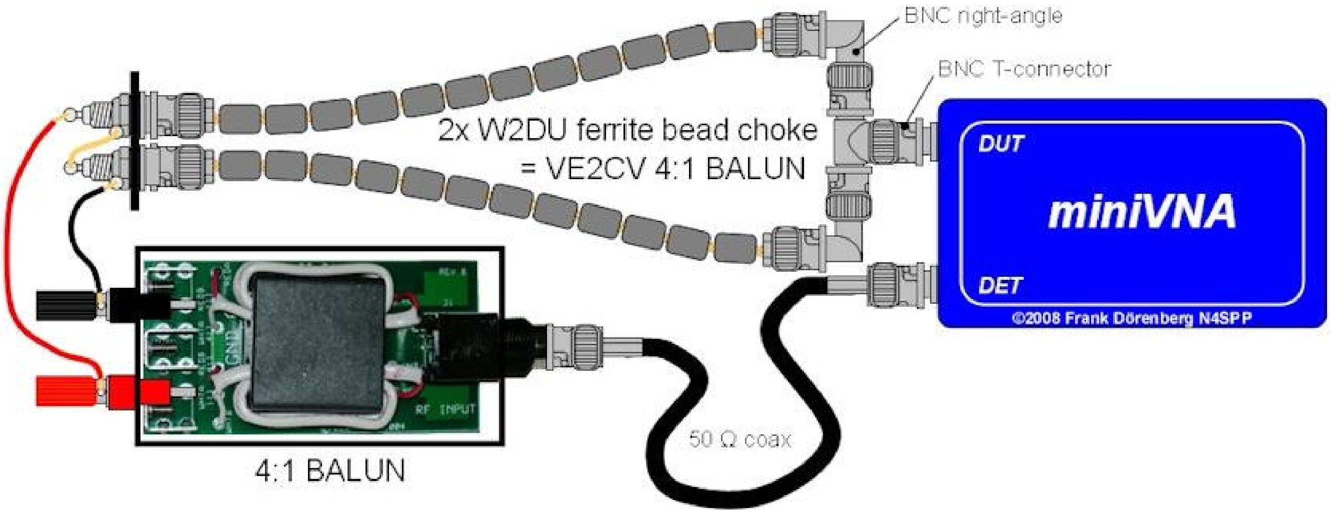
Note: the 1:1 balun can also be used as a 1.1 Un-Un. E.g., at the feedpoint of an antenna and a balanced feedline.

I have also tried a 4:1 balun that is composed of two 1:1 W2DU-style common-mode current choke baluns:

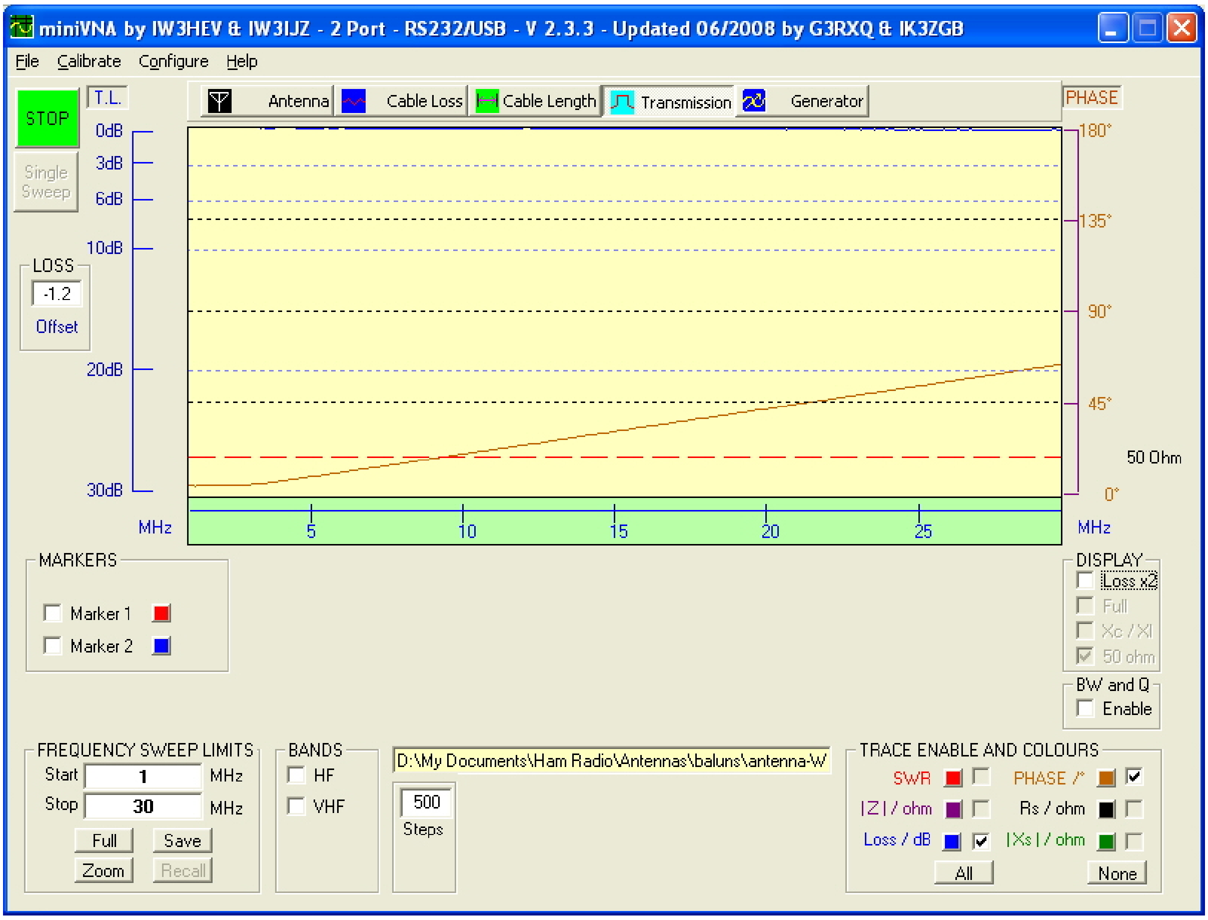


Two W2DU 1:1 chokes configured as a VE2CV 4:1 current balun
(ferrite beads on 93-100 Ω coax - not all beads shown; use at least 24 per W2DU choke)

Note: to obtain 50 Ω at the unbalanced (parallel) side with 200 Ω at the balanced side, the VE2CV configuration requires that the two W2DU chokes be made with sections of **100** Ω coax! Closest available coax-Z_0 is 93 Ω; 100 Ω is typically only available as twinax. Not having been able to locate either value, I used plain 50 Ω coax. Obviously this influences the measurement results! As the two current-chokes are put in series at the balanced output, the VE2CV can also be considered as a current-balun; the output is floating, which is not the case with voltage-baluns.



Test configuration with VE2CV and BL1 baluns back-to-back (1:4 + 4:1 = 1:1)

