EMF LAB MANUAL

1. Electric Field Pattern Between Two Circular Electrodes

With this experiment the students will investigate the electric field between two circular electrodes. This field corresponds to the attractive field between two point charges. It also referred to as a static dipole field and serves as an example of an inhomogeneous field.

To be well prepared for the experiment, the students should be familiar with the concepts of equipotential lines and field lines. They should know that a voltage is equivalent to the difference in electric potentials between two points of an electric field, and that applying a voltage to two electrodes causes an electric field to build up. What is more, they should know that, according to the concept of field lines, the density of the field lines is proportional to the electric field strength, or the strength of the electric force respectively.

PROCEDURE

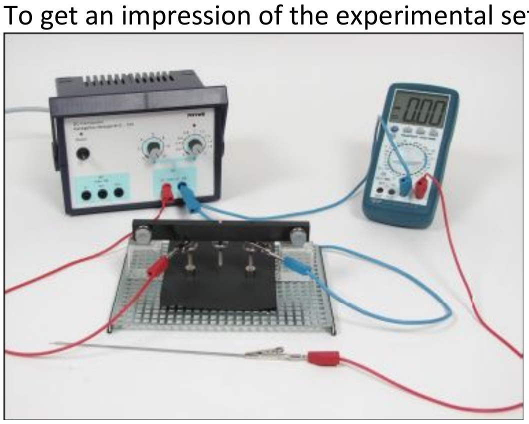
• If you put manifold paper and white paper between the carbon paper and the polycarbonate plate, you will be able to push the points of measurement through onto the white paper with the knitting needle. This way the carbon paper can be used multiple times.

• For a symmetric field distribution the electrodes need to be in good contact with the plane of resistance (the carbon paper). Thus check prior to the measurement of the field if the electrodes are pressed equally firmly onto the carbon paper. You should also create a conducting layer of graphite between the electrodes and the carbon paper using a soft pencil.

• The digital multimeter (DMM), which is used to measure the voltage, needs to have a high inner resistance (> 10 MΩ). Lacking this high resistance there will be an electric current in the measuring circuit on the carbon paper between the cathode (0 V) and the knitting needle. This current will change the electric field on the carbon paper and the measurement of the electric potential will be distorted.

Setup

To get an impression of the experimental set-up, please view Fig. 1.



Setting up the experiment, follow this procedure:

• Put the two universal holders onto the mounting plate, with the polycarbonate plate fitting just inbetween (Fig. 2).

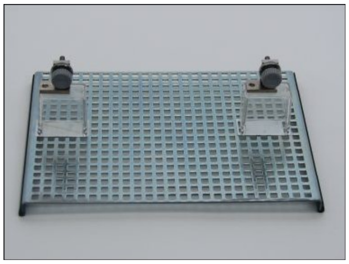


Fig. 2

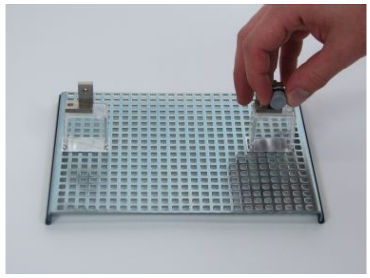


Fig. 3

Fig. 4

• Completely loosen the knurled screws on both holders and use them to fix the electrode holder onto the universal holders (Fig. 3-4).

Fig. 5

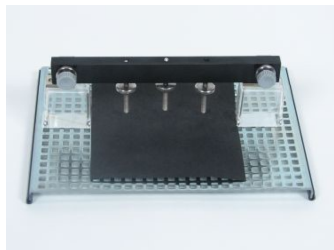


Fig. 6

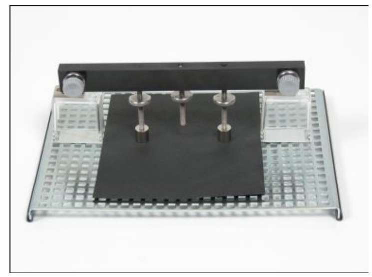


Fig. 7

• Cut a sheet of carbon paper, with a size of 130 mm x 100 mm, and put in on top of the polycarbonate plate (Fig. 5-6).
•Place the two circular electrodes below the outer knurled screws. By tightening the knurled screws, press both electrodes equally firmly onto the underlying plate (Fig. 7).
• Draw the profiles of the electrodes on the carbon paper, loosen the knurled screws slightly and remove the carbon paper again (Fig. 8).

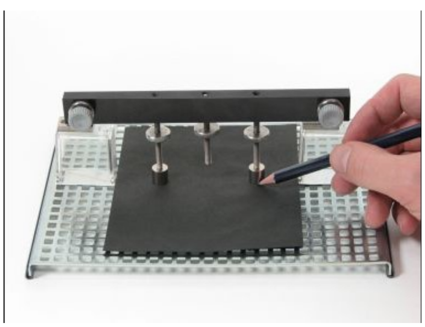


Fig. 8

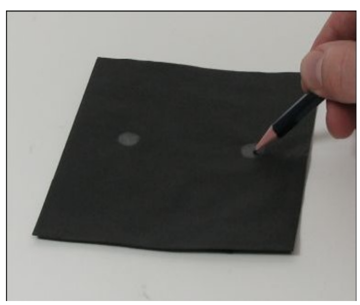


Fig. 9

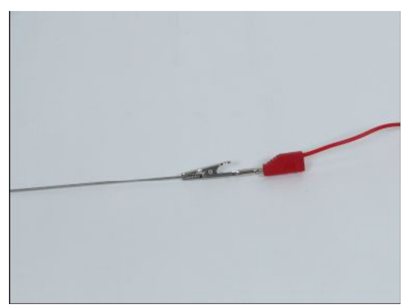


Fig. 10

• Accurately fill the marked areas with a soft pencil (Fig. 9). The graphite of the pencil creates better contact between the electrodes and the carbon paper so that, when applying a voltage to the electrodes, an electric field can be measured within the conducting carbon paper.
• Put the carbon paper back into its original position, place the electrodes onto the marked areas and tighten them with the knurled screws on the carbon paper (Fig. 7).
• Connect both electrodes to the outputs of the power supply (Fig. 11).

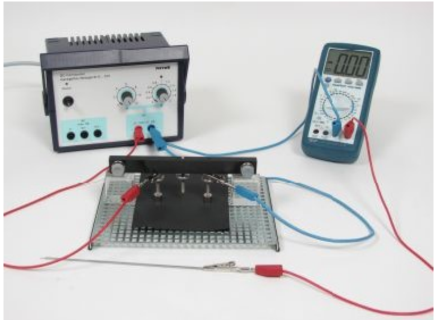


Fig. 11

• Connect the digital multimeter (DMM) to one output (0 V) of the power supply as well as with the knitting needle (Fig. 10-11). If the carbon paper contains an electric field and the knitting needle touches the carbon paper, the DMM will measure the voltage between the point of contact and the connected output of the power supply. If this output has 0 V, the measured voltage will be equivalent to the electric potential in the point of contact. Note: A voltage is always equivalent to a difference of electric potentials between two points.

Action

• Switch on the power supply and set its output to 10 V (DC). Attach the tip of the knitting needle to each of the two electrodes and check whether the electrodes have electric potentials of 0 V and 10 V betragen respectively (Fig. 12-13). If necessary, adjust the DC output of the power supply.

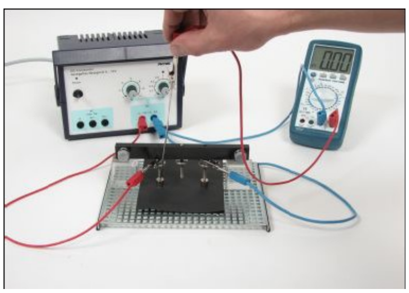


Fig. 12

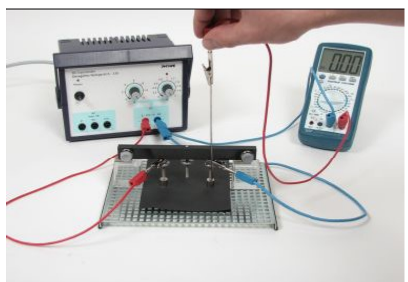


Fig 13

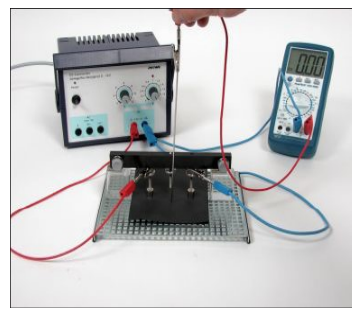


Fig 14

• Find points on the carbon paper, which have the same electric potential. For this purpose scan the carbon paper with the tip of the knitting needle and mark the points as small circles with a pencil (Fig. 14). Start with a value of 1 V and continue in steps of 2 V. Mark eight points for each value.

• After completing the measurement, loosen the screws and remove the carbon paper.

Observation

Use a pencil and connect the points of equal electric potential as equipotential lines. Label each line by its electric potential.

Equipotential lines of the electric field are plotted on the carbon paper (Fig. 15).

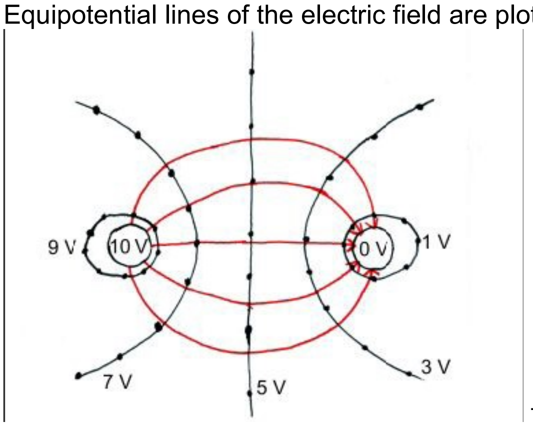
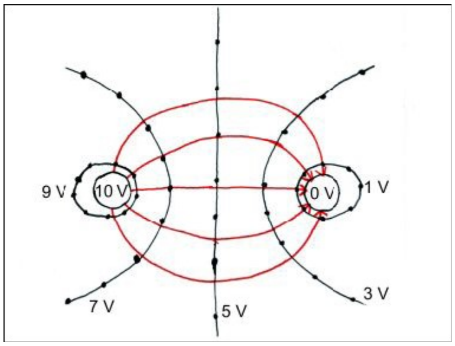


fig 15

Question 1
Draw five field lines of the electric field. Think about why these lines should start from the anode (10 V) at equal distance.

