WORKREADY ELECTRONICS

lab activity

Wireless

Acknowledgements: Developed by Jesus Casas, Faculty of Austin Community College, Austin, Texas.

Lab Summary: The purpose of the laboratory experiment is to introduce the concepts associated with wireless communication using amplitude and frequency modulation. Calculations will be made to determine the operating frequency of the circuits and to determine compliance with the Federal Communication Commission (FCC) regulations.

Lab Goal: The student will build both an AM and FM transmitter and send an audio signal to a receiver across the room.

Learning Objectives

1. Identify and understand the use of LC tuning circuits.
2. Calculate the resonant frequency of an LC circuit.
3. Calculate the value of an inductor required for resonance.
4. Understand the relationship between the physical dimensions of an inductor and its "Q".
5. Hand-wind an inductor based on calculated values.
6. Distinguish between Hartley and Colpitts LC oscillators.
7. Understand the basic relationship between wavelength and antenna length.

Grading Criteria: Your lab grade will be determined by your performance on the experiment and the lab questions.

Time Required: 3 hours

Lab Preparation

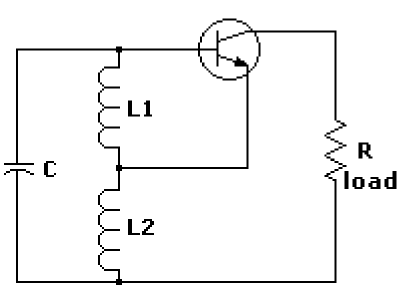
- Read the WRE Wireless Module and complete the Drill Down before starting this lab.
- Read this document completely before you start on this experiment.
- Acquire required test equipment and appropriate test leads.
- Gather all circuit components and the breadboard or electronic trainer.
- Review LC resonant circuit operation as needed.
- Print out the laboratory experiment procedure that follows.

Equipment and Materials

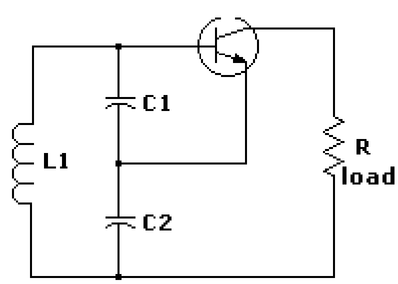
Part	Quantity
Spectrum Analyzer	1
Function Generator	1
Oscilloscope (20 MHz)	1
Inductance Meter	1
Electronic Trainer or Breadboard	1
9 Volt Battery	1
20 AWG Magnet Wire	Spool
30 AWG Magnet Wire	Spool
1 μF Electrolytic Capacitor	1
10 nF Ceramic Disk Capacitor	1
100 nF Ceramic Disk Capacitor	1
15 pF Ceramic Disk Capacitor	1
4.7 pF Ceramic Disk Capacitor	1
2N3906 Transistor	1
2N3904 Transistor	1
390 kΩ resistor	1
10 kΩ resistor	1
330 kΩ resistor	1
100 kΩ resistor	1
Portable CD Player	1
Portable AM/FM Radio	1
1/8” Stereo Shielded Cable	1

Introduction

The heart of any transmitter is the oscillator, which creates the sinusoidal carrier. Two such oscillators are the Hartley oscillator and the Colpitts oscillator.



Hartley Oscillator



Colpitts Oscillator

In both oscillators, the frequency is set by an LC tank circuit. In the Hartley oscillator, the inductor part of the LC circuit consists of L_1 and L_2. In the Colpitts oscillator, the capacitor part of the LC circuit consists of C_1 and C_2. For either oscillator, if either L or C is varied, the resonant frequency changes. This gives us a variable-frequency oscillator or VFO.

Oscillation is possible in both oscillators because of positive feedback. Positive feedback occurs when a portion of the output signal is combined in phase with the input signal. The Hartley oscillator uses a split inductor. Current flows through one section causing an induced voltage in the other section thus developing a feedback signal. The Colpitts oscillator uses two capacitors as a capacitive voltage divider. A phase shift of 180° is formed across the resonant circuit thus providing the necessary positive feedback.

All oscillators have at least one active device. In the oscillators shown, the active device is the transistor. When the oscillator circuit is first powered up, the LC tank circuit is excited and briefly provides an oscillating voltage. This oscillating voltage is fed back positively where it is amplified thus encouraging oscillations in the LC tank circuit. At some point, equilibrium is reached between the losses in the circuit and the power consumed from the power supply, therefore reaching an oscillation with a steady amplitude. The frequency of oscillation is determined by the LC tank circuit. In the Hartley oscillator, the amount of positive feedback to sustain oscillation can be controlled by adjusting the ratio of L_1 to L_2. In the Colpitts oscillator, positive feedback is controlled by the ratio of C_1 to C_2.

