4
CHAPTER
# Winding your own coils

Inductors and capacitors are the principal components used in RF tuning circuits. The resonant frequency of a tank circuit is the frequency to which the inductor–capacitor combination is tuned and is found from:

$$F = \frac{1}{2\pi\sqrt{LC}} \tag{4-1}$$

or, if either the inductance ($L$) or capacitance ($C$) is known or preselected then the other can be found by solving Eq. (4-1) for the unknown, or:

$$C = \frac{1}{39.5\, F^2 L} \tag{4-2}$$

and

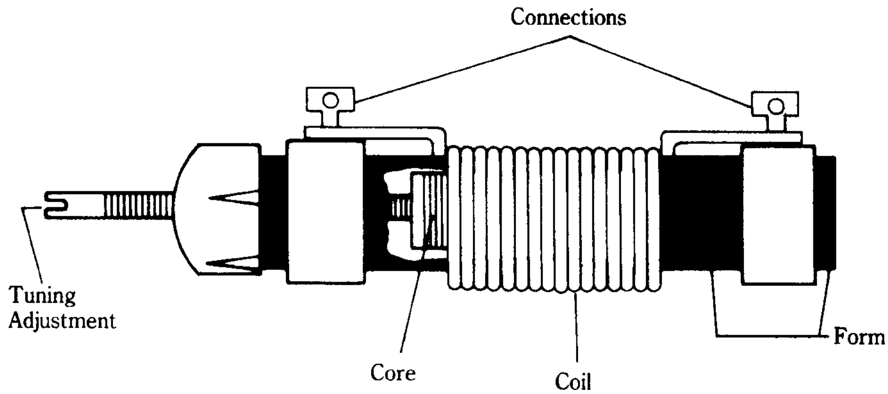
$$L = \frac{1}{39.5\, F^2 C}. \tag{4-3}$$

In all three equations, $L$ is in henrys, $C$ is in farads, and $F$ is in hertz (don't forget to convert values to microhenrys and picofarads after calculations are made).

Capacitors are easily obtained in a wide variety of values. But tuning inductors are either unavailable or are available in other people's ideas of what you need. As a result, it is often difficult to find the kinds of parts that you need. This chapter will look at how to make your own slug-tuned adjustable inductors, RF transformers, and IF transformers (yes, you can build your own IF transformers).

Tuning inductors can be either air-, ferrite-, or powdered-iron-core coils. The air-core coils are not adjustable unless either an expensive roller-contact mechanism or clumsy taps on the winding of the coil are provided. However, the ferrite- and powdered-iron slug-tuned core coils are adjustable.

Figure 4-1 shows one form of slug-tuned adjustable coil. The form is made of plastic, phenolic, fiberglass, nylon, or ceramic materials and is internally threaded. The windings of the coil (or coils in the case of RF/IF transformers) are wound onto the form. The equation for calculating the inductance of a single-layer air-core coil



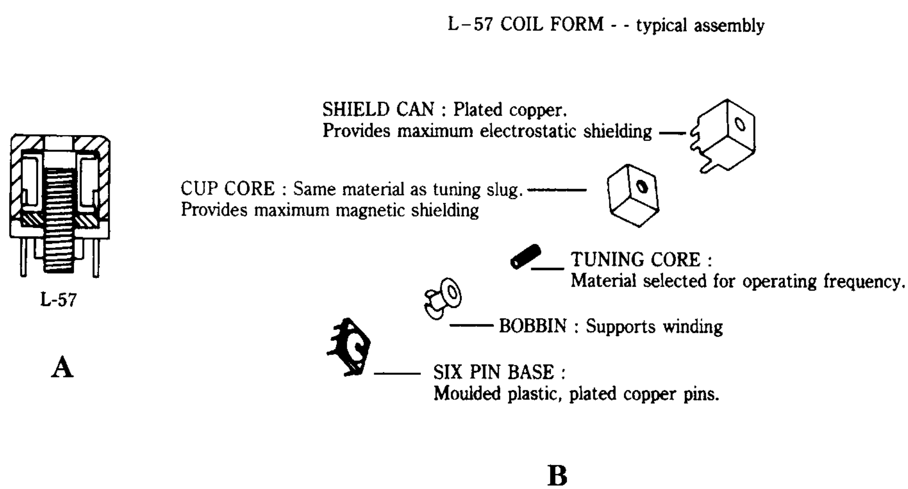

**4-1** Variable inductor on open coil form.

was discussed in Chapter 2. For non-air-core coils, the inductance is multiplied by a factor that is determined by the properties of the core material.

The tuning slug is a ferrite- or powdered-iron-core coil that mates with the internal threads in the coil form. A screwdriver slot or hex hole in either (or both) end allows you to adjust it. The inductance of the coil depends on how much of the core is inside the coil windings.

# Amidon Associates coil system

It was once difficult to obtain coil forms to make your own project inductors. Amidon Associates Inc. makes a series of slug-tuned inductor forms that can be used to make any-value coil that you are likely to need. Figure 4-2A shows an Amidon form, and Fig. 4-2B shows an exploded view.




**4-2** Shielded slug-tuned variable inductor.

Table 4-1 gives the type numbers, frequency ranges (in megaHertz), and other specifications for the coil forms made by Amidon. Three sizes of coil form are offered. The L-33s are 0.31" square and 0.40" high, the L-43s are 0.44" square and 0.50" high, and the L-57s are 0.56" square and 0.50" high. The last number (e.g., −1, −6, −10) in each type number indicates the type of material, which in turn translates to the operating frequency range (see Table 4-1). Now, see how the coil forms are used.

**Table 4-1. Amidon coil form specifications**

| Part number | Frequency range (MHz) | $A_L$ value | Ratio | $Q_{max}$ |
|---|---|---|---|---|
| L-33-1 | 0.30–1.0 | 76 | 1.7:1 | 80 |
| L-33-2 | 1.00–10 | 68 | 1.5:1 | 90 |
| L-33-3 | 0.01–0.5 | 80 | 1.8:1 | 70 |
| L-33-6 | 10–50 | 60 | 1.5:1 | 100 |
| L-33-10 | 25–100 | 54 | 1.4:1 | 120 |
| L-33-17 | 50–200 | 48 | 1.3:1 | 130 |
| L-43-1 | 0.30–1.00 | 115 | 1.6:1 | 110 |
| L-43-2 | 1.00–10 | 98 | 1.6:1 | 120 |
| L-43-3 | 0.01–0.5 | 133 | 1.8:1 | 90 |
| L-43-6 | 10–50 | 85 | 1.4:1 | 130 |
| L-43-10 | 25–100 | 72 | 1.3:1 | 150 |
| L-43-17 | 50–200 | 56 | 1.2:1 | 200 |
| L-57-1 | 0.30–1.00 | 175 | 3:1 | * |
| L-57-2 | 1.00–10 | 125 | 2:1 | * |
| L-57-3 | 0.01–0.5 | 204 | 3:1 | * |
| L-57-6 | 10–50 | 115 | 2:1 | * |
| L-57-10 | 25–100 | 100 | 2:1 | * |
| L-57-17 | 50–200 | 67 | 1.5:1 | * |

Determine the required inductance from Eq. (4-3). For an experiment to see how this coil system works, I decided to build a 15-MHz WWV converter that reduced the WWV radio station frequency to an 80- to 75-m ham-band frequency. Thus, I needed a circuit that would tune 15 MHz. It is generally a good idea to have a high capacitance-to-inductance ratio in order to maintain a high $Q$ factor. I selected a 56-pF NPO capacitor for the tuned circuit because it is in the right range, and a dozen or so were in my junk box. According to Eq. (4-3), therefore, I needed a 2-μH inductor.

To calculate the number of turns ($N$) required to make any specific inductance, use the following equation:

$$N = 100\sqrt{\frac{L}{0.9A_L}}, \tag{4-4}$$

where

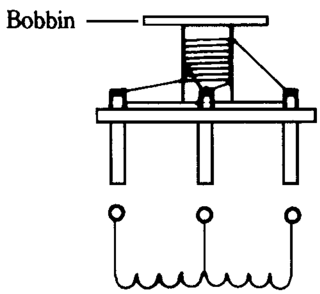
$L$ = inductance in microhenrys (μH)

$N$ = the number of turns.

The $A_L$ factor is a function of the properties of the core materials and is found in Table 4-1; the units are microhenrys per 100 turns (μH/100 turns). In my case, I selected an L-57-6, which covers the correct frequency range and has an $A_L$ value of 115 μH/100 turns. According to Eq. (4-4), therefore, I need 14 turns of wire.

The coil is wound from no. 26 to no. 32 wire. Ideally, Litz wire is used, but that is both hard to find and difficult to solder. For most projects ordinary enamel-coated magnet wire will suffice. A razor knife (such as X-acto) and soldering iron tip can be used to remove the enamel from the ends of the wire. Because the forms are small, I recommend using the no. 32 size.

Winding the coil can be a bit tricky if your vision needs augmentation as much as mine. But, using tweezers, needlenose pliers, and a magnifying glass on a stand made it relatively easy. Figure 4-3 shows the method for winding a coil with a tapped winding. Anchor one end of the wire with solder on one of the end posts and use this as the reference point. In my case, I wanted a 3-turn tap on the 14-turn coil, so I wound 3 turns then looped the wire around the center post. After this point was soldered, the rest of the coil was wound and then anchored at the remaining end post. A dab of glue or clear fingernail polish will keep the coil windings from moving.




**4-3**
Construction of a custom coil using Fig. 4-2.

If you make an RF/IF transformer, then there will be two windings. Try to separate the primary and secondary windings if both are tuned. If one winding is not tuned, then simply wind it over the "cold" (i.e., ground) end of the tuned winding—no separation is needed.

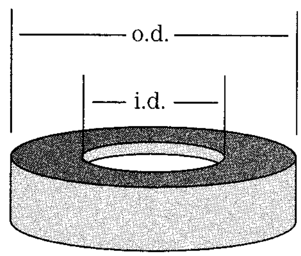
The Amidon coil forms are tight, but they do have sufficient space for very small disk ceramic capacitors inside. The 56-pF capacitors that I selected fit nicely inside the shielded can of the coil, so I elected to place it there. Thus, I've basically made a 15-MHz RF/IF transformer.

After constructing the 15-MHz RF coil, I tested it and found that the slug tuned the coil to 15 MHz with a nice tolerance on either side of the design resonant frequency. It worked!

Although slug-tuned inductors are sometimes considered a bit beyond the hobbyist or ham, that is not actually true. The Amidon L-series coil forms can easily be used to make almost any inductor that you are likely to need.

# Making your own toroid-core inductors and RF transformers

A lot of construction projects intended for electronic hobbyists and amateur radio operators call for inductors or radio-frequency (RF) transformers wound on toroidal cores. A toroid is a doughnut-shaped object, i.e., a short cylinder (often with rounded edges) that has a hole in the center (see Fig. 4-4). The toroidal shape is desirable for inductors because it permits a relatively high inductance value with few turns of wire, and, perhaps most important, the geometry of the core makes it self-shielding. That latter attribute makes the toroid inductor easier to use in practical RF circuits. Regular solenoid-wound cylindrical inductors have a magnetic field that goes outside the immediate vicinity of the windings and can thus intersect nearby inductors and other objects. Unintentional inductive coupling can cause a lot of serious problems in RF electronic circuits so they should be avoided wherever possible. The use of a toroidal shape factor, with its limited external magnetic field, makes it possible to mount the inductor close to other inductors (and other components) without too much undesired interaction.




