EC8701 ANTENNAS

AND

MICROWAVE ENGINEERING

UNIT - I

EC8701 ANTENNAS AND MICROWAVE ENGINEERING L T P C
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OBJECTIVES

- To enable the student to understand the basic principles in antenna and microwave system design
- To enhance the student knowledge in the area of various antenna designs.
- To enhance the student knowledge in the area of microwave components and antenna for practical applications.

UNIT I INTRODUCTION TO MICROWAVE SYSTEMS AND ANTENNAS 9

Microwave frequency bands, Physical concept of radiation, Near- and far-field regions, Fields and Power Radiated by an Antenna, Antenna Pattern Characteristics, Antenna Gain and Efficiency, Aperture Efficiency and Effective Area, Antenna Noise Temperature and G/T, Impedance matching, Friis transmission equation, Link budget and link margin, Noise Characterization of a microwave receiver.

UNIT II RADIATION MECHANISMS AND DESIGN ASPECTS 9

Radiation Mechanisms of Linear Wire and Loop antennas, Aperture antennas, Reflector antennas, Microstrip antennas and Frequency independent antennas, Design considerations and applications.

UNIT III ANTENNA ARRAYS AND APPLICATIONS 9

Two-element array, Array factor, Pattern multiplication, Uniformly spaced arrays with uniform and non-uniform excitation amplitudes, Smart antennas.

UNIT IV PASSIVE AND ACTIVE MICROWAVE DEVICES 9

Microwave Passive components: Directional Coupler, Power Divider, Magic Tee, attenuator, resonator, Principles of Microwave Semiconductor Devices: Gunn Diodes, IMPATT diodes, Schottky Barrier diodes, PIN diodes, Microwave tubes: Klystron, TWT, Magnetron.

UNIT V MICROWAVE DESIGN PRINCIPLES 9

Impedance transformation, Impedance Matching, Microwave Filter Design, RF and Microwave Amplifier Design, Microwave Power amplifier Design, Low Noise Amplifier Design, Microwave Mixer Design, Microwave Oscillator Design.

TOTAL: 45 PERIODS

OUTCOMES

The student should be able to:

- Apply the basic principles and evaluate antenna parameters and link power budgets
- Design and assess the performance of various antennas
- Design a microwave system given the application specifications

TEXTBOOKS

1. John D Krauss, Ronald J Marhefka and Ahmad S. Khan, "Antennas and Wave Propagation: Fourth Edition, Tata McGraw-Hill, 2006. (UNIT I, II, III)
2. David M. Pozar, "Microwave Engineering", Fourth Edition, Wiley India, 2012.(UNIT I,IV,V)

REFERENCES

1. Constantine A.Balanis, —Antenna Theory Analysis and Design‖, Third edition, John Wiley India Pvt Ltd., 2005.
2. R.E.Collin, "Foundations for Microwave Engineering", Second edition, IEEE Press, 2001

Praise The Lord

MICROWAVE FREQUENCY BANDS

Microwaves are electromagnetic waves with wavelengths ranging from 1 cm to 1mm. he corresponding frequency range is 1GHz to 300GHz. Microwave frequencies are upto nfrared and visible light regions.

U.S New Military Microwave Bands

Frequency	Microwave Band Designation
100 - 250 MHz	A
250 - 500 MHz	B
0.5 - 1 GHz	C
1 - 2 GHz	D
2 - 3 GHz	E
3 - 4 GHz	F
4 - 6 GHz	G
6 - 8 GHz	H
8 - 10 GHz	I
10 - 20 GHz	J
20 - 40 GHz	K
40 - 60 GHz	L
60 - 100 GHz	M

IEEE Microwave Frequency Bands

Frequency	Microwave Band Designation
3 - 30 MHz	HF
30 - 300 MHz	VHF
0.3 - 1 GHz	UHF
1 - 2 GHz	L
2 - 4 GHz	S
4 - 8 GHz	C
8 - 12 GHz	X
12 - 18 GHz	Ku
18 - 27 GHz	K
27 - 40 GHz	Ka
40 - 300 GHz	Millimeter Waves
> 300 GHz	Submillimeter Waves

Physical Concept of Radiation

Radiation is the term used to represent the emission or reception of wave front of the antenna, specifying its strength. The power when radiated from the antenna has its effect in the near and far field regions. In general, radiation is the process of transmitting electric energy.

The electric charges are the sources of electromagnetic fields. When these sources time varying, the electromagnetic waves propagate away from the sources and radiation takes place.

The radiation of the waves into space is effectively achieved with the help of conducting or dielectric structures called antennas or radiators.

Near and Far Field Regions

The fields surrounding an antenna are divided into three regions.

- Reactive Near Field
- Radiating Near Field
- Far Field

Reactive Near Field Region

This is the region that is adjacent to the antenna. In this region, E-field and H-field are 90° out of phase with each other and are therefore reactive. To radiate or propagate the E/H fields need to be orthogonal (perpendicular) and inphase with each other.

Reactive near field is the region where the fields are reactive. ie., E and H fields are out of phase by 90° to each other. For propagating or radiating fields, the fields must be orthogonal to each other but in phase. Reactive near field is also called the inductive near field.

Radiating Near Field Region

The radiating near field is the region between the reactive near field and far field. Near field is the region within a radius $r <<< \lambda$. It is also named as Fresnell Region.

Far Field Region

The region far from an antenna compared to the dimensions of the antenna and the wavelength of the radiation is termed as far field region. It is also named as far zone, radiation zone and Fraunhofer region.

Far field is the region for which radius $r >>> 2\lambda$. The transition zone is the region between $r = \lambda$ and $r = 2\lambda$.

Fields and Power Radiated by an Antenna

Near Field

$$E_r = \frac{I_0 L \cos\theta \, e^{j\omega(t - r/c)}}{2\pi \varepsilon_0 c} \left[\frac{1}{r^2} + \frac{c}{j\omega r^3} \right]$$

$$E_\theta = \frac{I_0 L \sin\theta \, e^{j\omega(t - r/c)}}{4\pi r} \left[\frac{j\omega}{c^2 \varepsilon_0} + \frac{1}{c \varepsilon_0 r} + \frac{1}{j\omega r^2 \varepsilon_0} \right]$$

$$H_\phi = \frac{I_0 L \sin\theta \, e^{j\omega(t - r/c)}}{4\pi} \left[\frac{j\omega}{c r} + \frac{1}{r^2} \right]$$

$$E_\phi = H_r = H_\theta = 0$$

Far Field

$$E_\theta = \frac{I_0 L \sin\theta \, e^{j\omega(t - r/c)}}{4\pi \varepsilon_0} \frac{j\omega}{c^2 r}$$

$$// \quad \omega/c = \frac{2\pi f}{f\lambda} = \frac{2\pi}{\lambda} = \beta \quad // \quad \because \lambda = c/f \Rightarrow c = f\lambda \quad //$$

$$\therefore \quad E_\theta = \frac{j\beta I_0 L \sin\theta \, e^{j\omega(t - r/c)}}{4\pi \varepsilon_0 c r}$$

$$H_\phi = \frac{j\beta I_0 L \sin\theta \, e^{j\omega(t - r/c)}}{4\pi r}$$

$E_r \rightarrow$ does not exist

Power

The total radiated power can be obtained by taking surface integral of poynting vector over any surface enclosing an antenna.

$$W = \int P_{avg}\, ds$$

where, $P_{avg} = \frac{1}{2} Re\left(E \times H^*\right)$

we know that,

$$E_\theta = \frac{j\beta I_0 L \sin\theta\, e^{j\omega(t - r/c)}}{4\pi \epsilon_0 c r}$$

$$H_\phi = \frac{j\beta I_0 L \sin\theta\, e^{j\omega(t - r/c)}}{4\pi r}$$

The radial component of the poynting vector is,

$$P_r = \frac{1}{2} Re\, E_\theta H_\phi^*$$

But, $\eta = \frac{E_\theta}{H_\phi} = 120\pi = 377\,\Omega$

$\nearrow$ Intrinsic Impedance $\Rightarrow E_\theta = \eta H_\phi$

$$\Rightarrow E_\theta = \sqrt{\frac{\mu_0}{\epsilon_0}}\, H_\phi$$

where,

$$\eta = \sqrt{\frac{\mu_0}{\epsilon_0}} = \frac{E_\theta}{H_\phi} = 120\pi$$

now,

$$W = \iint P_r \cdot ds \qquad // \, ds = r^2 \sin\theta \, d\theta \, d\phi$$

$$= \int_0^{2\pi} \int_0^{\pi} \frac{1}{2} \, \mathrm{Re} \, E_\theta H_\phi^* \cdot ds$$

$$= \frac{1}{2} \int_0^{2\pi} \int_0^{\pi} H_\phi \sqrt{\frac{\mu_0}{\varepsilon_0}} \, H_\phi^* \cdot r^2 \sin\theta \, d\theta \, d\phi$$

$$= \frac{1}{2} \sqrt{\frac{\mu_0}{\varepsilon_0}} \int_0^{2\pi} |H_\phi|^2 d\phi \int_0^{\pi} r^2 \sin\theta \, d\theta$$

$$// \; H_\phi \cdot H_\phi^* = |H_\phi|^2 , \quad H_\phi = \frac{j\omega I_0 \, dl \sin\theta \, e^{j\omega(t - r/c)}}{4\pi c r}$$

Length, $L = dl$

$$// \; |H_\phi| = \frac{\omega I_0 \, dl \sin\theta}{4\pi c r} , \quad |H_\phi|^2 = \frac{\omega^2 I_0^2 (dl)^2 \sin^2\theta}{16\pi^2 c^2 r^2}$$

$$= \frac{1}{2} \sqrt{\frac{\mu_0}{\varepsilon_0}} \int_0^{2\pi} \frac{\omega^2 I_0^2 (dl)^2 \sin^2\theta}{16\pi^2 c^2 r^2} d\phi \int_0^{\pi} r^2 \sin\theta \, d\theta$$

$$= \frac{1}{2} \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{\omega^2 I_0^2 (dl)^2}{16\pi^2 c^2 \cancel{r^2}} \cdot \cancel{r^2} \int_0^{2\pi} d\phi \int_0^{\pi} \sin^3\theta \, d\theta$$

$$= \frac{1}{2} \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{I_0^2 (dl)^2}{16\pi^2} \left(\frac{\omega^2}{c^2}\right) \left[[\phi]_0^{2\pi} \int_0^{\pi} \sin^3\theta \, d\theta \right]$$

$$= \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{I_0^2 (dl)^2}{32\pi^2} \left(\frac{2\pi \cancel{f}}{\cancel{f}\lambda}\right)^2 \cdot \left\{ [2\pi - 0] \cdot \frac{4}{3} \right\}$$

where,

$\lambda = c/f \Rightarrow c = \lambda f$, $\omega = 2\pi f$, $\int_0^{\pi} \sin^3\theta \, d\theta = 4/3$, $\beta = 2\pi/\lambda$

$$\Rightarrow \quad W = \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{I_0^2 (dl)^2}{32\pi^2} \cdot \left(\frac{2\pi}{\lambda}\right)^2 \cdot 2\pi \cdot \frac{4}{3}$$

Power, $\boxed{W = \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{(\beta I_0 \, dl)^2}{12\pi}}$ Watts

Definition of Antenna Parameters

Antenna is an important tool in communication engineering. An antenna is a structure, usually made from a good conducting material, that has bee designed to radiate or receive electromagnetic energy in an efficient manner.

Antenna Parameters

1. Gain
2. Directivity
3. Effective Aperture
4. Radiation Resistance
5. Band width
6. Beam width
7. Input impedance
8. Polarization

Gain

Gain of an antenna is defined as the ability of the antenna to concentrate the radiated power in a given direction or to absorb effectively the incident power from that direction.

Gain is also defined as the ratio of maximum radiation intensity of test antenna in a given direction to the maximum radiation intensity from a reference antenna produced in the same direction with same power input.

$$\text{Gain, } G = \frac{\text{Maximum Radiation Intensity from Test antenna}}{\text{Maximum Radiation Intensity from Reference Antenna with same power input}}$$

Directivity

Directivity of an antenna is defined as the ratio of the maximum radiation intensity to the average radiation intensity.

$$D = \frac{U(\theta,\phi)_{max}}{U(\theta,\phi)_{avg}} \quad (\text{dimensionless})$$

Directivity is also defined as the ratio of maximum poynting vector to the average poynting vector at a certain distance from the antenna.

$$D = \frac{S(\theta,\phi)_{max}}{S(\theta,\phi)_{avg}} \quad (\text{dimensionless})$$

Effective Aperture

Effective aperture is defined as the ratio of power received at the antenna load terminal to the power density of the incident wave.

$$A_e = \frac{\text{Power Received}}{\text{Power Density of the Incident Wave}}$$

ie., $A_e = \frac{P_T}{S}$ m^2

where,

P_T – Power received in watts

S – Power density watts/m^2

A_e – Effective aperture in m^2

Radiation Resistance

Radiation resistance is defined as a fictitious or hypothetical resistance that would dissipate an amount of power equal to the radiated power.

$$R_r = \frac{\text{Radiated Power}}{I_{rms}^2}$$

Antenna is a two terminal circuit element, as seen from the transmission line, having an impedance, $Z_A = (R_r + R_L) + jX_A$, where R_r is the radiation resistance. The radiation resistance represents the amount of radiation by the antenna.

Bandwidth

Bandwidth is defined as the range of frequencies over which the antenna maintains its characteristics and parameters.

Bandwidth is also defined as the ratio of operating frequency to the centre frequency.

$$BW\,\% = \frac{\text{Operating Frequency}}{\text{Centre Frequency}} \times 100$$

Beam Width

Antenna beam width is an angular width in degrees, measured on the radiation pattern between points where the radiated power has fallen to half its maximum value.

Antenna beam width is also defined as the angular width of the major lobe between the two directions at which the radiated power is one half the maximum power.

Antenna beam width is a measure of directivity of an antenna.

Input Impedance

Input impedance is defined as the ratio of input voltage to input current.

$$Z_a = \frac{V_i}{I_i} \ \Omega$$

→ Z_a is a complex quantity

$$Z_a = R_a + j X_a$$

Antenna impedance is defined as the impedance presented by an antenna at its terminals or the ratio of the appropriate components of the electric to magnetic fields at a point or the ratio of voltage to current at a pair of terminals.

Polarization

Polarization is defined as the direction of the electric vector of the electromagnetic wave produced by an antenna.

Types

1. Linear Polarization
2. Circular Polarization
3. Elliptical Polarization

Matching

The operation of an antenna system over a frequency range is not completely dependent upon the frequency response of the antenna element itself but rather on the frequency characteristics of the transmission line-antenna element combination.

In practic, the characteristic impedance of the transmission line is usually real whereas that of the antenna element is complex. Also the variation of each as a function of frequency is not the same.

Thus efficient coupling matching networks must be designed which attempt to couple - match the characteristics of the two elements over the desired frequency range.

There are many coupling - matching networks that can be used to connect the transmission line to the antenna element and which can be designed to provide acceptable frequency characteristics.

Matching Techniques

1. Stub - Matching
2. Quarter - Wavelength transformer
3. T - Match
4. Gamma Match
5. Omega Match
6. Baluns and Transformers

Baluns

A twin lead transmission line or two parallel conductor line is a symmetrical line whereas a coaxial cable is inherently unbalanced. Because the inner and outer conductors of the coax are not coupled to the antenna in the same way, they provide the unbalance. The result is a net current flow to ground on the outside part of the outer conductor.

