

# EXPERIMENT 10: THE CRYSTAL RADIO 182B/196L

## I. INTRODUCTION:

The crystal radio is one of the earliest types of radio receivers, dating back to near the beginning of the 20th century. Crystal radios do not use amplifying devices such as transistors or vacuum tubes, instead a headphone or earphone is **powered by the signal** that is picked up by an antenna consisting of perhaps 50 feet of wire. Generally, this lack of amplification is thought to limit crystal sets to receiving strong local radio stations. However, reception of stations hundreds or even thousands of miles away can be accomplished using well designed sets. As an example, the author has been able to receive AM radio stations from Sacramento and Salt Lake City during winter nights using a prototype of our crystal radio connected to a 20 ft. high, 100 foot long antenna. Retuning the set to resonant at the 49 meter (wavelength) International Broadcast Band and adding a wave trap (see below) he was able to receive the 5975 KHz. BBC relay station in Antigua, some 3,900 miles away! (See reception verification on page 54.) A wave trap is a parallel\* resonant circuit that is connected in **series** with the antenna, using its very high impedance at resonance to reject the signal from a strong local station, in this case KFMB, 760 KHz. Generally, crystal radios are used on the AM (Amplitude Modulation) radio band that operates between 540 KHz. and 1.71 MHz.

Early crystal radios actually made a detector (the device to recovers the audio information from the radio signal) by contacting a very sharp pointed wire, called a cat's whisker, to a galena (lead sulfide) crystal - that is a wire and a rock! The crystal sets in this experiment will use the 1N34A point contact diode detector, However, we have some cat's whisker detectors, so you can try "radio with a rock" if you like.

## II. AM (Amplitude Modulation) RADIO - TRANSMITTERS:

Before getting into a discussion of AM radio, we must first discuss the frequency properties of sound and electrical waves. Electrical waves of many frequencies are easy to generate. However, broadcast radio requires the radiation of an electrical wave from the generating circuit into the surrounding area. A device called an antenna can do this. But to avoid wasted power, the length of the antenna must be comparable to the *wave length* of the radiated signal.

Since radio waves travel at the speed of light, their wavelengths are equal to  $C/f$  where C is  $3.00 \times 10^8$  meters/second and f is frequency in Hz. The wavelength of a 600 KHz signal (KOGO) is 500 meters. Even if a quarter wavelength antenna were used, a 125 meter (410 feet) antenna is an expensive requirement. (Notice how large the antenna towers are at the AM transmitter sites in this area.) Lower frequency antennas would be proportionately worse. So practical limitations place a lower limit of 300-500 KHz for broadcast radio. An exception: The US Navy is trying to find a site for a 100 Hz antenna to broadcast through sea water to their subs. At last word they had given up their plan to use the entire upper peninsula of Michigan as an antenna!

Human hearing, on the other hand, is limited to 20 Hz to 20 KHz. So even when sound waves are converted to *electrical signals* via a microphone, it is impractical to broadcast audio frequencies directly. What AM radio stations do is use the audio frequencies to modulate or control the amplitude of a carrier wave of high enough frequency to be broadcast efficiently. A 1000 KHz AM radio station, for example, would take a pure sine wave tone of 5 KHz and feed it to the modulator. The output frequencies would be 995 KHz, 1000 KHz, and 1005 KHz, all of which could be efficiently broadcast by the same antenna (see the left side of Fig. 1).

### III. AM (Amplitude Modulation) RADIO - CRYSTAL RADIOS:

After the AM carrier wave is broadcast through the air, it is received by an antenna which picks up some small (very small) amount of the broadcast power. An adjustable LC resonance circuit is used to select out the desired 1000 KHz station and reject signals from any other stations in the area. The audio modulation is then recovered (detected) by rectification with a diode. The diode only allows current to pass through it in one direction. The "modulated carrier" in the left side of Fig. 1 crosses through zero volts, that is the current alternates between positive and negative. The diode produces the wave form in the right side of Fig. 1, this wave form contains only the positive half of the modulated carrier, a process known as detection. Detection converts the AM carrier into a mixture of audio and radio frequencies. Then a low pass filter removes the high frequency components leaving the original audio signal to reach the headphones and be converted back to sound.

