Transmission Line Transformers (TLT's) – Part 1

FERRITE TOROID CORES AND CHARACTERISTICS

INTRO

This series will only address sintered, ferrite material. Powdered iron cores are neither designed nor recommended for RF applications and therefore, will not be covered. Note that ALL HF antennas require a matching transformer or CM choke.

Ferrite toroid cores are doughnut-shaped rings, that are dark grey or black in color, and composed of either of two ceramic mixtures - nickel-zinc (NiZn), or magnesium-zinc (MnZn) to which various forms of iron oxide (**NOT** powdered iron) has been added to create functional characteristics such as desired permeability, operating frequency range, and temperature tolerance. The materials are combined by sintering. A link explaining core manufacture: https://search.app/4WMGAYmbxWZMMrfZ8

Additionally, many other shapes such as rods, split beads, sleeves, binoculars, etc., are made for specific RF uses. This series will focus on the doughnut-shaped and bead, snap-bead (barrel-shaped) cores for use in antenna matching transformers and common mode line chokes.

Ferrites are classified by a specific "MIX" or ratio of the above compounds to tailor its magnetic properties. Those are listed in **Table 1.** Naming conventions vary among manufacturers, but most are designated by first a letter, followed by a number and generally have a permeability tolerance of +/- 20%. Cores are relatively inexpensive, but, being made of a brittle, ceramic material, are prone to breaking if dropped on a hard surface (this has already been tested).

Cores are identified by type (ferrite), outer ring diameter (inch), and mix. **For example:** a **F**errite **T**oroid having an outer diameter of **1.40**-inches and composed of a #**61** mix would be identified as, **FT140-61**. Fair Rite Corp. also lists many of their cores by part numbers such as: 40**61**378111. The second pair of numbers indicates the mix. The rest of the specs are listed on the data sheet for that core. See **Fair-Rite Corp Materials** [Index - Fair Rite (fair-rite.com)](https://fair-rite.com) and click on 'Tech Resources.' It's an informative site but takes some poking around for the info.

Easily available cores come in various sizes from very small (⅛"dia. that slips over a resistor or capacitor lead to toroids having an outside diameter of 4 inches or more for custom cores.

So, What's The Big Deal About Ferrites And TLT's Anyway?

Simply put, it is about achieving maximum power transfer from source to different loads. In Direct Current circuits, in order to achieve maximum power transfer from source to load, both must present equal internal impedances (or resistance) to the flow of current (Ohm's Law $P=I^2R$). In RF TLT's, there's a little more to it than simply winding as much wire as will fit on a core. But for this series it's correct to say that TLT's "translate" the unequal impedances between source and load while minimizing 'translation' (or insertion) losses. Many factors cause insertion loss and is beyond the scope of this series but can be minimized with proper core and wire selection, and careful winding geometry.

THE UNUN

UNbalanced to **UN**balanced. Also called an autotransformer. This transformers job is to match the **UN**balanced impedance of the transmitter and feedline to a myriad of **UN**balanced antennas that may be referenced to ground. Ground can be anything from a deeply driven copper rod, multi-wire radial system (ground plane) or an end-fed antenna using a single wire counterpoise. Verticals and end-fed antennas can present a wide range of impedances ranging anywhere between 12 for vertical and 4,500 ohms for end-fed wire antennas. Antennas

THE BALUN

BALanced to **UN**balanced. The **BAL**anced terminals connect the output side of the transformer to an antenna , load or instrument. The **UN**balanced terminals connect the input side of the transformer to a transmitter, feedline or signal source. This transformers job is to match the unbalanced (or referenced to ground) impedance of the transmitter and feedline to that of an ungrounded, 'balanced' or floating antenna not connected to ground such as a dipole. These types of antennas present impedance ranges of 12 - 150 ohms.

THE COMMON MODE (CM) CHOKE

Common mode current is present and problematic in all coaxial feedline systems regardless of where it is terminated. CM chokes, are also referred to as 1:1 baluns, beads, ugly baluns, or line chokes. Common mode current will be discussed in later articles.