**4-4**
(A) Trifilar wound transformer circuit; (B) actual windings; (C) glue or silicone seal is used to hold the ends of the windings.

## Materials used in toroidal cores

Toroid cores are available in a variety of materials that are usually grouped into two general classes: powdered iron and ferrite. These groups are further subdivided.

### Powdered-iron materials

Powdered-iron cores are available in two basic formulations: carbonyl irons and hydrogen-reduced irons. The carbonyl materials are well-regarded for their temperature stability; they have permeability ($\mu$) values that range from $1\mu$ to about $35\mu$. The carbonyls offer very good $Q$ values to frequencies of 200 MHz. Carbonyls are used in high-power applications as well as in variable-frequency oscillators and wherever temperature stability becomes important. However, notice that no powdered-iron material or ferrite is totally free of temperature variation, so oscillators using these cores must be temperature compensated for proper operation. The hydrogen-reduced iron devices offer permeabilities up to $90\mu$, but are lower $Q$ than carbonyl devices. They are most used in electromagnetic interference (EMI) filters. The powdered-iron materials are the subject of Table 4-2.

**Table 4-2. Powdered-iron core materials**

| Material | Permeability (μ) | Comments |
|---|---|---|
| 0 | 1 | Used up to 200 MHz; inductance varies with method of winding |
| 1 | 20 | Made of carbonyl C; similar to mixture no. 3 but is more stable and has a higher volume resistivity |
| 2 | 10 | Made of carbonyl E; high *Q* and good volume resistivity over range of 1 to 30 MHz |
| 3 | 35 | Made of carbonyl HP; very good stability and good *Q* over range of 0.05 to 0.50 MHz |
| 6 | 8 | Made of carbonyl SF; similar to mixture no. 2 but has higher *Q* over range 20 to 50 MHz |
| 10 | 6 | Type W powdered iron; good *Q* and high stability from 40 to 100 MHz |
| 12 | 3 | Made of a synthetic oxide material; good *Q* but only moderate stability over the range 50 to 100 MHz |
| 15 | 25 | Made of carbonyl GS6; excellent stability and good *Q* over range 0.1 to 2 MHz; recommended for AM BCB and VLF applications |
| 17 | 3 | Carbonyl material similar to mixture no. 12 but has greater temperature stability but lower *Q* than no. 12 |
| 26 | 75 | Made of hydrogen reduced iron; has very high permeability; used in EMI filters and DC chokes |

### Ferrite materials

The name *ferrite* implies that the materials are iron-based (they are not), but ferrites are actually grouped into nickel-zinc and manganese-zinc types. The nickel-zinc material has a high-volume resistivity and high *Q* over the range 0.50 to 100 MHz. The temperature stability is only moderate, however. The permeabilities of nickel-zinc materials are found in the range 125 to 850μ. The manganese-zinc materials have higher permeabilities than nickel-zinc and are on the order of 850 to 5000μ. Manganese-zinc materials offer high *Q* over 0.001 to 1 MHz. They have low volume resistivity and moderate saturation flux density. These materials are used in switching power supplies from 20 to 100 kHz and for EMI attenuation in the range 20 to 400 MHz. See Table 4-3 for information on ferrite materials.

## Toroid-core nomenclature

Although there are several different ways to designate toroidal cores, the one used by Amidon Associates is perhaps that most commonly found in electronic hobbyist and amateur radio published projects.

Although the units of measure are the English system, which is used in the United States and Canada and formerly in the UK, rather than SI units, their use with respect to toroids seems widespread. The type number for any given core will consist of three elements: xx–yy–zz. The “xx” is a one- or two-letter designation of the

**Table 4-3. Ferrite materials**

| Material | Permeability ($\mu$) | Remarks[1] |
|---|---|---|
| 33 | 850 | M–Z; used over 0.001 to 1 MHz for loopstick antenna rods; low volume resistivity |
| 43 | 850 | N–Z; medium-wave inductors and wideband transformers to 50 MHz; high attenuation over 30 to 400 MHz; high volume resistivity |
| 61 | 125 | N–Z; high *Q* over 0.2 to 15 MHz; moderate temperature stability; used for wideband transformers to 200 MHz |
| 63 | 40 | High *Q* over 15 to 25 MHz; low permeability and high volume resistivity |
| 67 | 40 | N–Z; high *Q* operation over 10 to 80 MHz; relatively high flux density and good temperature stability; similar to Type 63, but has lower volume resistivity; used in wideband transformers to 200 MHz |
| 68 | 20 | N–Z; excellent temperature stability and high *Q* over 80 to 180 MHz; high volume resistivity |
| 72 | 2000 | High *Q* to 0.50 MHz but used in EMI filters from 0.50 to 50 MHz; low volume resistivity |
| J/75 | 5000 | Used in pulse and wideband transformers from 0.001 to 1 MHz and in EMI filters from 0.50 to 20 MHz; low volume resistivity and low core losses |
| 77 | 2000 | 0.001 to 1 MHz; used in wideband transformers and power converters and in EMI and noise filters from 0.5 to 50 MHz |
| F | 3000 | Is similar to Type 77 above but offers a higher volume resistivity, higher initial permeability, and higher flux saturation density; used for power converters and in EMI/noise filters from 0.50 to 50 MHz |

[1] N–Z: nickel–zinc;
M–Z: manganese–zinc.

general class of material, i.e., powdered iron (xx = "T") or ferrite (xx = "TF"). The "yy" is a rounded-off approximation of the outside diameter (*o.d.* in Fig. 4-4) of the core in inches; "37" indicates a 0.375" (9.53 mm) core, while "50" indicates a 0.50" (12.7 mm) core. The "zz" indicates the type (mixture) of material. A mixture no. 2 powdered-iron core of 0.50" diameter would be listed as a T-50-2 core. The cores are color-coded to assist in identification.

## Inductance of toroidal coils

The inductance of the toroidal core inductor is a function of the permeability of the core material, the number of turns, the inside diameter (*i.d.*) of the core, the outside diameter (*o.d.*) of the core, and the height (*h*) (see Fig. 4-1) and can be approximated by:

$$L = 0.011684\, h\, N^2\, \mu_r \log_{10}\left(\frac{o.d.}{i.d.}\right) H. \qquad (4\text{-}5)$$

This equation is rarely used directly, however, because toroid manufacturers provide a parameter called the $A_L$ *value,* which relates inductance per 100 or 100 turns of wire. Tables 4-4 and 4-5 show the $A_L$ values of common ferrite and powdered-iron cores.

**Table 4-4. Common powdered-iron $A_L$ values**

| Core | Core material type (mix) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **size** | **26** | **3** | **15** | **1** | **2** | **6** | **10** | **12** | **0** |
| 12 | — | 60 | 50 | 48 | 20 | 17 | 12 | 7 | 3 |
| 16 | — | 61 | 55 | 44 | 22 | 19 | 13 | 8 | 3 |
| 20 | — | 90 | 65 | 52 | 27 | 22 | 16 | 10 | 3.5 |
| 37 | 275 | 120 | 90 | 80 | 40 | 30 | 25 | 15 | 4.9 |
| 50 | 320 | 175 | 135 | 100 | 49 | 40 | 31 | 18 | 6.4 |
| 68 | 420 | 195 | 180 | 115 | 57 | 47 | 32 | 21 | 7.5 |
| 94 | 590 | 248 | 200 | 160 | 84 | 70 | 58 | 32 | 10.6 |
| 130 | 785 | 350 | 250 | 200 | 110 | 96 | — | — | 15 |
| 200 | 895 | 425 | — | 250 | 120 | 100 | — | — | — |

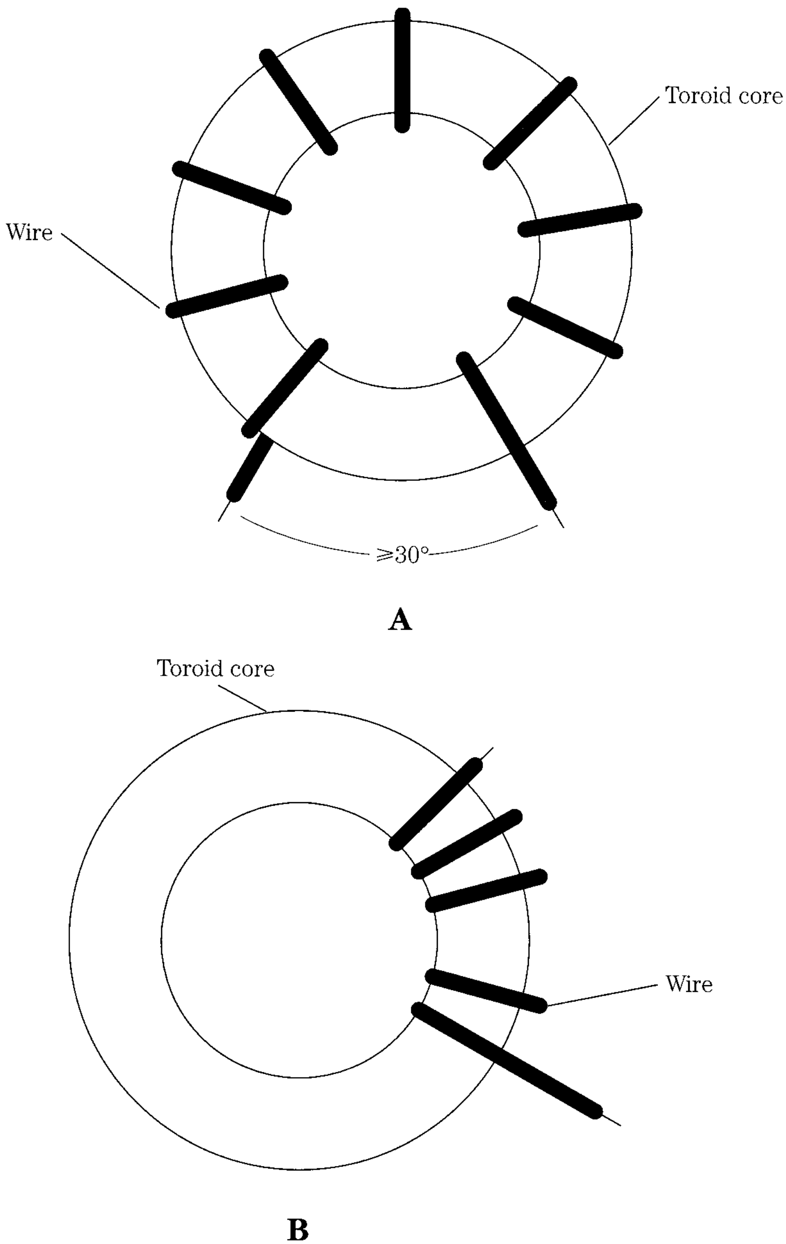
**Table 4-5. Common ferrite-core $A_L$ values**

| Core | Material type | | | | | |
|---|---|---|---|---|---|---|
| **size**[1] | **43** | **61** | **63** | **72** | **75** | **77** |
| 23 | 188 | 24.8 | 7.9 | 396 | 990 | 356 |
| 37 | 420 | 55.3 | 17.7 | 884 | 2210 | 796 |
| 50 | 523 | 68 | 22 | 1100 | 2750 | 990 |
| 50A | 570 | 75 | 24 | 1200 | 2990 | 1080 |
| 50B | 1140 | 150 | 48 | 2400 | — | 2160 |
| 82 | 557 | 73.3 | 22.8 | 1170 | 3020 | 1060 |
| 114 | 603 | 79.3 | 25.4 | 1270 | 3170 | 1140 |
| 114A | — | 146 | — | 2340 | — | — |
| 240 | 1249 | 173 | 53 | 3130 | 6845 | 3130 |

[1] Core type no. prefix: TF-yy-zz.

