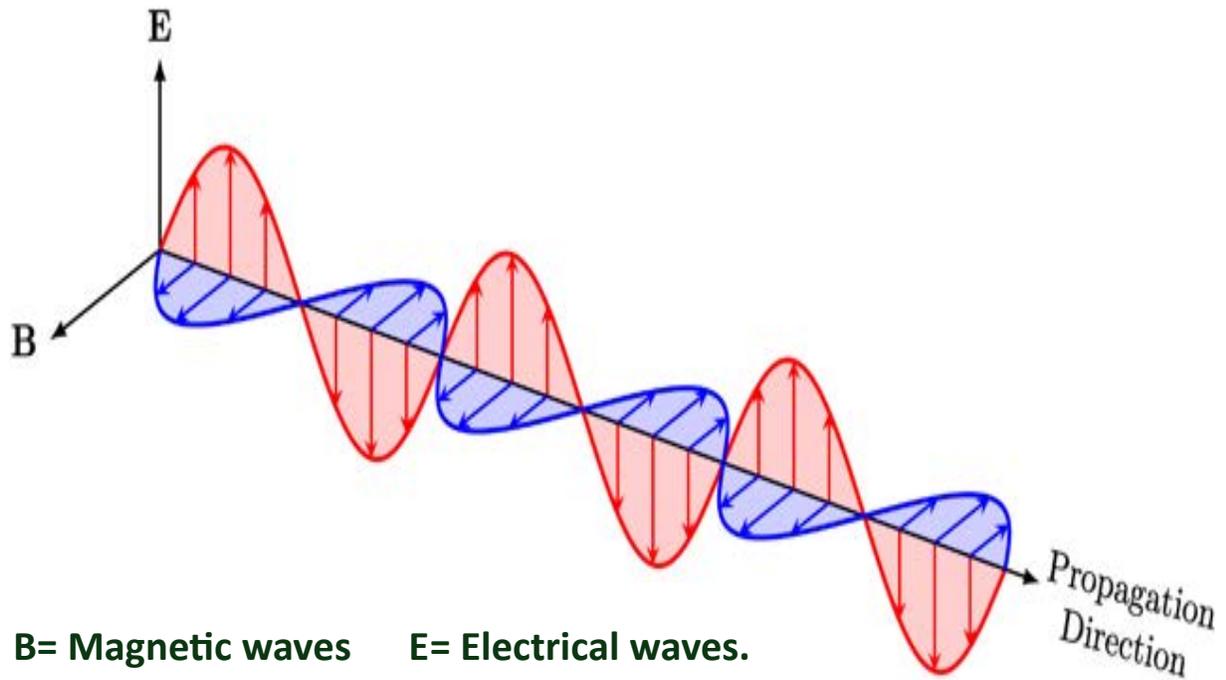


**SHORT NOTES ON BASIC ELECTRONICS FOR ASOC EXAMINATIONS.
(AMATEUR RADIO LICENSE EXAMINATIONS.)**



Compiled by:

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CHAPTER I: RESISTORS, CAPACITORS and INDUCTORS.

ELECTRONICS BASICS: OHM'S LAW

Ohm's Law can be stated as: "a current flowing through a conductor is directly proportional to the voltage, given the temperature of the conductor remains constant". Note: Ohm's Law is stated for a conductor at a constant temperature. Usually as temperature rises in a wire or resistor, Resistance also rises.

Using the symbols V for voltage, R for resistance and I for current the formula for Ohm's Law is $V = R \times I$.

Three relationships

By simple transformation of formulae,

two other equations can be written:

$R = V/I$ and $I = V/R$.

Putting these into words Ohm's Law states that

1. Voltage equals resistance multiplied by current.
2. Resistance equals voltage divided by current.
3. Current equals voltage divided by resistance.

$$1. V = R \times I$$

$$2. R = \frac{V}{I}$$

$$3. I = \frac{V}{R}$$

Conductor, Insulator

What is a conductor?

A conductor, or electrical conductor, is a substance or material that allows electricity to flow through it. In a conductor, electrical charge carriers, usually electrons or ions, move easily from atom to atom when voltage is applied.

In general, conductivity refers to the capacity of a substance to transmit electricity or heat. A conductor conducts electricity since it offers little or no resistance to the flow of electrons, thus leading to a flow of electrical current.

Typically, metals, metal alloys, electrolytes and even some nonmetals, like graphite and liquids, including water, are good electrical conductors. Pure elemental silver is one of the best electrical conductors.

What is an insulator?

An electrical insulator is a material in which electric current does not flow freely. The atoms of the insulator have tightly bound electrons which cannot readily move.

A perfect insulator does not exist because even insulators contain small numbers of mobile charges (charge carriers) which can carry current. In addition, all insulators become electrically conductive when a sufficiently large voltage is applied that the electric field tears electrons away from the atoms.

This is known as the breakdown voltage of an insulator. Some materials such as glass, paper etc., which have high resistivity, are very good electrical insulators.

Some key conductor and insulator differences are given in the table below.

Conductor	Insulator
Materials that permit electricity or heat to pass through it.	Materials that do not permit heat and electricity to pass through it.
A few examples of a conductor are silver, aluminum, and iron.	A few examples of an insulator are paper, wood, and rubber.
Electrons move freely within the conductor.	Electrons do not move freely within the insulator.
The electric field exists on the surface but remains zero on the inside.	The electric field doesn't exist.

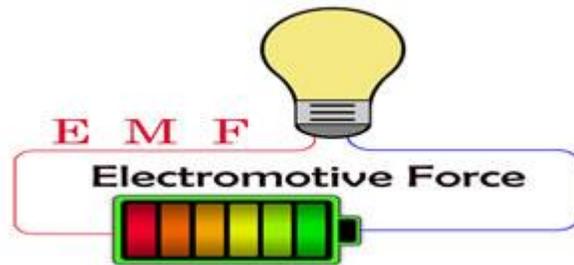
CURRENT, ELECTROMOTIVE FORCE, POTENTIAL DIFFERENCE

CURRENT:

It is the flow of free electric charge carriers from one point to another. The charge carriers can be electrons or ions.

Electric current is measured in units called AMPERES. A current of one Ampere consists of one Coulomb of charge per second.

Current can either be Alternate or Direct. Current is symbolised by the letter “I”, in most equations involving electrical quantities.



EMF: Electromotive Force

EMF stands for Electromotive Force. The electrical action generated by a non-electrical source, expressed in volts, is referred to as electromotive force in the fields of electromagnetism and electronics. Batteries, which transform chemical energy into electrical energy, or generators, are examples of devices (referred to as transducers) that produce an EMF (which converts mechanical energy). When describing electromotive force, a comparison to hydraulic pressure is occasionally utilized.

POTENTIAL DIFFERENCE:

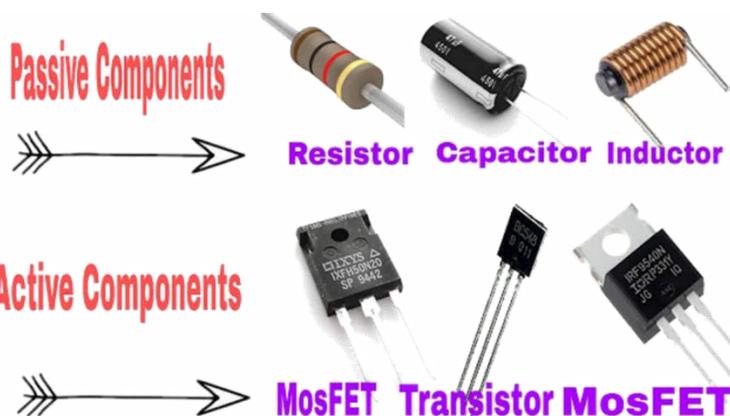
Two points in a circuit are said to have a difference of potential when the electric charge at one point is not the same as the electric charge at the other point.

Potential difference is measured in “VOLTS”.

Difference between Electromotive Force and Potential Difference

Electromotive Force	Potential Difference
EMF is defined as the work done on a unit charge	Potential difference is defined as the energy which is dissipated as the unit charge pass through the components
EMF remains constant	Potential difference is not constant
EMF is independent of circuit resistance	The potential difference depends on the resistance between the two points during the measurement
Due to EMF, electric, magnetic, and the gravitational field is caused	Due to the potential difference, the only electric field is induced
Electromotive force is frequently represented by the symbol \mathcal{E} (called Summation or Sigma).	It is represented by V

Components of electronic circuits: basics



Components are most important part of any electronic circuit or electrical circuit. There are mainly two types of components which are used in electronic as well as in electrical circuit. Two types of components are given as below:

1. Active Component

2. Passive Component

The electronic components are generally Active and Passive components. The passive components are which do not need any power for them to perform whereas the Active need power to operate.

What are active components? These components are parts of a circuit that rely on an external power source to control or modify electrical signals. Active components such as transistors and silicon-controlled rectifiers (SCRs) use electricity to control electricity.

Active components such as [amplifiers](#), vacuum tubes, and [transistors](#) make use of an external power source to add power to a system. They use one electrical signal to control another and are required for the circuit to be considered “electronic.” Technically, we don’t define circuits without active components as “electronics,” but in practice, virtually all electronic circuits have passive components as well.

Passive components like [resistors](#), [inductors](#), and [capacitors](#) influence the flow of power but do not require an external power source to function.

What are passive components? Like resistors, transformers, and [diodes](#) don’t need an external power source to function. These components use some other property to control the electrical signal. As a result, they only require the current traveling through the

connected circuit. Resistors impede the flow of electrons without introducing more electricity into the system.

WHAT'S THE DIFFERENCE?

Active Components	Passive Components
Active Device transforms and injects power or energy into a circuit.	Passive Device utilizes power or energy into a circuit.
Examples: Diode, Transistor, SCR, ICs, DC generator, Current & Voltage sources etc.	Examples: Resistors, Capacitors, Inductors, Transformer, Motors etc.
Active element produces energy in the form of voltage or current	Passive element stores energy in the form of voltage or current.
They have function and provide power gain (Amplifier).	They do not have function provide power gain.
It can control the flow of current.	It cannot control the flow of the current.
Active components require an external & conditional source to operate in the circuit.	Passive Components do not require any external source to operate in the circuit.

They have gain more than 1, so they can amplify the signal.	They have gain less than 1, so they can't amplify the signal.
They are energy donor.	They are energy acceptor
They lay in Linear category	They lay in Non-Linear category.

The Passive components starting with Resistors, Capacitors, and Inductors. We shall start with the resistors now.

Resistors are the devices which resists the flow of electrons in the circuit and their unit is Ohms.

What is a resistor:

The job of a Resistor is to limit the current flowing through an electrical circuit.

Resistance is measured in Ohm's and is given the symbol Ω

Carbon, Film and Wire wound are all types of resistors.

Resistor colour codes are used to identify the resistance and tolerance rating of small resistors. Tolerance is the percentage measure of the accuracy of a resistor from its preferred value.

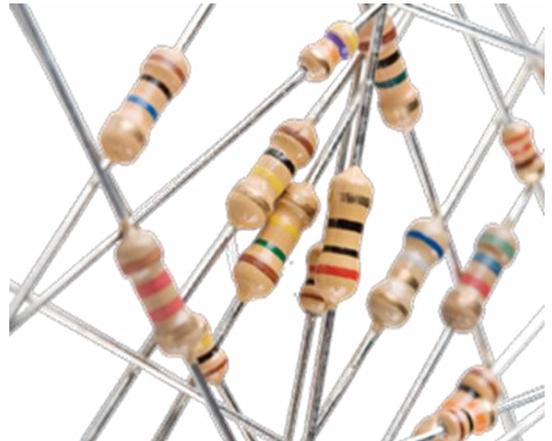
Resistor Basics

Resistors are electronic components which have a specific, never-changing electrical resistance.

The resistor's resistance limits the flow of electrons through a circuit.

They are passive components, meaning they only consume power (and can't generate it).

Resistors are usually added to circuits where they complement active components like op-amps, microcontrollers, and other integrated circuits. Commonly resistors are used to limit current, divide voltages, and pull-up I/O lines.



Resistor units

The electrical resistance of a resistor is measured in ohms. Ω .

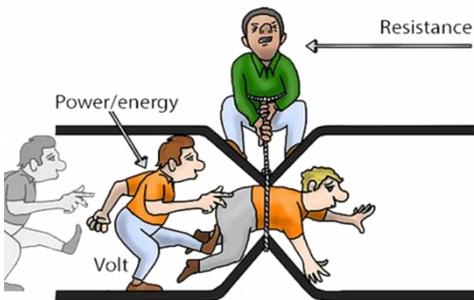
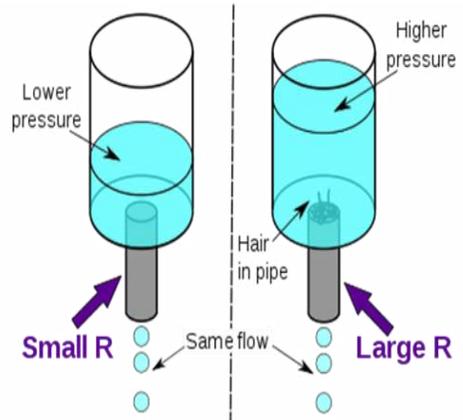


The definition of 1Ω is the resistance between two points where 1 volt (1V) of applied

potential energy will push 1 ampere (1A) of current.

The unit of resistor is Ohm. One ohm of resistance is the amount one volt of potential energy pushed with the current of one amp. We shall see shortly what the relation between Volt, Amp and Ohm is.

To make the understanding easier, let us assume that you have a tub of water with a smaller tube. As the size of the tube reduces, the flow of water would be constrained high, if you increase the diameter of the tube, the flow of the water would be wider. So, through the larger diameter of the tube more volume of the water flow through and with a lower resistance. If you are pushing more amount of water through a smaller tube, then you are applying lot of resistance to the water i.e., with a higher resistance value.



Now assume that you have lot of people in a smaller area and the pressure in which they are pushing in the smaller area is the energy of the area is VOLT. You see that, the resistance is the one controlling the aperture through which the people

were forced out. So, if you apply more resistance, you are contracting the tube to much smaller size. Meaning you need to push a person

with a lot of force. The force with which you apply to push a person through a small hole is the AMP or current.

Resistor Composition

Resistors can be constructed out of a variety of materials. Most common, modern resistors are made out of either a carbon, metal, or metal-oxide film

Most of the standard, no-frills, through-hole resistors will come in a carbon-film or metal-film composition.

Decoding the Color Bands



Though they may not display their value outright, most resistors are marked to show what their resistance is.

In the standard four band resistors, the first two bands indicate the two most-significant digits of the resistor's value. The third band is a weight value, which multiplies the two significant digits by a power of ten.

The final band indicates the tolerance of the resistor. The tolerance explains how much more or less the actual resistance of the resistor can be compared to what its nominal value is.

Colour	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	
Red	2	100	
Orange	3	1,000	
Yellow	4	10,000	
Green	5	1,00,000	
Blue	6	10,00,000	
Violet	7	1,00,00,000	
Grey	8		
White	9		
Gold		0.1	± 5%
Silver		0.01	± 10%
None			± 20%

How do you come up with this value, how is this standardized? Well, it is through a code commonly known as B B ROY of Great Britain had a Very Good Wife (Capital Letters are remembered). Black, brown,

red, orange, yellow, green, blue, violet, grey, white, gold, silver, and none. Black to white values goes 0 to 9. Apply these to the first two digits and the third is the multiplier. So let us take the value of 10k ohms, a common resistor, the colour bands would be Black, orange and the tolerance either gold or silver.

B. B. ROY of Great Britain had a Very Good Wife

(Capital Letters are remembered)

Decoding Resistor Colour Band

The 4.7kΩ resistor shown here has color bands of yellow and violet to begin - which have digit values of 4 and 7 (47). The third band of the 4.7kΩ is red, which indicates that the 47 should be multiplied by 10² (or 100). 47 times 100 is 4,700!

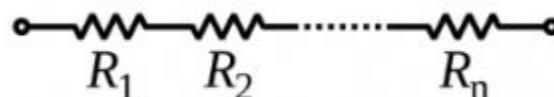


Value of Yellow	4	= 4	
Value of Violet	7	= 7	
multiplier Red	2	= 00	(4700)or 4.7kΩ

Serial Connection and Parallel Connection

The connections in electric circuits can be classified broadly as serial connections and parallel connections. When several resistors are connected, the combined resistance value will be different in serial and parallel connections as follows:

In a series circuit, the output current of the first resistor flows into the input of the second resistor; therefore, the current is the same in each resistor. In a parallel circuit, all of the resistor leads on one side of the resistors are connected together and all the leads on the other side are connected together.

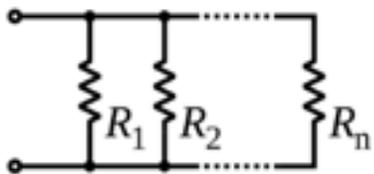


Resistors in series.

The total value of the combination is

$$R(\text{serial}) = R_1 + R_2 + R_3 + \dots + R_n$$

Resistors in parallel.



$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

The total value of the combination is the sum of reciprocals of resistance of an individual resistor is the total reciprocal resistance of the system.

A resistor with an electrical resistance value of 100 ohms is connected to another with a resistance value of 200 ohms. The two resistances are connected in series. What is the total resistance across the system?

Here, $R_1 = 100 \Omega$ and $R_2 = 200 \Omega$

$$R_{\text{total}} = 100 + 200 = 300 \Omega$$

When two resistance 10 ohms and 40 ohms are connected parallel, the total resistance across the system would be:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

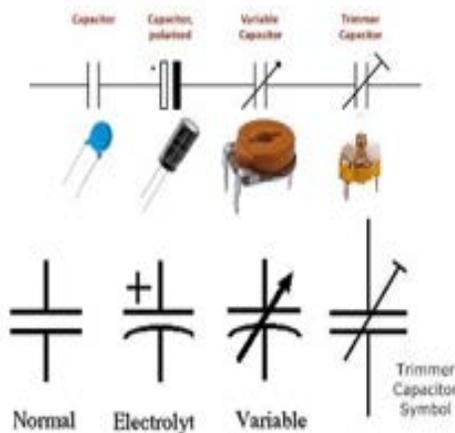
$$\frac{1}{R} = \frac{1}{10} + \frac{1}{40} = \frac{1}{8} \text{ . that is, } 8 \Omega$$

Introduction to Capacitors

The next interesting passive device is Capacitor. They come in a variety of forms and shapes. Capacitor is a device that has two conductors and in between these conductors there would be dielectric medium or a insulating medium. Depending on the surface area of the conductors, depending on the distance, and depending on the dielectric constant, the capacitance value is arrived.



The capacitors can either be of fixed value or could be of variable value. Most of the times, we use the fixed value capacitors in the circuit and use a variable value capacitor on places where you want tuning capacitors in the circuit. In other times it would be fixed (tuned) value circuit.

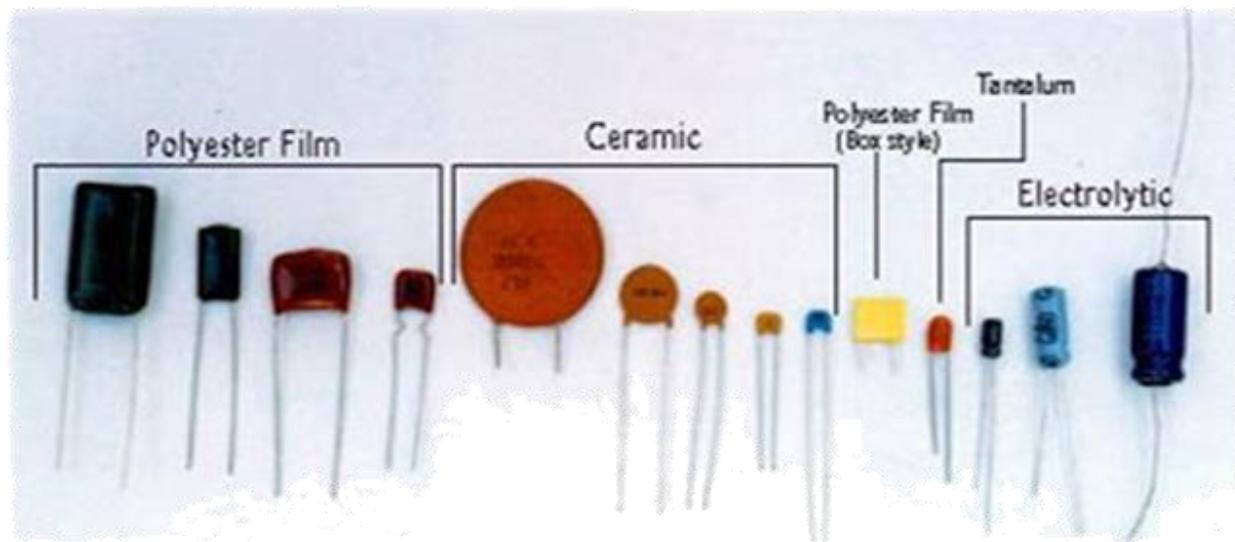


you see the symbols of the capacitors as per their properties. You find a variable capacitor with a sharp arrow, the other with a blunt arrow. The sharp arrow capacitors are called variable capacitors, as the user can change the value daily. The other capacitor with a blunt head is called Trimmer capacitors which is pre-set, tuned at the factory and normally not

adjustable by the user.

The fundamental function of the capacitor is to hold charge and store it for some future purposes. So, these capacitors can also be used to block out some section of the signals. For example, when you have DC and AC and by using a capacitor, it would let only the AC signals and blocking the DC signals. You can also use the capacitors basically short the AC values or AC current to the ground and you get the cleaner DC.

If you use high value capacitor or use a bank of capacitors, then they can also be used as a RIPPLE filter there by act as a shock absorber to prevent sudden surges in the current. So, if there is big surge in the current, then the capacitors will provide the stored charges, so a kind of balancing and they smooth out the ripple and give you smoother voltage and current value.



The capacitors come with the variety of shapes and sizes and even the materials in which they are made. Most of the capacitors don't have the polarity, which means you can use whichever form you want. There is no separate positive or negative lead for the capacitors.

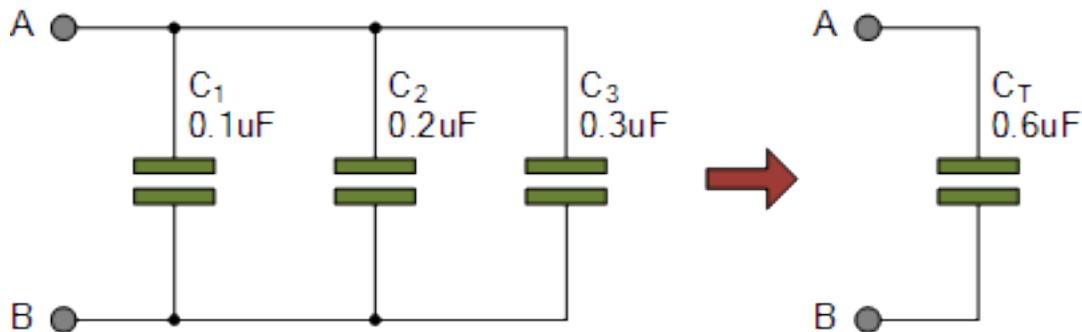
Having said that, these are special type of capacitors, Electrolytic capacitors, which essentially have a copper coated with some dielectric medium (say paper here). This dielectric coated paper rolled in between metal sheets would form a capacitor. This special type of electrolytic capacitors has the Polarity meaning, you cannot swap the positive and negative poles.

The other capacitors, ceramic, disc capacitors have no polarity and can be swapped in any form or in any orientation.

Like in the case of Resistors, the capacitors are also used in the combination of them, and they are hardly used as a single capacitor in a circuit. Again, as in the case of resistors, the capacitors can also be used in series and parallel combinations.

The major difference between capacitors and resistors in the value; either in a series combination or in a parallel combination they are just opposite that of a resistor.

Capacitors in Parallel



Capacitors are connected together in parallel when both of its terminals are connected to each terminal of another capacitor.

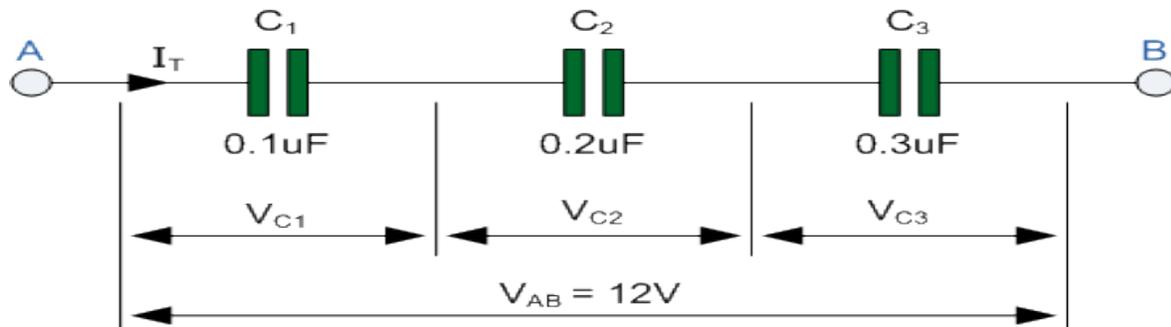
$$C_T = C_1 + C_2 + C_3 + \dots \text{etc}$$

ie., $C_T = C_1 + C_2 + C_3 = 0.1\mu\text{F} + 0.2\mu\text{F} + 0.3\mu\text{F} = 0.6\mu\text{F}$

When you add a capacitor in parallel you get much higher capacitor value. So on many occasions the parallel capacitors are used to obtain the larger capacitance value by using many smaller value capacitors.

Capacitors in Series

On the other hand, if you have the capacitors in a series combination, the capacitance value will be much lower. But adding the capacitors in parallel we should observe that much lower ESR (equivalent series resistance) value, which we will be covering later session, when we talk about RF circuits and TRX circuits.



Capacitors are connected in series when they are daisy chained together in a single line.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots \text{etc}$$

$$\frac{1}{C_T} = \frac{1}{0.1\mu\text{F}} + \frac{1}{0.2\mu\text{F}} + \frac{1}{0.3\mu\text{F}} = \frac{1}{18.33 \times 10^{-6}}$$

$$\therefore C_T = 0.055\mu\text{F} \text{ or } 55\text{nF}$$

Capacitances diminish in series.

Explaining the capacitor summary

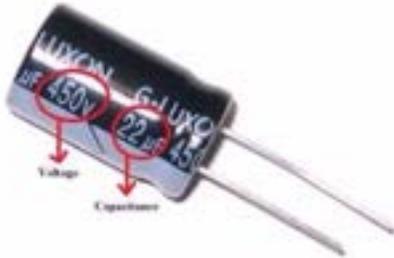
- A capacitor consists of two metal plates separated by a dielectric.
- The dielectric can be made of many insulating materials such as air, paper, plastic etc.
- A capacitor is capable of storing electrical charge and energy.

- The higher the value of capacitance, the more charge the capacitor can store.
- The larger the area of the plates or the smaller their separation the more charge the capacitor can store.
- A capacitor is said to be “Fully Charged” when the voltage across its plates equals the supply voltage.
- Capacitance is measured in Farads, which is a very large unit so micro-Farad (μF), nano-Farad (nF) and pico-Farad (pF) are generally used.
- Capacitors that are daisy chained together in a line are said to be connected in Series.

Capacitors that have both of their respective terminals connected to each terminal of another capacitor are said to be connected in Parallel.

