Transmission Line Transformers (TLT's) – Part 2

Core Selection, Wire Size and Insulation Plus Intro To Winding

NOTE: Never use an unknown Toroid for anything except experimentation! Stick to reputable suppliers like Fair Rite, Amidon Associates, Palomar Engineers, DX Engineering, and Mouser.

These tables will help you choose the best ferrite mix. **Note:** Common mode (CM) suppression chokes are wound using coaxial cable thru a large toroid or clip on, split ferrite beads. 1:1 chokes are also CM chokes but are bifilar-wound on a toroid core as are impedance matching transformers. A single turn means that the coax or conductor is simply threaded thru the center of the core. Multiple turns increases the impedance of one turn times the turns squared and is covered in Part 3.

Table 1 adapted from: Ferrite material choice – Ferrite-shop

Material (mix) Widely Available	Common Mode Choke Frequency Range (Single Turn)	Common Mode Choke Frequency Range (Multiple Turns)	Impedance Transformer (Balun/Unun)	1:1 Balun (Choke)
#31	3.5 – 100 MHz	1.5 – 50 MHz	***0.1 – 2 MHz***	***1.5 – 30 MHz***
#43	25 – 600 MHz	2 – 60 MHz	***2 – 50 MHz***	***2 – 30 MHz***
#52	150 – 1000 MHz	4 – 150 MHz	***1 – 60 MHz***	***1 – 60 MHz***
#61	200 – 2000 MHz	5 – 200 MHz	***15 – 200 MHz***	***10 – 100 MHz***
#75	200 kHz – 10 MHz	100 kHz – 10 MHz	***0.5 – 8 MHz***	***1 – 8 MHz***
#77	1 KHz – 14 MHz	1 KHz – 14 MHz	***0.01-14 MHz***	***1 KHz-14 MHz***
FT-150-A-K & FT-250-K	µ300 Amidon	See note on Table 3	**1.8 – 60 MHz**	**1.8 – 60 MHz**

We are primarily interested with columns in ***bold italics*** above.

Table 1.

Ferrite Suitability By Mix And Frequency Range

Table 2 adapted from: The broadband common mode choke, 1:1 balun and 1:1 unun - PA9X

This table also depicts the general range for broadband transformers.

Ferrite Mix And Best Operating Ranges													
Ferrite Mix		**Band (Meters)**											
	2200	**630**	**160**	**80**	**60**	**40**	**30**	**20**	**17**	**15**	**12**	**10**	**6**
#31	3-4 cores	2-3 cores	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	F	F	
#43			F	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	F
#52				F	F	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**
#61				F	F	F	F	**G**	**G**	**G**	**G**	**G**	**G**
#75/#77	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	F	F			
FT-150-A-K	**Amidon**	**Similar to #52**		**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**

Table 2.

Toroid Ferrite Core Types by Mix - Number of Cores – Power Handling

Table adapted from: Power - Ferrite Core Design **VK6YSF**

Actual Core Nomenclature Size and Mix	Balun/Unun or Common Mode Frequency Range	Power SSB/CW	Number of Cores (Stacked)	Notes
FT140-31	**0.1-30 MHz**	50/150	1	
FT240-31		100/300	2	
FT240-31		500/1500	3	
FT240-75		500/1500	2	Optimized for lower HF
FTXXX-77	**1 KHz-14 MHz**	Same specs as above	Same specs as above	Useful for audio and RF
FT140-43	**1.5-30 MHz**	50/150	1	Good overall core
FT240-43		100/300	2	
FT240-43		500/1500	3	
FT140-61	**1.5-30 MHz**	50/150	1	61 is good overall but
FT240-61		100/300	2	optimized for the upper HF
FT240-61		500/1500	3	– UHF frequencies
FT140-61	**50 MHz (VHF)**	50/150	1	61 is optimized for the
FT240-61		100/300	1	upper HF – UHF
FT240-61		500/1500	3	frequencies
***FT-150-AK**	**1.8-50 MHz**	500	1	Good overall core for TLT's.
***FT-240-K**		1500	2	Used by Jerry Sevick in his
Amidon Associates	**µ of 300**			books
***My additions**	***52 is similar µ of 250**			

Table 3.