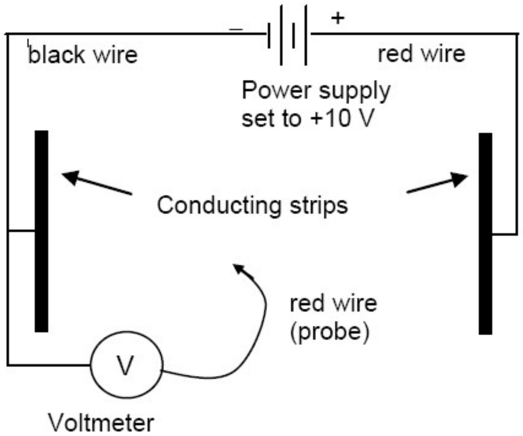
Exemplarily five field lines are drawn. They run perpendicular to all equipotential lines (Fig. 15). At the anode (10 V) their distances have to be equal in order to represent constant field strength in the area close to the electrode.

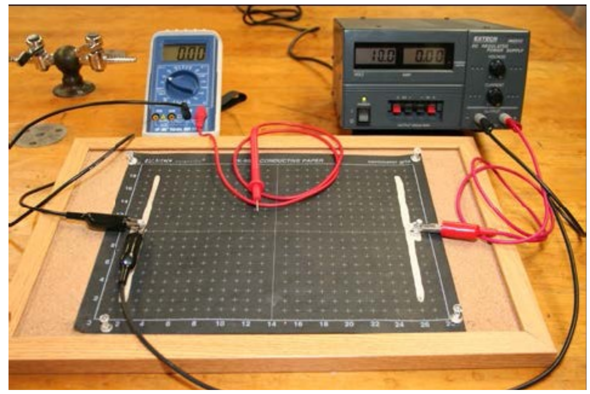


Question 2
Examine the electric field pattern and explain why this electric field is inhomogeneous.

Having equal distance at the anode (10 V) the field lines diverge (smaller electric field strength) and converge at the cathode (0 V) to their original distances (the field strengths close to the electrodes are the same). The further you move away from the electrodes, the weaker the electric field is. Further more, the field lines do not run parallel to each other. Hence the electric field strength is not constant, both in its direction and its magnitude, which makes this field an inhomogeneous electric field.

2. Electric Field between Parallel Conductors





PROCEDURE:

1. Mount the conductive paper with the two parallel conductors to the corkboard by placing a plastic pushpin in each corner of the semi-conducting paper.
Please place the pushpins in existing holes to prevent damaging the paper and putting unnecessary holes in the conductor.
2. Push an **aluminum** push pin into **each** of the two conducting electrodes (metallic stripes) on the paper. These aluminum push pins are electrically conducting, and are used to make connections to the electrodes.
3. Connect the (−) terminal of the power supply to one of the parallel conductors (the one on your left)and the (+) terminal to the one on your right using the banana-alligator clip leads.
A **power supply** is a source of voltage. It can be a battery, a cell phone charger, or a box like the one you will use. It has at least two output jacks to which you attach conducting wires. The knob on the power supply controls the difference in voltage, or electric potential difference, between the two jacks. While one always measures a voltage difference between two points, we often refer to one jack as "common" or zero voltage. So when we say a power supply "puts out 5 V" what we mean is that there is a difference of 5 V between the two output jacks.
4. The meter you will use can measure several things, and is called a "multimeter." You will become more familiar with it over the next few weeks. It can measure voltage differences, currents, and resistance, Today, you will use it **only** as a **voltmeter** to measure the voltage difference between two points that you touch the voltmeter probes to.
Connect the COM port of the multimeter to the aluminum pin on the left-hand (−) parallel conductor with an alligator clip, and connect the V∧ port of the multimeter to a probe.
To start your first experiment, turn your power supply on. Turn the dial of the multimeter to 20 V and make sure it is set to DC (bar with dots underneath it).
6. Touch the probe connected to the VΩ port of the voltmeter to the **aluminum** push pin that is connected to the (+) of the power supply. Adjust the voltage of the power supply so that the voltmeter reads 10.00 V. You may not get this voltage exactly, but it is sufficient to be within ±0.05 V (between 9.95 V and 10.05 V). Do **not** rely on the voltmeter on the power supply. You may have to adjust the current to make the current limiting light turn off. If you have trouble with this part, ask your TA for help.

7. Now move your probe off from the pushpin to touch the probe to the electrode into which this pin is pushed (connected to the (+) of the power). Make sure that the voltmeter reads 10V in several locations along the electrode. If it doesn't, you probably have a poor electrical contact between the pushpin and the paper, and you need to gently push the pin down. Ask your TA for help if you can't get a reliable reading of +10 V.
8. Touch the probe to the electrode that is connected to the (−) of the power supply. Make sure that the
voltmeter reads 0 V in several locations along the electrode.
9. At the back of this Lab Procedure, there are three sheets of paper that represent the electrode setups you will use today. Find the "map" with the two parallel bars. On this paper, label the right (+) electrode +10 V and the left (−) electrode 0 V.
10. Now **gently** use the probe to find points on the semi-conducting paper that have a potential of +2 V. One of you should put the probe in the correct spots, while another marks down the location of these spots on the paper map. Find at least 8 widely-spaced points for this voltage of +2 V. The points that you find should have voltages within ± 0.02V of the target voltage of +2 V. Please be **very careful** using the probe. If you press too hard, the probe will create a hole in the paper. Holes in the semi-conducting paper will disrupt your field lines, and ruin the paper for future groups. Even deep impressions (dents) left in the paper will distort the field lines. Keep the probe perpendicular to the surface of the paper when you touch it to the paper, and do not touch the paper with your fingers (or any other part of your body…). The conducting paper allows a small current to flow through it to enable the voltmeters to work properly. You will understand in future labs how this paper might work. For now, you can assume it allows you to measure the potential anywhere on its surface.
11. Use the points on your map that you have plotted to draw a smooth curve to represent the equipotential line corresponding to +2 V. Label this line "+2 V".
12. Repeat Steps 10 and 11 above for the voltages +4V, +6V, and +8V.
Note the symmetry of the equipotential lines from the top half of the page to the bottom half of the page.
13. Using this map you've made of the equipotential lines, now sketch at least five **electric field lines** on your map. Make use of the relation between the direction of the electric field and the equipotential lines. Indicate the correct direction of the electric field on the lines, and recall that the electric field lines must "start" on positive charges and "end" on negative ones.
In addition to sketching the electric field lines on your map, you will estimate the electric field strength between equipotential lines.

<u>Requirement:</u>
1. Conducting sheet
2. conducting strip
2.Multimeter
3.Powersupply
4.Probe

3. Electric Field And Potential Inside The Parallel Plate Capacitor

OBJECTIVE

To verify the relationship between the voltage, the electric field and the spacing of a parallel plate capacitor.

EQUIPMENT

1. Capacitor plate (two).
2. Electric field meter (1 *KV/m* = 1*mA*).
3. Power supply *DC* 12*V* and 250*V* (variable).
4. Multi-meters (two).
5. Plastic ruler (100 *cm*).
6. Plastic and wooden sheets.

INTRODUCTION

Assume one of the capacitor plates is placed in the y-z plane while the other is parallel to it at distance d as shown in Figure 1. The effect of the boundary disturbance due to the finite extent of the plates is negligible. In this case, the electric field intensity $\overline{\mathbf{E}}$ is uniform and directed in x-direction. Since the field is irrotational ($\overline{E} = -\overline{\nabla} V = \overline{0}$), it can be represented as the gradient of a scalar field V

$$\overline{E} = -\overline{\nabla} V = -\frac{\partial V}{\partial x} \quad \text{.......} (1)$$

which can be expressed as the quotient of differences

$$\overline{E} = -\frac{V_1 - V_o}{x_1 - x_o} = -\frac{V_A}{d} \quad \text{.......} (2)$$

where V_A is the applied voltage and d is the distance between the plates. The potential of a point at position x in the space between the plates is obtained by integrating the following equation

$$\frac{\partial V}{\partial x} = \frac{V_A}{d} \quad \text{.......} (3)$$

to give

$$V(x) = \frac{V_A}{d} x \quad \text{.......} (4)$$

EXPERIMENTAL SETUP AND PROCEDURE

1. The experimental setup is as shown in Figure 2. Adjust the plate spacing to d=10 cm. The electric field meter should be zero-balanced with a voltage of zero.
2. Measure the electric field strength at various voltages ranging from 0 to 250 Volts for d=10 cm and summarize the results in a table. Choose a suitable voltage step to produce a smooth curve.
3. Plot a graph of the data of step (2). On the same graph paper, plot the theoretical graph based on equation (2) and compare the theoretical and experimental graphs.
4. Adjust the potential V_A to 200V. Measure the electric field strength as the plate separation is varied from d=2 cm to d=12 cm. Summarize your results in a table.
5. Plot a graph of the data of step (4). On the same graph paper, plot the theoretical graph based on equation (2) and compare the theoretical and experimental graphs.
6. With a different medium (sheet) inserted between the plates, measure the electric field strength at various voltages ranging from 0 to 30V. The separation between the plates is fixed at d=1 cm. Repeat for all sheets.