## Winding toroid inductors

There are two basic ways to wind a toroidal core inductor: distributed (Fig. 4-5A) and close-spaced (Fig. 4-5B). In distributed toroidal inductors, the turns of wire that are wound on the toroidal core are spaced evenly around the circumference of the core, with the exception of a gap of at least 30° between the ends (see Fig. 4-5A). The gap ensures that stray capacitance is kept to a minimum. The winding covers 270° of the core. In close winding (Fig. 4-5B), the turns are made so that adjacent turns of wire touch each other. This pratice raises the stray capacitance of the winding, which affects the resonant frequency, but can be done in many cases with little or no ill effect (especially where the capacitance and resonant point shift are negli-




**4-5** Toroid winding styles: (A) distributed; (B) close wound.

gible). In general, close winding is used for inductors in narrowband-tuned circuits, and distributed winding is used for broadband situations, such as conventional and balun RF transformers. The method of winding has a small effect on the final inductance of the coil. Although this makes calculating the final inductance less predictable, it also provides a means of final adjustment of actual inductance in the circuit as-built.

## Calculating the number of turns

As in all inductors, the number of turns of wire determines the inductance of the finished coil. In powdered-iron cores, the $A_L$ rating of the core is used with fair confidence to predict the number of turns needed.

For powdered-iron cores:

$$N = 100\frac{\sqrt{L_{\mu H}}}{A_L} \qquad (4\text{-}6)$$

For ferrite cores:

$$N = 1000\sqrt{\frac{L_{mH}}{A_L}}, \qquad (4\text{-}7)$$

where

$N$ = the number of turns
$L_{\mu H}$ = inductance in microhenrys (μH)
$L_{mH}$ = inductance in millihenrys (mH)
$A_L$ is a property of the core material.

## Building the toroidal device

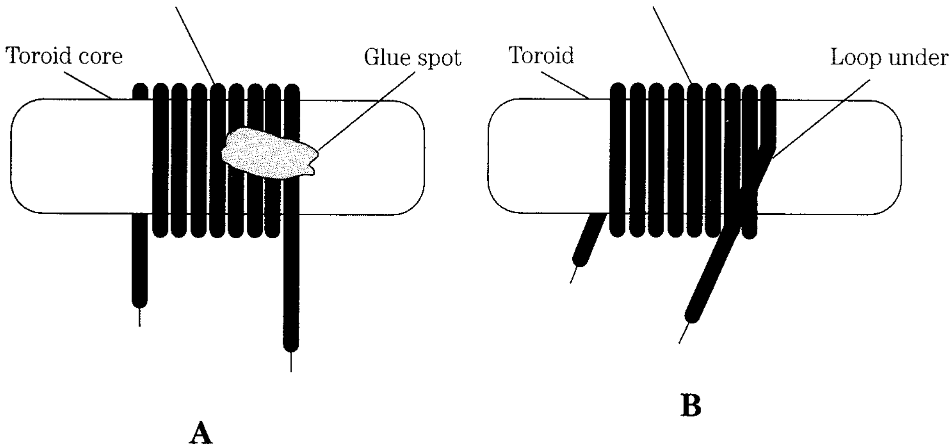
The toroid core or transformer is usually wound with enameled or formvar-insulated wire. For low-powered applications (receivers, VFOs, etc.) the wire will usually be no. 22 through no. 36 (with no. 26 being very common) AWG. For high-power applications, such as transmitters and RF power amplifiers, a heavier grade of wire is needed. For high-power RF applications, no. 14 or no. 12 wire is usually specified, although wire as large as no. 6 has been used in some commercial applications. Again, the wire is enameled or formvar-covered insulated wire.

In the high-power case, it is likely that high voltages will exist. In high-powered RF amplifiers, such as used by amateur radio operators in many countries, the potentials present across a 50-Ω circuit can reach hundreds of volts. In those cases, it is common practice to wrap the core with a glass-based tape, such as Scotch 27.

High-powered applications also require a large-area toroid rather than the small toroids that are practical at lower power levels. Cores in the FT-150-zz to FT-240-zz or T-130-zz to T-500-zz are typically used. In some high-powered cases, several identical toroids are stacked together and wrapped with tape to increase the power-handling capacity. This method is used quite commonly in RF power amplifier and antenna tuner projects.

## Binding the wires

It sometimes happens that the wires making up the toroidal inductor or transformer become loose. Some builders prefer to fasten the wire to the core using one of the two methods shown in Fig. 4-6. Figure 4-6A shows a dab of glue, silicone adhesive, or the high-voltage sealant Glyptol (sometimes used in television receiver high-voltage circuits) to anchor the end of the wire to the toroid core.




**4-6** Methods for fastening the wire on a toroid winding: (A) glue spot and (B) "tuck under" method.

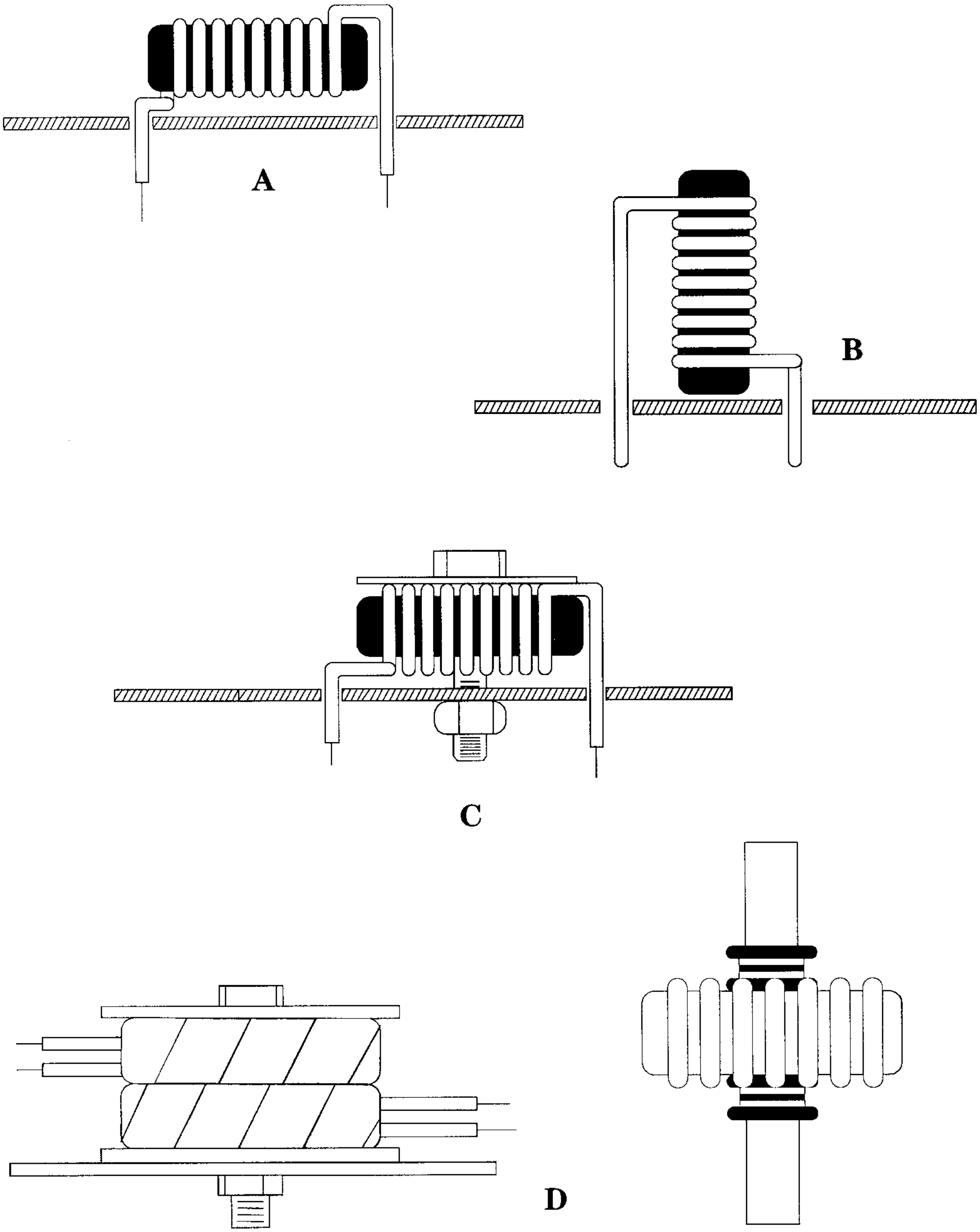
Other builders prefer the method shown in Fig. 4-6B. In this method, the end of the wire is looped underneath the first full turn and pulled taut. This method will effectively anchor the wire, but some say it creates an anomaly in the magnetic situation that might provoke interactions with nearby components. In my experience, that situation is not terribly likely, and I use the method regularly with no observed problems thus far.

When the final coil is ready, and both the turns count and spacing are adjusted to yield the required inductance, the turns can be anchored to the coil placed in service. A final sealant method is to coat the coil with a thin layer of clear lacquer, or "Q-dope" (this product is intended by its manufacturer as an inductor sealant).

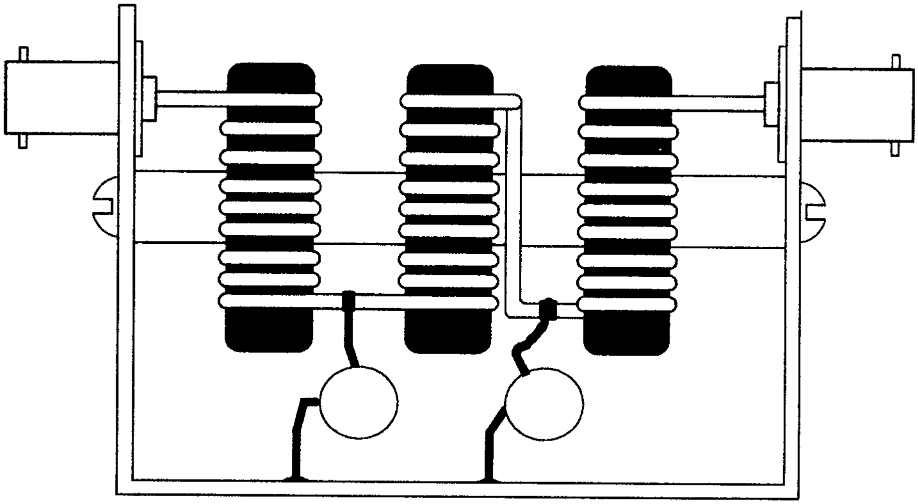
## Mounting the toroidal core

Toroids are a bit more difficult to mount than solenoid-wound coils (cylindrical coils), but the rules that one must follow are not as strict. The reason for loosening of the mounting rules is that the toroid, when built correctly, is essentially self-shielding, so less attention (not *no* attention!) can be paid to the components that surround the inductor. In the solenoid-wound coil, for example, the distance between adjacent coils and their orientation is important. Adjacent coils, unless well shielded, must be placed at right angles to each other to lessen the mutual coupling between the coils. However, toroidal inductors can be closer together and either coplanar or adjacent planar can be placed with respect to each other. Although some spacing must be maintained between toroidal cores (the winding and core manufacture not being perfect), the required average distance can be less than for solenoid-wound cores.