General efficiency notes regarding cores used for 1.8 - 30 MHz

Type 61, 52 and K materials can achieve 95–99% efficiency at 30 MHz, while 43 may only reach 50–70% due to core losses and heat dissipation. Type 31 should be reserved for 40 meters and below or common mode chokes. The inefficiency becomes more pronounced at higher power levels due to increased losses from heat. Use the mix that was specifically engineered for the frequency band of use. Generally, if using a 61 mix that is geared to higher HF and VHF, twisting the pairs may help in getting a usable impedance at 3.5 MHz.

Note: Stacking cores doubles the inductance, increases heat withstand, and reduces the length of conductors by requiring fewer turns for the same impedance. However, stacking also increases losses thru flux leakage between cores. Everything has a tradeoff.

Core Selection, Wire Size and Insulation, Heat Dissipation, Plus Intro To Winding

Ferrite cores are actually ceramic material that's molded, compressed then sintered. Most cores have the ring edges relieved to remove any sharp edges left from manufacture that could damage insulation. However, some sharp ridges may remain. I've found that using 400-600 grit sandpaper to smooth the edges, works very well without affecting any of the characteristics.

THERMAL CONSIDERATIONS

Excessive core heating can be reduced by housing transformers in a white PVC enclosure to reduce solar heating effects and having sufficient volume with ventilation to provide adequate cooling. Use the number of cores shown in **Table 3** as a guide for how much volume and ventilation may be required. The difference in heat generated between SSB and CW is considerable, so it is best to err on the side of CW duty cycle levels when designing higher power transformers.

If multiple cores are required, temporarily tie them together with string or zip ties until most of the windings are in place. There is no advantage to be gained by gluing them together. Cores larger than 2.4-inches (FT240-xx) and up are costlier, and one day may need to be separated for another use. Covering the core(s) in tape can impede heat dissipation.

WIRE INSULATION AND WINDING GEOMETRY

After selecting the proper core(s) for the power being used from the above tables, the correct wire size and insulation are then chosen. Approximate wire sizes to consider would be #20 or #18 AWG for 200 watts CW, #16 AWG for 300 watts CW, #14 for 500 watts CW and #12 AWG for anything above. Wire for low to medium power can be stranded or solid, silver plated, tinned, or bare copper; preferably covered with PVC, PTFE, Formvar, or Thermaleze plus PTFE tubing.

The absolute best wire for winding TLT's is solid, silver-plated copper with PTFE (Teflon) insulation. It's expensive but for individual use, not much will actually be needed.

If winding transformers for high power, cores should be wound using solid, silver-plated copper wire with Formvar or Thermaleze insulation then placed in 15mil thick wall, PTFE tubing. Both Formvar and Thermaleze insulations withstand high temperature, high voltage and are somewhat resistant to abrasion.

WINDING GEOMETRY

When winding toroids, a single turn is consists of a wire passed straight thru the center of the core. One full 360° turn, around a core is counted as two turns, etc. Or, count the outer loops and add one.

Proper winding technique and attention to detail can't be overemphasized. All TLT's are wound as a single layer using either a single conductor, or multi-filar windings that, if done properly, yield good performance (assuming the proper core material is used). Loosely laid, sloppy or overlapped windings are detrimental to proper operation so carefully wind them snugly. If multi-filar wound (2 to 5 conductors wound together), keep the groups touching and evenly spaced.

Using as small of a core as possible to accommodate the wire size used is ideal. The number of turns that fit on a core for the wire size selected, can be estimated by winding it with the same wire size or cordage of the same diameter, or the wire itself. There are also tables on the internet by wire and core diameter.

In reality, the total number of turns, for most HF TLT's using ferrite cores, that have ratios of 9:1 and below, fall between 5-12 bifilar, 5-8 trifilar, or 5-6 quadrifilar turns. I have seen only one quintafilar wound transformer. **Example:** A core wound with 12 monofilar turns of wire occupies the same area as 4-trifilar turns (4 turns of 3-wires flat-wound together). Higher ratio transformers, 9:1 and above, are generally wound as monofilar unun's because a much higher voltages exist at the high impedance or antenna end.

The center of the core is where the magnetizing force (coupled flux) is maximum, and impedance transformation takes place. The outer circumference, is where flux coupling is minimum, and little transformation occurs. Adjusting the outer turn positions, and proximity to each other can be used to fine-tune the overall response. Once satisfied, some builders place beads of hot melt glue, or PVC or glass tape to anchor the turns.