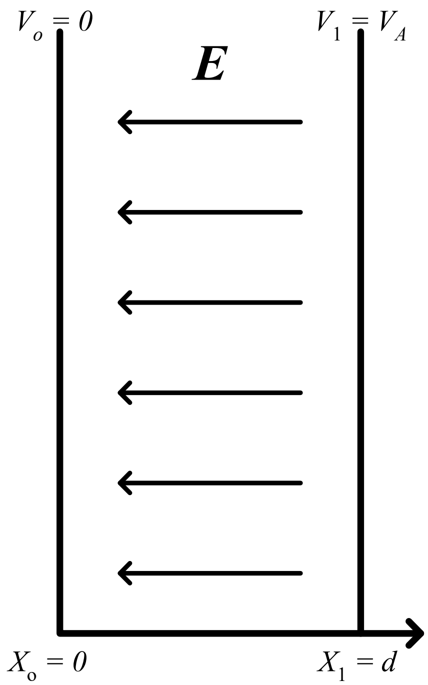


Figure 1: A parallel plate capacitor placed in the yz-plane

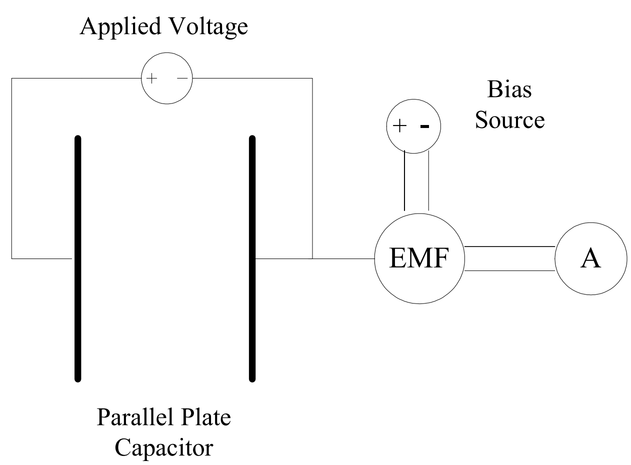


Figure 2: Experimental set-up

Calibration ➔ ___________________________________

Table 1: Electric field variation with Voltage (d = 10cm)

Voltage (Volts)	Current, ‘I’, (mA)	Experimental Electric Field Strength ‘E’ (V/m)	Theoretical ‘E’ from Eq(2) E=V/d
0			
25			
50			
75			
100			
125			
150			
175			
200			
225			
250			

Table 2: Electric field variation with Plate Separation “d” (V = 200 Volts)

Plate Separation, ‘d’ (cm)	Current, ‘I’, (mA)	Experimental Electric Field Strength ‘E’ (V/m)	Theoretical ‘E’ from Eq(2) E=V/d
2			
4			
6			
8			
10			
12			

Table 3: Electric field variation with Voltage when <u>Plastic</u> Sheet is used (d = 1 cm)

Voltage (Volts)	**Current, 'I', (mA)**	**Experimental Electric Field Strength 'E' (V/m)**
0		
5		
10		
15		
20		
25		
30		

Table 4: Electric field variation with Voltage when <u>Wooden</u> Sheet is used (d=1cm)

Voltage (Volts)	**Current, 'I', (mA)**	**Experimental Electric Field Strength 'E' (V/m)**
0		
5		
10		
15		
20		
25		
30		

QUESTIONS FOR DISCUSSION

1. What are the assumptions and simplifications in this experiment? Discuss their effects on the experimental results.

2. Plot theoretical relation between the potential and distance (equation 4) inside a parallel plate capacitor with d=10 cm and V_A =100 V.

4. CAPACITANCE AND INDUCTANCE OF TRANSMISSION LINES

OBJECTIVE

The capacitance and inductance per unit length of commonly used transmission lines are measured and compared to the theoretically calculated values and to manufacturer's supplied data.

EQUIPMENT

1. LCR meter (Digital).
2. A length of coaxial transmission line.
3. A length of twin-wire transmission line.
4. Caliper.
5. Meter stick.

INTRODUCTION

The two types of transmission lines to be studied in this experiment are the coaxial and the twin-wire transmission lines. The cross-section of these transmission lines are shown in Figures l-(a) and l-(b) respectively. The value of the capacitance C of any given structure can be analytically obtained by solving Laplace's equation. For the inductance L, analytical relations are obtained by calculating the magnetic flux linkage.

For the coaxial transmission line, the capacitance per unit length and the inductance per unit length are given, respectively, by:

$$C/l = \frac{2\pi\varepsilon}{\ln\left(\frac{b}{a}\right)} \qquad (1)$$

$$L/l = \frac{\mu}{2\pi}\ln\left(\frac{b}{a}\right) \qquad (2)$$

For the twin-wire transmission line:

$$C/l = \frac{\pi\varepsilon}{\ln\left(\frac{h}{a}+\sqrt{\frac{h^2}{a^2}-1}\right)} \qquad (3)$$

$$L/l = \frac{\mu}{\pi}\ln\left(\frac{2h}{a}\right) \qquad (4)$$

where l is the total length of the line and a, b, and h are as shown in Figure 1. The constants ε and μ are the permittivity and the permeability of the material of the line respectively.

The characteristic impedance Z_o is related to L and C by

$$Z_o = \sqrt{\frac{L}{C}} \qquad (5)$$

EXPERIMENTAL SETUP AND PROCEDURE

The available transmission lines are the following:

<u>Coaxial line:</u>

Type RG 59 B/U

Characteristic impedance 75 Ω

Capacitance/meter 68 *pF/m*

Maximum voltage 6 *kV*

<u>Twin-wire line:</u>

Characteristic impedance 300 Ω
Capacitance/meter 13.2 *pF/m*

In all of the measurements, make sure that the lines are fully extended (no loops). Also, avoid areas of electromagnetic interference inside the lab.

1. Measure the capacitance of the coaxial transmission line using the universal bridge. The far end of the line should be open-circuited.
2. Measure the length of the coaxial line, then find the capacitance per unit length (C/l) of the line.
3. Measure the relevant dimensions of the coaxial line using the caliper.
4. Repeat steps (1)-(3) for the inductance (L/l) of the coaxial transmission line. In this case, the far end of the line should be short-circuited.
5. Repeat all previous steps for the twin-wire line.

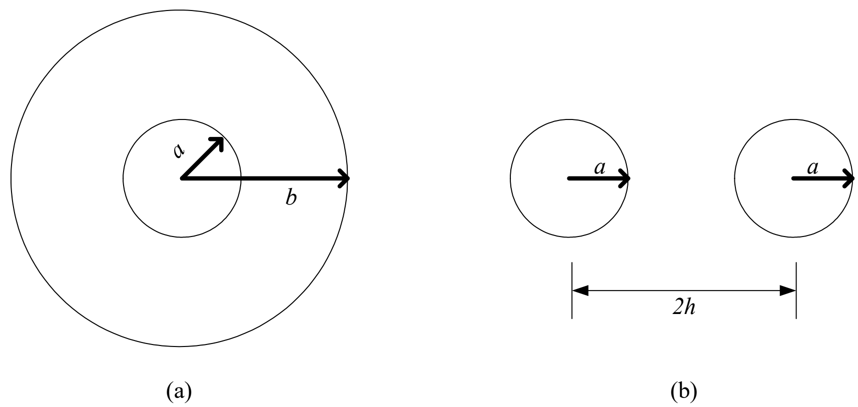


Figure 1. Cross sections of the transmission lines: (a) coaxial (b) twin wire

Table 1: <u>Measured data</u> of Coaxial and Twin-wire lines.

	Coaxial Line	**Twin-Wire Line**
Length 'l' (m)		
Inner radius 'a' (mm)		
Outer radius 'b' (mm)		-------
h (mm)	-------	
Measured Capacitance 'C' (pF)		
Measured Inductance 'L' (µH)		
Inductance per unit length 'L/l' (µH/m)		
Capacitance per unit length 'C/l' (pF/m) (Experimental)		
Z_0 (Ω) (Experimental)		
C/l (pF/m) (Theoretical)		
Z_0 (Ω) (Theoretical)		

C/l (pF/m) (Manufacturer)		
$\boldsymbol{Z_0}$ (Ω) (Manufacturer)		

QUESTIONS FOR DISCUSSION

1. Calculate (*C/l*) using equation (1). The dielectric occupying the space between the conductors of the coaxial line is made of polyethylene (ε=2.3 ε_o, μ= μ_o).

2. Compare the theoretical, experimental and the manufacturer's data values of (*C/l*).

3. Calculate Z_o of the coaxial line from the experimental values of *L* and *C* and compare to the theoretical and manufacturer's values.

4. Repeat for the twin-wire line.

5. What is the effect on the characteristic impedance of the transmission line when it is not fully extended?

6. Explain the dependence of your measurements on frequency.

5.MAGNETIC FIELD OUTSIDE A STRAIGHT CONDUCTOR

OBJECTIVE

To obtain the magnetic field due to current in a straight conductor as a function of the current and as a function of the normal distance from the conductor. Also the magnetic field due to current passing through two straight conductors is to be obtained.

WARNING: THIS EXPERIMENT INVOLVES HIGH CURRENT (100A) AND HIGH TEMPERATURE. DO NOT TOUCH THE CONDUCTOR OR THE TRANSFORMER.

EQUIPMENT REQUIRED

1. A straight conductor.
2. Teslameter with an axial probe.
3. Ammeter.
4. Multimeter.
5. Transformer.
6. Current transformer (100:1 ratio).
7. Power supply.

INTRODUCTION

It is known that the current passing through a long straight conductor (see figure 1) produces a magnetic flux density given by:

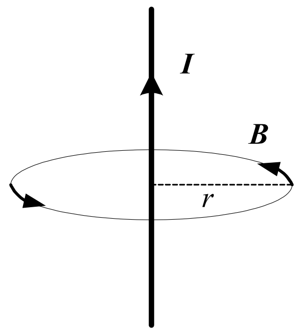
$$\left|\overline{B}\right| = \frac{\mu_o I}{2\pi r} \qquad (1)$$

It can also be easily shown that ***B*** due to current in two long and parallel straight conductors is given by:

$$\left|\overline{B}\right| = \frac{\mu_o I}{2\pi x} + \frac{\mu_o I}{2\pi (x-a)} \qquad (2)$$

$$\left|\overline{B}\right| = \frac{\mu_o I}{2\pi x} - \frac{\mu_o I}{2\pi (x-a)} \qquad (3)$$

where a is the distance between the conductors. Equation (2) applies to the case when the currents flow in the same direction and equation (3) applies when the currents flow in the opposite directions as shown in figures 2 (a) and (b) respectively.



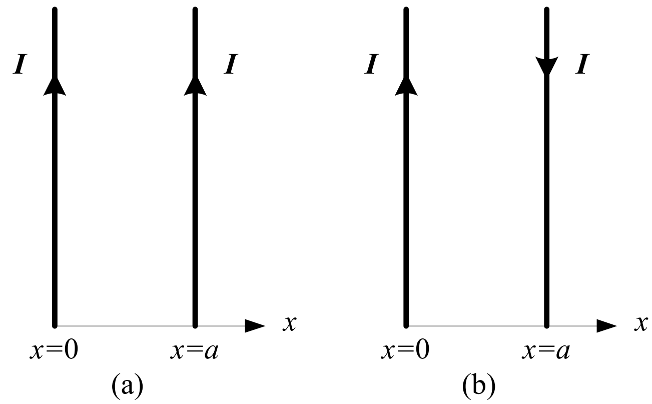


Figure 1: Magnetic field around a straight conductor

Figure 2: Two parallel straight conductors with
(a) currents in same directions
(b) currents in opposite directions

EXPERIMENTAL SETUP AND PROCEDURE

The experimental set up is shown in figure 3. The magnetic field readings will be taken from the voltmeter which is connected to the teslameter with appropriate calibration.