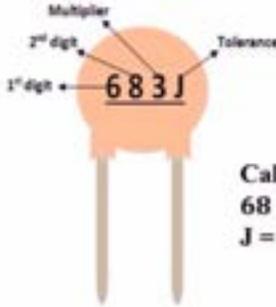
CAPACITANCE

Electrolytic Capacitor



MIN VALUE : 0.1 μF
MAX VALUE : 2.7 mF

Ceramic Capacitor



MIN VALUE : 0.1 pF
MAX VALUE : 100 μF

Calculation
 $68 \cdot 10^3 \cdot 10^{-12} = 68\text{nF}$
J = $\pm 5\%$

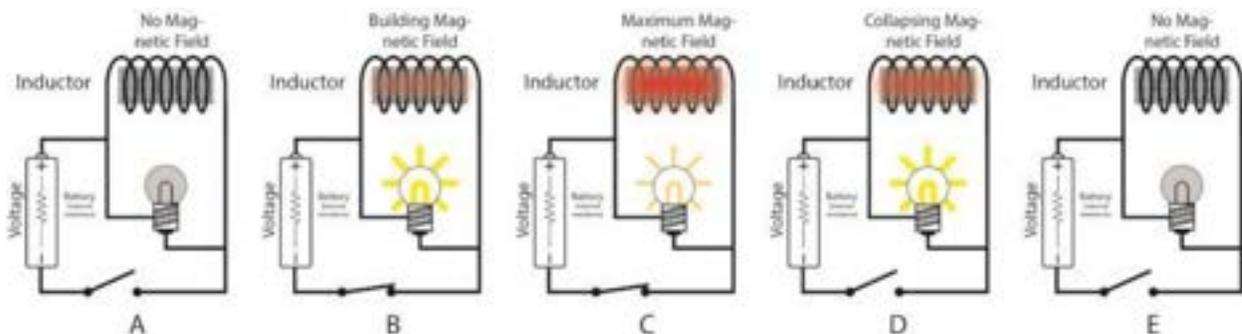
How to read the values in a ceramic capacitor is shown the picture.

The first two numbers indicate the capacitor value, and the third digit would indicate the multiplier. Once you have the multiplier, say in the case of 683, 68 is the value of the capacitor and 10^3 is the multiplier.

In most of the ceramic capacitor multiply them also with a factor of 10^{-12} . Now you have 10^{-12} plus 10^3 you get 10^{-9} , there by the value of the capacitor is 68 nano farad.

Introduction to Inductors.

The Inductor is the 3rd passive device after the resistors and Capacitors. The Inductors are like the capacitors in the sense, the energy that stored as magnetic field and not as the charge like capacitors. In a sense an inductor is nothing but a coil of wire, it should have a core and it may not be a coil of wire which creates an electromagnetic field when it is excited. But what is interesting in this case is, the magnetic field that induced in the coil only when there in the electrical field.



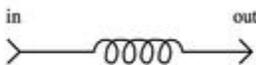
In the case of DC, because of its steady voltage value, the magnetic field itself, flux itself is not alternating or charging. So, it is only the very initial moment when it is excited with a DC voltage the coil produces the EM and stored in the coil.

So, if you look at the picture above, you can see from picture B, the moment the switch is closed, the light/bulb glows as the magnetic field stored in the coil. You also notice that from picture D, even though the coil/switch is OFF, the light/bulb still glows. where does the energy come for the light to glow even after the switch is off?. the energy is essentially coming from the coil itself. The stored energy from the coil is released in the form of electrical energy to glow the bulb. Once the energy is dissipated fully, the bulb does not glow anymore. (Picture E).

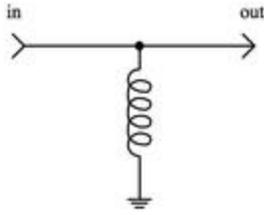
Inductor as a resistor: When the DC voltage is connected across to an inductor, the DC source would see the inductor as a dead shot.

Because it is essentially a coil of wire which is wound across a core. So, the inductor would exhibit very little resistance to the DC source. This also the reason why inductor has the similar symbol as that of a resistor.

But in the case of AC, we could see the coil behaviour a little different. So now let us consider about the DC only for the inductors.

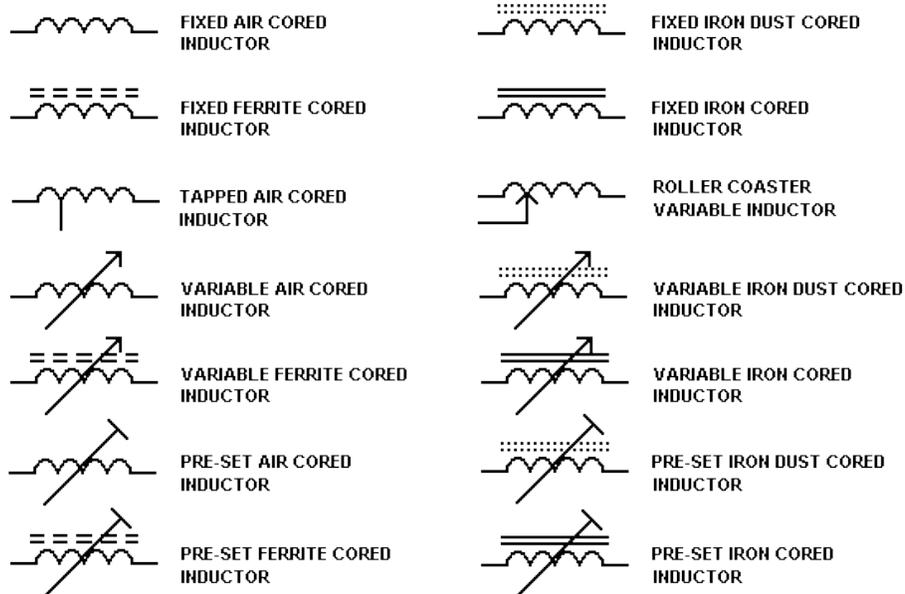


Example of signal filtering. In this configuration, the inductor blocks AC current, while allowing DC current to pass.



Example of signal filtering. In this configuration, the inductor **decouples** DC current, while allowing AC current to pass.

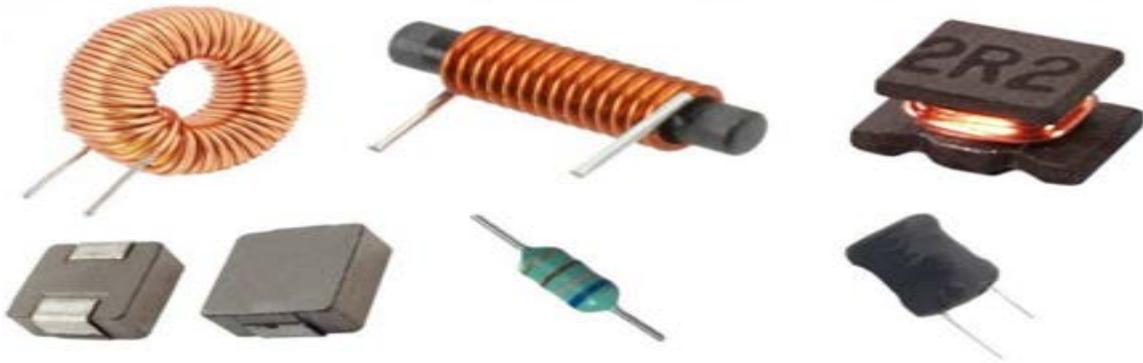
As always in the case of resistors and capacitors, the Inductors also come with pre-defined value or values can also be varied meaning, value of inductors can be static or variable.



Like the resistors and capacitors, the symbols of the inductors with a cross arrow, indicates that the values of this can be varied. If the arrow is a pointed one, then the value can be changed by the user on the field. If it is a flat arrow, then it is a factory set inductor.

The use of a core makes possible for you to concentrate the magnetic field more strongly than the inductor area. This is the reason you have different core materials, core types etc.,

The one you see as a circle is called as TOROID and the one that you see as a rod called as a ferrite rod. So, any ferro magnetic material would concentrate the magnetic flux close to the coil or within the coil area thereby giving you a higher inductance value.



The inductors are also colour coded as the way that resistors are. The chart shown below, the values are the same that of a resistor, using the same colour code (do you remember the phrase B B ROY Of Great Briton has a Very Good Wife). Here the inductors have four colour bars, the first three indicates the value of the inductor and the 4th one is the tolerance of the inductor.

Result Is In μH

4-BAND-CODE \rightarrow \rightarrow 270 $\mu\text{H} \pm 5\%$

COLOR	1st BAND	2nd BAND	MULTIPLIER	TOLERANCE
BLACK	0	0	1	$\pm 20\%$
BROWN	1	1	10	Military $\pm 1\%$
RED	2	2	100	Military $\pm 2\%$
ORANGE	3	3	1,000	Military $\pm 3\%$
YELLOW	4	4	10,000	Military $\pm 4\%$
GREEN	5	5		
BLUE	6	6		
VIOLET	7	7		
GREY	8	8		
WHITE	9	9		
NONE				Military $\pm 20\%$
GOLD			0.1 / Mil. Dec. Pt.	Both $\pm 5\%$
SILVER			0.01	Both $\pm 10\%$

Military Identifier \rightarrow \rightarrow 6.8 $\mu\text{H} \pm 10\%$
MILITARY CODE

them either in series, you add them all together and in the parallel combinations, you add the reciprocal values. So, the computation of inductor values is the same of resistors.

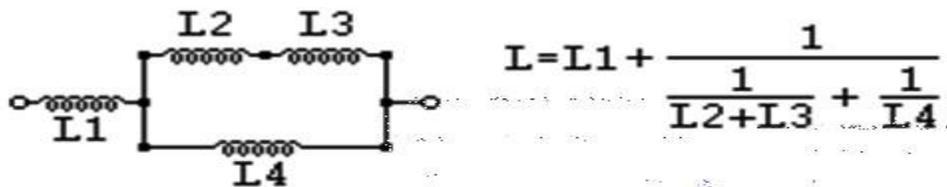
Inductors in series, just add them up.



Inductors in parallel.



Example



The inductors play a very important role in RF or radio as they block the AC signals and they form the fundamental building blocks for filters, oscillators etc., We would be covering in the later sessions.

Inductors, when we use in conjunction with capacitors, then that circuit is called LC circuit, L for inductors and C for capacitors. When it is used with the resistors, then it is called RL circuit, R for resistors and L for inductors. You can also form the combination of all the three of them and they are called as RLC circuit.

CHAPTER II: Semiconductor

What is a semiconductor device?

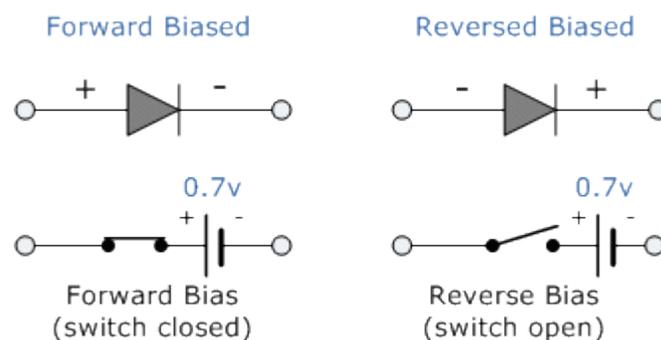
semiconductors are materials which have a conductivity between conductors (generally metals) and non-conductors or insulators (such as most ceramics). Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide or cadmium selenide.

Semiconductors are classified as intrinsic semiconductors and extrinsic semiconductors. Extrinsic semiconductors are further classified as N-type and P-type semiconductors.

So, semiconductors are essentially the material that has both the properties of insulator and conductor. To achieve this there are two separate materials: P element and N element that are fused together to form a PN junction and such diodes are called PN junction diodes.

In a semiconductor, the P-N junction is created by the method of doping. The p-side or the positive side of the semiconductor has an excess of holes, and the n-side or the negative side has an excess of electrons.

The symbol of a diode is represented by an arrow followed by a Bar. The place where the arrow meets is the PN junction. The reason why you see that an arrow followed by a bar, because it indicates the flow of electrons in a particular direction from +side to -side. So, a diode can be used as a switch by allowing the current flow in only one direction.

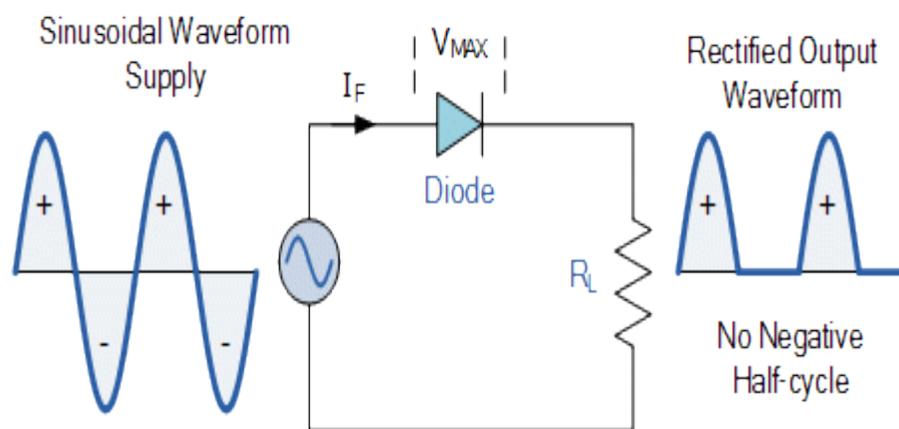


Diodes are basic unidirectional semiconductor devices that will only allow current to flow through them in one direction only, acting more like a one-way electrical valve, (Forward Biased Condition).

The Signal Diode: Signal Diodes are small two-terminals which conducts current when forward biased and blocks current flow when reverse biased.

One of the major applications of Diode is a switch and other major application of the diode is used as a rectifier. Say it takes an AC signal and convert in to DC signal. In the slide34, shows how a diode can be used as a rectifier. Here you need to have an Ac source and the current swings between positive and negative.

What is the diode going to do here, it is going to let the current to flow over the threshold of 0.7volts. so, you see a positive humps on the output of the diode. The positive side is passing through the diode and what we have not captured now is the negative side of the diode. Now we have half the cycle of current is captured and sent across the diode. Hence this construction is called Half wave rectifier.



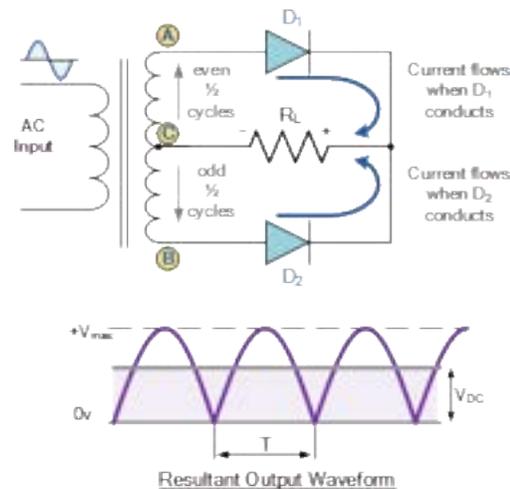
Half Wave Rectification

A rectifier is a circuit which converts the *Alternating Current (AC)* input power into a *Direct Current (DC)* output power. The input power supply may be either a single-phase or a multi-phase supply with the simplest of all the rectifier circuits being that of the Half Wave Rectifier. It rectifies the positive cycle of the pure sine wave.

The device you see on the left is a transformer and stepping down the AC voltage (say a step-down transformer) and then you have the rectifier diode, then you can see a small dead band which is 0.7volts, which I spoke about. Now you have the rectified voltage. You have the peak and a flat wave then next peak so on. The resistor that you see in the circuit is the resistance used by the user on the far side of the diode, is called the local resistance.

Center-tapped Full-Wave Rectifier

A rectifier circuit whose transformer secondary is tapped to get the desired output voltage, using two diodes alternatively, to rectify the complete cycle is called as a Center-tapped Full wave rectifier circuit. The transformer is center tapped here unlike the other cases.



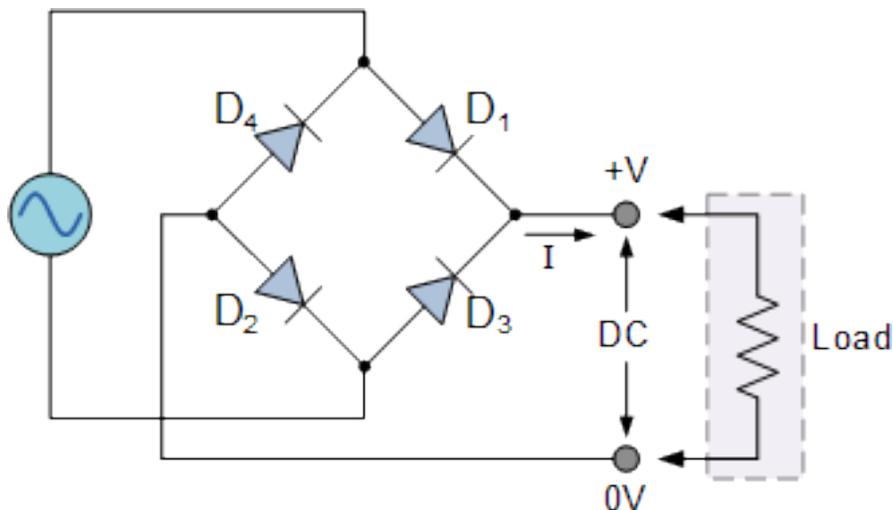
Two Power Diodes can be connected to form a full wave rectifier that convert AC voltage into pulsating DC voltage for use in power supplies.

The features of a center tapping transformer are –

- The tapping is done by drawing a lead at the mid-point on the secondary winding. This winding is split into two equal halves by doing so.
- The voltage at the tapped mid-point is zero. This forms a neutral point.
- The center tapping provides two separate output voltages which are equal in magnitude but opposite in polarity to each other.
- A number of tapings can be drawn out to obtain different levels of voltages.

The Full Wave Bridge Rectifier

- Another type of circuit that produces the same output waveform as the full wave rectifier circuit above, is that of the Full Wave Bridge Rectifier. This type of single-phase rectifier uses four individual rectifying diodes connected in a closed loop “bridge” configuration to produce the desired output.
- The main advantage of this bridge circuit is that it does not require a special center tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side.



The difference between the full wave rectifier and the bridge rectifier:

The bridge rectifier has 4 diodes in total 2 of them in each direction. Refer the picture above. You can see that; in one direction you have D₁ and D₃ and in another direction you have D₂ and D₄. By doing so you have two diodes which are on the same direction, means it can

handle much larger current. You also don't need a centre tap transformer as we have seen in the full wave rectifier. Doing so, you can handle much larger current (the transformer will be very heavy for a larger current).

What is a bridge in a bridge rectifier?

A rectifier converts an AC signal into DC, and a bridge rectifier does this using a diode bridge. A diode bridge is a system of four or more diodes in a bridge circuit configuration, wherein two circuit branches are branched by a third. A bridge rectifier provides full-wave rectification.



This is the typical form of rectification circuits you see in commercial applications. These bridge rectifiers are also commercially available as a single block. You can imagine a single 4-legged device, marking DC on two legs and AC on other two legs and use it as a single piece and you don't have to build a rectifier from the scratch.

Why do bridge rectifiers use 4 diodes?

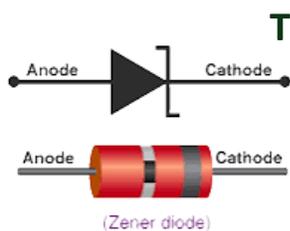
Bridge Rectifiers use four diodes that are arranged cleverly to convert the AC supply voltage to a DC supply voltage. The output signal of such a circuit is always of the same polarity regardless of the polarities of the input AC signal.

Why is capacitor used in bridge rectifier?

A capacitor is included in the circuit to act as a filter to reduce ripple voltage. Make sure that you connect the capacitor properly across the DC output terminals of the rectifier so that the polarities match. Being an electrolytic capacitor, it is sensitive to damage by polarity reversal.

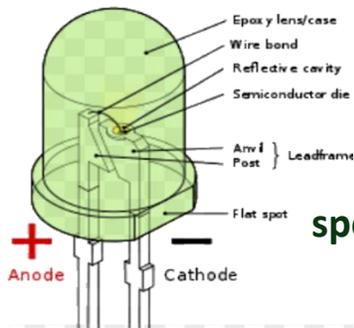
Zener diode.

The Zener diode is a very interesting form of a diode. The symbol is very similar to that of normal diode but if you look closely, you will see 2 arms on the edge of the bar.



These diodes are value specific as 5v, 7v etc. these values indicate as the break down value of the voltage. So, the breakdown voltage is when the diode is start conducting. In the circuit shown in the slide, you have a DC source fed to a resistor then forwards to the diode then to the LOAD Resistor, which is drawn parallel to that of the Zener diode. In this case you expect the Zener diode to act as the open switch as long as the voltage the voltage is less than the threshold voltage. So, if voltage is less than the threshold voltage, the Zener will act as if it is not present in the circuit. What happens when it crosses the threshold voltage it will start conduct with lesser resistance, the excess voltage will be grounded to dissipate as heat. This will make the voltage starts falling again and the Zener diode sophisticated but they do the job of a voltage regulator in most circuits.

The Light Emitting Diode



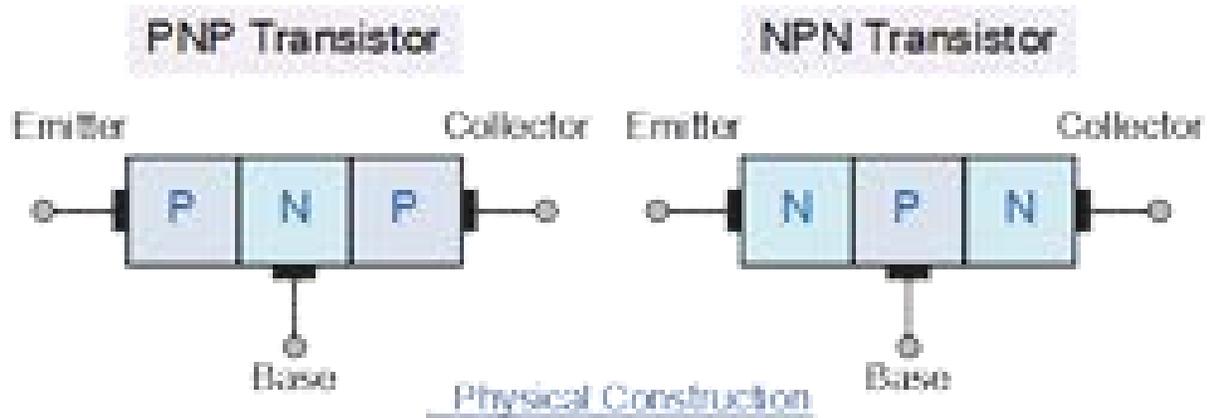
In a Rectifier Diode, the energy is dissipated as heat, but in an LED, the energy is radiated as light. The “Light Emitting Diode” or LED as it is more commonly called, is basically just a specialized type of diode as they have very similar electrical characteristics to a PN junction diode. This means that an LED will pass current in its

forward direction but block the flow of current in the reverse direction.

Transistors:

Transistors or BJT as formally called Bipolar Junction Transistors. It is called Bipolar because it has two junctions, which has two different polarities. There are two different types of BJTs based on their structures, they are known as PNP or NPN transistors.

If you remember about the PN junction diodes (we have seen earlier), imagine a transistor as to be two diodes formed back-to-back. One PN junction followed by NP junction to give you a PNP junction or PNP transistor. If you flip, it around you gets a NPN transistor.



The transistors are three terminal devices. The fundamental device is that is used in the modern circuitry which involves as switching, which involves as the amplification or as an oscillator.

I said, Transistors is a three-terminal device. The three terminals are the emitter, the base and the collector.

The Emitter is the one which emits the electrons out. The Collector is the one which collects the electrons back into the junction and base is the center junction between the emitter and the collector. When we talk about the transistors, we talk about, how to bias its junctions means the threshold it requires to activate the transistors.

Transistor Biasing

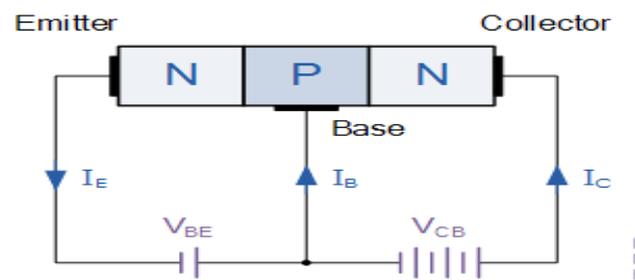
Transistor Biasing is the process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor.

The steady state operation of a bipolar transistor depends a great deal on its base current, collector voltage, and collector current values. Therefore, if the transistor is to operate correctly as a linear amplifier, it must be properly biased around its operating point as improper transistor biasing will result in a distorted output.

Establishing the correct operating point requires the selection of bias resistors and load resistors to provide the appropriate input current and collector voltage conditions. The correct biasing point for a bipolar transistor, either NPN or PNP, generally lies somewhere between the two extremes of operation with respect to it being either “fully-ON” or “fully-OFF” along its DC load line.

NPN Transistor.

The most commonly used transistor configuration is the NPN Transistor. We also learnt that the junctions of the bipolar transistor can be biased in one of three different ways – Common Base, Common Emitter and Common Collector.

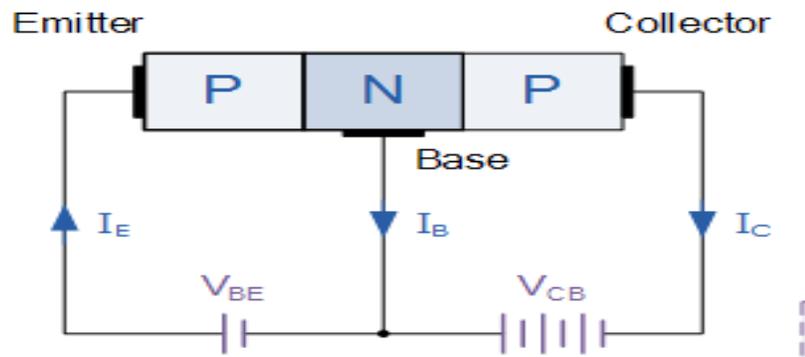


The voltage between the Base and Emitter (V_{BE}), is positive at the Base and negative at the Emitter because for an NPN transistor, the Base terminal is always positive with respect to the Emitter. Also the Collector supply voltage is positive with respect to the Emitter (V_{CE}). So for a bipolar NPN transistor to conduct the Collector is always more positive with respect to both the Base and the Emitter.

PNP Transistor

Basically, in this type of transistor construction the two diodes are reversed with respect to the NPN type giving a Positive-Negative-

Positive type of configuration, with the arrow which also defines the Emitter terminal this time pointing inwards in the transistor symbol.



The PNP Transistor has very similar characteristics to their NPN bipolar cousins, except that the polarities (or biasing) of the current and voltage directions are reversed for any one of the possible three configurations looked at in the first tutorial, Common Base, Common Emitter and Common Collector.

The difference between the PNP and NPN transistors is:

The first picture above showing you the PNP transistor in action and the other one is showing the NPN transistor in action.

In the case of PNP transistor, you have the output voltage that you can take it from the collector, while in the case of the NPN transistor you take the output from the emitter.

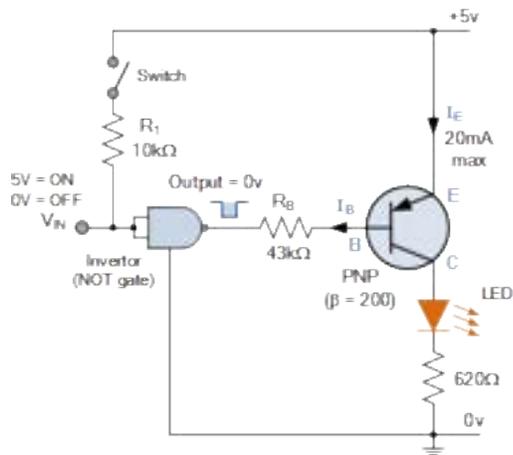
So, the bipolar BJT transistors can be effectively used in the saturation region and in the cut off region also. The saturation region is where the transistor is fully turned on and the Cut off region where it is fully turned off.

So, if you remember in the case of diode, I said that the minimum threshold voltage would be around 0.62 to 0.7 volts, that will hold true in transistors also.

The transistor is not a voltage driven device, it is current driven device and that's why you have the biasing resistor which would restrict the amount of current that flows through the junction to bias the transistor.

