

FERROMAGNETIC CORES IN rf CIRCUITS

Newly available core components are making the feasibility of home constructed rf circuits a more appealing proposition than ever before. Here we present a guide to home brewed toroidal cores.

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MODERN COMMUNICATIONS equipment has changed a lot since the valve circuits gave way to solid-state devices. One obvious result of the 'newer technology' has been the reduction in size of the equipment.

Because of the nature of solid-state circuitry, which tends to use lower impedances and lower voltages (not to mention the absence of heat from filaments), different methods of coupling and matching between stages have come into widespread use. The old familiar large diameter coils (remember how we took great care with the shape of our coils to get the best Q?) have largely vanished, replaced by small ferromagnetic devices which seem to be stacked into odd spaces throughout the rf sections of our black-boxes. One might well wonder how 'they' get away with it, when we think how much trouble we had with unwanted coupling.

There are still plenty of problems left in producing well designed rf equipment, but some things are certainly easier now that the newer components are readily available to the home constructor. This article will cover general aspects of the ferromagnetic cores and provide the home constructor with sufficient information to select a suitable core for a particular application.

Advantages of toroidal coils

The main advantages we get from using toroids are higher Q, self-shielding and compactness. Let's consider each of these benefits in turn.

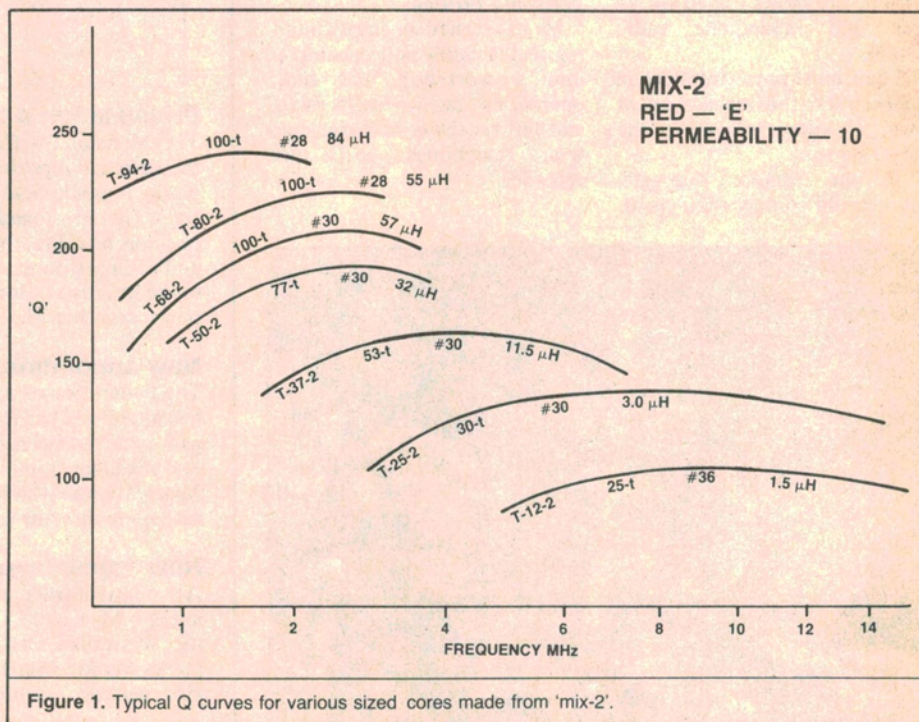
Having selected an appropriate core for the operating frequency and power (this will be clear later) we find that for a given inductance the toroidal inductor has fewer turns on it than an equivalent air cored inductor, because of the permeability of the material used in the core. This also means

