WINDING and USING TOROIDS

Do not be afraid to work with toroids. Think of them as donut-shaped coils that have magnetic cores. Compare this to slug-tuned coils that have adjustable iron or ferrite cores. The major difference is that a toroidal coil has a donut shape, while the slug-tuned coil has a cylindrical shape. The core material provides high inductance with a small number of coil turns, whereas an air-core coil of equivalent inductance would have many more turns than a toroid or slug-tuned coil. The latter assembly permits us to change the inductance when we vary the position of the slug within the coil. A toroid coil is also adjustable, but over a small range of inductance. This is done by spreading or compressing the turns of the winding. An ideal toroidal coil has its winding spread over 330 degrees of the core. This leaves a 30° gap at the ends of the winding.

There are two advantages when using toroids. (1) The coil Q (quality factor) is high, owing to the small number of turns. This is true only if the right core material is used for a specified operating frequency. (2) A toroidal coil or transformer is self-shielding. No metal enclosure is needed in order to keep the field of the coil confined to a small area.

FERRITE VERSUS POWDERED IRON CORES

You may be confused about when to use ferrite as opposed to powdered iron. This simple rule may be adopted for most amateur work: use powdered-iron cores for circuits that require high Q in narrow-band (tuned) networks. These include RF amplifiers, mixers, IF amplifiers, oscillators and RF filters. The charts and tables found in the manufacturer's data sheets indicate the best powdered-iron core for a given frequency range. Powdered-iron cores are sometimes used for audio inductors. These cores have high permeability. An example of an iron-core audio inductor is the popular 88-mH telephone toroid.

Ferrite toroids may also be used for narrow-band RF circuits up to, say, 10 MHz. I do not use them above this frequency if high Q is a criterion. Again, you must select the proper core mix (recipe) for high Q at the frequency of interest. Check the manufacturer's charts.

Ferrite cores are used mostly in broadband inductors and transformers. By this I mean RF chokes, baluns and matching transformers in solid-state circuits and antennas. Ferrite toroids of a specified size (diameter and thickness) have far greater permeability (u or mu) than equivalent-size powdered-iron toroids. This means that far fewer coil turns are required. But, the greater the core mu the lower the Q of the coil or transformer at a particular frequency. This rule applies also to powdered iron cores.

Ferrite is brittle because it is made from a ceramic material that is actually a semiconductor. It breaks easily when stressed, and may even break or shatter when used in a circuit that generates more power than the core can handle. This is not true of powdered iron. Both types of core will overheat if subjected to excessive power. Powdered iron will return to its rated mu after cooling.

Ferrite will not. The core may become permanently damaged from overheating. The mu will decrease and render the winding useless from insufficient inductance. Many antenna baluns are destroyed in this manner when high power is applied to an antenna that does not match the feed line (high SWR).

WHAT IS SATURATION?

The matter of overheating that we just discussed is an example of core saturation All magnetic cores have a gauss rating that relates to how much power they can handle before saturation occurs. This is a function of "flux density" in an operating circuit. The greater the cross-sectional area of a core the greater the power it can handle before saturation occurs. Equations exist for determining the core capability (gauss) for a particular circuit application. In-depth treatment of this subject is contained in **The ARRL Handbook** and in my Prentice-Hall book, **Ferromagnetic Core Design & Applications Handbook** (1).

Saturation is based on the core size, the number of coil turns and the voltage and current in the windings. It is too complex a subject to discuss here. I encourage you to read the aforementioned references if you wish to learn more about selecting the proper size core.

Another side effect from saturation is the generation of unwanted harmonic currents. As the core goes into saturation the sine wave (RF or audio) becomes distorted and degenerates into a square wave. Square waves are rich in harmonic energy, and this distortion can ruin an audio circuit or cause TVI and RFI in an RF circuit or antenna. This nonlinear operation can be avoided by making certain that you select a core than can handle the job. If a core is quite warm or hot to the touch during operation, chances are that the size is inadequate or marginal. Substitute a larger core if this happens.

