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Toroids for the Terrified

This month Tony goes into detail about toroids, both ferrite and dust iron. Stick with his explanations as they could be very useful in the shack.

The previous article about toroids in *Technical for the Terrified* stimulated several e-mails regarding the clarity of the description. Among the respondents was **Keith Stammers** who, after expressing his enjoyment of the article, went on to ask on what basis a radio experimenter should choose ferrite or dust iron toroidal cores.

Available Data

Over the years I have accumulated a great deal of data regarding both ferrite and dust-iron toroids and, more recently, even those two-eyed monsters, the binocular cores. I don't think experimenters are frightened off these devices because of lack of data but more likely the opposite.

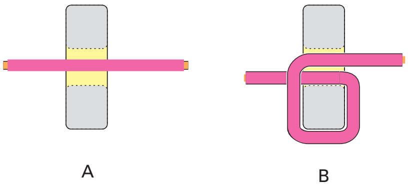
My first glimpse into the world of toroids was information supplied with a purchase of some dust-iron toroids back in the late 1960s or early 1970s from TMP Electronic Supplies, Leeswood, Mold in Wales. This data included information on grades 2, 6, 10 and 12 dust iron cores of a wide range of diameters. There were curves showing where each of the different size cores in each of these types produced the maximum *Q* against frequency.

Like many readers today, I was bewildered by which to choose, especially when information from elsewhere seemed to conflict with the choice based on maximum *Q*. In those days, there were many sorts of ferrite cores and no real guide as to when dust iron was required or when ferrite was best. Just the same problem, in fact, that readers still have nowadays.

The most useful data on toroids came from *Short Wave Magazine* in a series of three articles commencing in August 1998, with a wealth of information relating to types and sizes along with winding information.

Ferrite or Dust Iron?

Ferrite is a ceramic produced at very high temperature in order to make the material melt and flow into a single entity before solidifying, in the same way that 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.



An example of a toroid with one and two turns.”

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. These cores have the advantage over ferrite of lower losses and greater temperature stability of the magnetising factor.

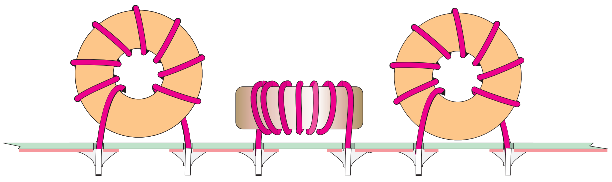
How They Work

Both types of toroid have the advantage over other types of coils or transformers 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 more closely and with less crosstalk than unscreened coils.

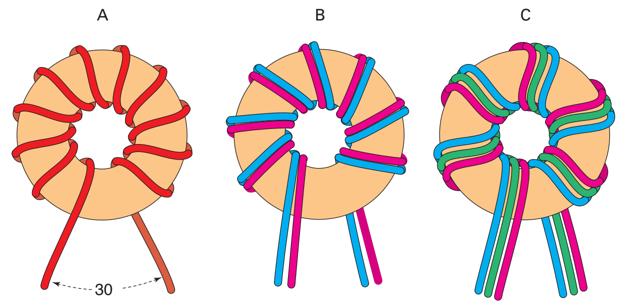
Toroids produce an inductive magnification (m) by concentrating the lines of force generated by the windings through the centre of the coil that just happens to be bent into a torus. The same happens with a ferrite rod aerial, but in that case it is deliberately made as a straight-line path to focus 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 b_{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. For this reason, you will often find in power amplifiers that one or more transformers are used for matching the amplifier up to 50W and another centre-tapped transformer used to connect the transistors to the DC supply.

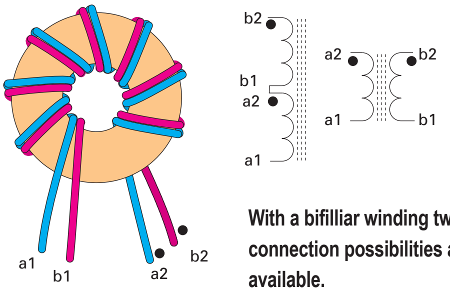
If you pass a wire through the core and then around the outside and back through the core, it looks like just one turn but is actually two turns. This is because every time the wire passes through the inside it constitutes a turn. A single turn is one where the wire passes once through the inside and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



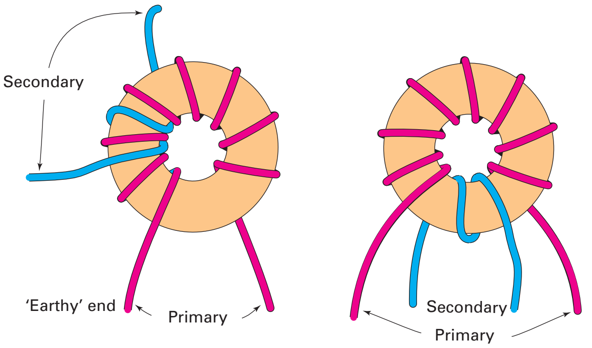
Optimum positioning for minimum coupling in critical applications.