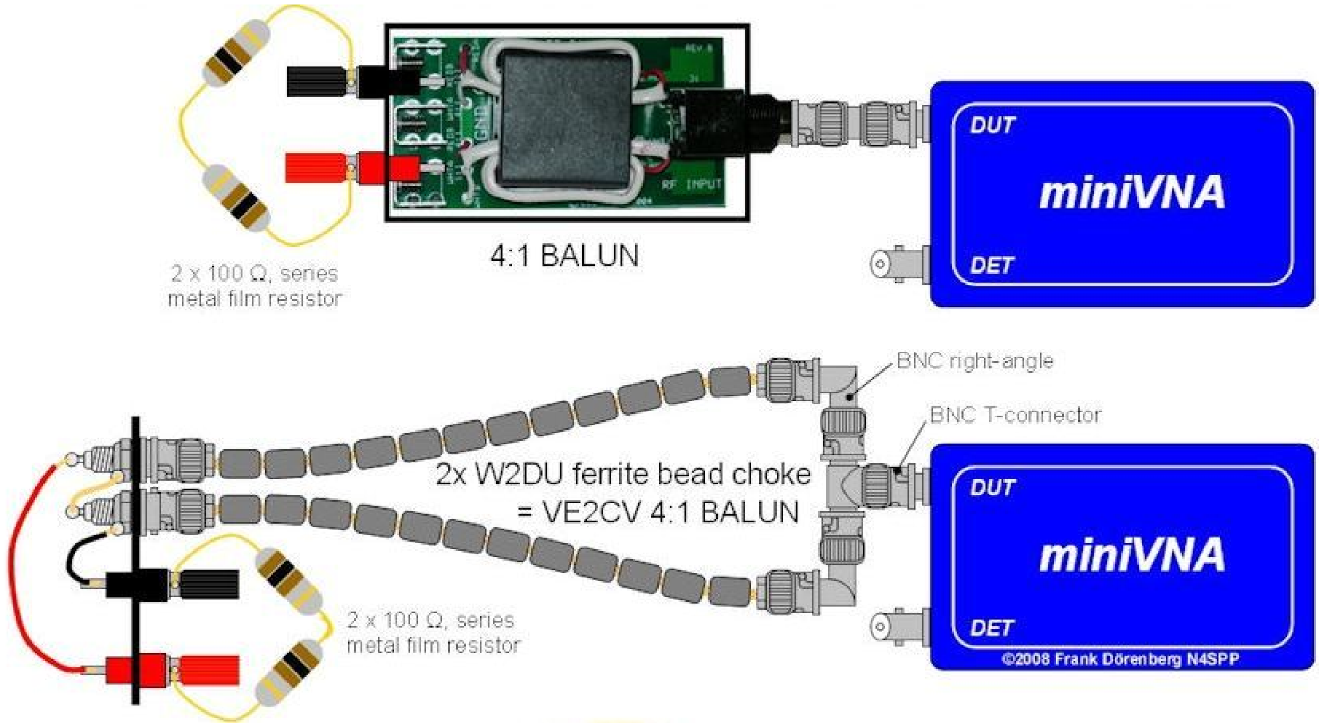


Transmission mode plot (insertion loss) of the above test configuration
(adjusted for coax and BNC connectors loss)

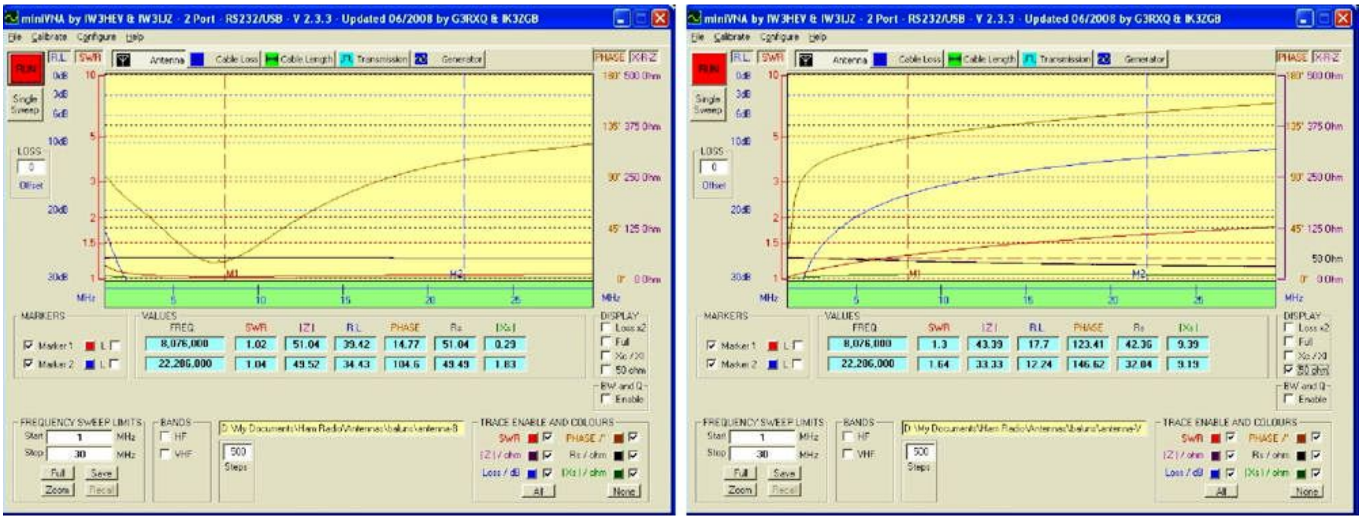
The back-to-back configuration shows a transmission loss from close to 0 dB at 1.8 MHz, to close to 1.8 dB at 30 MHz.

- For the BL1 terminated with 200 Ω, the analyzer sees a flat 50 Ω from, and an SWR better than 1.1 (1.8-30 MHz).
- For my VE2CV-balun by itself (but beads on 50 coax Ω), terminated with 200 Ω, the analyzer sees an Rs of 50 Ω around 1.8 MHz and gradually going down to 37 Ω at 30 MHz; SWR increases from better than 1.1 at 1.8 MHz to almost 1.8 at 30 MHz.

