CHAPTER 01

INTRODUCTION

A wireless microphone is a portable electronic microphone that allows the user to transmit

their voice to an amplifier without a cable connection, hence the name of a wireless microphone.

- Making a wireless microphone at home can be a lot of fun. Here we learn one of those simple projects that can be used to record and send back your wireless voice.
- Microphone units and wireless amplifiers are typically used during PA programs, stage entertainment, or any of the ways that voice signals are amplified to be audible in a larger area and distance.

However, since the microphones normally hold their hand while speaking, the device must be perfectly free of problems so that the person holding it can move freely in the premises. In this article, we learn how to create a simple wireless microphone circuit and how to use it exactly for the purposes described above.

- This FM Wireless Microphone Transmitter has been a very popular project for novice and experienced builders.
- It has been used inside guitars and as a basis for a remote control system. However, I get many requests for a higher power circuit and better microphone sensitivity. I can now introduce the new FM wireless microphone, which also offers better frequency stability, a range of over 1 km (in ideal conditions) and is suitable for microphone sensitivity. This was done by adding an RF amplifier buffer (with a 10 dB gain) and an AF preamplifier to slightly increase the modulation.

A wireless microphone, or a wireless microphone, is a microphone without a physical cable that connects it directly to the sound recording or amplification equipment with which it is associated. Also called a radio microphone, it has a small battery-powered radio transmitter in the body of the microphone, which transmits the audio signal from the radio microphone to a nearby receiving unit, which recovers the sound. The other audio equipment is connected to the cable receiving unit.

In one type, the transmitter is contained in the body of the handheld microphone. In another type, the transmitter is contained in a separate unit called "bottle", usually attached to the user's belt or concealed under his clothes.

The pocket pack is wired to a "lapel microphone" or "lava" (a small microphone attached to the user's tie), to a headset or other wired microphone. Most pocket designs also support a connection to a wired instrument (for example, to a guitar).

Wireless microphones are widely used in the entertainment, television, and speech industry to allow speakers, interviewers, artists, and artists to roam freely while using a microphone without the need for a cable. necessary.

Wireless microphones typically use the VHF or UHF frequency bands because they allow the transmitter to use a small discrete antenna. Cheap units use a fixed frequency, but most units allow you to choose multiple frequency channels, if there is interference in one channel or allow multiple microphones to be used at the same time.

FM modulation is generally used, although some models use digital modulation to prevent unauthorized reception by scanner radio receivers; These operate in the 900 MHz, 2.4 GHz or 6 GHz ISM bands. Some models use antenna diversity (two antennas) to prevent null transmitters from interrupting transmission when the artist moves. Some low-cost models (or specialists) use infrared light, although these require a direct line of sight between the microphone and the receiver.

CHAPTER 02

LITERATURE SURVEY

The design of transmitter was introduced by Guglielmo Marconi, first Marconi Marquis (Italian: April 25, 1874 - July 20, 1937) was an Italian inventor and electrical engineer, known for his pioneering work in long-distance radio transmission, the development of Marconi and a radio-telegraphy system. He is recognized as the inventor of radio and shared the 1909 Nobel Prize in Physics with Karl Ferdinand Braun "in recognition of his contributions to the development of wireless telegraphy".

- A breakthrough occurred in the summer of 1895, when Marconi found that a much larger range could be achieved by increasing the height of his antenna and using a technique used in cable telegraphy, he connected his transmitter and receiver to Earth.

Thanks to these improvements, the system was able to transmit signals up to 3.2 km and on hills. The unipolar antenna reduces the wave frequency relative to the dipole antennas used by Hertz and emits vertically polarized radio waves that can travel longer distances. At this point, he concluded that a device could cover greater distances, with additional funds and research, and would be of great commercial and military value. Marconi's experimental device proved to be the first commercially successful radio transmission system with complete engineering.

➢ DISCOVERY:

Edwin Howard Armstrong (Electrical Engineer and American inventor, born December 18, 1890 - February 1, 1954) developed the FM (Frequency Modulation) radio and super heterodyne receiving system. He holds 42 patents and receives numerous awards, including the first Medal of Honor from the Institute of Radio Engineers (IEEE), the French Legion of Honor, the Franklin Medal of 1941 and the Edison Medal of 1942.

➢ REFERED BOOK:

"CONSUMER ELECTRONICS"

AUTHOR:

- **S P BALI**

Former Faculty member,

Military college of electronics and mechanical engineering,

Secundrabad , India.

LAVALIER MICROPHONE:

For many applications mobility is a primary requirement for a microphones, gun microphones has some advantages over those permanently mounted on a stand as they can be used in the hand and carried around to the limit of the connecting cable length.