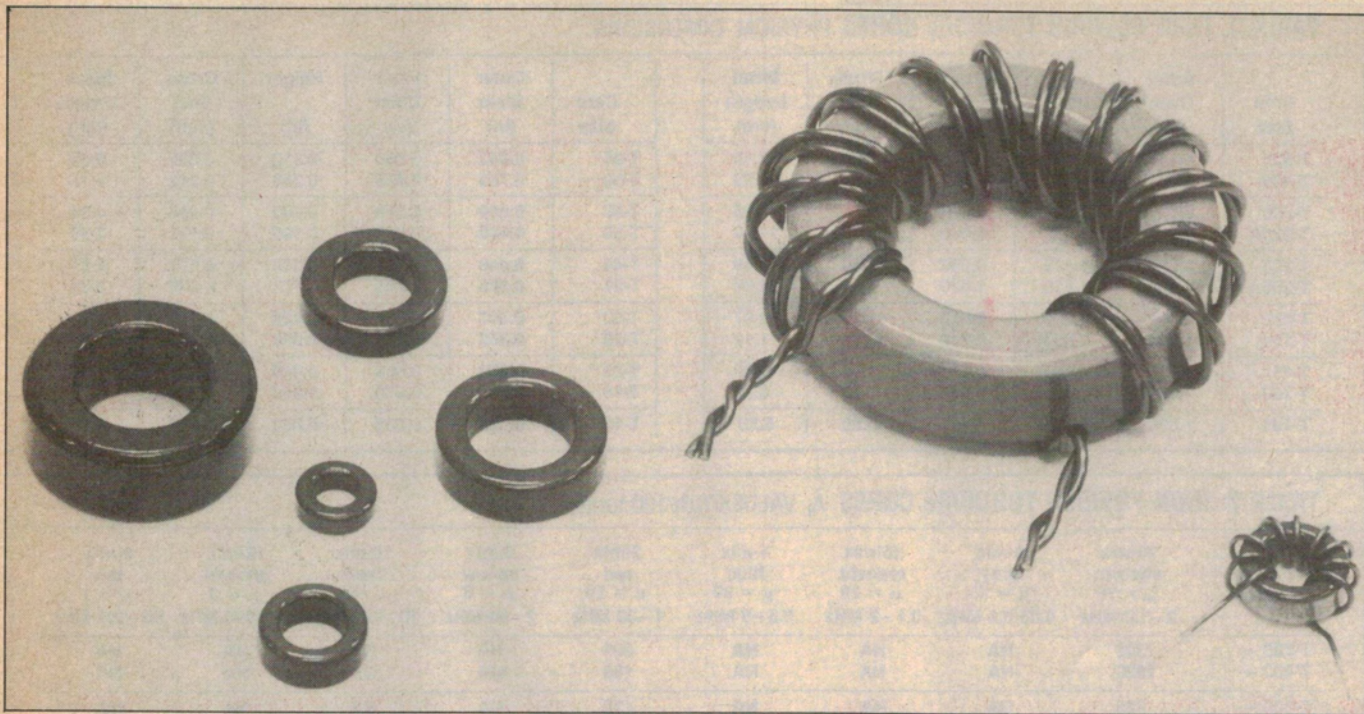
that the winding resistance is lower, and since both inductors have the same inductance and therefore the same value of inductive reactance, the value of XL/R will be greater for the toroid winding. This expression is the same as that for the Q of a coil and so the Q will also be greater. An additional benefit is gained with low voltage equipment which passes dc current through the inductor, by reducing voltage drop and hence heating in the component.

Unlike normal (solenoid wound) coils which have large external magnetic fields,

the toroid winding has a field which is almost completely contained within itself. This means there is almost no magnetic coupling between toroidal coils and other circuit elements. (Try coupling a gdo [grid deposit oscillator] to a tuned circuit containing a toroid!) We are therefore free to place toroid coils fairly close to other circuit components (including ground plane) without complicated shielding. It should be noted that capacitive coupling can occur and normal precautions must be taken against this.

The two benefits mentioned above allow





us to create a much more compact circuit layout when toroid coils are employed. This is particularly important when portable equipment is being considered or when an expensive pc board is used.