Note that VNAs such as the one that I used (a "miniVNA"), is not a professional VNA and has significant limitations (ref. 5)! I do calibrate it, to the extent possible...



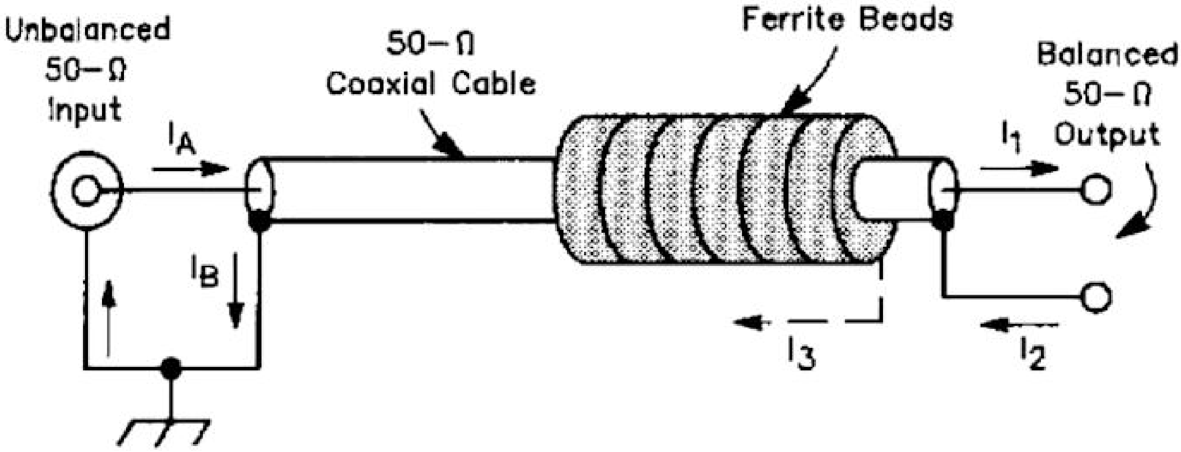
Test configurations for 4:1 BL1 balun, 4:1 VE2CV balun, and 50 Ω terminator resi stor



Analyzer plots for BL1 with 200 Ω termination (left) and VE2CV with 200 Ω

COMMON-MODE CHOKES THAT I USE

One of my 1:1 common-mode "chokes" is a W2DU-type balun. It is simply a number of ferrite beads (the more the better) on a section of coax cable:



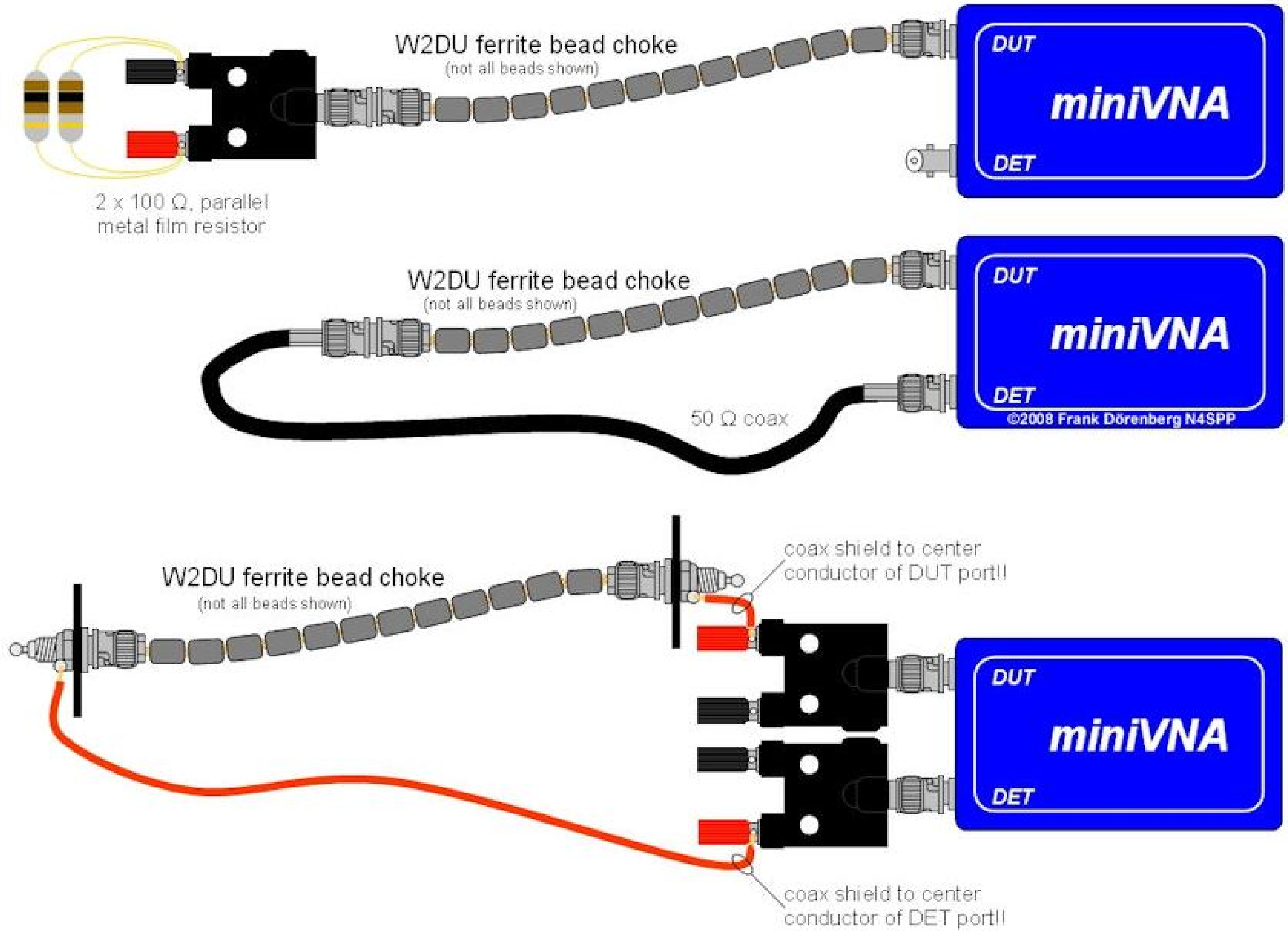
W2DU ferrite-bead choke

Note: the coax is passed through the beads only **once**! That is: one turn. The effectiveness of a ferrite-core choke increases with the square of the number of turns. As the number of turns is (fixed at one), it is very hard to increase the common-mode suppression ability of this type of choke. The only variables are basically the number of beads and the ferrite material...

I am using (only) 24 ferrite beads (I only had beads of ferrite material no. 77 at the time). They fit snugly on about 30 cm (1 ft) of RG-400 coax.

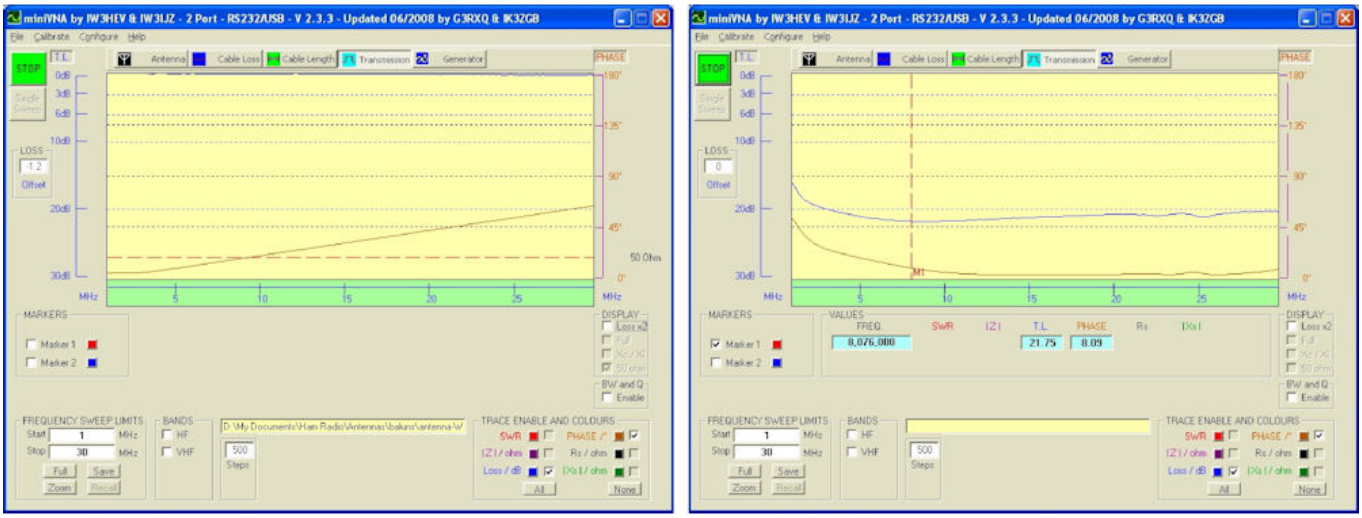
My W2DU-style common-mode current choke

I conducted some measurements of the W2DU chokes, to try and get a good feel for the signal attenuation (0 dB loss desired), and common-mode attenuation (high-dB loss desired). Test-configuration set-ups are illustrated below.