TRANSISTOR AS A SWITCH: While using the transistor as a switch, it is important to bias it. You know that when you have enough current flowing through the Base to the collector junction, then the transistors are put on the active mode.

When it is in active mode, the transistor will start allowing the electrons to flow through the emitter, collector junction and then you have the closed circuit. This is how a transistor is used to switch on a current drawing application.



The switch that can operate, through a very small current like you can control through a micro controller. You would be able to operate a larger drawing current applications like that of a bulb, motor etc.,

Transistor switches can be used to switch and control lamps, relays or even motors.

When using the bipolar transistor as a switch they must be either “fully-OFF” or “fully-ON”.

Transistors that are fully “ON” are said to be in their Saturation region.

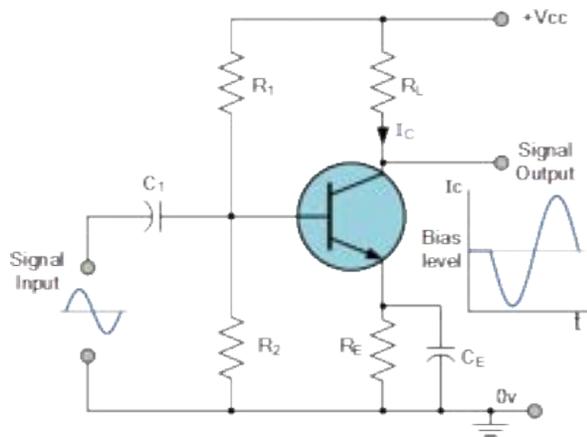
Transistors that are fully “OFF” are said to be in their Cut-off region.

When using the transistor as a switch, a small Base current control a much larger Collector load current.

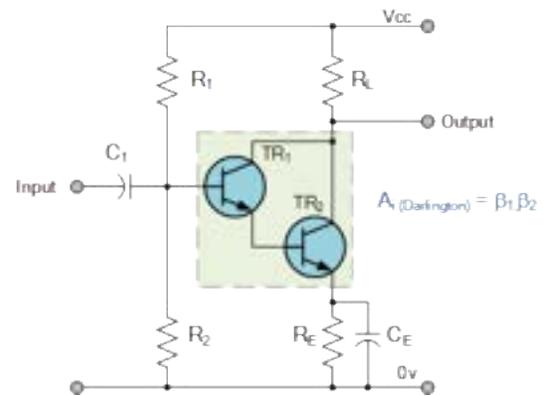
When using transistors to switch inductive loads such as relays and solenoids, a “Flywheel Diode” is used.

When large currents or voltages need to be controlled, Darlington Transistors can be used.

DORLINGTON PAIR.



Pic1



Pic2

Please refer two circuits on the as shown above. They are two forms of amplifiers. The first on the LEFT TOP (Pic1) is used as single stage amplifier ad the second on the RIGHT TOP (Pic2) is called Darlington pair amplifier.

The first stage is a quiet simple to understand, look at the circuit from the its left, you have a capacitor (if you remember what we learnt about the capacitors, the CAPS would block the DC and let the AC to flow through it and it is called a coupling capacitor) that will block all the incoming DC as an input to the circuit.

Then the current that passed the capacitor is a AC current. Then you have 2 resistors in a formation called voltage dividers. What are they

doing? These two transistors are matched in such a way that they can BIAS the transistors in the proper region of operation.

Once you have the biased transistors, you can get an amplified signal from the emitter and collector junction, and you get the larger amplitude and a higher voltage.

Now look at the Circuit on the top right carefully, you could see that the signals are out of phase, they are 180 degree out of phase, means when it is positive maximum, in the input negative maximum on the output that is 180 degree out of phase.

Any single stage amplifier like this is good enough to have a higher voltage and not higher current. But if you want to design high inductive load like that of a speaker then you need a higher current. The speaker also has a very low resistance and you need to have a much higher current. To do this you pair two similar transistors together in the formation as shown, it is called DARLINGTON PAIR. The Darlington pair has much current handling capacity than the single stage amplifier.

CHAPTER III: Amplifier, Oscillators, Filters

Transistor as an amplifier.

The other important use of a transistor is that it can be used as an Amplifier.

What is Preamplifier?

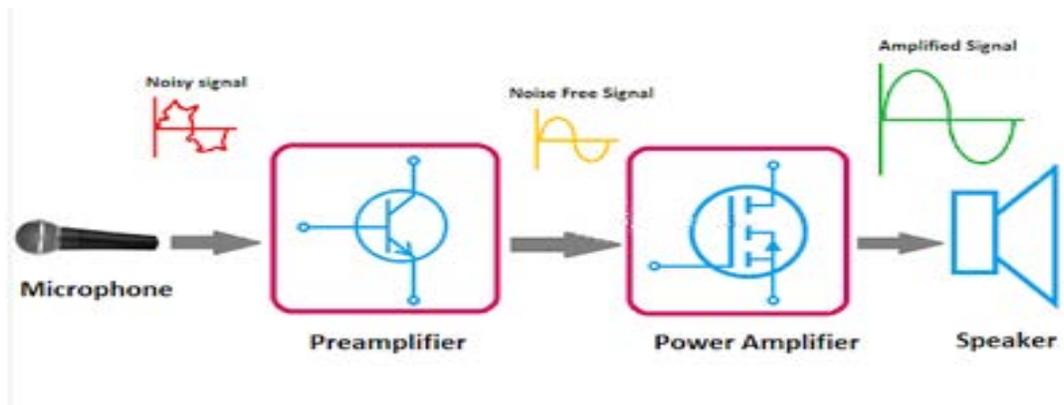
The preamplifier is an electronic circuit or device which is suitable for the amplification of electronic signals in low range. When an electrical or electronic signal is created by a sensor or transducer, first, it is amplified by the preamplifier. Then that signal is fed to the power amplifier or any other device. The main function of the preamplifier is to remove noise, distortion and amplifying of raw electronic signals coming from analog sensors, transducers, etc. The first objective of using a preamplifier is to remove noise and interference from electronic signals than amplifying those signals. The preamplifier also takes more than one signal from multiple sources and routes them to a single amplifier or output.

What is the power Amplifier?

Power Amplifiers only focus to amplify the electronic signal at the high range they are not able to remove noise and interference from the signal. For the high-rate amplification of the electronic signal, a noise-free, strengthened electronic signal needs to give to the power amplifier. But the output of the analog sensors, transducers, microphones, etc., is not suitable for the input of power amplifier because they produce only weak, noise, interference embedded

signals.

So to prepare the signal for the input of the power amplifier, the preamplifier is used. If the preamplifier is not connected before the power amplifier, then the output of the power amplifier will be noisy and distorted.



The other important use of a transistor is that it can be used as an Amplifier. Amplifier is a device where a small electrical signal can be made to a larger electrical signal.

What we mean by a larger electrical signal, is going to be the much larger voltage. A typical example would be a microphone. The mic will reduce the voltage in the range of a few micro volts to millivolts. For any practical application, this voltage needs to be stepped up to a few volts.

Let us assume, you want to drive a loudspeaker, the signal from a mic, you need to have a sample or get the data from the mic and then you need to amplify it, then need to drive the loudspeaker accordingly.

So, in a typical case of a MIC and driving a loudspeaker, you have two stages of amplifiers. The Preamp and Power amp stages.

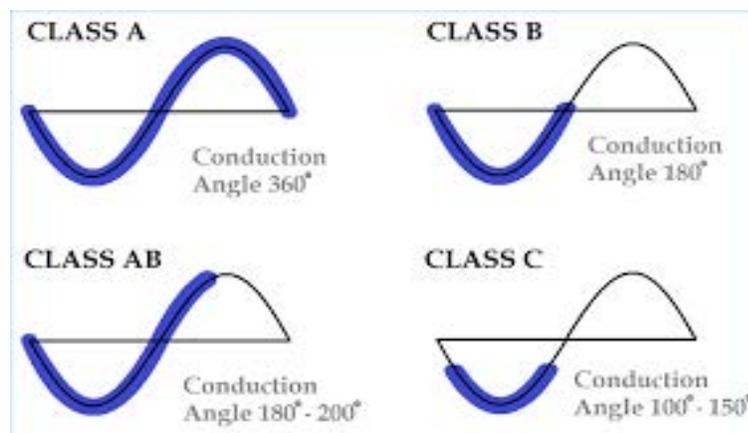
Preamp is something which is going to get the noisy microphone signals and cleans it with a filter, then it will put in the range of voltage acceptable to the power amplifier in the next stage.

The power amplifier is also a type of amplifier, but it is designed to handle much larger current, capable of doing the inductive level as that of a loudspeaker.

So, to prepare the signal for the input of the power amplifier, the preamplifier is used. If the preamplifier is not connected before the power amplifier, then the output of the power amplifier will be noisy and distorted.

whenever you read about a transistor, in any literature, any user manual, data sheet of a circuit, there is always a mention about a factor called BETA. Beta is the amplification factor, or the amplification gain of the transistor. So, in the case of a single stage transistor, you have only one transistor and the amplification factor of that of beta. In the case of the Darlington pattern, you have two transistors involved, the effective amplification value is the product of the two beta values. That is represented a BT which is the product of B1 and B2.

Summary. In summary, BJT has three terminal device, typically current operated device. They come in two forms, NPN and PNP types.



In the case of a transistor being used as a switch, you can either operate them in a saturation mode, which is fully in ON state or the cut off region is fully OFF state.

If you are using it as an amplifier, you can also use it in the active region, but you will have to have a lot of consideration do before operating the transistor in the active region.

To operate the transistor as an amplifier there are four different classes of amps which is commonly known as CLASS A, B, C and AB. Most of the RF amps in the circuit going to be Class B amps, called push pull types, where two transistors will be used to amplify different sections of the positive and negative sections of the AC signals. These two transistors will have to be matched, and they will also have to be biased approximately to amplify the whole signal, without losing them at the threshold value.

Oscillator.

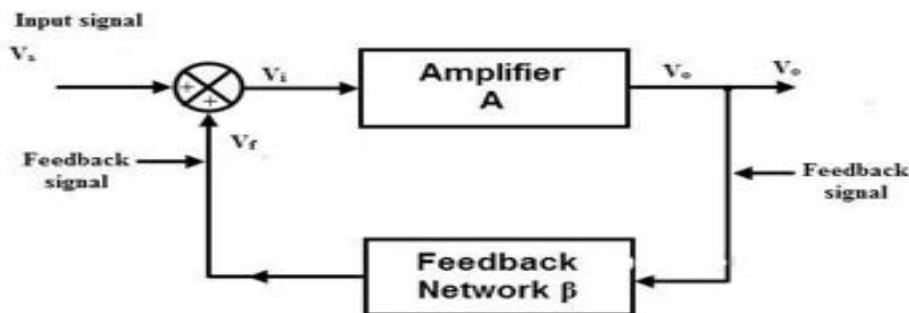
Oscillators convert a DC input (the supply voltage) into an AC output (the waveform), which can have a wide range of different wave shapes and frequencies that can be either complicated in nature or simple sine waves depending upon the application.

Oscillators are also used in many pieces of test equipment producing either sinusoidal sine waves, square, sawtooth or triangular shaped waveforms or just a train of pulses of a variable or constant width. LC Oscillators are commonly used in radio-frequency circuits because of their good phase noise characteristics and their ease of implementation.

An Oscillator is basically an Amplifier with “Positive Feedback”, or regenerative feedback (in-phase) and one of the many problems in

electronic circuit design is stopping amplifiers from oscillating while trying to get oscillators to oscillate

An Oscillator is a group of circuits that generate an oscillation, as the name suggests or a AC value or AC output. What an oscillator typically does is, they generate a frequency as an output frequency value or range.



How an oscillator tied up to an amplifier? Well, amps will have negative feedback and this negative feedback is used to control the oscillation in the amps.

There are many ways in which you can create oscillations. In most cases, you build a LC circuit or a Tank circuit which is the combination of an inductor and a capacitor.

You arrive at the critical frequency of the inductor and capacitor and form the L/C circuit. once the tank circuit is formed, you excite this to a small signal DC source, the impulse signal from the DC source would excite the inductor and cap and they start oscillating in that desired frequency and the transistor that is connected to the tank circuit will start amplifying it. This cycle continues till the point where the amplifier can efficiently reproduce the signal in high voltage. This is

how you create an oscillator. The oscillators are one of the fundamental blocks for most of the radios and in most of the RF circuits.

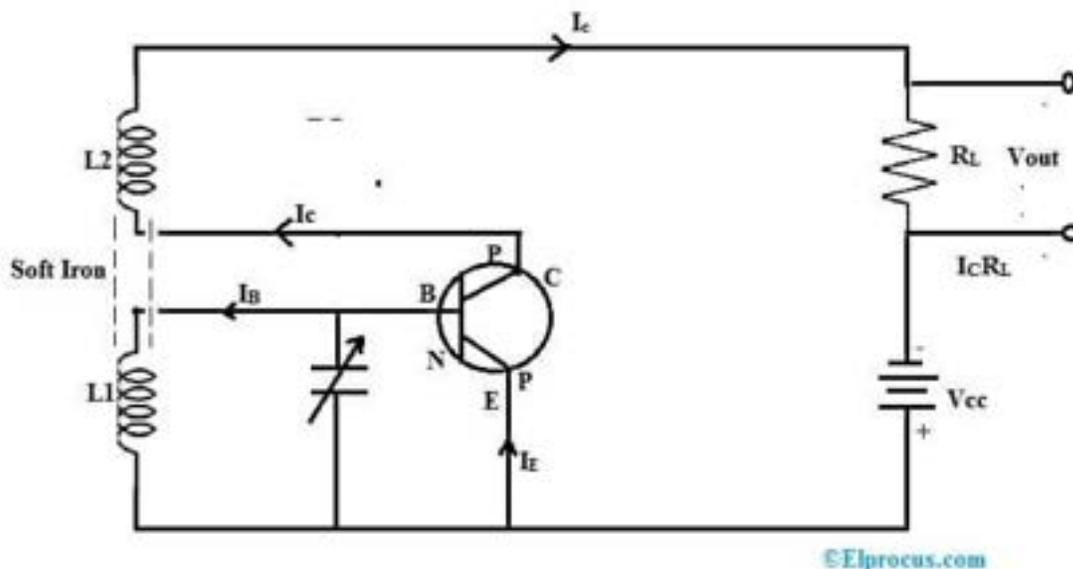
Types of oscillators:

Define Transistor Oscillator

When a transistor acts as an oscillator with proper positive feedback then it is known as a transistor oscillator. This oscillator generates undamped oscillations continuously for any desired frequency if tank & feedback circuits are connected to it properly.

Transistor Oscillator Circuit Diagram

The circuit diagram of the transistor oscillator is shown below. By using this circuit, we can simply explain how to utilize a transistor as an oscillator. This circuit is separated into three parts like the following.



Tank Circuit

The tank circuit generates oscillations that are changed with the transistor & generates amplified output within the collector side.

Amplifier Circuit

This circuit is used to amplify the tiny sinusoidal oscillations available within the base-emitter circuit & output is produced in the amplified form.

Feedback Circuit

The feedback circuit is a very significant section in this circuit because, for an amplifier, it requires some energy to amplify at the tank circuit. So, the energy of the collector circuit is fed back to the base circuit using the Mutual induction phenomenon. By using this circuit, the energy is fed back from the output to the input.

Working Transistor as an Oscillator

In the above transistor oscillator circuit, the transistor is used as a CE (common emitter) circuit where the emitter is common to both the base & collector terminals. Between the emitter and base input terminals, a tank circuit is connected. In the tank circuit, the inductor & capacitor are parallelly connected to generate oscillations within the circuit.

Because of the voltage & charge oscillations within the tank circuit, the flow of current at the base terminal fluctuates, so the forward biasing of the base current periodically changes then the collector current also changes periodically.

LC oscillations are sinusoidal in nature so both the base and collector currents sinusoidally vary. As shown in the diagram, if the current at the collector terminal sinusoidally changes then the output voltage attained can be simply written as $I_c R_L$. This output is considered a sinusoidal output.

Once we draw a graph in-between time and output voltage then the curve will be sinusoidal. To get oscillations continuously within the tank circuit, we require some energy. But in this circuit, no dc source or battery is available.

So we connected L1 & L2 inductors within the collector & base circuits using a soft iron rod. So, this rod will connect the L2 inductor to L1 inductor because of its mutual induction, A part of the energy within the collector circuit will be connected to the base side of the circuit. Thus, the oscillation within the tank circuit is sustained & amplified continuously.

Oscillation Conditions

The transistor oscillator circuit must follow the following:

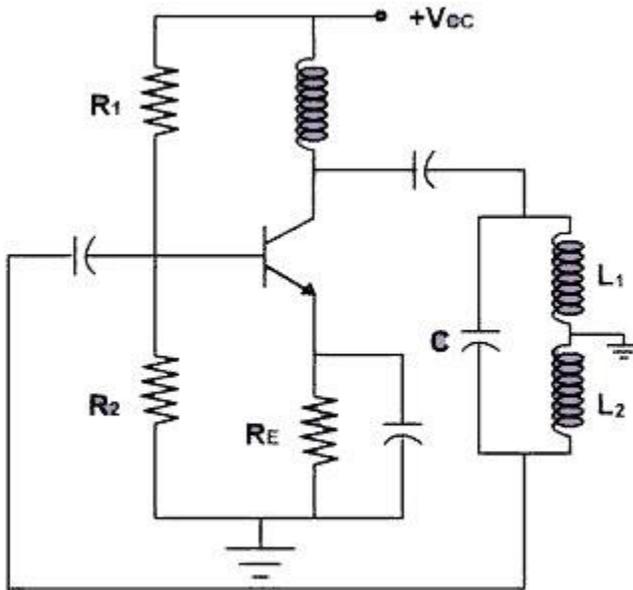
- The phase shift of the loop should be 0 & 360 degrees.
- The loop gain must be >1 .
- If a sinusoidal signal is a preferred output, then a loop gain > 1 will quickly cause the o/p to saturate at both waveform peaks & generating unacceptable distortion.
- If the gain of the amplifier is >100 , then it will cause the oscillator to limit both the waveform peaks. To meet the above conditions, the oscillator circuit should include some type of amplifier, as well as a part of its output, which should be fed back to the input. To conquer the losses within the input circuit, we utilize the feedback circuit. If the amplifier's gain is <1 , then the oscillator circuit will not oscillate and if it is > 1 , then the circuit will oscillate and generate distorted signals.

Types of Transistor Oscillator

There are different kinds of oscillators available, but each oscillator has the same function. So, they generate continuous undamped output. But they change in supplying energy to the oscillatory or tank circuit to meet the frequency ranges as well as losses over which they are utilized.

Transistor oscillators which use LC circuits as their oscillatory or tank circuits are extremely popular for producing high-frequency outputs. The different types of transistor oscillators are discussed below.

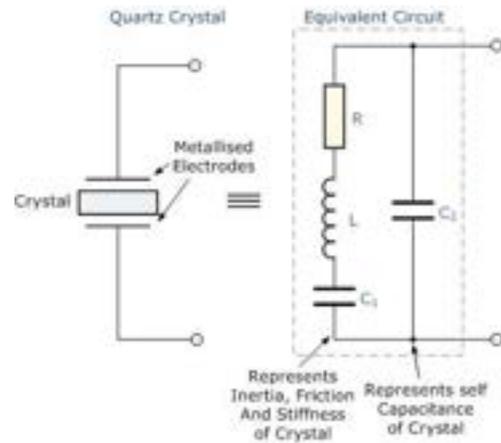
Hartley Oscillator



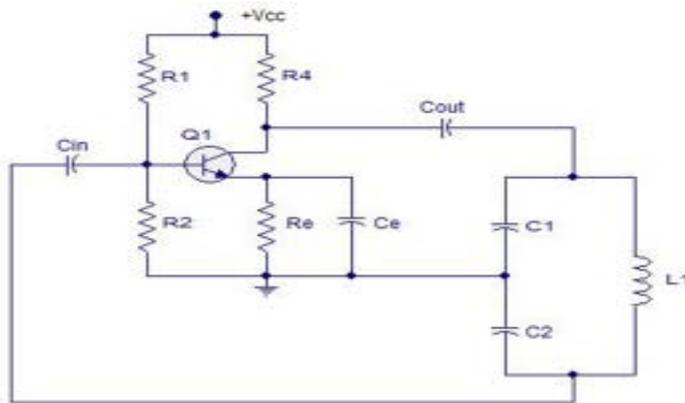
The Hartley oscillator is one kind of electronic oscillator that is used to determine the oscillation frequency through a tuned circuit. The main feature of this oscillator is that the tuned circuit includes a single capacitor connected in parallel through two inductors in series & the feedback signal required for oscillation is obtained from the two inductors' center connection. Hartley oscillator is appropriate for oscillations in the RF range up to 30MHz.

Crystal Oscillator

Transistor crystal oscillator is applicable in different areas of electronics as well as radio. These types of oscillators play a key role in providing a cheap CLK signal to use in logic or digital circuits. In other examples, this oscillator may be used for providing a constant and precise RF signal source. So, these oscillators are frequently used by radio amateurs or radio hams within radio transmitter circuits, wherever they can be most effective.



Colpitt's Oscillator

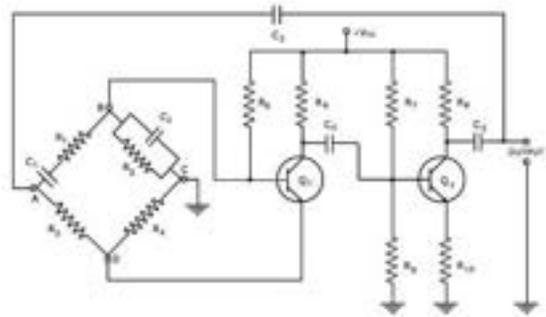


The Colpitts oscillator is quite opposite to Hartley Oscillator except the inductors & capacitors are replaced with each other within the tank circuit. The main benefit of this kind of oscillator is that by less mutual & self-inductance in the tank circuit, the oscillator's frequency stability is improved. This oscillator generates very high

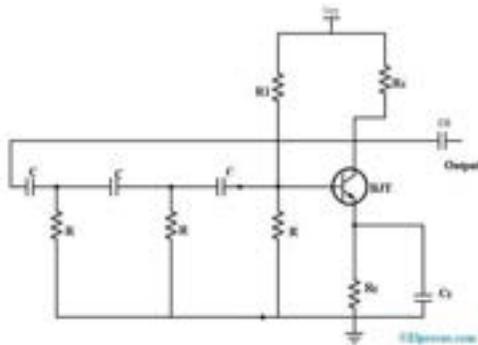
frequencies based on sinusoidal signals. These oscillators have high-frequency stability and they can withstand low and high temperatures.

Wien Bridge Oscillator

Wien bridge oscillator is an audio frequency oscillator that is frequently used due to its significant features. This type of oscillator is free from fluctuations as well as the ambient temperature of the circuit. The main benefit of this kind of oscillator is that the frequency is changed from 10Hz to 1MHz range. So this oscillator circuit gives good stability of frequency.



RC Phase Shift Oscillator



RC phase shift oscillator is one kind of oscillator wherever a simple RC network is used to provide the necessary phase shift toward the feedback signal. Like Hartley & Colpitts oscillator, this oscillator uses an LC network to provide the required positive feedback. This oscillator has outstanding frequency stability, and it generates pure sine waves over an extensive range of loads.

Frequency ranges of different transistor oscillators are:

- Wien bridge (1Hz to 1MHz),
- phase shift oscillator (1Hz to 10MHz),
- Hartley oscillator (10kHz to 100MHz),
- Colpitts (10kHz to 100MHz) &
- negative resistance oscillator >100MHz

Applications

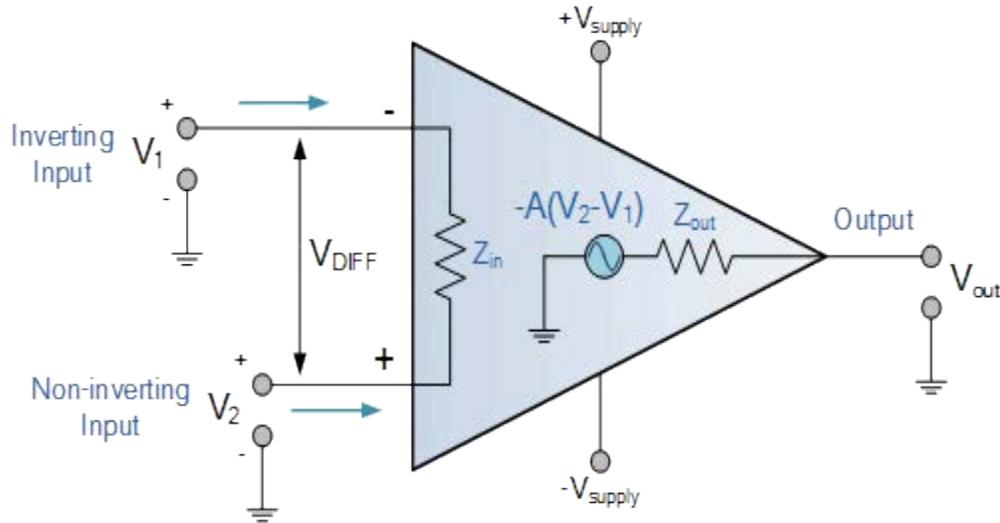
The applications of a transistor as an oscillator include the following.

- **A transistor oscillator is used to generate constant undamped oscillations for any desired frequency if oscillatory & feedback circuits are connected properly to it.**
- **Wien bridge oscillator is highly used in audio testing, power amplifiers distortion testing, and used for the AC bridge excitation.**
- **Hartley oscillators are used in radio receivers.**
- **Colpitts's oscillator is used to generate sinusoidal output signals with extremely high frequencies.**
- **These are extensively used in instruments, computers, modems, digital systems, marine, in phase-locked loop systems, sensors, disk drives & telecommunications.**

OPERATIONAL AMPLIFIERS:

Let us learn about the operational amplifiers which are special form of amplifiers. These amps are used for a lot of applications.

Operational Amplifiers, or Op-amps as they are more commonly called, are one of the basic building blocks of Analogue Electronic Circuits.



An Operational Amplifier, or op-amp for short, is fundamentally a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. These feedback components determine the resulting function or “operation” of the amplifier and by virtue of the different feedback configurations whether resistive, capacitive or both, the amplifier can perform a variety of different operations, giving rise to its name of “Operational Amplifier”.

Normally an amplifier will amplify the entire AC signals only. But sometimes we need to amplify the DC signals only and not AC signals. Here, we use the OP-AMP.

The opamp is often called comparators because they have negative inputs and positive inputs. So, based on how the signal is fed you can use them as summers or subtractors. You can use the opamp as differentiators or integrators. Op-amps can be used as “Active Filters”, where in you can easily specify the range, you need to operate.

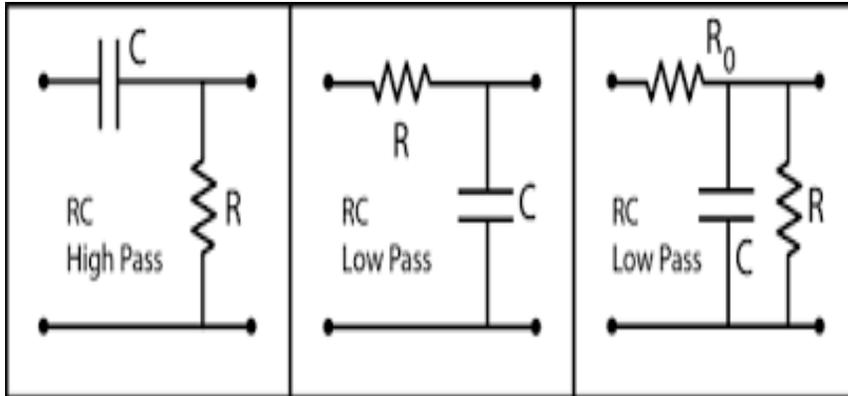
Operational amplifiers are linear devices that have all the properties required for nearly ideal DC amplification and are therefore used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation.