- As these can be fitted to a stand with quick release clips, they have a versatility to which no doubt is due to the popularity of this type of instrument.

A disadvantage is that one hand of the user is always occupied and held up in an unnatural position this can impose a serious restriction on speaker or "LECTURERS" who may wish to demonstrate points with models or exhibits, use a black board or just be free to use gestures.

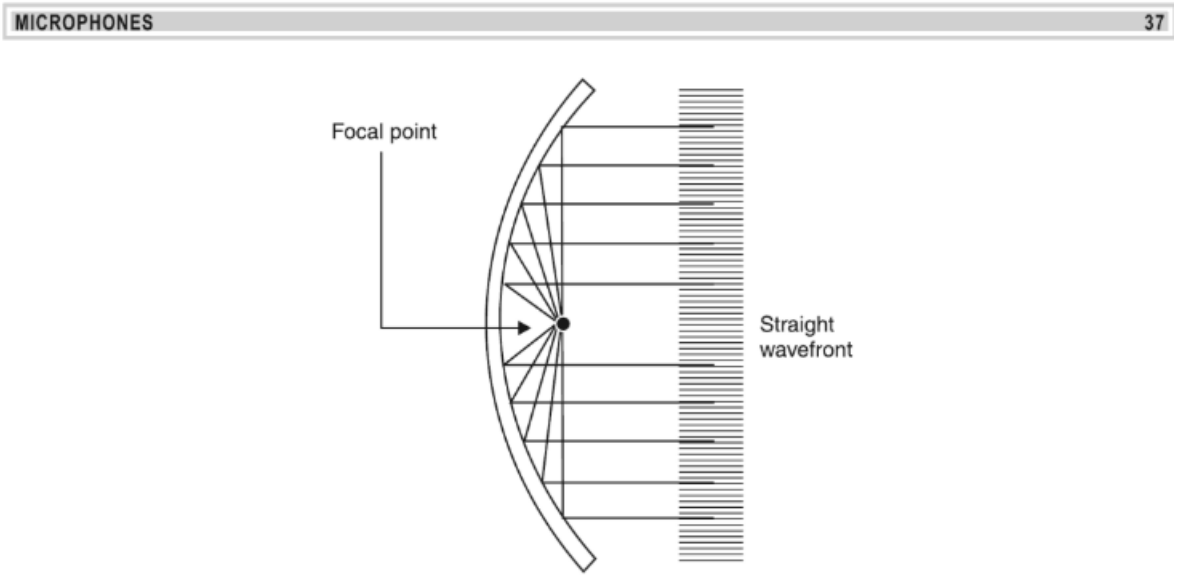


Fig. 2.20 *Paths from a straight wavefront to a point of focus in front of a reflector must be of equal length so that sound arrives at the same time. This is ensured by using a parabola.*

- **Fig no:1**

One answer to these problems is the **" Lavalier microphone".**

Which is a small transducer suspended on the cheat by means of a cord around the neck.

Any type of instrument can be used for the purpose by arranging suitable fittings to take the cord.

- There are problems involved in using a microphone in this way, one of these is the resonance of the human chest cavity which emphasizes frequencies around 700HZ and a rise from 3KHZ and 10KHZ and give a muffled reproduction.

In order to overcome these effects special microphones have been developed for lavalier use .these have a dip in their response around 700HZ and a rise of 3KHZ upward, these characteristics balance the deficiencies and result in a more or less flat overall response. The frequency curve in free air and that when used as a lavalier is shown below graph.

In the graph in this respect an electrical microphone would be ideal for this application as the frequency characteristic of most of these instruments is that of rising treble and falling bass response.