Choice of core material

Contrary to information which sometimes appears in magazines, the choice of material is of prime importance if the expected results are to be realized from any design using ferromagnetic cores. Let's look at the two most common core materials in use: ferrite and iron powder. The choice between the two is made by considering whether the core will be used in a wideband or narrowband application and how much signal power will be handled.

For a given size core, ferrite material will saturate at a much lower flux density than one made from iron powder. Permeability for ferrite materials ranges from 20 to 5000 while for iron-powder it is from 2 to 75. As a 'rule of thumb' the higher the permeability of the material the greater the temperature coefficient will be, so that it is desirable to use a material which exhibits the lowest practical temperature coefficient in a narrowband circuit. On the other hand this is not so important in wideband use.

For wideband circuits a ferrite is commonly used because it has a higher permeability and hence can provide a larger inductance for a given number of turns than is possible with an equivalent size iron powder core. The grade of ferrite chosen must exhibit low loss over the range of operating frequencies; refer to the manufacturer's data. The common rule for the design of wideband transformers is that the reactance (XL) of a winding must not be less than four times the design impedance at the lowest frequency.

'What about the effects of this at the high frequency end?' you may ask. Well luckily there is no cause for concern, as the effective permeability of the core material decreases with increasing frequency, and the core tends to 'disappear', so that the inductance of the winding is also reduced. With the proper selection of core material it is easy to make wideband transformers which cover one decade in frequency; eg 3-30 MHz.

Narrowband applications (tuned circuits) above 1.5 MHz usually use iron powder cores which can provide good Q values into the VHF frequencies. Wideband circuits by their very nature cannot have a high Q (circuit Q = centre frequency/bandwidth). The characteristics of iron powder are less temperature sensitive so with changing temperature the circuit remains more closely tuned to the design frequency than is possible with ferrite materials. When tuned circuits are used in rf amplifiers at almost any power level, we should choose an iron powder core.

Ferrite materials can be divided into two groups: those with initial permeabilities below 1000 which are nickel-zinc compounds, and those above 1000 which are made from manganese-zinc compounds. Nickel-zinc ferrites exhibit high volume resistivity, moderate stability and can offer high Q factors for the 0.5 to 100 MHz frequency range. They are well suited for low power, high inductance applications and their high permeability factors make them very useful for wideband transformer applications. The manganese-zinc group has fairly low volume resistivity and moderate saturation flux density. It can give high Q factors for the 1 kHz to 1 MHz frequency range, and some are suitable for switched-mode power conversion transformers oper-

ating between 20 and 100 kHz.

Apart from the physical dimensions of a toroid (outside and inside diameter thickness) there is a value given for each particular core size and material, which is usually called the 'A_L value', and is the manufacturer's inductance index for the core. Manufacturers' data for iron powder and ferrite cores are given in Tables 1-6 and show all the required core information. The A_L figure for powdered iron cores is normally given as $\mu\text{H}/100$ turns, but for ferrite cores it is usually quoted as mH/1000 turns. The relevant A_L value is used in many calculations involving toroids. One of the most common uses is to calculate the turns required to produce a given value of inductance on a particular core, as shown below:

iron powder:

$$\text{turns} = 100 (\text{desired } L_{\mu\text{H}}/A_L)^{0.5}$$

ferrite:

$$\text{turns} = 1000 (\text{desired } L_{\text{mH}}/A_L)^{0.5}$$

What size toroid?

Toroid cores come in sizes ranging from 3 mm up to 150 mm outside diameter, with the common sizes between 6 mm and 50 mm. The power rating of a given size core will depend upon the particular ferromagnetic material used, and the calculation of this is probably the most complex consideration of all.