PERMEABILITY (µ)

Permeability (µ) is the degree to which a magnetic substance changes or influences the magnetic flux in a magnetic field, and how well the material allows or restricts magnetic lines of force pass thru it. The higher the permeability, the higher the flux flow.

High permeability provides high flow of flux at low frequencies. By the same token, it also restricts the flow of flux at higher frequencies. Specific mixes are generally used for specific frequency ranges. **Table 1.** shows commonly used cores that are best suited for HF with #31, #43, #52 and #61 Mixes being suitable for TTL applications in this series.

VOLUME RESISTIVITY

A fancy term for the surface resistance of a toroid core. Unmarked cores can ofttimes be identified by measuring the surface resistance with an ohmmeter. A low ohmic reading between 200-2000 ohms indicates an MnZn material. A high or infinite ohmic reading indicates a NiZn material. This method may work to ID unmarked cores at ham-fests but won't indicate the mix. Further research will give the method used to measure the unknown 'per turn' inductance or A_L that's expressed in nano-Henries per turn. Even then, it's dubious and should be avoided for anything beyond experimentation.

AN EXCELLENT PAPER FROM PALOMAR ENGINEERS

This is one of the best written articles I've seen on the subject. So, I've pasted it here and tweaked it a bit for clarity *(italics are mine)*. One thing I added to Table 1., was data for a #77 mix that I copied from Fair Rite Corp. It was mentioned in Palomar's narrative, but not entered in the table.

From Palomar Engineers

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Follow the above link for more information.

FERRITE MATERIAL TYPES

Ferrite Mix Selection Guidelines. Quite often we are asked which mix is best for a certain application or frequency range and there is a lot of misinformation on the internet and elsewhere regarding the selection of proper mix for a given application.

There are two basic ferrite material groups: (1) Those having a low initial permeability *(μ_i)* range from 20 to 850 µ *(permeability)* that are of the Nickel Zinc (NiZn) class (mixes 43, 52, 61); and **(2)** those having a high initial permeability *(μ_i)* above 850 µ are usually of the Manganese Zinc (MnZn) class (mixes 31, 73, 75, 77).

The Nickel Zinc (NiZn) ferrite cores (mixes 43, 52, 61) have low initial permeability *(μ_i),* exhibit high volume resistivity *(high ohmic core surface resistance),* moderate temperature stability and high 'Q' factors *(figure of merit or level of operational performance)* in the 500 KHz to 100 MHz range.

They are well suited for low power, high inductance, resonant circuits. Their low permeability factors also make them useful for broadband transformer applications *(baluns, ununs, chokes).* Nickel-zinc ferrites have a higher resistivity and are used at frequencies from 2 MHz to several hundred megahertz. The exception is common mode inductors where the impedance of NiZn material is recommended for use from 70 MHz to several hundred GHz.

The MnZn ferrite cores (Mix 31, 73, 75) have high initial permeabilities *(μ_i),* that are above 800 µ, have fairly low volume resistivity *(low ohmic core surface resistance),* and moderate saturation flux density. They offer high 'Q' factors for the 1 KHz to 1 MHz range. Cores from this group of materials are widely used for switching mode power conversion transformers operating in the 20 KHz to 100 KHz range. These cores are also very useful for the attenuation of unwanted RF noise signals *(line or CM chokes)* in the range of 2 MHz to 250 MHz. Manganese-zinc ferrites are generally used in inductor applications where the operating frequency is less than 5 MHz. **The exception** is common mode inductors where the impedance of MnZn material makes it the best choice up to 10 MHz.

What's Different between Mixes? The "Mix" is the chemical formula of the iron oxide. Ferrite is a actually a sintered, ceramic compound consisting of iron oxide and generally either of two types of ceramic *(Google sintering for the definition)*:

- Manganese-zinc (MnZn) is available as Mixes 31, *73,* 75 and 77 (and others) and work well for common mode chokes
- Nickel-Zinc (NiZn) is available as Mixes 43, 52, and 61, (and others) and are the preferred material for baluns and ununs.