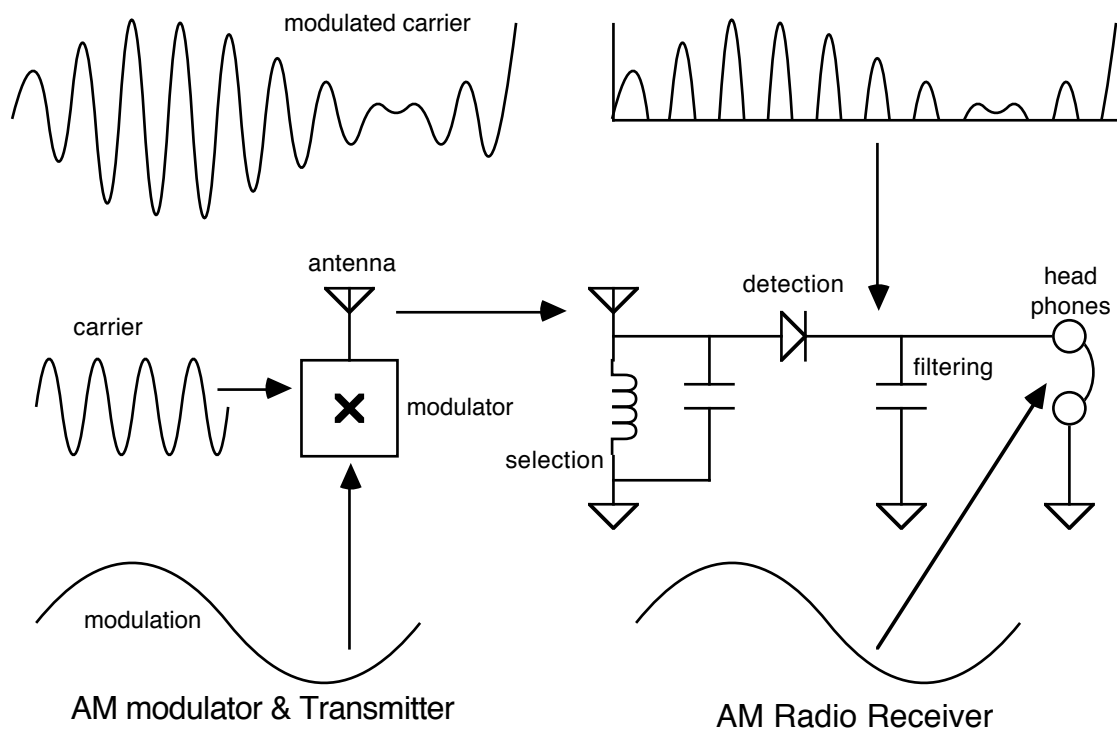


Fig. 1. The simplified AM transmitter-receiver circuit consists of a modulator and antenna at the transmitter with an antenna, frequency selective LC filter, diode detector, low pass filter, and headphones at the receiver.

Actually a separate low pass filter is unnecessary because the mechanical parts of the headphones cannot move rapidly enough to respond to the remaining radio frequency components in the detected signal. So the headphones themselves function as a kind of mechanical low pass filter.

Interested in additional information about the hobby of building and experimenting with Crystal Sets? Try The Xtal Set Society on the Web at [www.xtalset@midnightscience.com/](http://www.xtalset@midnightscience.com/)

## IV. THE SDSU PHYSICS DEPARTMENT CRYSTAL SET

### A. *Radios That Work For Free* <sup>1</sup>

Crystal radios operate by converting energy picked up by an antenna to sound that you can hear, with no amplification, no batteries, etc. That said, we will use a small audio amplifier and speaker for convenience throughout most of this experiment.