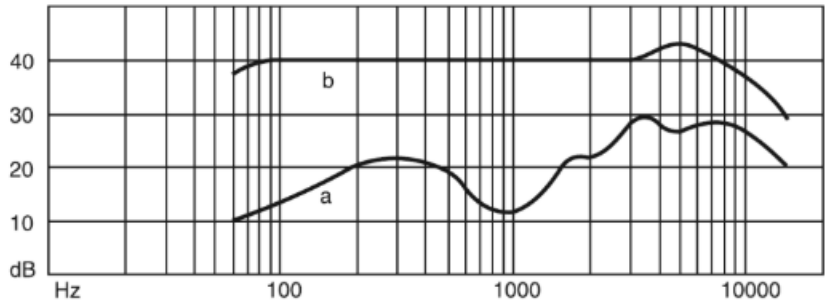


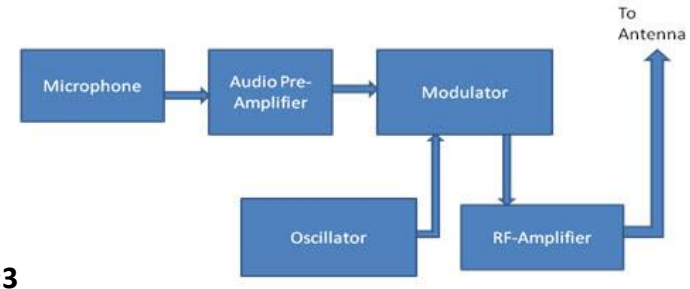
Fig. 2.21(a) *Curve (a) shows the response of a typical lavalier microphone in free air but curve (b) gives the response when used as a lavalier. The trough at 700 Hz has equalised the chest resistance and the rising treble, the masking effect of the clothing.*

- **Fig no:2**

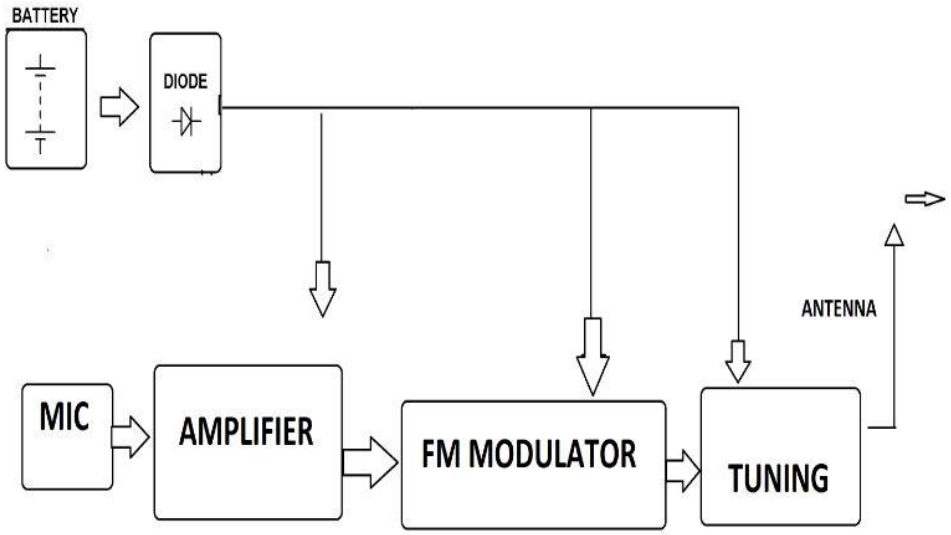
CHAPTER 03

PROPOSED METHODOLOGY

BLOCK DIAGRAMS OF FM TRANSMITTER:

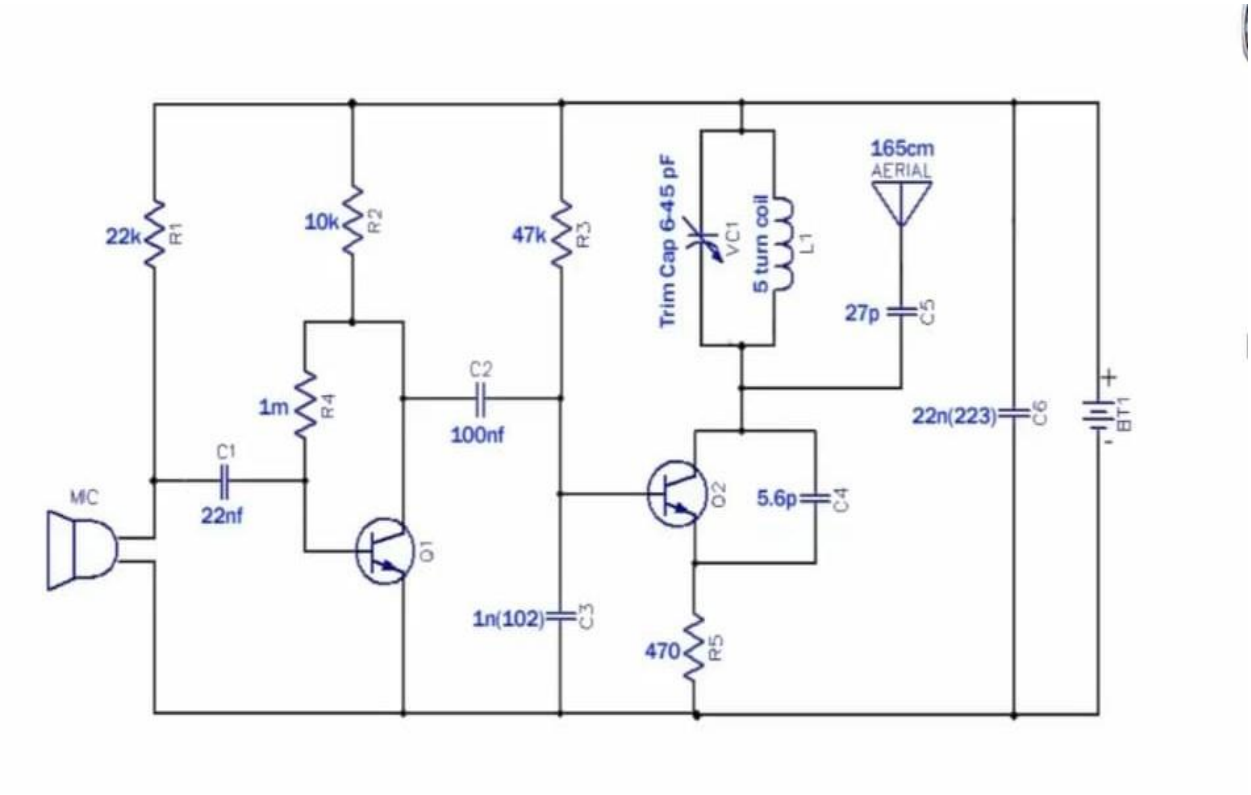


❖ **Fig no:3**



❖ **Fig no:4**

CIRCUIT DIAGRAM USED:



❖ **Fig no:5**

➔ The diagram shows the circuit which we have used to make this project "FM TRANSMITTER (LAVALIER MICROPHONE)".

Which consists of different components such as MIC, resistors, capacitors, transistors, Antenna, inductor coil(0.1uH),battery , e. t. c…

FM TRANSMITTER CIRCUIT PRINCIPLE: The FM transmission is done through the process of audio preamplification, modulation and transmission. Here, we adapted the same formula by first amplifying the audio signal, generating a carrier signal using an oscillator, then modulating the carrier signal with the amplified audio signal. The amplification is performed using an amplifier, while the modulation and the generation of the carrier signal are performed using a variable frequency oscillator circuit. The frequency is set anywhere in the FM frequency range 88 MHz to 108 MHz. The power of the oscillator FM signal is amplified using a power amplifier to produce a low impedance output adapted to the antenna.

Theory behind the FM transmitter circuit:

The audio signal from the microphone is a very low signal, of the order of factory volts. This extremely low voltage must first be amplified. A common emitter configuration of a bipolar transistor, biased to operate in the class A region, produces an amplified inverted signal.

- Another important aspect of this circuit is the Colpitt oscillator circuit. It is an LC oscillator in which the energy moves back and forth between the inductor and the capacitor by forming oscillations. It is mainly used for RF applications.

When this oscillator receives an input voltage, the output signal is a mixture of the input signal and the oscillating output signal, producing a modulated signal. In other words, the frequency of the circuit generated by the oscillator varies with the application of an input signal, producing a modulated frequency signal.

FM transmitter circuit design:

- **Audio Preamp Design:**

We design here a single-stage emitter amplifier as a preamp.

1) Vcc selection: Here we have selected the NPN bipolar junction transistor, QN222. As the VCEO for this transistor is around 40V, we choose a much smaller VCC, around 9V.

2) Selecting the load resistor, R4: To calculate the load resistor value, the inactive collector current must first be calculated. The collector voltage should be approximately half Vcc. This gives the value of the load resistance, R4 as: Vc / Iq

3) Selection of the resistors of the voltage divider R2 and R3: To calculate the value of the resistances of the voltage divider, we must calculate the bias current and the voltage across the resistors. The bias current approaches 10 times the base current. Now, the base current, Ib is equal to the collector current divided by the current gain, HFE. This gives the value of Ib.

Therefore, R2 = V b / bias

R3 = (Vcc -Vb / bias)

4) Selection of transmitter resistance R5: Ve / Ie gives the value of R5, where Ie is the current of the transmitter and is approximately equal to the current of the collector. This gives R5 = (Ve / Ie). It is used to bypass the current of the transmitter.

5) Selection of coupling capacitor C1: this capacitor is used here to modulate the current flowing through the transistor. A high value indicates a low frequency (bass), while a lower value increases the treble (higher frequency).

6) Selection of the resistance of the microphone R1: the purpose of this resistance is to limit the current passing through the microphone, which must be less than the maximum current that a microphone can handle.

7) Selection of the shunt capacitor, C4: Here, we select an electrolyte capacitor, which omits the continuous signal.

Since we need a low power output, we prefer to use a Class A power amplifier with an LC tank circuit at the output. The values of the components of the tank circuit are the same as in the oscillator circuit. Here, we select the bias resistor the coupling capacitor.

