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# Toroids for the Terrified

## Ferrite or Dust Iron?

Ferrite is a ceramic produced at very high temperature to make the material melt and flow into a single entity and solidify, like glass does. There are no individual particles and magnetic flow around it is continuous, rather than hopping from particle to particle. This structure leads to a strong magnetic field that results in significant inductive reactance for every turn.

Dust Iron is a composite of chemical particles of iron compounds mixed like cement. The magnetic path is not smooth but has the field hopping from particle to particle. The result is a lower magnetic density and hence a lower inductive reactance per turn. An advantage of these cores over ferrite is lower losses and greater temperature stability of the inductance factor.

## How they work

Both types of toroid have the advantage over other types of coils or transformers in that the magnetic field has a smooth circuit to concentrate the field of the coil within the torus. This means that several toroidal cores making up a filter can be grouped closer and with less crosstalk than unscreened coils.

They produce an inductive magnification ($\mu$) by concentrating the lines of force generated by the windings through the centre of the coil that just happens to be bent into a torus. The same happens with a ferrite rod aerial but in that case it is deliberately made as a straight-line path to focus received radio signals through the core of the coil.

The limiting factor of a toroid, or indeed any other type of core including iron, is magnetic saturation, denoted $\beta_{max}$ and is directly proportional to the number of turns and the current flowing through them.

This saturation can be caused by both direct current and alternating current. In power amplifiers usually one or two transformers are used for matching the amplifier up to 50Ω and another centre tapped transformer used to connect the transistors to the DC supply.

If you pass a wire through the core then around the outside and back through the core is looks like just one turn but is actually two turns. This is because every time the wire passes through the inside it constitutes a turn. A single turn is one where the wire passes once through the inside and then crosses over at the outside.

## Dust Iron toroids

Due to good temperature characteristics and relatively low inductance factor these types are normally used for RF coils or relatively narrow band transformers. Conversely the large T200-2 is often used in antenna baluns where its saturation flux density is lower than a comparable ferrite device. Simply stated it can handle more power than a ferrite version.

The most commonly used dust iron cores are types 2 red and 6 yellow. Type 2 is best for 500kHz-20MHz in sizes 0.375” OD and above. Type 6 is best for 2-30MHz for sizes 0.375” and above. Cores are classified by size, material type and the inductance factor.
The following table shows the commonly used cores types and sizes and inductance factors of $A_L$ in µH per 25 turns for types 2 & 6.

Table 1. Dust Iron Toroids Outside diameter (OD). Inside diameter (ID). Height (H).
Type 2 $A_L$ uH/25t. Type 6 $A_L$ uH/25t.

| Core | OD”(mm) | ID”(mm) | H”(mm) | $A_L(2)$ | $A_L(6)$ |
|---|---|---|---|---|---|
| T37 | 0.375”(9.5) | 0.2”(5.2) | 0.128”(3.3) | 2.5 | 1.9 |
| T50 | 0.5”(12.7) | 0.3”(7.6) | 0.19”(4.8) | 3 | 2.5 |
| T68 | 0.69”(17.5) | 0.37”(9.4) | 0.19”(4.8) | 3.6 | 2.9 |
| T130 | 1.3”(33) | 0.78”(19.8) | 0.437”(11.1) | 6.9 | 6.0 |
| T200 | 2.0”(50.8) | 1.25”(31.8) | 0.55”(14) | 7.5 | 6.3 |

Now the inductance is proportional to the square of the turns ratio, so to determine the number of turns (N) required for a specific inductance ($L_{\mu H}$) use this formula;

$$\mathbf{N = 25*\sqrt{(L_{\mu H}/A_L)}.}$$

Table 2. Dust Iron Toroids. G4CFY turns N by SWG.

| Core\SWG | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 |
|---|---|---|---|---|---|---|---|---|---|---|
| T37 | - | - | 9 | 12 | 16 | 21 | 26 | 32 | 36 | 43 |
| T50 | - | 10 | 14 | 18 | 25 | 31 | 39 | 47 | 54 | 64 |
| T68 | 9 | 12 | 18 | 24 | 32 | 40 | 49 | 59 | 68 | 80 |
| T130 | 23 | 30 | 42 | 53 | 70 | 86 | 106 | 127 | 146 | 171 |
| T200 | 38 | 50 | 69 | 87 | 115 | 140 | 173 | 206 | - | - |

Dust Iron Toroid Worked example 1.

If a coil of 5µH is required for a coil to operate on 40 metres (7MHz) we will try with the smallest type 2 core, T37-2. $N = 25*\sqrt{(5/2.5)} = 25*\sqrt{2} = 25*1.414 = 35$ turns.
Now by referring to Table 2 you can put up to 36 turns of 32 SWG on the T37-2 core. So that would work quite well. 32 SWG it quite easy to use and just needs a single scrape to expose sufficient bare copper to burn off the enamel.

Dust Iron Toroid Worked example 2.

Now lets do the same again but this time using a T50-2 core.
$N = 25*\sqrt{(5/3)} = 25*\sqrt{1.666} = 25*1.29 = 32$ turns. Referring again to Table 2 you can put up to 31 turns of 26 SWG on a T50-2 core, otherwise use 28swg. Either would also work well and have a higher Q than the T37-2 version due to lower wire resistance. It would take up more board space, would be easier to wind but would require more scraping before soldering.

