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Ferrite-Core Loop Antennas

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The ferrite-core loop antenna is a special case of the air-core receiving loops considered up to now. Because of its use in every AM broadcast-band portable radio, the ferrite-core loop is, by quantity, the most popular form of the loop antenna. Broadcast-band reception is far from its only use; it is commonly found in radio-direction-finding equipment and low-frequency-receiving systems (below 500 kHz) for time and frequency standard systems. In recent years, design information on these types of antennas has been a bit sparse in the amateur literature, so the next few paragraphs are devoted to providing some details.

Ferrite-loop antennas are characteristically very small compared to the frequency of use. For example, a 3.5-MHz version may be in the range of 15 to 30 cm long and about 1.25 cm in diameter. Earlier in this chapter, effective height was introduced as a measure of loop sensitivity. The effective height of an air-core loop antenna is given by

$$h = \frac{2 \pi N A}{\lambda}$$

where

h = effective height (length) in meters
N = number of turns in the loop
A = area of loop in square meters
λ = wavelength of operation in meters

If an air-core loop is placed in a field, in essence it cuts the lines of flux without disturbing them (**Figure 1A**). On the other hand, when a ferrite (magnetic) core is placed in the field, the nearby field lines are redirected into the loop (Figure 1B). This is because the reluctance of the ferrite material is less than that of the surrounding air, so the nearby flux lines tend to flow through the loop rather than through the air. (*Reluctance* is the magnetic analogy of resistance, while *flux* is analogous to current.) The reluctance is inversely proportional to the permeability of the rod core, μ_{rod}. (In some texts the rod permeability is referred to as effective permeability, μ_{eff}).

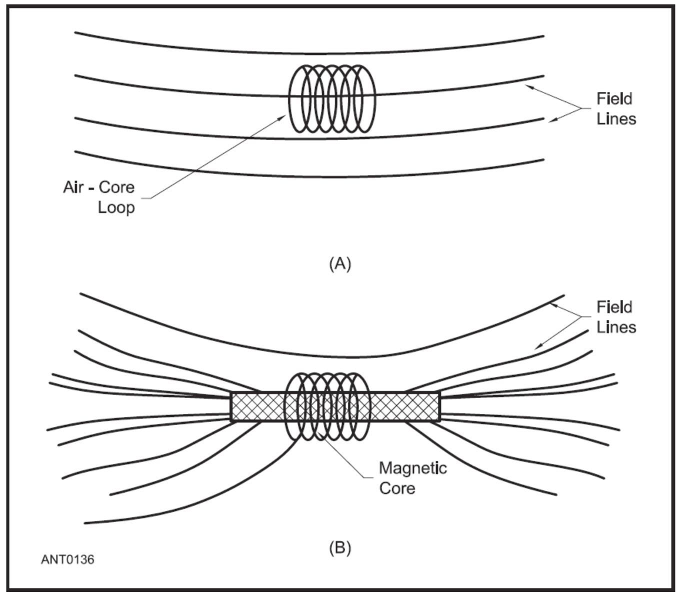

Figure 1 – At A, an air-core loop has no effect on nearby field lines. B illustrates the effect of a ferrite core on nearby field lines. The field is altered by the reluctance of the ferrite material.

This effect modifies the equation for effective height of a ferrite-core loop to

$$h = \frac{2 \pi N A \mu_{rod}}{\lambda} \qquad \text{(Eq 1)}$$

where

h = effective height (length) in meters
N = number of turns in the loop
A = area of loop in square meters
μ_{rod} = permeability of the ferrite rod
λ = wavelength of operation in meters

This obviously is a large increase in "collected" signal. If the rod permeability were 90, this would be the same as making the loop area 90 times larger with the same number of turns. For example, a 1.25-cm diameter ferrite-core loop would have an effective height equal to an air-core loop 22.5 cm in diameter (with the same number of turns).

By now you might have noticed we have been very careful to refer to rod permeability. There is a very important reason for this. The permeability that a rod of ferrite exhibits is a combination of the material permeability or μ, the shape of the rod, and the dimensions of the rod. In ferrite rods, μ is sometimes referred to as initial permeability, μ_i, or toroidal permeability, μ_{tor}. Because most amateur ferrite loops are in the form of rods, we will discuss only this shape.