- **Antenna selection**:

Since the range is about 500m, we can prepare an antenna using an antenna or a cable of about 165 cm, which is about 1/4 of the length of the antenna. transmission wave.

FM transmitter circuit operation:

The above circuit diagram shows the FM transmitter circuit and the electrical and electronic components required for this circuit are the power supply, the resistor, the capacitor, the trimmer, the inductor, the microphone, the transmitter and the transmitter. 'antenna.

Consider the microphone to understand the sound signals and inside the microphone is a capacitive sensor. It produces according to the vibration during the change of atmospheric pressure and the AC signal.

The formation of the oscillating vessel circuit can be performed via the qn222 transistor using the inductance and the variable capacitor. The transistor used in this circuit is an NPN transistor used for general purpose amplification. If the current passes through the inductor L1 and the variable capacitor, the tank circuit will oscillate at the resonant carrier frequency of the FM modulation. The negative reaction will be capacitor C2 to the oscillating tank circuit.

To generate the radio frequency carrier waves, the FM transmitter circuit requires an oscillator. The tank circuit is derived from the LC circuit to store the energy required for the oscillations.

The audio input signal from the microphone is input to the base of the transistor, which modulates the carrier frequency of the LC tank circuit to the FM format. The variable capacitor is used to change the resonance frequency for fine modification of the FM frequency band. The modulated antenna signal is transmitted in the form of radio waves in the FM frequency band and the antenna is only a copper wire 20 cm long and 24 gauge. In this circuit, the length of the antenna is antenna should be important. And here you can use the 165 cm long copper wire from the antenna.

CHAPTER 04

PROJECT DESCRIPTION

S. No	Required Components	Remarks	Quantity
1	MIC		1
2	INDUCTOR COIL	0.1uH(5 turns)	1
3	AERIAL ANTENNA	165 CM	1
4	TRIM CAP	6-45 pF	1
5	RESISTORS	Quarter watt	R1=22K ohm --------1 R2=10K ohm-------- 1 R3=47K ohm---------1 R4=1m ohm--------- 1 R5=470 ohm---------1
6	CAPACITORS	Ceramic, electrolytic	C1=22 nF----------1 C2=100 nF----------1 C3=0.1 uF----------1 C4=5.6 pF----------1 C5=27pF----------1 C6=22n(223)----------1
7	TRANSISTOR	Qn222 NPN transistor	2
8	Power supply		1

MIC:

❖ **Fig no:6**

A Lavalier or lapel microphone (also called a lava, lapel microphone, clip-on microphone, body microphone, neck microphone, neck microphone or personal microphone) is a small microphone used for television, theater and television.

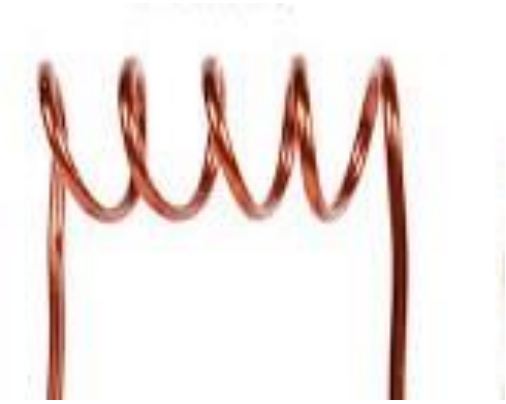
Speaking in public to allow hands free operation. Usually, small clips are provided to attach to necklaces, ties or other clothing. The cable can be hidden by clothing and routed to a radio frequency transmitter stored in a pocket or attached to a belt, or directed directly to the mixer or recording device.

These miniature microphones are often supplied with a selection of slip-on grids of different lengths that provide a smooth, high-frequency pulse when forming a resonant cavity.

A peak of about 6 dB at 6-8 kHz is considered beneficial to compensate for the loss of clarity when mounted on the chest, just like a peak of a few decibels at 10-15 kHz when mounted on the speakers. Hair on the forehead. . This method of increasing high frequencies does not worsen the performance in terms of noise, unlike an electronic equalization.

The lavalier microphones date back to 1932. Several models have been manufactured, including those with condenser diaphragms, ribbons, moving coils and carbon buttons. The term refers to any small microphone likely to get caught in the eyelet of a flap. The lapel microphone offers freedom of movement.

INDUCTOR COIL:



❖ **Fig no:7**

The inductor we used in this project is 0.1uH inductance consists of 5 turns. An inductor, also called a coil, choke or reactor, is a two-terminal passive electrical component that stores energy in a magnetic field when the electric current passes through it. An inductor generally consists of an insulated wire wound in a coil around a core.