The teslameter must first be calibrated. For calibration it does not matter if a magnetic field is present or not. The calibration procedure is as follows:

a) *Adjust the multimeter knob to the 3V position (choose AC).*

b) *Push the DC button of the teslameter.*

c) *Push the "Eichen" button of the teslameter.*

d) *Turn the "Eichen" knob unth the multimeter reads exactly 3 volts.*

e) *Release the "Eichen" button. The teslameter is now calibrated.*

Turn the knob of the teslameter to the $3mT$ position and keep it set at this position throughout the experiment. This makes $3mT$ equivalent to $3V$ or $1mT = 1\ V$. Push the *AC* button of the teslameter.

The power supply output (0…15V~, 5A) is connected to the upper most and lower most ports of the

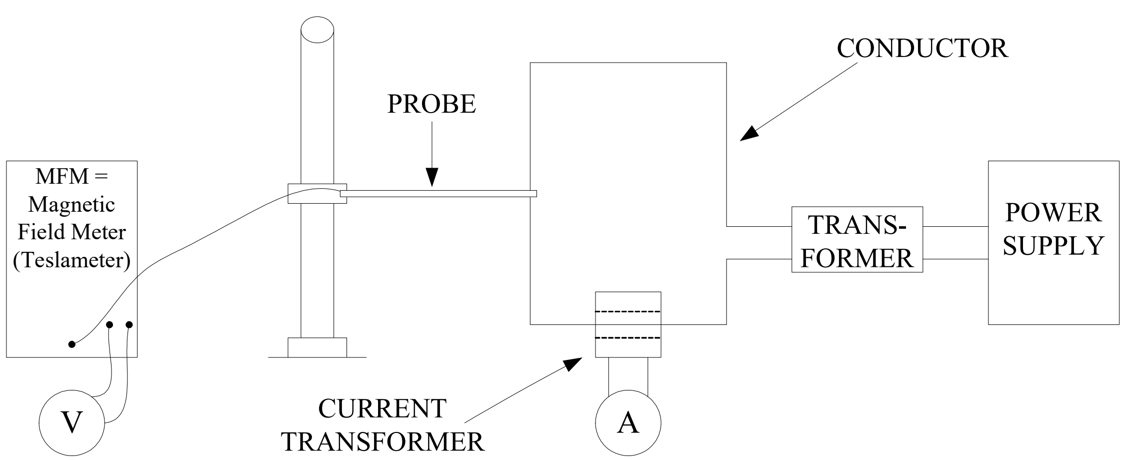


Figure 3: Experimental set-up

transformer for maximum power output.

1. Fix the distance between the tip of the probe and the conductor to 1 *cm* (keep the probe tip near the middle of the vertical conductor). Change the current through the conductor and measure the resulting ***B*** field. (Keep the tip of the probe in the plane of the conducting loop. Also keep the probe perpendicular to the plane of the loop throughout this experiment).

2. Fix the current to 100*A* and change the distance between the probe and the conductor. Record the magnetic field at several distances to produce a smooth curve.

Calibration ➔ ________________________________

Table 1: Magnetic Field variation with Current (r = 1 cm)

Current '*I*' (A)	**Magnetic Field '*B*' (mT)**		**Percentage Error**
	Experimental	**Theoretical**	
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			

Table 2: Magnetic Field variation with Distance (I = 100 A)

Distance '*r*' (cm)	Magnetic Field '*B*' (mT)		Percentage Error
	Experimental	Theoretical	
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

QUESTIONS FOR DISCUSSION

1. Plot a graph of the experimental relation between the current in the wire and the resulting magnetic field. Compare with the theoretical results based on equation (1). (Note: plot both results on top of each other).

2. Plot a graph of the experimental relation between the magnetic field of the wire and distance. Compare with the theoretical results based on equation (1). (Note: plot both results on top of each other).

3. Based on your experimental curve for a single wire, sketch the expected field from the structures in figures 2 (a) and (b).

4. How can you experimentally determine the direction of the magnetic field due to the straight line?

6.MAGNETIC FIELD OF COILS

OBJECTIVE

To measure the magnetic field at the center of wire loops and along the axis of a coil and verify the analytical expressions.

EQUIPMENT REQUIRED

1. Ammeter l*A*/5*A DC*.
2. Universal power supply.
3. Teslameter with an axial probe.
4. Induction coils.
5. Digital meter.
6. Conducting circular loops.
7. Meter scale.

INTRODUCTION

The magnetic flux density ***B*** at a point on the axis of a circular loop of radius b that carries a direct current I (see Figure 1) is given by:

$$\left|\overline{B}\right| = \frac{\mu_o I b^2}{2(z^2 + b^2)^{3/2}} \qquad (1)$$

If there is a number of identical loops close together, the magnetic flux density is obtained by multiplying by the number of turns N. At the center of the loop (z=0), equation (1) becomes:

$$\left|\overline{B}(0)\right| = \frac{\mu_o N I}{2b} \qquad (2)$$

To calculate the magnetic flux density of a uniformly wound coil of length L and N turns (see figure 2), we multiply the magnetic flux density of one loop by the density of turns, N/L and integrate over the length of the coil. The resulting magnetic flux density is given by

$$\left|\overline{B}(z)\right| = \frac{\mu_o N I}{2L}\left(\frac{a}{\sqrt{b^2 + a^2}} - \frac{c}{\sqrt{b^2 + c^2}}\right) \qquad (3)$$

where $a = z + L/2$ and $c = z - L/2$.

If the length of the coil is much larger than its radius, the magnetic flux density near the center of the coil axis can be obtained by approximating equation (3), yielding:

$$\left|\overline{B}(z)\right| \cong \frac{\mu_o NI}{L} \quad (4)$$

(provided that $b << L$ and z is smaller than $L/2$).

PROCEDURE

<u>Calibration and measurement of the teslameter</u>

The calibration steps are as follows

f) Adjust the multimeter knob to the 3V position (choose AC).

g) Push the DC button of the teslameter.

h) Push the "Eichen" button of the teslameter.

i) Turn the "Eichen" knob unth the multimeter reads exactly 3 volts.

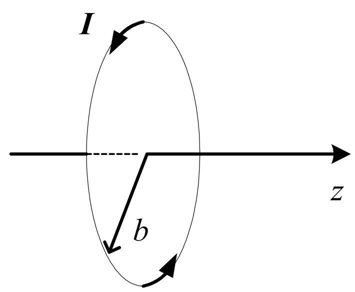
j) Release the "Eichen" button. The teslameter is now calibrated.

Note: Because part *A* of this experiment involves the measurement of relatively weak *DC* magnetic fields, a procedure must be followed to cancel out the contribution to measurement from the naturally occurring magnetic fields.

1. Set the digital multimeter to read *AC* voltage and choose the 20 V setting.
2. Set the knob of the teslameter to $0.3mT$ (i.e., $0.3mT = 3V$ or $0.1mT = 1V$).
3. Push the *DC* button of the teslameter.
4. Place the tip of the axial probe in the location where the magnetic field is to be evaluated (at the center of the coil) and leave it there. The magnetic field must be parallel to the axis of the axial probe.
5. Switch the current I to zero.
6. Turn the "*O* adjust" knob until the multimeter gives minimum reading (for the purpose of this experiment, the reading of the multimeter should be < 0.4 V).
7. Switch the current I on to +5 A. Record the multimeter's reading, call it V_1.
8. Reverse the direction of the current I (i.e., $I = -5A$), record the multimeter's reading and call it V_2. To reverse the direction of I without moving the probe, turn off the power supply, interchange the leads at the output of the power supply, and turn on the power supply again.

9. Take the average of the voltage readings in steps (7) and (8). The average voltage $V=(V_1+V_2)/2$ is the voltage due only to the magnetic field to be measured.

10. Finally, multiply V by the appropriate factor to obtain the value of ***B***.



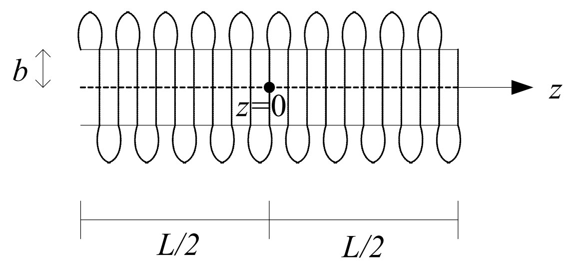


Figure 1: A circular loop of radius b.

Figure 2: A coil

<u>PART A: Magnetic Field at the Center of a Circular Conductor</u>

1. Connect the *DC* output of the power supply to the single-turn circular conductor of diameter $2b=12$ *cm*. Connect the ammeter to measure the current in the conductor. Adjust the current to 5 *A*. Using the Teslameter, measure the resulting *DC* magnetic field ***B*** at the center of the circular conductor.

2. Repeat step (1) for the circular conductor of diameter $2b=12$ *cm* and $N=2$ and $N=3$ turns.

Table 1: Magnetic Field Measurement at the Center of Conductor.

No. of Turns '*N*'	V_1 (Volt)	V_2 (Volt)	$V = (V_1+V_2)/2$ (Volt)	$B_{(experimental)}$ (mT)	$B_{(Theoretical)}$ (mT)
1					
2					
3					

<u>PART B: Magnetic Field inside a Coil</u>

1. Connect the coil of length $L=160$ *mm*, diameter $2b=33$ *mm* and $N=300$ turns to the *DC* output of the power supply. Adjust the current I to $1A$. Measure ***B*** inside the coil at several distances along the axis of the coil.

Table 2: Magnetic Field Measurement inside a Coil.

Distance ‘z’ cm	**V** (Volt)	$\mathbf{B}_{\mathbf{(experimental)}}$ (mT)	$\mathbf{B}_{\mathbf{(Theoretical)}}$ (mT)
0			
2			
4			
6			
8			
10			
12			
14			
16			

QUESTIONS FOR DISCUSSION

1. Plot the relation between the magnitude of the magnetic field and the number of turns and compare it with the theoretical result based on equation (2). (Note: plot both results on top of each other).

2. Why did we need to eliminate the field of the surrounding in part *A* of the experiment but not in part *B*?

3. Plot the magnetic field inside the coil as a function of distance. Compare it with the theoretical graph based on equation (3). (Note: plot both results on top of each other).

4. Plot a curve representing equation (4) on top of the two curves in step (3). Do you think equation (4) is a valid approximation of equation (3) in this case'? Why or why not?