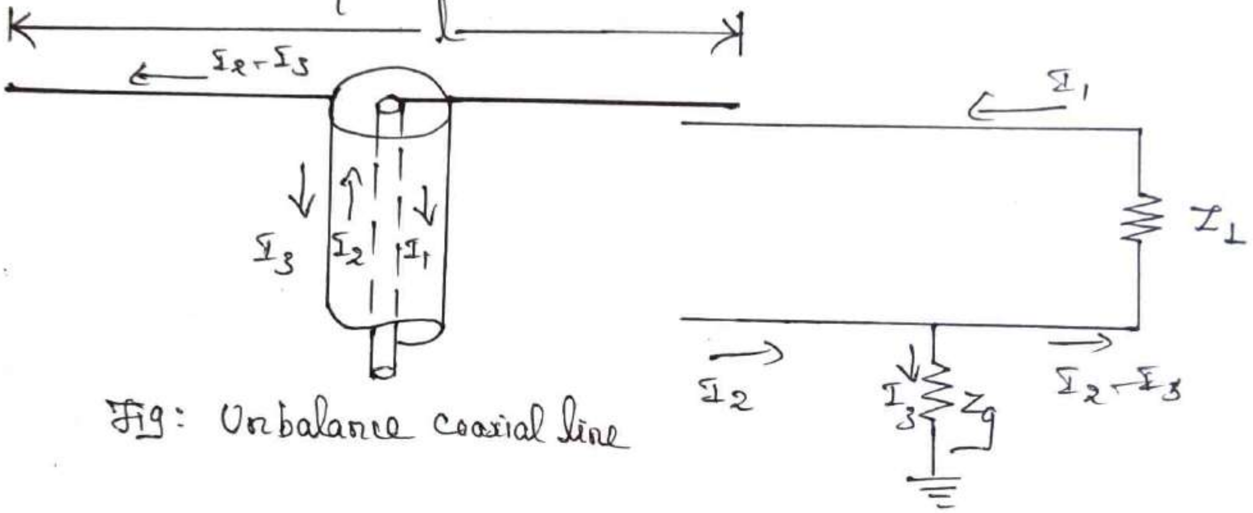


Fig: Unbalance coaxial line

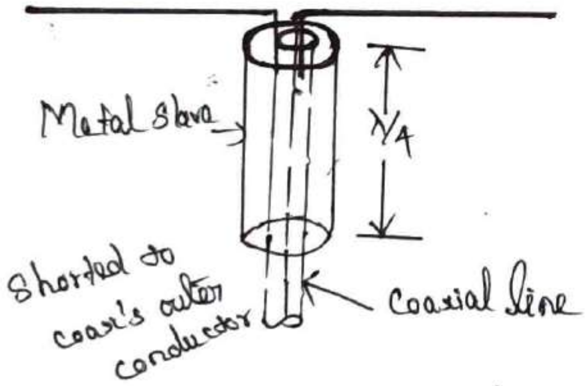


Fig: Bazooka Balun

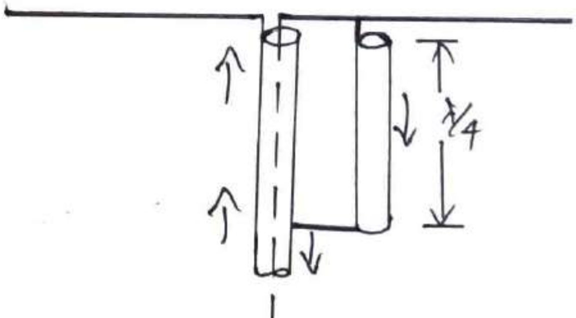


Fig: λ/4 Coaxial Balun

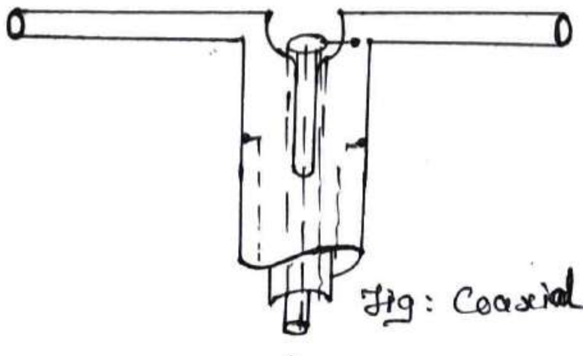


Fig: Coaxial Balun

Fig: Balun Configurations

In an unbalanced coaxial line, the amount of current flow I_3 on the outside surface of the outer conductor is determined by the impedance Z_g from the outer shield to ground. If Z_g can be made very large, I_3 can be reduced significantly.

Devices that can be used to balance inherently unbalanced systems, by changing or canceling or choking the outside current are known as baluns.

Balun — Balance to Unbalance

Bazooka Balun

Mechanically it requires that a $\lambda/4$ in length metal sleeve and shorted at its one end, encapsulates the coaxial line. Electrically the input impedance at the opend end of the $\lambda/4$ shorted transmission line, which is equivalent to Z_g, will be very large. Thus the current I_3 will be choked, if not completely eliminated, and the system will be nearly balanced.

Coaxial Balun

A compact construction of the balun is coaxial balun. The outside metal sleeve is split and a portion of it is removed on opposite sides. The remaining opposite parts of the outer sleeve represent electrically the two shorted $\lambda/4$ parallel transmission lines. All type of baluns are narrowband devices.

Antenna Noise Temperature

Antenna temperature is defined as the temperature of distant regions of space and near surroundings which are coupled to the antenna through radiation resistance.

- * antenna temperature has no relation with the physical temperature of the antenna.
- * it depends on the temperature of the region to which the antenna is radiating.
- * in this connection, a receiving antenna is regarded as a remote sensing, temperature measuring device.

The noise introduced by a network may also be expressed as effective noise temperature.

Antenna noise temperature is defined as that fictional temperature at the input of the network which would account for the noise ΔN at the output.

$$T_N = T_0 (F_N - 1)$$

where,

ΔN - additional noise introduced by the network itself.

-> noise temperature is related to noise figure.

$$F_N = 1 + \frac{T_N}{T_0} \quad (or) \quad F_N - 1 = \frac{T_N}{T_0}$$

where,

F_N - Noise Figure (dimensionless)

T_N - Noise Temperature, °K

T_0 - Standard Temperature, $T_0 = 290°K$ $(273+17)K$

Noise figure in decibel,

$$(F_N)_{db} = 10 \log_{10} F_N$$

Impedance Matching

Impedance matching is the process of matching the antenna's input impedance to the corresponding RF circuitry's output impedance.

Impedance matching is designing source and load impedances to minimize signal reflection and maximize power transfer.

It is important to transfer radio frequency signal from the source to the load through transmission lines without power loss. To achieve this, the source impedance and load impedance have to be matched.

In DC circuits, the source and load (impedance) should be equal.

In AC circuits, the source should either equal the load or the complex conjugate of the load.

A network which is used to match the load impedance with source impedance is called matching network.

One eigth waveline ($\lambda/8$), quarter wave line ($\lambda/4$) and half wave line ($\lambda/2$) are used as matching networks.

Link Budget and Link Margin

Link budget is a way of quantifying the link performance. Link budget is an accounting of all of the power gains and losses that a communication signal experiences in communication system, from a transmitter through a communication medium such as radio waves, cable, waveguide or optical fiber to the receiver.

Link budget is a design aid, calculated during the design of a communication system to determine the received power, to ensure that the information is received intelligibly with an adequate signal to noise ratio.

Simple link budget equation is,

$$\boxed{\text{Received Power (dB)} = \text{Transmitted power (dBm)} + \text{Gain (dB)} - \text{Losses (dB)}}$$

Link margin is the difference between the minimum received signal level and the actual received power. It is also defined as, the difference between the minimum expected power received at the receiver's end, and the receiver's sensitivity ie, the received power at which the receiver will stop working.

Friis Transmission Equation

Friis transmission formula was developed by Prof. H.T. Friis of the Bell Telephone Laboratories in 1946. This formula is useful in obtaining the power received by the receiver. This formula is based on the concept of the effective aperture.

Consider a radio link between the transmitter and receiver.

let,

* two antennas be separated by distance 'd' expressed in meter
* P_T be the power radiated or transmitted by the transmitting antenna
* P_R be the power received by the receiving antenna
* A_{eT} be the effective aperture area of the transmitting antenna
* A_{eR} be the effective aperture area of the receiving antenna

Assuming that the transmitting antenna is isotropic, then the power density, ie., the power received per unit area at the receiving antenna is,

$$P_R = \frac{P_T}{4\pi d^2} \longrightarrow (1)$$

where, $P_{rad} = P_T$ and $r = d$

If G_T is the directional gain of the transmitting antenna, then the power density produced at the distance 'd' by the transmitting antenna is,

$$P_d = G_T \times \frac{P_T}{4\pi d^2}, \ W/m^2 \longrightarrow (2)$$

Power received at the receiving antenna is,

$$P_R = \frac{P_T}{4\pi d^2} \cdot G_T \cdot A_{eR}, \ W \longrightarrow (3)$$

But the directive gain of the transmitting antenna can be expressed in terms of the effective aperture of the transmitting antenna is,

$$G_T = \frac{4\pi A_{eT}}{\lambda^2} \longrightarrow (4)$$

Substitute the value of G_T in equation (3),

$$\boxed{P_R = P_T \frac{A_{eT} \cdot A_{eR}}{d^2 \lambda^2}}, \text{ W} \longrightarrow (5)$$

where,

P_T - Transmitted Power, watts

A_{eT}, A_{eR} - Effective aperture of the transmitting and receiving antennas in m^2

d - distance of seperation between two antennas in metre

λ - wavelength in metre

NOISE CHARACTERIZATION OF MICROWAVE RECEIVER

Microwave receiver is used to amplify the weak signal that is gathered by the antenna in a radar, radio or other communication system or sensor.

To analyse the noise characteristics of complete antenna – transmission line – receiver front end, consider simple microwave receiver.

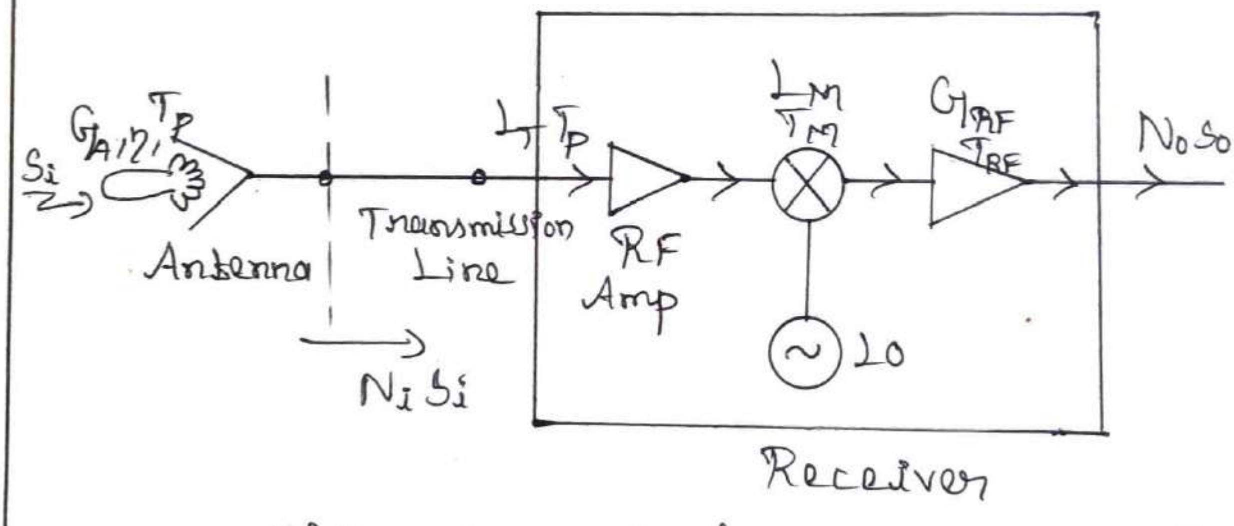


Fig: Noise Analysis of Microwave Receiver

In this system the total noise power at the output of the receiver, N_o, will be due to contributions from the antenna pattern, the loss in the (antenna) transmission line and from the receiver components. This noise power will determine the minimum detectable signal level for the receiver and for a given transmitter power, the maximum range of the communication link.

The receiver components consists of an RF amplifier with gain G_{RF} and noise temperture T_{RF}, a mixer with an RF to IF conversion loss factor L_M and noise temperature T_M and an IF amplifier with gain G_{IF} and noise temperature T_{IF}.

The noise effects of later stages can be ignored, since the overall noise figure is dominated by the characteristics of the first few stages. The component noise temperature (of the receiver) can be related to noise figures as $T = (F-1)T_0$.

From the equivalent noise temperature of the receiver is,

$$T_{REC} = T_{RF} + \frac{T_M}{G_{RF}} + \frac{T_{IF} L_M}{G_{RF}}$$

Radiation from Oscillating Dipole

[Radiation from Alternating Current Element]

Oscillating dipole is a short linear antenna in which the current along its length is assumed to be constant.

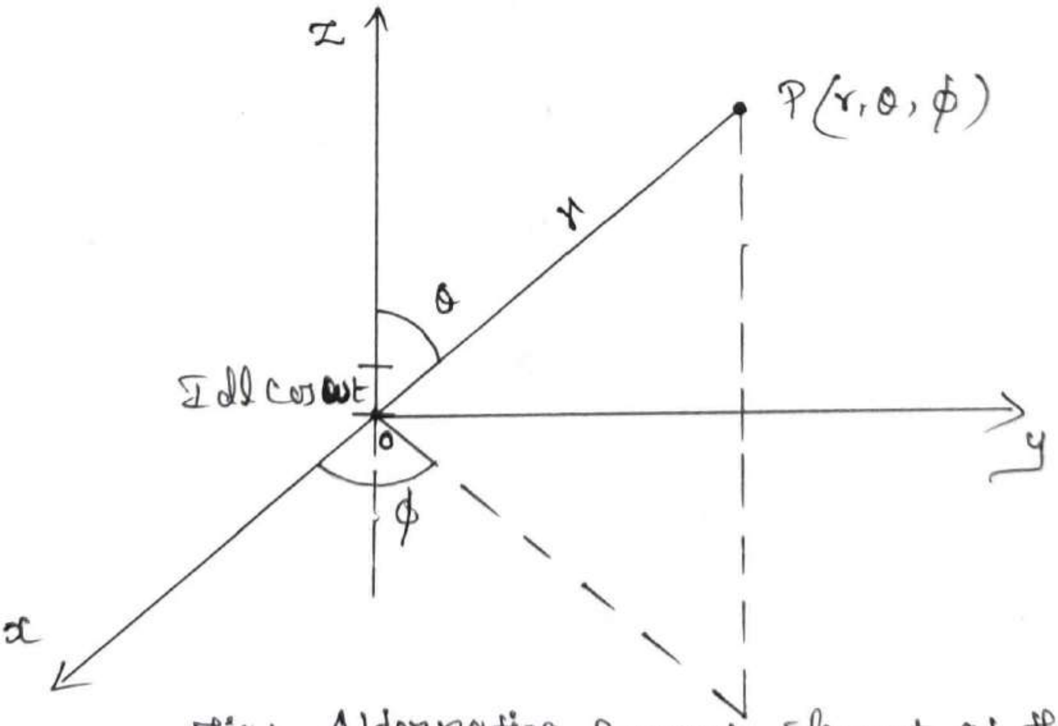
The concept of retarded vector magnetic potential is very useful to derive radiation fields of antenna elements including current element.