AUDIO FILTERS:

A Filter means, it is something that is going to either attenuate or let the signal pass through a particular frequency. Just the way you have filters that you use to filter the particles of different sizes. Similarly, you have the filters that you can use for different frequencies/ ranges. Filters form the fundamental building blocks when you want to select a particular signal of interest.

An audio filter is a frequency dependent amplifier circuit, working in the [audio frequency](#) range, 0 Hz to beyond 20 kHz. Audio filters can amplify (boost), pass or attenuate (cut) some frequency ranges. Many types of filters exist for different audio applications including [hifi](#) stereo systems, etc.,

The main difference between the two methods is that a digital filter circuit must sample the analogue signal and convert it into a set of binary numbers. In contrast, analogue filters do not have to do this type of conversion, and the signal remains in its pure analogue form throughout the filtering process.



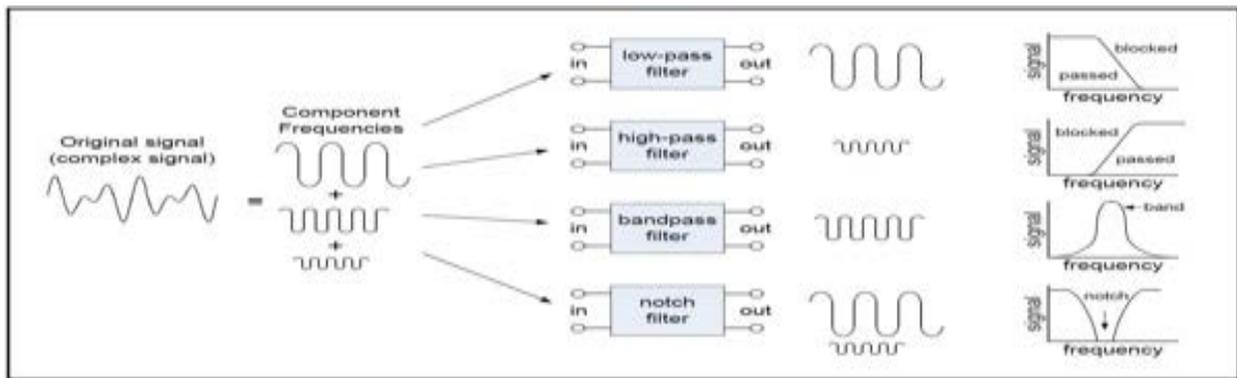
So, basically the filters are structures or circuits which are going to either restrict or let in the set of frequencies pass through them. There are different types of filters that many of us use often without realizing that they are filters. BASS is a filter that is active in the much lower frequency where you have drums and other base where the sound comes from. TREBLE is at the higher frequencies, that you hear the shrill sound in the signals. So, the BASS is the lower frequency that carries a lot of energy. Whereas the Shrill carries a large amount of information with very little amount of energy. The key difference between bass and treble is that bass sounds have the lowest frequencies whereas treble sounds have the highest frequencies.

So, how do you filter between Bass and Treble, when the signal passes through a set of filters. In most cases, they have multiple filters connected to an amp. When you attenuate the frequencies that are interesting to you.

To get a clear BASS frequency or signals, you attenuate the higher frequency by using a LOW PASS FILTERS. In the case of TREBLE, you

attenuate the lower frequency by using a HIGH PASS FILTER by allowing only the high frequency to pass through it.

Low-pass: Low-pass filters pass through frequencies below their cutoff frequencies, and progressively attenuates frequencies above the cutoff frequency. Low-pass filters are used in audio crossovers to remove high-frequency content from signals being sent to a low-frequency subwoofer system.



High-pass: A high-pass filter does the opposite, passing high frequencies above the cutoff frequency, and progressively attenuating frequencies below the cutoff frequency. A high-pass filter can be used in an audio crossover to remove low-frequency content from a signal being sent to a tweeter.

What is a Band Pass Filter?

A band pass filter (also known as a BPF or pass band filter) is defined as a device that allows frequencies within a specific frequency range and rejects (attenuates) frequencies outside that range. The [low pass filter](#) is used to isolate the signals which have frequencies higher than

the cutoff frequency. Similarly, the [high pass filter](#) is used to isolate the signals which have frequencies lower than the cutoff frequency.

By the cascade connection of high pass and low pass filter makes another filter, which allows the signal with specific frequency range or band and attenuate the signals which frequencies are outside of this band. This type of filter is known as Band Pass Filter. [The](#) Band Pass Filter has two cutoff frequencies. The first cutoff frequency is from a high pass filter. This will decide the higher frequency limit of a band that is known as the higher cutoff frequency (f_{c-high}). The second cutoff frequency is from the low pass filter. This will decide the lower frequency limit of the band and that is known as lower cutoff frequency (f_{c-low}).

All-pass An all-pass filter passes all frequencies but affects the phase of any given sinusoidal component according to its frequency.

CHAPTER IV: Communication

Communication begins when somebody wants to convey information to somebody else. That information must be presented as some kind of pattern.

For example, speech is a pattern, smoke signals are a pattern, talking drums are a pattern, telephone calls are a pattern, Morse code is a pattern.

These patterns then travel over a communication channel, typically involving a medium. For instance, smoke passing through air, electrical signals passing through wire, or speech passing through the atmosphere as a series of pressure waves.

Once the pattern reaches the recipient, it needs to be decoded and it needs to be understood. Somebody needs to understand what the dots and dashes of Morse code mean or what the patterns of smoke signals mean, or simply to process the sounds that make up human speech.

Lastly, it's received in a form in which the recipient can understand the information and act on it. That's the basic model of all types of communication.

This is the way in which radio communication works. Somebody speaks into a radio; it gets encoded or turned into a pattern by the transmitter. It then gets sent as electromagnetic waves through a communication channel (the atmosphere), which is received by receiving a radio. It gets decoded so the pattern is understood, and it get converted again to sound that the receiver understands and can act on.

For radio communication we need a transmitter and a receiver. Let us understand these two.

Modulation.

The audio frequency signals cannot be radiated from the antenna directly because the transmission at audio frequencies is not practical. :

To radiate the audio signals the purpose of oscillations of very high frequency or radio frequency are produced by oscillators. These EM waves produced are of constant amplitude and of extremely high frequencies.

The audio frequency (AF) signal is then super imposed with radio signals is also called as the carrier waves because they carry AF signals through space to distant places. The processes of super imposing AF waves with carrier waves is known as Modulation.

The concept of modulation (at the transmitter) and demodulation (at receiving side) is the backbone of a communication system.

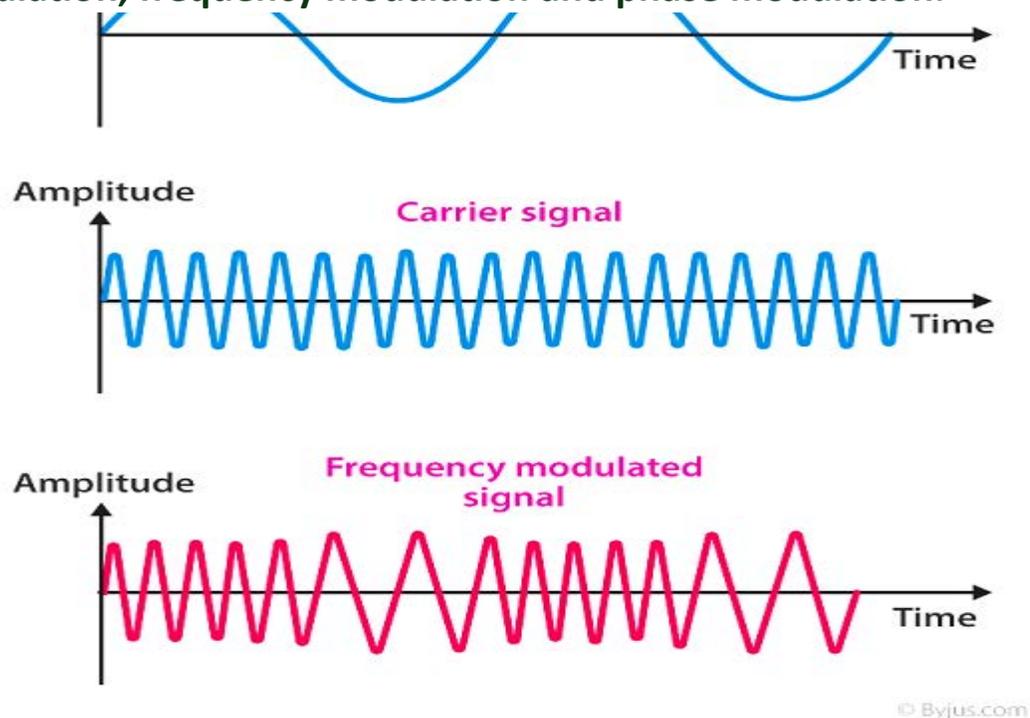
A simple illustrative example is. If you want to throw a piece of paper at some distance, say 50 m then what will you do? A very simple solution is that you wrap the paper on the stone and then throw it right.

So that is the philosophy of modulation. You modulate the carrier signal (stone) with your information signal (paper) and then throw it using a transmitter so that your information can travel to a longer distance. At the receiver side of the communication system the

demodulator separates the information signal from the carrier and then your information signal is processed.

Types of Modulation:

Modulations are carried over by varying any one of the three parameters by taking the other two as constant. In this way, the modulation is classified into three and they are amplitude modulation, frequency modulation and phase modulation.



Amplitude Modulation

In amplitude modulation the amplitude of the signal is varied following the carrier signal. The frequency of the carrier waves and phase of the carrier wave does not change. No information is carried by the carrier signal, but its amplitude is varied with the amplitude of the signal wave.

Frequency Modulation

There is a change in the frequency of the carrier wave if the instantaneous signal voltage changes. It is known as frequency modulation. So, the amplitude and phase of the carrier wave are not changing.

Phase Modulation – The change in amplitude of the instantaneous signal makes changes in the phase of the carrier wave which is called phase modulation.

Mostly it has similarities with frequency modulation. If the modulating signal's amplitude reaches maximum in the positive side, then the carrier signal's phase leads and shows compression. If the modulating signal's amplitude falls and reaches a minimum on the negative side, then the carrier signal's phase lags and shows rarefaction.

What is AM, FM, and PM?

AM – It is known as amplitude modulation used to increase the amplitude of the signals.

FM – It is known as frequency modulation used to amplify the frequency of signals.

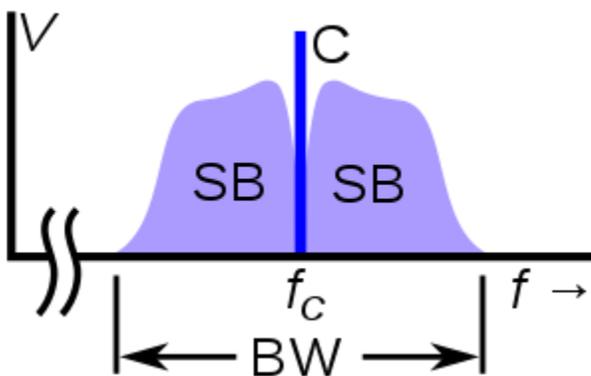
PM – Phase modulation is modulation in which the phase of the carrier wave is varied and is used for the transmission of signals.

Side Bands.

In the process of Amplitude Modulation or Phase Modulation, the modulated wave consists of the carrier wave and two sidebands. The modulated signal has information in the whole band except at the carrier frequency.

A Sideband is a band of frequencies, containing power, which are the lower and higher frequencies of the carrier frequency. Both the sidebands contain the same information.

The transmission of such a signal which contains a carrier along with two sidebands, can be termed as Double Sideband Full Carrier system.

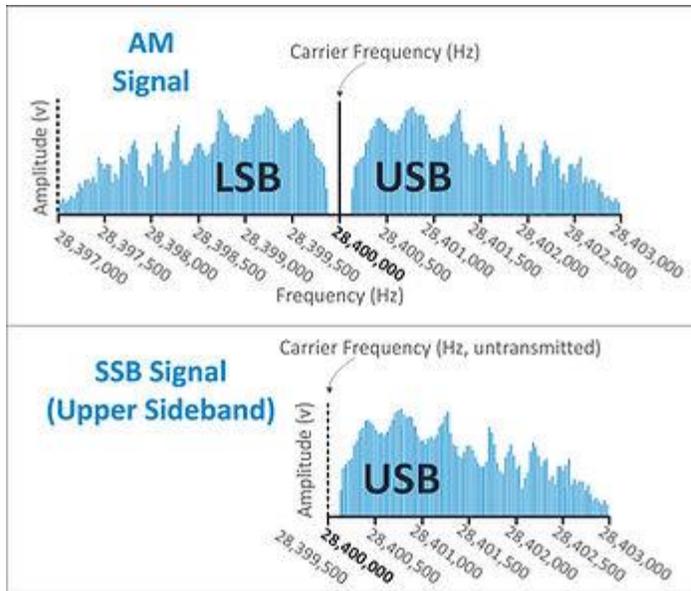


The sidebands comprise all the spectral components of the modulated signal except the carrier. The signal components above the carrier frequency constitute the upper sideband (USB), and those below the carrier frequency constitute the lower sideband (LSB). All forms of modulation produce sidebands.

single sideband

As the name implies, single sideband mode utilizes only one of the two AM sidebands and suppresses the carrier frequency in transmission. So, the SSB signal is just under one-half the bandwidth of the double sideband conventional AM signal.

SSB utilizes only one of the double sidebands of AM and omits the carrier frequency transmission. The upper sideband SSB signal is illustrated here.



The narrower bandwidth of SSB has a couple of important implications:

1) The SSB signal consumes less of the available spectrum within an amateur band, thereby allowing more signals simultaneously on the band without interference; and

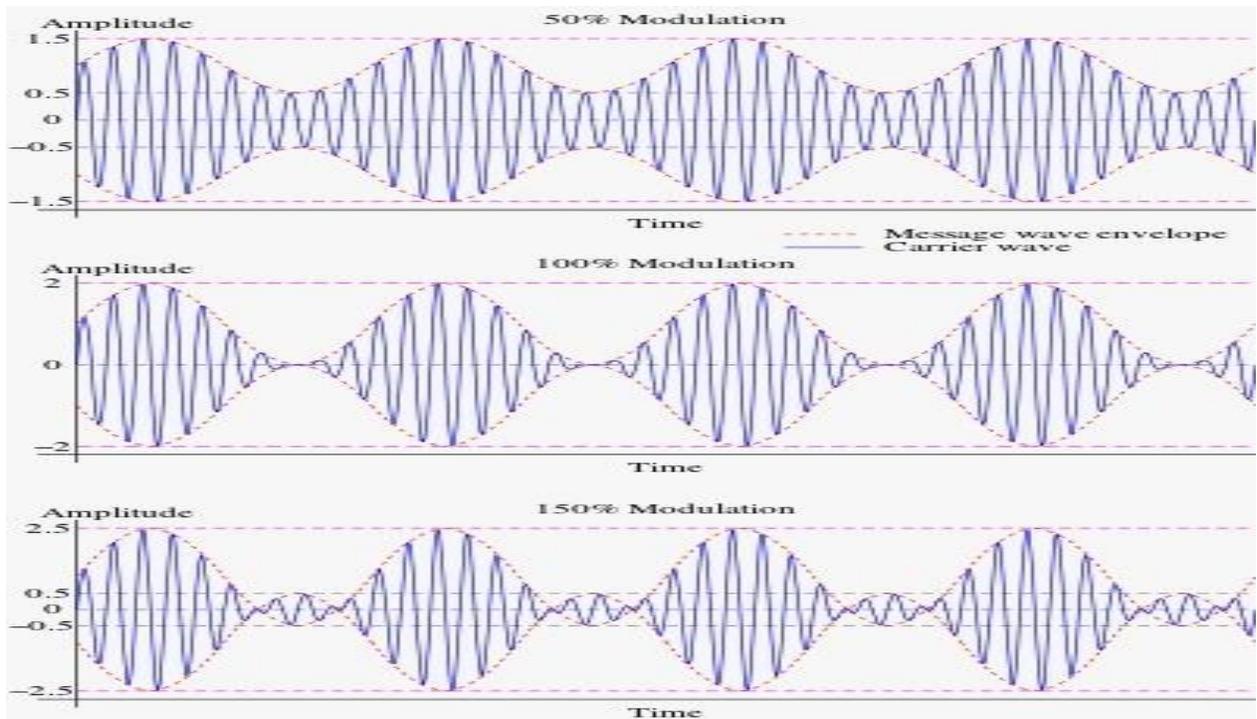
2) The power of a transmission is more densely applied in the narrower band, providing a higher average effective power across the transmitted band, and thereby giving the SSB signal more ‘punch’ than a comparably powered FM or

AM signal in which the power is spread across a much broader range of frequencies.

Modulation percentage.

As the modulation percentage increases the amount of energy that put through the system increases. We want to achieve 100% modulation without any distortion; means you want to transfer 100% of the energy from the message wave to the carrier wave to get the modulated signal. You see a peak when you transmit.

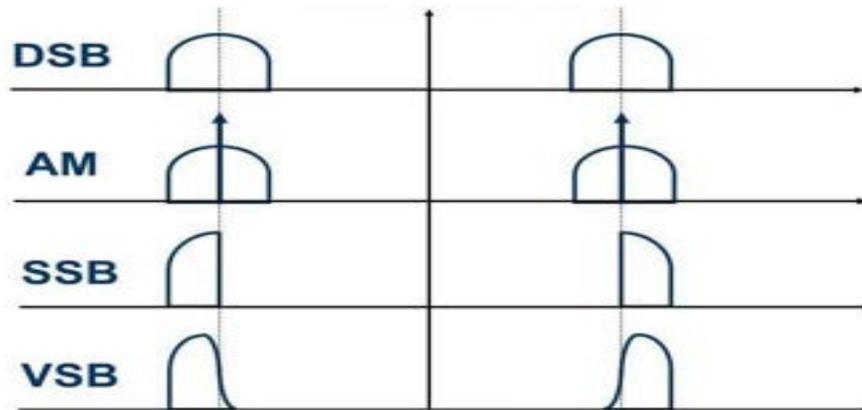
When it comes to HF, you want to make sure that it is very clearly audible. You will hear a lot of noise on the HF bands. So, you want to make sure that your signals are well modulated and if it is not 100% modulated, then you are conveying or you are not putting in enough energy and your signals are reaching the other end.



On the other hand, if you put more than 100% modulation, you will have a lot of distortion on your signals and your signals are not picked well at the other end, when you receive an overmodulated signal. Sometimes you hear the comment "overmodulated or overdoing" in the regular nets.

Spectrum usage in the case of AM, DSB, SSB(LSB/USB) AND THE VESTIGIAL SB.

If you look at the spectrum, in the case of DSB, you are occupying both the ranges lower and upper side bands, you are tuned to the full band width and using the whole signal. It is going to consume lot of power when compared to SSB operations.

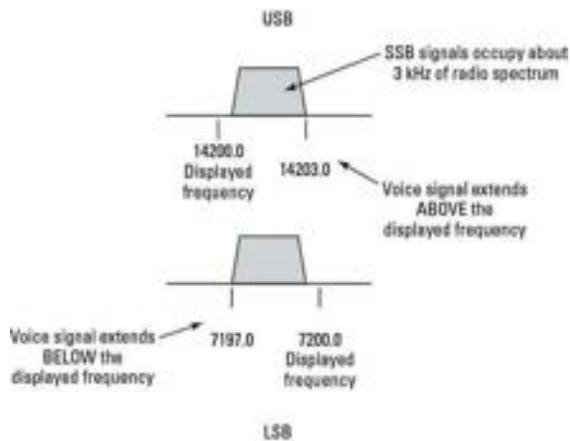


In the case of AM, you have the DSB signal plus the carrier signal that is the spike you see in the middle of the hump. In the case of SSB you choose what you want to operate, either LSB or USB and you remove the other side band and the carrier signal as you don't require them.

In the case of the vestigial side band, it acts very similar to that of SSB, but there is a small piece of frequency band that we use on the other side band in the spectrum hence the name, Vestigial side band.

Vestigial meaning: forming a very small remnant of something that was once greater or more noticeable. (Dictionary meaning)

In most common use of the HAM radio, whenever you are going to less than 10MHz, say 160m/1.6MHZ, 80m/3MHZ, 40m/ 7MHz, 20m/14MHZ, 30m/10MHZ you have sideband mode. Anything below 7200mhz it is in the LSB mode and other lower bands are USB.



Nowadays, most HF amateur operation is single sideband (see below). That means your radio will use either the upper sideband (USB) or the lower sideband (LSB) for a particular contact.

You can legally use either on any frequency band. But by convention, some frequency bands use one; some use the other. Why?

Lower sideband (LSB)--The common single-sideband operating mode on the 40, 80 and 160-meter amateur bands. Upper sideband (USB)--The common single-sideband operating mode on the 20, 17, 15, 12 and 10-meter HF amateur bands, and all the VHF and UHF bands.

Classification of Emission:

We have learnt about the types of modulation, carrier waves, side bands and band width. Based on these the classification of radio emissions.

The International Telecommunication Union (ITU) uses an internationally agreed system for classifying radio frequency signals. Each type of radio emission is classified according to its bandwidth, method of modulation, nature of the modulating signal, and type of information transmitted on the carrier signal. It is based on characteristics of the *signal*, not on the transmitter used.

Two letters and a numeral in the center are designated as emission classification.

The following table gives the details for ready reference.

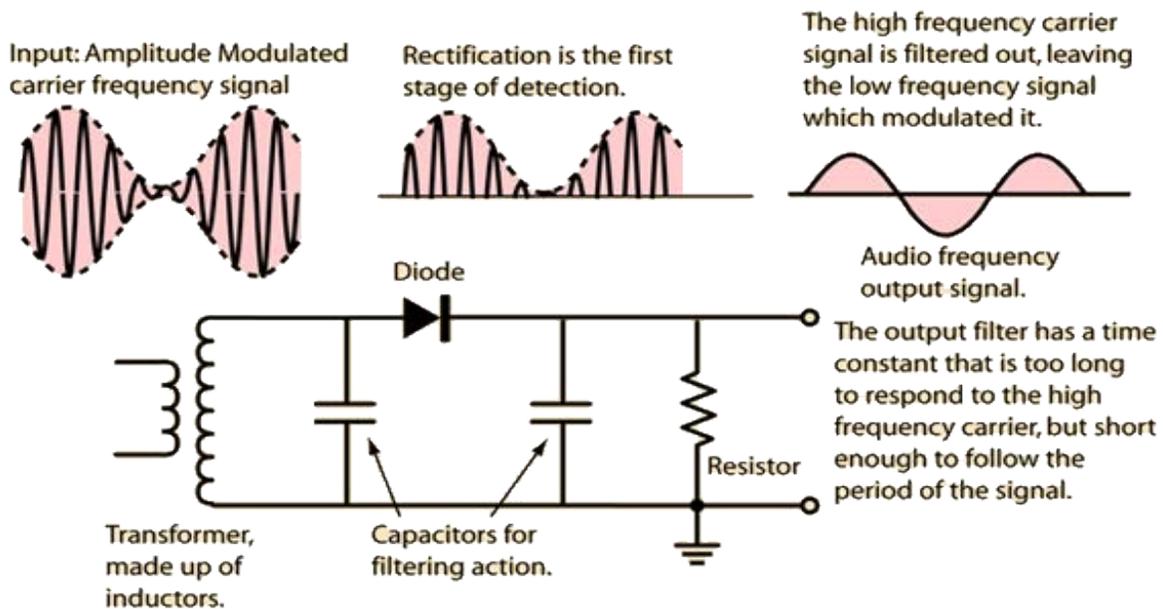
first symbol – type of modulation of the main carrier;	second symbol – nature of signal(s) modulating the main carrier;	third symbol – type of information to be transmitted.
--	--	---

N- Unmodulated carrier	0- No modulating signal	N- No transmitted information
A- Double-sideband AM	1 - One channel containing digital information, no subcarrier	A- Aural telegraphy,
B- Independent sideband	2- One channel containing digital information, using a subcarrier	intended to be decoded by ear,
C- Vestigial sideband	3- One channel containing analog information	B- Electronic telegraphy,
F- Frequency modulation	7- More than one channel containing digital information	intended to be decoded by machine
G-Phase modulation	3- One channel containing analog information	C-Facsimile
J-Single-sideband with suppressed carrier	7- More than one channel containing digital information	D-Data transmission
K-Pulse-amplitude modulation	7- More than one channel containing digital information	E-Telephony
		F-Video

L-Pulse-width modulation	8- More than one channel	W-Combination of any of the above
M- Pulse-position modulation	containing analog information	X- None of the above
P- Sequence of pulses without modulation	9-Combination of analog and digital channels	
Q- Sequence of pulses, with phase or frequency modulation in each pulse	X- None of the above	
R- Single-sideband with reduced or variable carrier		

Single sideband with suppressed carrier (J) + One channel containing analog information (3) + Telephony (E) is denoted by J3E. You confirm the Emission classification and the Power allowed for your category of license before establishing any contacts on the air (QSO)

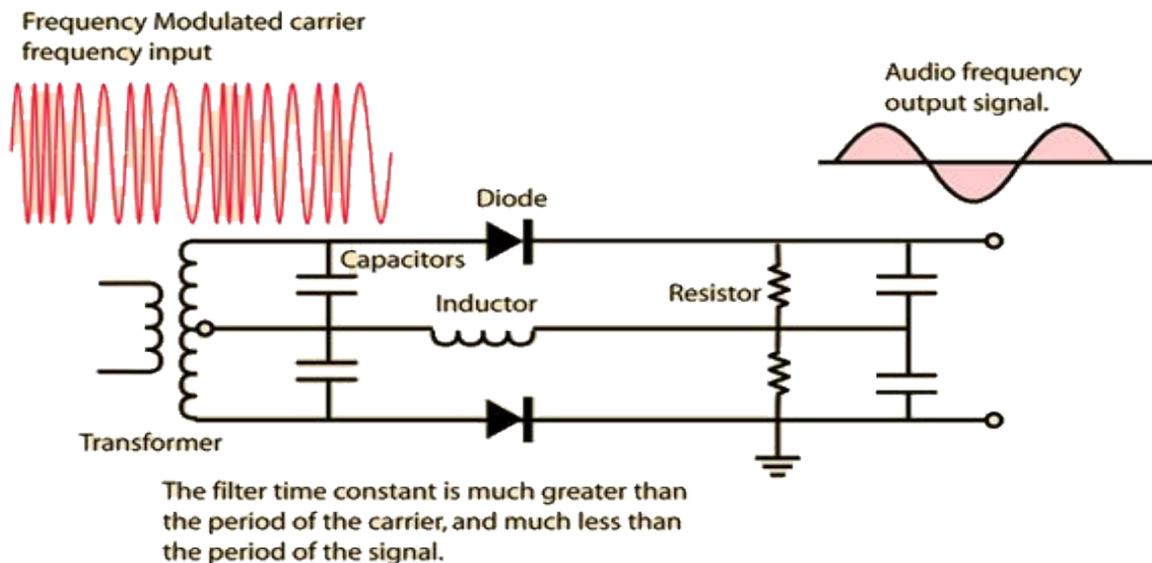
Detector for the AM signal



Here is shown the simple form of detector for the AM signal. If you start from the transformer, the transformer is a coupling transformer for your antenna. Once we couple it, we have the filtering capacitor. The filtering capacitor will remove most of the RF energy in it. What is left behind is the base band signal or your audio signal. This audio signal will be rectified by the diode, that is placed before the resistor. So, the capacitor and the resistor will act as filters and gives you very low audio signal. After this filtered signal, you need some kind of amplification, or you need a super sensitive headphones/earphone to convert these few milliwatts of audio to the level you could listen to it.

Detector for the FM signals.

Here, we have the detector for the FM signals. The difference between



the AM and FM detectors is that you see the circuit is mirrored. That is mirrored around the center tap of the transformer as in the full wave rectifier. In this case this forms very similar to the full wave rectifier, with a type of filter formed by the combination of these capacitors and inductors. By doing this we can filter out the fast-changing frequencies and you get the required audio base band signals to generate the FM signals. These are very basic or rudimentary form of detector, often asked in your exams.