Amplitude Modulation (AM)

Amplitude modulation is probably the simplest scheme for wireless communication and was the first to commercially carry audio information over the airwaves. AM works by transmitting the wanted low frequency signal on the amplitude of a high frequency sinusoid (the carrier) thus forming the envelope of the modulated signal.

The low frequency wanted signal (f_m) is a varying voltage that is used to vary the strength of the transmitter's output. The result is amplitude modulation, which is actually three separate frequencies being transmitted: the original carrier frequency (f_c), a lower sideband (LSB) which is f_c-f_m, and an upper sideband (USB) which is f_c+f_m. The sidebands are "mirror images" of each other and contain the same information. The distance in frequency of the sideband signal in respect to the carrier is as high as the frequency of the wanted signal. When the AM signal is received, these frequencies are combined to produce the sounds heard. A simple AM receiver makes use of these three combined frequencies.

One advantage of AM is that transmitters and receivers are simple in design. On the other hand, there are several significant disadvantages. Since only the sidebands carry the wanted signal and only one is really needed, power is essentially “wasted” on the carrier and on one of the sidebands. About two-thirds of the transmitted power is concentrated in the carrier while the other one-third is found in the sidebands. In general, only about one-sixth of the total transmitted power is useful output.

RF engineers have developed a method of concentrating all of the transmitted power into just one sideband. This is known as single sideband (SSB). Single sideband transmitters transmit in either the upper sideband (USB) or the lower sideband (LSB). Unfortunately, a SSB signal cannot be received intelligibly on an AM receiver because of the missing carrier. Due to the lack of a carrier, SSB transmitters and receivers are far more complicated than that of AM. Remember that the carrier of an AM signal plays a major role in demodulating the sidebands of an AM signal.

Another disadvantage of AM is the wide amount of frequency space that an AM signal requires and its susceptibility to electrical noise and static. AM signals also have difficulty passing through physical barriers such as buildings, walls, and water.

Despite these disadvantages, AM is simple to tune and is still very much used for almost all shortwave broadcasting.

Frequency Modulation (FM)

As we have learned, amplitude modulation conveys the wanted signal by changing the amplitude but not the frequency of the carrier. In frequency modulation, the wanted signal is conveyed by changing the frequency but not the amplitude of the carrier. The wanted signal is represented as variations in the instantaneous frequency of the carrier. When an audio signal is frequency modulated, the frequency of the carrier changes in step with the audio signal.

In analog applications, the carrier frequency varies in direct proportion to changes in the amplitude of the input signal. The amount by which the carrier frequency changes is called the deviation. In narrowband FM, the deviation can be up to 5 kHz above and below the carrier frequency. In wideband FM, the deviation can be up to several MHz. When the input signal has positive polarity, the carrier frequency shifts in one direction; when the input signal has a negative polarity the carrier frequency shifts in the other direction. At any given instance, the deviation of the carrier frequency will be directly proportional to the polarity and amplitude of the input signal. In digital applications, data can be represented, by shifting the carrier frequency among a set of discrete values. This technique is known as frequency-shift keying.

Commercial FM radio stations operate on the FM bandwidth between 88 MHz and 108 MHz. Their carriers are separated by 200 kHz and allowed to have a maximum deviation of 75 kHz from the center frequency. This “spacing” of stations is much larger than that of AM. This allows the broadcast of a wider frequency bandwidth for higher fidelity sound. This wider frequency bandwidth allows the transmission of sub-carriers which carry the FM stereo signals.

Some of the advantages of FM are an improved signal to noise ratio with regard to man-made noise and the ability to travel through many different types of material. Some disadvantages of FM are that FM signals requires greater bandwidth, FM signals do not travel very far when compared to AM, and FM equipment is more complicated than that of AM.

This lab contains very simple circuits to allow exposure to both AM and FM concepts. The wireless realm is broad and what is covered in this lab is but a small “foot-step” in what is a long journey.