The reason that μ_{rod} is different from μ is a very complex physics problem that is well beyond the scope of this book. For those interested in the details, books by Polydoroff and by Snelling cover this subject in considerable detail. (See Bibliography.) For our purposes a simple explanation will suffice. The rod is in fact not a perfect director of flux, as is illustrated in **Figure 2**. Note that some lines impinge on the sides of the core and also exit from the sides. These lines therefore would not pass through all the turns of the coil if it were wound from one end of the core to the other. These flux lines are referred to as *leakage flux*, or sometimes as flux leakage.

Leakage flux causes the flux density in the core to be non-uniform along its length. From Figure 2 it can be seen that the flux has a maximum at the geometric center of the length of the core, and decreases as the ends of the core are approached. This causes some noticeable effects. As a short coil is placed at different locations along a long core, its inductance will change. The maximum inductance exists when the coil is centered on the rod. The Q of a short coil on a long rod is greatest at the center. On the other hand, if you require a higher Q than this, it is recommended that you spread the coil turns along the whole length of the core, even though this will result in a lower value of inductance. (The inductance can be increased to the original value by adding turns.) **Figure 3** gives the relationship of rod permeability to material permeability for a variety of values.

The change in μ over the length of the rod results in an adjustment in the term μ_{rod} for its so called "free ends" (those not covered by the winding). This adjustment factor is given by

$$\mu' = \mu_{rod}\sqrt{a/b} \qquad \text{(Eq 2)}$$

where

μ' = the corrected permeability
a = the length of the core
b = the length of the coil

This value of μ' should be used in place of μ_{rod} in Eq 1 to obtain the most accurate value of effective height.

All these variables make the calculation of ferrite loop antenna inductance somewhat less accurate than for the air-core version.

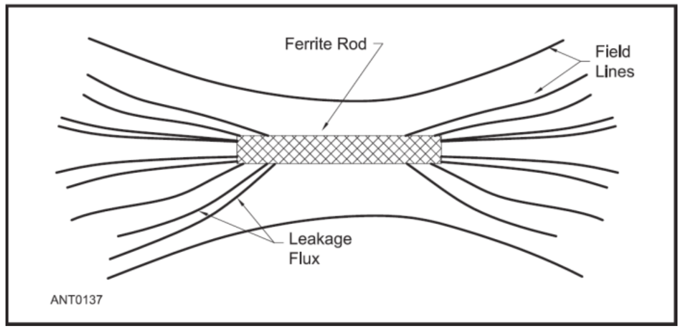

Figure 2 – Example of magnetic field lines near a practical ferrite rod, showing leakage flux.