What is RF and IF signal?

RF = Radio Frequency (LO + IF) IF = Intermediate Frequency (LO - RF)

Relation Between RF and IF When the IF is up-converted (The frequency of IF is increased) through an UC (Up-converter) by adding it

to the Local Oscillator frequency (LO), the new frequency obtained is called an RF.

What are IF and RF?

Put another way, RF stands for “radio frequency” which is a general term and could mean any high frequency signal; say greater than a few MHz. IF stands for “intermediate frequency” and is the frequency of a specific signal in a receiver.

Why do we convert RF to IF?

Conversion to intermediate frequency is useful for several reasons. When several stages of filters are used, they can all be set to a fixed frequency, which makes them easier to build and to tune. Lower frequency transistors generally have higher gains, so fewer stages are required.

How does a signal mixer work?

An RF mixer is a three-port passive or active device that can modulate or demodulate a signal. The purpose is to change the frequency of an electromagnetic signal while (hopefully) preserving every other characteristic (such as phase and amplitude) of the initial signal.

What is RC and LC oscillator?

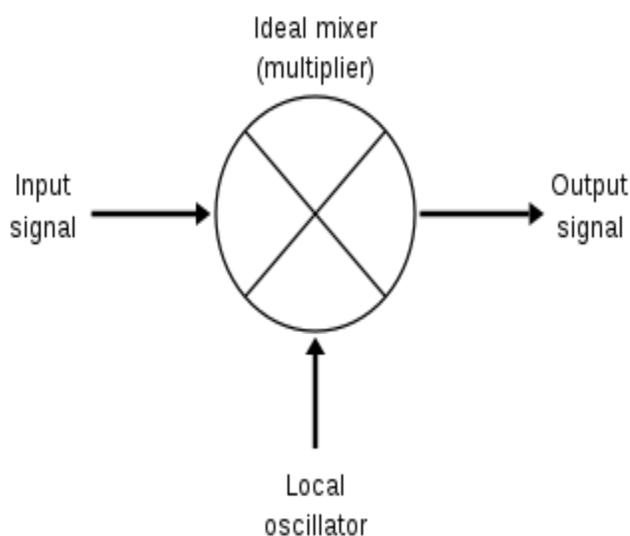
The oscillation frequency is proportional to the inverse of the capacitance or resistance, whereas in an LC oscillator the frequency is proportional to inverse square root of the capacitance or inductance.

So a much wider frequency range can be covered by a given variable capacitor in an RC oscillator.

The next important circuit to build a radio is called Mixers.

The Ideal Mixer is shown in Figure below.

An RF (or IF) mixer (not to be confused with video and audio mixers) is an active or passive device that converts a signal from one frequency to another. It can either modulate or demodulate a signal. It has three signal connections, which are called ports in the language of radio engineers. These three ports are the radio frequency (RF) input, the local oscillator (LO) input, and the intermediate frequency (IF) output.



What happens in the mixers, for example if you take two signals A and B, then output of the mixer would be either $A+B$ or $A-B$. Here, A and B signify the signal frequencies. So, if your input says, 7MHz and your local oscillator signal say, 3Mhz, the output would be either $7+3=10\text{Mhz}$ or $7-3=4\text{MHz}$. Now you have

these two signals and output of the mixer is called as IF, intermediate frequency.

Once you have the IF, then you can choose the value of the frequency of your choice. Now you use a very narrow band filter, typically built with a crystal or a LC circuit, that would choose either 10Mhz or

3MHz. Once you choose either of these two, you can decide what type of operation you want to perform on it.

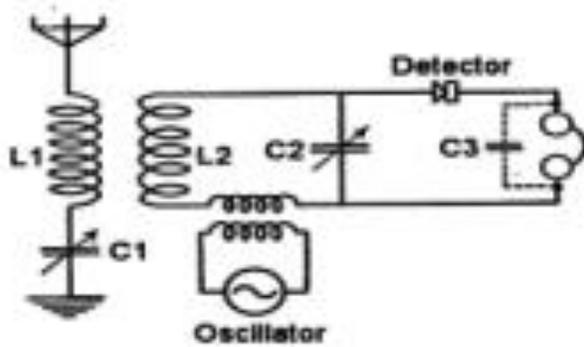
So, to summarize, the mixer is the circuit that is going to take two separate frequencies and going to produce the sum of the two signals and the difference of two signals. This is called double balanced mixtures.

In electronics, a local oscillator (LO) is an electronic oscillator used with a mixer to change the frequency of a signal. This frequency conversion process, also called heterodyning, produces the sum and difference frequencies from the frequency of the local oscillator and frequency of the input signal.

Processing a signal at a fixed frequency gives a radio receiver improved performance. In many receivers, the function of local oscillator and mixer is combined in one stage called a "converter" - this reduces the space, cost, and power consumption by combining both functions into one active device.

Local oscillators are used in the heterodyne receiver, the most common type of radio receiver circuit. They are also used in many other communications circuits such as modems, cable television set top boxes, etc.,

The main reason for using an intermediate frequency is to improve frequency selectivity. In communication circuits, a very common task is to separate out or extract signals or components of a signal that are close together in frequency. This is called filtering.



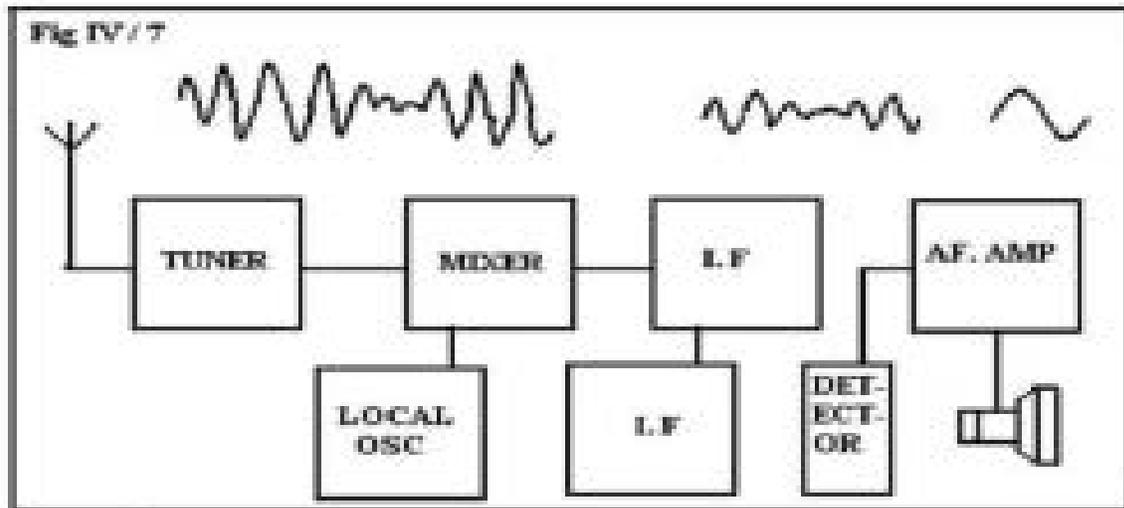
Assuming what detectors do and what the mixers do and with this understanding of detectors and mixers, let us learn about the Heterodyne Receivers.

How does a heterodyne receiver work?

The "heterodyne" or "beat" receiver has a local oscillator that produces a radio signal adjusted to be close in frequency to the incoming signal being received. When the two signals are mixed, a "beat" frequency equal to the difference between the two frequencies is created.

Adjusting the local oscillator frequency correctly puts the beat frequency in the audio range, where it can be heard as a tone in the receiver's earphones whenever the transmitter signal is present. Thus, the Morse code "dots" and "dashes" are audible as beeping sounds. This technique is still used in radio telegraphy; the local oscillator now being called the beat frequency oscillator or BFO. Fessenden coined the word *heterodyne* from the Greek roots *hetero-* "different", and *dyn-* "power".

Let us look at the block diagram of a Heterodyne Receiver:



It is called Heterodyne because you mix two signals to receive the added signal.

So, if you start from the antenna next is tuner: the tuner is nothing but a filter to filter the frequency of interest and the noise from the band.

To avoid many tuned circuits, we have a design shown in the previous slide where we convert the incoming signal into a single frequency called the intermediate frequency (IF).

To avoid many tuned circuits, we have a design shown in the previous slide where we convert the incoming signal into a single frequency called the intermediate frequency (IF).

After the tuner, the signal is pushed to the mixer where the frequency of the local oscillator is being mixed with the incoming signal. Suppose the incoming signal is of 7 Mhz, the local oscillator frequency will be 7 Mhz + 455 KHz (Intermediate frequency). After the mixer, we will have two different frequencies:

1. $(7\text{Mhz} + 455\text{ KHz}) + 7\text{ Mhz}$ Local Oscillator freq. Incoming Signal

2. $(7\text{ Mhz} + 455\text{ KHz}) - 7\text{ Mhz} = 455\text{ KHz}$. As the tuned circuit at the mixer is tuned for 455 KHz, the signal passed to the next stage is only 455 kHz.

If the incoming signal changes to any other frequency, say 7.1 Mhz the local

oscillator should oscillate at $7.1\text{ Mhz} + 455\text{ KHz}$ so that the difference of incoming signal plus the oscillator frequency will be 455 KHz only.

As seen above, alteration of the tuned circuit is necessary only at the stages i.e. the Tuner and the local Oscillator (which are ganged for simultaneous change). We have no problem in putting any number of IF amplifiers to increase the incoming signal, After the IF amplifier, the signal is being injected to a stage called Detector / AF Amplifier. After this stage, it is once again amplified by the AF amplifier and given to speaker.

THERE ARE FIVE IMPORTANT CHARACTERISTIC QUALITIES FOR ANY GOOD RECEIVER:

They are 1. Sensitivity 2. Selectivity 3. Stability 4. Hi-Fidelity and 5. Signal to noise ratio.

1.Sensitivity is how well you receive the weak signal.

2.Selectivity is how well you can differentiate two signals which are very close to each other. Say, someone is transmitting at 7100 and the other signal from 7105, the receiver should be capable of receiving

both the signals distinctively. you should be able to hear both 7100 and 7105 clearly and separately.

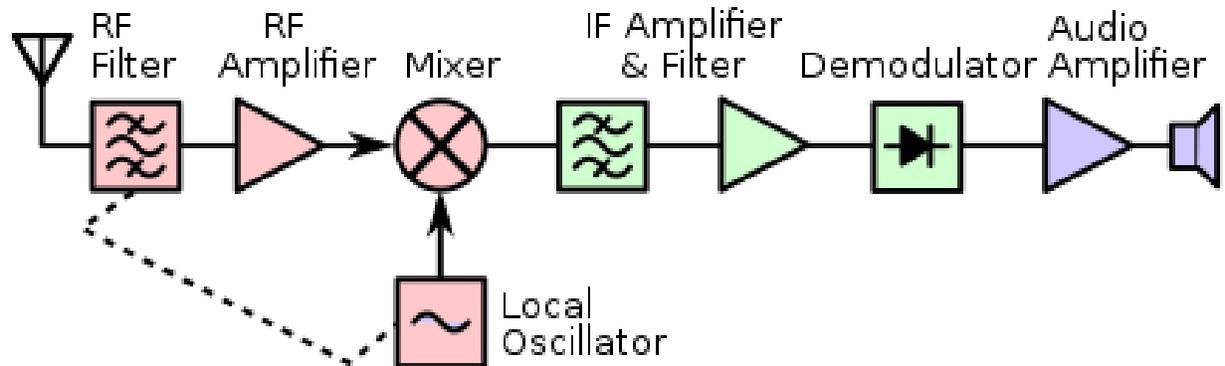
3.Stability is something very important, given the solid-state devices we have now, we don't worry very much about stability. But in the olden days, the radios got hot on continuous use because of the valves used there. The oscillators would drift; the capacitor would behave different as the heat rises. The ability to maintain the said frequency irrespective of the temperature variations is called Stability.

4.Hi-Fidelity is like any other audio receiver, how well / how true to reproduce the audio signal is called fidelity. HI FI is how deep you can reproduce the signals.

5.Signal to noise ratio is, assuming you have the weak signals and there is lot of noise around it. How well your radio can pick up the signal that is buried in the noise is the signal to noise ratio.

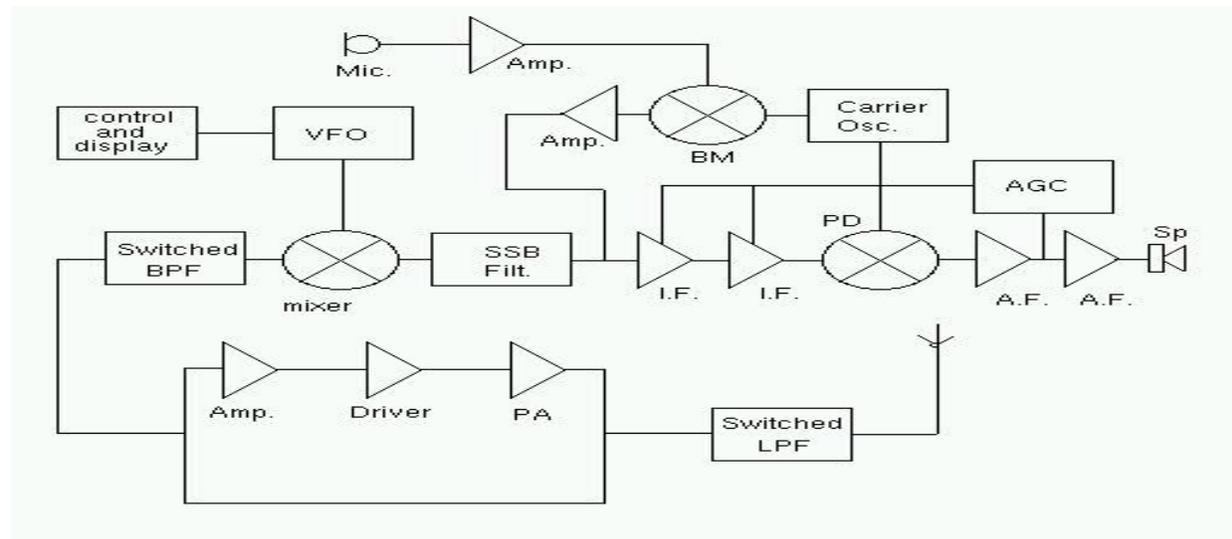
Often, SN ratio is tying the S2N ratio to the sensitivity. If you have a good preamp, then it is possible to make your receiver very sensitive to it being possible for you to pick up the signals which are buried in the noise. So, S2N ratio can be managed with a good RF pre -amp and a good set of filters.

An important and widely used application of the heterodyne technique is in the **superheterodyne receiver (superhet)**,



1. Signals enter the receiver from the antenna and are applied to the RF amplifier where they are tuned to remove the image signal and also reduce the general level of unwanted signals on other frequencies that are not required (RF Filter).
2. The signals are then applied to the mixer along with the local oscillator where the wanted signal is converted down to the intermediate frequency (IF). Here significant levels of amplification are applied, and the signals are filtered.
3. Once filtered the next block in the superheterodyne receiver is the demodulator. This could be for amplitude modulation, single sideband, frequency modulation, or indeed any form of modulation. It is also possible to switch different demodulators in according to the mode being received.
4. The final element in the superheterodyne receiver block diagram is shown as an audio amplifier, although this could be any form of circuit block that is used to process or amplify the demodulated signal.
5. From an audio amplifier we get the audio through the speaker at the desired level.

HF Transceiver Block Diagram: Let us see how the HF radio is built showing the block diagram.



This is for the transmitter: Start from the antenna, you have the LPF switch to enable you to select the band of interest to you. (let us forget about the amps, drivers and the power amps) As we are on the receiver, we are on the lower line, and we go to switch the BPF. The switch BPF is again going to filter further to ensure with much clearer clean signal of interest to you.

We have a VFO or variable frequency oscillator, that would generate the signal close to the first IF. Once you do that, you have the SSB filter. The SSB filter (if you remember what the mixer does, it will give two frequencies) will pick up one of the frequencies either the sum or difference based on your design, you pick one of them. The filtered signal is passed on to the IF amplifier which is controlled by the AGC.

Now you can assume that the AGC would tell you what the amplitude of the IF signal could be, you amplify it to a little and pass on to the next stage. The next stage has the detector and the mixer. you multiply with the carrier oscillator to get the audio signal that is amplified. Based on the amplification value the ACG decides whether to amplify further the IF signals or need to attenuate it. Then you have the speaker to her the audio signals.

This is for the receiver: if you start with the mic, as you speak on the mic it is amplified and based on the base band mixer, which takes two signals, one is the carrier oscillator signal, and the other is the audio signal itself.

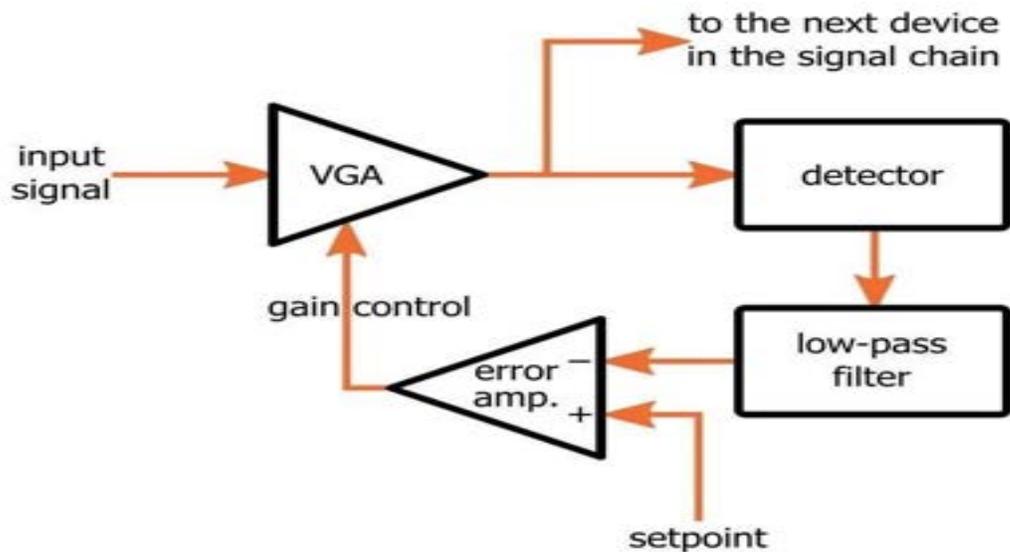
So, the base band mixers output is further amplified and fed back to the SSB filter and again to the mixer. Now, the mixer is going to do the reverse of it. Now the Base band signals are mixing it with the VFO which gives you the signal that you want to transmit. You mix it to get the RF range of your interest. This is pass it through the BPF to filter all the hardness in the signal that arise out of the mixer. Then you amplify it with a power amp.

Since the amp can introduce some signals of harmonics, you pass it through the LPF to remove all harmonics and then pass the clean signal to the antenna to transmit the RF out.

This is how you take the audio signals and slowly increase the frequency to the required RF frequency and then modulate it. Then increase the frequency and transmit the signal out.

THE OTHER IMPORTANT PIECE OF RADIO STRUCTURE IS CALLED ACG- AUTOMATIC GAIN CONTROL.

In ACG, you receive the incoming signals and based on your choice, you set a particular threshold and that is the set point to input to the error amp. Now if you start from the input signal side, the first



component you see is VGA – variable gain amp, the input is the gain control value. Based on the gain control value, the input signal is either amplified or attenuated. The output of VGA is then fed to the detector. The detector would then detect the audio signals to pass it to the LPF.

Here are two reasons, why we pass it through the LPF. One is to remove the RF and other spurious signals. The other is, once it passes it through the LPF you get a smooth variation in the signals. These signals are passed to the error amp. Error amps are like OP AMP. It will

compare between the two values and gives a output a gain value either by amplifying or attenuate the signal.

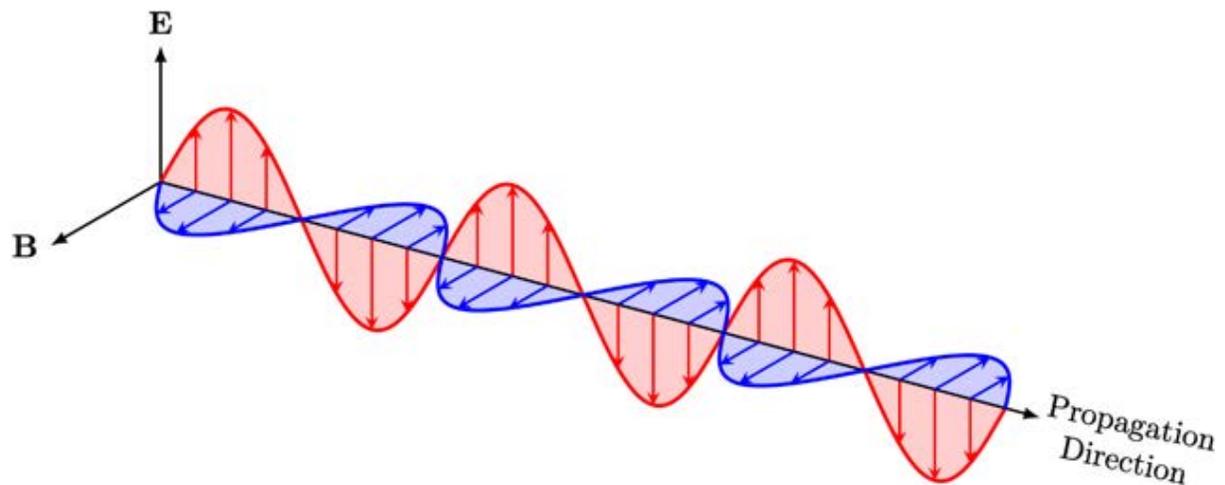
Few reasons why you need an AGC in any radio circuit: One is you could have signals which are extremely loud and followed by extremely soft. When you get a loud signal, you adjust the volume control and when you get the low signals you increase the volume control. So, you need some kind of mechanism you want to adjust the amplitude to more comfortable value. This is what the AGC does. So, the AGC in this case is set, based on the audio level. Similarly, you can set the AGC based on the RF level. Most common AGC in the radio, based only on the Audio threshold only.

Similar to this there is another circuit called squelch, which basically lets the receiver operate only when it is beyond the particular range, the other times will not make any noise. Usually, when you are on an open channel with no signal, you will hear the constant hiss of white noise which can be annoying. The squelch circuit suppresses/mutes this noise and only turns the speaker on when a transmission comes through. On most radios this can be suppressed by the turn of a rotary knob or by a press up and down on an assigned button.

CHAPTER V: Propagation of Electromagnetic Waves

To understand the propagation of electromagnetic waves, it is important to understand what an electromagnetic wave is. Electromagnetic waves are created because of vibrations produced between an electric field and the magnetic field.

Electromagnetic Waves also called Electromagnetic Radiations are basically defined as superimposed oscillations of an Electric and a Magnetic Field in space with their direction of propagation perpendicular to both of them. In simple words, electromagnetic waves are oscillations produced due to crossing over of an electric and a magnetic field.



B= Magnetic waves E= Electrical waves.

The direction of the propagation of such waves is perpendicular to the direction of the force of either of these fields as seen in the above figure. Like all waveforms, these have some properties as well. Let us have a look at the properties of electromagnetic wave propagation.

Propagation of EM waves

EM waves are another name for electromagnetic waves. EM radiation uses electromagnetic waves, which are created when an electric field collides with a magnetic field. The frequency of electromagnetic waves is their intrinsic feature. According to Maxwell, modifying the magnetic field can greatly increase the electric field. A time-varying magnetic field was created as a result of the acceleration of charges, and it is a key component in generating a time-varying electric field. As a result, electromagnetic waves have a sinusoidal magnetic and electric field that changes over time. Both fields operate normally to each other.

Properties of Electromagnetic Waves

There are many properties of electromagnetic waves which are given as

- **EM waves travel at the speed of light.**
- **A medium is not required for the propagation of these waves.**
- **Interference and diffraction occur in these waves.**

- An electric or magnetic field has no effect on these waves.
- EM waves move in a transverse direction.
- EM waves can be polarized.

Modes of Propagation of EM waves

1. Ground Wave
2. Sky Waves
3. Space Waves

Ground Wave

Ground wave is used for transmissions with a low frequency range, usually less than 1 MHz. This kind of propagation makes use of huge antennas, the order of which is equal to the wavelength of the waves and propagates via the ground or troposphere. This technology is not used to send signals across long distances. It generates considerable attenuation, which worsens as the frequency of the waves rises.

To radiate signals with high efficiency, the antennas should have a size comparable to the wavelength λ - LAMBDA of the signal (at least $\lambda/4$)

In standard AM broadcast, ground based vertical towers are generally used as transmitting antennas. For such antennas, the ground has the strong influence on the propagation of the signal.

This mode of propagation is called surface wave propagation and the waves glides over the surface of the earth.

Sky Wave

The radio waves travel directly or via reflection from the ground from the transmitting antenna across the sky to the receiver. Sky wave propagation is the name given to this type of wave propagation. Ionospheric wave propagation is another name for it. Short-wave broadcasting services use it.

We can also achieve long-distance communication by using the ionospheric reflection of radio waves back towards the ground. The ionosphere is named after the presence of numerous ions or charged particles in this environment.

The phenomenon of bending of EM waves so that they are diverted towards the earth is similar to the total internal reflection in optics.

In the frequency range from a few Mhz up to 30 to 40 Mhz long distance communication can be achieved by Ionospheric reflection of radio waves back towards the earth.

Space Waves

Line of sight communication system, often known as LoS, is used by space waves. This technique of propagation is used in space satellite communication and very high-frequency waves. It entails delivering a signal from the transmitter to the receiver in a straight line. We must guarantee that the height of the transmission tower is sufficient to avoid waves from colliding with the earth's curvature, resulting in attenuation and signal loss over long distances.

Applications of Electromagnetic Waves

There are many applications of electromagnetic waves, some of which are given here.

- 1. An electromagnetic wave can be used in a variety of ways in communication technology, as it aids in the transmission of signals from one source to another.**
- 2. These rays have the ability to transport energy in a vacuum or without the use of any medium at all.**
- 3. An electromagnetic wave can be used in a variety of ways in communication technology, as it aids in the transmission of signals from one source to another.**
- 4. Ultraviolet rays can easily be used to identify banknotes and determine whether they are forged. Original banknotes do not become luminous when exposed to UV radiation.**

Conclusion

Electromagnetic waves caused oscillations when an electric and magnetic field crossed across.

The propagation direction of such waves is perpendicular to the force direction of any of these fields.

EM waves travel at the speed of light.

A medium is not required for the propagation of these waves.