Antenna Considerations

Ideally, an antenna would be one wavelength long. This would allow the antenna to resonate, thus allowing all of the RF energy to be transmitted. Otherwise, standing waves would result. Wavelength for a transmit frequency can be determined using the following equation. (Wavelength is in meters; frequency is in Hertz.)

$$\text{Wavelength} = \frac{3 \times 10^8 \text{ M/S}}{\text{freq}}$$

The signal is not really traveling at the speed of light in a vacuum. It is being slowed down due to traveling through an electrical conductor. Therefore, a variance of 5% is deducted from the result of the wavelength formula stated above.

It is quickly apparent that a full wavelength antenna could possibly be very long and, in many cases, not practical. However, it is possible to use fractional parts of the wavelength such as 1/2, 5/8, 1/4, and 1/8 without much loss. These are all common wavelengths for antennas. But even these lengths may be too long to be practical.

Fortunately, a short antenna can be made to have the same electrical length as one of the common wavelengths by adding an inductance in series with the antenna. Often an inductor, often called a loading coil, is used to compensate for the high capacitive reactance of the shorter antenna.

A good antenna is matched and tuned to the transmitter. Antennas can be tuned either mechanically or electronically. Electronic tuning matches the antenna to the transmitter by making the antenna appear to be the proper length. Mechanical tuning involves physical adjustment of the antenna length to match the wavelength of the transmit frequency.

For most antennas, a ground plane is necessary for greatest efficiency. The ground plane completes the antenna circuit and must have an electrical connection to the ground of the transmit circuit or the shield of the coax cable which carries the RF signal. A large metal plate, a large metal object, or a large area of ground directly underneath the antenna will act as a ground plane. Depending on the transmit frequency, a ground plane can even be the ground traces on the transmitter's PC board.

<u>Lab Procedure 1: Simple AM Transmitter</u>

Note: All lab questions, schematic drawings, and breadboard photos are shown at the end of this procedure.

Schematic #1 at the end of this procedure shows a one transistor AM transmitter based on the Hartley oscillator. Advantages of the Hartley oscillator are it has one tapped inductor whose feedback ratio remains constant, its rare-to-fail design, and its constant output amplitude. A disadvantage is the output is rich in harmonic content and therefore not suitable for producing pure sine waves.

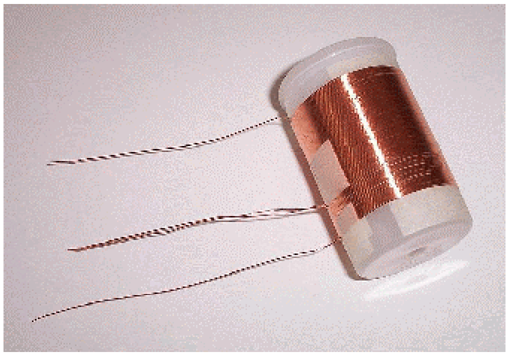
All components can be purchased except the hand-built tapped air inductor. Directions for building the tapped air inductor are given in the first steps of the procedure. Coupling capacitor C_1 provides the feedback signal from the tank circuit to the base of the transistor. It also prevents the low DC resistance of the inductor from placing a short between the collector-to-base junction of the transistor.

The amount of feedback is controlled by the location of the tap on the inductor and only that amount of feedback necessary to provide oscillation should be used. Generally, the tap is between 10 and 25 percent of the total coil turns. In the circuit, the tap will be at 25 percent of the total coil turns from point "a".

1. Determine the frequency of operation. The commercial AM band extends from 520 kHz thru 1720 kHz because AM receivers are readily available. An ideal frequency choice would be 1.1 MHz since it is in the middle of the AM band. Answer question 1 and 2 at the end of this procedure.
2. The inductor will be a single-layer coil wound on a circular form, therefore a diameter must be chosen. Make this decision carefully because the physical dimensions of the coil directly affect the "Q" rating. The optimum dimensions for a high "Q" air core inductor is where the length of the coil is the same as the diameter of the coil. Note: A form that works well for this lab is a semi-translucent 35mm film canister or a 3" length of 1" SCH40 PVC pipe which can be found at any home improvement center.
3. Use the following equation to establish the required number of turns for the inductor. L is inductance in uH, r is coil radius in centimeters, and N is the number of turns. Answer question 3 at the end of the procedure.

$$N = \sqrt{\frac{29\,L}{.394\,r}}$$

4. Wind the inductor. The direction of the winding itself is not critical, but all of the inductor should be wound in the same direction.
   a. Attach the magnet wire about 1/4" away from one end of the form, leaving about a 4" lead. Use masking tape to hold the magnet wire in place.
   b. Commence winding while keeping the magnet wire turns tight and right next to adjacent turns forming a single layer coil.
   c. Keep track of the number of turns completed.
   d. Upon reaching the turn where the tap needs to be, make a loop to bring out a connection point and then continue winding until the total numbers of turns for the inductor have been reached.
   e. Secure the magnet wire to the form leaving about a 4" lead.