The retarded vector magnetic potential is,

$$A = \frac{\mu}{4\pi} \int_V \frac{I\left(r, t - r/v_0\right)}{r} \, dv \longrightarrow (1)$$

→ as the element is z directed, A is also z-directed

→ r/v_0 – delay time →(10)



→(13)

Fig: Alternating Current Element at the Origin

The volume integral in equation (1) can be simplified by taking integration over the cross-sectional area of the element and an integration along its length.

we know that, $\oint J.ds = I \quad \rightarrow (2)$

and $\int_0^{dl} I\,dl = I\,dl \quad \rightarrow (3)$

$$A = A_z a_z = \frac{\mu_0}{4\pi} \frac{I\,dl \cos w(t - r/v_0)}{r} a_z \quad \rightarrow (4)$$

→ A has only z component and $A_x = A_y = 0$

Changing cartesian components to spherical coordinate components,

$$A_r = A_z \cos\theta$$
$$A_\theta = -A_z \sin\theta$$
$$A_\phi = 0$$

But we know that, $H = \frac{1}{\mu_0} \nabla \times A$

$$\therefore \quad H_r = \frac{1}{\mu_0}(\nabla \times A)_r$$
$$H_\theta = \frac{1}{\mu_0}(\nabla \times A)_\theta$$
$$H_\phi = \frac{1}{\mu_0}(\nabla \times A)_\phi$$

$$\Rightarrow H_r = \frac{1}{\mu_0 r \sin\theta}\left\{\frac{\partial}{\partial\theta}\left[\sin\theta A_\phi\right] - \frac{\partial A_\theta}{\partial\phi}\right\} \quad \rightarrow (5)$$

→ as $A_\phi = 0$ and $A_\theta \neq f(\phi)$, $H_r = 0$

$|||^{ly}$

$$H_\theta = \frac{1}{\mu_0}\left[\frac{1}{r\sin\theta}\frac{\partial A_r}{\partial\phi} - \frac{1}{r}\frac{\partial(rA_\phi)}{\partial t}\right] = 0 \quad \rightarrow (6)$$

$$H_\phi = \frac{1}{\mu_0 r}\left[\frac{\partial}{\partial t}(rA_\theta) - \frac{\partial A_r}{\partial t}\right] \quad \rightarrow (7)$$

[as $A_r \neq f(\phi)$]

here, $A_\theta = -A_z \sin\theta$

$$\Rightarrow A_\theta = -\frac{\mu_0}{4\pi}\frac{I\,dl \cos\omega(t - r/v_0)}{r}\sin\theta \rightarrow (8)$$

$$A_r = -A_z \cos\theta$$

$$\Rightarrow A_r = -\frac{\mu_0}{4\pi}\frac{I\,dl \cos\omega(t - r/v_0)}{r}\cos\theta \rightarrow (9)$$

Substituting equations (8) and (9) in equation (7),

$$H_\phi = \frac{1}{\mu_0 r}\left\{\frac{\partial}{\partial t}\left[r\left(-\frac{\mu_0}{4\pi}\frac{I\,dl\cos\omega(t - r/v_0)}{r}\sin\theta\right)\right] - \frac{\partial}{\partial t}\left[\frac{\mu_0}{4\pi}\left(I\,dl\cos\omega(t - r/v_0)\cos\theta\right)\right]\right\}$$

$$H_\phi = \frac{I\,dl\sin\theta}{4\pi}\left[\frac{-\omega\sin\omega(t - r/v_0)}{r v_0}\;\frac{\cos\omega(t - r/v_0)}{r^2}\right] \rightarrow (10)$$

From maxwell's equation,

$$\nabla \times H = \dot{D} = \varepsilon_0 \dot{E} \longrightarrow (11)$$

$$E = \frac{1}{\varepsilon_0}\int (\nabla \times H)\,dt \longrightarrow (12)$$

From equations (8) and (12) we can get E_r, E_θ and E_ϕ

→ but $E_\phi = 0$ $\quad [\text{as } H = H_\phi a_\phi]$

On simplification of equation (12),

$$E_\theta = \frac{I\,dl\sin\theta}{4\pi\varepsilon_0}\left[\frac{\omega\sin\omega t_d}{r v_0^2} + \frac{\cos\omega t_d}{r^2 v_0} + \frac{\sin\omega t_d}{\omega r^3}\right] \rightarrow (13)$$

and

$$E_r = \frac{2 I\,dl\cos\theta}{4\pi\varepsilon_0}\left[\frac{\cos\omega t_d}{r^2 v_0} + \frac{\sin\omega t_d}{\omega r^3}\right] \longrightarrow (14)$$

where,

$$t_d = t - r/v_0 \longrightarrow (15)$$

The resultant field components of an alternating current element are,

$$H_\phi = \frac{I\,dl \sin\theta}{4\pi}\left[-\frac{\omega \sin t_d}{r V_0} + \frac{\cos \omega t_d}{r^2}\right]$$

$$E_\theta = \frac{I\,dl \sin\theta}{4\pi \varepsilon_0}\left[-\frac{\omega \sin \omega t_d}{r V_0^2} + \frac{\cos \omega t_d}{r^2 V_0} + \frac{\sin \omega t_d}{\omega r^3}\right]$$

$$E_r = \frac{2 I\,dl}{4\pi \varepsilon_0}\cos\theta\left[\frac{\cos \omega t_d}{r V_0^2} + \frac{\sin \omega t_d}{\omega r^3}\right]$$

$$H_r = 0, \quad H_\theta = 0, \quad E_\phi = 0$$

UNIT - II

RADIATION MECHANISM OF LINEAR WIRE & LOOP ANTENN

Radiation is the process of transmitting electric energy from one place to another.

Radiation Sources

- Single wire antennas
- Two wire antennas
- Dipole antennas
- Loop antennas

Single Wire Antennas

Wire antenna is a radio antenna consisting of long wire suspended above the ground. Length of the wire does not have a relation to the wavelength of the radio waves used.

Basically, conducting wires are characterized by the motion of electric charges and the creation of current flow. Assume that an electric volume charge density, q_v (coulombs/m^3), is distributed uniformly in a circular wire of cross-sectional area 'A' and volume 'V'.

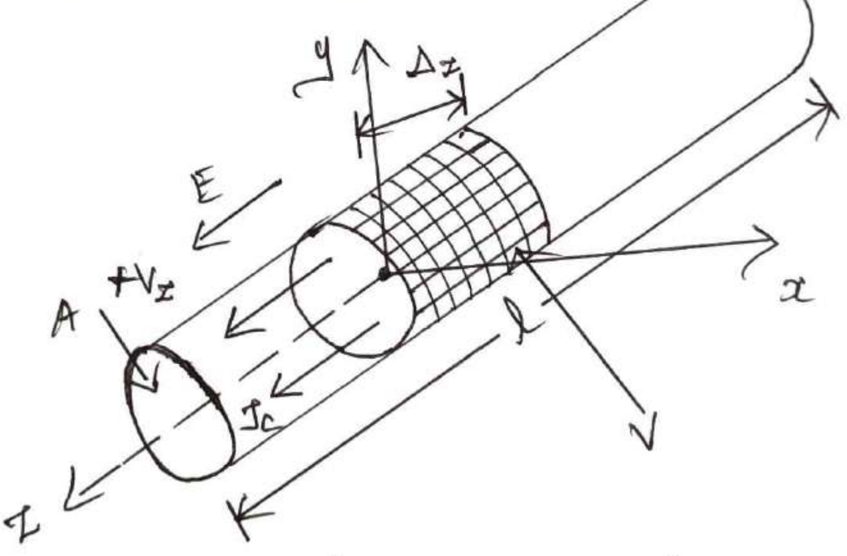


Fig: Charge Uniformly Distributed in a Circular cross section Cylinder Wire

Current density in a volume with volume charge density q_v (C/m²) and with velocity v_z m/s is,

$$J_z = q_v v_z , A/m^2 \longrightarrow (1)$$

Surface current density in a surface with a surface charge density q_s (C/m²) is,

$$J_s = q_s v_z \, , \; A/m \rightarrow (2)$$ [Ampere/metre]

Current in a thin wire with a linear charge density q_l (C/m) is, [C/m - coulomb/metre]

$$I_z = q_l v_z \, , \; A \rightarrow (3)$$

If the current is time varying, then the derivative of the current is,

$$\frac{dI_z}{dt} = q_l \frac{dv_z}{dt} = q_l a_z \rightarrow (4)$$

where,

a_z - m/s^2 is the acceleration

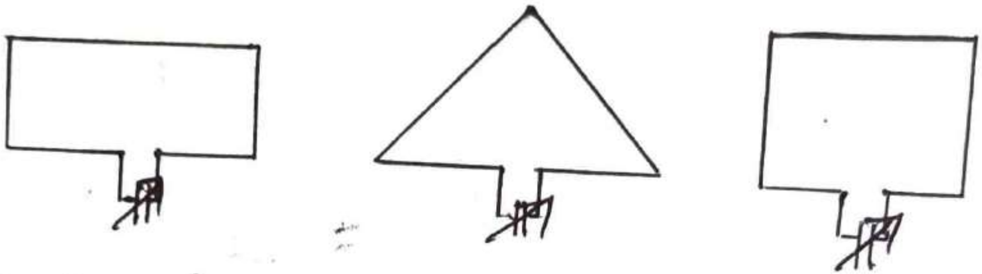
If the wire is of length 'l',

$$l\frac{dI_z}{dt} = l q_l \frac{dv_z}{dt} = l q_l a_z \rightarrow (5)$$

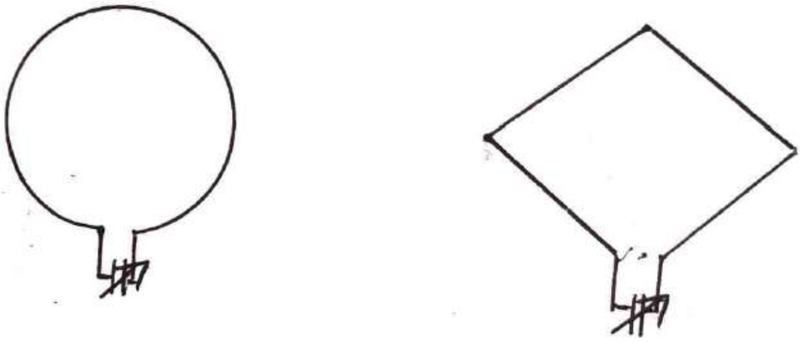
Equation (5) gives the basic relation between current and charge and it is the fundamental relation of electromagnetic radiation.

Loop Antenna

Loop antenna is a radiating coil of any convenient cross section of one or more turns carrying RF currents.



Rectangular   Triangular   Square



Circular   Rhombus

Fig: Different shapes of Loop Antenna

A loop antenna of more than one turn is called as frame. Currents are of the same magnitude and phase throughout the loop if dimensions are small in comparison to wave length ($a << \lambda$). The radiation efficiency of closed loop antenna is low for transmission purposes.

Radiated Fields

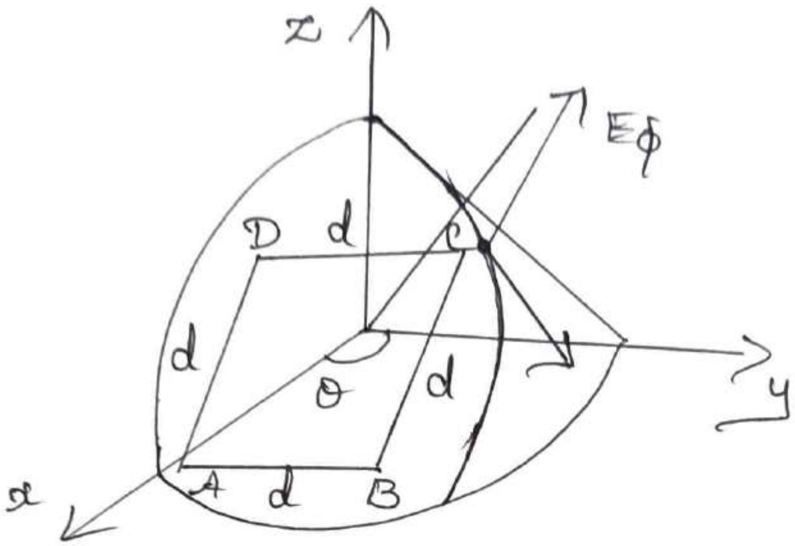


Fig: Square Loop [Spherical Coordinate System]

Let the circular loop of radius 'r' be represented by square loop of side length 'd' such that areas of both are same. The loop is placed at the centre of the coordinate system.

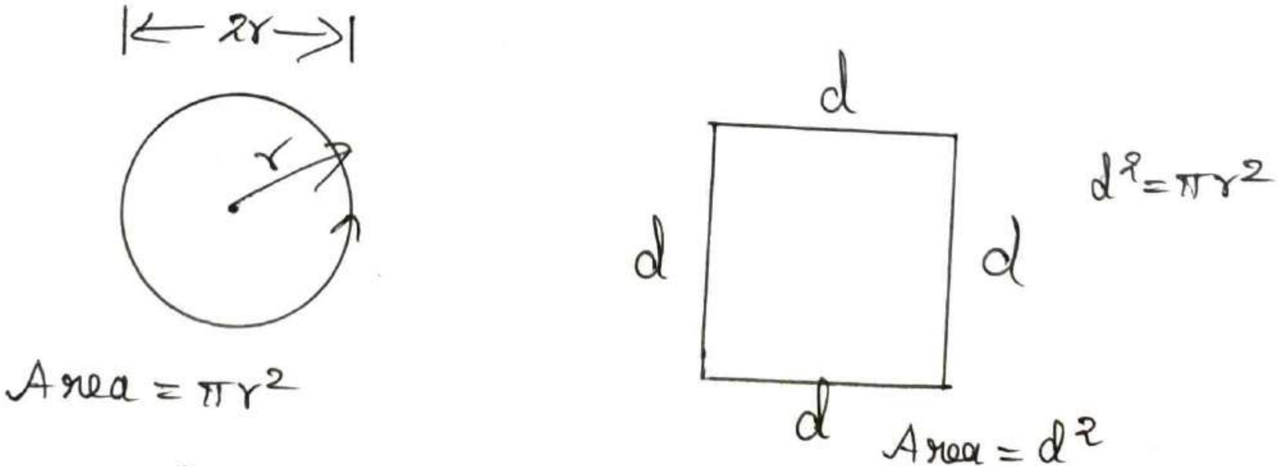


Fig: Circular and square Loop of Equal Area

The sides AD and BC of the loop are being treated as short dipoles, their radiation pattern in horizontal plane x-y and vertical plane y-z.


Fig: Radiation Pattern in xy-plane

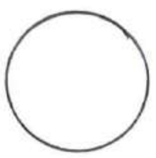


Fig: Radiation Pattern in yz-plane

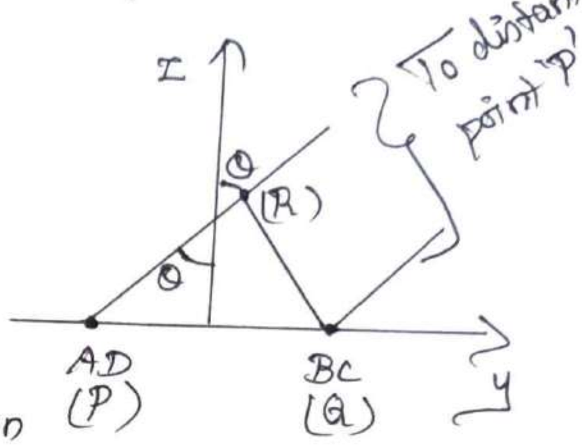


Fig: Dipole AD and BC in yz plane

Both the dipoles radiating uniformly in all directions. Individuals dipoles AD and BC will behave like two isotropic point sources in yz plane.

E_ϕ = Field component due to AD + Field component due to BC

$$E_\phi = -E_0 e^{j\psi/2} + E_0 e^{-j\psi/2}$$

From triangle, $\angle RPQ \cos(90-\theta) = \frac{PR}{PQ} = \frac{PR}{d}$

$$\Rightarrow PR = d\cos(90^\circ-\theta)$$
$$PR = d\sin\theta$$

$$\Rightarrow \quad E_\phi = -E_0 e^{j\psi/2} + E_0 e^{-j\psi/2}$$

$$= -E_0 \left[e^{j\psi/2} - e^{-j\psi/2}\right]$$

$$E_\phi = -2j E_0 \sin \psi/2$$

where,

$$\psi = \beta d \cos(90^\circ - \theta) = \frac{2\pi}{\lambda} d \cos(90^\circ - \theta)$$

$$= \frac{2\pi}{\lambda} d \sin\theta$$

Phase difference, $\psi = \beta d \sin\theta$

$$\therefore \quad E_\phi = -2j E_0 \sin\left(\frac{\beta d \sin\theta}{2}\right)$$

where,

E_0 = Electric field component of dipoles AD or BC

$\Rightarrow$ to find E_0, consider the far field of the individual dipole

$$E_0 = \frac{[I] L \sin\theta}{4\pi\epsilon_0} \frac{j\omega}{c^2 r}$$

* short dipole was oriented in z-direction, where as the dipoles AD and BC are oriented along y direction.

$$E_\theta = \frac{[I]\, l \sin\theta}{4\pi\epsilon_0} \frac{j\omega}{c^2 r}$$

where,

$$\omega = 2\pi f, \quad c = \frac{1}{\sqrt{\mu\epsilon}} = f\lambda \Rightarrow c^2 = \frac{1}{\mu\epsilon} = f^2\lambda^2$$

$$\therefore E_\theta = \frac{[I]\, l \sin\theta}{4\pi\epsilon} \cdot \frac{j 2\pi f}{\underset{(c)}{(f\lambda)}\, r} \cdot \underset{(c)}{\sqrt{\mu\epsilon}}$$

The angle θ is measured from the dipole axis and it is 90° ($\sin 90^\circ = 1$).

$$\therefore E_\theta = \frac{[I]\, l \sin 90^\circ}{2\lambda r} \sqrt{\frac{\mu}{\epsilon}}$$

$$= \frac{j [I]\, l}{2\lambda r} \cdot 120\pi \qquad // \eta = \sqrt{\frac{\mu}{\epsilon}} = 120\pi$$

3

$$E_\theta = \frac{j [I]\, l}{\lambda r} \cdot 60\pi$$

$$\text{But, } E_\phi = -2j \frac{j 60\pi [I]\, l}{\lambda r} \frac{\beta d \sin\theta}{2}$$

$$= \frac{60\pi [I]}{\lambda r} \frac{2\pi l d \sin\theta}{\lambda}$$

$$\boxed{E_\phi = \frac{120\pi^2 [I] \sin\theta\, A}{\lambda^2 r}} \text{ V/m} \quad \left[\because A = ld, \text{ area of the loop}\right]$$

* Other far field is magnetic field component H_ϕ

we know that,

$$\eta = \frac{E\phi}{H_\theta}$$

$$\Rightarrow H_\theta = \frac{E\phi}{\eta}$$

$$= \frac{120\pi^2 [I] \sin\theta . A}{\lambda^2 r . 120\pi}$$

$$\boxed{H_\theta = \frac{\pi [I] \sin\theta \, A}{\lambda^2 r}} \; A/m$$

Radiation from Rectangular Aperture

Aperture antenna is an opening in a surface designed to radiate. It is more convenient to calculate aperture radiation patterns from the electromagnetic fields of the aperture rather than from the currents on the antenna.