Ferrite materials are basically limited by flux saturation and iron powder by temperature rise. Many ferrites can permanently change their permeability after being subjected to relatively high power (flux) levels, whereas powdered iron cores return to their original values after they cool down. In circuits up to 500 mW, saturation is not usually of any concern, but when we use a ferromagnetic core at levels above 1 W it must ▶

TABLE 1. IRON POWDER TOROIDAL CORES PHYSICAL DIMENSIONS

Core Size	Outer Diam (in)	Inner Diam (in)	Height (in)	Cross Sect (cm ²)	Mean Length (cm)	Core Size	Outer Diam (in)	Inner Diam (in)	Height (in)	Cross Sect (cm ²)	Mean Length (cm)
T-520	5.218	3.081	0.800	5.50	33.10	T-94	0.942	0.560	0.312	0.385	6.00
T-400	4.000	2.250	0.650	3.66	24.93	T-80	0.795	0.495	0.250	0.242	5.15
T-300	3.048	1.925	0.500	1.81	19.83	T-68	0.690	0.370	0.190	0.196	4.24
T-225A	2.250	1.405	1.000	2.73	14.59	T-50	0.500	0.303	0.190	0.121	3.20
T-225	2.250	1.405	0.550	1.50	14.59	T-44	0.440	0.229	0.159	0.107	2.67
T-200A	2.000	1.250	1.000	2.42	12.97	T-37	0.375	0.205	0.128	0.070	2.32
T-200	2.000	1.250	0.550	1.33	12.97	T-30	0.307	0.151	0.128	0.065	1.83
T-184	1.840	0.950	0.710	2.04	11.12	T-25	0.255	0.120	0.096	0.042	1.50
T-157	1.570	0.950	0.570	1.14	10.05	T-20	0.200	0.088	0.070	0.025	1.15
T-130	1.300	0.780	0.437	0.73	8.29	T-16	0.160	0.078	0.060	0.016	0.95
T-106	1.060	0.570	0.437	0.69	6.50	T-12	0.125	0.062	0.050	0.010	0.75

TABLE 2. IRON POWDER TOROIDAL CORES A_L VALUES (μ h/100 turns)

Core Size	26-mix ylw-wht $\mu = 75$ 0-1.0 MHz	3-mix grey $\mu = 35$ 0.05-0.5 MHz	15-mix red/wht $\mu = 25$ 0.1-2 MHz	1-mix blue $\mu = 20$ 0.5-5 MHz	2-mix red $\mu = 10$ 1-30 MHz	6-mix yellow $\mu = 8$ 2-50 MHz	10-mix black $\mu = 6$ 10-100 MHz	12-mix grn/wht $\mu = 3$ 20-200 MHz	0-mix tan $\mu = 1$ 50-300 MHz
T-520 —	1500	NA	NA	NA	205	NA	NA	NA	NA
T-400 —	1320	NA	NA	NA	185	NA	NA	NA	NA
T-300 —	825	NA	NA	NA	115	NA	NA	NA	NA
T-225A —	1600	NA	NA	NA	215	NA	NA	NA	NA
T-225 —	950	425	NA	NA	120	100	NA	NA	NA
T-200A —	1550	460	NA	455	218	180	NA	NA	NA
T-200 —	895	425	NA	250	120	100	NA	NA	NA
T-184 —	1640	720	NA	500	240	195	NA	NA	NA
T-157 —	970	420	360	320	140	115	NA	NA	NA
T-130 —	785	350	250	200	110	96	NA	NA	15
T-106 —	900	450	345	325	135	116	NA	NA	19
T- 94 —	590	248	200	160	84	70	58	32	10.6
T- 80 —	450	180	170	115	55	45	32	22	8.5
T- 68 —	420	195	180	115	57	47	32	21	7.5
T- 50 —	320	175	135	100	49	40	31	18	6.4
T- 44 —	360	180	160	105	52	42	33	19	6.5
T- 37 —	275	120	90	80	40	30	25	15	4.9
T- 30 —	325	140	93	85	43	36	25	16	6.0
T- 25 —	NA	100	100	70	34	27	19	12	4.5
T- 20 —	NA	90	65	52	27	22	16	10	3.5
T-16 —	NA	61	55	44	22	19	13	8	3.9
T- 12 —	NA	60	50	48	20	17	12	7	3.0