7.MAGNETIC INDUCTION

OBJECTIVE

To verify Faraday's law of induction. The induced voltage in the secondary circuit is measured as a function of the amplitude and frequency of the current in the primary circuit. The variation of the induced voltage with the number of turns and the cross-sectional area of the secondary circuit is also studied.

EQUIPMENT REQUIRED

1. Frequency counter.
2. Function generator.
3. Digital multimeter.
4. Analog multimeter.
5. Voltage transformers 125/220 (two).
6. Field coil 485 turns/meter, 750 *mm* long.
7. Induction coil, 300 turns, 41 *mm* diameter.
8. Induction coil, 300 turns, 33 *mm* diameter.
9. Induction coil, 300 turns, 26 *mm* diameter.
10. Induction coil, 200 turns, 41 *mm* diameter.
11. Induction coil, 100 turns, 41 *mm* diameter.

INTRODUCTION

According to Faraday's law of induction, voltage can be induced in a circuit due to current passing through a nearby circuit. In this experiment, a large solenoidal field coil (item 6 in the equipment list) is used to generate a time-varying magnetic field by passing an *AC* current (I_1) through it. Smaller coils (items 7-11 in the equipment list) are used for induction (see Figure 1).

The *AC* current I_1 passing through the field coil produces a time-varying magnetic field given by:

$$\overline{B} = \mu_o n I_1 \qquad (1)$$

where n is the turns density (turns/meter) of the coil. If the current I_1 is sinusoidal and given by:

$$I_1 = I_o \cos(\omega t) \qquad (2)$$

then, the induced voltage, *v*, in the induction coil is given by:

$$v = \mu_o n \pi a^2 N \omega I_o \sin(\omega t) \qquad (3)$$

where *a* and *N* are the radius and the number of turns of the induction coil, respectively.

PROCEDURE

PART A: Induced voltage vs. current

1. Connect the function generator to the field coil and to the frequency counter.
2. Adjust the frequency to 10.7 *kHz*.
3. Measure the amplitude of I_1, using the analog multimeter.
4. Insert the 300-turn, 41 *mm* diameter coil into the field coil. Insure that the coil is well into the field coil. Measure the induced voltage in the coil using the digital multimeter.
5. Repeat for a range of I_1 from 0 to 30*mA*.

Table 1: Induced Voltage vs. Current

f = 10.7 kHz, N = 300 turns, diameter = 2a = 41 mm

Current **I_1 (mA)**	**Induced Voltage** **‘*v*’ (Volts)**	**Theoretical** **‘*v*’ (Volts)**
0		
5		
10		
15		
20		
25		
30		

PART B: Induced voltage vs. number of turns

1. Fix the current I_1 to 30mA and the frequency to 10.7 kHz. Measure the induced voltage across the 300-tum, 41 mm diameter coil.
2. Repeat step (1) for the 200-turn, 41 mm diameter and the 100-turn, 41 mm diameter coils.
3. Repeat step (1) for a 400-turn, 41 mm diameter coil (not provided but a combination can be used).
4. Repeat step (1) for a 500-turn, 41 mm diameter coil.

Table 2: Induced Voltage vs. Number of Turns

f = 10.7 kHz, I_1 = 30 mA turns, diameter = 2a = 41 mm

No. of Turns **N**	**Induced Voltage** **'*v*' (Volts)**	**Theoretical** **'*v*' (Volts)**
200		
300		
400		
500		

PART C: Induced voltage vs. coil diameter

1. Fix the current I_1 to 30mA and the frequency to 10.7kHz. Measure the induced voltage across the 300-tum, 41 mm diameter coil.
2. Repeat step (1) for the 300-tum coils of diameters 33 mm and 26 mm.

Table 3: Induced Voltage vs. Coil Diameter

f = 10.7 kHz, I_1 = 30 mA turns, N = 300 turns

Diameter	**Induced Voltage**	**Theoretical**

mm	'*v*' (Volts)	'*v*' (Volts)
26		
33		
41		

PART D: Induced voltage vs. frequency

1. Fix the current I_1 to 30mA and the frequency to 1 kHz. Measure the induced voltage across the 300-turn, 41 mm diameter coil.
2. Repeat step (1) for a frequency range from 1 to 12 kHz (make sure that the current is maintained at 30mA each time you change the frequency).

Table 4: Induced Voltage vs. Frequency

I_1 = 30 mA turns, N = 300 turns, Diameter = 2a = 41 mm.

Frequency **kHz**	**Induced Voltage** **'*v*' (Volts)**	**Theoretical** **'*v*' (Volts)**
1		
2		
4		
6		
8		
10		
12		

QUESTIONS FOR DISCUSSION

1. Plot the experimental and the theoretical relations between the induced voltage and current, number of turns, coil diameter and frequency.

2. From your experimental curves, find the induced voltage for the case: N=350, a= 15 mm, I_1= 10mA and f=10 kHz.

3. Use equation (3) to find a theoretical value of the induced voltage for the case in question (2). Compare with your answer of question (2). This is a good measure of the accuracy of your experimental results.

4.

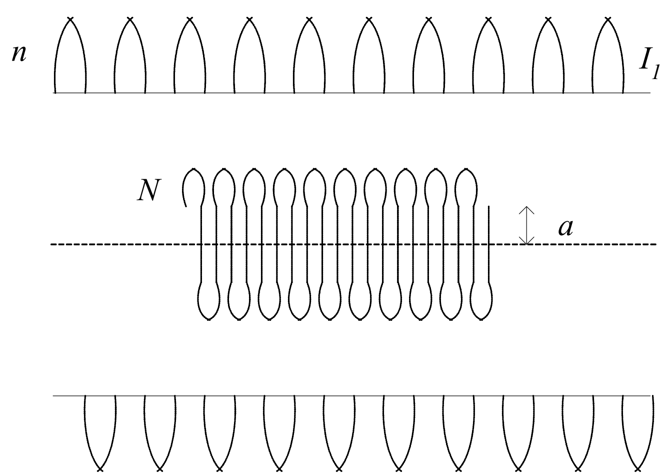


Figure 1: Field and induction coils

8.Hertz's Experiment to demonstrate the production and reception of radio waves

Hertz demonstrated the production of radio waves and confirmed Maxwell's prediction that there were EM waves with frequencies outside the visible light spectrum.

Aim

Hertz wanted to produce EM waves with frequencies and wavelengths other than visible light.

Requirement

1.Aluminium foil

2.conducting Rod

3.LED

4.Electric Lighter

5.Wooden Arrangement

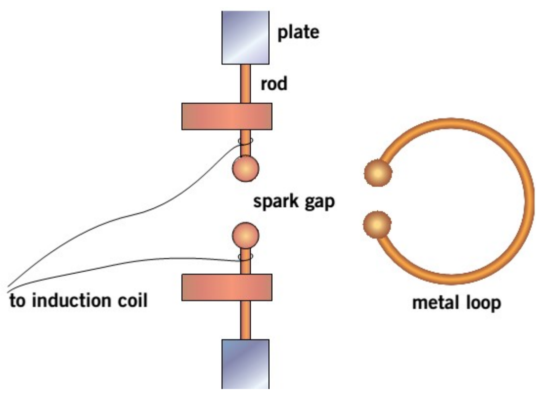
Setup and Method

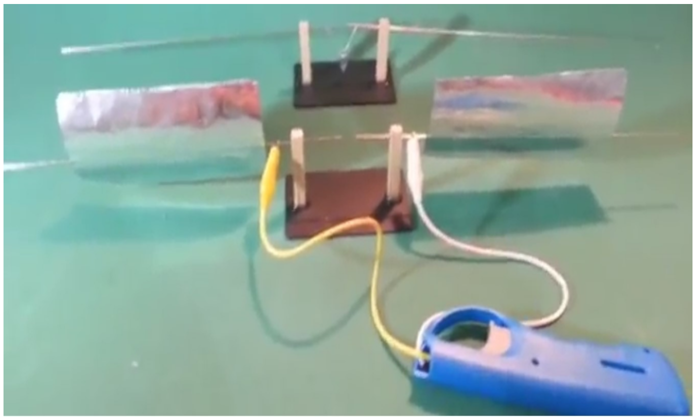
An induction coil was used to create a rapidly oscillating B-field which caused a rapid sparking across a gap between spherical electrodes in a conducting circuit.

This circuit formed the transmitter and a receiving loop also with a gap in it, was placed some distance from the transmitter.

The high voltage induction coil connected to the transmitter was switched on and changes observed

Changes in the receiving electrodes were observed





Observations and Explanations

When the power was on, sparking occurred between the electrodes at the transmitter and this also resulted in sparks at the receiver.

- The high voltage AC produced sparking and a rapidly oscillating electric field which gave rise to a magnetic field and so on.
- Thus, EM radiation (radio waves) were produced and traversed the distance to the receiver
- The EM radiation travelling towards the receiver struck the electrodes of the receiver, **energising electrons** in the conducting surface and caused them to jump across the gap as a spark.
- Note: there were no electrical connections between the transmitter and receiver

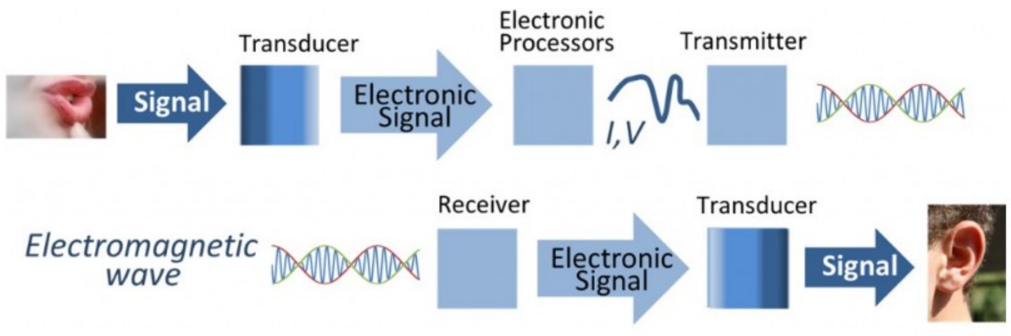
Other properties observed

- **Reflection** – Hertz reflected waves off a zinc plate and they still reached receiver to cause sparking
- **Refraction** – Radio waves were refracted through a prism
- **Polarisation –** He rotated the receiver's plane relative to the transmitter
    - The receiver's intensity and length of sparking at the receiver was a maximum when the plane was parallel and a minimum when perpendicular.
- **Interference** – he observed that waves reaching the receiver from 2 different paths interfered constructively and destructively to produce interference pattern of light and dark patches.
- **Distance –** the length and intensity of sparking at the receiver was not affected by the distance between transmitter and receiver. Suggested that light waves are self-propagating
- **Speed** – The speed was accurately measured to be "c"