### B. Design Considerations - The SDSU Physics Department Crystal Set

The keys to good performance, that is, good sensitivity (the ability to hear weak stations) and good selectivity (the ability to separate stations that are near to one another in frequency) are very high Q resonance circuit(s) and efficient signal coupling from the antenna to the headphones.

Our set is tuned by a single parallel\* resonance circuit with a tapped coil (inductor). The tapped coil serves as a transformer that allows for efficient signal coupling from the antenna to the headphones. The transformer action does not make energy, it works exactly like the transmission in your car, by improving power transfer. Just as your car has very different characteristics in 1st gear versus 4th gear, this crystal set has very different characteristics when different taps are used - matching it to different receiving conditions.

#### 1. Resonance Circuit Performance (specifications)

Tuning Range: 500 KHz to 1600 KHz.

Unloaded Q: 150 @ 750KHz.

Loaded Q: 100 (tap 6) to 6 (tap 90) @ 750KHz.

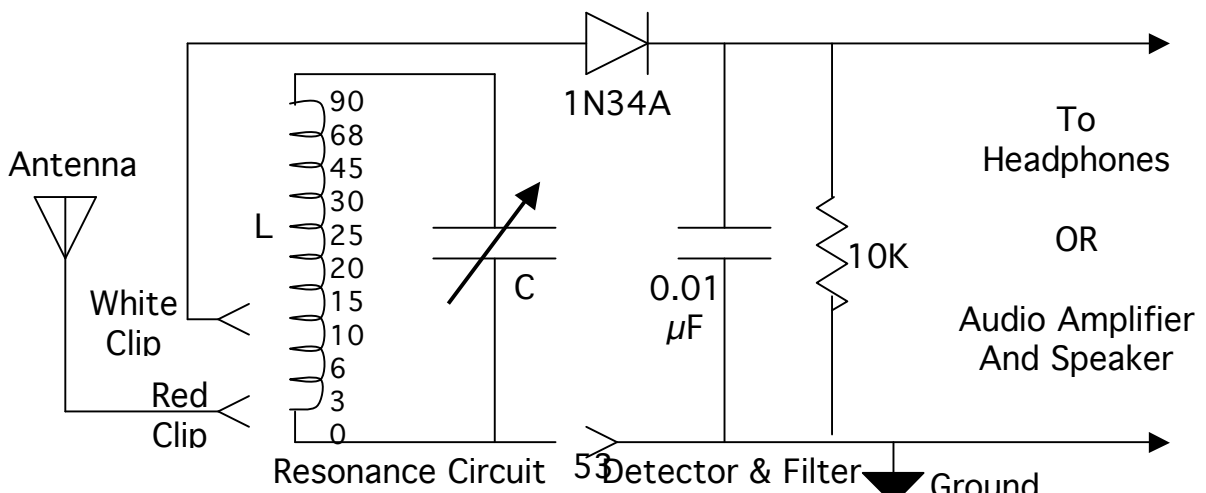
#### 2. The Coil (Inductor)

The inductor is the "air core single layer solenoid coil" that you have heard about. It is designed to have a very high Q, using the following techniques:

- The length of the coil (2.25") is approximately equal to its diameter (2")\*\*;
- The plastic material (polystyrene) used as the coil form and surrounding structures has very low dielectric energy absorption; and
- No metal, except for wires connecting to the taps, is within a coil diameter of the inductor.

#### 3. The Variable Capacitor

The resonance circuit is tuned by varying capacitance. Capacitance is changed by changing the amount of overlap between adjacent parallel plates. An air dielectric variable capacitor is used to avoid losses that would lower Q. The maximum capacitance can be calculated. The area of individual plates is  $4 \times 10^{-4} \text{ m}^2$ , with 16 "gaps" between the plates, therefore, the effective total plate area is equal to  $(16) \times (4 \times 10^{-4}) \text{ m}^2 = 6.4 \times 10^{-3} \text{ m}^2$ . The distance between adjacent plates is  $1.5 \times 10^{-4}$  meters.