 μ = relative permeability

NA — not available in that size

Add mix number to core size in space provided (—) for complete part number

$$\text{Turns} = 100 \sqrt{\frac{\text{desired } L (\mu\text{h})}{A_L \text{ value } (\mu\text{h}/100 \text{ t})}}$$

be taken into account in the design. Another 'rule of thumb': when in doubt use the largest core which will conveniently fit into your layout. At high power levels considerable heat can be generated in ferromagnetic cores and the constructor must make provision for adequate ventilation and removal of heat, which can affect nearby circuit components. The surface area of the core largely determines the allowable dissipation, so once again 'use the largest core which is practical', and don't try to build a high power solid state amplifier into a closed box without ventilation.

To determine the operating flux density (Bop) of a core we must take into account the applied voltage (Erms), the equivalent area of the magnetic path in cm² (Ae), the

number of turns (N) and the operating frequency (f). These terms are used in the following formula:

$$Bop = \frac{Erms \times 10^8}{4.44 f N Ae \text{ (gauss)}}$$

and if dc is passed through the winding add the following:

$$+ \frac{N Idc A_L}{10 Ae}$$

The manufacturer's data will give the saturating flux density of the core, and the calculated value of Bop should be quite a bit below this value to be on the safe side. The

formula shows that we should use the lowest operating frequency expected in our design (3 MHz in a 3-30 MHz wideband circuit) and the highest value of Erms (calculated from the required rf power and the winding impedance) to give a conservative design figure for flux density. The saturating flux density (Bsat) for iron powder materials is about 10,000 gauss, while for ferrites below 1000 μ it is 1500 gauss, and for those above 1000 μ it is about 3000 gauss.

Using the data sheets

Two principal sets of data are given in Tables 1 to 6, and cover iron powder and ferrite toroids. First, let's look in detail at Tables 1 and 2 which give all the essential information for some iron powder toroids.

Iron powder toroids

The physical dimensions are important since we must know how big the toroid is to allow sufficient space in our project. The cross sectional area and mean length (magnetic path length) are included so that flux density and magnetising force calculations can be made. You will notice that this manufacturer uses a type number which begins with 'T' for iron powder cores and is followed by a figure which denotes the outside diameter in hundredths of an inch (made in USA!).

Table 2 lists the A_L values for all the combinations of core size and mix (material types) that are available. The different materials have different values of relative permeability (μ), which also determines the useful range of frequencies for each material, and the cores are colour-coded for easy

recognition. The formula for turns calculation is also given.

Another useful table (Table 3) gives the maximum turns vs wire gauge and core size for single layer windings. This saves a lot of 'cut and try', so we can make a good 'first approximation' for our winding. Figure 1 shows typical Q curves for different sized cores made from mix-2. Notice that the larger cores are used at the lower end of the frequency range for mix-2 and they produce correspondingly larger values of Q. This principle is used generally for all core materials.

Suppose we wish to wind a toroid coil for use in a receiver front-end tuned to 7 MHz. Since there is no rf 'power' involved we do not have to worry about saturation of the core and can choose almost any size core. Without going overboard it is best to choose

the largest size consistent with our circuit layout as that will enable us to achieve a better Q, which is a common requirement in receiver front-ends. If we want to tune this coil with a 100 pF capacitor we will require an inductance of approximately 5 μ H.

With a frequency of 7 MHz we have a choice of mix-2 or mix-6, but let's decide on a (red) T-50-2 as our core. The A_L of this core is given as 49 and so we can calculate the required turns to produce 5 μ H from the formula given in section 2. This works out to 31.9 which we will round up to 32 since we cannot have fractional turns on a toroid.

Next we look up the table showing turns vs core size for different wire gauges and see that we can fit 39 turns of 24 g enamelled wire on a T-50-2 core. Our toroidal inductance would have an unloaded Q of about 200, which is quite a respectable figure for this application. If a coupling link is required on the toroid, it should be put on at the 'cold end' of the winding, and in this case, could consist of two or three turns.