The radiation pattern of an aperture antenna has been derived from fields associated with rays which pass through the aperture and rays diffracted by the aperture edges.

Example for aperture antennas:
1. **Radiating** slots
2. Horns
3. Reflectors
4. Lens antennas
5. Open ended waveguides

The radiation fields from aperature antennas are determined from the knowledge of the fields over the aperture of the antenna.

The aperture fields becomes the sources of the radiated fields at large distances.

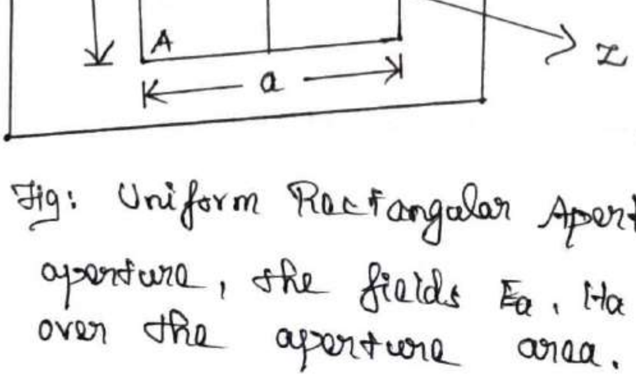


Fig: Uniform Rectangular Aperture

In uniform aperture, the fields Ea, Ha are assumed to be constant over the aperture area.

The field E_a have an arbitrary direction, with constant x and y components, $E_a = \hat{x} E_{0x} + \hat{y} E_{0y}$, because E_a is constant. $\longrightarrow (1)$

Fourier transform of equ(1) is,

$$f(\theta, \phi) = \int_A E_a(r') e^{jk.r'} ds'$$

$$f(\theta, \phi) = E_a \int_A e^{jk.r'} ds' \equiv A f(\theta, \phi) E_a \longrightarrow (2)$$

By normalizing,

$$f(\theta, \phi) = \frac{1}{A} \int_A e^{jk.r'} ds' \longrightarrow (3)$$

The quantity $f(\theta, \phi)$ depends on the assumed geometry of the aperture and it alone determines the radiation pattern.

The normalized gain and field strength is,

$$\frac{|E(\theta, \phi)|}{|E_{max}|} = \sqrt{g(\theta, \phi)} = \frac{1+\cos\theta}{2} |f(\theta, \phi)| \longrightarrow (4)$$

For a rectangular aperture of sides a, b the area integral equation (3) is separable in the x & y direction.

ie., $$f(\theta, \phi) = \frac{1}{ab} \int_{-a/2}^{a/2} \int_{-b/2}^{b/2} e^{jk_x x' + jk_y y'} dx dy'$$

$$\Rightarrow f(\theta, \phi) = \frac{1}{a} \int_{-a/2}^{a/2} e^{jk_x x'} dx' \cdot \frac{1}{b} \int_{-b/2}^{b/2} e^{jk_y y'} dy' \longrightarrow (5)$$

The result of above integral in the sinc-function pattern;

$$\boxed{f(\theta, \phi) = \frac{\sin k_x a/2}{k_x a/2} \cdot \frac{\sin k_y b/2}{k_y b/2} = \frac{\sin(\pi v_x)}{\pi v_x} \cdot \frac{\sin(\pi v_y)}{\pi v_y}} \longrightarrow (6)$$

where,

$$V_x = \frac{1}{2\pi} k_x a = \frac{1}{2\pi} ka \sin\theta \cos\phi = \frac{a}{\lambda} \sin\theta \cos\phi \rightarrow (7)$$

$$V_y = \frac{1}{2\pi} k_y b = \frac{1}{2\pi} kb \sin\theta \sin\phi = \frac{b}{\lambda} \sin\theta \sin\phi \rightarrow (8)$$

The pattern simplifies along the two principal planes, the xz and yz plane, corresponding to $\phi = 0°$ and $\phi = 90°$.

$$f(\theta, 0°) = \frac{\sin(\pi V_x)}{\pi V_x} = \frac{\sin(\pi a/\lambda)\sin\theta}{(\pi a/\lambda)\sin\theta} \longrightarrow (9)$$

$$f(\theta, 90°) = \frac{\sin(\pi V_y)}{\pi V_y} = \frac{\sin(\pi b/\lambda)\sin\theta}{(\pi b/\lambda)\sin\theta} \longrightarrow (10)$$

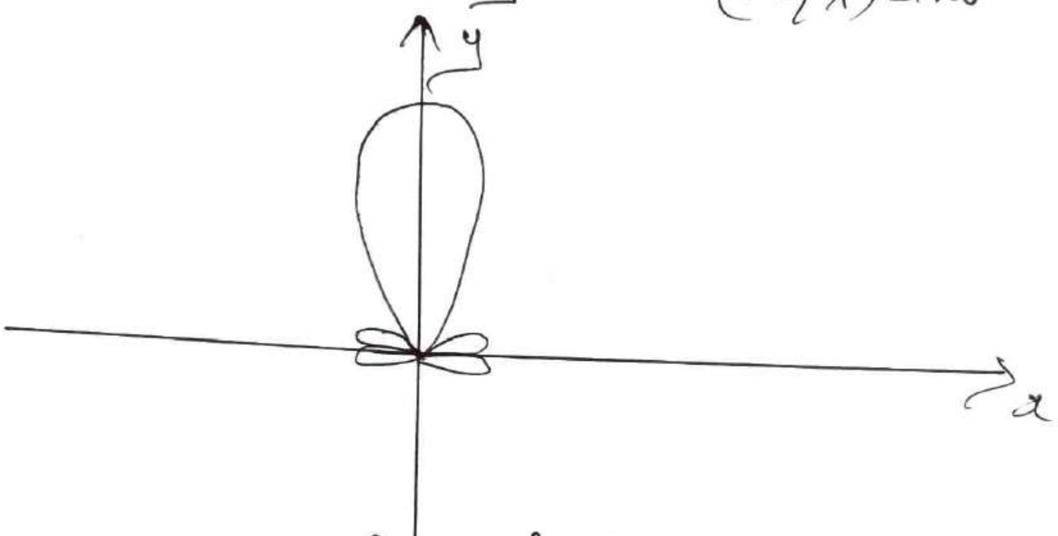


Fig: Radiation Pattern

As the polar angles vary over $0 \leq \theta \leq 90°$ and $0 \leq \theta \leq 360°$, the quantities V_x and V_y vary over the limits $-a/\lambda \leq V_x \leq a/\lambda$ and $-b/\lambda \leq V_y \leq b/\lambda$. The physically realizable values of V_x, V_y are those that lie in the ellipse in the $V_x V_y$ plane.

$$\frac{V_x^2}{a} + \frac{V_y^2}{b} \leq \frac{1}{\lambda^2} \longrightarrow (11)$$

The realizable values V_x, V_y are referred to as the visible region. The radiation pattern consists of a narrow main lobe directed towards the forward direction and several sidelobes. The first side lobe occur at the angles $\theta_a = a\sin(1.403\,\lambda/a) = 10.50^\circ$ and $\theta_b = a\sin(1.405\,\lambda/b) = 20.95^\circ$.

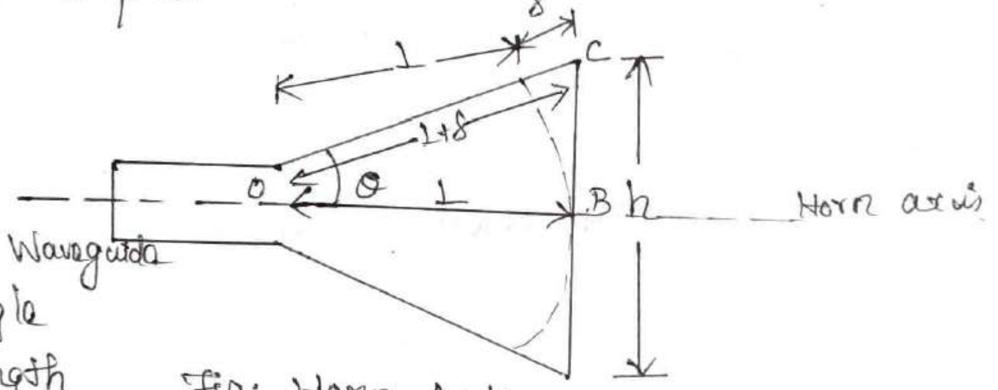
For aperture antennas, the gain is approximately equal to the directivity because the losses tend to be very small. The gain of the uniform rectangular aperture is, $G \approx D = 4\pi(ab)/\lambda^2$.

Horn Antenna

Horn antenna is a flared out or opened out wave guide. Waveguide is capable of radiating radiation into open space provided the same is excited at one end and opened at the other end.

The radiation is much greater through wave guide than transmission line. In wave guide, a small portion of the incident wave is radiated and large portion is reflected back by the open circuit.

To minimize reflections of the guided wave, the region between the waveguide at the throat and free space at the aperature could be given a gradual exponential taper.



θ - flare angle
l - Axial length
A - Aperture

Fig: Horn Antenna

From figure, $\angle COB$, $\cos\theta = \dfrac{OB}{OC} = \dfrac{l}{l+\delta}$

$$\tan\theta = \frac{h/2}{l} = \frac{h}{2l}$$

$$\theta = \tan^{-1}(h/2l) = \cos^{-1}\left(\frac{l}{l+\delta}\right)$$

From $\angle OBC$, $(l+\delta)^2 = l^2 + (h/2)^2$

$$l^2 + \delta^2 + 2l\delta = l^2 + h^2/4$$

[δ is small it can be neglected]

$$2l\delta = h^2/4$$

$$l = h^2/8\delta$$

Design Parameters

1. Flare angle (θ)
2. Axial length (L)

If flare angle is very large,

- wavefront on the mouth of the horn will be curved
- non uniform phase distribution over the aperature
- Beam width increased
- Directivity decreased

If flare angle is small,

- small aperature area
- Beamwidth decreased
- Directivity increased

Uses

1. Extremely used at microwave frequencies

Reflector Antenna

Reflector antenna is a microwave antenna. Microwave antennas are popular for their small size and better radiation characteristics. The size of the antenna depends mainly on the frequency of operation. If the frequency is low, size of the antenna is large and vice-versa.

In general, a beam of predetermined characteristics may be produced by means of a large, suitably shaped and illuminated reflector surface.

Reflector antennas are widely used to modify the radiation pattern of a radiating element. The backward radiation from an antenna may be eliminated with a plane sheet reflector of large dimensions.

Types

1. Rod Reflector
2. Plane Reflector
3. Corner Reflector
4. Horn Reflector
5. Parabolic Reflector
6. Spherical Reflector
7. Cylindrical Reflector
8. Flat Reflector

Flat Reflector

Flat reflector is the simplest reflector to direct electromagnetic energy in a desired direction. It has a large flat sheet near a linear dipole antenna. It reduces backward radiation. It provides substantial gain in the forward direction by reducing the spacing between the antenna and the sheet. The desirable properties of the sheet reflector may be largely preserved with the reflector reduced in size.

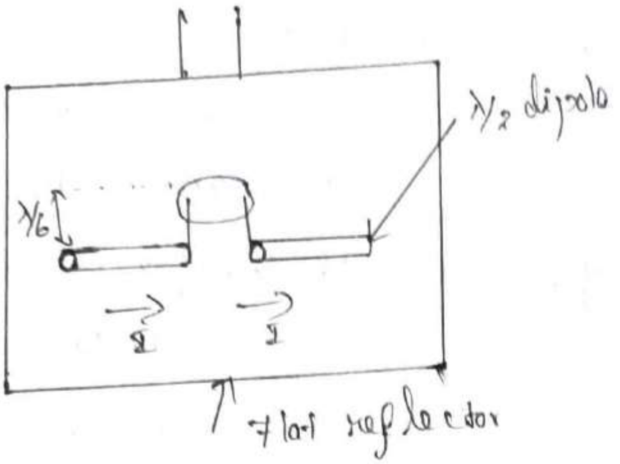


Fig : λ/2 dipole with reflector

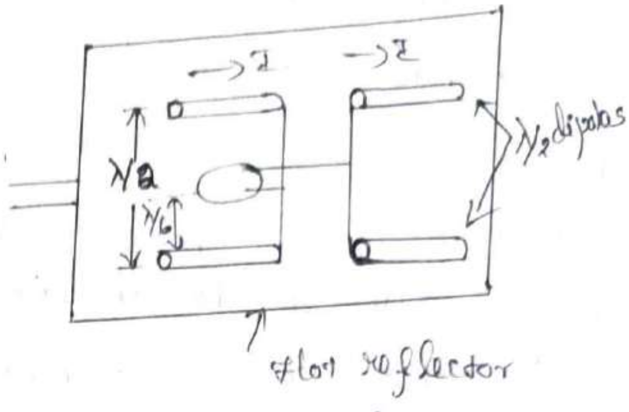


Fig: Two λ/2 dipole with reflector

The properties of large sheet reflector are insensitive to small frequency changes. The directivity of λ/2 dipole can be increased by placing it in front of a flat conducting reflector.

Field Pattern

Fig: λ/2 dipole with reflector

Fig: Two λ/2 dipole with reflector

An array of two λ/2 dipoles placed infront of a flat reflector produces higher directivity. The directivity approximately doubles going from single dipole to double dipole. The large flat sheet reflector can convert a bidirectional pattern into unidirectional pattern.

Applications

used in,

1. Television
2. Point to Point Communication

Feeding Structures

The antenna placed at the focus of paraboloid is known as feed radiator or simply feed. An ideal feed would be that radiator which radiates towards reflector in such a way that it illuminates the entire surface of the reflector and no energy is radiated in any other directions.

Different Feeds

1. Dipole antenna feed
2. Horn antenna feed
3. End fire feed
4. Cassegrain feed

Dipole Antenna Feed

The simplest and generally used feed system is a dipole with parasitic reflector, which is fed with a coaxial line.

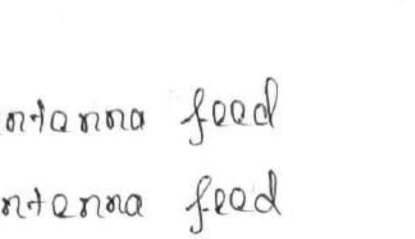


Fig: Dipole Feed

Spacing between driven element and parasitic element is 0.125 λ and for a plane reflector, it may be around 0.4 λ.

Horn Feed

The most common feed radiation for paraboloid reflector antenna is waveguide horn. The horn feed is a waveguide feed. Horn antenna is pointing the paraboloid and the direct radiation from the horn antenna is minimum. If circular polarization is required, conical horn or helix antenna can be used as feed at the focus of paraboloid.

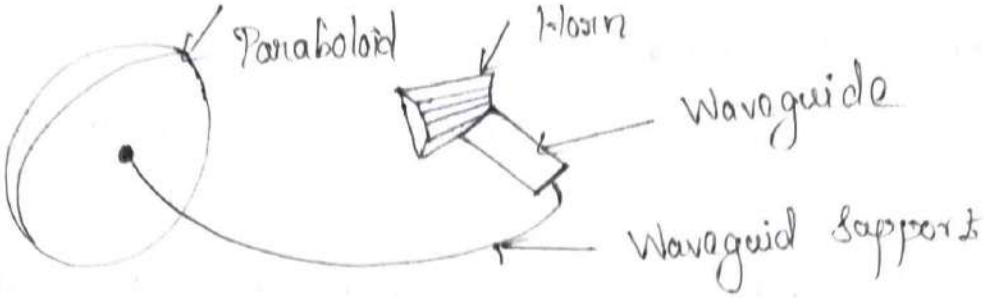


Fig: Horn Feed

For getting maximized beam pattern along the paraboloid axis, feed is placed at the focus. But if the feed is moved laterally from the focus ie, perpendicular to axis, limited beam motion can be obtained.

If the feed is moved along the axis, the pattern is broadened. Thus important position of feed is the focus and for the small reflector of short focal length, the position of feed is shown in figure.

Advantages:

1. Simple in construction
2. Quite inexpensive
3. Widely used in fixed point to point microwave communication.
4. Satellite reception and tracking
5. Ability to place feed in a convenient location.

Slot Antennas

Slot antenna is an opening cut in a sheet of a conductor which is energised via a coaxial cable or waveguide.