CORE NOMENCLATURE

The numbers assigned to toroids may confuse you. Micrometals cores are the ones used most frequently by hams, so I will mention the numbering system that relates to those components. Powdered-iron cores have a T prefix (toroid). By way of an example, suppose you have a T68-2 core. T stands for toroid and 68 indicates the core diameter (0.68 inch). The no. 2 in the suffix tells you what the core mix is. The color code for no. 2 cores is red. The Colored powdered-iron cores are manufactured by Micrometals Corp.

Ferrite cores have a slightly different numbering system. For example, assume you have an FT-50-43 toroid. The "FT" indicates ferrite toroid. The 50 means that the diameter is 0.5 inch. The number suffix, 43, tells you what the core mix or permeability is. All OF the ferrite cores are gray (uncoded), so it is important to keep them separated in your workshop. I like to use spray paint to color-code my ferrite cores when I receive them. This saves many headaches later on!

THE RIGHT WIRE SIZE

Micrometals catalog contains charts that suggest the proper wire gauge versus the required number of coil turns for a given core size. Try to use the largest wire diameter practicable, consistent with ease of winding. This will help to ensure minimum circuit losses and highest Q. Enamel-covered magnet wire is used for most toroidal coils and transformers. Use care when winding ferrite toroids, because most of them have rough edges. These sharp surfaces can scrape the insulation from the wire and cause shorted turns. Shorted turns kill the Q of the circuit and ruin performance. I like to wrap the larger ferrite cores with 3M glass tape or strips of masking tape before I apply the windings. Damage to the insulation can be avoided when doing this. Most powdered-iron toroids have been tumbled. Therefore, their edges are smooth and do not present a hazard to the wire. Do not tension the wire too much when winding a powdered-iron core. These cores will break in half if too much pressure is applied.

WINDING YOUR TOROID

We tend to waste magnet wire when we wind toroids. This is because we guess at the required length for X number of turns. You can avoid this waste by first determining the necessary number of turns. Next, wrap one turn around the toroid, remove it, then measure its length. Multiply the length by the required number of turns, and allow two extra inches of wire for the leads at the end of the winding.

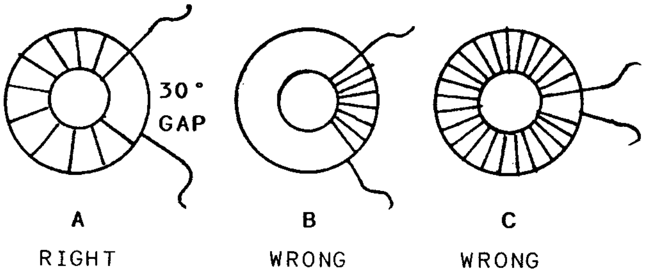

Fig 1 -- Right and wrong methods for toroid winding. The example at A is the recommended technique. Note the 30° gap between the ends of the winding. This minimizes unwanted capacitive effects and inductance cancellation. Compressing the turns (B) increases the inductance. Spreading the turns (C) decreases the inductance.

Fig 1 illustrates the right and wrong ways to wind toroid cores. However, at a moderate sacrifice in coil quality you may compress or spread the coil turns (B and C) to vary the effective inductance. This is a useful method when tweaking a tuned circuit that contains fixed-value capacitance.

COILS THAT HAVE LINKS

There seems to be confusion concerning placement of the link on a toroid that has a main winding. There are two philosophies we can embrace in this regard. (1) The link can occupy the same area on the core as the main winding. This appears to provide the greatest efficiency (reduced losses) in coupling. I prefer this technique for broadband transformers. See Fig 2.

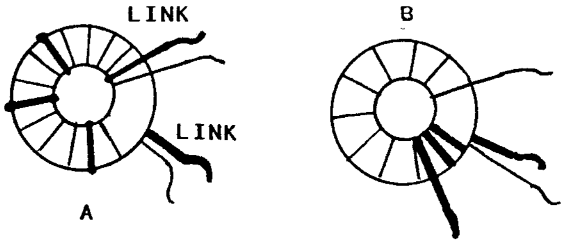

Fig 2 -- The dark lines represent the link winding at A and B. Example A shows the link winding spread over all of the main winding. In drawing B is a link that is crowded at one end of the main toroid winding. In both examples the link should be wound in the same sense as the main winding.