#### 4. The Antenna

Our antenna is a 50 foot long wire on the roof of the Physics Building. It can be seen from the driveway to the south of the building. Since one antenna can not successfully feed 12 crystal sets, we have an arrangement allot like a Cable TV System (but without the high bills!) that distributes an un-amplified copy of the antenna signal to each lab station.

#### 5. The Signal Detector

See the first page of Exp. 10. We will use a 1N34A Germanium Diode for the experiment, but you can try "radio with a rock" if you like.

#### 6. The Low Pass Filter

See the first page of Exp. 10.

#### DESIGN NOTES:

\* PARTIAL EXPLANATION OF PARALLEL RESONANCE: One can build a Crystal Radio using a series resonance circuit of the type we using in Exp. 8. The impedance of a series LC circuit is the sum of  $X_L$  and  $X_C$ , vector quantities that cancel at resonance, producing a 0 impedance. The impedance of a parallel connected LC circuit is equal to:  $(\text{product of } X_L \text{ and } X_C)/(\text{sum of } X_L \text{ and } X_C)$ . As a result, the parallel LC circuit has an infinite impedance at resonance, when the denominator of its impedance equation is equal to 0. The choice of a parallel connected LC circuit allows us to use the tapped coil as an adjustable signal coupling transformer from the antenna to the diode and headphones, making the Crystal Set much more efficient.

\*\* INCREASING COIL Q: Bigger air core coils can have higher Qs. As an example, if you used a 4" diameter, much bigger wire with gaps between the windings, and did everything right you might double our Q. As a practical point though, it is easier said than done!

### V. DEMONSTRATION: DIODE ACTION, A ONE-WAY CONDUCTOR

1. Using the Component Board, wire the circuit in Fig. 2

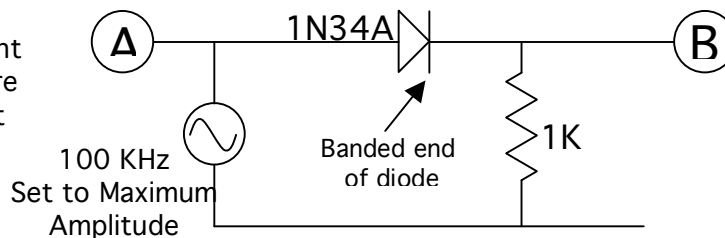


Fig. 2

2. Set the Audio Generator to produce 100 KHz. sine waves, set amplitude at max.
3. Using the x10 (times 10) low capacitance probe, connect the scope to Pt. A. Set the scope to 0.2 V/Div. and 5  $\mu$ S./Div.
4. Using the Gnd. Position on the scope's Input Coupling Switch, center the trace vertically.
5. Switch to DC coupling.
6. Observe the waveform on the scope.
7. Move the probe to Pt. B.
8. Observe the change in the waveform.

## VI. CALCULATIONS (GROUP WRITE-UP)

### A. Theoretical Calculation of Coil's Inductance

Using data from IV. B. 2. and an equation that is quite accurate for single layer solenoid coils in which the length exceeds 0.6 times the diameter, the following results are obtained:

$$L (\mu\text{H}) = R^2 N^2 / (9R + 10L) \text{ with } R \text{ and } L \text{ in inches}$$

$$L = 1290^2 / (90 + 22.5) = 257 \mu\text{H}$$

### B. Theoretical Calculation of the Variable Capacitor's Maximum Capacitance

Using data from IV. B. 2. and the parallel plate capacitance formula, the following results are obtained:

$$C (\text{farads}) = \epsilon(A/D) = (8.85 \times 10^{-12})(6.4 \times 10^{-3} / 1.5 \times 10^{-4}) = 378 \text{ pf.}$$

### C. Theoretical Calculation of Crystal Set's Minimum Operating Frequency

Using the results from VI. A. and VI. B. above, calculate the Set's minimum operating frequency.