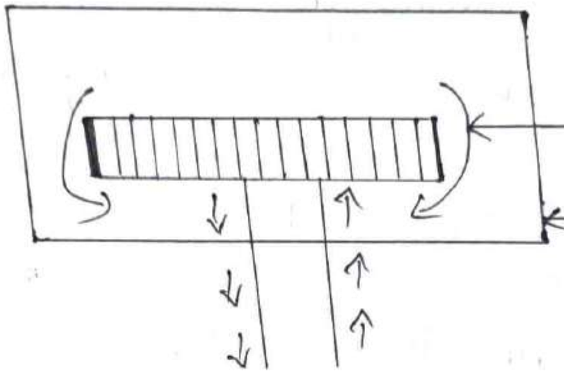


Fig: Slot Antenna

One simplest type of slot antenna is a half wavelength long with narrow width and excited via a 50 Ω coaxial cable normally connected about 0.05λ from one end of the slot to achieve reasonable matching conditions.

Here the fields are excited by a two wire transmission line. The electric field across the slot is maximum at the centre and tappers off towards the edges.

When the slot is exactly half wavelength long, the electric field distribution is sinusoidal and the impedance offered by the slot to the two wire transmission line is a resistance of 565 Ω.

The analysis of slot antenna is greatly faciliated by considering the slot's complementary antenna.

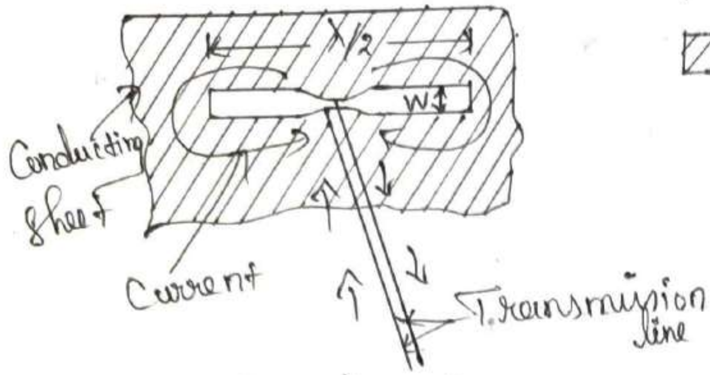


Fig: Slot Antenna

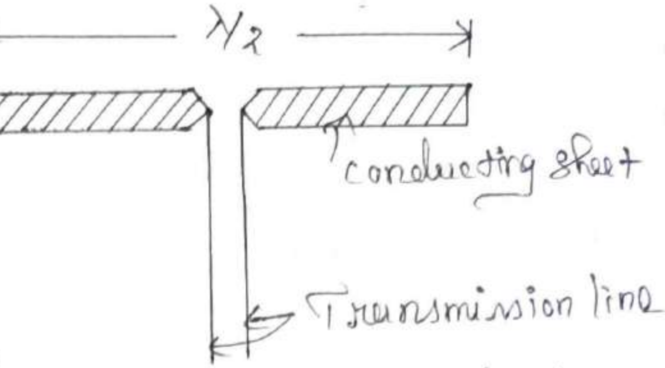


Fig: Complementary dipole antenna

- * metal and air regions of the slot are interchanged for the dipole
- * pattern of the slot is idendical in shape to that of the dipole
- * electric field is vertically polarized for the slot
- * electric field is horizontally polarized for the dipole
- * terminal impedance of the slot is related to the terminal impedance of the dipole by intrinsic impedance

ie, $Z_s Z_d = \frac{\eta_0^2}{4} = \frac{(377)^2}{4}$

$$Z_s \approx \frac{35,476}{Z_d}\ \Omega$$

→ hence by knowing the properties of dipole antenna the properties of the complementary slot antenna can be determined

→ if terminal impedance of dipole antenna is,

$$Z_d = 73 + j42.5\ \Omega$$

→ then terminal impedance of complementary slot is,

$$Z_s = 35,476/Z_d$$

$$= \frac{35,476}{73+j42.5} \times \frac{73-j42.5}{73-j42.5}$$

$$= \frac{35,476}{(73)^2+(42.5)^2} \times (73-j42.5)$$

$$Z_s \approx 363 - j211\ \Omega$$

Difference between slot antenna and complementary Dipole Antenna

1. Polarization are different
   i.e., the electric fields associated with the slot antenna are idential with the magnetic field of the complementary dipole antenna
2. Radiation from the back side of the conducting plane has the opposite polarity from that of the complementary antenna, because of the way in which the fields are directed.

Types

1. Horizontal slot – produces vertical polarization
2. Vertical slot – produces horizontal polarization

Advantage

* Slot antenna can be fabricated and concealed within a metallic objects and with a small transmitter it can provide covert communications.

Microstrip Antennas

Microstrip antennas are low profile antennas. It consists of a very thin metallic strip placed above ground plane. The strip and groundplane are separated by a dielectric sheet called substrate. The radiating element and the feed lines are normally photoetched on the dielectric substrate.

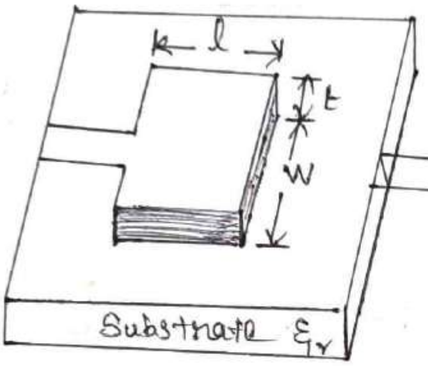


Fig: Microstrip Patch

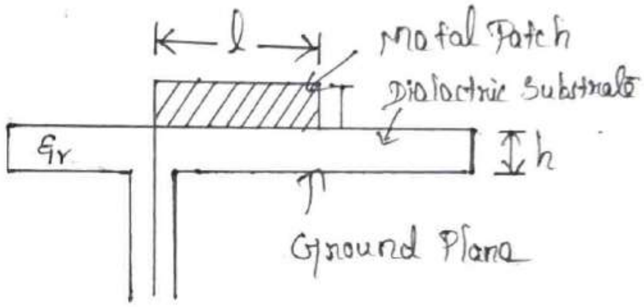


Fig: Patch Antenna Fed by coaxial line at left edge

The feedline is also a conducting strip normally of smaller width. Coaxial line feeds where the inner conductor of the coaxial line is attached to the radiating patch are widely used.

Linear and circular polarization can be achieved with microstrip antennas.

- * arrays of microstrip elements with single feed or multiple feeds may be used for greater directivity
- * thickness of the microstrip antenna is very small
- * waves generated within dielectric substrate undergo reflection

The patch antenna acts as a resonant λ/2 parallel plate microstrip transmission line with characteristic impedance equal to reciprocal of the number of parallel field cell transmission lines.

Each field transmission line has a characteristic impedance equal to the intrinsic impedance of the medium.

$$Z_i = \eta_i = \sqrt{\frac{\mu}{\epsilon}} = \sqrt{\frac{\mu_0 \mu_r}{\epsilon_0 \epsilon_r}}$$

$$Z_i = 120\pi \sqrt{\frac{\mu_r}{\epsilon_r}} \qquad \eta = \sqrt{\frac{\mu_0}{\epsilon_0}} = 120\pi$$

Advantages

1. Linear and circular polarization are possible.
2. Using high dielectric constant ϵ_r substrate
3. Increasing inductance
4. Adding reactive components to reduce the VSWR.
5. Small size and weight
6. Narrow beam of radiation
7. Ease of installation and fabrication

Disadvantages

1. Narrow bandwidth
2. Poor and fire radiation performance
3. Low power handling capability
4. No provision for adjusting any design value after fabrication.

Applications

1. Spacecraft applications
2. Aircraft applications

RADIATION MECHANISM.

When a transmitting antenna is excited with an alternating voltage, the initial motion is started by the balanced motion of charges in the antenna. Resonant oscillations are produced by the supplied energy. Electric and magnetic fields are generated due to sudden changes in charge. When the charges around the antenna are set in motion first, the other charges are separated from the antenna and they are also set in motion.

The disturbance is spread from the antenna into space. The electric and magnetic fields so produced are perpendicular to each other. EM waves have no boundaries. The EM energy decreases as it propagates.

The radiation properties include power flux density, radiation intensity, field strength, directivity and polarization.

The antenna appears from the transmission line as a two terminal circuit element having an impedance Z_A while from space, the antenna is characterized by its radiation pattern.

Antenna radiation pattern is defined as a mathematical function or a graphical representation of the radiation properties as a function of space coordinates.

Applications.

1. National Broadcasting
2. Short wave reception
3. Commercial point to point communications
4. Radio receivers
5. Direction finding applications
6. UHF transmitters
7. TV home reception
8. Short distance communication
9. Satellite communication
10. Space probe communication
11. Radio astronomy
12. Space communication.
13. Transmitting telemetry data from moon to earth
14. Satellite, Radar application
15. Spacecraft and aircraft applications
16. FM transmission
17. Television broadcasting
18. HF communication
19. Radio, television, relay links
20. All round monitoring

Principle of Frequency Independent Antennas

An antenna in which the impedance, radiation pattern and directivity remain constant as a function of frequency is called as frequency independent antenna.

An antenna to be frequency independent, the antenna should expand or contract in proportion to the wavelength or if the antenna structure is not mathematically adjustable, the size of active or radiating region should be proportional to the wavelength.

The performance of a lossless antenna is independent of frequency, if its dimensions in terms of wavelength remain constant. Such a result could be achieved if the antenna could be specified in terms of angles. This requirement would be fulfilled by any antenna whose equation in spherical co-ordinates.

ie.,

$$\boxed{r = e^{a(\phi + \phi_0)} f(\theta)}$$

where,

r – (radius) distance along the surface

a – (distance) rate of expansion

$f(\theta)$ – any function of θ

ϕ_0 – orientation

Ex:

1. Spiral Antenna
2. Log Periodic Antenna

Spiral Antenna

In many applications, same antenna is used to send or receive signals over a wide range of frequencies.

If the shape of the antenna is specified only in terms of angles, then the impedance and pattern properties of that antenna will be independent of frequency.

Spiral antenna and their variations are usually constructed to be either exactly or nearly self-complementary. This yield extremely wide bandwidth, up to 40:1.

Logarithmic Spiral Antenna

A spiral can be geometrically described using polar coordinates. Spiral is a geometrical shape found in nature.

-> let (r, θ) be a point in the polar coordinate system

The equation for a log spiral is,

$$r = r_0 a^{\theta} \longrightarrow (1)$$

where,

r - radial distance to point P
θ - angle with respect to x-axis
a - constant controlling the flare rate of the spiral
r_0 - radius for $\theta = 0$

Logarithmic spiral is also called as log spiral or equiangular spiral antenna.

By taking natural logarithmic on both sides,

$$\ln r = \ln r_0 + \theta \ln a \longrightarrow (2)$$

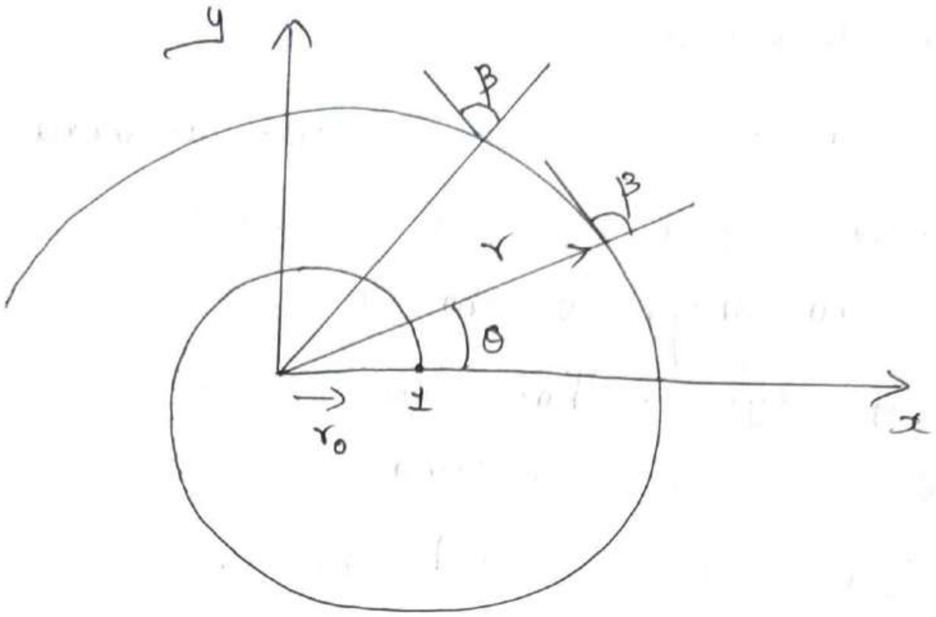


Fig: Logarithmic spiral for $r_0 = 1$
[right handed spiral]

Differentiating with respect to θ,

$$\frac{1}{r}\frac{dr}{d\theta} = \ln a \longrightarrow (3)$$

a - constant

↳ relates the angle β between the tangent at any point on the spiral and the radial line from the origin to that point

$$\ln a = \frac{1}{\tan\beta} \longrightarrow (4)$$

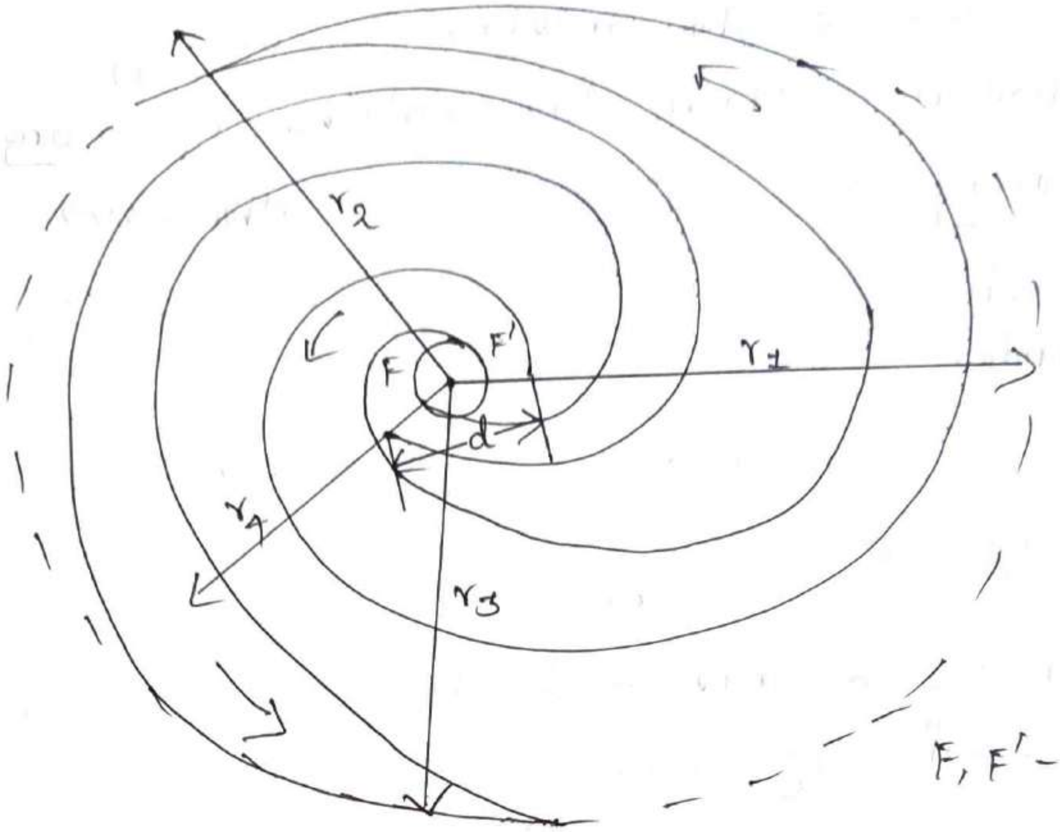
substitute (4) in (2),

$$\theta = \frac{\ln r}{\ln a} = \tan\beta \ln r$$

$$\theta = \tan\beta \ln r \longrightarrow (5)$$

→ β is same for all points as the spiral

→ log spiral is constructed with $r=1$ at $\theta=0$ and $r=2$ at $\theta=\pi$.



F, F' - feed points

Fig: Frequency Independent Planar Spiral Antenna

Consider a spiral described by,

$$r_1 = r_0 a^{\theta}$$

* dimensions of the antenna is designed to operate at a frequency of 'fo'.
* antenna is scaled by a factor K
* antenna would have the same radiation and input properties at a frequency fo/K

Multiplying the equation by a factor K,

$$r_2 = K r_0 a^{\theta}$$

let $K = a^{-\delta}$

$$r_2 = a^{-\delta} r_0 a^{\theta}$$

$$\Rightarrow r_2 = r_0 a^{(\theta - \delta)}$$

→ second antenna is obtained by rotating the original antenna structure by an angle δ.