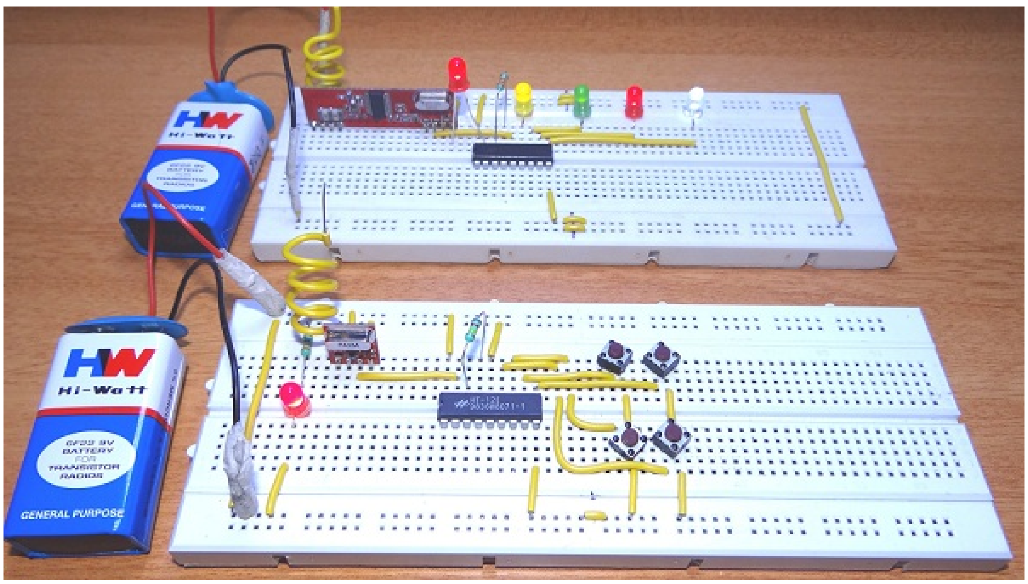
Conclusions

These observations strongly supported Maxwell's prediction of EM radiation and model of light: self-propagating, transverse waves of alternating electric and magnetic fields that are perpendicular to one another. Hertz concluded that radio waves were able to cause sparking at the receiver.

9.Wireless RF Transmitter and Receiver



A sample diagram as to how signal is being processed in electronic communications.



An RF Transmitter and Receiver pair is used for wireless communication. The wireless data transmission is done using 433 MHz Radio Frequency signals that are modulated using Amplitude Shift Keying (ASK) Modulation technique.

In order to implement the wireless transmitter and receiver, we use an encoder IC HT12E and a decoder IC HT12D.

Circuit Diagram

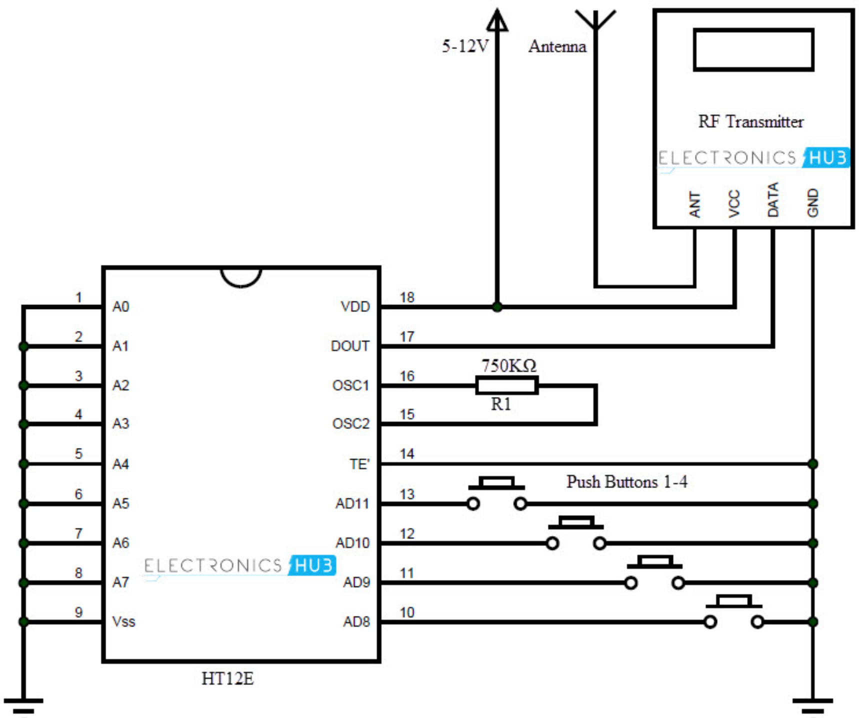
The circuit is divided into transmitter and receiver sections. The transmitter section consists of an RF Transmitter, HT12E encoder IC and four push buttons.

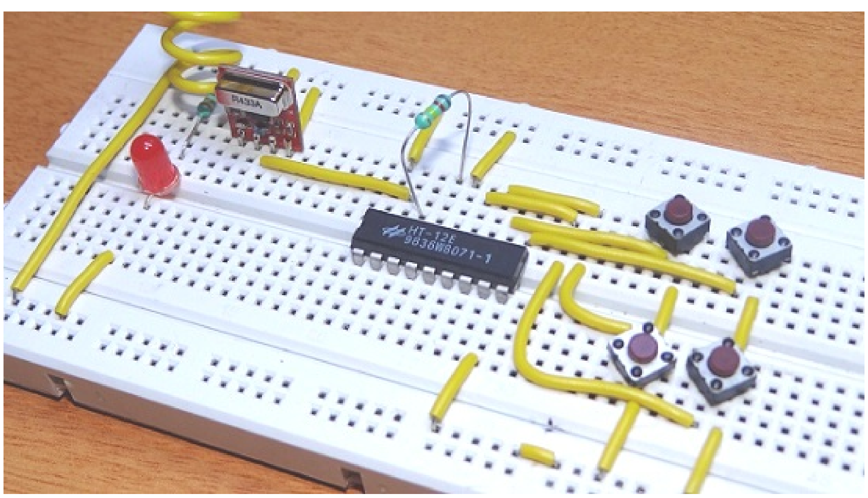
The receiver section consists of RF Receiver, HT12D Decoder IC and four LEDs. An extra LED is connected to VT (Valid Transmission) pin of the decoder IC. This is used to indicate a successful transmission of data.

A 750 KΩ resistor is connected between the oscillator terminals of encoder IC. This is to enable the oscillator.
Similarly, a 33 KΩ resistor is connected between the oscillator pins of decoder IC.

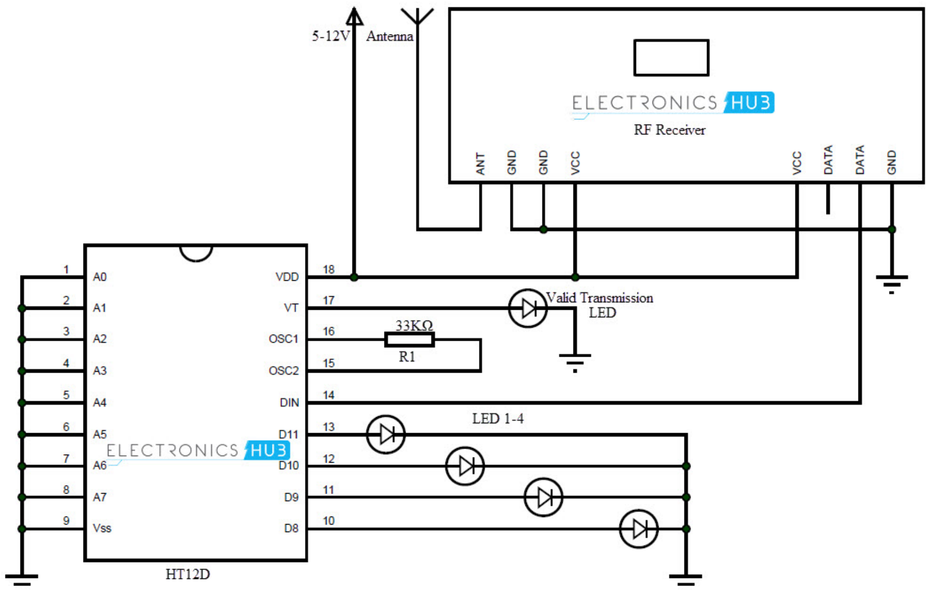
Output

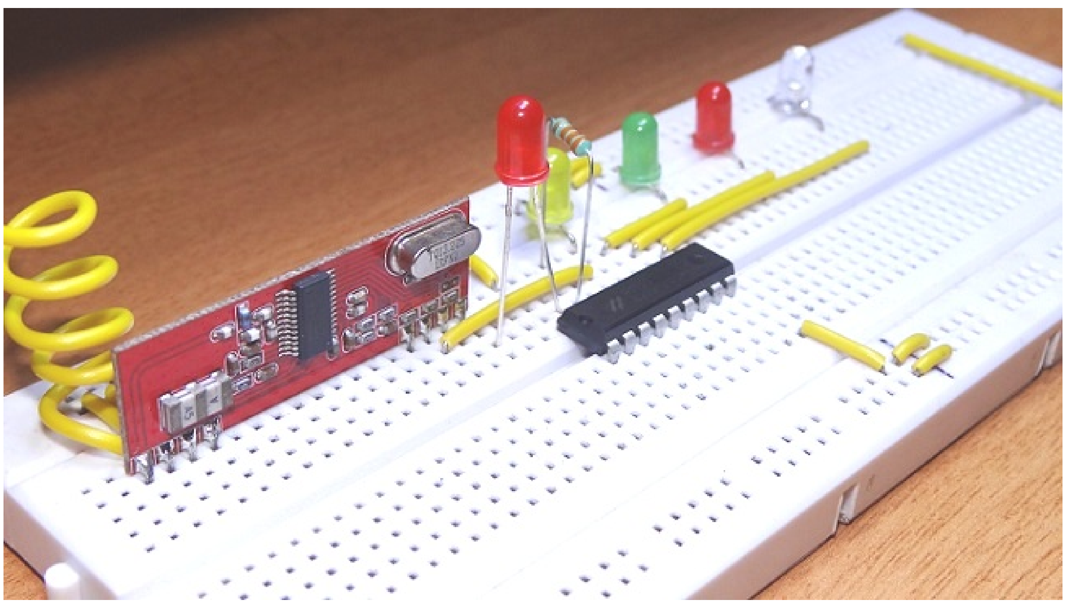
Transmitter





Receiver





Component Description

RF Transmitter and Receiver Modules: The wireless communication between transmitter and receiver sections is achieved using RF modules. A 433 MHz transmitter and receiver pair are used in this project.