When the current flowing in an inductor changes, the time-varying magnetic field induces an electromotive force (e.m.f.) (voltage) in the conductor, described by the Faraday induction law. According to Lenz's law, the induced voltage has a polarity (direction) that opposes the change of current that created it. As a result, the inductors oppose any change in the current flowing through them.

An inductor is characterized by its inductance, which is the relationship between the voltage and the rate of change of current. In the International System of Units (SI), the unit of inductance is Henry (H) named after the American scientist Joseph Henry of the nineteenth century. In the measurement of magnetic circuits, this equates to weber / amps. The inductances have values that typically vary from 1 µH (10-6 H) to 20 H. Many inductors have a magnetic core of iron or ferrite inside the coil, which serves to increase the magnetic field and therefore inductance With capacitors and resistors, inductances are one of the three elements of the passive linear circuit that form electronic circuits. Inductors are widely used in AC electronic equipment, especially radio equipment. They are used to block the alternating current while allowing the direct current to pass; Inductors designed for this purpose are called joysticks. They are also used in electronic filters to separate signals of different frequencies and, in combination with capacitors for making tuned circuits, they are used to tune radio and television receivers.

August 23, 2019

AERIAL ANTENNA:

❖ **Fig no:8**

You have probably noticed that almost all the radios you see (like your mobile phone, your car radio, etc.) have an antenna. Antennas come in all shapes and sizes, depending on the frequency the antenna is trying to receive. The antenna can be a long and rigid cable (like in AM / FM radio antennas in most cars) to something as strange as a satellite dish. Radio transmitters also use extremely high antenna towers to transmit their signals.

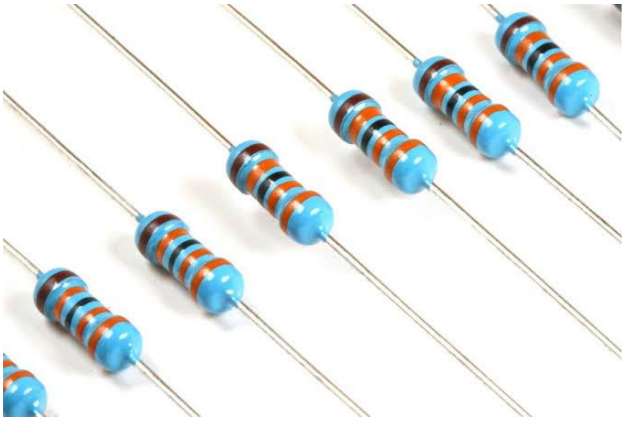
The idea behind an antenna in a radio transmitter is to launch radio waves into space. In a receiver, the idea is to collect as much current as possible from the transmitter and supply it to the tuner. For satellites spaced several million kilometers apart, NASA uses huge satellite dishes up to 60 meters (200 feet) in diameter.

The size of an optimal radio antenna depends on the frequency of the signal that the antenna is trying to transmit or receive. The reason for this relationship is related to the speed of light and, consequently, the distance traveled by the electrons. The speed of light is 300 000 km / s. On the next page, we will use this number to calculate the size of an actual antenna.

Antenna Modulation in improve signal quality dramatically when using much smaller antennas. The researchers have demonstrated the concept using antennas one-third the size of a conventional antenna for a given wavelength.

Antenna plays a very important and key role in transmitting the signal and modulating the signal to faraway places which is very far distance.

RESISTORS:



❖ **Fig no:9**

A resistor is a passive two-component electrical component that implements an electrical resistor as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, divide voltages, bias active elements, and terminate transmission lines, among other uses. High power resistors that can dissipate many watts of electrical energy in the form of heat can be used in motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that change only slightly with temperature, duration or operating voltage. Variable resistors may be used to adjust circuit elements (such as a volume control or lamp dimmer), or as devices for detecting heat, light, moisture, force, or chemical activity.

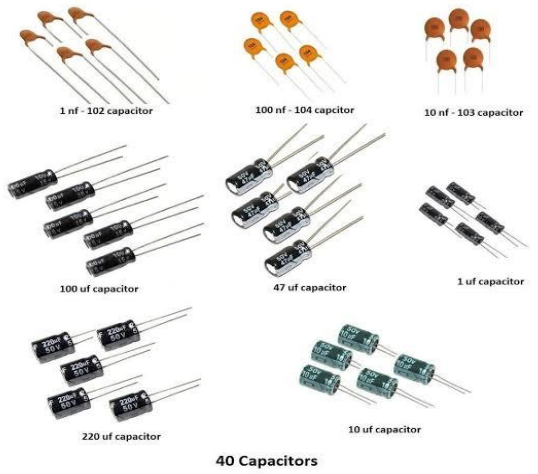
Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. Practical resistors as discrete components may be composed of various compounds and forms. Resistors are also implemented in integrated circuits.