Ferrite toroids

Tables 4-6 list all the data for ferrite toroids. Table 4 shows the physical dimensions of the various sized ferrite cores, which are different to the iron powder cores and are all prefixed by FT (ferrite toroid).

Table 5 lists the A_L values for all the combinations of core size and ferrite material, and also gives the formula for calculating turns. Notice that these cores are not colour coded, so be careful to keep track of the types if you acquire some ferrite cores, otherwise you will finish up with a heap of cores with unknown characteristics. A good idea is to paint coloured dots on the core to indicate the material type: eg blue and brown dots for 61 material.

Table 6 is interesting in that it gives information for narrowband (tuned circuit) and wideband use, as well as the permeability for each different ferrite mix. This enables us to select the correct mix for any particular application.

Let's work out an example. Suppose we want to design a wideband transformer for use between 3.5 MHz and 30 MHz and it has to match a 200 ohm source to a 50 ohm load. From the previous rule we know that the primary winding should have an inductive reactance of not less than 800 ohms at 3.5 MHz. Using the formula ($L\mu\text{H} = XL/2\pi f$, where f is in MHz) we see that we need a primary winding of 37 μ H. Similarly, the secondary winding would need an XL of 200 ohms which works out to be a winding of 9.2 μ H. Since these are minimum values let's round them off to 40 μ H and 10 μ H.

Now let's work out the turns required for a ferrite core of suitable material for the frequency range. Assuming that this is a low

TABLE 3. NUMBER OF TURNS v WIRE SIZE and CORE SIZE

Approximate maximum number of turns — single layer wound — enamelled wire

Wire Size	T-200	T-130	T-106	T-94	T-80	T-68	T-50	T-37	T-25	T-12
10	33	20	12	12	10	6	4	1		
12	43	25	16	16	14	9	6	3		
14	54	32	21	21	18	13	8	5	1	
16	69	41	28	28	24	17	13	7	2	
18	88	53	37	37	32	23	18	10	4	1
20	111	67	47	47	41	29	23	14	6	1
22	140	86	60	60	53	38	30	19	9	2
24	177	109	77	77	67	49	39	25	13	4
26	223	137	97	97	85	63	50	33	17	7
28	281	173	123	123	108	80	64	42	23	9
30	355	217	154	154	136	101	81	54	29	13
32	439	272	194	194	171	127	103	68	38	17
34	557	346	247	247	218	162	132	88	49	23
36	683	424	304	304	268	199	162	108	62	30
38	875	544	389	389	344	256	209	140	80	39
40	1103	687	492	492	434	324	264	178	102	51

Actual number of turns may vary slightly according to tightness of wind

TABLE 4. FERRITE TOROIDAL CORES PHYSICAL DIMENSIONS

Core Size	Outer Diam (in)	Inner Diam (in)	Height (in)	Cross Sect (cm ²)	Mean Length (cm)	Volume (cm ³)
FT-23	0.230	0.120	0.060	0.021	1.34	0.029
FT-37	0.375	0.187	0.125	0.076	2.15	0.163
FT-50	0.500	0.281	0.188	0.133	3.02	0.401
FT-50A	0.500	0.312	0.250	0.152	3.18	0.483
FT-50B	0.500	0.312	0.500	0.303	3.18	0.964
FT-82	0.825	0.520	0.250	0.246	5.26	1.29
FT-87A	0.870	0.540	0.500	0.522	5.42	2.83
FT-114	1.142	0.750	0.295	0.375	7.42	2.79
FT-114A	1.142	0.750	0.545	0.690	7.42	5.13
FT-150	1.500	0.750	0.250	0.581	8.30	4.82
FT-150A	1.500	0.750	0.500	1.110	8.30	9.21
FT-193	1.930	1.250	0.750	1.460	12.30	18.00
FT-240	2.400	1.400	0.500	1.570	14.40	22.70