Inductor Winding

5. Strip off about 1/4" of the enamel from the lead ends including the tap lead. Shiny copper should be seen.

6. Measure the inductance of the entire coil. Answer question 4 at the end of this procedure.

7. The value of inductance can also be calculated from the physical dimensions of the inductor coil. Use the following equation to calculate the inductance of the inductor. (r is the coil radius in centimeters, N is the number of turns, l is the length of the coil in centimeters, and L is the inductance in uH.) Answer question 5 at the end of this procedure.

$$L = \frac{(.394\, r^2)\, N^2}{9r + 10l}$$

8. Using the measured inductance value, calculate the resonant frequency of the tank circuit. This is the transmit frequency. Ensure that it is inside the AM band.

9. Use the photo and the schematic at the end of this procedure to assemble the AM transmitter circuit on a breadboard.

10. Use a two-meter length of hook-up wire for the antenna. Place it in a vertical position.

11. Power up the circuit and monitor the signal at the antenna with an oscilloscope. A sine wave with an amplitude of about 19 V_{pp} should be present. Answer question 6 at the end of this procedure.

12. Place a 500 Hz sine wave signal from a function generator to the input of the transmitter. Starting with an amplitude of 0 V_{pp}, slowly increase the amplitude of the input signal until modulation is seen on the oscilloscope. This can be verified by seeing the amplitude of the sine wave “dance” without a change in frequency.

13. Remove the oscilloscope and replace it with a spectrum analyzer. Use your transmit frequency as the Center setting on the spectrum analyzer and use a span of 250 kHz.

14. Adjust the function generator to provide a 10 kHz sine wave signal to the input of the transmitter. While monitoring the spectrum analyzer, adjust the amplitude of the input signal from 0 V_{pp} to the point where the carrier, the lower sideband, and the upper sideband are seen. Answer question 7 at the end of this procedure.

15. Remove the function generator and the spectrum analyzer. Set the oscilloscope to monitor the signal at the antenna one more time.

16. Connect the audio signal from the headphone output of a CD player to the input of the transmitter circuit. Place the volume at about a third of the way up. Answer question 8 at the end of this procedure.

17. Tune a portable radio to the frequency found in the above step. Answer question 9 at the end of this procedure.

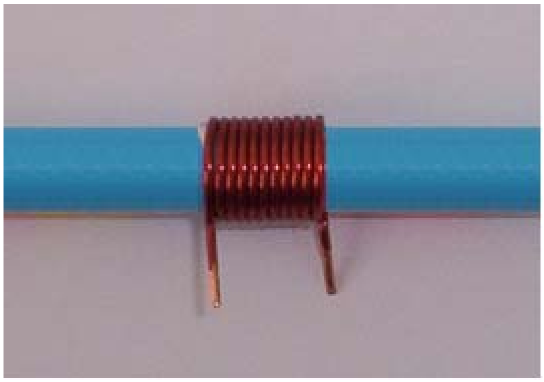
18. Measure the current being drawn from the 9 volt supply by the transmitter. Calculate the power being used. Answer questions 10 to 14 at the end of this procedure.

Lab Procedure 2: Simple FM Transmitter

Note: All lab questions and schematic drawings are shown at the end of this procedure.

As with AM transmitters, the heart of an FM transmitter is an oscillator. The schematic at the end of this procedure shows a one-transistor FM transmitter whose frequency is controlled by C_1 and L_1 which form the LC tank circuit. This frequency is the carrier frequency. Deviation from the carrier frequency can be varied by the signal applied to the base of the transistor.

1. Build the inductor coil aiming for an inductor value of .2 uH. The resonant frequency will be around 92 MHz.
    a. Cut a 12" length of 20 AWG magnet wire and wind a coil using a round pencil as the form. Keep the coil windings close and tight.



Coil Winding

    b. Strip the enamel off the ends of the coil and measure the inductance. The inductance will probably be higher than .2 uH.
    c. If the inductance if greater than .2 uH, remove one coil turn and measure again. Remember to strip the enamel off the new end.
    d. Continue removing one coil turn at a time until a value of .2 uH is reached.
2. Use the photo and schematic at the end of this procedure to assemble the FM transmitter circuit on a breadboard. Answer questions 15 and 16 at the end of this procedure.
3. Cut a piece of hook-up wire to reflect the length in question 16 and attach it to the transmitter circuit. Place the antenna in a vertical position.