The electrical function of a resistor is specified by its resistance: common commercial resistors are manufactured in a range of more than nine orders of magnitude. The nominal resistance value is within the manufacturing tolerance specified in the component.

There are two connections which electrical components are connected within the circuit- series and parallel.

they consists of different color codes: BBROYGBPGW.

Capacitors:



❖ **Fig no:10**

A capacitor is a device that stores electrical energy in an electric field. It is a passive electronic component with two terminals.

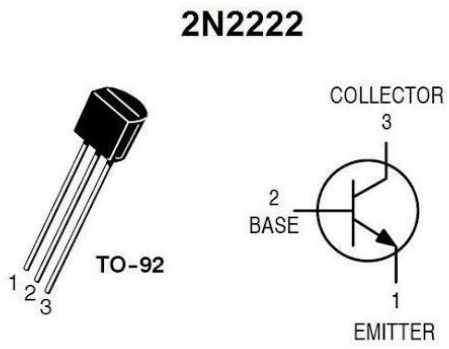
The effect of a capacitor is called capacitance. Although there is some capacitance between two nearby electrical conductors in a circuit, a capacitor is a component designed to add capacitance to a circuit. The capacitor was originally known as a capacitor or capacitor. The original name is still widely used in many languages, but not fluently in English.

The physical form and construction of the practical capacitors vary widely and many types of capacitors are commonly used. Most capacitors contain at least two electrical conductors often in the form of metal plates or surfaces separated by a dielectric medium. A conductor may be a sheet, a thin film, a sintered metal bead, or an electrolyte. The non-conductive dielectric acts to increase the capacitance of the capacitor.

Commonly used materials such as dielectrics include glass, ceramic, plastic films, paper, mica, air and oxide layers. Capacitors are widely used as parts of electrical circuits in many common electrical devices. Unlike a resistor, an ideal capacitor does not dissipate energy.

When an electrical potential is applied, a voltage across a capacitor, for example when a capacitor is connected across a battery, an electric field develops across the dielectric, causing a net net charge to accumulate on a base and a net negative charge. pick up on the other plate. No current actually flows through the dielectric. However, there is a charge flow through the source circuit. If the condition is maintained sufficiently, the current through the source circuit ceases. If a variable voltage is applied over time through the capacitor leads, the source experiences a DC current because of the charge and discharge cycles of the capacitor.

TRANSISTOR:



- **Fig no:11**

A transistor is a device with three terminals. BASE,EMMITER,COLLECTOR

Base: is responsible for activating the transistor.

Collector: This is the positive thread.

Transmitter: it's the negative cable.

The basic idea behind a transistor is that it allows you to control the flow of current in a channel by varying the intensity of a much smaller current flowing through a second channel.

A transistor is a semiconductor device used to amplify or modify electronic signals and electrical energy. It is composed of semiconductor material, usually with at least three terminals for connection to an external circuit.A voltage or current applied to a pair of transistor terminals controls the current through another pair of terminals. Since the controlled power (output) may be greater than the control power (input), a transistor may amplify a signal. Today, some transistors are individually packaged, but many more are integrated in integrated circuits.

Most transistors are very pure silicon and germanium, but other semiconductor materials can also be used. A transistor can have only one type of load carrier, in a field effect transistor, or two types of load carrier in bipolar junction transistor devices. Compared to the vacuum tube, the transistors are generally smaller and require less energy to operate. Some vacuum tubes have advantages over transistors at very high operating frequencies or at high operating voltages. Many transistor manufacturers are manufactured to standard specifications by several manufacturers.

TRIM CAP:

❖ **Fig no:12**

❖ **Fig no:13**

TRIM CAP:

- To allow the oscillator to tune the entire FM range
- The transmission band has two adjustment plugs on the circuit.
- The yellow adjustment cover is used to tune the transmittera clear part of the tape and the blank can be used to
- Set the transmitter to the desired frequency.

POWER SUPPLY:

RF energy can save energy if the supply voltage is modulated dynamically. The power supply requires a small output capacity to obtain a fast voltage modulation with a very high efficiency and a small size.

These requirements become a challenge if a very good regulation is also required in case of aggressive changes in the charging current. In this document, a detailed analysis of the filter design and reduction converter control leads to a very low efficiency and a small design that meets the requirements of dynamic regulation, including aggressive load current variations. , with a low output capacity.