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power application (eg receiver) we will decide on a ferrite toroid of 12.5 mm od and with an initial permeability of 850, which, according to Table 6 is suitable for 1-50 MHz. The A_L value for an FT-50-43 is given in Table 5 as 523. Using the formula for ferrite cores, the turns required to give 40 μ H will be 8.7 (don't forget that this formula uses mH in the A_L value calculation!). Since we require an impedance ratio of 4 to 1 in our example, the final transformer should have a turns ratio of 2 to 1. A toroid core cannot have partial turns (see "Winding hints") so we cannot have a primary with 8.7 turns and a secondary with 4.35 turns! Our original rule stated that a wideband winding should have a minimum of four times the load impedance, so we are able to increase our calculated secondary turns to 5 (instead of the 4.35) and the primary turns will then become 10, which preserves the 2 to 1 turns ratio.

Although the rule states a *minimum* of four times it should be noted that if too many turns are wound on the core, troubles can arise at the high frequency end of the wideband transformer; it would be wrong to put say, 40 turns on the primary and 20 turns on the secondary in our example.

Some winding hints

One aspect of toroidal windings which often causes newcomers some trouble is counting turns. A toroidal coil cannot have partial turns. If a straight wire passes through the centre of a core it counts as one turn, even though the ends are not brought back together. With any toroid winding it is good practice to have the winding cover 300-330 degrees of circumference. If the winding covers the whole length of the core 'end capacity' effects cause unwanted resonances which are particularly troublesome with tuned circuits, and cause a lowering of the effective Q of the winding. With tuned circuits any coupling winding should be placed over the 'cold' end of other windings on the core to prevent undesirable capacitive coupling between windings.

Broadband transformers are often made up with 'multi-winding' windings which are then joined in series to form one larger winding. This method of winding is referred to as a multifilar winding. The most common types are bifilar, trifilar and quadrifilar, which refer to two, three and four separate windings wound on the core at the same time by using two, three or four separate pieces of wire. The groups of wires are often twisted together before winding (about 3 turns per cm) by holding one set of ends in a vice and the other ends in the chuck of a hand drill which is then slowly rotated while keeping the wires taut. Since all the wires are wound together they are also wound on the core in the same sense; ie all the starts are at the same end. With the aid

TABLE 5. FERRITE TOROIDAL CORES A_L VALUES (mh/1000 turns)

Core Size	#68 $\mu = 20$	#63 $\mu = 40$	#67 $\mu = 40$	#61 $\mu = 125$	#43 $\mu = 850$	#77 $\mu = 1800$	#72 $\mu = 2000$	#F $\mu = 3000$	#75 $\mu = 5000$	#J $\mu = 5000$
FT-23 —	4.0	7.9	7.9	24.8	188	356	396	NA	990	NA
FT-37 —	8.8	17.7	17.7	55.3	420	796	884	NA	2210	NA
FT-50 —	11.0	22.0	22.0	68.0	523	990	1100	NA	2750	NA
FT-50A —	12.0	24.0	24.0	75.0	570	1080	1200	NA	2900	NA
FT-50B —	NA	48.0	48.0	150.0	1140	2160	2400	NA	NA	NA
FT-82 —	11.7	22.4	22.4	73.3	557	1060	1170	NA	2930	NA
FT-87A —	NA	NA	NA	NA	NA	NA	NA	3620	NA	6040
FT-114 —	12.7	25.4	25.4	79.3	603	1140	1270	1900	3170	3170
FT-114A —	NA	NA	NA	146.0	NA	NA	2340	NA	NA	NA
FT-150 —	NA	NA	NA	NA	NA	NA	NA	2640	NA	4400
FT-150A —	NA	NA	NA	NA	NA	NA	NA	5020	NA	8370
FT-193 —	NA	NA	NA	NA	NA	NA	NA	4460	NA	7440
FT-240 —	NA	53.0	NA	173.0	1240	NA	3130	NA	NA	NA