Palomar Engineers uses mix 31, 43, 52, 61, 73, 75 and 77 for most applications from RFI/EMI common mode suppression; multi-ratio toroid baluns and ununs; and sleeve baluns for line isolation. Each mix number has a measurable permeability and suggested frequency range for certain applications.

Table 1. gives our recommended applications for various mixes and effective frequency ranges

Mix #	Material	Initial Permeability µi	RFI/EMI Common Mode Suppression Range	Tuned Circuits – Coil	Wide Band Transformer (Balun & Unun)
31 (1)	MnZn	1,500	1-300 MHz	–	1:1 only, <300 MHz
43 (2)	NiZn	800	25-300 MHz	< 10 MHz	3-60 MHz
52 (6)	NiZn	250	200-1000 MHz	< 20 MHz	1-60 MHz
61 (3)	NiZn	125	200-1000 MHz	<100 MHz	1-300 MHz
73 (7)	MnZn	2,500	< 50 MHz	< 2 MHz	<10 MHz
75/J (4)	MnZn	5,000	150 KHz – 10 MHz	< .75 MHz	.1-10 MHz
77 (8)	MnZn	2,000	200 kHz - 15 MHz	<4 MHz	.5-8 MHz

Table 1.

Notes:

(1) Mix 31 excellent for 1-10 MHz common mode suppression, then performs similar to 43 up to 250 MHz. It is NOT recommended for multi-ratio impedance transformers (baluns/ununs) due to material characteristics and power handling capability but OK for ham radio 1:1 feed line chokes. Its Curie temperature is >130 C (*temperature above which the magnetic properties begin to fail and permanently destroys the usefulness of the core).* Mix 31 is available in TOROIDS, SLIP ON BEADS, and SNAP ON SPLIT BEADS

(2) Mix 43 is excellent for common mode chokes from 25-300 MHz, Use Mix 31 below 10 MHz for higher choking impedance. Curie temperature >130 C.. Mix 43 is available in TOROIDS, and SLIP ON BEADS

(3) Mix 61 will withstand high power in multi ratio (2:1, 4:1, 9:1) impedance transformers (baluns/ununs). Currie temperature > 300 C. Mix 61 is available in TOROIDS, SLIP ON BEADS, and SNAP ON SPLIT BEADS

(4) Mix 75 (also known as Mix J) Beads only. Go to Palomar Engineers link above for applications.

(5) There's no footnote 5.

(6) Jerry Sevick, W2FMI's broadband transformers (baluns/ununs) used a permeability of 250 (Mix 52). The F240-52 ring toroids are ideal for replicating his designs. *For a free archived download of his book, "Transmission Line Transformers Handbook, 48 Improved Designs", paste this link into your browser: Ham Radio Transmission Line Transformers Handbook*

(7) Mix 73 is only available in small bead size from Palomar but exists elsewhere in standard sizes, for larger inside diameter requirements use Mix 77.

(8) *Mix 77 has a much lower permeability of 2,000 instead of 5,000 like mix 73.* I cut and pasted the relevant data for 77 mix into Table 1 that I copied from Fair Rite.

General Comments On Frequency Ranges And Application

When selecting a mix to use for tuned circuits or broadband transformers, the frequency range should allow for operation in the **INDUCTIVE range** of the ferrite mix frequency curve. For best results use the proper mix with a **RESISTIVE-dominant** range for RFI/EMI suppression at the fundamental RFI frequency. Additionally, **Mix 31** is only appropriate for 1:1 impedance *(CM)* transformers and for RFI suppression from 1-300 MHz; it should not be used for <1:1 or > 1:1 impedance transformers as the material resistivity is high when used above 5 MHz.

We have experienced excellent RFI common mode suppression under 5 MHz with mixes 75 and 77 when using multi-turn toroidal topology *(translated, 1:1 Guanella current balun. Transformer construction will be covered later.)*

Part 2 will continue with more details on core selection and winding with regards to frequency, and power handling capability, plus enclosures, plus lots of other useful stuff.