Transmission Line Transformers (TLT's) – Part 3

When is a Balun an Unun? Calculating Winding Ratios. Winding and Testing Them.

TRANSFORMER TYPES

Understand that **ALL** matching transformers lack sufficient common mode current suppression. Therefore, a Common Mode Choke must/should be installed between the coax and the input to the matching transformer. Suitable chokes and their best location will be detailed in a subsequent part.

Two classes of TLT's are used in the amateur community: Current or Guanella and Voltage or Ruthroff and so named after their inventors. A third type, an autotransformer (voltage) is a variation of a Ruthruff voltage transformer. There are arguments that support when to use either type, but voltage transformers are very versatile, the easiest to understand, visualize, and wind. We will start there.

Proper design and winding techniques are imperative to ensure both amplitude and phase balance which, in turn, improves performance and reduces losses but do not provide adequate common mode suppression.

WHEN IS A BALUN AN UNUN?

Below is an easy to understand schematic diagram from the VK5AJL website that I've redrawn. For more detailed explanations visit his very informative website: [VK5AJL - Why buy baluns - make your own.]

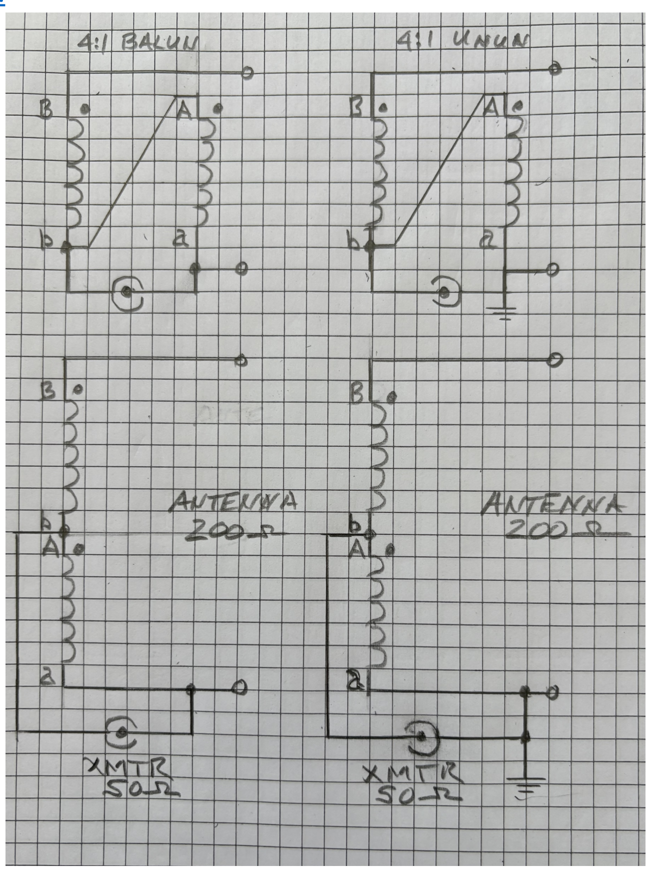


Figure 1

Figure 1, shows two identical 4:1, bifilar-wound, series connected, voltage transformers. The only difference is the coaxial cable attachment polarity. On the Left is a **Balun** (for a dipole antenna) and on the Right an **Unun** (for a vertical or end-fed antenna). When redrawn as shown, these transformers are actually autotransformers consisting of two bifilar windings connected in series-aiding polarity as indicated by the sense, or polarity dots, and are “in phase” with each other.

Note that on the **Balun**, the coax shield is connected to the center-tap of the windings at (**bA**). Therefore, winding (**A-a**) is the transformer’s primary (input). The center conductor of the coax connects to the common leg of the two windings, coils (**B-b & A-a**). The transformer is connected to the system ground via the coaxial cable shield at **bA**).

Note that on the **Unun**, the coax **shield** attaches directly to the common leg of both windings (**a**) and also earth and coax cable ground. The **center** conductor connects to the primary at (**bA**), the primary winding, (**A-a**). The primary and secondary connections are the **same** for both transformers. **Only the “input” polarity is reversed.**

The naming convention, “four-to-one “is written 4:1, and implies that the **output** impedance (**4**) is four-times the input impedance (**1**). It is sometimes shown as 1:4 but, unless stated otherwise, both assume that a 50-ohm **input** impedance is being matched to either a higher **output** impedance.