- → structure of the antenna is unchanged
- → radiation pattern alone rotates by an angle δ
- → keeping all other properties the same

Such an antenna is known as frequency independent antenna.

The third antenna is obtained by rotating the first spiral by 180°, $r_3 = a^{\theta - \pi}$

The fourth antenna is obtained by rotating the second spiral by 180°, $r_4 = a^{\theta - \pi - \delta}$

The areas between spiral 1 and 4 and spiral 2 and 3 are metalised with other areas open. It satisfies the self complementary and congruence conditions.

Design Parameters

1. δ – determines the width of the arm
2. r_0 – determines the radius of the feed region
3. a – determines the rate of growth of the spiral
4. θ – determines the radius of the spiral

Radiation Pattern

- * radiation for the antenna is bidirectional broadside to the plane of the spiral
- * pattern in both directions has a single broad lobe
- * gain is only a few dBi.

Helical Antenna

Helical antenna is the simplest antenna to provide circularly polarized waves. It is a broadband VHF and UHF antenna to provide circular polarization characteristics.

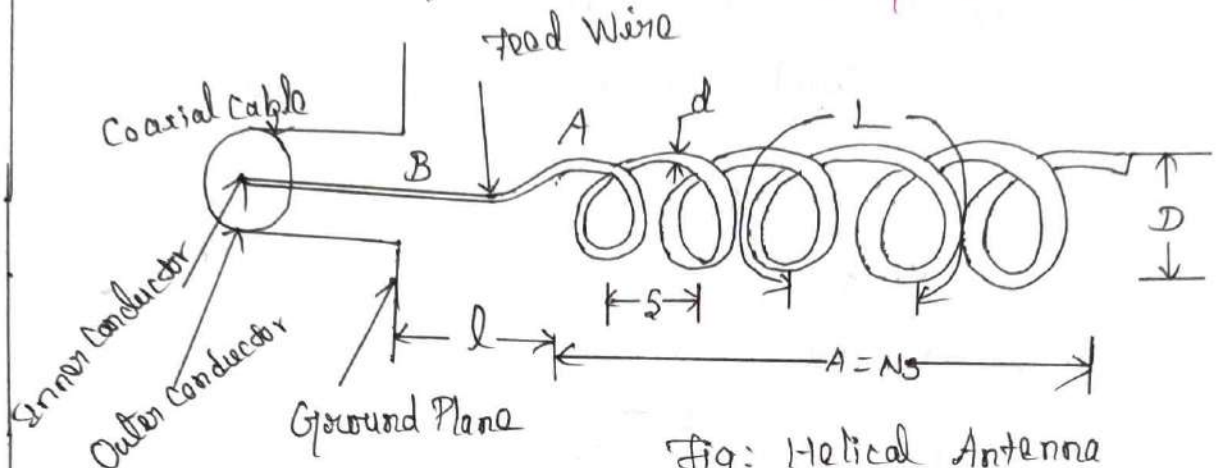


Fig: Helical Antenna

Construction

It consists of a helix of thick copper wire or tubing wound in the shape of screw thread and used as an antenna in conjuction with a flat metal plate called a ground plane.

The ground plane is simply made of sheets and concentric conductors. The helix is fed by a coaxial cable. The one end of the helix is connected to the inner conductor of the coaxial cable and the outer conductor is connected to the ground plane.

Various Dimensions

C – circumference of helix, $C = \pi D$

α – pitch angle, $\alpha = \tan^{-1}(S/\pi D)$

d – diameter of helix conductor

D – diameter of helix

N – number of turns

L - length of one turn

A - Axial length , $A = NS$

S - turn spacing

l - spacing of helix from ground plane

→ for N turns, the total length of helix antenna is NS.

If one turn of helix is unrolled on a plane surface, the circumference, spacing (S), turn length (L) and pitch angle α are related by the triangle,

$$L = \sqrt{S^2 + C^2} = \sqrt{S^2 + (\pi D)^2}$$

Pitch angle - angle between a line tangent to the helix wire and the plane normal to the helix axis

$$\tan \alpha = \frac{S}{C} = \frac{S}{\pi D}$$

$$\alpha = \tan^{-1}(S/\pi D)$$

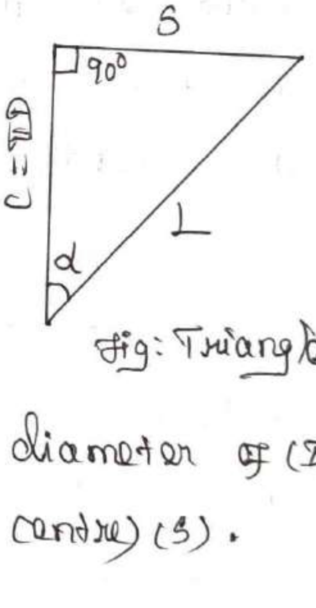


Fig: Triangle

Radiation

- mode of radiation depends on the diameter of (D) helix and turn spacing (centre to centre) (S).

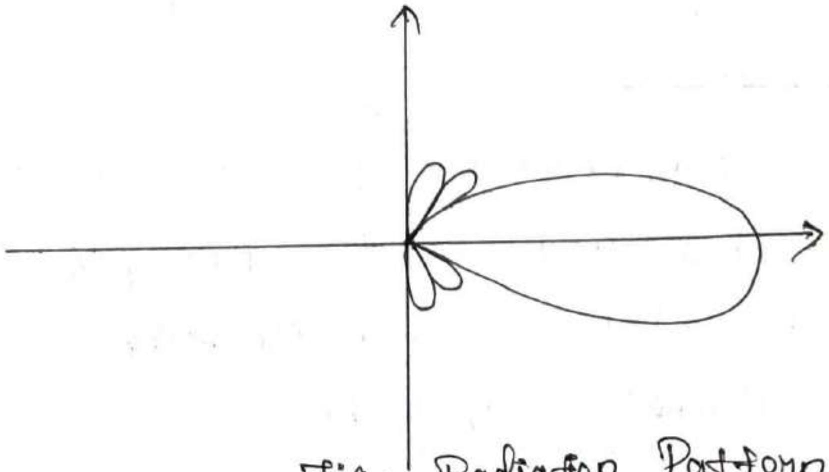


Fig: Radiation Pattern

-> the coaxial cable is coincidant with the helix axis and feed wire lies in the plane through helix axis

-> helix axial length starts at point A

-> length of feed wire which is parallel to the axis is 'l'

-> length of feed wire is S/2.

Modes of Operation

Helical antenna may radiate in many modes. But prominent modes of radiations are two.

1. Normal or Perpendicular mode of radiation
2. Axial or Endfire or Beam mode of radiation

Applications

1. VHF and UHF transmission such as satellite communication
2. Space telemetry link with ballistic missiles, satellites ... etc...
3. Used in extraterrestrial communication in which satellite relays are involved.

Log Periodic Antenna (LPDA)

An antenna whose electrical properties repeat periodically with logarithm of the frequency is called as log periodic antenna.

- * log periodic antennas are broad band antennas
- * frequency independance can be obtained when the variation of the properties over one period
- * log periodic antenna is frequency idependent antenna
- * design of log periodic antenna involves a basic geometric structure
- * structure is repeated with a changing size of the structure
- * structure size changes with each repetition by a constant scale factor
- * so that the structure expand or contract

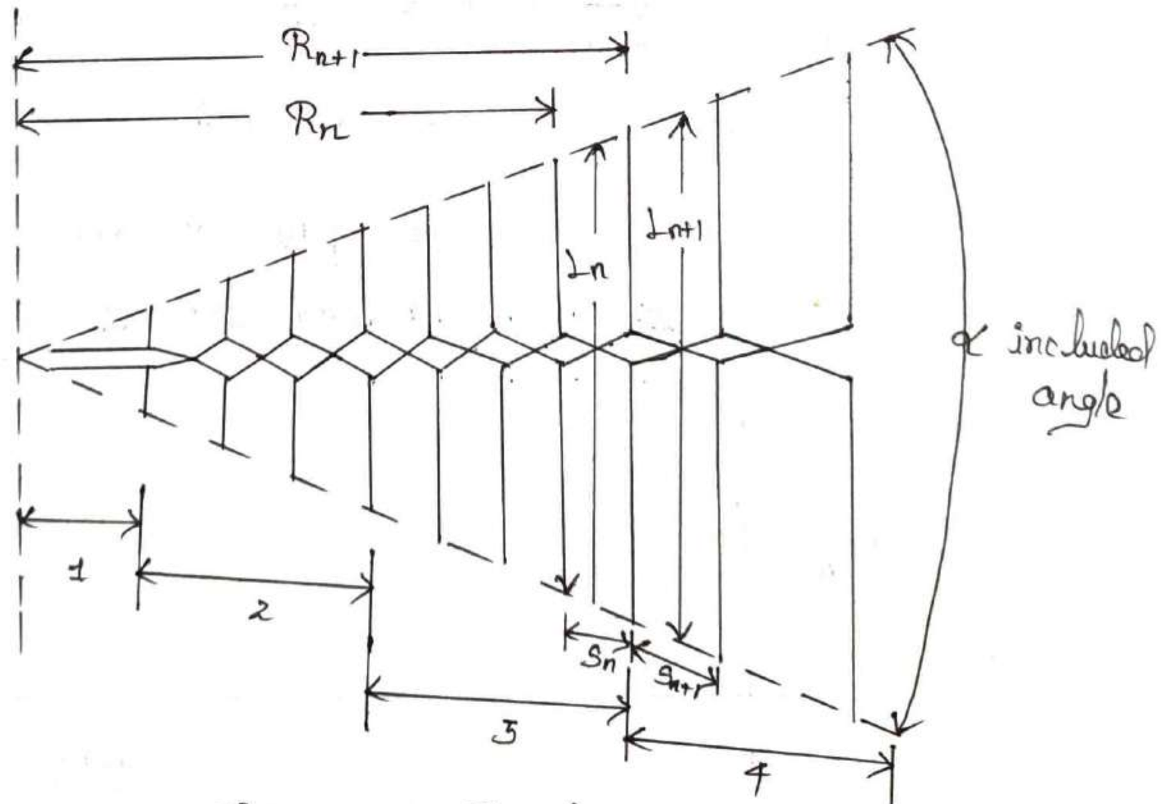


Fig: Log Periodic Dipole Array

ision from region

All dimensions increase in proportion to the distance from the origin. It has a number of dipoles of different lengths and spacing and is fed by balanced two wire transmission line. It is fed at the narrow end.

- dipole length increases in such a way that included angle α is constant
- scale factor or design ratio is designated by τ whose value is less that 1.

The dipole lengths and spacings are related as,

$$\frac{R_1}{R_2} = \frac{R_2}{R_3} = \cdots = \frac{R_n}{R_{n+1}} = \tau = \frac{L_1}{L_2} = \frac{L_2}{L_3} = \cdots = \frac{L_n}{L_{n+1}}$$

$$\frac{R_n}{R_{n+1}} = \frac{L_n}{L_{n+1}} = \tau$$

where, τ - periodicity factor

$$\frac{S_{n+1}}{S_n} = \frac{L_{n+1}}{L_n} = k = \frac{1}{\tau} \quad ; \quad k > 1$$

→ typical values of $\alpha = 30^\circ$ and $\tau = 0.7$

→ repetitiveness in the physical structure which provides repetitive behaviours of the electrical characteristics

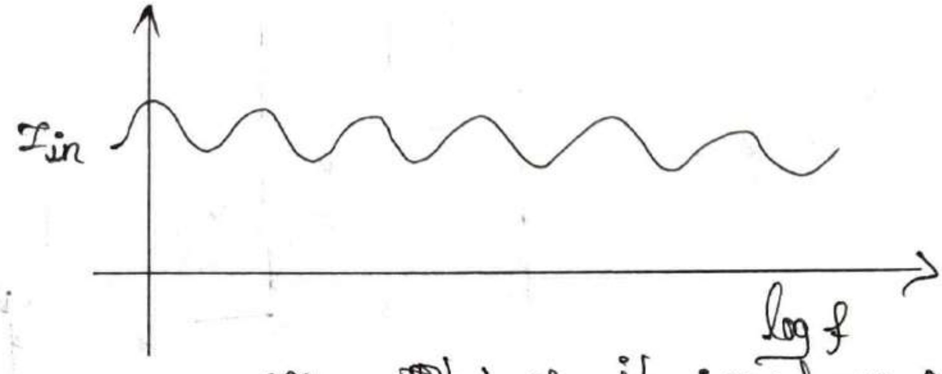


Fig: Plot of i/p impedance Vs log f

From fig (LPDA),

1. Included transmission line region
2. Loaded transmission line region

} Inactive region

3. Active region
4. Reflective region

→ input impedance is a logarithmically periodic function of the frequency

→ all the electrical properties undergo similar periodic variation

Different Regions of LPDA

1. Inactive Region
2. Active Region
3. Inactive Reflective Region

Log periodic structure must be terminated in either direction at some points. These terminated ends in either directions determine high and low cut-off frequencies. Beyond these cut-off frequencies, the log periodic property stops.

Design

Log periodic dipole array consists of a sequence of side by side parallel linear dipole forming coplanar array.

$$\frac{L_{n+1}}{L_n} = \frac{R_{n+1}}{R_n} = \frac{S_{n+1}}{S_n} = \frac{d_{n+1}}{d_n} = \frac{a_{n+1}}{a_n} = \frac{1}{\tau}$$

where, $n = 1, 2, 3 \ldots$

a_n - gap spacing's at dipole centres

Spacing factor σ is,

$$\sigma = \frac{R_{n+1} - R_n}{2L_n} = \frac{S_n}{2L_n}$$

R_n - distance of dipole from origin

The dipole lengths increases along the antenn so that the included angle α is constant and the length L and spacing S of adjacent elements are scaled.

→ so that $\frac{L_{n+1}}{L_n} = \frac{S_{n+1}}{S_n} = k = \frac{1}{\tau}$

k - constant

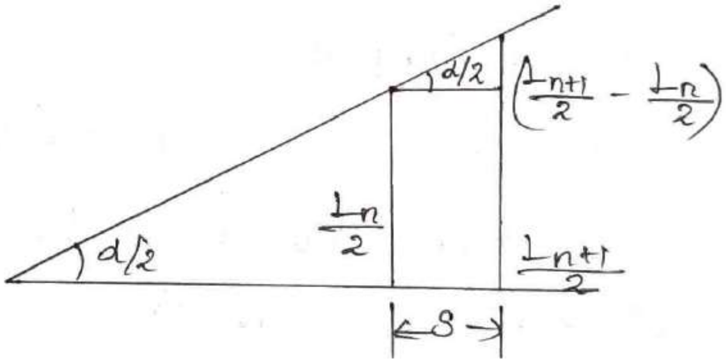


Fig: Section of Log Periodic Array

From figure,

$$\tan \alpha/2 = \frac{\frac{L_{n+1} - L_n}{2}}{S} = \frac{L_{n+1} - L_n}{2S}$$

$$\tan \alpha/2 = \frac{\frac{L_{n+1}}{2}\left[1 - \frac{L_n}{L_{n+1}}\right]}{S}$$

$$\tan \alpha/2 = \frac{L_{n+1}}{2S}\left[1 - \frac{1}{k}\right]$$

→ taking $L_{n+1} = \lambda/2$

$$\tan \alpha/2 = \frac{1 - 1/k}{4\frac{s}{\lambda}}$$

where,

α – apex angle , k – scale factor

s/λ – spacing in wave length

→ now the length L for any element $n+1$ is k^n greater than for element 1,

$$\frac{L_{n+1}}{L_1} = k^n = F$$

F – frequency ratio or bandwidth

For optimum design,

$$k = 1.19$$

→ then for $n = 4$, $F = k^n = (1.19)^4 = 2.0053$

$$F \approx 2$$

$$n+1 = 4+1 = 5 \; ; \; \frac{L_5}{L_1} = 2$$

The spacing factor gives the successive dipole spacing and the scale factor determines the length of the successive dipoles forming a wedge shaped cone.

$$\tan \alpha/2 = \frac{1 - 1/k}{4\, s/\lambda} = \frac{1-\tau}{4\, s/\lambda}$$

$$\sigma = s/\lambda = \frac{1-\tau}{4\tan \alpha/2}$$

$$\tan \alpha/2 = \frac{1-\tau}{4\sigma}$$

$$\alpha/2 = \tan^{-1}\left(\frac{1-\tau}{4\sigma}\right)$$

$$\alpha = 2\tan^{-1}\left(\frac{1-\tau}{4\sigma}\right)$$

General Characteristics

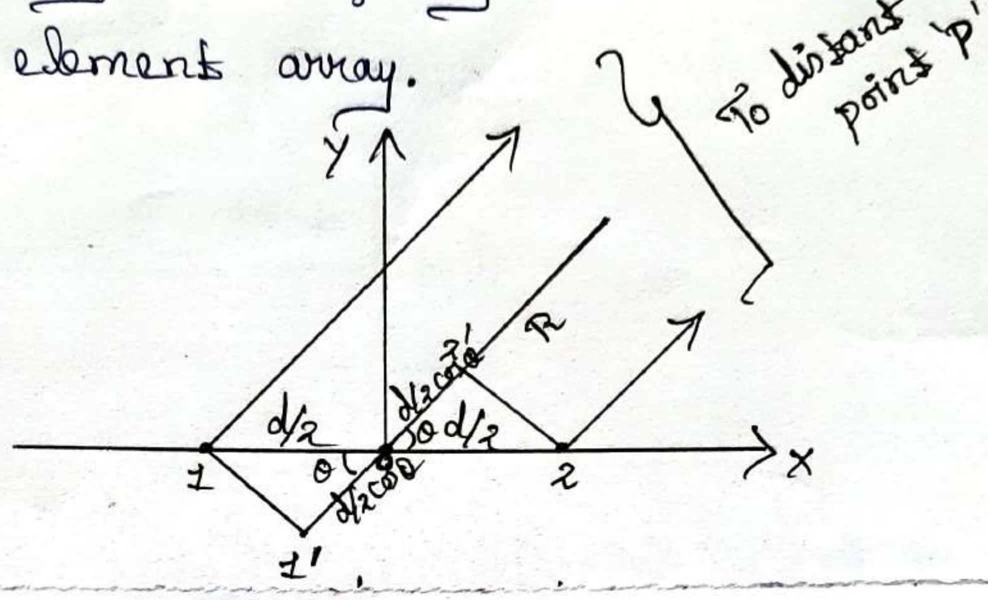
1. Log periodic antenna is excited from the shorter length side for one active region LPA and at the centre for two active region log periodic antenna.
2. For unidirectional log periodic antenna, the structure fires in backward direction.
3. For bidirectional log periodic antenna, the maximum radiation is in broadside direction.
4. Transmission line inactive region must have proper characteristic impedance with negligible radiation.
5. In active region, the magnitude and phasing of currents should be proper so that strong radiation occur along backward direction.
6. In inactive reflective region, there should be rapid decay of current.