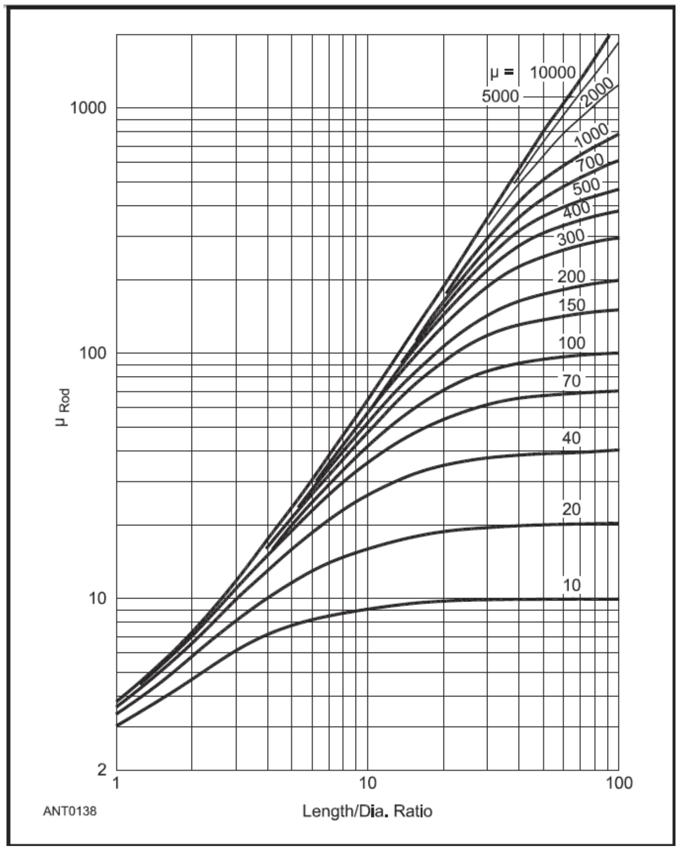

Figure 3 – Rod permeability, μ_{rod}, versus material permeability, μ, for different rod length-to-diameter ratios.

The inductance of a ferrite loop is given by

$$L = \frac{4\,\pi\,N^2 A\,\mu_{rod} \times 10^{-4}}{\ell} \qquad \text{(Eq 3)}$$

where

L = inductance in μH
N = number of turns
A = cross-sectional area of the core in square mm
μ_{rod} = permeability of the ferrite rod
ℓ = magnetic length of core in mm

Experiments indicate that the winding diameter should be as close to that of the rod diameter as practical in order to maximize both inductance value and Q. By using all this information, we may determine the voltage at the loop terminals and its signal-to-noise ratio (SNR). The voltage may be determined from

$$V = \frac{2\pi A N \mu' Q E}{\lambda} \qquad \text{(Eq 4)}$$

where

V = output voltage across the loop terminals
A = loop area in square meters
N = number of turns in the loop winding
μ' = corrected rod permeability
Q = loaded Q of the loop
E = RF field strength in volts per meter
λ = wavelength of operation in meters

Lankford's equation for the sensitivity of the loop for a 10 dB SNR is

$$E = \frac{1.09\times10^{-10}\,\lambda\sqrt{f\,L\,b}}{A\,N\,\mu'\sqrt{Q}} \qquad \text{(Eq 5)}$$

where

f = operating frequency in Hz
L = loop inductance in henrys
b = receiver bandwidth in Hz

Similarly, Belrose gives the SNR of a tuned loop antenna as

$$SNR = \frac{66.3\,N\,A\,\mu_{rod}\,E}{\sqrt{b}}\sqrt{\frac{Qf}{L}} \qquad \text{(Eq 6)}$$

From this, if the field strength E, μ_{rod}, b, and A are fixed, then Q or N must increase (or L decrease) to yield a better SNR. Higher sensitivity can also be obtained (especially at frequencies below 2000 kHz) by bunching ferrite cores together to increase the loop area over that which would be possible with a single rod. Bowers and Bryant have built both 4 and 8-foot long ferrite loops for broadcast band DXing by using multiple ferrites cores bunched together and stacked lengthwise. Their 8-foot loop used over 100 pounds of ferrite cores. Marris, G2BZQ, also adopted the multiple core approach on 160 and 80 meters, constructing a 18 inch long multiple core ferrite loop using twelve ferrite rods each 6 inches long and 1/2 inch in diameter. He reported that there was no need for a preamp even when used for transatlantic reception. Marris noted that it is important to prepare the ends of the rods or cores before bonding them together. From a magnetic design point of view this is important to reduce the physical length of the air gaps between the individual lengthwise rods. This will maintain the best magnetic path (and maintain apparent permeability) for the antenna rods.

High sensitivity is important because loop antennas are not the most efficient collectors of signals, but they do offer improvement over other receiving antennas in terms of SNR. For this reason, you should attempt to maximize the SNR when using a small loop receiving antenna. In some cases there may be physical constraints that limit how large you can make a ferrite-core loop.

After working through Eq 5 or 6, in many cases you might find you still require some increase in antenna system gain to effectively use your loop. In these cases the addition of a low noise, high dynamic range preamplifier may be quite valuable even on the lower frequency bands where they are not commonly used.

The electrostatic shield discussed earlier with reference to air-core loops can be used effectively with ferrite-core loops. The question of how big this shield should be is hard to answer without some experimentation. A good starting point is found in Langford-Smith's book in which he recommends the shield diameter be at least twice the outside diameter of the coil. As in the air-core loop, a shield will reduce electrical noise and improve loop balance.

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