SPECIAL CONSIDERATIONS

Transformers used to match loads that are very reactive such as end fed and random wire antennas, must handle both high impedance and high VSWR which in turn creates extremely high winding-to-winding, and winding-to-core voltages. Nicked or low voltage insulation, especially when using higher power, can result in turn-to-turn or turn-to-core arcing and instantly destroy the transformer.

Adding PTFE sleeving over enameled copper or using PTFE insulated wire, will greatly minimize that possibility. Some builders wind layers of electrical insulating tape, glass tape, or pink or white Teflon tape, over the core to prevent nicking the enamel. While that might be considered to be good in practice mechanically, it's bad magnetically, and may cause core overheating.

Using quality wire is preferred for good results and longevity. Prototypes may be wound with almost any scrap wire. However, for the final build, use the correct wire size and insulation. The type and thickness of insulation has an influence on the overall impedance. So, turns may need to be adjusted for acceptable performance over the frequency of use.

SELF SHIELDING

The phenomena that the concentration of magnetic flux is confined to the center axis and not the outside diameter of the toroid is why they make very efficient inductors that are also self-shielding. Proximity to metal surfaces or other magnetic components have little or no effect because the field at the outer perimeter in minimal. However, good engineering practice suggests allowing ¼ inch of space between metal surfaces and other toroid transformers.

Equally spreading turns over the entire core so that the turns in the center of the core are also spaced, while pleasing in appearance, actually reduces efficiency by creating excess flux leakage (reduced coupling) between turns. Keep turns tight in the center without overlapping and, in the case of multi-filar windings, evenly spaced in tight groups as wound (groups of 2 for bifilar, 3 for trifilar, etc.) around the outer perimeter. If only half the core is needed to wind the transformer, then so be it. It's all about magnetic coupling, not appearance.

Because there are so many variables, calculating turns for transformers is not an exact science. It is actually more about experimentation, understanding basic turns-squared ratios, proper winding technique, quality materials, application and patience more so than it is complex engineering physics.

Here is an excellent link to "The RF Café" and contains a lot of great information from connectors to calculations in easy to understand formats. Electrical / Electronics Conversions Formulas & References - RF Cafe

Below are some photos of ferrite cores and clamp-on, split beads. The beads will be covered later in **Part 6, Common Mode Suppression**.

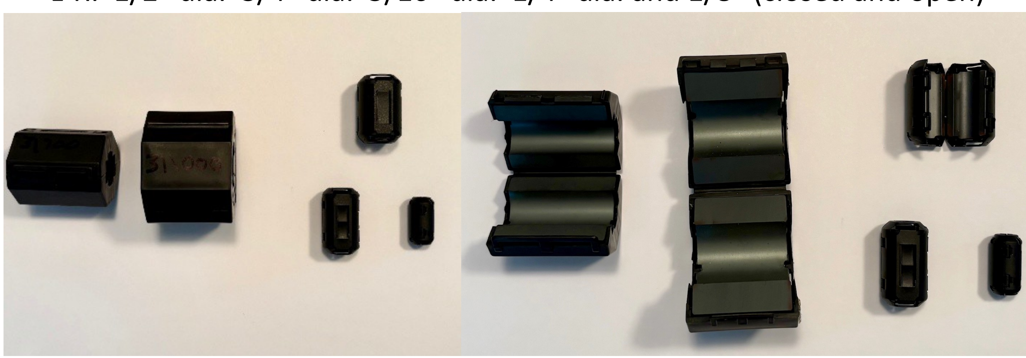
Ferrite Torodial Cores

FT37-43 FT50-43 FT50B-43 FT82-43 FT114-43 FT250-43

The FTxx-xx is somewhat standardized but some manufacturers use part numbers (Fair Rite). The third from the left is a “B” core which indicates that it is the tickness of three of the FT50-43 to its left. Iron powder cores (not shown) come in different colors that indicate the Mix and have a Txxx-xx nomenclature (The Red T200-2 is the most popular for HF transformers). In this example, T200 is the diameter in inches (2.00 inches), 2 is the iron mix and is Red. Irom Powder will be covered later in **Part 6.**

Split or Clip-on Ferrite Suppression Beads (31 Mix)

L-R: 1/2” dia. 3/4” dia. 5/16” dia. 1/4" dia. and 1/8” (closed and open)



Next up: Part 3. Calculating Widing Ratios for Transformers. Transformer Types. When is a Balun an Unun?