For narrow-band transformers, such as those in RF amplifiers, mixers and oscillators, I use method B of Fig 2. The link is wound over the grounded or +V end of the main coil, whichever may apply. This minimizes unwanted capacitive coupling between the windings. Harmonic currents are not so easily passed through the link when method B is used. In any event, wind the link with the same sense (clockwise or counter clockwise) as the main winding. This will ensure that the polarity of the windings is the same at the start of each winding. The black dots that you often see above the windings of a toroidal transformer are there to show that the tops of the windings have the same polarity or phase, as indicated in the circuit diagram.

TAPPED WINDINGS

You must be careful when placing a tap on a toroidal winding. It is easy to damage the wire insulation and cause a shorted turn or turns. I use the method shown in Fig 3 when I need to tap a winding. It consists of keeping track of the coil turns during the winding process, then allowing excess wire at the tap point. This excess wire is twisted into a small loop (two or three tight twists). The remainder of the winding is then placed on the core. I next scrape the insulation from the loop with a hobby knife or Moto Tool with an abrasive bit. The bare wire can now be tinned with a soldering iron. An alternative and neater looking technique results from scraping the insulation from the wire at the tap point, but not making a loop. The bare section is tinned and a short piece of bus wire is wrapped around it and soldered in place. This serves as a connection point. A thin piece of meat-wrapping paper or glass tape is placed around the tap area (U shaped) and the winding is continued until completed. The insulating material prevents shorted turns.

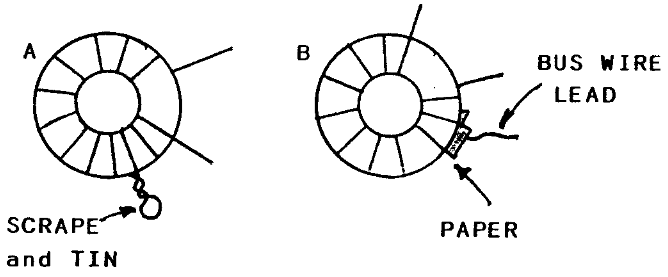

Fig 3 -- Two methods for placing a tap on a toroidal winding. Method A involves twisting a loop in the winding for the tap point. At B is a technique that requires scraping the winding and using a piece of bus wire for the tap (see text).

A third method for making a coil tap is to cut the winding at the tap point. Allow a 3/8-inch pigtail. Scrape off the pigtail insulation and tin it. Create a similar pigtail with the wire for the remainder of the winding. Twist the pigtails and solder them. This becomes the coil tap.

FINDING THE CORRECT NUMBER OF COIL TURNS

Each toroid has what is called an A_L factor. This relates to the resultant inductance for a specified number of turns. The A_L factor varies with the permeability of the core being used. The Amidon Assoc. catalog lists the A_L factors for powdered-iron and ferrite toroids. This information is available also from Micrometals Corp. (powdered iron) and Fair-Rite Corp. for ferrites (3).

Let's examine an example of how the A_L formula works. Suppose you need a toroid inductor that is for use at 14 MHz and the required inductance is 1.2 uH. A T50-6 (yellow) core will, according to the Amidon charts, provide high Q at this frequency. We check the A_L rating in the Amidon catalog. It is listed as 40.

$N(\text{turns}) = 100\sqrt{L(\text{uH})/A_L}$, thus $N = 100\sqrt{1.2/40}$ or 17.3 turns.

We will use 17 turns in order to avoid the impracticality of a fractional part of a turn.

The equation for ferrite cores is similar. But, owing to the high mu of ferrites, the formula is expressed in mH rather than uH. For example, suppose you need a coil that has an inductance of 10 uH for use at 7 MHz. We will use an FT-37-61 core. The A_L for this core is 55.3. Hence,

$N(\text{turns}) = 1000\sqrt{L(\text{mH})/A_L}$, hence $N = 1000\sqrt{0.01\ \text{mH}/55.3}$ or 13.44 turns.