Uses

1. Mainly used in the field of HF communication where multiband steerable and fixed antennas are used.
2. Used for television reception.
3. Suited for all round monitoring

Two Element Array [Array of two point sources]

Array consists of only two antennas is named as two element array.



UNIT - III

are separated by a distance 'd' and have the same polarization.

Two point sources (antennas) are symmetrically situated with respect to the origin in the cartesian coordinate system.

Now we have to calculate fields at a distant point 'P' at distance 'R' from the origin 'O'. Origin is taken as reference point for phase calculation.

Two Element Array [Array of two point sources]

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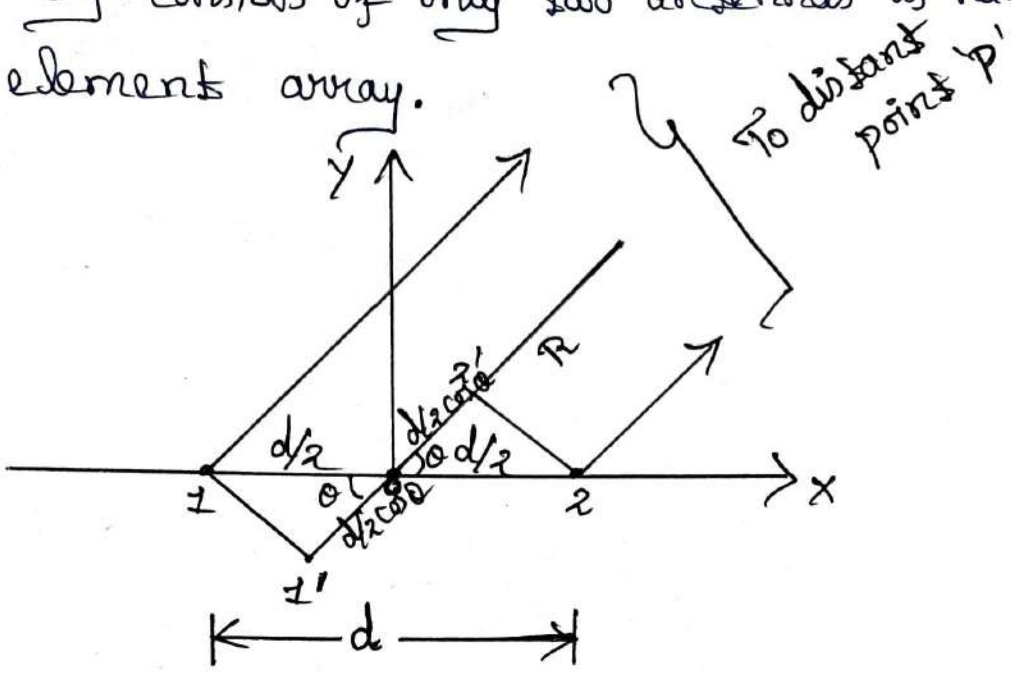

Fig: Two Element Array

An antenna is considered as point source or volumeless radiator. An antenna which occupies zero volume is considered as point source.

Assume that two point sources (two antennas) are separated by a distance 'd' and have the same polarization.

Two point sources (antennas) are symmetrically situated with respect to the origin in the cartesian coordinate system.

Now we have to calculate fields at a distant point 'P' at distance 'R' from the origin 'O'. Origin is taken as reference point for phase calculation.

The waves from source 1 reaches the point 'P' at a latter time than the waves from source 2 because of path difference (1'2') between the two waves.

Thus the fields due to source 1 lags while that due to source 2 leads.

Path Difference = 1'2' meters

$$= \left[\frac{d}{2}\cos\theta + \frac{d}{2}\cos\theta\right] m$$

$$= d\cos\theta \ m$$

Interms of wavelength,

Path Difference = $\frac{d}{\lambda}\cos\theta$ wavelengths

Phase angle, $\psi = 2\pi \times$ path difference

$$= 2\pi \times \frac{d}{\lambda}\cos\theta, \text{ radians}$$

$$= \frac{2\pi}{\lambda} d\cos\theta, \text{ radians}$$

$$\boxed{\psi = \beta d\cos\theta, \text{ radians}} \quad \left[\because \beta = \frac{2\pi}{\lambda}\right]$$

N Element Linear Array

Antenna array is defined as, a radiating system consisting of several spaced and properly phased radiators. The total field produced by an antenna array system is the vector sum of the fields produced by the individual antennas of the array system.

Antenna array is said to be linear, if the individu antennas of the array are equally spaced along a straight line.

A uniform linear array is one, in which the elements are fed with a current of equal magnitude with uniform progressive phase shift along the line.

At higher frequencies, for point to point communications it is necessary to have a pattern with single beam radiation. Such highly directive single beam pattern can be obtained by increasing the point sources.

Consider a linear array of n-isotropic point sources in which point sources are spaced equally and are fed with in-phase currents of equal amplitude.

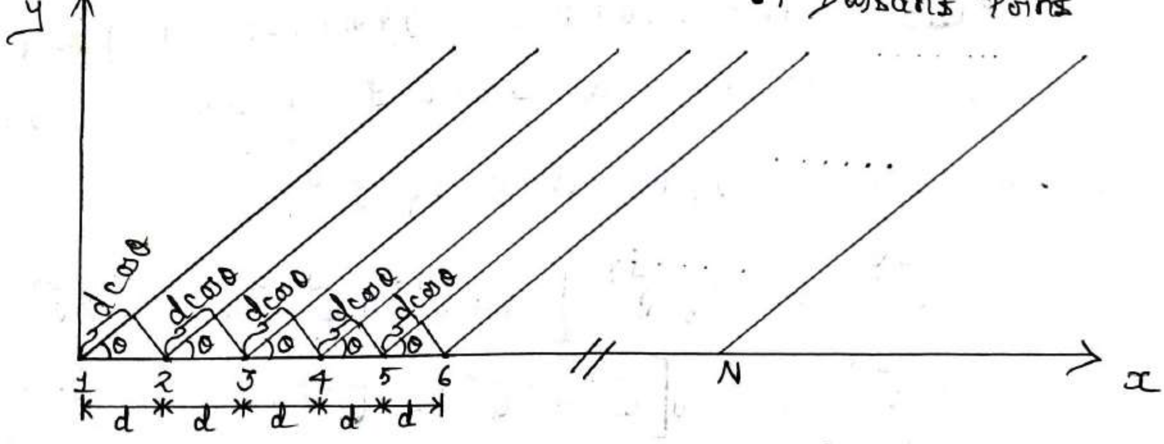

Fig: Linear array with n-isotropic point sources

Subtracting equation (2) from (1)

where,

d - distance between adjacent point sources

E_0 - amplitude of each point source

P - distant point

The total field at a distant point P is obtained by adding the fields due to individual sources vectorially.

$$\text{Total Field, } E_t = E_0 e^{0j\psi} + E_0 e^{j\psi} + E_0 e^{2j\psi} + E_0 e^{3j\psi} + \cdots + E_0 e^{j(n-1)\psi}$$

$$E_t = E_0 \left[1 + e^{j\psi} + e^{2j\psi} + e^{3j\psi} + \cdots + e^{j(n-1)\psi} \right] \rightarrow (1)$$

where,

ψ - total phase difference of the fields at point 'P' from adjacent sources

$\psi = (\beta d \cos\theta + \alpha)$ radian

α - phase difference in adjacent point sources

Assume,

- * source 1 is a phase reference
- * field from source 2 is advanced in phase with respect to source 1 by ψ
- * field from source 3 is advanced in phase with respect to source 1 by 2ψ
- * field from source 4 is advanced in phase with respect to source 1 by 3ψ, ... etc...

By multiplying equation (1) by $e^{j\psi}$,

$$E_t e^{j\psi} = E_0 e^{j\psi} \left[1 + e^{j\psi} + e^{j2\psi} + \cdots + e^{j(n-1)\psi} \right]$$

$$E_t e^{j\psi} = E_0 \left[e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \cdots + e^{jn\psi} \right] \rightarrow (2)$$

Subtracting equation (2) from (1),

$$E_t - E_t e^{j\psi} = E_0\left[1+e^{j\psi}+e^{j2\psi}+\cdots+e^{j(n-1)\psi}\right]$$

$$- E_0\left[e^{j\psi}+e^{j2\psi}+\cdots+e^{jn\psi}\right]$$

$$E_t\left[1-e^{j\psi}\right] = E_0\left[1-e^{jn\psi}\right] \longrightarrow (3)$$

$$\Rightarrow \quad E_t = E_0\,\frac{\left[1-e^{jn\psi}\right]}{\left[1-e^{j\psi}\right]}$$

$$= E_0\left[\frac{1-e^{jn(\psi/2+\psi/2)}}{1-e^{j(\psi/2+\psi/2)}}\right]$$

$$= E_0\left\{\frac{1-e^{jn\psi/2}\cdot e^{jn\psi/2}}{1-e^{j\psi/2}\cdot e^{j\psi/2}}\right\}$$

$$= E_0\,\frac{e^{jn\psi/2}}{e^{j\psi/2}}\left[\frac{e^{-jn\psi/2}-e^{jn\psi/2}}{e^{-j\psi/2}-e^{j\psi/2}}\right]$$

$$= E_0\,e^{jn\psi/2}\cdot e^{-j\psi/2}\left\{\frac{\cancel{-}\left[e^{jn\psi/2}-e^{-jn\psi/2}\right]}{\cancel{-}\left[e^{j\psi/2}-e^{-j\psi/2}\right]}\right\}$$

$$E_t = E_0\,e^{j(n-1)\psi/2}\left[\frac{\cancel{2j}\sin n\psi/2}{\cancel{2j}\sin\psi/2}\right] \longrightarrow (4)$$

$$E_t = E_0\,e^{j\phi}\,\frac{\sin n\psi/2}{\sin\psi/2} \longrightarrow (5)$$

where,

$$\phi = \frac{(n-1)\psi}{2}, \qquad \frac{e^{j\theta}-e^{-j\theta}}{2j} = \sin\theta$$

$$e^{j\phi} = \cancel{\phi} = \cos\phi + j\sin\phi \qquad \Rightarrow e^{j\theta}-e^{-j\theta} = 2j\sin\theta$$

$$E_t = E_0 \frac{\sin n\psi/2}{\sin \psi/2}\left[\cos\phi + j\sin\phi\right] \longrightarrow (6)$$

$$\boxed{E_t = E_0 \frac{\sin n\psi/2}{\sin\psi/2} \angle\phi} \longrightarrow (7)$$

↳ this is the equation of total field of linear array of n-isotropic point sources.

If the reference point (source 1) is shifted to the centre of the array from the source or origin of the coordinate, then phase angle ϕ is automatically eliminated.

→ now equation (7) reduces to,

$$E_t = E_0 \frac{\sin n\psi/2}{\sin\psi/2} \longrightarrow (8)$$

$$\Rightarrow \boxed{\frac{E_t}{E_0} = \frac{\sin n\psi/2}{\sin\psi/2}} \longrightarrow (9)$$

↳ this ratio is called as antenna array factor.

⇒ for $\psi = 0$,

Equation (8) becomes indeterminant.

ie., $E_t = E_0 \frac{\sin 0}{\sin 0} = \frac{0}{0}$ indeterminant

→ to evaluate the function L-hospital rule is applied.

→ separately differentiate the numerator and denominator under the limit when $\psi = 0$

$$\lim_{\psi\to 0} E_t = E_0\left\{\lim_{\psi\to 0}\frac{d}{d\psi}\left(\sin n\psi/2\right) \Big/ \lim_{\psi\to 0}\frac{d}{d\psi}\left(\sin\psi/2\right)\right\}$$

$$= E_0 \frac{\lim\limits_{\psi \to 0} \frac{n}{2} \cos n\psi/2}{\lim\limits_{\psi \to 0} \frac{1}{2} \cos \psi/2}$$

$$= E_0 \frac{\frac{n}{2} \cos 0}{\frac{1}{2} \cos 0} = E_0 \frac{n}{\cancel{2}} \cdot \frac{\cancel{2}}{1}$$

$$E_{t\,max} = E_0 n \qquad [\because \cos 0 = 1]$$

$$\Rightarrow \quad E_{t\,max} = nE_0 \longrightarrow (10)$$

Thus the maximum value of E_t is 'n' times the field from a single source.

For normalization, E_0 is considered to be unity.

$$E_{t\,max} = n \longrightarrow (11)$$

The normalized field pattern is obtained as,

$$E_{norm} = \frac{E_t}{E_{t\,max}} = \frac{\cancel{E_0} \frac{\sin n\psi/2}{\sin \psi/2}}{\cancel{E_0}\, n}$$

$$E_{norm} = \frac{\sin n\psi/2}{n \sin \psi/2} = (\text{Array Factor})_n$$

The factor by which the array increases the field strength over that of a single element radiating the same total power is called as array factor.

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Pattern Multiplication

The total field pattern of an array of non-isotropic but similar sources is the multiplication of the individual source patterns.

The total phase pattern is the addition of the phase pattern of the individual sources and that of the array of isotropic point sources.

