6. Square Loop Antennas

<u>Chapter 6 Goals</u>

- Design and construct a square loop antenna
- Tune antenna for optimum reception

A variety of antenna architectures have been used for AM reception. We will employ a basic square loop antenna, as indicated in Figures 6.1 – 6.3. Square loop antennas are often constructed on a wooden frame (generally a square cross with one end supported by a board). Larger area loops provide a stronger received signal (more sensitive). The antenna has a primary coil defined by side length A, winding depth B and number of turns N, as indicated in Figure 6.1. The turns or loops are assumed evenly distributed over the winding depth, B. The received signal is sometimes transformer-coupled to a secondary loop (a "pick-up coil"), as shown in Figure 6.2.

For a given frequency, the gain of a loop antenna is less than a well-designed dipole antenna. But the output voltage can be increased by adding a capacitor (in our case, a *trimmer capacitor*[1]) to the primary windings, thus creating a resonant structure. Here, the loops provide the inductance. The antenna is first oriented so that the magnetic fields from the transmitting station passes normally through the loops. Then the antenna is tuned (i.e. the resonance frequency is adjusted) by adjusting the trimmer capacitor.

The primary AM Radio stations in the Auburn area are at 1230 kHz, 1400 kHz and 1520 kHz. Thus, we need to be able to tune the antenna over this range. This will be simpler than building an antenna to cover the entire AM band. Our trimmer capacitors have a range of 8.5 pF to 120 pF. This range can be shifted up by adding an appropriate fixed capacitance in parallel.

Tips:

1. *A knife and tape (duct or electrical) is handy for constructing the loop antennas.*
2. *Make sure you bare the ends of the magnet wire (scrape off the enamel).*
3. *"magnet wire" is copper wire that has an enamel coating; it is used to make multiple winding electromagnets.*

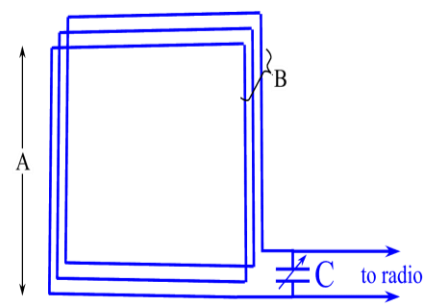

Figure 6.1: Primary portion of the square loop antenna

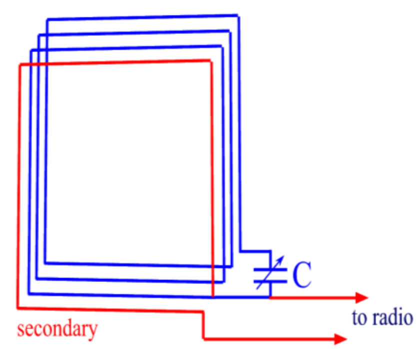

Figure 6.2: Square loop antenna after adding a pick-up coil

Figure 6.3: a square loop antenna from http://www.schmarder.com/radios/visitors/v3.htm)

[1] Larger adjustable air-core capacitors have a higher capacitance and tuning range. But they are quite a bit more expensive than trimmer caps. Hobbyists use them when they can be scrounged from old radios.

6.1 Square Loop Antenna

Square loop antenna inductance, in μH, is given by Joe Carr's formula[2], where A and B are in cm:

$$L(\mu H) = .008N^2 A \times \left[\ln\left(\frac{1.4142AN}{(N+1)B} \right) + .37942 + \left(\frac{.3333(N+1)B}{AN} \right) \right]$$

Equation (1)

When variable capacitor C is added to the inductive loop, the resonance frequency is

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (2)$$

The resonance frequency can be rearranged to find C for a given frequency:

$$C(pF) = \frac{1\times10^{18}}{4\pi^2 f^2 L(\mu H)} \qquad (3)$$

6.1a Preliminary Antenna Study

1. Compose a MATLAB routine to calculate L and C required for a given frequency and assumed square-loop parameters A, B and N. You may also wish to calculate total length of wire needed (don't forget the pick-up loop).

Exercise: As a check of your program, suppose A = 14 inches, B = 2 inches, and N = 10 turns. (a) Calculate L for this antenna. *(Hint: Joe Carr's formula requires A and B in centimeters. Note that 2.54 cm = 1 inch.)* (b) Calculate C required to achieve resonance at 1230 kHz.
(answers: L = 74.8 μH, C = 224 pF)

2. Use your MATLAB code to fill in the data of Table 6.1. This will give you an idea of how inductance varies with the loop area (A^2), and how inductance varies with number of loops, N.

3. Use the blank chart of Figure 6.4 to neatly plot the data of Table 6.1.

6.1b Practical Square Loop Antenna Design

1. Your design should consider the following:

- Frame dimensions: The loops may be strung around a square wooden cross such as the one shown in Figure 6.3. Notches or grooves may be cut into the cross ends to hold the wires in place. Alternatively, wires could be wrapped around a cardboard box (a pizza box might work well for this). If you choose the pizza box, it is a good idea to measure the box dimensions prior to lab, or bring a ruler to lab.
- trimmer capacitor range: 8 pF – 120 pF. Note that we can shift this up by adding a fixed capacitance in parallel.
- Best-received AM radio stations in the Auburn area: **1230 kHz**, 1400 kHz, 1520 kHz
- Use care when handling the thin wire as it will easily tangle and break. Cutting slots in the frame to hold and separate the wire, and securing the wire in place with tape (electrical or duct) makes this task easier.