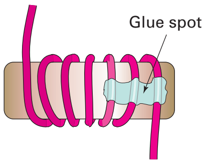
Single, bifilliar and trifilliar windings.



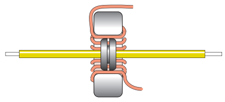
With a bifilliar winding two connection possibilities are available.



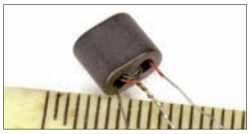
Two possibilities of winding an 8:2 transformer for RF.



A spot of glue holds the ends in place.

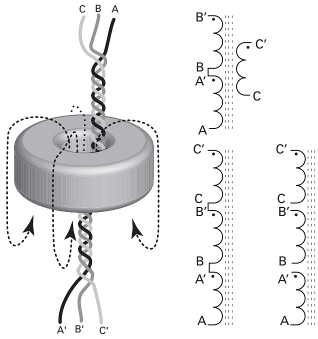


This form may be used to sense RF current flowing in the yellow wire.



Use two colours of wire for easier identification.

Binocular cores come in differing sizes and material types.



A set of trifilliar windings and their possibilities.

Powdered Iron Toroids

Because of their good temperature characteristics and relatively low magnetising factor, powdered iron toroids are normally used for inductances 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.

In the information I have accrued over the years, there are eleven choices of dust iron core materials, although in practice only two types, 2 and 6, are available off the shelf from several vendors. Type 2 is best for 500kHz to 20MHz in sizes 9.5mm (0.375") OD and above. Type 6 is best for 2-30MHz for sizes 9.5mm (0.375") and above. As far as I am aware, they all originate from Micrometals in the USA, with one of the principle agents being Amidon Associates in California. Micrometals supposedly make 24 sizes of these toroids but, again, only a limited number of these are readily available. **Table 1** shows the common sizes, with their core designations. **Table 2** shows ten wire sizes and their standard wire gauge (SWG) designations that can be accommodated on various core sizes.

In practice it is very difficult to wind relatively heavy wire gauges on small cores without breaking them. Neither is it a delightful job winding several hundred turns on any toroid by hand, which is why I have left several fields blank in the tables.

Cores are classified by the inductance magnification effect and have values of inductance proportional to the square of the number of turns. Because different sizes of dust-iron core for a given material produce different inductance magnification factors, they are designated using the parameter A_L, which is measured in mH per hundred turns. This is presented in **Table 3**.

To determine the number of turns (N) required for a specific inductance (L_{mH}) the formula $N = 100\times\sqrt{(L_{mH}/A_L)}$ is used. Don't panic at this point!

If, for example, a coil of 5μH is required for operation on the 40m (7MHz) band, we will try with the smallest type 2 core, T37-2. $N = 100\times\sqrt{(5/40)} = 100\times\sqrt{0.125} = 100\times0.353 = 35$ turns.

Now, by referring to Table 2, you will see that you can put up to 41 turns of 30SWG on the T37-2 core. That would work quite well. 30SWG it quite easy to use and just needs a single scrape to expose sufficient bare copper to burn off the enamel. Let's do the same again, but this time using a T50-2 core. In this case $N = 100\times\sqrt{(5/49)} = 100\times\sqrt{0.102} = 100\times0.32 = 32$ turns. Referring again to Table 2, you can put up to 37 turns of 26SWG on a T50-2 core. That would also work well and have a higher Q than the previous design due to lower wire resistance. It would take up more board space and would be easier to wind but would require more scraping before soldering.

Ferrite Toroids

Generally speaking, ferrite toroids are used to significantly extend the electrical length of twisted pairs, triple and quads

Table 1. Common sizes. Outside diameter (OD). Inside diameter (ID). Height (H).

Core	OD inch	OD mm	ID inch	ID mm	H inch	H mm
T37	0.375	9.5	0.2	5.2	0.128	3.3
T50	0.5	12.7	0.3	7.6	0.19	4.8
T68	0.69	17.5	0.37	9.4	0.19	4.8
T130	1.3	33	0.78	19.8	0.437	11.1
T200	2	50.8	1.25	31.75	0.55	14

Table 2. N turns SWG/core size.