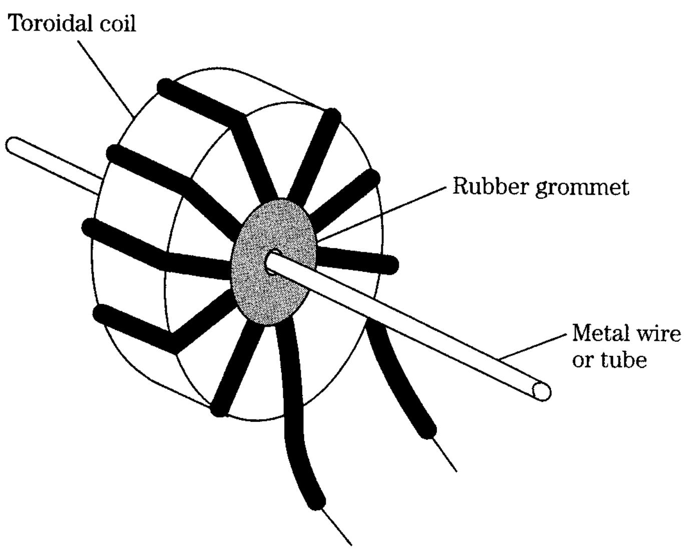
Mechanical stability of the mounting is always a consideration for any coil (indeed, any electronic component). For most benign environments, the core can be mounted directly to a printed wiring board (PWB) in the manner of Figs. 4-7A and 4-7B. In Fig. 4-7A, the toroidal inductor is mounted flat against the board; its leads




**4-7** (A) Flat mounting; (B) on-end mounting; (C) secured mounting (use nylon machine screws); (D) mounting high-power or high-voltage toroidal inductors or transformers; (E) suspending toroid inductors on a dowel; (F) mounting method for a "single-turn primary" transformer in RF watt-meters or VSWR meters.



**E**




**F**

**4-7** *Continued*

are passed through holes in the board to solder pads underneath. The method of Fig. 4-7B places the toroid at right angles to the board, but it still uses the leads soldered to copper pads on the PWB to anchor the coil. It is wise to use a small amount of RTV silicone sealant or glue to held the coil to the board once it is found to work satisfactorily.

If the environment is less benign with respect to vibration levels, then a method similar to Fig. 4-7C can be used. Here, the toroid is fastened to the PWB with a set of nylon machine screw and nut hardware and a nylon or fiber washer. In high-powered antenna tuning units, it is common to see an arrangement similar to that in Fig. 4-7D. In this configuration, several toroidal cores are individually wrapped in glass tape, then the entire assembly is wrapped as a unit with the same tape. This assembly is mounted between two insulators, such as plastics, ceramic, or fiberboard, which are held together as a "sandwich" by a nylon bolt and hex nut.

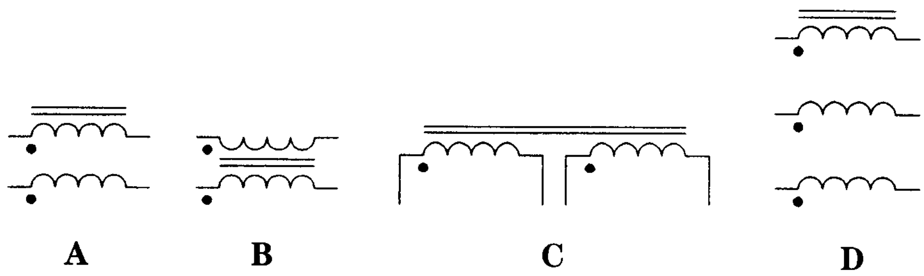
Figure 4-7E shows a method for suspending toroidal cores in a shielded enclosure. I've used this method to make five-element low-pass filters for use in my basement laboratory. The toroidal inductors are mounted on a dowel, which is made of some insulating material, such as wood, plastic, plexiglass, Lexan, or other synthetic. If the dowel is sized correctly, then the inductors will be a tight slip fit and there will be no need for further anchoring. Otherwise, a small amount of glue or RTV silicone sealant can be used to stabilize the position of the inductor.

Some people use a pair of undersized rubber grommets over the dowel, one pressed against either side of the inductor (see inset to Fig. 4-7E). If the grommets are taut enough, then no further action is needed. Otherwise, they can be glued to the rod.

A related mounting method is used to make current transformers in homemade RF power meters (Fig. 4-7F). In this case, a rubber grommet is fitted into the center of the toroid, and a small brass or copper rod is passed through the center hole of the grommet. The metal rod serves as a one-turn primary winding. A sample of the RF current flowing in the metal rod is magnetically coupled to the secondary winding on the toroid, where it can be fed to an oscilloscope for display or rectified, filtered, and displayed on a dc current meter that is calibrated in watts or VSWR units.

## Torodial RF transformers

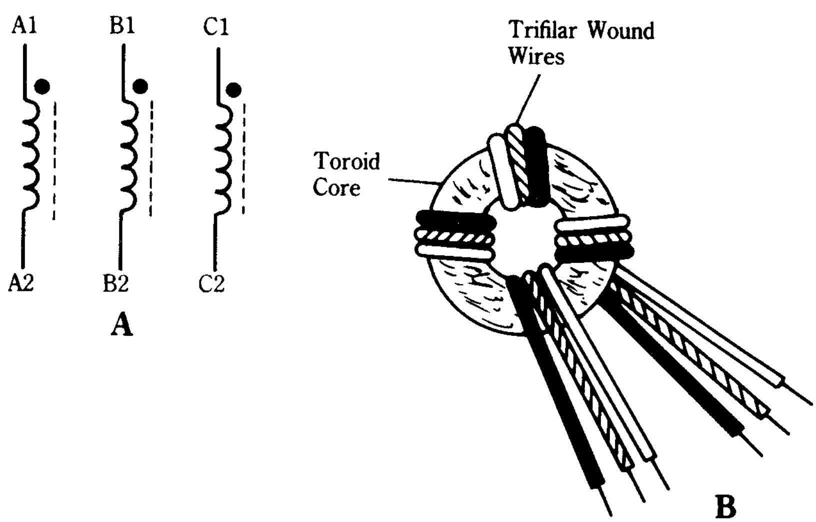
Both narrowband-tuned and broadband RF transformers can be accommodated by toroidal powdered-iron and ferrite cores. The schematic symbols used for transformers are shown in Fig. 4-8. These symbols are largely interchangeable and are all seen from time to time. In Fig. 4-8A, the two windings are shown adjacent to each other, but the core is shown along only one of them. This method is used to keep the drawing simple and does not imply in any way that the core does not affect one of the windings. The core can be represented either by one or more straight lines, as shown, or by dotted lines. The method shown in Fig. 4-8B is like the conventional transformer representation in which the windings are juxtaposed opposite each other with the core between them. In Fig. 4-8C, the core is extended and the two windings are along one side of the core bars.



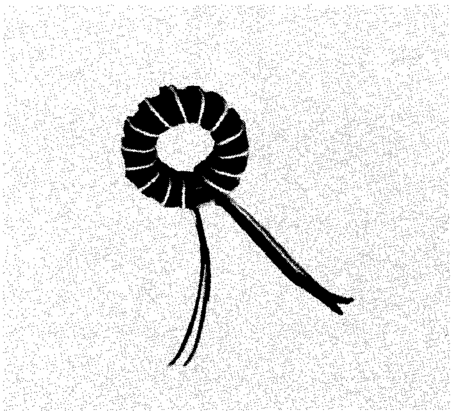

**4-8** Transformer schematic styles.

In each of the transformer representations of Fig. 4-8, dots are on the windings. These dots show the "sense" of the winding and represent the same end of the coils. Thus, the wires from two dotted ends are brought to the same location, and the two coils are wound in the same direction. Another way of looking at it is that if a third winding were used to excite the core from an RF source, the phase of the signals at the dot end will be the same; the phase of the signal at the undotted ends will also be the same, but will be opposite that of the dotted ends.

I was once questioned by a reader concerning the winding protocol for toroidal transformers, as shown in books and magazine articles. My correspondent included a partial circuit (Fig. 4-9A) as typical of the dilemma. The question was How do you wind it? and a couple of alternative methods were proposed. At first I thought it was a silly question because the answer was obvious, and then I realized that perhaps I was wrong; to many people, the answer was not that obvious. The answer to this question is that all windings are wound together in a multifilar manner.




**4-9** Trifilar wound transformer: (A) circuit symbol; (B) winding details; (C) using parallel wires; (D) using twisted wires; and (E) glue spot for securing windings.



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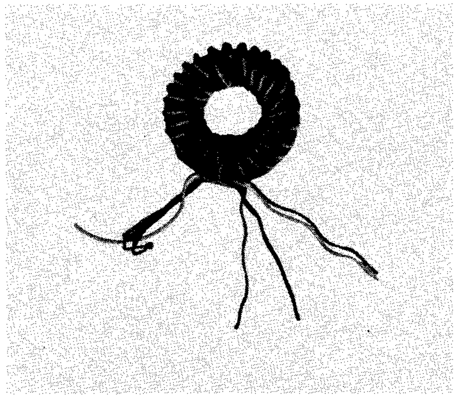

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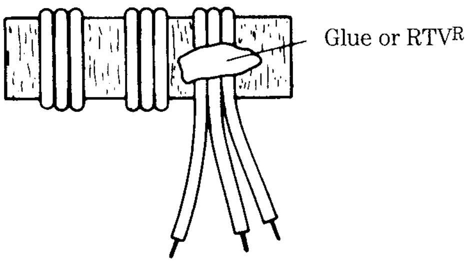



E

**4-9** *Continued.*

Because there are three windings, in this case, we are talking about trifilar windings. Figure 4-9B shows the trifilar winding method. For the sake of clarity, I have colored all the three wires differently so that you can follow it. This practice is also a good idea for practical situations. Because most of my projects use nos. 26, 28, or 30 enameled wire to wind coils, I keep three colors of each size on hand and wind each winding with a different color. That makes it a whole lot easier to identify which ends go with each other.

The dots in the schematic and on the pictorial are provided to identify one end of the coil windings. Thus, the dot and no-dot ends are different from each other; in circuit operation, it usually makes a difference which way the ends are connected into the circuit (the issue is signal phasing).

Figures 4-9C and 4-9D shows two accepted methods for winding a multifilar coil on a toroidal core. Figure 4-9C is the same method as in Fig. 4-9B, but on an actual toroid instead of a pictorial representation. The wires are laid down parallel to each other as shown previously. The method in Fig. 4-9D uses twisted wires. The three wires are chucked up in a drill and twisted together before being wound on the core.

With one end of the three wires secured in the drill chuck, anchor the other end of the three wires in something that will hold it taut. I use a bench vise for this purpose. Turn the drill on the slow speed and allow the wires to twist together until the desired pitch is achieved.

Be very careful when performing this operation. If you don't have a variable-speed electric drill (so that it can be run at very low speeds), then use an old-fashioned manual hand drill. If you use an electric drill, wear eye protection. If the wire breaks or gets loose from its mooring, it will whip around wildly until the drill stops. That whipping wire can cause painful welts on your skin, and it can easily cause permanent eye damage.