Test configurations of the W2DU current choke

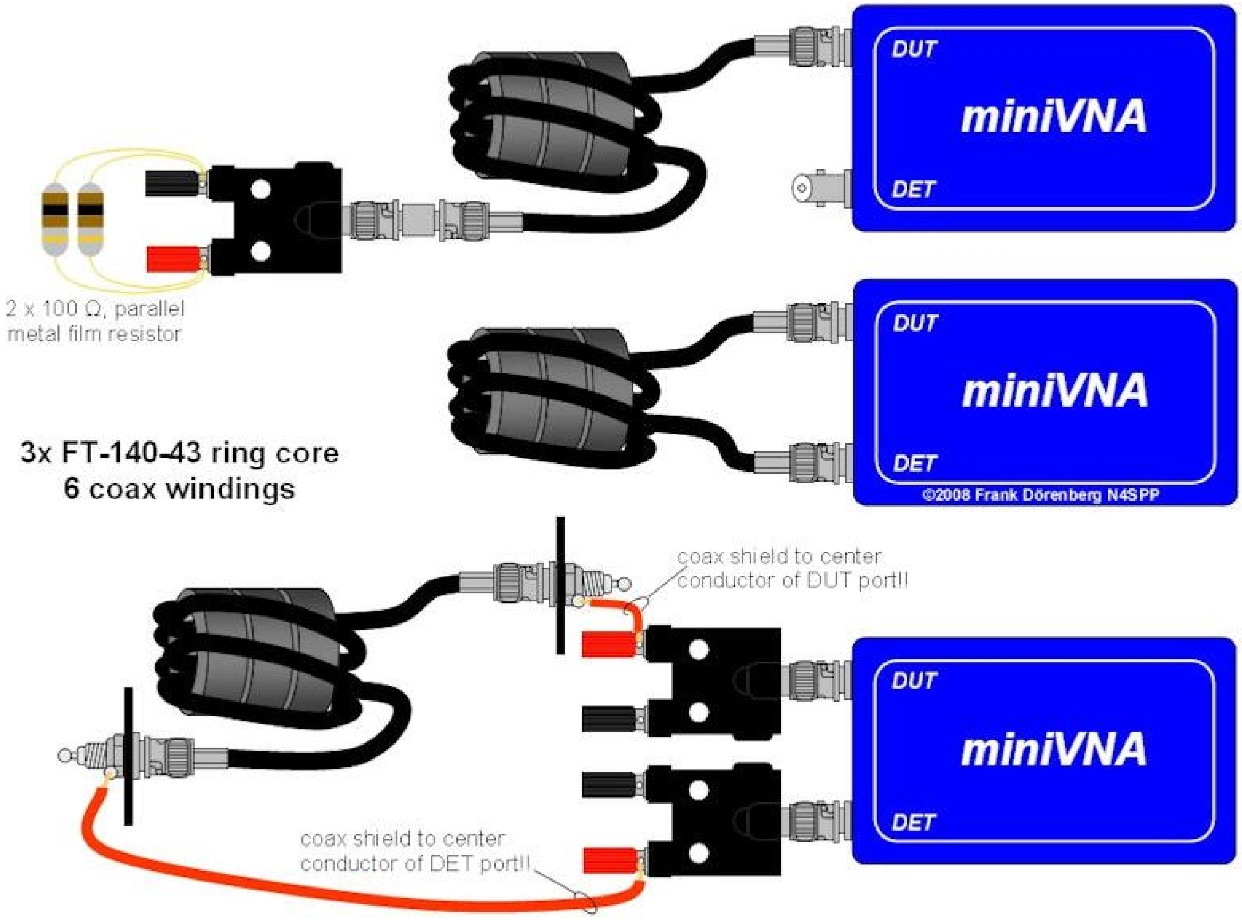
The analyzer plots below it show something close to 0 dB insertion loss (after correcting for losses of the "black" coax and BNC connectors) and about 20 dB common-mode attenuation on the shield (1-30 MHz). The latter is not bad, but not great either. A minimum of 25-30 dB would be good. I have put two of these chokes in series (2 x 24 beads): transmission loss 1.1-1.3 dB (several connectors more in series than with the depicted single choke configuration), and 25-34 dB common-mode attenuation on the shield (1.8-30 MHz). That's better! Note that the resulting choke is not nearly as compact as the coax-on-toroid choke described further below (which uses different ferrite material).