I have changed uH to a decimal value of mH. This makes the formula easier to use when working with uH.

CHECKING TOROID RESONANCE

If you do not have access to an inductance bridge or a Q meter, try the following technique for finding the approximate resonance of a toroidal tuned circuit. It involves the use of a dip meter. Details are given in Fig 4.

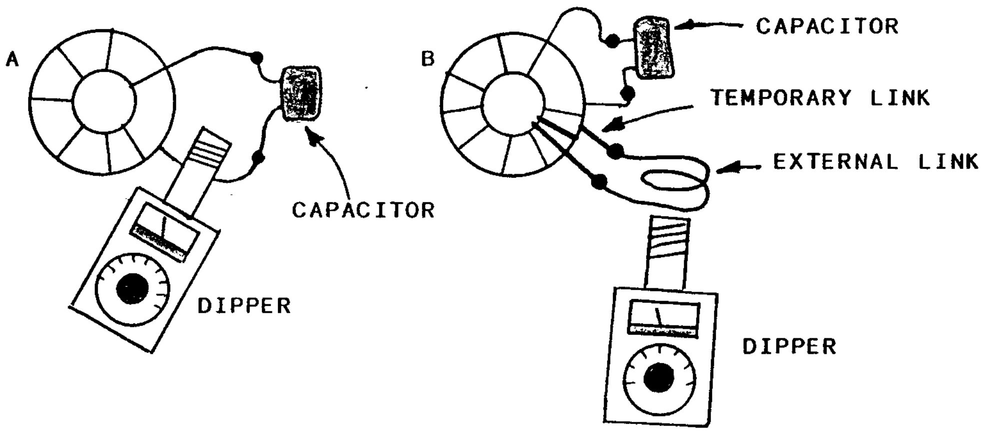

Fig 4 -- Two methods for checking toroids for resonance. Method A shows that the dipper coil is inserted in the loop formed by the winding and capacitor leads. At B is a technique that requires adding a temporary 1- or 2-turn link to the toroid coil. A similar external link is joined to the first one, as shown. The dipper coil is placed in the external link to sample the resonance. The inductance of the toroid may be checked in this manner if a known value of capacitance is used in parallel with the toroid coil. The coupling methods at A and B are necessary because of the self-shielding properties of toroids. They cannot be dipped like conventional coils.

TOROID DOPING AND AFFIXING

Toroidal coils may be used in VFOs and other frequency-critical circuits, but they can cause drift problems. The drift is related to changes in ambient temperature, which causes changes in core permeability. These shifts in mu cause the coil inductance to vary, and hence frequency shift. No. 6 powdered iron seems to be the most stable of the core mixes for use in VFOs. After you wind the VFO coil, coat it and the toroid with polystyrene Q Dope. As the layer dries, add another until three coatings have been applied. This helps to keep the winding securely in place on the core, and hence improves frequency stability. Q Dope is available at Ocean State Electronics, #10-3702.

Completed toroidal coils and transformers should not be supported by their leads when they are mounted vertically on a PC board. Vibration will cause the leads to break when small-gauge wire is used. Place the vertically mounted toroid in its position on the PC board. Next, put a generous dab of quick-setting epoxy cement between the bottom edge of the toroid and the PC board. When the cement has dried the toroid will be held firmly in place. This can be done also to flush-mounted toroids if better stability is desired. You may also use Dow or GE silastic compound for this purpose. It will be easier to remove later.

SUMMARIZATION

I have covered the subjects that appear to confuse most builders. You may want to place this file in a notebook for future reference. I have prepared similar files on other subjects of interest to builders. They are available from Oak Hills Research.

If you break a ferrite toroid or rod, don't throw it away. You may glue the pieces together by means of epoxy cement, and the core will work properly. Be sure to interface the broken pieces firmly when gluing them together. This technique has not proven practical when I have broken powdered-iron cores.