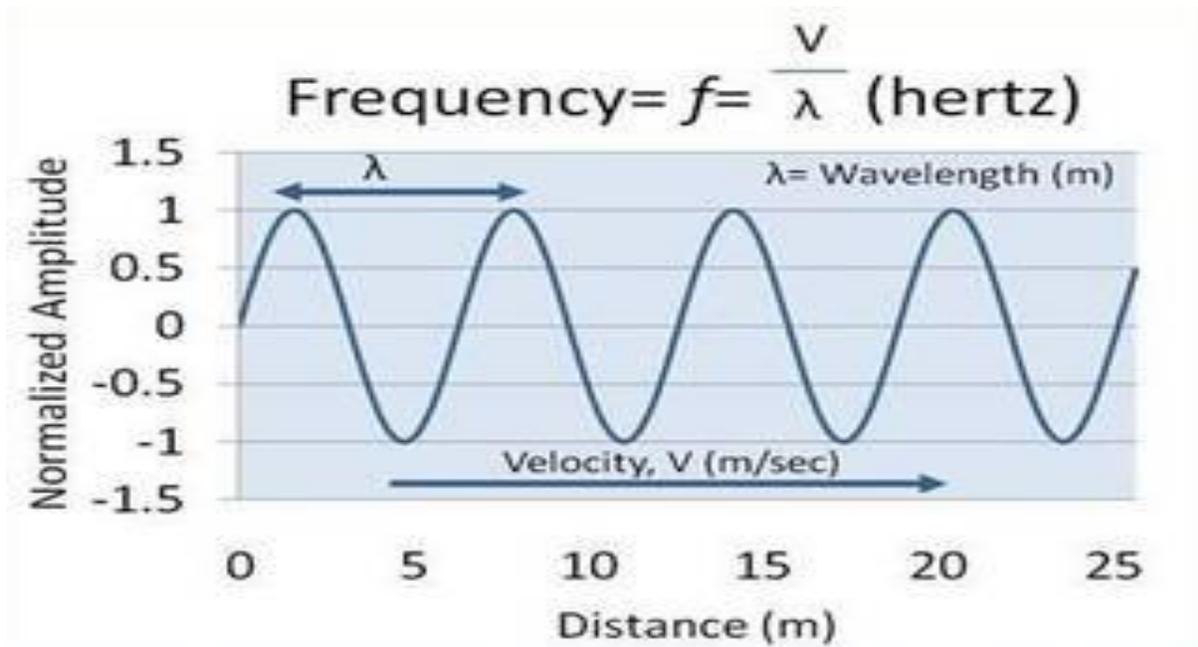
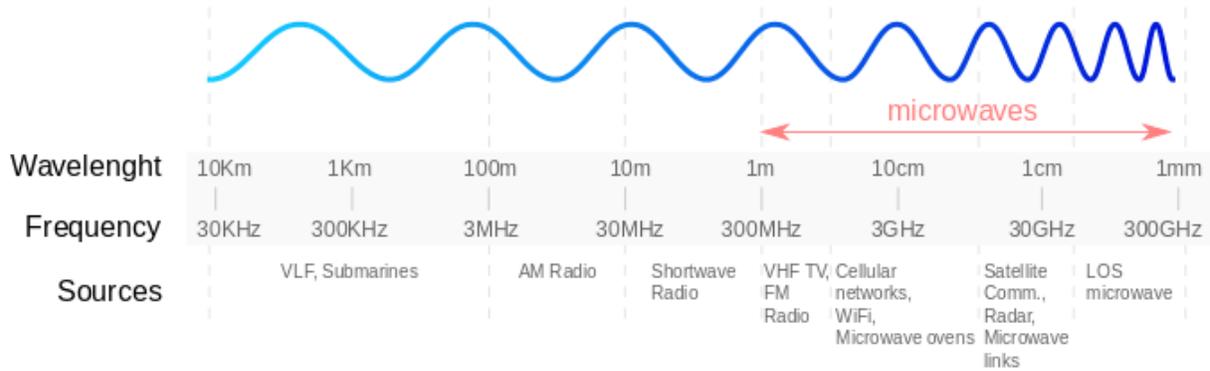
The propagation of EM waves is normal to the direction of the force of either of these fields.

The Electromagnetic Spectrum

The electromagnetic (EM) Spectrum is the range of all types of EM Radiation is energy that travels and spreads out as it goes – the visible light that comes from a lamp in your house and the radio waves that come from a radio station are two types of electromagnetic radiation. The other types of EM radiation that make up the electromagnetic spectrum are microwaves, infrared light, ultraviolet light, X-rays and gamma rays.

Radio spectrum

The radio frequency (RF) spectrum is a set of frequencies that range from 30 Hz to 300 GHz. It is divided into several bands, or ranges, and given labels for easier identification. These labels include low frequency (LF), medium frequency (MF), and high frequency (HF).



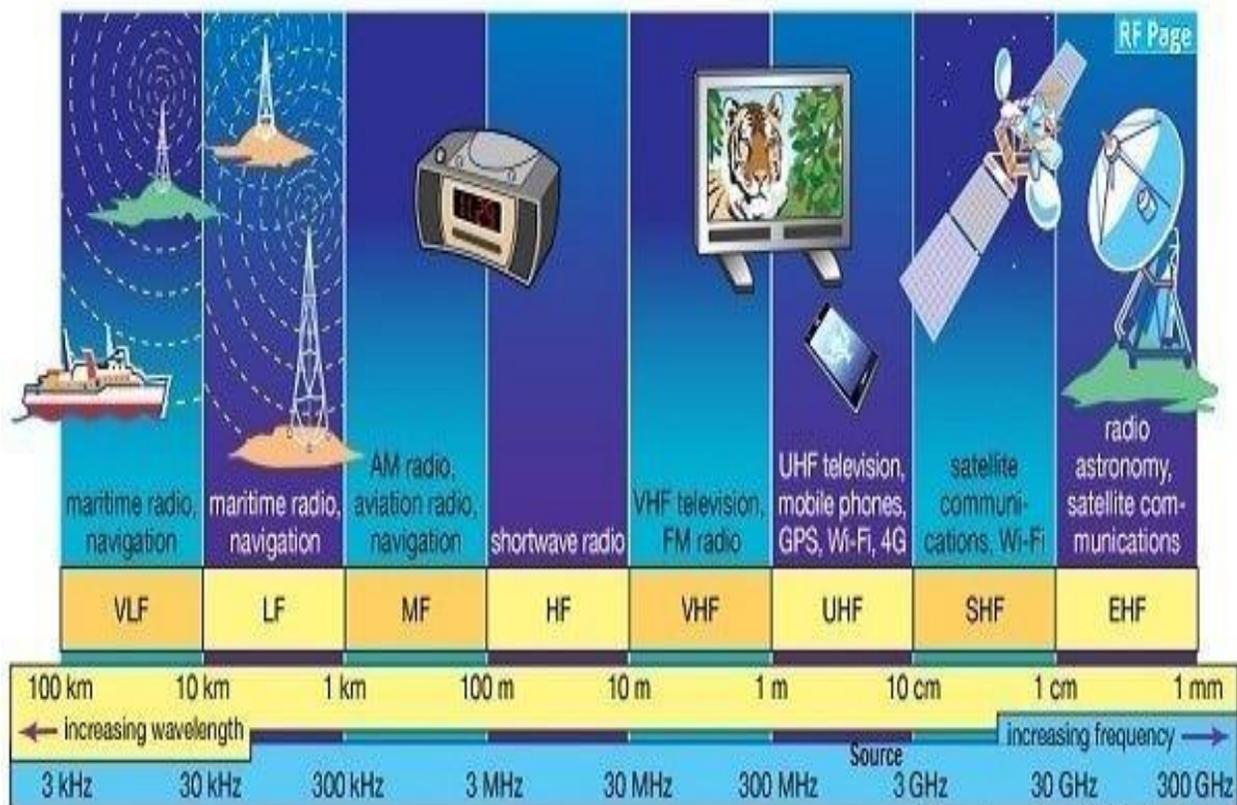
Radio waves are the waves having the longest wavelength in the electromagnetic spectrum. These waves are a kind of electromagnetic radiation and have a frequency from high 300 GHz to low as 3 kHz, though somewhere it is defined as above 3 GHz as microwaves. At 300 GHz, the wavelength is 1 mm, and at 3 kHz is 100 km. They travel at the speed of light just like all other electromagnetic waves do. Lightning or

astronomical objects make all the waves that have naturally occurred. Artificially formed radio waves are used in radio communication, radar, computer networks, broadcasting, different navigation systems, and different applications.

Radio Frequency Spectrum: Ranges

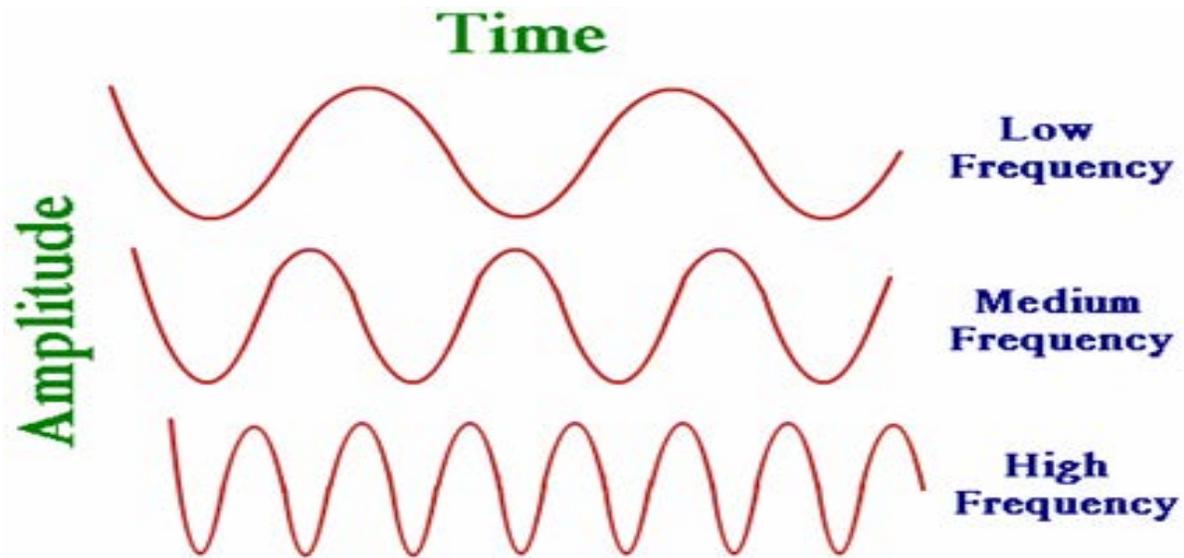
Designation	Abbreviation	Frequencies	Wavelengths
Very Low Frequency	VLF	3 kHz - 30 kHz	100 km - 10 km
Low Frequency	LF	30 kHz - 300 kHz	10 km - 1 km
Medium Frequency	MF	300 kHz - 3 MHz	1 km - 100 m
High Frequency	HF	3 MHz - 30 MHz	100 m - 10 m
Very High Frequency	VHF	30 MHz - 300 MHz	10 m - 1 m
Ultra High Frequency	UHF	300 MHz - 3 GHz	1 m - 100 mm
Super High Frequency	SHF	3 GHz - 30 GHz	100 mm - 10 mm
Extremely High Frequency	EHF	30 GHz - 300 GHz	10 mm - 1 mm

The radio frequency spectrum is made up of a virtually infinite set of discrete frequencies. These frequencies are characterized as wavelengths that correspond to the frequencies. The frequency can be calculated using the formula: $f=c\lambda$ Where: f: is the frequency c: is the speed of light λ : is the wavelength



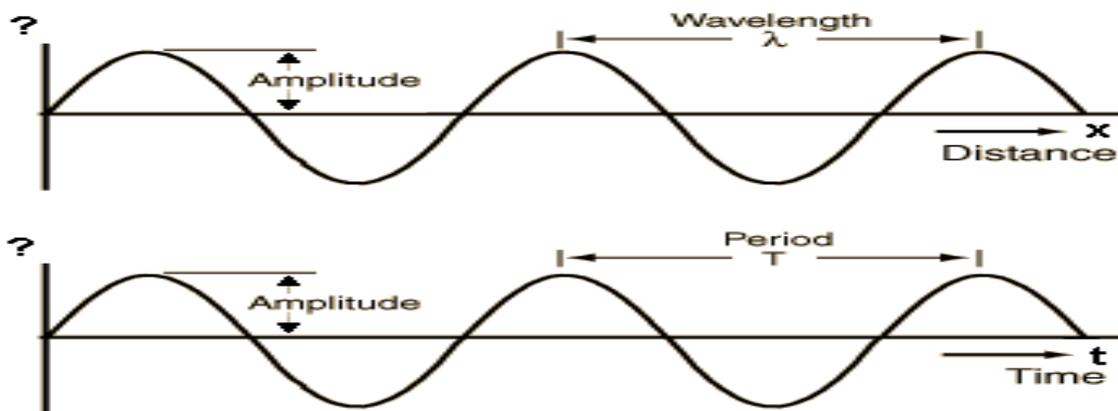
Source: Encyclopaedia Britannica, Inc.

What is Frequency?



The frequency of a waveform is the number of times a complete waveform is repeated in a fixed time period. The unit of frequency is Hz which corresponds to the number of waveforms that repeat in 1 second. So if a wave repeats 5 times in one second its frequency would be 5 Hz.

What is Wavelength?



The wavelength of a wave is the distance between two adjacent peaks or troughs of adjacent cycles. It is represented by lambda (λ) and has

units of distance like meters, cm, mm etc. The wavelength applies to both traveling waves and standing waves. The Wavelength is inversely proportional to frequency.

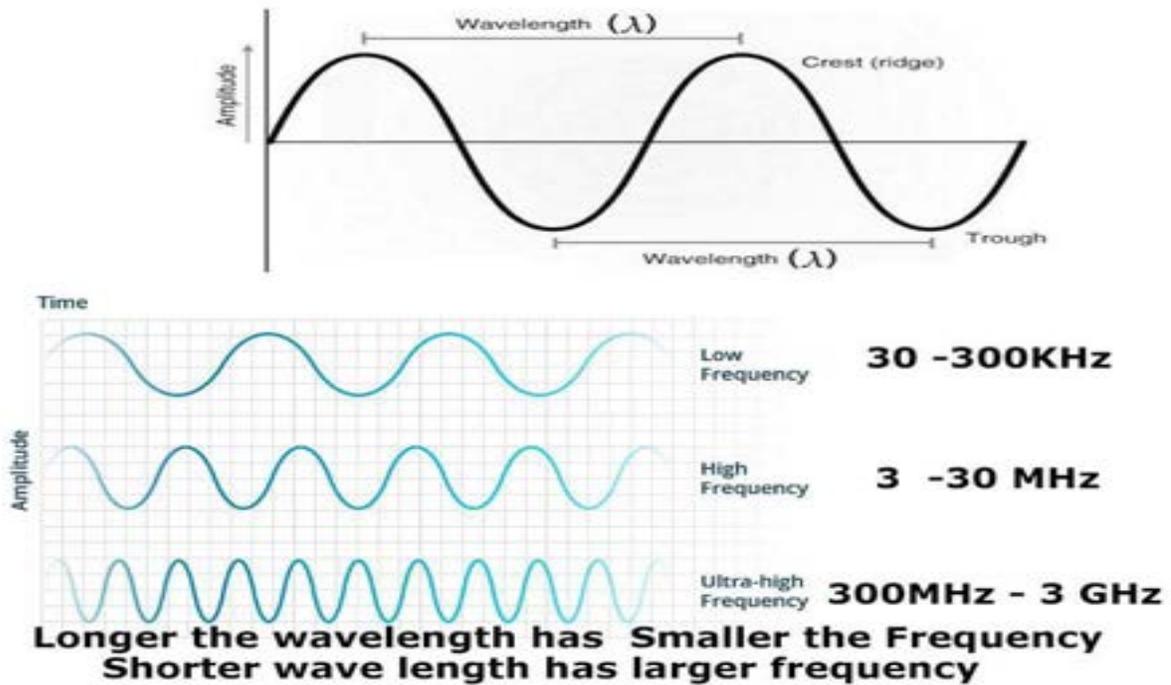
Relationship between frequency and wavelength

In the case of traveling waves, the frequency of a wave is correlated to the wavelength of the wave and the speed at which the wave is traveling. If a wave is moving faster, the number of complete wave cycles that will complete in 1 second is higher than when compared to a slower wave. So, the speed at which a wave is moving is a very important factor when determining its frequency. An important point to note is that two waves with different wavelengths can have the same frequency. So, let's assume that Wave 1 has a wavelength of 1 cm and Wave 2 has a wavelength of 2 cm. To have the same frequency, Wave 2 will need to travel at a speed that is times Wave

$$\lambda \text{ or Wavelength (m)} = \frac{\text{Velocity of light (m/s)}}{\text{Frequency (Hz)}}$$

The electromagnetic waves, or radio waves travel in the space in a constant velocity of 3×10^8 to the power of eight.

300,000,000 m/s



This is equivalent to the speed of Light the most accepted value of the speed of light till date is 299,792,458 m/s which is taken as $3 \times 10^8 \text{ ms}^{-1}$ (after rounding off.) Light is also another form of electromagnetic energy.

So, if we know the values of any two the third value could be found out.

For example, if the frequency of a EM wave is ;

14.350 MHz, then the wavelength is.

$$\text{Lamda } \lambda = c / f$$

That is $\lambda = 3 \times 10^8$ divided by 14.350×10^6

That is $\lambda = 300$ divided by 14.350 equals 20.90 meters.

That is $\lambda = 20\text{m}$ (what we say)

HAM band lies between 14.00 to 14.350 MHz

Conclusion: a longer wavelength means a lower frequency, and a shorter wavelength means a higher frequency!

Ultra-High Frequency (UHF) : Very High Frequency (VHF) : High Frequency (HF)

Several factors influence the propagation of the EM waves and the path they follow.

First Let us know the EM waves required for our syllabus:

UHF: $300\text{--}3000$ MHz - *Line-of-sight propagation.*

VHF: $30\text{--}300$ MHz - *Line-of-sight propagation.*

HF: $3\text{--}30$ MHz - *E,F1, F2 layer ionospheric refraction.*

We will learn about these bands, about their nature, properties, usages etc.,

UHF and VHF

Very High Frequency (VHF) and Ultra High Frequency (UHF) radios are by far the mostly commonly used radio type by governments, military, police, maritime organizations, emergency responders and other entities that operate in environments when regular communications networks may be inconsistent or not properly functioning.

VHF radio waves occupy a band between 30 to 300 megahertz (MHz), while UHF radio waves occupy the range between 300 MHz and 3 gigahertz (GHz). VHF/UHF radio waves are propagated by a line-of-sight path; they will not reach around the curvature of the earth and they can be blocked by hills, mountains and other large dense objects. The maximum broadcast distance of a VHF radio is around 160 km while the maximum broadcast distance of UHF radio is around 60 km – these distances are greatly variable however and depend on a number of operating and environmental factors. In almost all contexts, VHF and UHF signals will not reach their maximum potential distances. Ultra High Frequency (UHF) radios are by far the mostly commonly used radio type by governments, military, police, maritime organizations, emergency responders and other entities that operate in environments when regular communications networks may be inconsistent or not properly functioning.

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There are a wide variety of applications and devices for VHF/UHF radio transmission, including traditional FM radio and broadcast television, GPS devices and mobile phones. VHF/UHF waves can penetrate buildings and other radio transparent structures, but any object will cause some form of interference; though a VHF/UHF radio may work in a building, the signal will be weaker, and the more buildings in the surrounding area the more impacted the signal will be. Use of VHF/UHF communications in dense urban settings, thick forests, or deep valleys will significantly limit ranges even further.

Common Problems with VHF/UHF Communications:

Some common problems encountered by users of VHF/UHF might include:

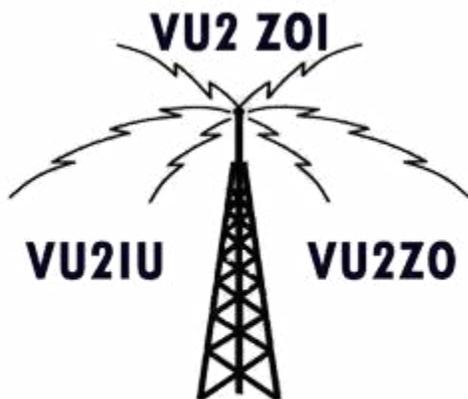
Dead spots - areas where signal is impossible to find and communication cannot occur. Dead spots are caused by an object of sufficient size/density blocking the incoming/outbound signal. If radio users are in a dead spot, they may need to relocate to obtain a proper connection, if that means moving only a few meters in one direction or another.

Electromagnetic Interference - Objects that produce sufficient electric currents, such as overhead power lines or electrical plants can also block or interfere with signals, even if the source of the electromagnetic radiation isn't directly between the two radios experiencing interference. If experiencing issues, radio users should

try moving away from overhead powerlines or other possible causes to get a better signal.

Antenna Direction - VHF/UHF radios transmit signals using line of sight propagation, meaning that their signals work best when perpendicular to the earth's surface. For the best experience and best signal, the long edge of the antenna should be pointing at the horizon, while the tip of the antenna should be facing the sky.

Repeater: how does it work?



Indian Institute of Hams

A radio repeater is a combination of a radio receiver and a radio transmitter that receives a signal and retransmits it, so that two-way radio signals can cover longer distances. VU2ZO: you Receive:145.275 MHz transmit:144.675 MHz

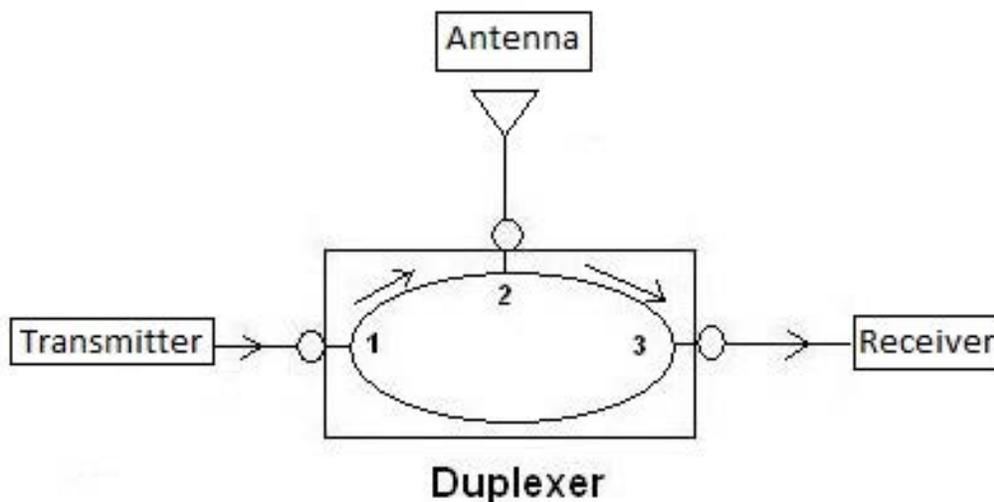
- VU2IU: you Receive:145.800 MHz transmit:145.200 MHz
- SHIFT (offset) + or – 600KHz
- International standard for VHF and 1600KHz for UHF
- Repeater systems use two different radio frequencies; the mobiles transmit on one frequency, and the repeater station

receives those transmission and transmits on a second frequency.

- The repeater receives on one radio frequency (the "input" frequency), demodulates the signal, and simultaneously re-transmits the information on its "output" frequency.
- Since the repeater is usually located at an elevation higher than the other radios using it, their range is greatly extended.

- Therefore, it follows that if the repeater receives on a high frequency and transmits on a low frequency, the mobile or handheld radio will conversely transmit high and low receive.
- If separate TX and RX antennas were to be used, they would have to be physically spaced a certain distance apart, either vertically or horizontally, to provide the necessary isolation.
- This is usually referred to as space isolation. For example, a 2 meter repeater using separate TX and RX antennas would require about 10 feet of vertical space isolation as compared to about 30 feet of horizontal space isolation to gain 30 dB of isolation between the transmit and the receive

A Duplexer is a 3-port device that allows the transmitter and receiver to use a single antenna, while operating at the same/similar frequencies. It is a device that allows two-way communication over a single channel by isolating the receiver from transmitter while transmitting a pulse and isolating the transmitter from receiver while receiving a pulse, allowing them to share the same antenna. In a duplexer there is no direct path between the transmitter and receiver. It can be thought of as a circulator i.e the signal from port 1 is routed to port 2 and the signal from port 2 is routed to port 3. Port 1 and Port 3 are isolated from each other.



The duplexers at repeaters may serve several objectives:

- **Reduce the number of antennas required due to cost or space limits.**
- **Reduce the transmission line costs or allow a better and more expensive single cable to be used instead of two.**
- **Reduce the potential of intermodulation generated from the transmitter.**
- **Reduce the nearby broadband noise generated from the transmitter.**
- **Improve the receiver 'front-end' rejection of off-frequency interference.**

WHY NOT USE TWO ANTENNAS?

Two antennas may be used instead of a duplexer, provided the antennas are placed far enough apart that the transmitter signals do not interfere with the receiver. Two transmission lines will also be required.

The isolation required between the transmitter and receiver is a complex issue and influenced greatly by the specific transmitter and frequencies used, the bandwidth of the channel, the difference in frequencies of the two frequencies to be used and the minimum amount of receiver degradation that is acceptable to the user.

It is not unusual to have a radio system requires as much as 80 to 100 dB isolation between the transmitter output and the receiver input.

When two antennas are used, the type of antennas, the physical spacing and the orientation of the antennas to one another are also major concerns.

Antenna-to-antenna isolation can also be influenced by the presence of other antennas on the same tower as well as other nearby transmitters and mechanical structures. These factors may change over time and be out of the control of the repeat operator.

Antenna separation designs should also consider any additional receiver protection that may be required for other transmitters that may be present on the same tower.

VHF vs UHF Which is Better?

- **The two frequency ranges (also called "frequency bands") used in most two-way radios are VHF and UHF We are often asked "Is VHF or UHF better?" Neither is inherently better, they each have strong points and weaknesses.**
- **If a VHF wave and a UHF wave were transmitted over an area without barriers, the VHF wave would travel almost twice as far..**
- **the general rule-of-thumb is if you are using the radio primarily outdoors where you will have clear line-of-sight then VHF is a better choice because it's signal will travel farther.**
- **BUT, if you will be using your radio in or around buildings, in urban areas, or heavily wooded areas, then UHF is a better choice because it's signal will navigate around structures better, not being blocked as easily as VHF.**

HF wave propagation: Ionospheric Radio Propagation

Earth's Atmosphere:

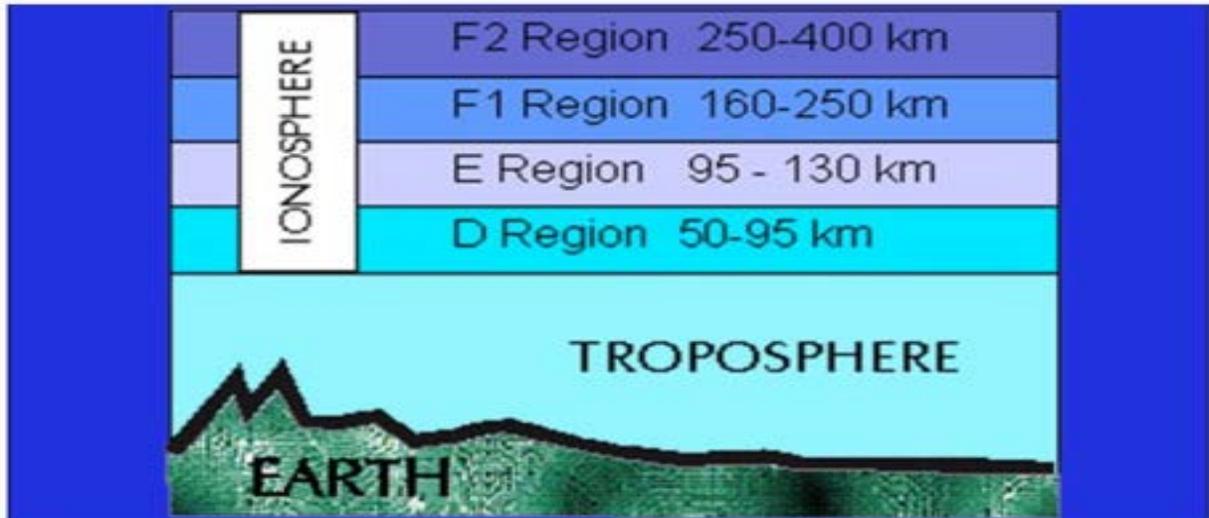
The *Troposphere* lies between the Earth's surface and average altitude of 10 km (6 mi).

The troposphere is the lowest layer of the Earth's atmosphere in direct contact with the Earth's surface. Most of the weather phenomena, systems, convection, turbulence, and clouds occur in this layer, although some may extend into the lower portion of the stratosphere, immediately above the troposphere.

The *Stratosphere* is between 10 and 50 km (6 and 30 mi) altitude.

The stratosphere is a layer of Earth's atmosphere. It is the second layer of the atmosphere as you go upward. The troposphere, the lowest layer, is right below the stratosphere. The next higher layer above the stratosphere is the mesosphere.

The *Ionosphere* is above 50 km (30 mi) to about 600 km (370 mi) altitude.



The ionosphere

The regions of the ionosphere

In a region extending from a height of about 50 km to over 600 km, some of the atoms and molecules are electrically charged (ionised) by radiation from the Sun. This region is called the ionosphere.