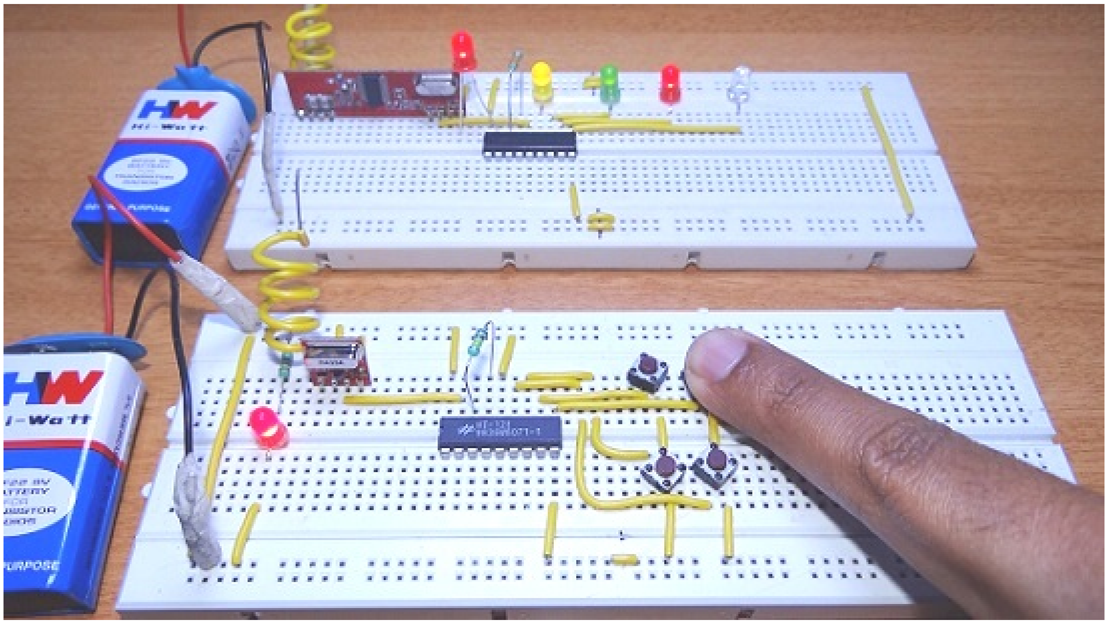
HT12E

It is an encoder IC that converts the 4-bit parallel data from the 4 data pins into serial data in order to transmit over RF link using transmitter.

HT12D

It is a decoder IC that converts the serial data received by the RF Receiver into 4-bit parallel data and drives the LEDs accordingly.

Working



The aim of this project is to implement a wireless transmitter and receiver using RF modules. It uses radio signals to transmit the data. The working of the project is as follows.

The transmitter and receiver sections are placed at a distance of at least 20 meters. In order to show the working of wireless communication between transmitter and receiver, 4 LEDs at receiver side are controlled by 4 buttons at transmitter section.

The HT12E encoder IC converts the 4-bit data from the 4 data pins that are connected to buttons into serial data. This serial data is sent to RF transmitter. The RF transmitter transmits this serial data using radio signals.

At the receiver side, the RF receiver receives the serial data. This serial data is sent to HT12D decoder IC which converts into 4 bit parallel data.

The 4 data pins of decoder are connected to LEDs. According to the buttons pushed, the LEDs can be turned ON or OFF.

Applications

- As RF Modules doesn't require line of sight communication, the transmitter and receiver can be isolated over a distance and data can be transmitted successfully.
- The wireless transmitter and receiver can be used in car door and garage door controllers.
- They can also be used in home automation systems.

10.Simple AM Transmitter / Receiver

Morse code has its origins back to the first telegraph as a method for communicating. Since the only data that could be transferred was either the presence of electrical current or not, all letters and numbers were encoded in such a way that all could be interpreted with either a long pulse or short pulse. In this series of projects, I will show you how to create a Morse code system that you can use to communicate with others at distance! This project will start with the most basic of systems and you will transmit Morse code via a switch and a transmitter/receiver pair.

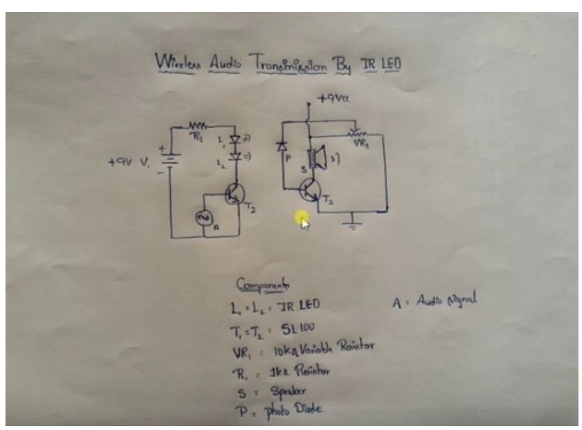
Required Materials

Transmitter

- 10K Resistor (R1)
- 22K Resistor (R2)
- 100nF Capacitor (C1, C3, C5, C6)
- 100uF Capacitor (C2, C4)
- 1n4148 Diode (D1)
- 1n5817 Schottky Diode (D2)
- Tactile Switch (SW1)
- 7805 Regulator (U1)
- CMOS 4093 (U2)
- 433Mhz Transmitter (P2)

Receiver

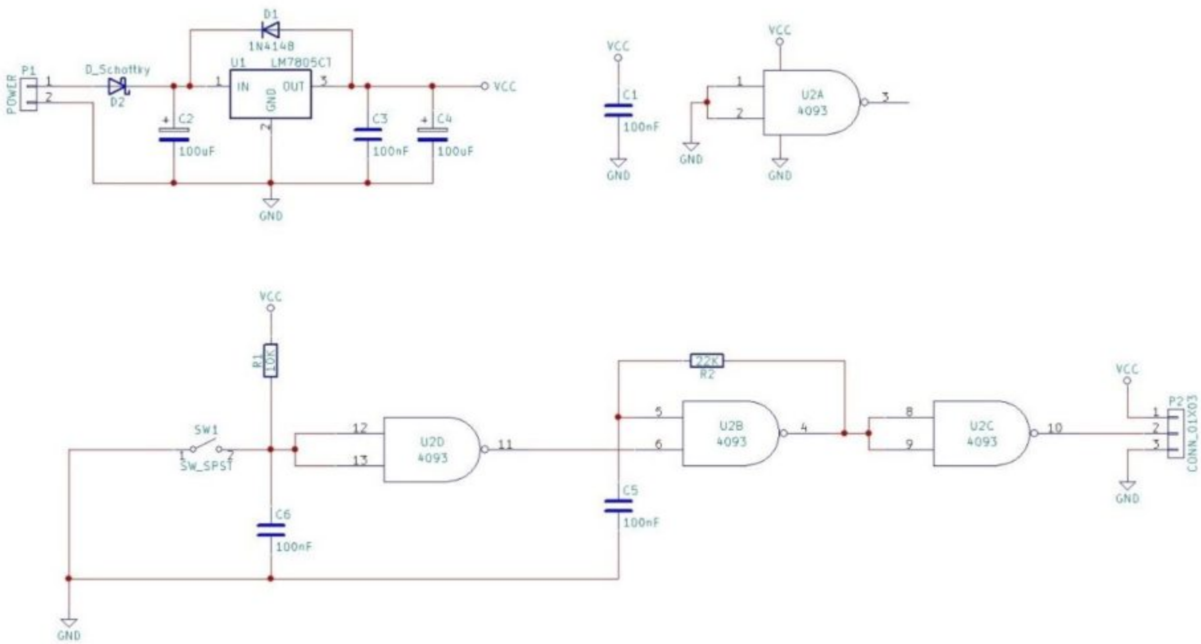
- 100K linear potentiometer (RV1, RV2)
- 100nF Capacitor (C3, C5, C6, C7)
- 100uF Capacitor (C1, C2, C4)
- 1n4148 Diode (D1)
- 1n5817 Schottky Diode (D2)
- 7805 Regulator (U3)
- 74HC14 (U1)
- LM358 (U2)
- Phono Jack
- 433MHz Receiver



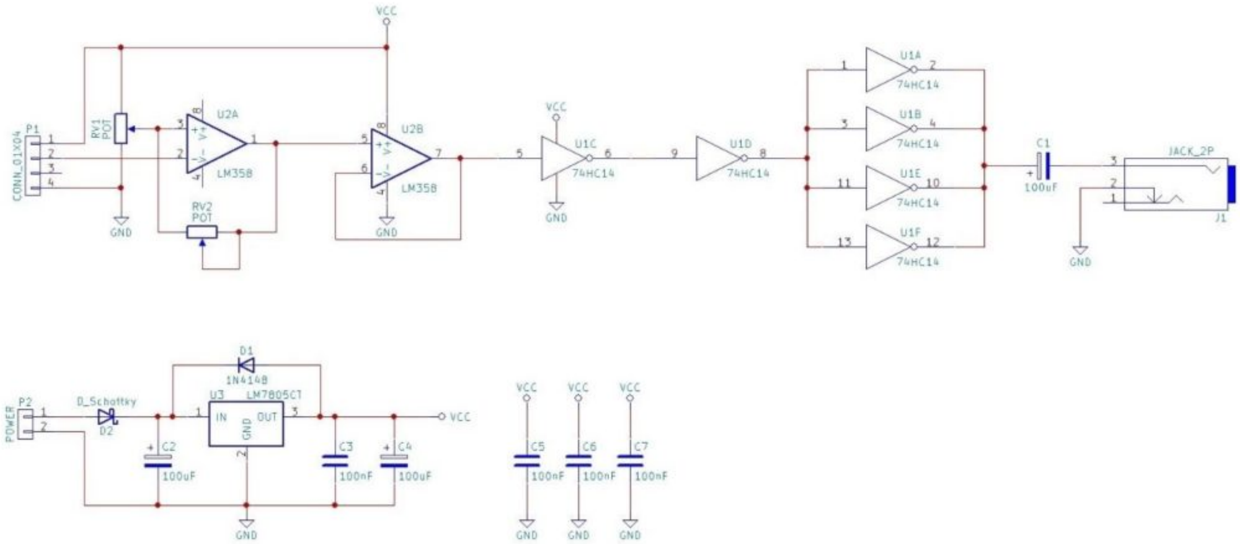
- speaker- 8ohm

- for audio signal input use 3.5mm Audio pin

Transmitter Schematic



Receiver Schematic



How Does it Work?

