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.*

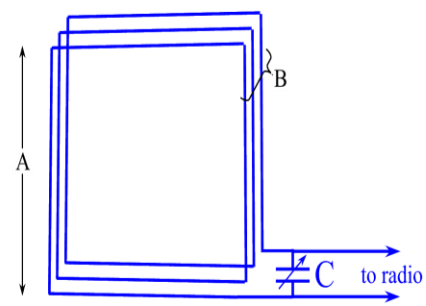

Figure 6.1: Primary portion of the square loop antenna

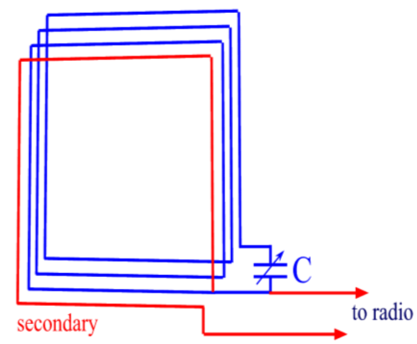

Figure 6.2: Square loop antenna after adding a pick-up coil

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:

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

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:

$$C(pF) = \frac{1\times 10^{18}}{4\pi^2 f^2 L(\mu H)} \qquad (3)$$

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

This lab you complete with your partner.

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

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			

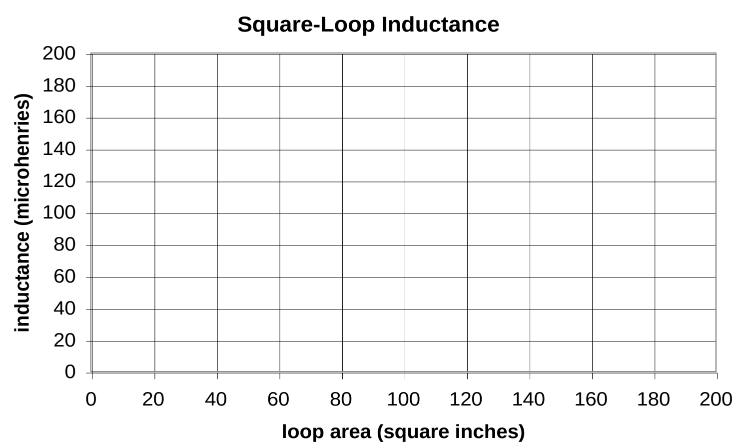

Figure 6.4: Blank chart for filling in inductance as a function of loop area for different numbers of loops from Table 6.1. B is fixed at 2 inches.

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

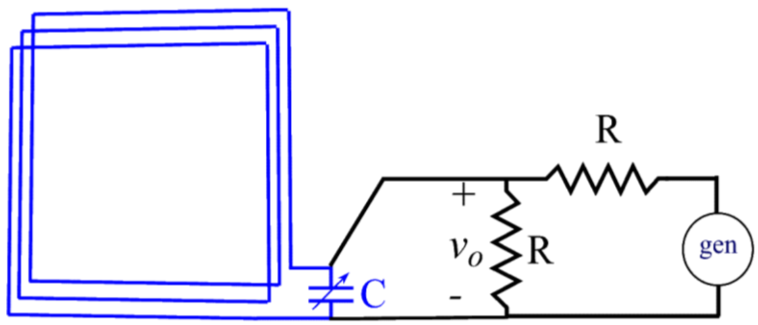

Figure 6.4: antenna testing setup

or duct) makes this task easier.

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. Second antenna adjustment technique:
Spectrum Analyzer Technique

- Press the *RF* button on the o-scope to start the spectrum analyzer
- Now it is time to configure the display. Press the *Freq/Span* button (see Fig. 1.8) and set the *Center Frequency* as the frequency of interest: 1.23 MHz, and set the *Span* to 50 kHz. Feel free to vary the center frequency and span.
- Select the *Ampl* button and set the *Ref Level* to -20 dBm. Verify that *Vertical Units* are set to dBm
- Select the *BW* button and set the *RBW* (resolution bandwidth) to 200 or 300 Hz. A lower (narrower) RBW makes the results more accurate, but takes longer to sweep.
- Use a BNC-to-clip cable to attach the antenna and capacitor to the *RF* port of the oscilloscope.
- Now using the *Markers* button (cursors don't work in the RF mode) measure the power level received by the 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. Record your max value in Table 6.2 then convert the power level to V_{amp}.
- **Helpful Hint:** It may be useful to use the max hold function of the spectrum analyzer to find the max power range. To do this, long press the *RF* button. Using the menu on the bottom of the screen, select *Spectrum Traces*. Then turn *Max Hold* on. This will display the value of the maximum received value in a white trace and the last received value in an orange trace. To remove the Max Hold line, repeat above to turn it off.

- **Note**: a plastic screwdriver or guitar pick will work best to tune the trimmer capacitor. A fingernail can also be used. A metal screwdriver may detune the antenna, so make small adjustments and remove the screwdriver to see the effect of tuning.
- **Note:** These settings for center frequency, span, and resolution bandwidth (RBW) are suggestions only. Please feel free to play with the settings to see if there are other stations your antenna works at!

6. Connect your antenna to your radio and test the system.

7. Spectrogram (**Time Permitting**)

- A spectrogram is a useful tool when measuring signals that vary with. It outputs a plot that uses color to show the variance of power received at the frequencies of interest over time. The plot it outputs is often called a spectral waterfall.
- Let us take some interesting measurements.
- First, connect up the antenna and trimming cap to the spectrum analyzer as you did in Part 5. Set up the measurement the same as before. Now, long hold the *RF* button to bring up a menu at the bottom of the screen. On this menu turn on the *Spectrogram* and be amazed! Wiggle the antenna position around slowly and look at the variance on the waterfall plot. **Comment** on what you see and if you the plot has any usefulness.
- Now, set the *Span* to 1 MHz. Do you see any other stations that your antenna might be able to receive?
- If you still have time remaining, you will now make a nifty waterfall plot for your eportfolio! Disconnect the antenna from the spectrum analyzer. Keep the *Center Frequency* at 1230 kHz and set the *Span* to 20 kHz. Then set the *RBW* to 200 Hz. Turn on the function generator and set the *Amp* to 10 mVpp. Set the frequency to 1230 kHz and turn off modulation (click *Mod* then *Continuous*). Connect it to the RF port of your spectrum analyzer. Observe the waterfall plot!
- Now, turn on AM modulation. Let it record for a few seconds, then change the intelligence frequency and depth if you want. Do this a few times as it looks neat. Notice how the sidebands neatly shift around. Now change the *Shape* of the modulation to *Square* and *Ramp* letting it run for a few seconds between each setting. **Comment**: what do you notice about sideband levels (and noise) with different shapes? Try to recall and apply some signals and systems knowledge.

Note: R = system impedance = 50Ω

$$dB = 10log\left(\frac{P(W)}{1}\right)$$

$$dBm = 10log\left(P(mW)\right) = 10log(P(W)) + 30$$

$$P(W) = 10^{\frac{dBm-30}{10}}$$

$$P(W) = \frac{V_{rms}^2}{R}$$

$$V_{amplitude} = \sqrt{2} * V_{rms}$$

Table 6.2: Measured Power Level at 1230 kHz and Other Frequencies of Interest

Frequency	Power level (dBm)	V_{amp} (μV)
1230 kHz		