Of the two methods for winding toroids, the method shown in Figs. 4-9B and 4-9C is preferred. When winding toroids, at least those of relatively few windings, pass the wire through the doughnut hole until the toroid is about in the middle of the length of wire. Then, loop the wire over the outside surface of the toroid and pass it through the hole again. Repeat this process until the correct number of turns are wound onto the core. Be sure to press the wire against the toroid form and keep it taut as you wind the coils.

Enameled wire is usually used for toroid transformers and inductors, and that type of wire can lead to a problem. The enamel can chip and cause the copper conductor to contact the core. On larger cores, such as those used for matching transformers and baluns used at kilowatt power levels, the practical solution is to wrap the bare toroid core in a layer of fiberglass packing tape. Wrap the tape exactly as if it were wire, but overlap the turns slightly to ensure that the entire circumference of the core is covered.

On some projects, especially those in which the coils and transformers use very fine wire (e.g., no. 30), I have experienced a tendency for the wire windings to unravel after the winding is completed. This problem is also easily curable. At the ends of the windings place a tiny dab of rubber cement or RTV silicone sealer (see Fig. 4-5E).

## Conventional RF transformers

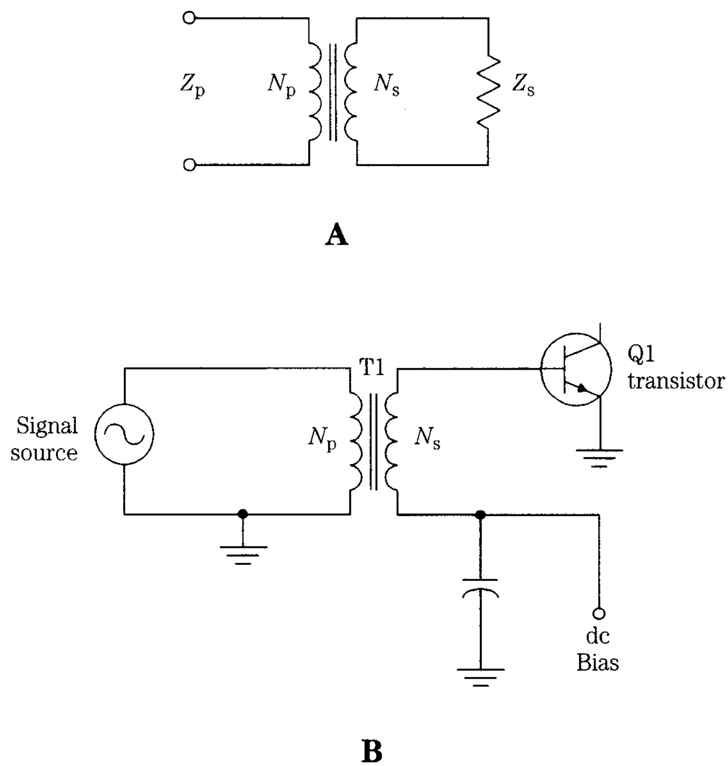
One of the principal uses of transformers in RF circuits is impedance transformation. When the secondary winding of a transformer is connected to a load impedance, the impedance seen "looking into" the primary will be a function of the load impedance and the turns ratio of the transformer (see Fig. 4-10A). The relationship is:

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}. \qquad (4\text{-}8)$$

With the relationship of Eq. (4-8), you can match source and load impedances in RF circuits.

### Example

Assume that you have a 3- to 30-MHz transistor RF amplifier with a base input impedance of 4 Ω ($Z_s$), and that transistor amplifier has to be matched to a 50-Ω




**4-10** (A) A transformer with primary and secondary labels; (B) typical transformer circuit with transistor load.

source impedance ($Z_p$), as shown in Fig. 4-10B. What turns ratio is needed to effect the impedance match? Let's calculate:

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

$$\frac{N_p}{N_s} = \sqrt{\frac{50\,\Omega}{4\,\Omega}} \qquad (4\text{-}9)$$

$$\frac{N_p}{N_s} = \sqrt{12.5} = 3.53{:}1.$$

A general design rule for the value of inductance used in transformers is that the inductive reactance at the lowest frequency must be 4 times (4×) the impedance connected to that winding. In the case of the 50-Ω primary of this transformer, the inductive reactance of the primary winding should be 4 × 50 = 200 Ω. The inductance should be:

$$L = \frac{200\,\Omega\,10^6}{2\pi F}$$

$$L = \frac{200\ \Omega 10^6}{(2)(3.1415)(3{,}000{,}000\ \text{Hz})} = 10.6\mu\text{H}.$$

Now that you know that a 10.6-μH inductance is needed, you can select a toroidal core and calculate the number of turns needed. The T-50-2 (RED) core covers the correct frequency range and is of a size that is congenial to easy construction. The T-50-2 (RED) core has an $A_L$ value of 49, so the number of turns required is as follows:

$$N = 100\sqrt{\frac{10.6\mu\text{H}}{49}} = 46.5\ \text{turns} \approx 47\ \text{turns}.$$

The number of turns in the secondary must be such that the 3.53 : 1 ratio is preserved when 47 turns are used in the primary:

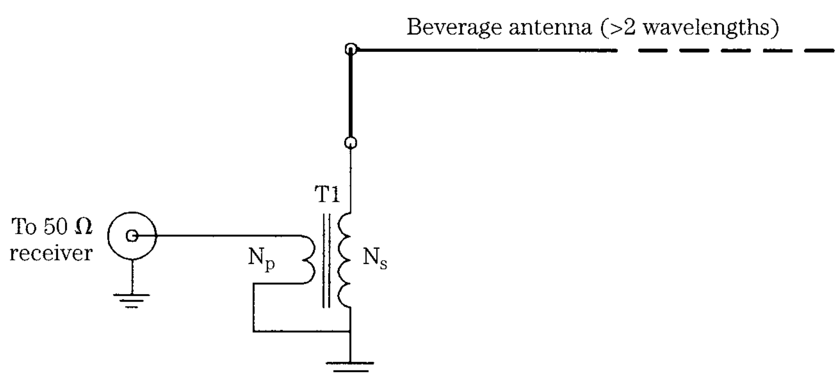
$$N_s = \frac{47}{3.53} = 13.3\ \text{turns}.$$

If you wind the primary with 47 turns and the secondary with 13 turns, then you can convert the 4-Ω transistor base impedance to the 50-Ω systems impedance.

**Example**

A beverage antenna can be constructed for the AM broadcast band (530 to 1700 kHz). By virtue of its construction and installation, it exhibits a characteristic impedance, $Z_o$, of 600 Ω. What is the turns ratio required of a transformer at the feed end (Fig. 4-11) to match a 50-Ω receiver input impedance?

$$\frac{N_s}{N_p} = \sqrt{\frac{600\ \Omega}{50\ \Omega}} = 3.46{:}1.$$




**4-11** Coupling transformer used to feed a Beverage antenna.

The secondary requires an inductive reactance of 4 × 600 Ω = 2400 Ω. To obtain this inductive reactance at the lowest frequency of operation requires an inductance of:

$$L = \frac{(2400\,\Omega)(10^6)}{(2)(\pi)(530{,}000\text{ Hz})} = 721\,\mu\text{H}.$$

Checking a table of powdered-iron toroid cores, you will find that the −15 (RED/WHT) mixture will operate over 0.1 to 2 MHz (see Table 4-6.). Selecting a T-106-15 (Red/White) core provides an $A_L$ value of 345. The number of turns required to create an inductance of 721 μH is:

$$N = 100\sqrt{\frac{721\,\mu\text{H}}{345}} = 145\text{ turns}.$$

The primary winding must have:

$$N_p = \frac{145}{3.46}\text{ turns} = 42\text{ turns}.$$

Winding this transformer, as designed, should provide adequate service.

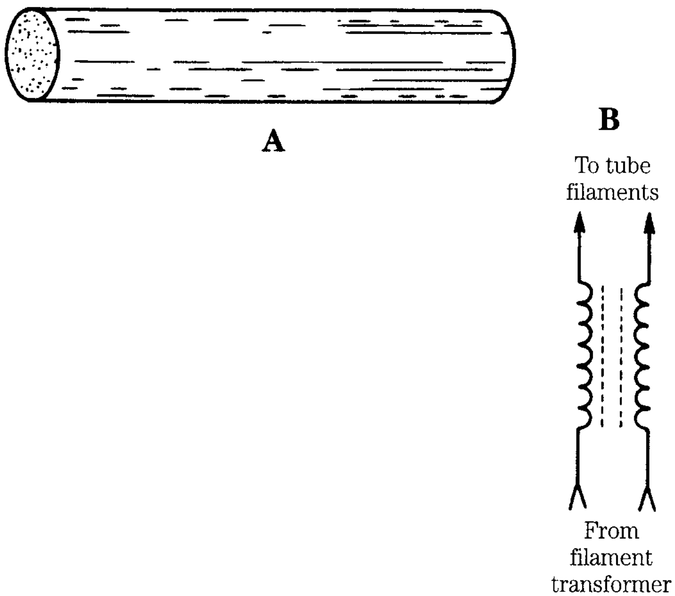
**Table 4-6. Properties of powdered-iron core types**

| **Material type** | **Color code** | **Mu (μ)** | **Frequency (MHz)** |
|---|---|---|---|
| 41 | Green | 75 | — |
| 3 | Grey | 35 | 0.05–0.5 |
| 15 | Red/white | 25 | 0.1–2 |
| 1 | Blue | 20 | 0.5–5 |
| 2 | Red | 10 | 1–30 |
| 6 | Yellow | 8 | 10–90 |
| 10 | Black | 6 | 60–150 |
| 12 | Green/white | 3 | 100–200 |
| 0 | Tan | 1 | 150–300 |

# Ferrite and powdered-iron rods

Ferrite rods (Fig. 4-12A) are used in the low-frequency medium wave, AM broadcast band, and LF/VLF receivers to form “loopstick” antennas. These antennas are often used in radio-direction finders because they possess a “figure-8” reception pattern that counterposes two deep nulls with a pair of main lobes. Another application of ferrite rods is to make balun transformers (Fig. 4-12B) or filament transformers in vacuum-tube high-power RF amplifiers. Ferrite rod inductors are also used in any application, up to about 10 MHz, where a high inductance is needed.

Two permeability figures are associated with the ferrite rod, but only one of them is easily available (see Table 4-7): the initial permeability. This figure is used in the equations for inductance. The effective permeability is a little harder to pin down and is dependent on such factors as (a) the length/diameter ratio of the rod, (b) location of the coil on the rod (centered is most predictable), (c) the spacing between turns of wire, and (d) the amount of air space between the wire and the rod. In general, maximizing effective $A_L$ and inductance requires placing the coil in the center of the rod. The best $Q$, on the other hand, is achieved when the coil runs nearly the entire length of the rod.




**4-12** (A) Ferrite rod; (B) filament transformer RF choke.

**Table 4-7. Properties of some common ferrite rods**

| Part no. turns | Permeability | Approx. $A_L$[1] | Ampere |
|---|---|---|---|
| R61-025-400 | 125 | 26 | 110 |
| R61-033-400 | 125 | 32 | 185 |
| R61-050-400 | 125 | 43 | 575 |
| R61-050-750 | 125 | 49 | 260 |
| R33-037-400 | 800 | 62 | 290 |
| R33-050-200 | 800 | 51 | 465 |
| R33-050-400 | 800 | 59 | 300 |
| R33-050-750 | 800 | 70 | 200 |

[1] Approximate value for coil centered on rod, covering nearly the entire length, made of no. 22 wire. Actual $A_L$ may vary with situation.