μ = relative permeability

NA — not available in that size

Add mix number to core size in space provided (—) for complete part number

Turns = 1000

$$\sqrt{\frac{\text{desired } L \text{ (mh)}}{A_L \text{ (mh/1000 t)}}}$$

TABLE 6. FERRITE MAGNETIC PROPERTIES

Property	#68	#63	#67	#61	#43	#77	#72	#F	#75	#J
Relative Permeability (μ)	20	40	40	125	850	1800	2000	3000	5000	5000
Saturation Flux (Gauss)	2000	1850	3000	2350	2750	4600	3500	4700	3900	4300
Curie Temp °C	500	450	500	350	130	200	150	250	160	140
Temp Coef %/°C	0.06	0.10	0.13	0.15	1.0	0.60	0.60	0.60	0.90	0.90
Tuned Circuit Frequency (MHz)	80-180	15-25	10-80	0.2-10	0.01-1	0.001-1	0.001-1	0.001-1	0.001-1	0.001-1
Wideband Frequency (MHz)	200-1000	25-200	50-500	10-200	1-50	0.5-30	0.5-30	0.5-30	0.2-15	0.2-15

of an ohm-meter the separate wires can then have their starts and finishes identified, so that it is an easy matter to join up the finish of one winding to the start of another.

If two windings are series connected in this way the winding is called a bifilar winding. The purpose of this type of winding is to reduce the stray winding capacitances which would result from a single winding of the same number of turns. This is most important at the higher frequencies. Another benefit with this type of winding is that it is easy to make up transformers with turns ratios of 1:1, 2:1 or 3:1 by joining 1, 2 or 3 windings in series for the high impedance winding and using a single winding for the low impedance. In practice it is difficult to make a good broadband transformer with a turns ratio greater than 4:1, and for greater ratios it is better to use two separate transformers which, when combined, produce the required ratio.

It is often necessary to adjust the inductance of a toroidal winding in tuned circuit applications to achieve resonance with a fixed capacitor in the circuit. Apart from adding or removing turns (a coarse adjustment) it is possible to make fine adjustments by slightly closing up or spreading apart the turns around the core. Pushing the

turns together will increase the inductance and, conversely, spreading them apart will decrease the value. Finished windings can be fixed in place with polystyrene dope, and complete toroidal inductors may be attached to a printed circuit board with silastic adhesive so that the assembly can be removed later if necessary. When fixing to an earthed base be careful of unwanted capacitive coupling to the winding itself.

Ferromagnetic materials are hard and brittle, so do not clamp cores in a vice or pliers. To prevent any sharp corners from cutting through the insulation on the wire it is good practice to wind a layer of PTFE tape (as used by plumbers for sealing threaded joints) over the entire core before laying on the winding. Always put the winding with the largest number of turns on first so that additional windings have an even base to sit on. The sealing tape can also be used as insulation between windings.

It is important to know how to measure the resonant frequency of a tuned circuit containing a toroid inductor. As mentioned earlier, toroidal coils have very little external field, so it is almost impossible to couple a gdo to such a winding. To overcome this, use a 1 or 2 turn link coupling between the gdo coil and the 'cold end' of the toroid winding.

Where ferromagnetic cores are used with transmitters quite high rf voltages can exist across windings and ordinary enamel insulation is often not sufficient to prevent breakdown between turns or breakdown between turns and the core. In these cases good spacing between turns and good HV insulation (eg PTFE insulation) must be used. Because of these restrictions, it is not usual to use ferromagnetic cores at high power levels (>200 W) where the circuit impedance exceeds 600 ohms. Fortunately, most solid state circuits operate at much lower impedances.

Suppliers

Toroidal cores are available from a number of suppliers including the following: Truscott's Electronic World, 30 Lacey St, Croydon, Vic 3136. (03)723-3094; Geoff Wood Electronics, 656A Darling St, Rozelle, NSW 2039, (02)810-6845; Electronic Components Pty Ltd, Unit 10, Fyshwick Plaza, Fyshwick, ACT 2609; Willis Trading Co, 445 Murray St, Perth, WA 6000.

I wish to acknowledge the kind permission given by Amidon Associates Inc for inclusion of the data tables. ●