The intertwining of currency converters turns out to be the enabling solution. A prototype has been built and the measurements are in agreement with the theoretical results.

CHAPTER 05

RESULT AND DISCUSSION

DISCUSSION:

FM transmitter application:

• FM transmitters are used at home as audio systems in hallways to fill the sound with the audio source.

• They are also used in cars and fitness centers.

• Correctional facilities have been used in FM transmitters to reduce prison noise in communal areas.

Advantages of FM transmitters:

• FM transmitters are easy to use and their price is low.

• The efficiency of the transmitter is very high.

• It has a wide operating range

• This transmitter will reject the noise signal of a variation of amplitude.

Disadvantages of the FM transmitter:

• A larger, larger channel is needed on the FM transmitter.

• The FM transmitter and receiver will tend to be more complex.

• Due to some interference, the quality of the received signals is poor.

RESULT:

The project to transmit voice /signal through fm transmitter using lavalier microphone has been successfully implemented and favorable results are obtained.

We can hear the voice of the speaker through fm at the certain range of frequency and distance.

CHAPTER 06

CONCLUSION AND FUTURE SCOPE

Conclusion:

The project to transmit voice /signal through FM transmitter using lavalier microphone has been successfully implemented and favorable results are obtained, We can hear the voice of the speaker through FM at the certain range of frequency and distance.

This is commercially viable product and its application is widespread these days with almost of all home audio systems ,FM radio ,broadcasting over higher range of distance and with a frequency ,since transmission is made use of here, each task can be designed to be performed at different frequencies ,each specific to a particular range. As a result of which several uses can be performed on a single FM transmitter, as in case of cars , fitness centers .this product already has a great scope and vision now and futuristically, as a part of an environment where man restricts his motion and performs his day-to day activities on a FM transmitter using lavalier microphone.

- The Lavaliers microphones are very cheaper in general. Of course, you can find a more expensive lava microphone in the $ 2,000 zone
- The Lavaliers are easy to hide.
- The Lavaliers microphones knows how to hide the constant background noise.
- Lavaliers can connect to wireless talent.
- Lavaliers can be used to record meetings in secret.

- Improved signal-to-noise ratio (about 25dB) The man made some interference.
- Less geographic interference between neighboring stations.
- Less radiated power.
- Well-defined service areas for given transmitter power.

Therefore, we conclude that this project is truly suitable for electrical and communication engineering learning students, particularly students who are dedicated to FM transmission and reception in their subject of electronics and communications theory. By realizing this application and project theory more,

Thanks to this project, we have now been able to observe an exact application of our lessons, such as analog and basic electronic and wireless communications, FM modulation, transmission, demodulation, reception, as well as oscillators, amplifiers And much more. FM wireless communication is really fascinating.

FUTURE SCOPE:

FM transmitter already has acquired a great scope now and futuristically also, This project covers the design of the FM transmitter for quality audio transmission and explains some of the modern trends in FM signal generation, highlighting their perspectives.

It also covers the benefits of these technologies over traditional radio transmission and highlights several of the distinctive features that these technologies possess.

The role that radio plays in the society is an important issue to consider in discussions about which technology can best distribute radio in the future.The fact that radio has an important role in society can be clearly seen in the number of listeners according to a survey reported In [3,pp,40-49].

- Noise reduction
- Improvement of the sensitivity of antenna
- Development of SNR.

The "Wireless TV Audio Transmitter" is still a young technology. As a result, many consumers are unaware of the benefits that this type of interaction can bring to everyday life. In this project, we mention some future systems based on "wireless TV audio transmitter" that looks like the fluidity of this technique compared to others.

The main goal of this project is to receive an audio signal from the television and listen to it from a distance. Nowadays, everyone wants home theater, which is a home-built theater, designed to mimic the performance and feel of commercial theater, more commonly known as home theater.

In addition, this sound system or home theater is very expensive, but this project can really help you to experience a theatrical performance at no cost. The cost of wireless TP transmission is significantly reduced.

The most important thing is that it can be used not only in television applications, but also in computers. laptops, mobile and portable music systems. This is very effective when the sound volume needs to be reduced. In addition, it can be used as an alternative to Bluetooth technology because it consumes less power.

REFERENCES

[1] Nelson D tineo ,"FM Transmitter", California State University, Nelson D. Tineo , Year of Publication-2014

[2] Tips on using FM Transmitters," Guides at Overstock.com", Overstock.com, 14 october 2014.

[3] serway, Raymond,Faughn,jerry ,vuille," college physics,8th Ed", cegage learning.p.714, ISBN 0495386936 ,NOV-2014

[4] S P BALI, Former Faculty member, Military college of electronics and mechanical engineering,

APPENDIX