Several common ferrite rods available from Amidon Associates are shown in Table 4-7. The "R" indicates "rod" while the number associated with the "R" (e.g., R61) indicates the type of ferrite material used in the rod. The following numbers (e.g., 025) denote the diameter (025 = 0.25″, 033 = 0.33″, and 050 = 0.50″); the length of the rod is given by the last three digits (200 = 2″, 400 = 4″, and 750 = 7.5″. The Type 61 material is used from 0.2 to 10 MHz, and the Type 33 material is used in VLF applications.

In some cases, the $A_L$ rating of the rod will be known, and in others, only the permeability ($\mu$) is known. If either is known, you can calculate the inductance produced by any given number of turns.

For the case where the $A_L$ is known:

$$L_{\mu H} = N_p^2 A_L \times 10^{-4} \tag{4-10}$$

For the case where $\mu$ is known:

$$L_{\mu H} = (4 \times 10^{-9})\pi N_p^2 \mu \left(\frac{A_e(\text{cm}^2)}{l_e(\text{cm})}\right), \tag{4-11}$$

where

$N_p$ is the number of turns of wire
$\mu$ is the core permeability
$A_e$ is the cross-sectional area of the core (cm$^2$)
$l_e$ is the length of the rod's flux path (cm)

**Example**

Find the number of turns required on an R61-050-750 ferrite rod to make a 220-$\mu$H inductor for use in the AM receiver with a 10- to 365-pF variable capacitor.

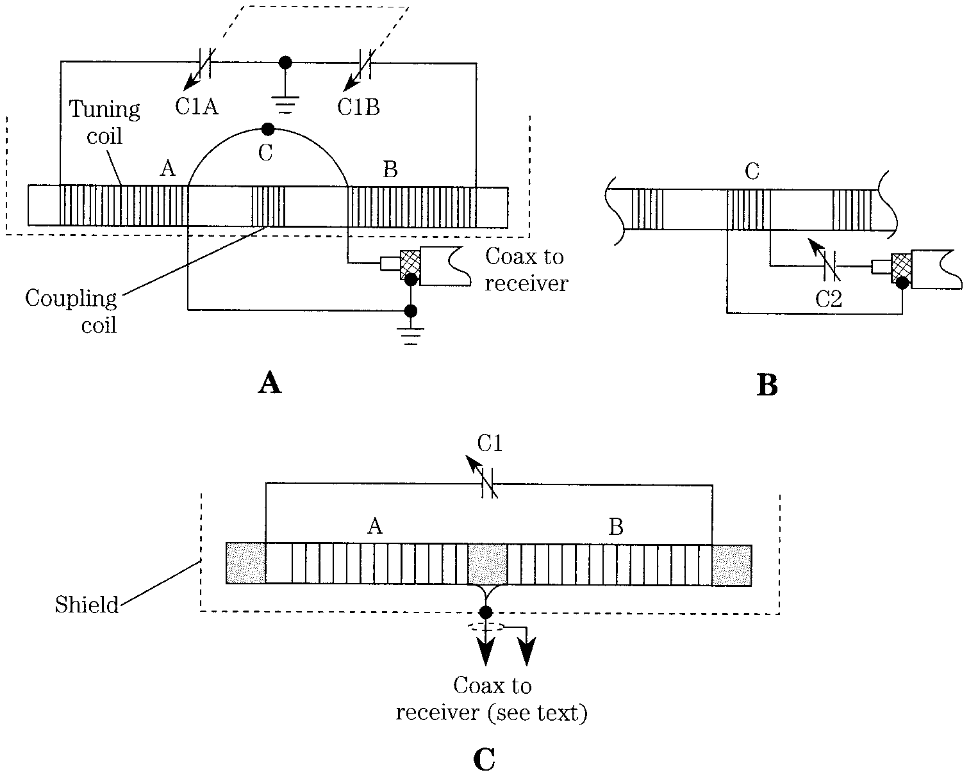
**Solution**

Solving Eq. (4-11) for $N$:

$$N = \sqrt{\frac{L_{\mu H}}{A_L \times 10^{-4}}}$$

$$N = \sqrt{\frac{220\,\mu\text{H}}{(43)(10^{-4})}} = 226.$$

Figure 4-13 shows several popular ways for ferrite rod inductors to be wound for service as loopstick antennas in radio receivers. Figure 4-13A shows a transformer circuit in which the main tuned winding is broken into two halves, A and B. These windings are at the end regions of the rod but are connected together in series at the center. The main coils are resonated by a dual capacitor, $C_{1A}$ and $C_{1B}$. A coupling winding, of fewer turns, is placed at the center of the rod and is connected to the coaxial cable going to the receiver. In some cases, the small coil is also tuned but usually with a series capacitor (see Fig. 4-13B). Capacitor $C_2$ is usually a much larger value than $C_1$ because the coupling winding has so many fewer turns than the main tuning windings. The antenna in Fig. 4-13C is a little different. The two halves of the



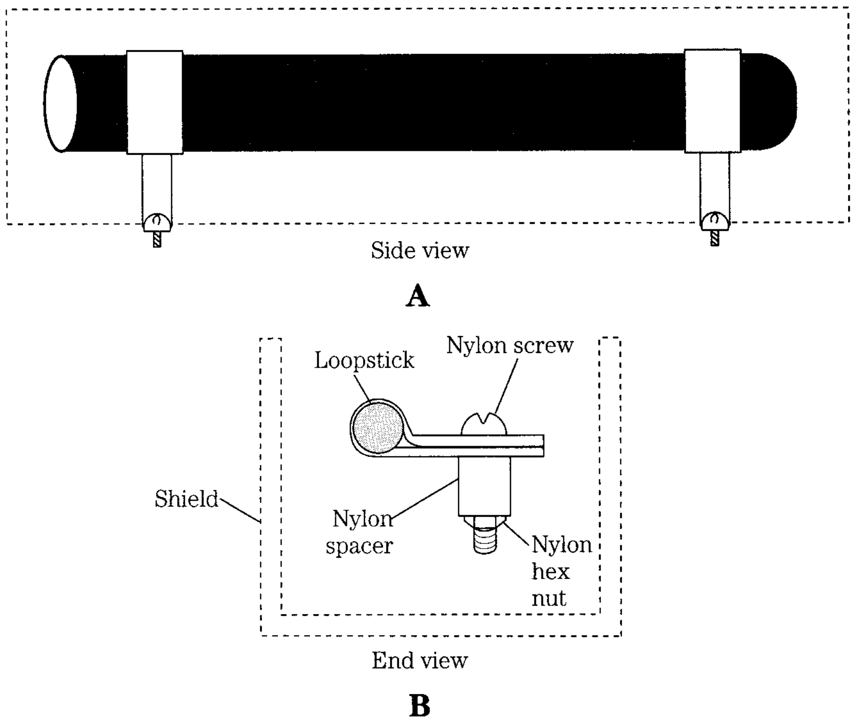

**4-13** Loopstick antenna: (A) overall circuit for doubled-tuned winding; (B) tuning the coupling loop; and (C) singled tuned variety.

tuning winding are connected together at the center and connected directly to the center conductor of the coaxial cable or to a single downlead. A single capacitor is used to resonate the entire winding (both halves).

# Project 4-1

A radio direction-finding antenna can be used for a number of purposes, only one of which is finding the direction from which a radio signal arrives. Another use is in suppressing cochannel and adjacent-channel interference. This becomes possible when the desired station is in a direction close to right angles from the line between the receiver and the desired transmitter. Reduction of the signal strength of the interfering signal is possible because the loopstick antenna has nulls off both ends.

Figure 4-14 shows a loopstick antenna mounted in a shielded compartment for radio direction finding. The shield is used to prevent electrical field coupling from nearby sources, such as power lines and other stations, yet doesn't affect the reception of the magnetic field of radio stations. The aluminum can be one-half of an electronic hobbyist's utility box, of appropriate dimensions, or can be built custom from




**4-14** Mounting the loopstick antenna in a shielded enclosure.

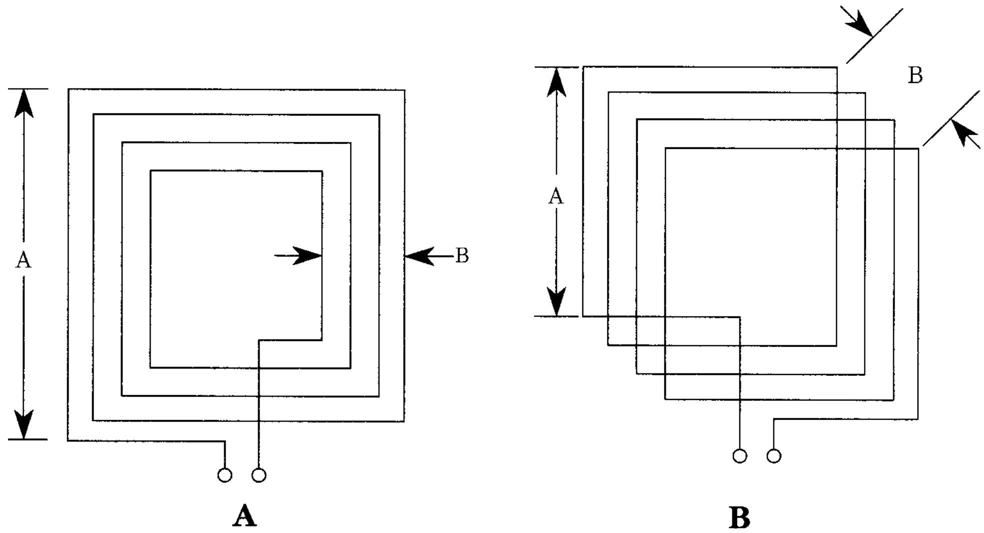
Harry & Harriet Homeowner Do-It-Yourself hardware stores. The loopstick antenna is mounted by nonmetallic cable ties to nylon spacers that are, in turn, fastened to the aluminum surface with nylon hardware.

The number of turns required for the winding can be found experimentally, but starting with the number called for by the preceding formula. The actual number of turns depends in part on the frequency of the band being received and the value of the capacitors used to resonate the loopstick antenna.