4. Connect the audio signal from the headphone output of a CD player to the input of the transmitter circuit. Place the volume at about a third of the way up.
5. Set the spectrum analyzer to cover the frequency range of 50 MHz thru 150 MHz.
6. Power up the circuit and monitor the RF signal with the spectrum analyzer. Answer questions 17 and 18 at the end of this procedure.
7. Tune the FM receiver to the fundamental frequency. Answer question 19 at the end of this procedure. What do you hear? Is the audio track from the CD player coming through on the FM receiver?
8. Set the spectrum analyzer to cover 10 MHz below and above the fundamental frequency. Answer question 17 at the end of this procedure.
9. Adjust the volume output on the CD player. Answer questions 20, 21, and 22 at the end of this procedure.

Lab Questions

1. What frequency did you choose for the operation of the AM receiver?

2. Use the frequency from question 1 and a fixed value of 100 pF for the tank capacitor to solve for the value of inductance using the resonant frequency equation.

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

3. Calculate at what turn the tap of the inductor will be. This will be 1/4 of the value calculated from the formula.

4. What is the inductance of the entire coil? How does this value compare to the calculated value from question 2?

5. What is the new calculated value of inductance? How does this calculated value compare to the measured value from question 4?

6. What is the frequency of the sine wave? How does it compare to the calculated transmit frequency?

7. Which sideband is the strongest? Do both sidebands have about the same amplitude?

8. What is the frequency of the transmitted signal of the CD player?

9. What do you hear when you attach the portable radio? Adjust the volume of the CD player. How does this affect the audio signal being received on the portable radio?

10. Is the transmitter operating within the Federal Communications Commission (FCC) regulations?

11. What is the distance from the transmitter that a signal can still be received on the portable radio? What do you think could be done to increase the transmitter's range?

12. Use the following equation to determine the wavelength for your transmit frequency.

$$\text{Wavelength} = \frac{3 \times 10^8 \text{ M/S}}{\text{freq}}$$

13. How long would a half-wavelength antenna be for your transmit frequency?

14. How long would a quarter-wavelength antenna be for your transmit frequency?

15. Calculate the wavelength for the FM circuit using a transmit frequency of 92 MHz .

16. This transmitter will use a quarter-wave antenna. Calculate how long the antenna will be using a quarter wavelength with 5% variance.

17. What do you see when you attach the spectrum analyzer to the FM circuit? There will be several signals showing. The signal from the FM transmitter is composed of a fundamental frequency and harmonic frequencies. The fundamental frequency is the one with the greatest amplitude and is the frequency that the LC tank circuit is tuned for. Even though both the fundamental frequency and the harmonic frequencies carry the same information, the fundamental frequency is the strongest.

18. Is the fundamental frequency within the range of 88 MHz and 108 MHz? (Note: If it is slightly below this range, the inductance value of the inductor can be lowered by spreading the coil turns to allow a small amount of spacing between them. This decrease in inductance causes the resonant frequency to increase.)

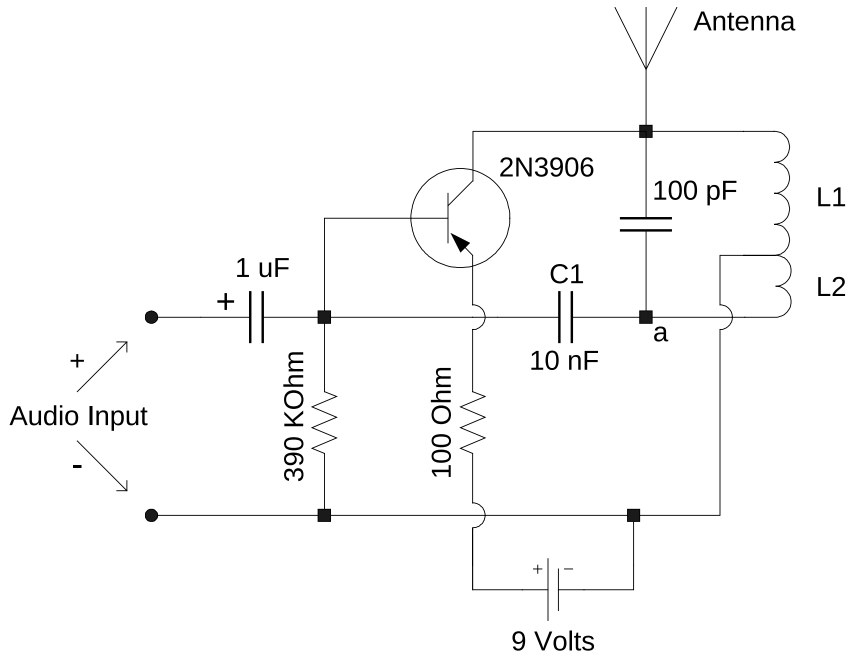
19. What do you hear when you tune the FM receiver to the fundamental frequency? Is the audio track from the CD player coming through on the FM receiver?