## Ferrite Toroids

Generally these toroids are used to significantly extend the electrical length of twisted pairs, triple, and quads of wires used to form wideband transformers. They are also popular for making the transformation from **BAL**anced to **UN**balanced circuitry. Known as Balun.

There are just two commonly used material types, 43 with a characteristic µ of 850 and suitable for use from low frequency up to 50MHz, and type 61 with a µ of 125 and suitable for use in high Q coils from 150kHz to 15MHz and in baluns and transformers to 200MHz.

Table 3. Cross reference

| TYPE | FAIR-RITE | | TYPE | FAIR-RITE |
|---|---|---|---|---|
| FT37-43 | 5943000201 | | FT37-61 | 5961000201 |
| FT50-43 | 5943000301 | | FT50-61 | 5961000301 |
| FT50A-43 | 5943001101 | | FT50A-61 | 5961001101 |
| FT140-43 | 5943002701 | | FT140-61 | 5961002701 |

Table 4. Ferrite Toroids Outside diameter (OD). Inside diameter (ID). Height (H). Type 43 $A_L$ uH/25t. Type 61 $A_L$ uH/25t

| Core | OD”(mm) | ID”(mm) | H”(mm) | $A_L$ (43) | $A_L$ (61) |
|---|---|---|---|---|---|
| FT37 | 0.375”(9.5) | 0.19”(4.8) | 0.125”(3.2) | 260 | 34 |
| FT50 | 0.5”(12.7) | 0.28”(7.1) | 0.19”(4.8) | 327 | 42.5 |
| FT50A | 0.5”(12.7) | 0.31”(7.9) | 0.25”(6.3) | 356 | 46.9 |
| FT140 | 1.4”(35.6) | 0.9”(22.9) | 0.5”(12.7) | 595 | 87.5 |

To determine the number of turns (N) required for a specific inductance ($L_{uH}$) use this formula;

$$\mathbf{N = 25*\sqrt{(L_{uH}/A_L)}.}$$

Table 5. Ferrite Toroids G4CFY turns N by SWG.

| Core\SWG | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 |
|---|---|---|---|---|---|---|---|---|---|---|
| FT37 | - | - | 8 | 11 | 15 | 19 | 23 | 29 | 33 | 39 |
| FT50 | 6 | 9 | 13 | 17 | 23 | 29 | 36 | 44 | 50 | 60 |
| FT50A | 7 | 10 | 15 | 19 | 26 | 33 | 41 | 49 | 57 | 67 |
| FT140 | 27 | 35 | 49 | 62 | 82 | 100 | 124 | 148 | - | - |

Calculate a reactance 4 to 5 times the impedance being matched. Convert this reactance to inductance at the lowest operating frequency and try a calculation to determine number of turns on a reasonably large core. Often you look for a large core with a high enough inductance factor to give just one turn for the primary side.

Ferrite Toroid Worked example 1.

Calculate a suitable step-up wideband transformer from say 50Ω to 200Ω in a low power circuit. A 1:4 impedance step-up requires a 1:2 turns ratio primary to secondary.
If the secondary load is 200Ω then the minimum core reactance required will be 800Ω.

If the lowest frequency of operation is say 3.5MHz then the inductance calculates by
$L = X_L/(2*\Pi*f) = 800/(2*\Pi*3.5*10^6) = 800/22\ \mathrm{uH} = 36.4\mu\mathrm{H}$.
Choosing the FT37-43 core as a first try, with $A_L = 260/25t$,
$N = 25*\surd(36.4/260)$, $N = 25*\surd 0.14 = 25*0.374 = 9t$.

Three wires twisted together wound on the core and then two of them wired in series. By using 5 turns of the trifilar wire, when two windings are in series there is ten turns. The total wires through the core will then be 5 times 3 = 15. Referring to table 5 you can put 15 turns of 24 SWG through a T37 core. I would use 26 SWG to be on the safe side and spread the turns evenly around the core.

### Ferrite toroid worked example 2

I recently tried to match a 140 Ohm filter to a 560 Ohm load using the usual tiny ferrite bead (like the old FX1115), with three wires twisted together and wound through the core three times, then wiring two windings in series. It was rubbish!

The reason was that the FX1115 bead a wideband transformer has relatively low reactance in the windings, so was good for 50 Ohms but not for 560 Ohms. The secondary winding needed to have a reactance at least 4 times the load, in this case that is 2240 Ohms.

Worked example. Operating frequency 9MHz. Primary 140 Ohms. Secondary 560 Ohms.
Required main winding reactance 2240 Ohms.
$X_L = 2\pi fL$. $L = X_L/2\pi f$. $L = 2240/2\pi*9*10^6 = 40\mathrm{uH}$.

Choosing the FT37-43 core as a first try, with $A_L = 260/25t$,
$N = 25*\surd(40/260)$, $N = 25*\surd 0.154 = 25*0.39 = 9.8t$. (Use 10 turns).

As in the previous example the transformer can be wound with 5 turns trifilar 26swg, and with two windings connected in series. The transformer is identical physically to that in the first example but intended to transform quite different impedances at a different frequency.

### Concluding remarks

Don’t be scared of these clever little components. If when handling them to wind them you break them, don’t be too concerned. They can be repaired with super-glue. For small signal work, ferrite and dust iron can be super-glued without noticeable effect. For large signal work dust iron toroids can be repaired but ferrite need to be replaced.