## Noncylindrical air-core inductors

Most inductors used in radio and other RF circuits are either toroidal or solenoid-wound cylindrical. There is, however, a class of inductors that are neither solenoidal nor toroidal. Many loop antennas are actually inductors fashioned into either triangle, square, hexagon, or octagon shapes. Of these, the most common is the square-wound loop coil (Fig. 4-15). The two basic forms are: flat wound (Fig. 4-15A) and depth wound (Fig. 4-15B). The equation for the inductance of these shaped coils is a bit difficult to calculate, but the equation provided by F. W. Grover of the U.S. National Bureau of Standards in 1946 is workable:

$$L_{\mu H} = K_1 N^2 A\left(Ln\left(\frac{K_2 AN}{(N+1)B}\right) + K_3 + \left(\frac{K_4(N+1)B}{AN}\right)\right), \qquad (4\text{-}12)$$




**4-15** Inductive-loop direction-finding antenna.

where

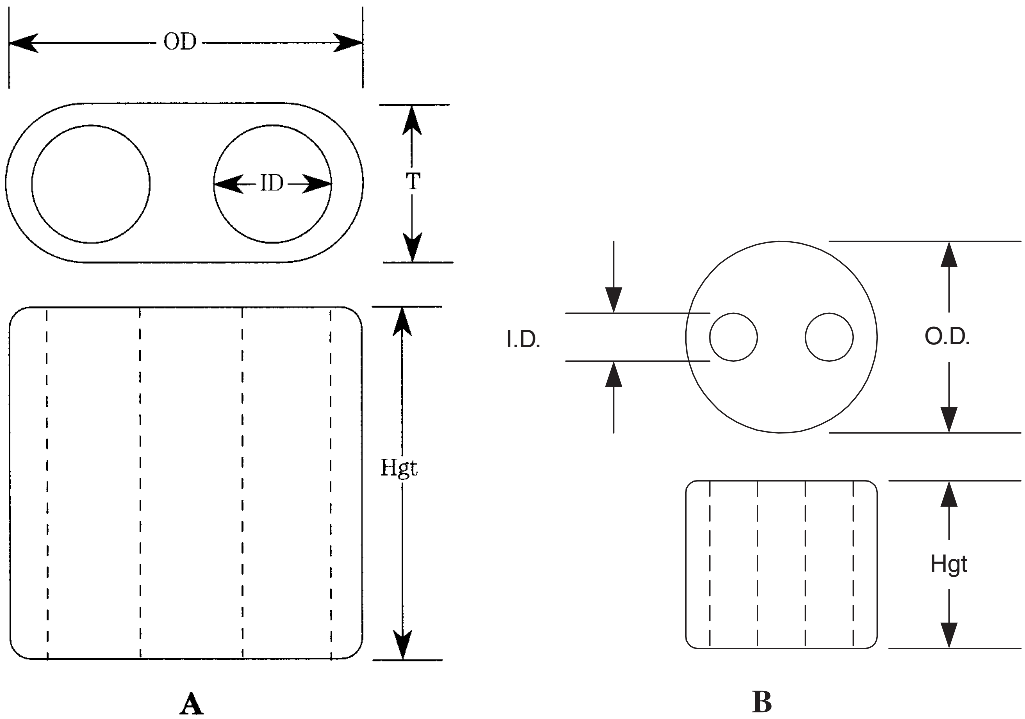
$A$ is the length of each side in centimeters (cm)
$B$ is the width of the coil in centimeters (cm)
$N$ is the number of turns in the coil (close wound)
$K_1$, $K_2$, $K_3$, and $K_4$ are 0.008, 1.4142, 0.37942, and 0.3333 respectively.

Whenever conductors are placed side by side, as in the case of the loop-wound coil, there is a capacitance between the conductors (even if formed by a single loop of wire, as in a coil). This capacitance can be significant when dealing with radio circuits. The estimate of distributed loop capacitance (in picofarads) for square loops is given by Bramslev as about $60A$, where $A$ is expressed in meters (m). The distributed capacitance must be accounted for in making calculations of resonance. Subtract the distributed capacitance from the total capacitance required in order to find the value of the capacitor required to resonate the loop-wound coil.

## Binocular- ("balun" or "bazooka") core inductors

The toroidal core has a certain charm because it is easy to use, is predictable, and is inherently self-shielding because of its geometry. But there is another core shape that offers very high inductance values in a small volume. The binocular core (Fig. 4-16) offers very high $A_L$ values in small packages, so you can create very high inductance values without them being excessively large. A binocular core that uses type 43 ferrite, and is about the same weight and size as the T-50-43 ($A_L = 523$), has an $A_L$ value of 2890. Only 8.8 turns are required to achieve 225 μH on this core.

There are actually two different types of binocular core in Fig. 4-16. The Type 1 binocular core is shown in Fig. 4-16A. It is larger than the Type 2 (Fig. 4-16B) and has larger holes. It can, therefore, be used for larger-value inductors and transformers. The Type 2 core can be considered as a two-hole ferrite bead.




**4-16** Bazooka balun cores: (A) Type 1 and (B) Type 2.

Table 4-8 shows several popular-sized binocular cores and their associated $A_L$ values. The center two digits of each part number is the type of ferrite material used to make the core (e.g., BN-xx-202), and the last digits refer to the size and style of the core.

Three different ferrite materials are commonly used in binocular cores. The type 43 material is a nickel-zinc ferrite and has a permeability of 850. It is used for wide-band transformers up to 50 MHz and has high attenuation, from 30 to 400 MHz. It can be used in tuned RF circuits from 10 to 1000 kHz. The type 61 material is also nickel-

**Table 4-8. Binocular cores**

| Part no. | Material | $A_L$ value | Size | Style |
|---|---|---|---|---|
| BN-43-202 | 43 | 2890 | A | 1 |
| BN-43-2302 | 43 | 680 | B | 1 |
| BN-43-2402 | 43 | 1277 | C | 1 |
| BN-43-3312 | 43 | 5400 | D | 1 |
| BN-43-7051 | 43 | 6000 | E | 1 |
| BN-61-202 | 61 | 425 | A | 1 |
| BN-61-2302 | 61 | 100 | B | 1 |

zinc and has a permeability of 125. It offers moderate to good thermal stability and a high $Q$ over the range 200 kHz to 15 MHz. It can be used for wideband transformers up to 200 MHz. The type 73 material has a permeability of 2500 and offers high attenuation from 500 kHz to 50 MHz.

The binocular core can be used for a variety of different RF inductor devices. Besides the single, fixed inductor, it is also possible to wind conventional transformers and balun transformers of various types on the core.

Figure 4-17 shows Type 1 binocular cores wound in various ways. The normal manner of winding the turns of the inductor is shown in Fig. 4-17A; the wire is passed from hole to hole around the central wall between the holes. The published $A_L$ values for each core are based on this style of winding, and it is the most commonly used.

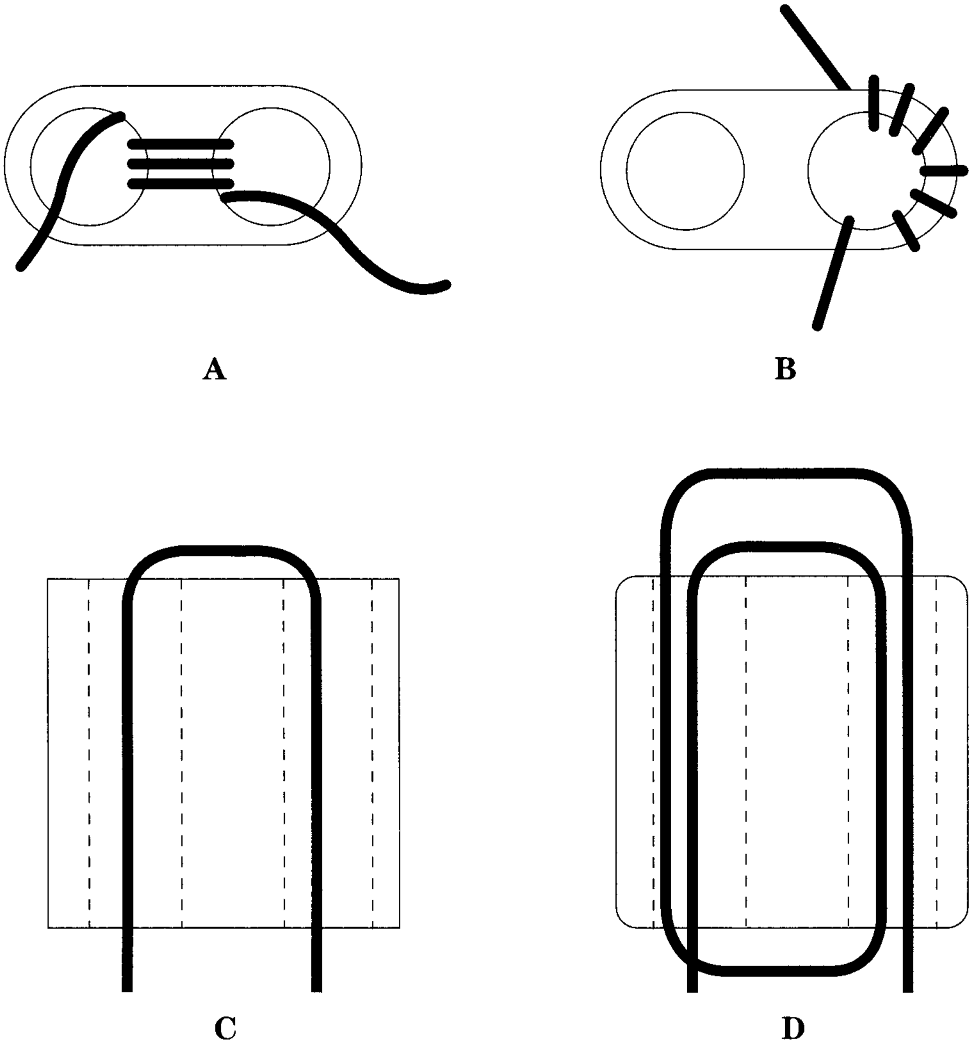
An edge-wound coil is shown in Fig. 4-17B. In this coil, the turns are wound around the outside of the binocular core. To check the difference, I wound a pair of BN-43-202 cores with 10 turns of no. 26 wire; one in the center (Fig. 4-17A) and one around the edge (Fig. 4-17B). The center-wound version produced 326 μH of inductance, and the edge-wound version produced 276 μH with the same number of turns.

Counting the turns on a binocular core is a little different than you might expect. A single U-shaped loop that enters and exits the core on the same side (Fig. 4-17C) counts as one turn. When the wire is looped back through a second time (Fig. 4-17D), there are two turns.

### Winding the binocular core

Some people think that it is easier to use these cores than toroids, and after spending a rainy weekend winding LF and AM BCB coils (after pumping groundwater out of the basement workshop!), I am inclined to agree partially. The "partially" means that they are easier to work than toroids if you do it correctly. It took me some experimenting to figure out a better way than holding the core in one hand and the existing wires already on the core in another hand and then winding the remaining coils with a third hand. Not being a Martian, I don't have three hands, and my "Third Hand" bench tool didn't seem to offer much help. Its alligator clip jaws were too coarse for the no. 36 enameled wire that I was using for the windings. So, enter a little "mother of invention" ingenuity (it's amazing how breaking a few wires can focus one's attention on the problem). In fact, I came up with two related methods between gurgles of my portable sump pump.