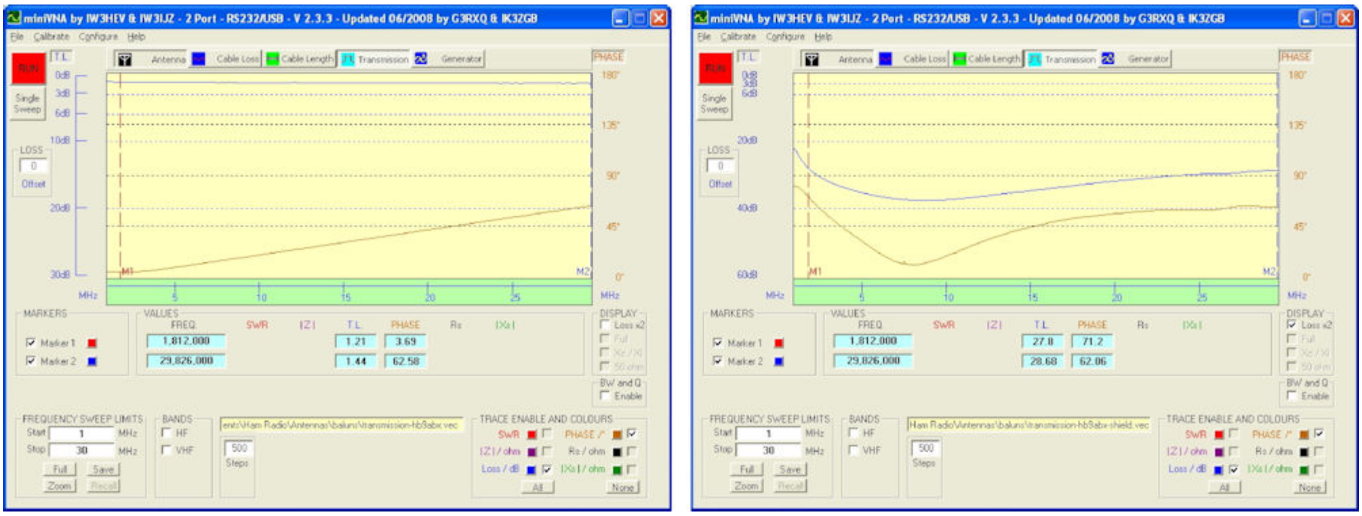


Analyzer plots (left-to-right): insertion loss, common-mode attenuation

I also evaluated a different form of current-choke: 6 windings of coax on a triple-stack of ferrite rings made of #43 ferrite material. I used Amidon FT-140-43 cores. Using RG-58A/U coax (quite thin), it is hard to fit more than 6 windings on these toroids. The windings are spread out evenly around the cores. The same toroids can be used to suppress TVI/RFI problems (e.g., by winding several turns of the wire-pair from your stereo set to your speakers). That's why I had eight of them in stock, just in case. I stacked three of them with a couple of tie-wrap cable ties.

The test-configuratio n set-ups are illustrated below. The corresponding analyzer plots show SWR better than 1.1, about 1.3 dB insertion loss (I actually used a configuration with more connectors than shown in the diagrams; at least several tenths of a dB right there) and between 28 and 38 dB common-mode attenuation on the shield. This is a decent broad-band current choke for 1.8-30 MHz!