Ionisation is the process in which electrically charged and neutral atoms and molecules gain or lose electrons. Of specific interest to High Frequency (HF: 3 to 30 MHz) radio communications via the ionosphere (sky wave) is the process where negatively charged electrons are stripped from atoms and molecules to produce free electrons. While the ionosphere is named after the ions, it is the free electrons which are essential for HF sky wave communications. The variations in density of free electrons in the ionosphere cause HF radio waves to refract (bend), allowing the upper atmosphere to be used as a reflector for communications between distant locations on the ground.

The density of free electrons in the ionosphere is not uniform, regions of higher electron density form at different altitudes. The height at which a particular frequency is refracted depends on the electron density profile, with higher frequencies being refracted from the regions of higher electron density. The region of highest electron density determines the highest frequency capable of being refracted by the ionosphere.

In the day ionosphere there may be four regions present, the D, E, F1 and F2 regions. Their approximate height ranges are:

- **D region - 50 to 90 km;**
- **E region - 90 to 140 km;**
- **F1 region - 140 to 210 km;**
- **F2 region - over 210 km.**

At night the D, E and F1 regions become depleted of free electrons so as to be insignificant to HF sky wave. The F2 electron density also decreases during the night so that lower frequencies are required for use then; higher frequencies may penetrate the ionosphere.

At certain times during the solar cycle (mostly during winter at solar maximum) the daytime F1 and F2 regions merge. During these times and at night the F2 region is called the F region.

Only the E, F1 and F2 regions refract HF waves. The D region, through which an HF sky wave must pass to reach the refracting region, absorbs the energy of the wave, and reduces signal strength.

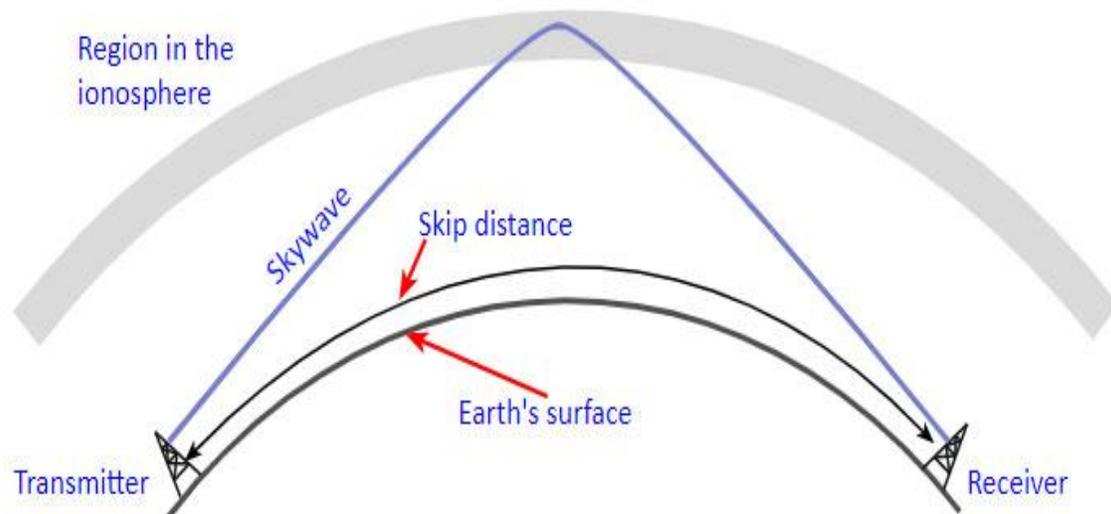
A thin, dense layer of electrons called sporadic E sometimes forms in the E region. Sporadic E can occur day or night and is capable of refracting HF sky waves.

The F2 region is the most important region for HF sky wave propagation because:

- **it is present 24 hours of the day.**
- **for long communication paths, its high altitude reduces the required number of hops.**
- **it usually refracts the highest frequencies in the HF range.**

The radio signals travelling away from the Earth's surface are termed sky waves for obvious reasons. If they are returned to Earth, then the ionosphere may (very simply) be viewed as a vast reflecting surface encompassing the Earth that enables signals to travel over much greater distances than would otherwise NOT be possible.

SKIP DISTANCE.



The skip distance is the distance over the Earth's surface between the point where a radio signal is transmitted, and the point where it is received having travelled to the ionosphere, and been refracted back by the ionosphere.

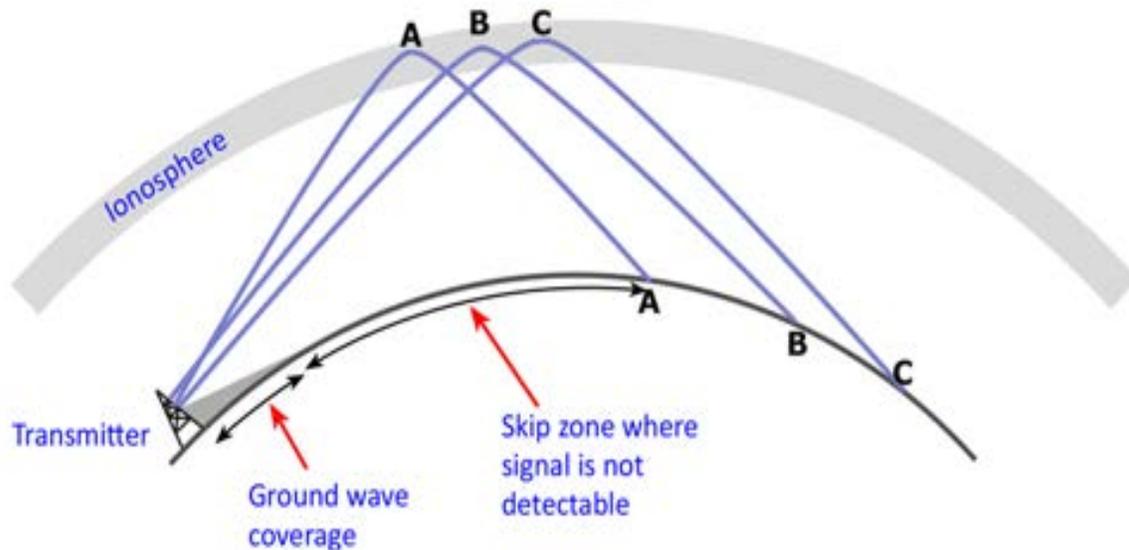
The skip distance is the distance between: **Transmitter and receiver** .

The skip distance is dependent upon a variety of factors:

- **Frequency:** The frequency of operation has a major influence on the skip distance that can be achieved. Typically, as the frequency increases a lower angle of radiation is needed to return the signals to Earth in a shorter distance. Also, higher frequencies tend to be reflected or refracted by higher layers or regions in the ionosphere. This will mean that higher frequencies tend to lead to longer skip distances.

- **Ionospheric conditions:** The ionospheric conditions play a major role in governing the skip distance. Under some circumstances when ionisation levels are high it may be possible for signals to achieve very short skip distances.
- **Angle of radiation:** The angle of radiation from the transmitting antenna will also have an impact on the skip distance. A lower angle of radiation will lead to longer skip distances as a result of the geometry.

Skip zone



The skip zone, which may also be called a silent zone or dead zone, is a region where a radio transmission can not be received. The skip zone is the region between the point where the ground wave signals can no longer be heard and the point where the skywave first returns to Earth.

The skip zone or dead zone depends upon a variety of factors:

- ***Ground wave coverage:*** The local coverage around the transmitter is governed by the ground wave. The extent of the coverage and the start of the skip zone will be dependent upon the frequency used. The ground wave coverage will be greater for lower frequencies. At MF it may extend as far as 100 miles or so, but for higher frequencies, e.g. 10MHz and above it may only extend for a mile or two.
- ***Skywave minimum skip distance:*** The minimum skip distance is influenced by several factors including the frequency of operation; the state of the ionosphere and the angle of radiation.

Summary;

UHF waves are “line of sight “– shorter distance and can penetrate through any surface.

VHF waves are “line of sight “waves above the Ground level. It can travel longer distances if there is no blockade in between.

HF waves are “Sky waves”. Propagation via the ionosphere, radio signals can be heard around the globe –international broadcasting, Military communications etc., are major users.

CHAPTER VI: FUNDAMENTALS OF ANTENNA



An antenna is a device or mechanism that is made of metallic material and absorbs or emits electromagnetic waves, also called electromagnetic radiation. Antennas are used for many types of telecommunications, a type of long-distance communication that uses radio waves to transmit messages which are then converted into audio or other mediums.

An antenna is basically a transducer. It converts radio frequency (RF) signal into an electromagnetic (EM) wave of the same frequency. It forms a part of transmitter as well as the receiver circuits. Its equivalent circuit is characterized by the presence of resistance, inductance, and capacitance. The current produces a magnetic field, and a charge produces an electrostatic field. These two in turn create an induction field.

Definition of antenna: An antenna can be defined in the following different ways:

1. An antenna may be a piece of conducting material in the form of a wire, rod or any other shape with excitation.
2. An antenna is a source or radiator of electromagnetic waves.
3. An antenna is a sensor of electromagnetic waves.

- 4. An antenna is a transducer.**
- 5. An antenna is an impedance matching device.**
- 6. An antenna is a couple between a generator and space or vice versa.**

HOW DOES AN ANTENNA WORK?

Antennas have many uses. Telecommunication requires two antennas, a transmitter, and a receiver. What is antenna transmission and reception? First, the information is converted into an electric current, which is sent to the transmitter. Next, the transmitter sends the electric current through the transmitter's antenna. When the antenna conducts this electric current, it sends out electromagnetic radio waves. Then, radio waves are detected by the receiver's antenna, which absorbs incoming radio waves, making the electrons in the antenna vibrate. The antenna conducts this electric current to the receiver of the radio. Finally, the signal is converted into sound, or whatever other information is being transmitted.

Antennas are classified to help us understand their physical structure and functionality. There are many types of antennas depending upon the applications. The following table provides the list of various types of antennas along with examples and applications.

Type of antenna	Examples	Applications
Wire antenna	Dipole antenna, Monopole antenna, Helix antenna, Loop antenna	Personal applications, buildings, ships, automobiles, space crafts
Aperture Antennas	Waveguide (opening), Horn antenna	Flush-mounted applications, aircraft, spacecraft
Reflector Antennas	Parabolic reflectors, Corner reflectors	Microwave communication, satellite tracking, radio astronomy
Lens Antennas	Convex-plane, Concave-plane, Convex-convex, Concaveconcave lenses	Used for very high-frequency applications
Microstrip Antennas	Circular-shaped, Rectangular shaped metallic patch above the ground plane	Aircraft, spacecraft, satellites, missiles, cars, mobile phones etc.
Array Antennas	Yagi-Uda antenna, Micro strip patch array, Aperture array, Slotted wave guide array	Used for very high gain applications, mostly when needs to control the radiation pattern

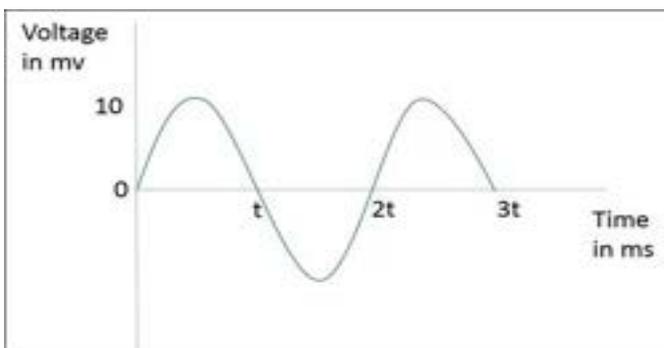
The basic communication parameters are discussed here to have a better idea about wireless communication using antennas. Wireless communication is done in the form of waves. Hence, we need to have a look at the properties of waves in communications.

we are going to discuss about the following parameters:

- Frequency
- Wavelength
- Impedance matching
- VSWR & reflected power
- Bandwidth

Frequency

According to the standard definition, “The rate of repetition of a wave over a particular period of time, is called as frequency.”



Simply, frequency refers to the process of how often an event occurs. A periodic wave repeats itself after every ‘T’ seconds (time period). Frequency of periodic wave is nothing but the

reciprocal of time period (T).

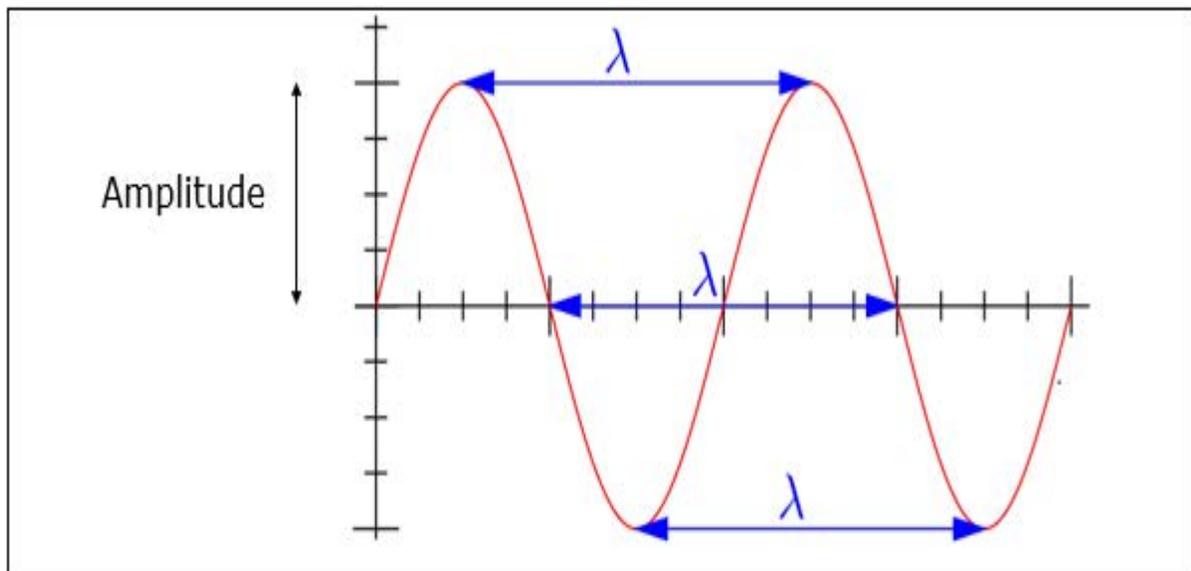
The unit of frequency is Hertz, abbreviated as Hz.

The figure given above represents a sine wave, which is plotted here for Voltage in millivolts against time in milliseconds. This wave repeats after every 2t milliseconds. So, time period, $T=2t$ milliseconds and frequency, $f=12\text{TKHz}$

Wavelength

According to the standard definition, “The distance between two consecutive maximum points (crests) or between two consecutive minimum points (troughs) is known as the wavelength.”

Simply, the distance between two immediate positive peaks or two immediate negative peaks is nothing but the length of that wave. It can be termed as the Wavelength.



The above figure shows a periodic waveform. The wavelength (λ) and amplitude are denoted in the figure. The higher the frequency, the lesser will be the wavelength and vice versa.

The formula for wavelength is,

$$\lambda = c/f$$

- λ is the wavelength
- c is the speed of light ($3 \times 10^8 \times 10^8$ meters/second)
- f is the frequency

The wavelength λ is expressed in the units of length such as meters, feet or inches. The commonly used term is meters.

Impedance Matching

According to the standard definition, “The approximate value of impedance of a transmitter, when equals the approximate value of the impedance of a receiver, or vice versa, it is termed as Impedance matching.”

Impedance matching is necessary between the antenna and the circuitry. The impedance of the antenna, the transmission line, and the circuitry should match so that maximum power transfer takes place between the antenna and the receiver or the transmitter.

Necessity of Matching

A resonant device is one, which gives better output at certain narrow band of frequencies. Antennas are such resonant devices whose impedance if matched, delivers a better output.

- The power radiated by an antenna, will be effectively radiated, if the antenna impedance matches the free space impedance.

- For a receiver antenna, antenna's output impedance should match with the input impedance of the receiver amplifier circuit.
- For a transmitter antenna, antenna's input impedance should match with transmitter amplifier's output impedance, along with the transmission line impedance.

Units: The unit of impedance (Z) is Ohms.

VSWR & Reflected Power:

According to the standard definition, "The ratio of the maximum voltage to the minimum voltage in a standing wave is known as Voltage Standing Wave Ratio."

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

If the impedance of the antenna, the transmission line and the circuitry do not match with each other, then the power will not be radiated effectively. Instead, some of the power is reflected back.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

- Voltage Standing Wave Ratio (VSWR – sometimes pronounced "Viz-Wer") or Standing Wave Ratio (SWR) is a measure of how well matched the impedance of the radio (transmitter or receiver) and antenna and transmission line carrying Radio Frequencies (RF).
- It is the ratio of the maximum and minimum voltage levels along the entire length of the transmission line and antenna.
- This could also be the ratio between the forward voltage and the reflected voltage.
- $SWR = (V_f + V_r) / (V_f - V_r)$

$$VSWR = \frac{V_{max}}{V_{min}}$$

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The key features are –

- The term, which indicates the impedance mismatch is VSWR.
- VSWR stands for Voltage Standing Wave Ratio. It is also called as SWR.
- The higher the impedance mismatch, the higher will be the value of VSWR.
- The ideal value of VSWR should be 1:1 for effective radiation.
- Reflected power is the power wasted out of the forward power. Both reflected power and VSWR indicate the same thing.
- A perfectly tuned antenna systems has a VSWR of 1.0, this means that no power is being reflected back along the transmission line to the radio.
- However, as you can see in the VSWR table, having a VSWR of just 3 means that 25% of the Tx power is being reflected back to the radio transmitter.
- A VSWR of 6 and over more than 50% is going straight back in to the radio.

VSWR and Reflected Power (%)

VSWR	% of Reflected Power
1.0	0
1.5	4
2.0	11.1
3.0	25
4.0	36
5.0	44
6.0	51
7.0	56.3
8.0	60.5
9.0	64
10	66.9
15	76.6
20	81.9

SWR - Why bother?

- There are several reasons why SWR is important.
- It is well known that a high SWR means that the antenna is not transmitting all the power, and so a good SWR will ensure that you get the most signal out that you can.
- More serious problems can be caused by the power that is not radiated.
- This power is reflected back towards the transmitter, where it causes extra heat in the output stage.
- This can lead to serious damage within the transmitter.
- With a high SWR, the coaxial cable starts to radiate signal as if it is part of the antenna.
- As the cable is likely to run nearer to the ground and closer to other electronic equipment and cables, the chances of causing interference are greatly increased by this problem.
- Interference problems which may occur include interference to TV, Radio, telephone and other electronic devices.
- As the cable is acting as part of the antenna, the position of the cable will also affect the directivity of the antenna, and so reduce your signal to most areas.

Bandwidth

According to the standard definition, “A band of frequencies in a wavelength, specified for the particular communication, is known as bandwidth.”

The signal when transmitted or received, is done over a range of frequencies. This range of frequencies are allotted to a particular signal, so that other signals may not interfere in its transmission.

- Bandwidth is the band of frequencies between the higher and lower frequencies over which a signal is transmitted.
- The bandwidth once allotted, cannot be used by others.

- The whole spectrum is divided into bandwidths to allot to different transmitters.

The bandwidth, which we just discussed can also be called as **Absolute Bandwidth**.

Directivity

According to the standard definition, “The ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna, radiating the same total power is called the directivity.” An Antenna radiates power, but the direction in which it radiates matters a lot.

Antenna Efficiency

According to the standard definition, “Antenna Efficiency is the ratio of the radiated power of the antenna to the input power accepted by the antenna.”

Simply, an Antenna is meant to radiate power given at its input, with minimum losses. The efficiency of an antenna explains how much an antenna is able to deliver its output effectively with minimum losses in the transmission line.

This is otherwise called as **Radiation Efficiency Factor** of the antenna.

Antenna Gain

According to the standard definition, “Gain of an antenna is the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.”

Simply, gain of an antenna takes the directivity of antenna into account along with its effective performance. If the power accepted by the antenna was radiated isotropically (that means in all directions), then the radiation intensity we get can be taken as a referential.

- The term antenna gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source.
- Gain is usually measured in dB.
- Unlike directivity, antenna gain takes the losses that occur also into account and hence focuses on the efficiency.

The equation of gain, G is as shown below.

$G = \eta e D$ Where

G is gain of the antenna. ηe is the antenna's efficiency. D is the directivity of the antenna.

Units: The unit of gain is decibels or simply dB.

Antenna Gain

Antenna Gain G: ratio of transmit/receive power in a particular direction, to that of an isotropic antenna

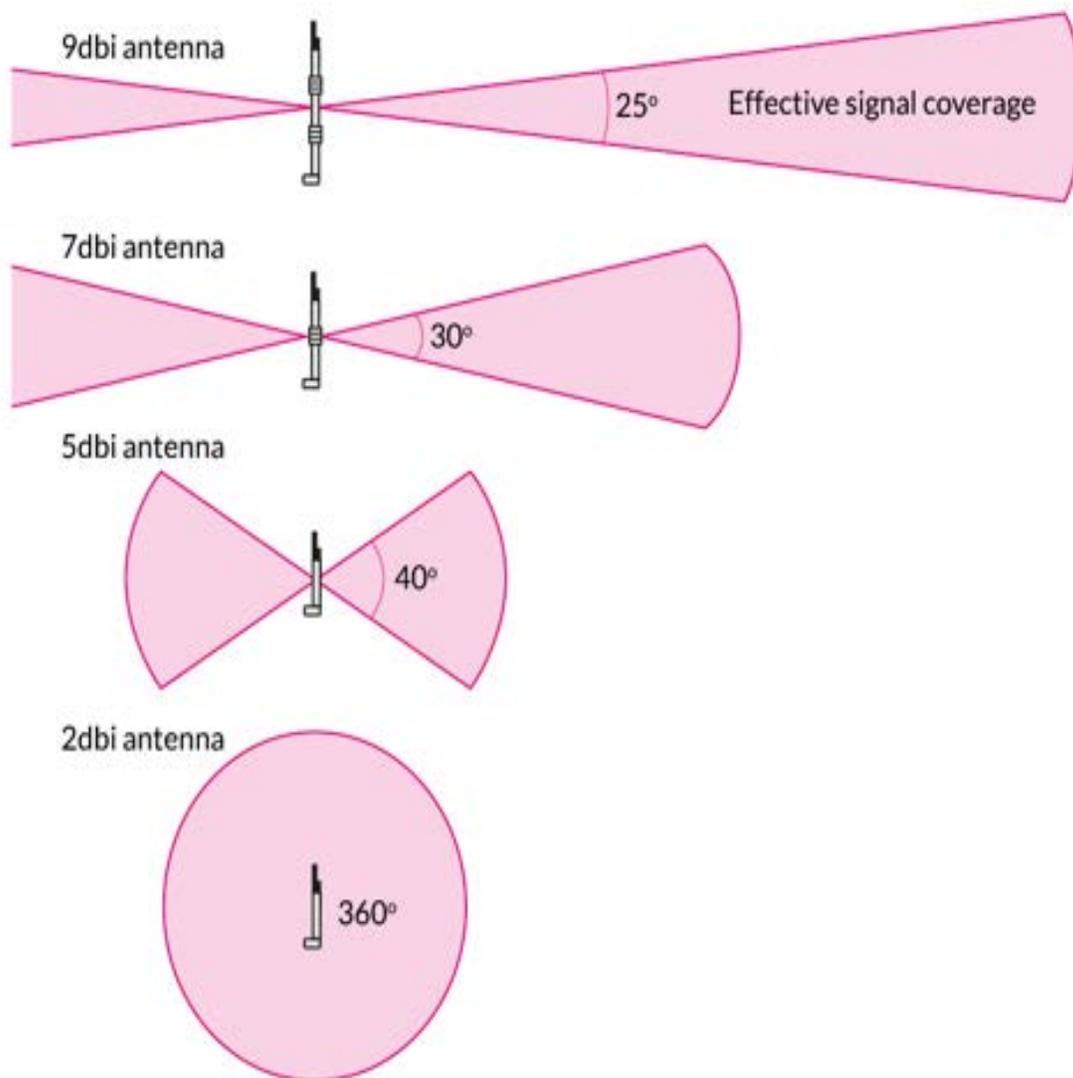
$$G = \frac{P_{\text{directional}}}{P_{\text{isotropic}}}$$

Transmit gain == Receive gain

Typically, gain is expressed in dBi

$$A_{\text{eff}} = \frac{G_r \times \lambda^2}{4 \times \pi}$$

Remember, "gain" is simply stealing radiated energy from some directions to intensify others. The higher the dBi number of the antenna, the higher the gain, but less of a broad field pattern,



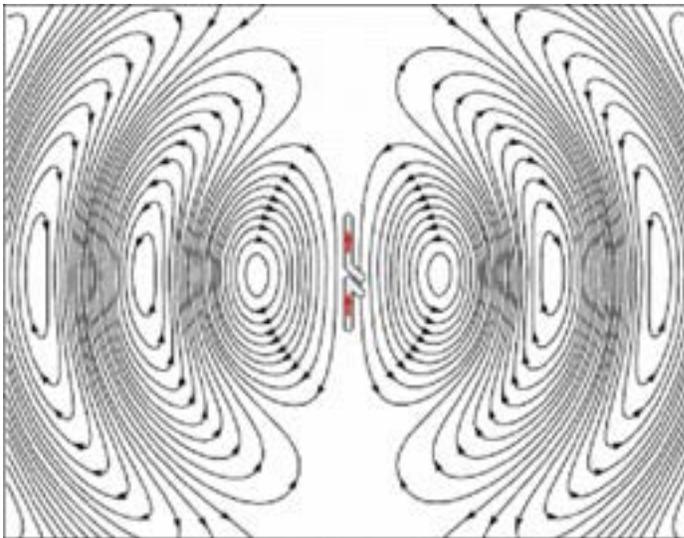
meaning that the signal strength will go further but in a narrower direction, as illustrated here.

Radiation pattern.

Radiation is the term used to represent the emission or reception of wave front at the antenna, specifying its strength. In any illustration, the sketch drawn to represent the radiation of an antenna is its radiation pattern. One can simply understand the function and directivity of an antenna by having a look at its radiation pattern.

The energy radiated by an antenna is represented by the Radiation pattern of the antenna. Radiation Patterns are diagrammatical representations of the distribution of radiated energy into space, as a function of direction.

Let us look at the pattern of energy radiation.

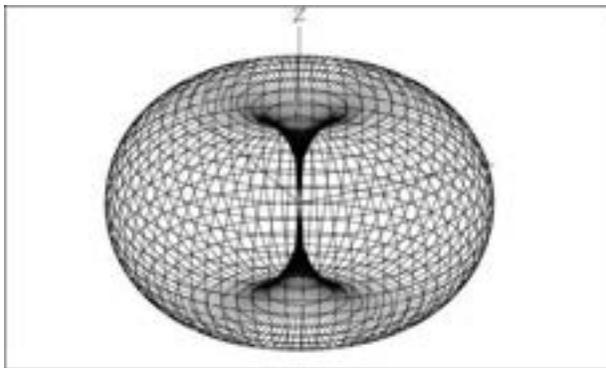


The figure given shows the radiation pattern of a dipole antenna. The energy being radiated is represented by the patterns drawn in a particular direction. The arrows represent directions of radiation.

The radiation patterns can be field patterns or power patterns.

- The field patterns are plotted as a function of electric and magnetic fields. They are plotted on logarithmic scale.
- The power patterns are plotted as a function of square of the magnitude of electric and magnetic fields. They are plotted on logarithmic or commonly on dB scale.