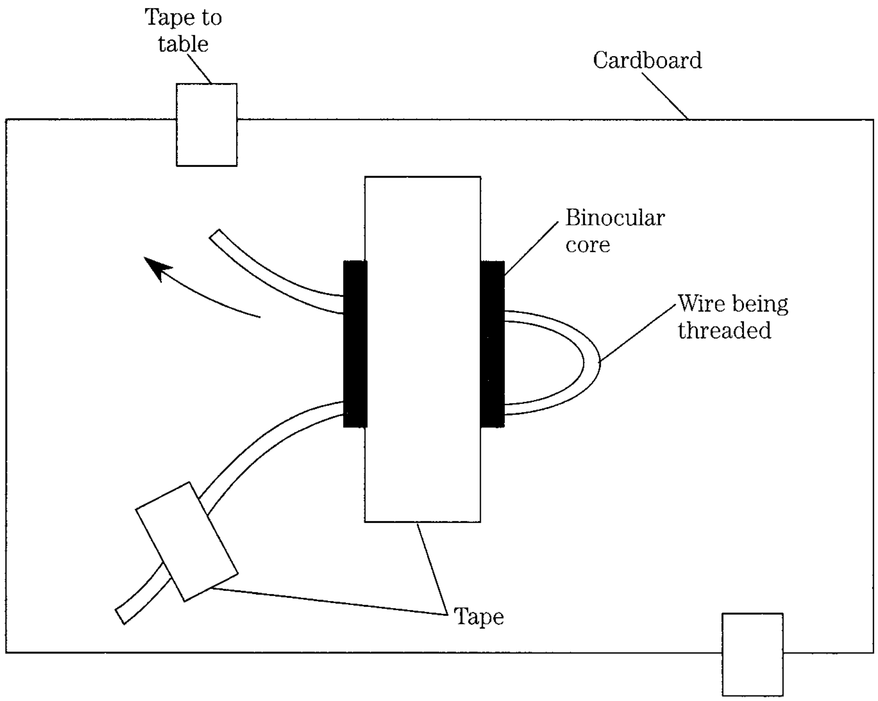
The first method is shown in Fig. 4-18. The binocular core is temporarily affixed to a stiff piece of cardboard stock such as a 5 × 7″ card or a piece cut from the stiffener used in men's shirts at the laundry. The cardboard is taped to the work surface, and the core is taped to the cardboard. One end of the wire that will be used for the winding is taped to the cardboard with enough leader to permit working the end of the coil once it is finished (2 to 3"). Pass the wire through the holes enough times to make the coil needed and then anchor the free end to the cardboard with tape. If the device has more than one winding, make each one in this manner, keeping the ends taped down as you go. Once all of the windings are in place, seal the assembly




**4-17** Winding style for Bazooka balun cores: (A) through the center; (B) around the edge (less-predictable inductance); (C) single turn winding (note: no doubling back); and (D) two-turn winding.

with Q-Dope or some other sealant (RTV silicone, rubber cement, etc.). Q-Dope is intended for inductors and can be purchased from G-C dealers or by mail from Ocean State Electronics [P.O. Box 1458, 6 Industrial Drive, Westerly, RI, 02891; phone 1-800-866-6626 (orders only), 401-596-3080 (voice) or 401-596-3590 (fax)].

The second method involves making a header for the binocular core. This header can be permanent and can be installed into the circuit just like any other coil with a header. When built correctly, the header will be spaced on 0.100" centers, so it is compatible with DIP printed circuit boards and perforated wiring board. I used




**4-18** Winding "jig" for Bazooka balun core.

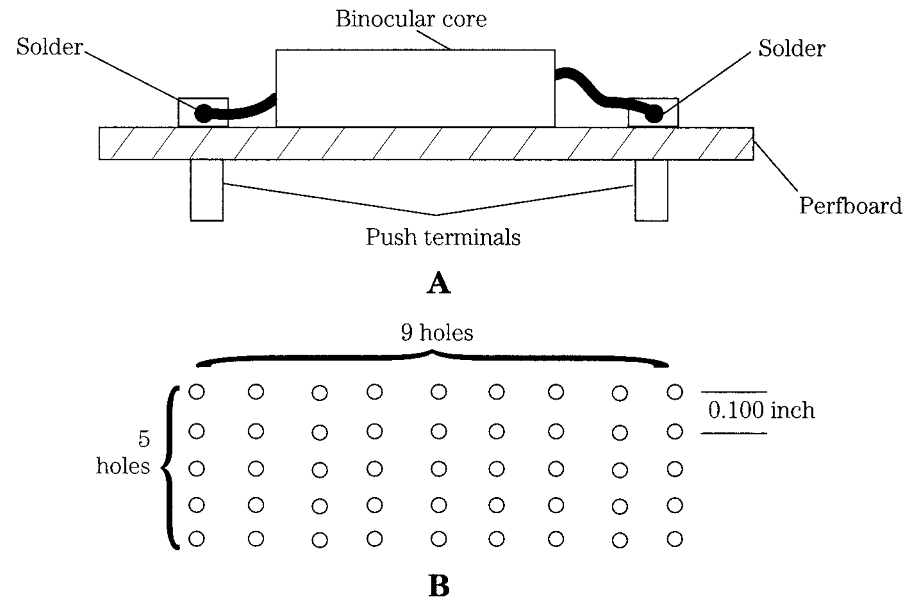
perforated wiring board of the sort that has printed circuit pads (none of which connected to each other) at each hole.

Figure 4-19A shows the basic configuration for my homebrew header (a DIP header can also be used). These connectors are intended to connect wiring or other components to a DIP printed circuit board designed for digital integrated circuits. I found that a small segment of printed perfboard, 0.100″ centers on the holes, that contained five rows by nine columns of holes (see inset to Fig. 4-19B) was sufficient for the 0.525 × 0.550″ BN-xx-202. Larger or smaller hole matrices can be cut for larger or smaller binocular cores.

The connections to the header are perfboard push terminals (available any place that perfboard and printed-circuit making supplies are sold). I used the type of perfboard that had solder terminals so that the push terminals can be held to the board with solder. Otherwise, they have a distinct tendency to back out of the board with handling.

When the header is finished, the binocular core is fastened to the top surface of the header with tape, then the pins of the header are pushed into a large piece of perfboard. This step is done to stabilize the assembly on the work surface. It might be a good idea to stabilize the perfboard to the table with tape to keep it from moving as you wind the coils.

Once the header and core are prepared, then it is time to make the windings. Scrape the insulation off one end of the wire for about 1/4″. An X-acto knife, scalpel,



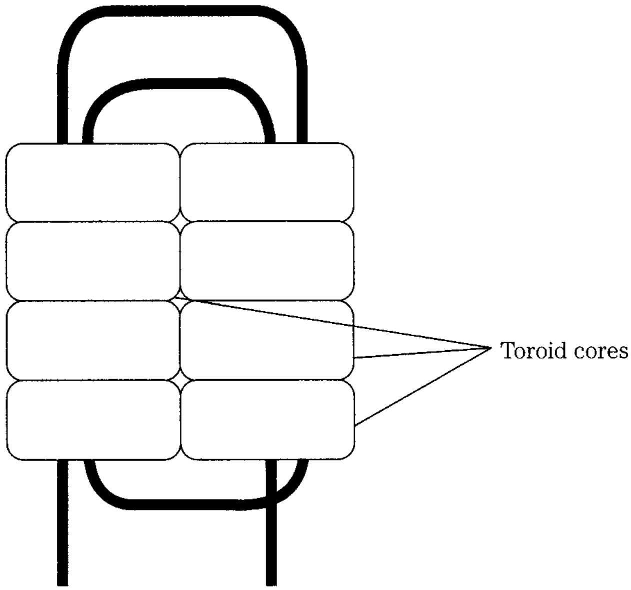

**4-19** Construction of a perfboard carrier or header for Bazooka balun cores.

or similar tool can be used to do this job. Turn the wire over several times to make sure that the enamel insulation is scraped around the entire circumference. Some people prefer to burn the insulation off with a soldering iron, which tins the end of the wire as it burns the insulation away. I've found that method to be successful when the smaller gauges are used, but when good-quality no. 26 or larger wire is used, the scraping method seems to work better. If the scraping method is used, then follow the scraping by tinning the exposed end of the wire with solder. Each winding of the transformer can be made by threading the wire through the core as needed. As each winding is finished, the loose end is cleaned, tinned, and soldered to its push terminal. After all windings are completed, then seal the assembly with Q-Dope or equivalent.

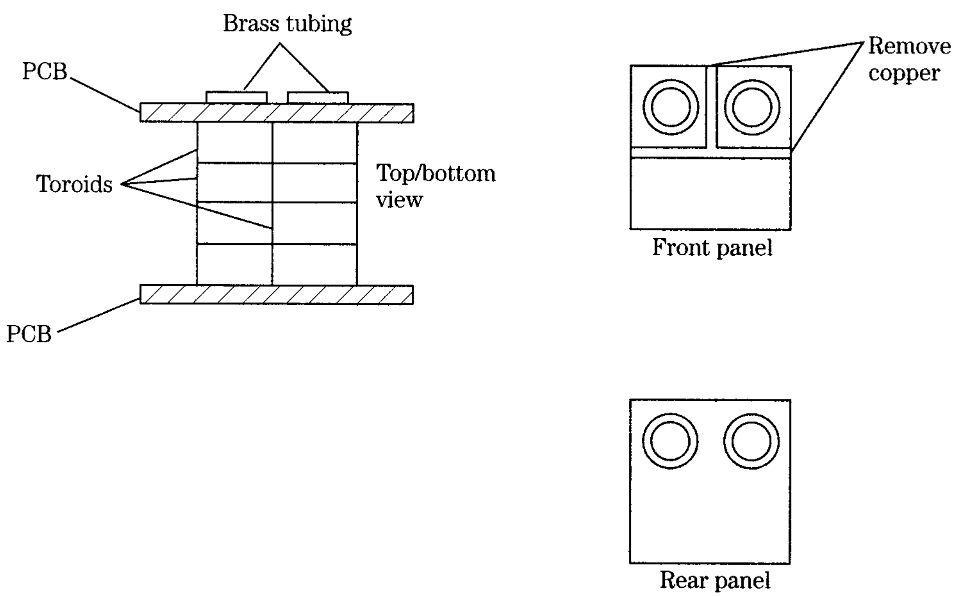
### Homebrew binocular cores

You can build custom "binocular cores" from toroidal cores. The toroids are easily obtained from many sources and in many different mixtures of both powdered iron and ferrite. You can also make larger binocular cores using toroids because of the wide range of toroid sizes. Actual binocular cores are available in a limited range of mixtures and sizes. Figure 4-20 shows the common way to make your own binocular core: Stack a number of toroid cores in the manner shown. It is common practice to wrap each stack in tape, then place the two stacks together and wrap the assembly together. Although four toroids are shown on each side, any number can be used.

A variation on the theme is shown in Fig. 4-21. This binocular core is designed to have a single-turn winding consisting of a pair of brass tubes passed through the




**4-20**
Stacking toroid cores to make a higher-power Bazooka balun.




**4-21** Construction of the high-power Bazooka balun core with stacked toroid cores and copper (PCB material) end plates.

center holes of the toroid stacks. The ends of the stacks are held together with a pair of copper-clad PC boards. The read panel has no copper removed, and the front panel is etched to isolate the two brass tubes. The pads around the brass tubes at the front end are used to make connections to the tubing (which serves as a single-turn winding). The other winding of the transformer is made of ordinary insulated wire, which is passed through the brass tubes the correct number of turns to achieve the desired turns ratio. This type of binocular core was once popular with ham operators who built their own solid-state RF power amplifiers. The higher-power transformers needed to match the impedances of the base and collector terminals of the RF transistors were not easily available on the market, so they had to "roll their own."

The binocular core is not as well-known as the toroid core, but for many applications, it is the core of choice. This is especially true when low frequencies are used or when large inductances are needed in a small package . . . and you don't want to work your arm off hand-winding the large number of turns that would be required on a solenoid-wound or toroidal core.

# References

F. W. Grover, *Inductance Calculation: Working Formulas and Tables,* D. VanNostrand Co., Inc. (New York, 1946).

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