Real world antennas are not purely resistive loads isolated in space. In addition to resistance, they have complex capacitive and inductive impedances that are affected by environmental factors ranging from trees and height above ground, to the neighbors chain link fence. Those may present a less than ideal matching problem when using commercially available transformers with common ratios of: 2:1, 4:1, 6:1, 9:1, etc. to pair with non-standard antennas. Designing your own may make the match closer.

CALCULATING TURNS RATIOS USING INPUT AND OUTPUT IMPEDANCES

Calculating turns for impedance transformers is straightforward, and uses the “turns-squared” formula where: $\mathbf{N^2 = Z_{out}/Z_{in}}$ meaning that the turns squared ($\mathbf{N^2}$) equals the output impedance ($\mathbf{Z_{out}}$) divided by the input impedance ($\mathbf{Z_{in}}$). To simplify $\mathbf{N^2}$ and remove the $^{(2)}$ exponent, we take the square root of both sides and rewrite the equation as: $\mathbf{N = \sqrt{}Z_{out}/Z_{in}}$ where **N** equals the square root of $\mathbf{Z_{out}}$ divided by $\mathbf{Z_{in}}$.

Examples with values: In Figure 1, the impedance of the transceiver connected to the transformer’s input ($\mathbf{Z_{in}}$) is 50-ohms; the output impedance of the transformer needs to match an off-center fed dipole with an impedance ($\mathbf{Z_{out}}$) of 200-ohms. Using the turns squared formula: $\mathbf{N = \sqrt{}Z_{out}/Z_{in}}$. assign values, then solve for **N**: **N = √200/50** = **√4** = **2**; or a turns ratio of **2:1** for **both** configurations.

Another example for an Unun: An end-fed antenna measures 4,000 ohms and needs a transformer that will match it to a 50-ohm transmitter. Using the same equation: **N = √4000/50 = √80 = 8.94** or **9:1**. There are no partial turns for toroids, any fractional ratio needed for an unun, can be handled by adding or subtracting a turn on either winding (usually the top (high impedance) one, and then testing it. When adjusting the turns on a balun, turns must be added or subtracted on both bifilar windings for balance.

The broadband characteristics of toroidal transformers, enable them to handle large impedance variations and therefore, might make such minor adjustments unnecessary.

You can see that when plugging in various numbers for the load impedance, the same transformer matches fairly wide load impedances to within a turn or two on the transformer.

While the above illustrations are mathematically correct, further adjustments to the number and/or spacing of turns or even changing core mixes to a higher or lower permeability, may be necessary to achieve the best frequency response. This is not an exact science but one of “cut and try.”

WINDING AND TESTING THE TRANSFORMER

Now that the turns ratio is calculated, refer to Figure 1. Recall that the dots at the top of the windings indicate winding “sense” or the beginning of the wires that are simultaneously would together

– in this case two – or bifilar. The input (winding **A-a)** is the primary. The primary uses only one bifilar winding. The secondary winding uses both bifilar windings (windings **Bb-Aa)** and are connected as "series-aiding" where the bottom of one winding is connected to the top of the other.

The Balun: Take two 24-inch lengths of #20 gage stranded (or solid) wire, with PVC insulation and wind them bifilar on an FT140-43 ferrite core. Arbitrarily assign 8 turns as the number of bifilar turns for the primary coil (**A-a). Note:** 8 is a commonly used, empirically derived, number of turns that most builders start with. We just want to get close and then test. Allow some extra length of wire.

Referring to Figure 1, use the turns-squared formula to calculate the total number of turns for the secondary. ***Eight*** turns are assigned as the number of primary turns. The secondary is the ***total of both*** windings that represents the unknown value. From the above calculation we know the turns ratio is **1.86:1**. For illustration purposes, do not round up. Otherwise, you would actually round up to 2.