Analyzer plots (left-to-right): insertion loss and common-mode attenuation

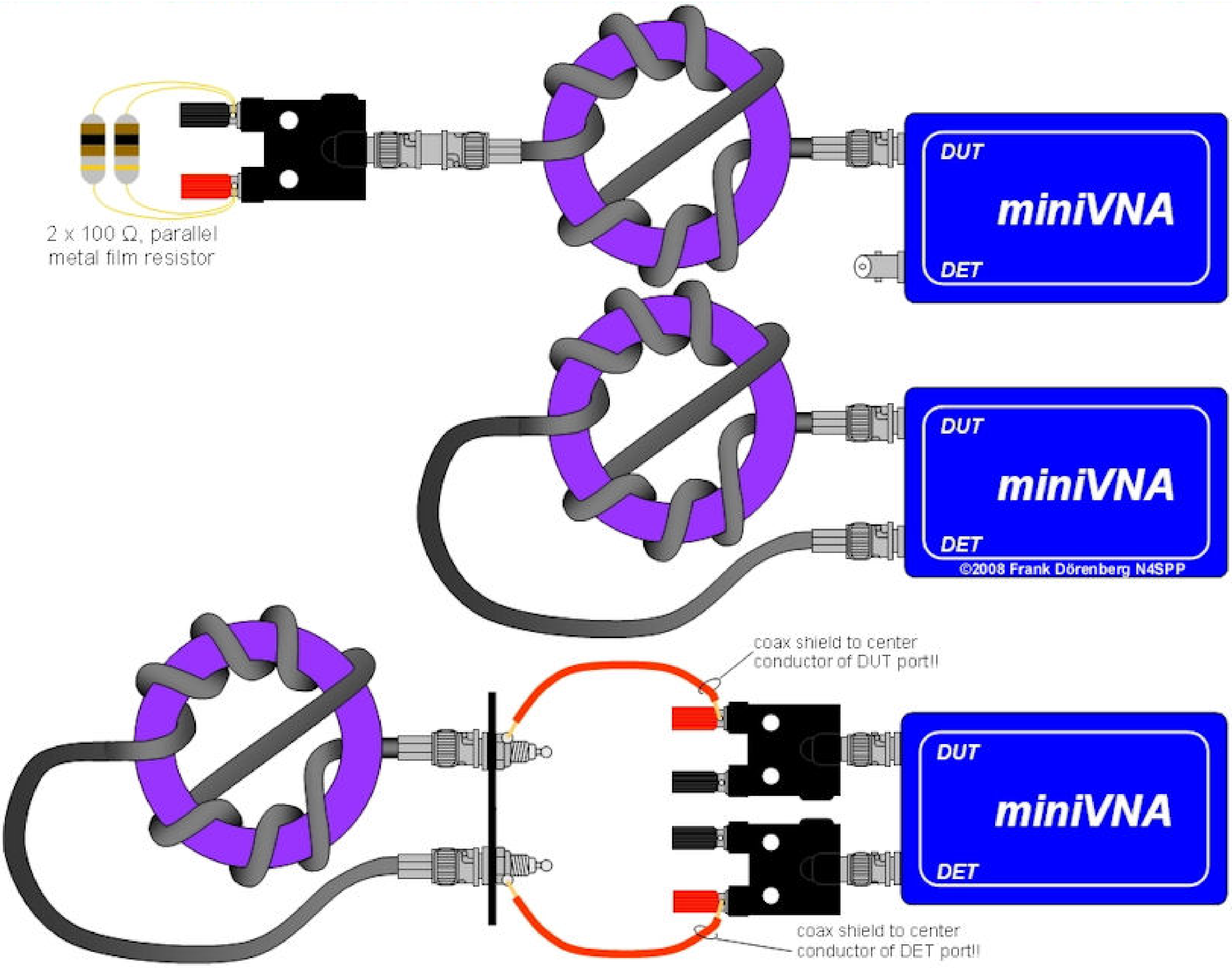
Later on, I mounted this choke balun in a sturdy 50mm OD PVC sleeve:

The choke + 50mm OD PVC female-to-female sleeve + PVC 50 mm end-caps with BNC chassis jacks

I use a similar type of choke balun on the RG8 coax between my automatic antenna tuner (installed at the feedpoint of my dipole antenna) and my transceiver. Here, I am using very large clamp-on ferrite ("split round cable assembly"): lar ge ferrite rings are not large enough to pass the PL-259 connector of the coax through them several times, and I didn't feel like de-soldering & re-soldering the coax plug. This ferrite is made of type #31 material. It has better characteristics below 5-10 MHz than #43 material. I have not yet measured the performance of this choke.

A large ferrite clamp on the coax of my A TU, an FT-140-43 on the control cable

Another way to loop coax through a ferrite ring is the "split winding" method illustrated below. When I have some time on my hands again, I will compare its performance against the "contiguous winding" method used above. However, this is not necessarily the case (ref. 7).



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For measurement of the insertion-loss and cross-talk damping (isolation) of a coax switch with the miniVNA (or similar) analyzer, see this page.

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