Crystal Radio Engineering
Loop Antennas

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Introduction

An alternative to constructing a long wire antenna and ground system is to build the resonator as a large loop that picks up enough energy to power the radio. This approach is only useful in strong signal areas as the energy picked up by a loop is small in comparison to that of a long wire antenna.

A loop antenna responds to the magnetic field of the radio signal whereas a long wire antenna responds to the electric field. Unlike wire antennas that are less than a quarter wavelength and thus have little directional characteristics, loop antennas are very directional and the plane of the loop must be oriented towards the broadcast antenna to receive a signal.

Loop antennas can either be large air loops (with typical dimensions between 0.5 and 1 meter square) or small loops wound on a ferrite rod. Small ferrite rod antennas are very inefficient but are the only practical method to construct a small antenna for common purchased AM broadcast band radios. Large air loops can work as antennas for crystal radios but only in a strong signal area. A crystal radio can be built using a ferrite rod antenna but is only useful in a very strong signal area. This chapter will discuss both types but with an emphasis on the large air loop.

Electrical height

The signal voltage developed across a loop antenna is the strength of the radio wave in volts/meter multiplied by the electrical height in meters of the loop. The electrical height is not a physical dimension (although it is proportional to the loop area) but a characteristic.

Reference 1 provides the equation to calculate the electrical height of a loop antenna.

$$h_e = \frac{2 * \pi * N * A * \mu_e}{\lambda} \qquad \text{Eq. 1}$$

where

- h_e is the electrical height in meters
- N is the number of turns
- A is the area of one turn in square meters
- μ_e is the relative permeability of the core (air = 1, ferrite is several 10s)
- λ is the wavelength in meters

As an example, a practical air loop might be 18 turns of wire wound on a square with sides of 0.43 meters. The electrical height of this loop at a frequency of 1 MHz (300 meters) is

$$h_e = 6.28 * 18 * 0.43^2 * 1 / 300 = 0.070 \text{ meters}$$

Thus, a strong 100 mV/meter radio signal will develop 7 mV across the loop. This calculation assumes the loop is not resonant. If the loop is resonant at 1 MHz then the 7 mV signal is multiplied by the net Q of resonance as loaded by the diode detector. That Q can typically be 20 or more for an effective height of 1.4 meters so the net signal developed could be in the range of 140 mV which will readily heard in headphones.

A ferrite loop might consist of 100 turns of wire around a 9 mm diameter rod with an initial permeability of 125 (Initial permeability is a term used by the manufactures). The real or effective permeability will always be less and is a complicated function of rod geometry. The process for calculating that is beyond the scope of this chapter but a representative value is 50. The electrical height of this loop at 1 MHz is

$$h_e = 6.28 * 100 * (3.14 * 0.009^2 / 4) * 50 / 300 = 0.0067 \text{ meters}$$

With a resonant Q of 20 the effective value becomes 0.133 meters and the total received signal is 13.3 mV – over a factor of ten less than the large air loop. The conclusion here is to not waste time and effort with ferrite rod antennas unless you are in a very strong (i.e. 1000 mV/meter) signal area.

A square loop in the 40 to 50 cm range on a side is about the maximum practical for transporting. If transportation is not an issue then one can consider loops over a meter on a side for higher received strength. A larger loop requires fewer turns of wire to achieve a given inductance and is more efficient.

Inductance

Reference 2 provides an accurate equation for the inductance of an air-core square loop as follows.

$$L = 0.008*N^2*a*\{\ln[1.414*a*N /((N+1)* b)] + 0.379 + 0.33*(N+1)*b/(a*N)\} \qquad \text{Eq. 2}$$

where

L is the inductance in microhenries
N is the number of turns
a is the length of a side in cm
b is the winding width in cm

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The inductance of the loop in the previous example is 343 microhenries using a winding width (b) of 4 cm.

The length of wire required is $4 * a * N$ Eq. 3

Calculating the inductance of a ferrite rod antenna is a challenge. A rough estimate is provided below based on the author's notes. The constants shown below are selected to be representative of typical ferrite rods you might encounter – but significant variation is likely.

$L = k * \pi * \mu_{net} * A * N^2 / \text{length}$ Eq. 4

where

- L is the inductance in microhenries
- k is a constant (use 0.004)
- μ_{net} is derived (complicated) from rod initial permeability and geometry (use 50)
- A is the cross section area in cm^2 of the rod
- N is the number of turns
- length is the length of the rod in cm

The inductance of the ferrite rod antenna (length is 9.3 cm) in the previous example is

$L = 0.004 * 3.14 * 50 * (3.14 * 0.9^2 / 4) * 100^2 / 9.3 = 430$ microhenries

Construction of air loops

Air loops are typically constructed using two equal lengths (typically two to three feet) of 1x2 or 1x3 wood. The center of each length is notched out so that the two pieces can be glued together as a cross so that the wire can be evenly wound on the outside width of each piece. Some supporting structure (made of wood) connects this to a base for sitting the unit on a table – or sometimes it is just a handle to make it easier to hold. The wire (often 100 feet or more) is wound on the outside of the wooden cross. The tuning capacitor and radio circuit are often assembled either at the center of the cross or on the base. In operation, one must remember to orient the loop for maximum pickup – the plane of the loop should point to the station's antenna.

References

1. Ferromagnetic Core Design and Application Handbook, M. F. "Doug" DeMaw, Prentice-Hall, Inc. Englewood Cliffs, New Jersey 07632, 1981, p 49

2. Practical Antenna Handbook, second edition, Joseph J. Carr, TAB Books, 1994, p 301