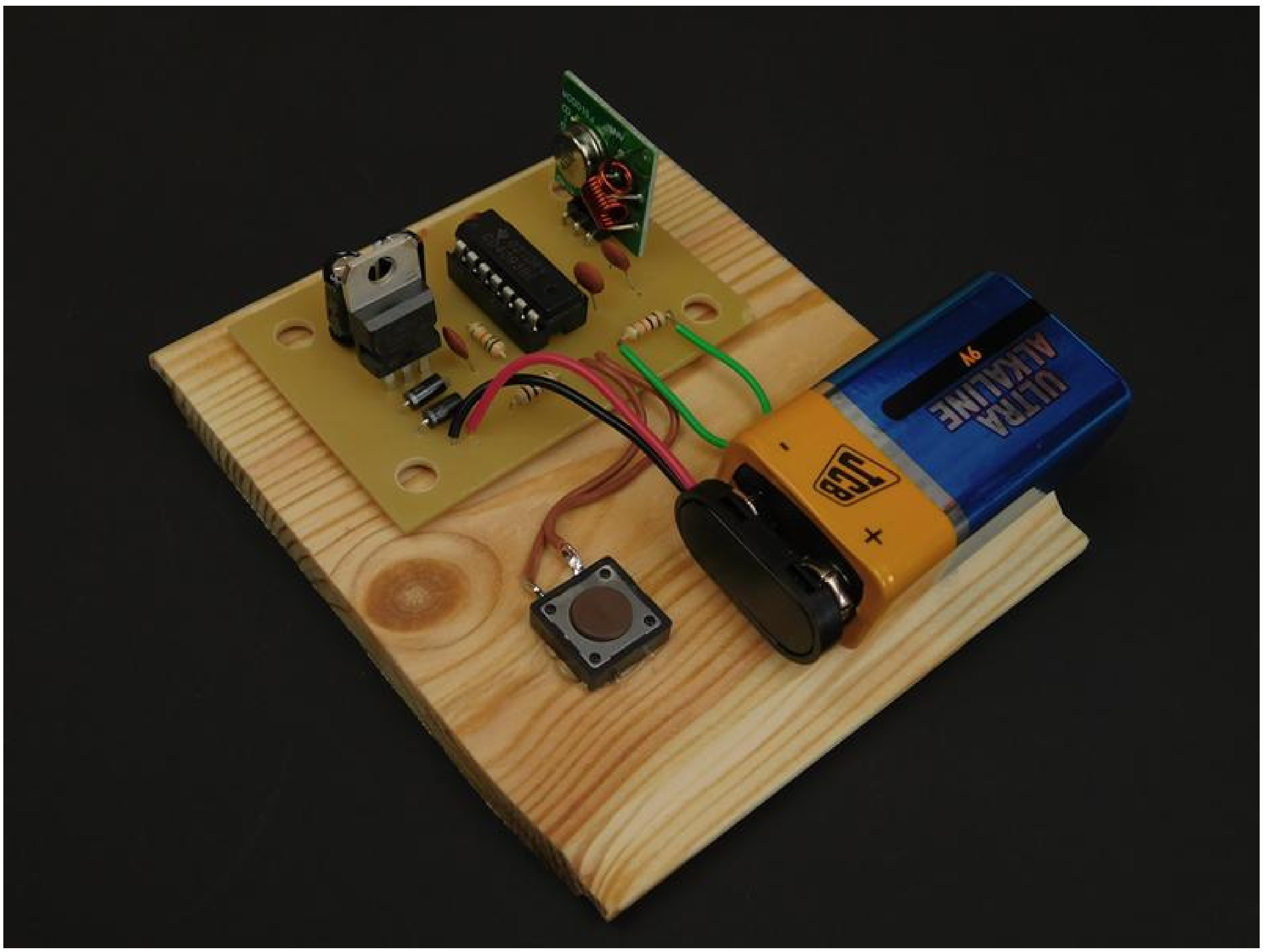
The heart of both the transmitter and receiver is the use of premade modules that help dramatically. The reason for using premade modules is due to the difficulty in getting radio transmitters and receivers at that frequency to function correctly. Some problems that can occur include incorrect inductor sizes, PCB tracing issues, proven circuitry, and tuning.

The transmitter itself consists of a switch, a 4093-based oscillator with enable, and the 433Mhz transmitter module. If the switch is open, then the NAND gate U2D outputs 0V which in turn feeds 0V into one of the inputs to the NAND gate U2B. U2B is configured as an inverting Schmitt trigger oscillator where the frequency of the oscillator is determined by the size of C5 and R2. Increasing the value of either of these components decreases the output frequency of U2B and in this circuit, they have been chosen to produce an audible tone near 500Hz. But for the oscillator to oscillate it requires its second input to be connected to VCC and so when the switch is pressed, U2D feeds a voltage of VCC into the second input of U2B. When this happens, U2B outputs the 500Hz tone into U2C and then into the data input on the 433MHz transmitter. So, to summarize, when the switch is not pressed the transmitter transmits nothing and when the switch is pressed it transmits a 500Hz tone.

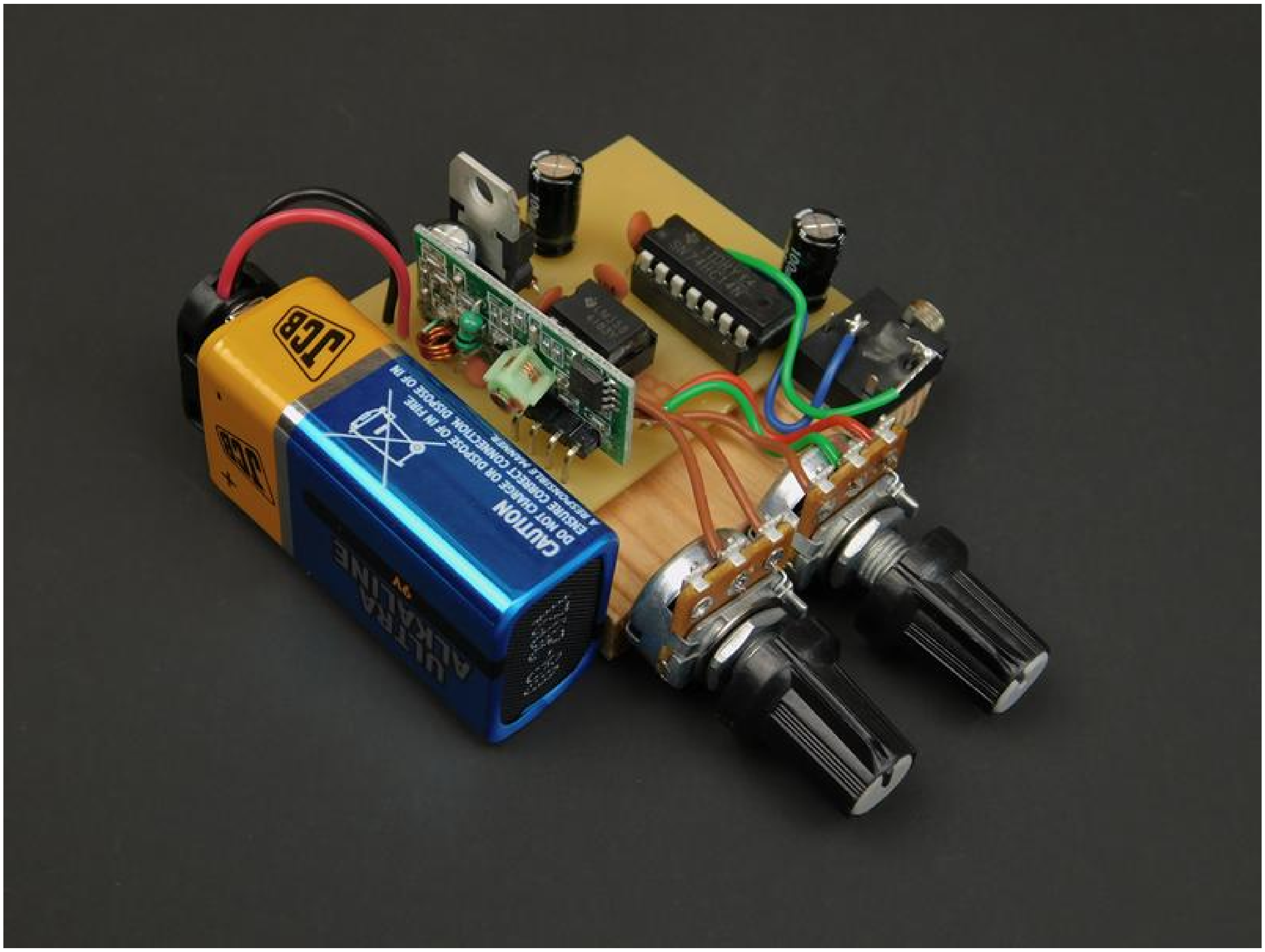
The receiver consists of a configurable Schmitt trigger input, an inverter, and output buffer. The input Schmitt trigger that takes the signal from the receiver module is used as to prevent noise on the input (RV1 and RV2 can be adjusted to give a clean signal from the receiver). The signal is then buffered with U2B to improve output impedance and this buffered signal is finally fed into a basic driver consisting of U1A, U1B, U1C, U1E, and U1F all in parallel to improve output current capabilities. The final output is fed into C1 to remove the DC offset so the signal can be fed into headphones.

Construction

Like all electronic projects posted by myself, this circuit is ideal for most circuit construction techniques. These include the use of a custom PCB (design files provided), stripboard, breadboard, and for those who are feeling adventurous, point-to-point. When building this project, the application that the circuit is used in should be considered. For example, if the objective is to have the transmitter/receiver portable, mount the circuit on a single board and use a project enclosure. Powering the circuits can be done with any voltage source about 6V and lower than 30V. The project built here uses 9V batteries that fit nicely to the side of the project base. You can find a downloadable version of the project files below:



Transmitter Circuit



Receiver Circuit