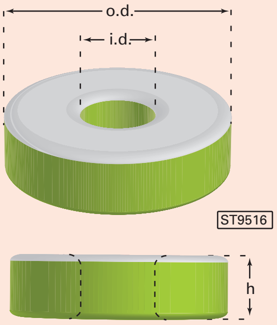
Core\SWG	16	18	20	22	24	26	28	30	32	34
T37	-	-	9	12	17	23	31	41	53	67
T50	-	11	16	21	28	37	49	63	81	103
T68	12	15	21	28	36	47	61	79	101	127
T130	30	40	51	66	83	107	137	173	220	-
T200	53	68	86	109	139	176	223	-	-	-

Table 3. A_L in mH/100t.

Type\size	T37	T50	T68	T130	T200
Type 2	40	49	57	110	120
Type 6	30	40	47	96	100

Table 4. Common sizes. Outside diameter (OD). Inside diameter (ID). Height (H).

Core mm	OD inch	OD mm	ID inch	ID mm	H inch	H
FT37	0.375	9.5	0.19	4.75	0.125	3.18
FT50	0.5	12.7	0.28	7.14	0.19	4.8
FT50A	0.5	12.7	0.31	7.9	0.25	6.35
T82	0.825	20.9	0.52	13.2	0.25	6.35
T140	1.4	35.6	0.9	22.9	0.5	12.7



Toroids often have differing colour schemes, but are all measured the same way.

Table 5. A_L in mH/1000t.

Type\size	FT37	FT50	FT50A	FT82	FT140
Type 43	420	523	570	557	952
Type 61	55	68	75	73	140

of wires used to form wideband transformers. They are also popular for making the transformation from BALanced to UNbalanced circuitry, hence the term BAL-UN or balun. They can also be supplied as an auto-transformer, just achieving an impedance step up or down, when they are referred to as UN-UN or unun.

When trying to achieve an impedance transformation using a ferrite core, the winding should have a reactance between four and ten times the impedance it connects to. In semiconductor power amplifiers with very low collector impedance, say 1W, you can understand that this poses serious difficulties in the design of the matching transformer.

Due to the saturation problem from turns times current you should choose a reactance of just four or five times the impedance. You then convert the reactance to inductance at the lowest operating frequency and try a calculation to determine the 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. I won't go through the procedure on this occasion because I have done it previously in *Doing it by Design*, although it is worthy of another article.

The majority of commonly used ferrite cores are manufactured by Fair-Rite in New York State USA. They are also marketed by Amidon in the USA and are available from several UK stockists. **Table 4** shows the sizes that are commonly available.

I haven't found a handy look-up table for turns per gauge per core yet and normally use Table 2 as a guide. Erring on the side of the lower numbers of turns per core is best because it is awfully frustrating to run out of winding room.

There are just two commonly used material types, type 43 with a characteristic m of 850 and suitable for use from low frequencies up to 50MHz and type 61 with an m of 125 and suitable for use in high Q coils from 150kHz to 15MHz as well as in baluns and transformers to 200MHz. Because of the high inductance magnification factor, types 43 and 61 are designated with A_L in mH/1000t, see **Table 5**.

Although at a glance it looks as though type 61 material is not much greater in inductance factor than the dust iron types, inductors made with this material are rated at a thousand times the inductance for just ten times the number of turns.

To determine the number of turns (N) required for a specific inductance (L_{mH}) the formula $N = 1000\times\sqrt{(L_{mH}/A_L)}$ is used. So let's give it a go and calculate a suitable step-up wideband transformer from, say, 50Ω to 200Ω. A 1:4 step up requires a 1:2 turns ratio primary to secondary. If the secondary load is 200Ω, then the minimum reactance will be 800Ω. If the lowest frequency of operation is, say, 3.5MHz, then the inductance calculates by $L = X_L/(2\times P\times f)$ to be 36.4µH, or 0.036mH.

Choosing the FT37-43 core as a first try, with $A_L = 420$, $N = 1000\times\sqrt{(0.036/420)}$, $N = 1000\times\sqrt{0.0000857} = 1000\times 0.009 = 9$t. Wow! To achieve this will require three wires, twisted together, wound on the core and then two of them wired in series. By using five turns of the trifilar wire, when two windings are in series there are then ten turns. The total wires through the core will then be 5×3 = 15. Referring to table 2, you can put 17 turns of 24SWG through a T37 core. I would use 26SWG to be on the safe side. How about that then?

Concluding Remarks

Clearly this subject requires a number of different examples to provide the reader with rules of thumb to make proper choices. 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.

Dust-iron toroids, being a particulate composite, retain almost identical flux handling and magnification factor after being glued. Ferrite toroids lose about 10% of magnification factor after being glued. The flux handling, though, is likely to be reduced by 50%. In small signal work, therefore, ferrite and dust iron can be super-glued without noticeable effect. For large signal work dust iron toroids can be repaired but ferrite needs to be replaced.

If there is significant demand by readers for more examples of applications of toroids, or even binocular cores, then I will do a follow-on article in the next *T4T*.

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