Radiation Pattern in 3D

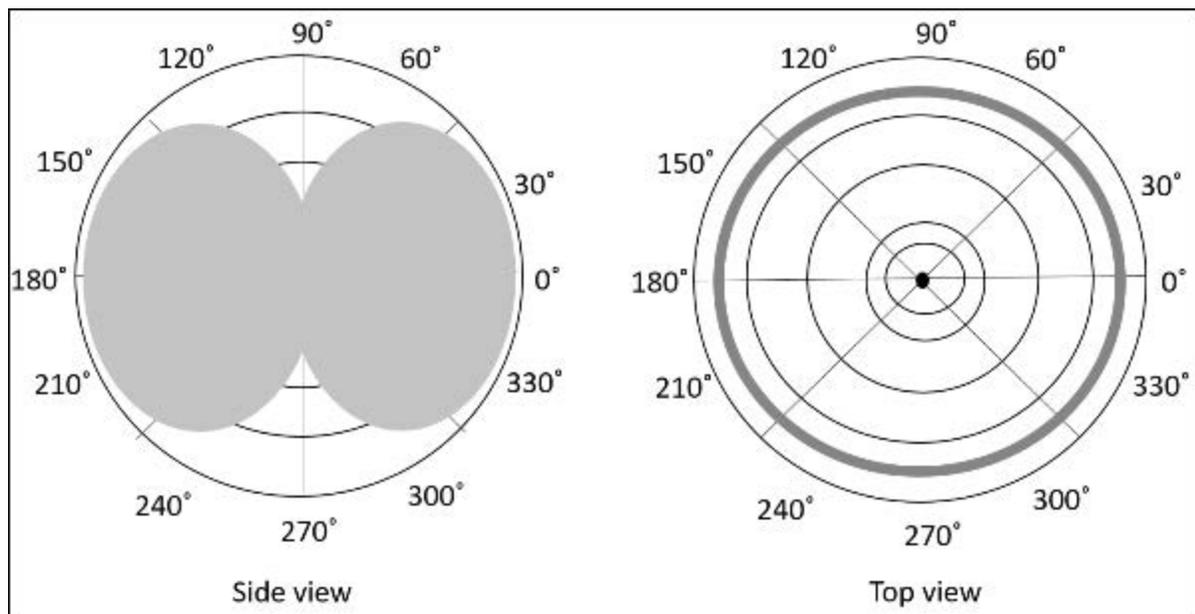


The radiation pattern is a three-dimensional figure and represented in spherical coordinates (r, θ, Φ) assuming its origin at the center of spherical coordinate system. It looks like the given figure.

The given figure is a three-dimensional radiation pattern for an Omni directional pattern. This clearly indicates the three co-ordinates (x, y, z) .

Radiation Pattern in 2D

Two-dimensional pattern can be obtained from three-dimensional pattern by dividing it into horizontal and vertical planes. These resultant patterns are known as Horizontal pattern and Vertical pattern respectively.

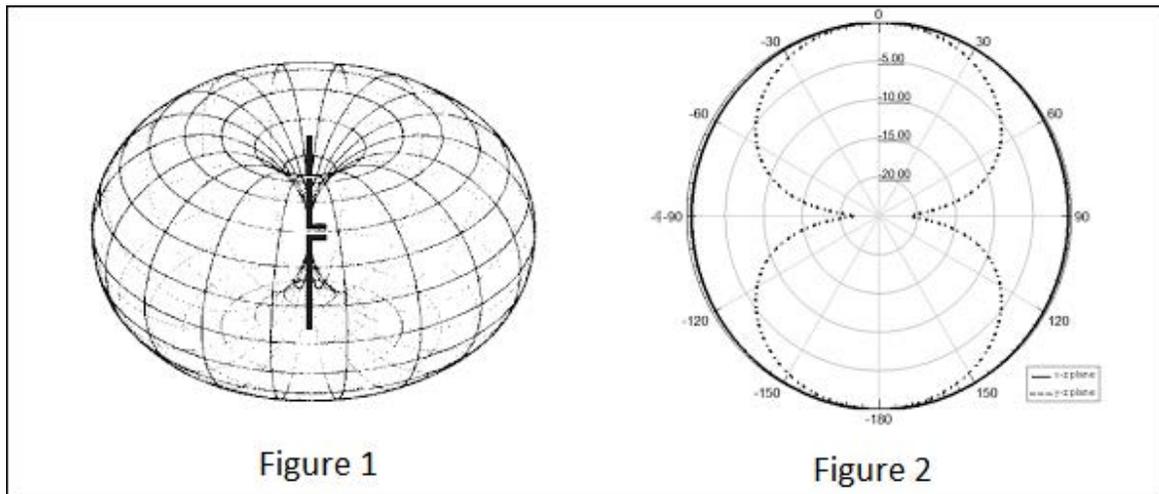


The figures show the Omni directional radiation pattern in H and V planes as explained above. H-plane represents the Horizontal pattern, whereas V-plane represents the Vertical pattern.

Isotropic radiation is radiation from a point source, radiating uniformly in all directions, with same intensity regardless of the direction of measurement.

The improvement of radiation pattern of an antenna is always assessed using the isotropic radiation of that antenna. If the radiation is equal in all directions, then it is known as isotropic radiation.

- The point source is an example of isotropic radiator. However, this isotropic radiation is practically impossible, because every antenna radiates its energy with some directivity.
- The isotropic radiation is nothing but Omni-directional radiation.
- It has a doughnut-shaped pattern when viewed in 3D and a figure-of-eight pattern when viewed in 2D.

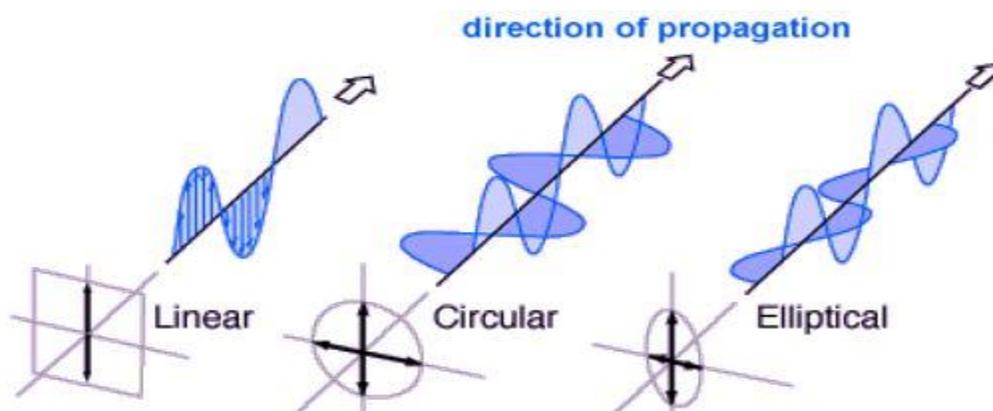


The figures given above show the radiation pattern of an isotropic or Omni-directional pattern. Figure 1 illustrates the doughnut shaped pattern in 3D and Figure 2 illustrates the figure-of-eight pattern in 2D.

Gain:The isotropic radiator has unity gain, which means having a gain factor of 1 in all directions. In terms of dB, it can be called as 0dB gain (zero loss).

Antenna Polarization

An Antenna can be polarized depending upon our requirement. It can be linearly polarized or circularly polarized. The type of antenna polarization decides the pattern of the beam and polarization at the reception or transmission.



Linear polarization

When a wave is transmitted or received, it may be done in different directions. The linear polarization of the antenna helps in maintaining the wave in a particular direction, avoiding all the other directions. Though this linear polarization is used, the electric field vector stays in the same plane. Hence, we use this linear polarization to improve the directivity of the antenna.

Circular polarization

When a wave is circularly polarized, the electric field vector appears to be rotated with all its components losing orientation. The mode of rotation may also be different at times. However, by using circular polarization, the effect of multi-path gets reduced and hence it is used in satellite communications such as GPS.

Horizontal polarization

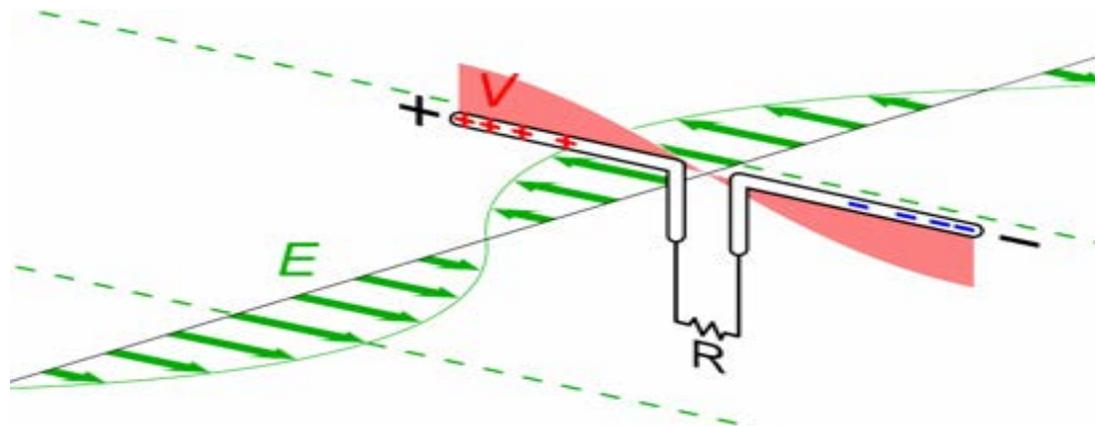
Horizontal polarization makes the wave weak, as the reflections from the earth surface affect it. They are usually weak at low frequencies below 1GHz. Horizontal polarization is used in the transmission of TV signals to achieve a better signal to noise ratio.

Vertical polarization

The low frequency vertically polarized waves are advantageous for ground wave transmission. These are not affected by the surface reflections like the horizontally polarized ones. Hence, the vertical polarization is used for mobile communications.

Each type of polarization has its own advantages and disadvantages. A RF system designer is free to select the type of polarization, according to the system requirements.

How can current flow through an open wire (like a dipole antenna)?



A diagram of a half-wave dipole antenna receiving a radio wave. The antenna consists of two metal rods connected to a receiver *R*.

The electric field (*E*, green arrows) of the incoming wave pushes the electrons in the rods back and forth, charging the ends alternately positive (+) and negative (-).

Since the length of the antenna is one half the wavelength of the wave, the oscillating field induces standing waves of voltage (*V*, represented by red band) and current in the rods.

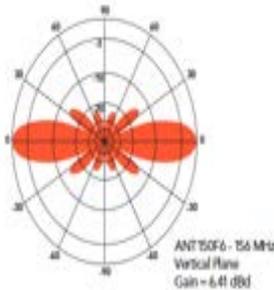
The oscillating currents (*black arrows*) flow down the transmission line and through the receiver (represented by the resistance R).

You see a varying electric field coming in towards a pair of horizontal conductors (antenna). Charges are moved in the conductor, and this sets up a potential difference across the resistor which could be the input stage of a radio receiver.

A transmitting antenna works the same way except that an alternating voltage is applied where the resistor is and the alternating voltage causes the charges in the metal conductor to accelerate.

Accelerating charges emit electromagnetic radiation which in this case will be of the same frequency as that of the alternating voltage.

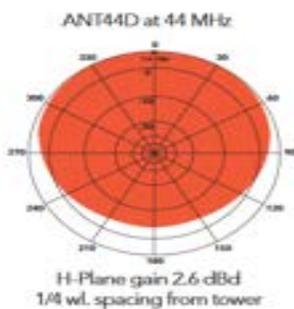
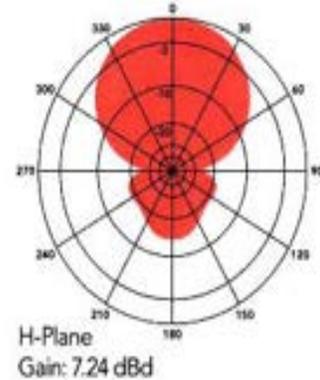
Different antenna types have different antenna wave patterns.



A dipole antenna is, at its simplest, two straight rods or wires oriented end to end on the same axis, with a balanced feedline connected to the two adjacent ends. By itself, a dipole antenna is close to omnidirectional, with nearly equal power transmission in all directions. In addition to VHF

transmissions, dipole antennas are often used in shortwave applications or as FM broadcast receivers.

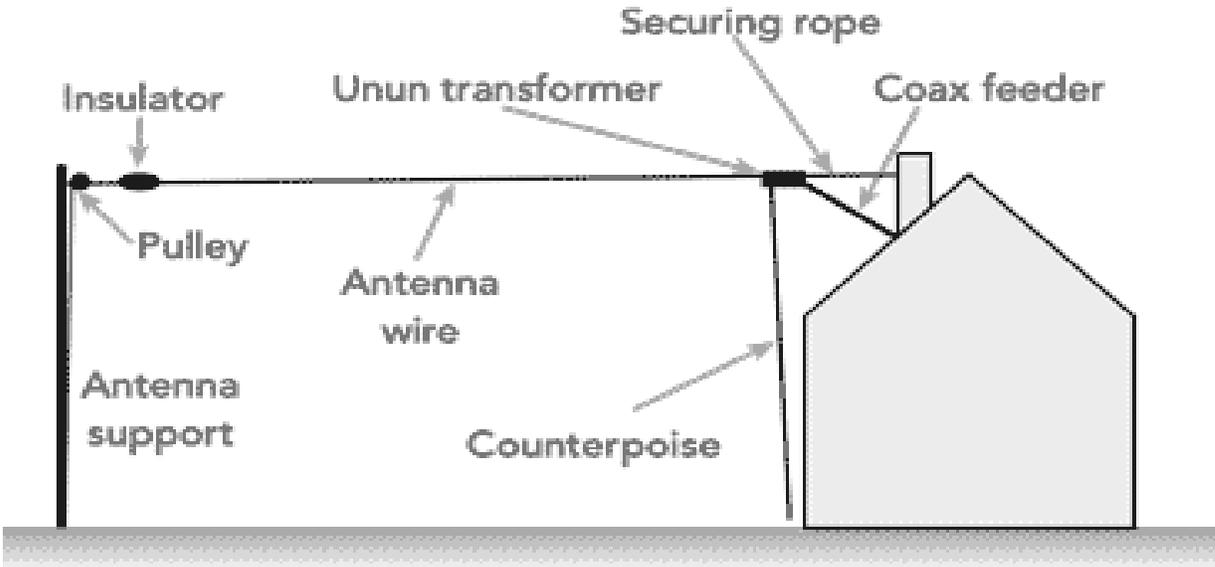
A Yagi antenna is an array of dipole elements, where one dipole is connected to receive the signal, and the other elements are designated to reflect or redirect the energy in the desired direction. Yagi antennas are directional and need to be mounted facing the intended signal path. The main lobe is wide, with a somewhat smaller back lobe. This type of antenna can be mounted horizontally or vertically, depending on the desired signal polarization. Yagi antennas work well for point to point as well as multipoint applications.



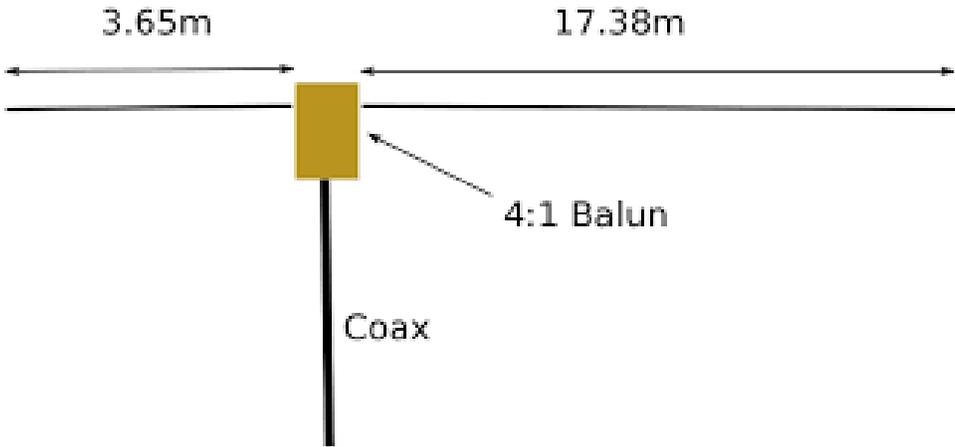
A collinear antenna array is a series of dipoles mounted end-to-end. With up to 10dBd gain, they have a narrow band width and multiple side lobes. They are often used in mobile communications, such as police, fire, and taxi dispatchers.

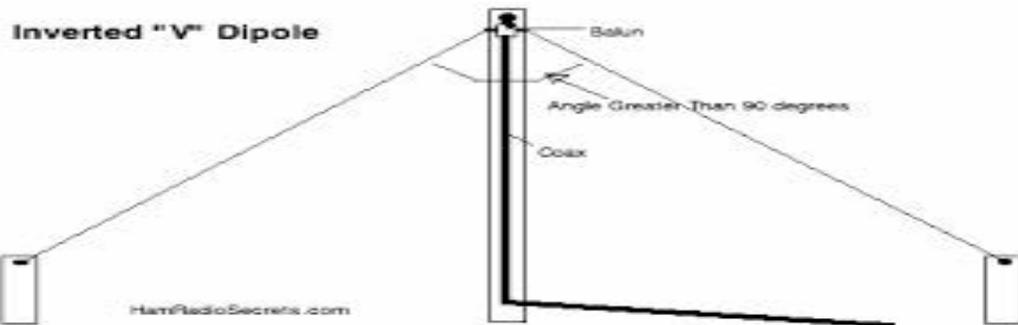
High frequency ANTENNAS.

End fed Half wave



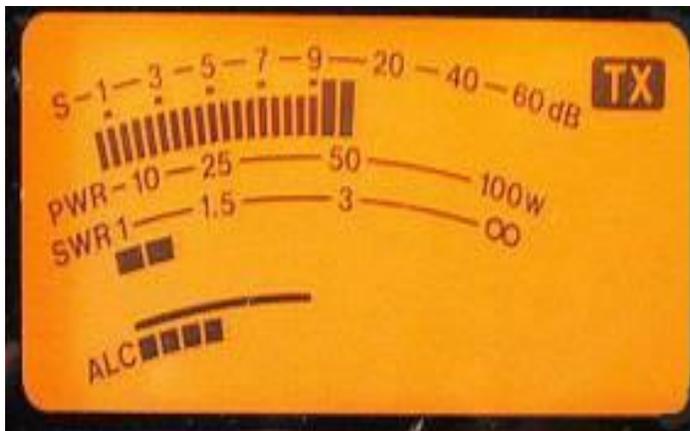
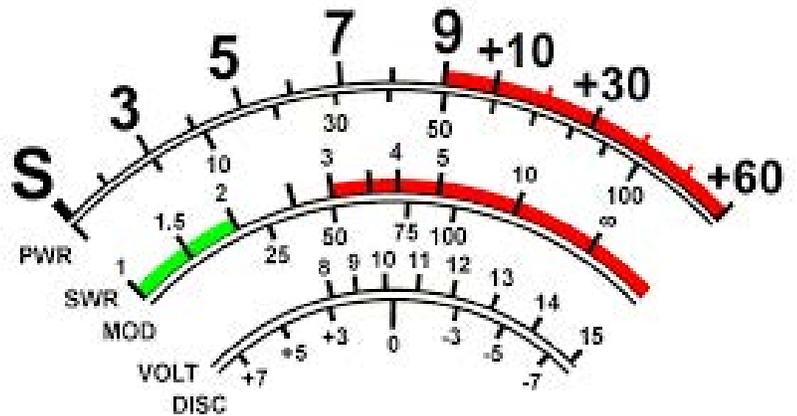
Off Centre Half wave





ADD-ON NOTES:

S meter (signal strength meter) is an indicator often provided on communications receivers, such as amateur radio receivers or shortwave broadcast receivers. The scale markings are derived from a system of reporting signal strength from S1 to S9 as part of the R-S-T system.

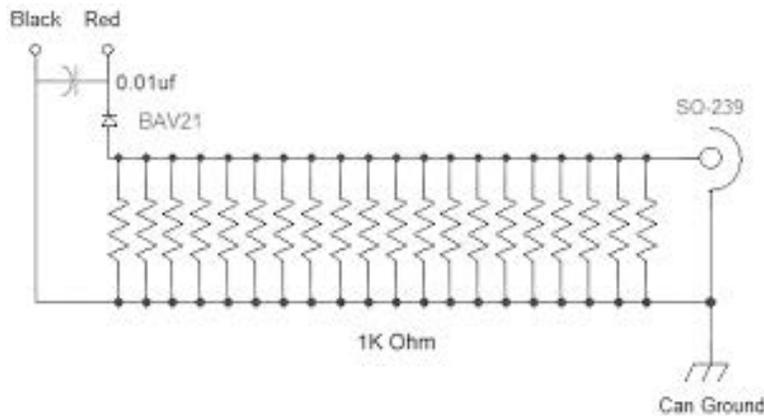


S-points go from S1 to S9 and each S-point is defined as a 6 dB change in signal strength. This means that each time the voltage is halved (-6 dB) the signal strength decreases by one point. S9 is already a very strong signal, but to describe larger signals, steps of 10 dB

are used instead of 6 dB, noted "S9+20" meaning 20 dB above S9.

S1 -48dB, S8 -dB S9 0dB

Dummy load ; what is it?



- A dummy load is a device used to simulate an electrical load, usually for testing purposes.
- In radio a dummy antenna is connected to the output

of a radio transmitter and electrically simulates an antenna, to allow the transmitter to be adjusted and tested without radiating radio waves.

- How do you test a dummy load?



- The simplest test on a dummy load you can perform is to measure it with an ohmmeter — it should be 50 Ω (or whatever the specified impedance is). ...

- The above test tells us that it is 50 Ω at DC, or 0 Hz. ...

- A dummy load should

have the expected impedance, but so does an antenna.

- A dummy load, or terminator, consists of a non-inductive power resistor (or multiple resistors in series and parallel) and a heat sink, both rated for the maximum power to be dissipated.

- A dummy load should have the expected impedance, but so does an antenna. The difference between a dummy load and an antenna is that the dummy load mostly does not radiate.

Log-periodic antennas (LPDA – Log periodic dipole array)



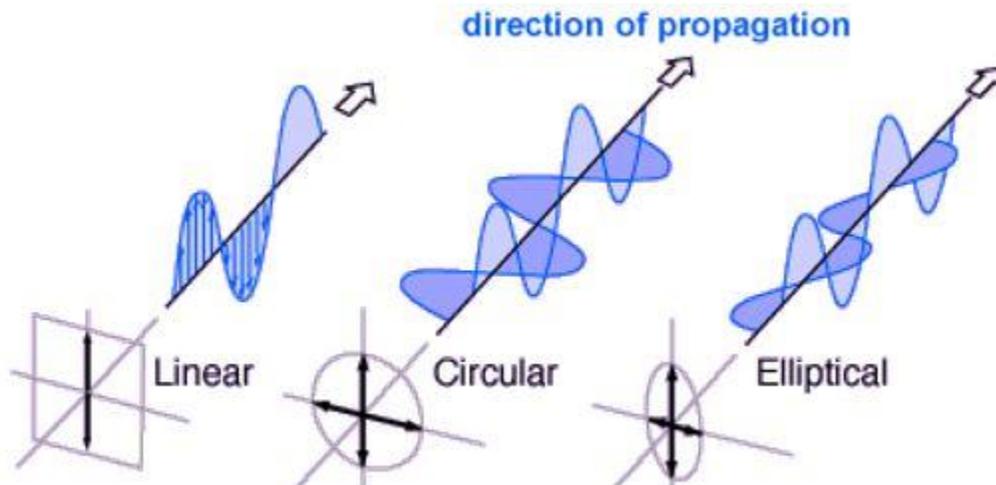
- the most common form of log-periodic antenna, The LPDA consists of a number of half-wave dipole driven elements of gradually increasing length, each consisting of a pair of metal rods. The dipoles are mounted close together in a line,

connected in parallel to the feedline with alternating phase. Electrically, it simulates a series of two or three-element Yagi antennas connected together, each set tuned to a different frequency.

- Log-periodic antennas are designed to work across a wide range of frequencies.
- Yagi-Uda is optimised for one frequency.
- Yagi-Uda will give higher gain at its optimal frequency; log-periodic will have lower gain across a wide range of frequencies.
- LPDA is a frequency independent antenna and the lengths of the dipoles increases from the apex of the feed line toward other end by maintaining constant included angle.

Antenna Polarization:

Polarity is a key electrical characteristic to be considered when selecting an antenna. Like-matched antennas in an RF set-up will have optimal power or signal transfer in point-to-point applications.



Types of Polarization:

The most common forms of polarization are Linear and Vertical, but polarization can be any of the following:

- Linear or Vertical Polarization refers to the oscillation of an antennas electrical field on either the horizontal or vertical plane.
- Slant Polarization describes an electromagnetic field that oscillates at a 45 degree angle to the reference plane.
- Circular Polarization (CP) regards a radio wave that rotates as the signal propagates. This rotation can be to the right as in Right

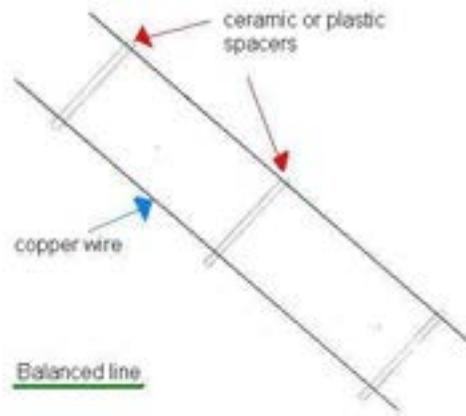
Hand Circular Polarization (RHCP) or to the left, as in the case of Left Hand Circular Polarization (LHCP).

- Elliptical Polarization is characterized by an electric field that is propagated in an elliptical helix.

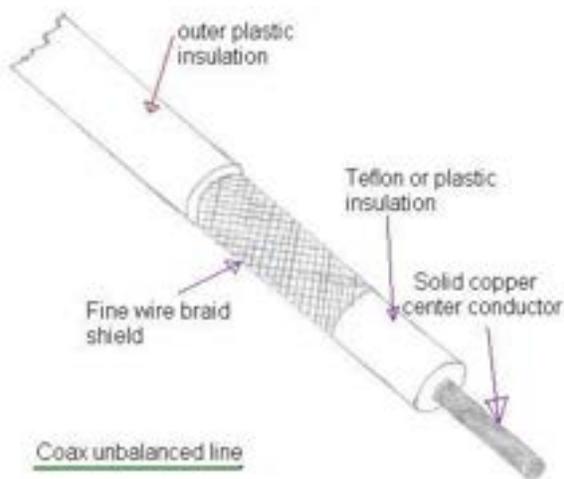
- ❖ Polarity is as important as gain, radiation pattern and VSWR, in the selection of an antenna.
- ❖ An antenna with horizontal polarization cannot receive any electromagnetic energy in a vertical polarizing plane.
- ❖ Alignment of the orientation and polarization of transmitting and receiving antennas will improve signal strength and the optimal transfer of power.
- ❖ Omnidirectional antennas have different polarization and performance compared to linear or directional antennas.

Balanced Line

The term "balanced line" means same amount of current flows in each wire with reference to ground. The direction of current in one wire is 180 degree out of phase with the current in the other wire. In balanced line, none of the wires are connected to the ground.



UNBalanced Line:



As shown in the figure, coaxial cable (i.e. coax) consists of solid center conductor surrounded by plastic insulator (e.g. teflon). Over the insulator there is another conductor made of fine wires. At outer cover is made of plastic which protects the fine wire braid shield.

Coaxial cable is unbalanced line because current in center conductor is referenced to braid. The braid conductor is connected to the ground..

Comparison of Return Loss and VSWR

Return loss can be related to the reflection coefficient and voltage standing wave ratio (VSWR). The reflection coefficient is the ratio of incident or forwards voltage to output or reflected voltage

VSWR indicates how well the source or load is matched in impedance with the antenna and the transmission line used for power transmission.

	VSWR	Return Loss (RL)
1	Ratio of voltage applied to voltage reflected	Portion of a signal reflected due to discontinuity in line to indicate the loss
2	Preferred in the connector industry	Preferred in the cable industry
3	It is a linear measurement	It is a logarithmic measurement
4	Useful when displaying larger reflections	Useful when displaying very small reflections
5	$VSWR = V_{max}/V_{min}$	Return Loss = $20 * \text{Log}_{10} (VSWR + 1 / VSWR - 1)$