Table 6.1: Calculated Square Loop Inductance (in μH), (B = 2 inches)

A(in)	$A^2(in^2)$	L(N=8)	L(N=12)	L(N=16)
6	36			
8	64			
10	100			
12	144			
14	196			

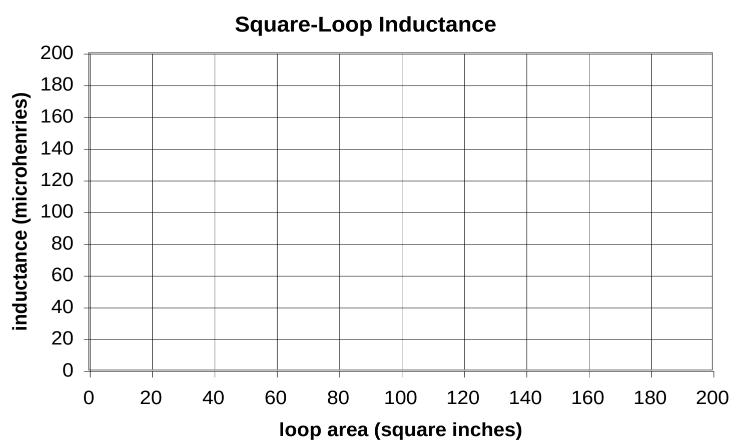

Figure 6.4: Blank chart for filling in inductance as a function of loop area for different numbers of loops from Table 6.1. B is fixed at 2 inches.

[2] Joe Carr's Radio Tech-Notes – Small Loop Antennas: http://www.dxing.com/tnotes/tnote08.pdf

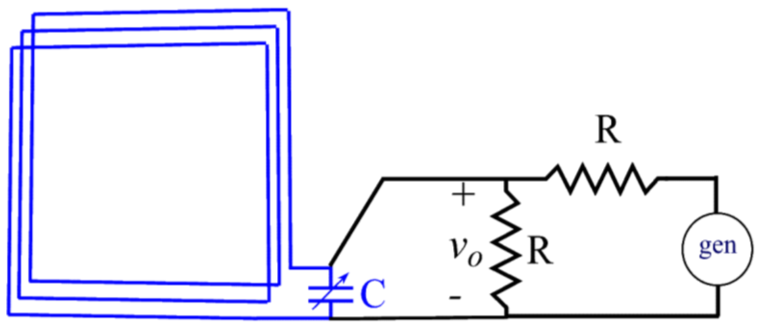

Figure 6.4: antenna testing setup

2. One approach to take in your design:

- Calculate what inductance is required for the middle station (1400 kHz), using a 60 pF capacitance (roughly the middle of your trimmer value).
- Vary the number of turns (assuming fixed frame dimensions) to try to achieve a value close to this inductance.
- With the inductance from the previous step, see what capacitance is required to pick up the lowest frequency station (1230 kHz). This will be the maximum capacitance you will need.
- Now see what the lowest capacitance needed will be to pick up the 1520 kHz station.

Can your trimmer capacitor handle the range required from parts c and d?

3. Referring to Figure 6.4, you can test the inductance of your antenna by replacing the trimmer capacitor with a known capacitor. Then hook up a signal generator with resistors as shown (1 kΩ resistor values should be fine) and measure the voltage across the tank circuit. At resonance, this voltage will be maximized and you can use Eqn. (2) to calculate L.

- You may need to rewrap your antenna with a different number of turns in order to get a suitable inductance.
- The generator output may change amplitude while changing frequency, especially above 1 MHz. Observing input and output signals on the scope at the same time allows you to adjust/maintain a constant input signal amplitude.

4. Once you've achieved a suitable inductance, reinstall the trimmer capacitance. Now set the generator to a good AM station frequency (for instance, 1230 kHz) and adjust the trimmer capacitor to achieve a maximum output (that is, adjust the trimmer capacitor to make the resonance frequency of your antenna equal to 1230 kHz).

5. *Alternate antenna adjustment approach*:
HP 8920A RF Communications Test Set

- Your GTA will prepare the test set for use. Do not adjust the test set. It will be set to display the received 1230 kHz radio station.
- Use a BNC-to-clip cable to attach the test set ("ANT IN" port) to your antenna.
- Adjust the angle/position of the antenna to maximize the spike at 1230 kHz.
- Now adjust your trimming capacitor to maximize the received signal (make the spike taller) at 1230 kHz.
- Note: a plastic screwdriver or guitar pick will work best to tune the trimmer capacitor. A fingernail can also be used. A metal screwdriver can detune the antenna, so make small adjustments and remove the screwdriver to see the effect of tuning.

6. Build your antenna and test it with your radio.