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## VII. PROCEDURE: MEASUREMENTS (GROUP WRITE-UP)

### A. Minimum Tuning Frequency

1. Set the controls of the Elenco Audio Generator/Counter as described below:

Output Attenuators	0 dB (Both Buttons Out)
Output FINE	Maximum (Fully Clockwise)
0.1 Second Measurement Period	FINE Control gently pulled Out
INT/HF/VHF Switch	INT
Sine Wave/Square Wave	Sine (Button Out)
FREQ. RANGE	Button E pushed in

#### IMPORTANT NOTES:

- Remove any resistors that are connected across the Audio Generator's output.
- Disconnect the Antenna, it may remain connected to the Crystal Set from a previous laboratory section.

- and
2. Connect the "Ground Side" of Elenco Audio Generator to the Crystal Set's "GND" the Scope's Ground.
  3. Connect the Output of the Audio Generator to the Crystal Set's "ANT" (Antenna) **through the 3900 ohm resistor on the Component Board.**

#### Fig. 3 Deleted

- set
4. On the Crystal Set:
    - a. Connect the Black Clip from "G" to tap "0" of the coil;
    - b. Connect the Red Clip from "A" to tap "3" of the coil; and
    - c. If the White Clip from "D" is connected to the coil, disconnect it.
  5. Connect the Oscilloscope to tap "10" of the coil, using the Low Capacitance Probe to its X10 position.
  6. Turn the Crystal Set's variable capacitor to "0" (full counter-clockwise).
  7. After looking at your results for Step VI. C, carefully adjust the frequency of the Audio Generator until a sharp resonance is indicated by the oscilloscope. Record the frequency indicated by the Audio Generator's Counter \_\_\_\_\_
  8. Compare your Theoretical Minimum Operating Frequency (Step VI. C.) to your results for Step VII. A. 7.

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### B. Experimental Measurement of the Coil's Inductance

1. Carefully adjust the frequency of the Audio Generator to 750 KHz. You won't be perfect, close (within a few hundred Hz.) will do nicely!
2. Carefully tune the Crystal Set to resonant at 750 KHz, as indicated by the scope. *THIS SET TUNES VERY SHARPLY -- HIGH Q RESONANCE Strikes Again!*
3. Record the number from the Crystal Set's Tuning Dial. \_\_\_\_\_

- Use the table below, interpolating from the chart as necessary, determine the capacitance of the variable capacitor at the Dial Setting in Step VII. B. 3.

Dial Setting	Measured Capacitance
0	409 pf.
10	367 pf.
20	324 pf.
30	281 pf.
40	236 pf.
50	199 pf.
60	159 pf.
70	119 pf.
80	79 pf.
90	44 pf.
100	27 pf.

- Using the data from the steps 1 through 4, calculate the experimental inductance of the coil. *The series LC resonance formula from Exp. 8 can be used for a high Q parallel LC circuit such as this one.*

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- Compare the Theoretical Inductance (Step VI. A.) to your results for Step VII. B. 5.

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### C. Measurement of Unloaded Q

- Adjust the frequency, if needed, to achieve resonance at about 750 KHz.
- Record  $F_r$ . \_\_\_\_\_
- Using the oscilloscope's Volts/Div Switch and VAR (Darker Gray Variable Control on inside of Volts/Div. Switch) to make the sine wave displayed on the scope 7 Divisions peak-to-peak.
- Carefully adjust the frequency of the Audio Generator upward until the indicated peak-to-peak amplitude reads 5 Divisions. This is the Upper Half Power Frequency or "Upper Corner Frequency." ( $5/7 \approx 0.707$ , see Exp. 8.)  
Record  $F_{Upper}$ . \_\_\_\_\_
- Carefully adjust the frequency of the Audio Generator downward until the indicated peak-to-peak amplitude reads 5 Divisions. This is the Lower Half Power Frequency or "Lower Corner Frequency." ( $5/7 \approx 0.707$ , see Exp. 8.)  
Record  $F_{Lower}$ . \_\_\_\_\_
- Using  $Q = F_r / (F_{Upper} - F_{Lower})$ , calculate the unloaded Q.  
*This result should be greater than 100.*