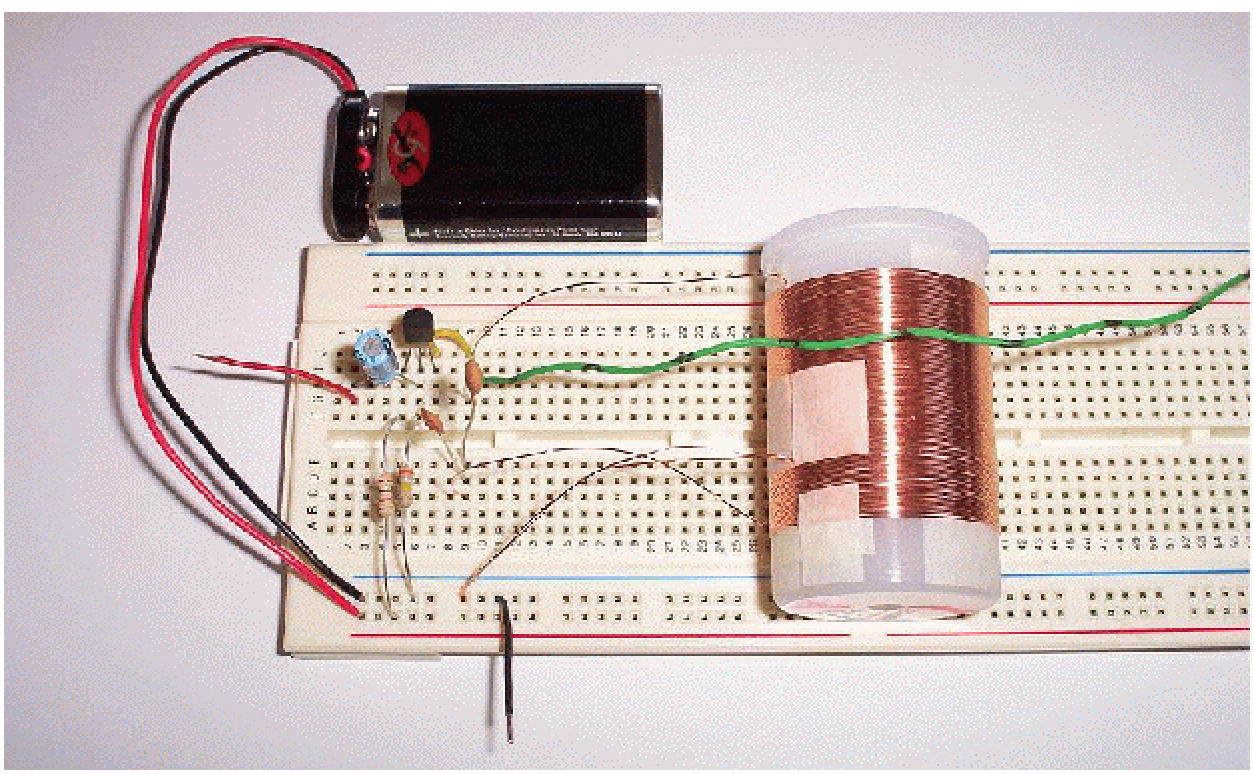
20. What happened to the fundamental frequency when you adjusted the volume output on the CD player?

21. Does changing the volume affect the amplitude? Does changing the volume affect frequency deviation?

22. With the FM receiver tuned to the fundamental frequency, adjust the volume output on the CD player. How does this affect your listening enjoyment? Does the amount of frequency deviation matter?

Schematic and Breadboard Layout Figure 1: AM Transmitter





<u>Schematic and Breadboard Layout Figure 2: FM Transmitter:</u>