Multiplying **8** by **1.86** gives **15** turns. However, ***do not add*** an additional 15 turns to the existing 8. Instead, ***subtract*** the 8 primary turns from the 15 total turns as calculated. The number of secondary turns is now the <u>combined</u> turns of **B-b (7 turns) & A-a (8 turns)** or a total of 15 turns.

A 4:1 **balun** transformer has an <u>equal number</u> of bifilar turns, and means that, for this example, had we rounded up to 2, that the actual secondary turns would have totaled 16.

The 9:1 Unun: For a high turns ratios, wind in a single coil and tap the number of turns from the bottom of the winding for the primary. Again, assign the empirical value of 3-turns for the primary. The ratio is 9:1 therefore: 3x9=27. This transformer is not bifilar wound, but is still an autotransformer. The **3 primary** turns are subtracted from **27** for **24 secondary** turns. *More on high ratio transformers later.*

This exercise demonstrates how easy it is for the radio amateur to develop a prototype for a working transformer or at least have a better grasp of the mechanics behind them.

Earlier, I mentioned the minimum number of turns on a transformer as being those that will just produce sufficient impedance for a low VSWR at 3.5 MHz without causing a high VSWR at 30 MHz that result from excessive wire lengths. One reason is mentioned in the 'Notes' below and requires some experimentation. Later on, some techniques will be suggested to aid the overall performance.

WINDING A 4:1 BALUN THEN TESTING

MATERIALS

- **Core:** FT140-43 (Fair Rite # 2643251002)**Wire:** #18 gage, stranded or solid wire, tinned, silver plated or bare copper; PVC, FEP (Amazon-) or PTFE insulation. **Length:** 2 pieces 26 in. long each of a different color and labeled on each end. **One wire:** A & a; and the **Other wire:** B & b.
- **Zip ties:** Pack of 50, 4 to 6 inches long
- **Resistors:** Two, 100-ohm, ½ watt, carbon film resistors
- **Equipment:** Antenna analyzer with short clip leads

WINDING and TESTING AS A BALUN

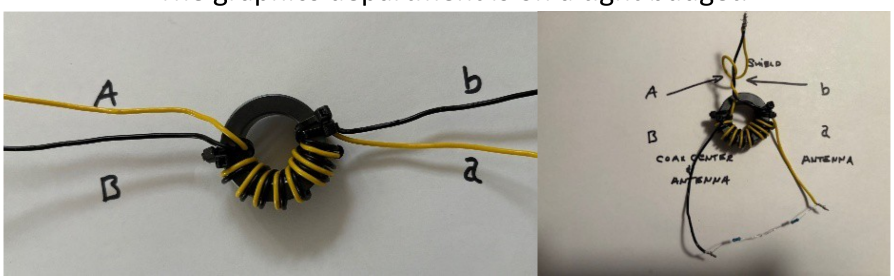
Working with FEP or PTFE insulated wire is like pushing a chain. Therefore, I suggest prototyping using PVC hookup wire – it's cheaper and much easier to manage but using the correct wore for the permanent transformer may require an adjustment of a turn or two.

1. Leaving 3-inch long pigtails, hold wires A&B together and tightly zip-tie them to the core.
2. Keeping pairs together, tightly wind 8-turns in the same direction. Zip-tie in place.
3. Strip insulation from all four wire ends; connect A to b; solder. There should be three pigtails; one from each end of the windings (**B & a**) and one from the middle (**bA**).
4. Evenly arrange turns together in pairs, as shown in photo.

5. Temporarily solder two 100-ohm resistors together in series to total 200-ohms.
6. Connect (**A to b**). Connect coax shield to (**Ab**). Connect coax center to (**a**). Tack solder resistor pair between leads (**B & a**).
7. Connect analyzer to input (**A-a**); Measure and record R, X and VSWR for the following tests: Before soldering to the transformer leads, check resistors: 200-ohms (meter), or SWR of ≈4 (analyzer). These are autotransformers so the asymmetry test (line 3) does not apply and are presented for reference only. In Part 4, current balun transformers will easily pass line 3 tests.

BALUN	UNUN
1. VSWR – 3.5 MHz (<1.2).	VSWR – 3.5 MHz (<1.2).
2. VSWR - center of resistors grounded (<1.2).	VSWR - center of resistors grounded (≈2.0).
3. VSWR - antenna terminal grounded (very high).	VSWR - antenna terminal grounded (very high).
4. VSWR – ground terminal grounded (<1.2)	VSWR – ground terminal grounded (<1.2)

Perform & record readings for the amateur bands from 1.8 to 30 MHz (VSWR <1.2:1 to <1.4:1)
If necessary, adjust number of turns or pair spacings for best overall VSWR. See Notes below.
~~The graphics department is on a tight budget.~~



Connections Shown as a BIFILAR Wound 4:1 (Ruthroff) Voltage Balun Transformer

Finished 4:1 Ruthroff Voltage Balun Transformer Wound on a FT140-43 Core

Notes: The transformer tested the same whether connected as a Balun or an Unun from 1.8-30 MHz. Here is one problem with voltage transformers: Thy are touchy. The VSWR with 8 turns was 1.0 at 3.5 MHz but 1.6 at 30 MHz. Increasing turns to 9 gave a better reading at 30 MHz at 1.4. 7 turns were too few and 10 turns, too many. VSWR at 3.5 MHz and below, was 1.0 regardless of the turns. A higher µ core (maybe #52) may test better but the number of turns will change.

Calculations are only for turns ratio. Excluding CM chokes, when transformer winding lengths exceed 1/10λ or 39-inches at 30 MHz, phase distortion comes into play that negatively impacts transformer operation, drives up VSWR and losses.

FUN FACT: Instead of connecting the transformer as a 4:1 balun or unun, connect A to the coax shield and B to the center conductor; connect the other ends a & b to a dipole (polarity does not matter with any dipole); this then becomes a 1:1 current (Guanella) balun or Common Mode Choke. Maintain polarity if using on a vertical – center of coax to (A); and antenna to (a); shield to (B); and radials or ground to (b). To make it more effective (higher choking), simply add 4-5 more turns. **Ref:** VK5AJL explanation at the link above.

Resources. Cores: Digikey, Mouser, Fair Rite or Amidon FT140-43 (Fair Rite # 2643251002)**. Wire:** Amazon PVC Solid: 18 AWG Solid Core Hookup Wire Kit , Stranded: 18 awg Wire,18 awg PVC , FEP/PTFE Stranded: FEP Teflon High Temperature Wire of 18awg . eBay: Stranded, silver plated, #18, PTFE.

Caution: Working with PTFE insulated wire is a lot like pushing a chain. A third hand would be nice to help keep it in place, but practice makes perfect. It is the best wire for good operation.

SOMETHING TO DO IF BORED

Autotransformer's are actually bi-directional devices and will transform impedances in both directions and often work as well when connected in reverse as an impedance **step down** transformer. Using either transformer configuration, move the coax connection from the center-tap (**b-A**) to terminal (**B**); move the upper antenna connection from (**B**) to (**b-A**). The above 4:1 transformer should now become a 1/4:1 to transform 50-ohms down to 12.5 ohms. The upper end may suffer because of the higher number of turns on the new primary. However, the lower end may be improved for the same reason. An autotransformer can be wound as a single coil with the input or output connections "tapped" to get improved transformation as is done with high impedance 9:1 up to 49:1 ratio ununs used in end-fed or longwire antennas.

One core characteristic I neglected to mention in Part 1 was **Curie Temperature**. Curie temperature, or Curie point, is the temperature above which certain materials lose their magnetic properties (mu) and become almost non-magnetic. **Plain language interpretation:** It permanently destroys the magnetic properties of the ferrite core.

Part 4 will cover 1:1 and 4:1 current or Guanella transformers, Common Mode Chokes, Coiled Transmission Line Chokes, Split Bead Chokes, and anything else I can think of that's relevant. For ratios 4:1 and below, current transformers outperform voltage transformers. Winding and asymmetry testing will demonstrate their ability to balance unequal loads. Combining them with voltage transformers will also be addressed to utilize the best characteristics of both.