→ the pattern of the individual sources is assumed to be same whether it is in the array or isolated

→ the reference point for total phase pattern is the phase centre of the array

→ multiplication pattern is applicable for two and three dimensional patterns

The total field pattern of an array of non-isotropic but similar source is,

$$E = \{E_i(\theta, \phi) \times E_a(\theta, \phi)\} \times \{E_{pi}(\theta, \phi) + E_{pa}(\theta, \phi)\}$$

E = Multiflication of Field Pattern × Addition of phase pattern

where,

E - total field

$E_i(\theta, \phi)$ - Field pattern of individual source

$E_a(\theta, \phi)$ - Field pattern of array of isotropic point sources

$E_{pi}(\theta, \phi)$ - Phase pattern of individual source

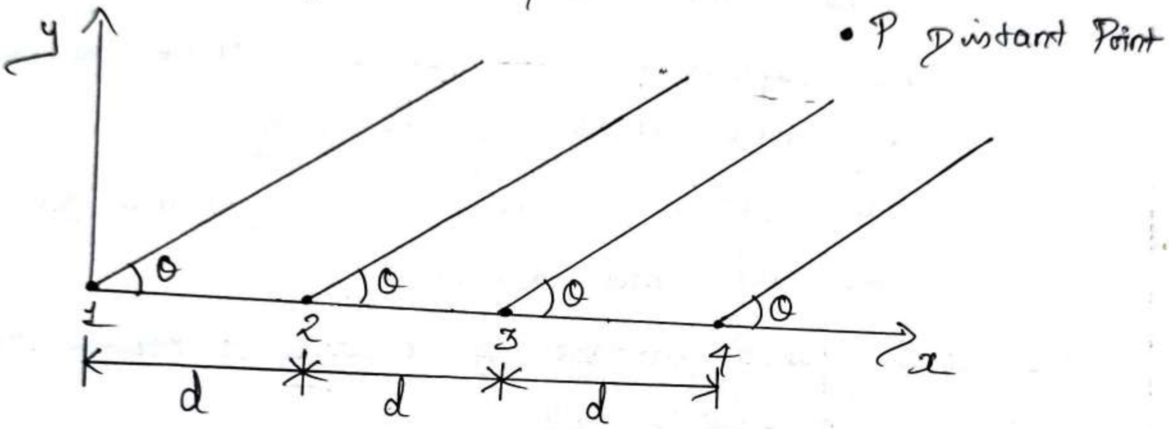
$E_{pa}(\theta, \phi)$ - Phase pattern of array of isotropic point sources

* elimination of secon

This principle may be applied to any number of sources provided that they are similar.

Ex: Radiation Pattern of 4 isotropic elements fed in phase, spaced $\lambda/2$ apart.

* let the 4 elements of isotropic radiators in a linear array
* elements are placed at a distance of $\lambda/2$
* elements are fed in phase



→ two ways are available to get the radiation pattern

1. to get the radiation pattern of the array is to add the fields of individual four elements at a distant point 'P' vectorially.
2. uses the principle of multiplicity of pattern to get the radiation pattern

* two isotropic point sources, spaced $\lambda/2$ apart fed inphase provides a bidirectional pattern

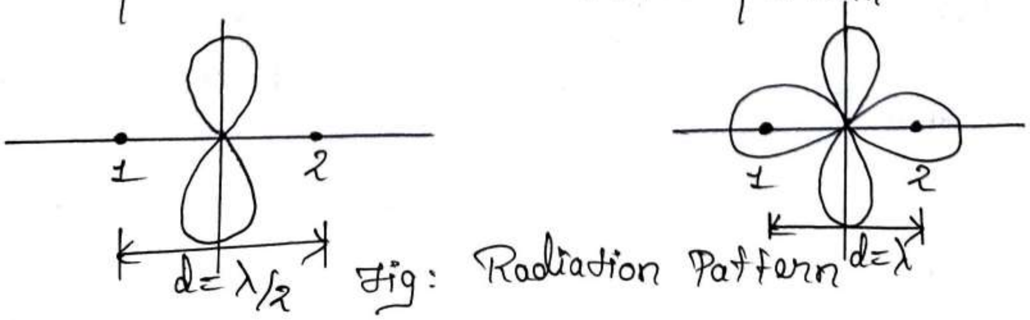


Fig: Radiation Pattern

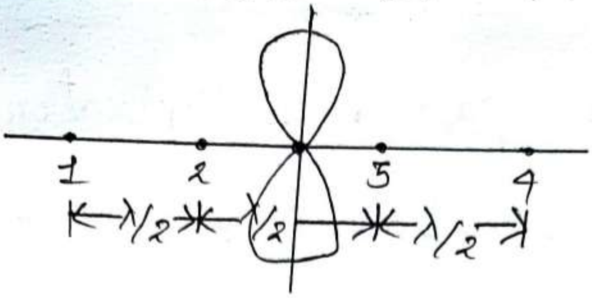
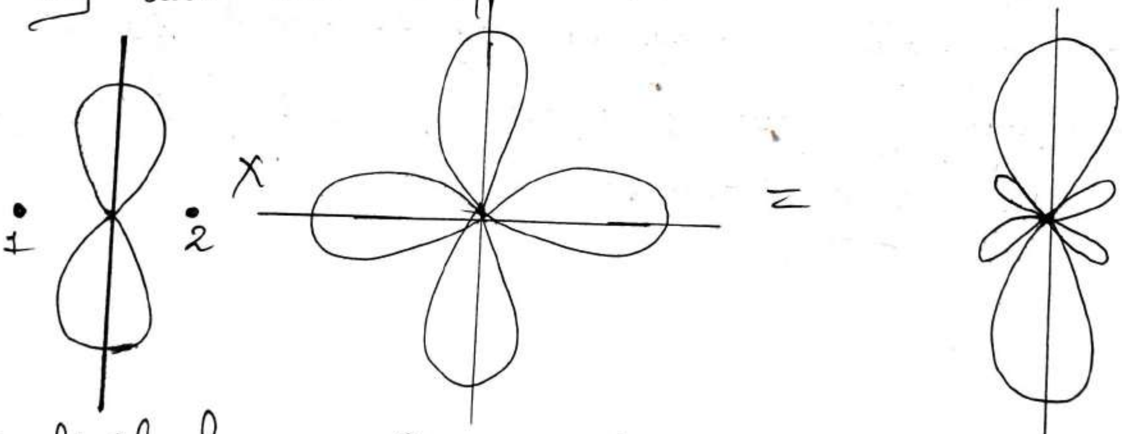


Fig: Radiation Pattern of 4 isotropic elements

- elements 1 & 2 are considered as one unit [unit 1]
- this unit is placed between the midway of the elements.

- elements 3 & 4 are considered as one unit [unit 2]
- this unit is placed between the two elements
- thus 4 elements spaced λ/2 have been replaced by two units spaced λ.



Individual [two individual elements]

Group pattern [array of 2 isotropic]

Resultant pattern of four isotropic elements

Fig: Resultant radiation pattern of 4 Isotropic Elements by pattern multiplication

Broadside Array

According to pattern multiplication, the radiation pattern of 4 element is obtained by multiplying the radiation pattern of individual element and array of two units spaced λ.

Advantages

1. Provides a speedy method for sketching the pattern of complicated arrays.
2. Useful tool in design of antenna arrays.
3. Width of principle lobe and the corresponding width of array pattern are same.
4. Secondary lobes are determined from the number of nulls in the resultant pattern
5. Number of nulls in the resultant pattern are equal to sum of nulls of individual pattern and array pattern.

Broadside Array

Broadside array is one in which number of identical parallel antennas are set up along a line drawn perpendicular to their respective axes.

An array is said to be broadside array if the direction of maximum radiation is perpendicular to the array axis.

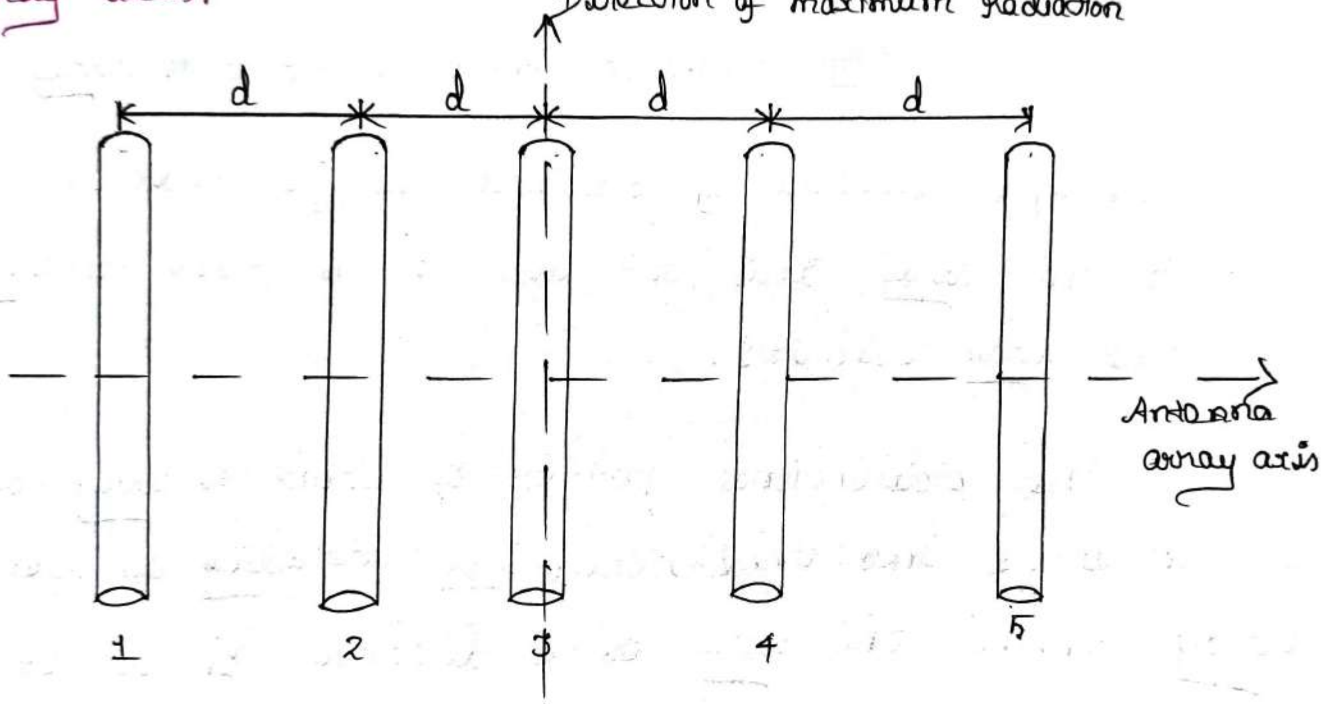


Fig: Broadside Array Arrangement

* individual antennas are equally spaced along a line
* each element is fed with current of equal magnitude and all in the same phase
* maximum radiation - perpendicular to the array axis
* minimum radiation - other direction
* radiation pattern - bidirectional
* radiates equally well in either direction of maximum radiation

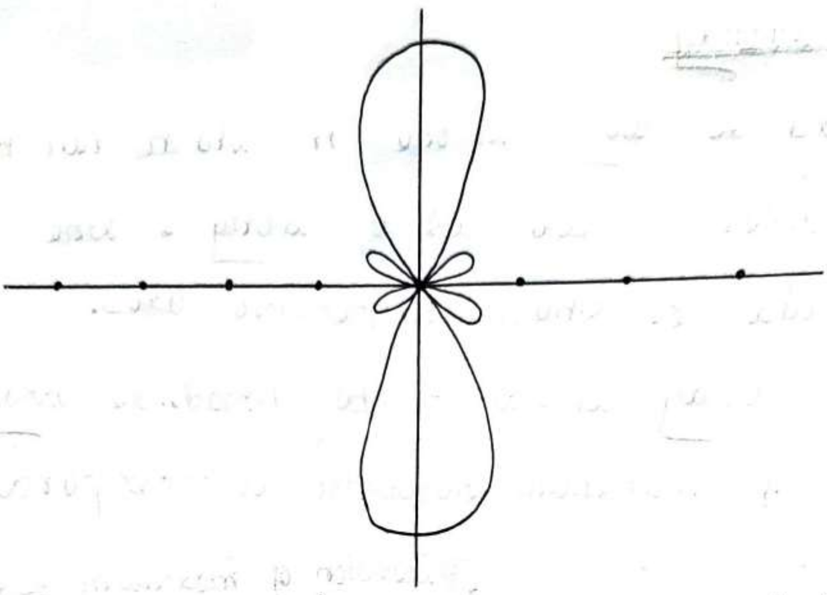


Fig: Radiation Pattern of Broadside Array

* principal direction of radiation is perpendicular to the array axis and also to the plane containing the array element.

The bidirectional pattern of broadside array can be converted into unidirectional by installing an identical array behind this array at a distance $\lambda/4$ and exciting it by a current leading in phase by 90° or $\pi/2$ radians.

End Fire Array

End fire array is one in which number of identical parallel antennas are set up along a line drawn perpendicular to their respective axes.

An array is said to be end fire array if the direction of maximum radiation is coincide with the array axis.

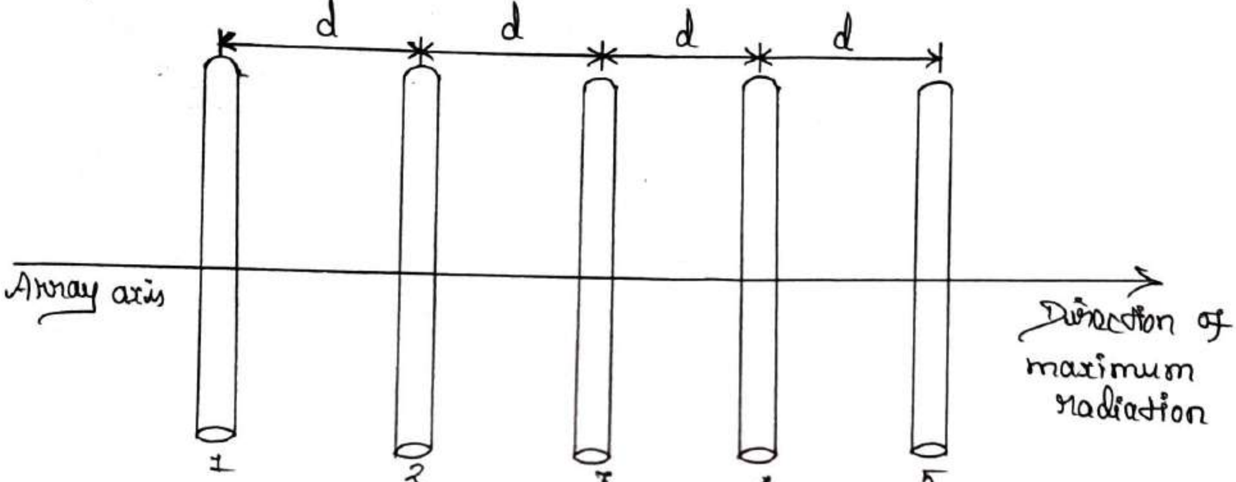


Fig: End Fire Array Arrangement

- individual antennas are equally spaced along a line
- each element is fed with current of equal amplitude but their phases varies progressively along the line
- ie., individual elements are fed in, out of phase (180°)
- phase difference between adjacent elements becomes equal to the spacing between the elements

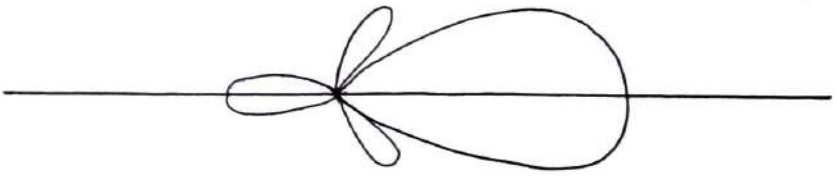


Fig: Radiation Pattern of End Fire Array [illegible] secondary lobes takes place

- * principal direction of radiation coincides with the direction of array axis
- * radiation pattern - unidirectional
- * maximum radiation - parallel to the array axis
- * minimum radiation - other direction

The end fire array may be bidirectional.

lobes takes place

Phased Array

Assume,

- → that maximum radiation can be oriented in any direction to form a scanning array
- → that maximum radiation of the array is required to be oriented at an angle θ_0
  where θ_0 lies between, $0 \le \theta_0 \le 180°$
- → to achieve this phase excitation α between the element must be adjusted

$$\Rightarrow \psi = \beta d \cos\theta + \alpha \Big|_{\theta=\theta_0}$$

$$= \beta d \cos\theta_0 + \alpha = 0$$

$$\Longrightarrow \alpha = -\beta d \cos\theta_0$$

Thus by controlling the progressive phase difference between the elements, the maximum radiation can be squinted in any desired direction to form a phased array.

In phased arrays,

- * electronic scanning is necessary
- * scanning must be continuous
- * system should be capable of continuously varying the progressive phase between the elements.
- * phased arrays also called as scanning arrays

* scanning is accomplished electronically by the use of ferrite or diode phase shifters.

For Ferrite Phase shifters,

* phase shift is controlled by the magnetic field within the ferrite
* phase shift is controlled by the amount of current flowing through the wires wrapped around the phase shifter.

For Diode Phase shifters,

* phase shift is controlled by varying the analog bias dc voltage (0-30 volts)
* phase shift is controlled by varying a digital command through a digital to analog (D/A) converter.

Adaptive Arrays

When an antenna array is in transmission, it should produce a beam in predetermined directions. When it is a receiving antenna, these antenna arrays look in a given direction regardless of whether any signals are arriving in that direction or not.

However, by processing the signals from the individual elements, an array can become active and reacts intelligently to its environment, steering its beam toward a desired signal and Null toward an undesired interfering signal. This is done for maximizing the signal to noise ratio of the desired signal. This type of arrays are called as adaptive arrays.

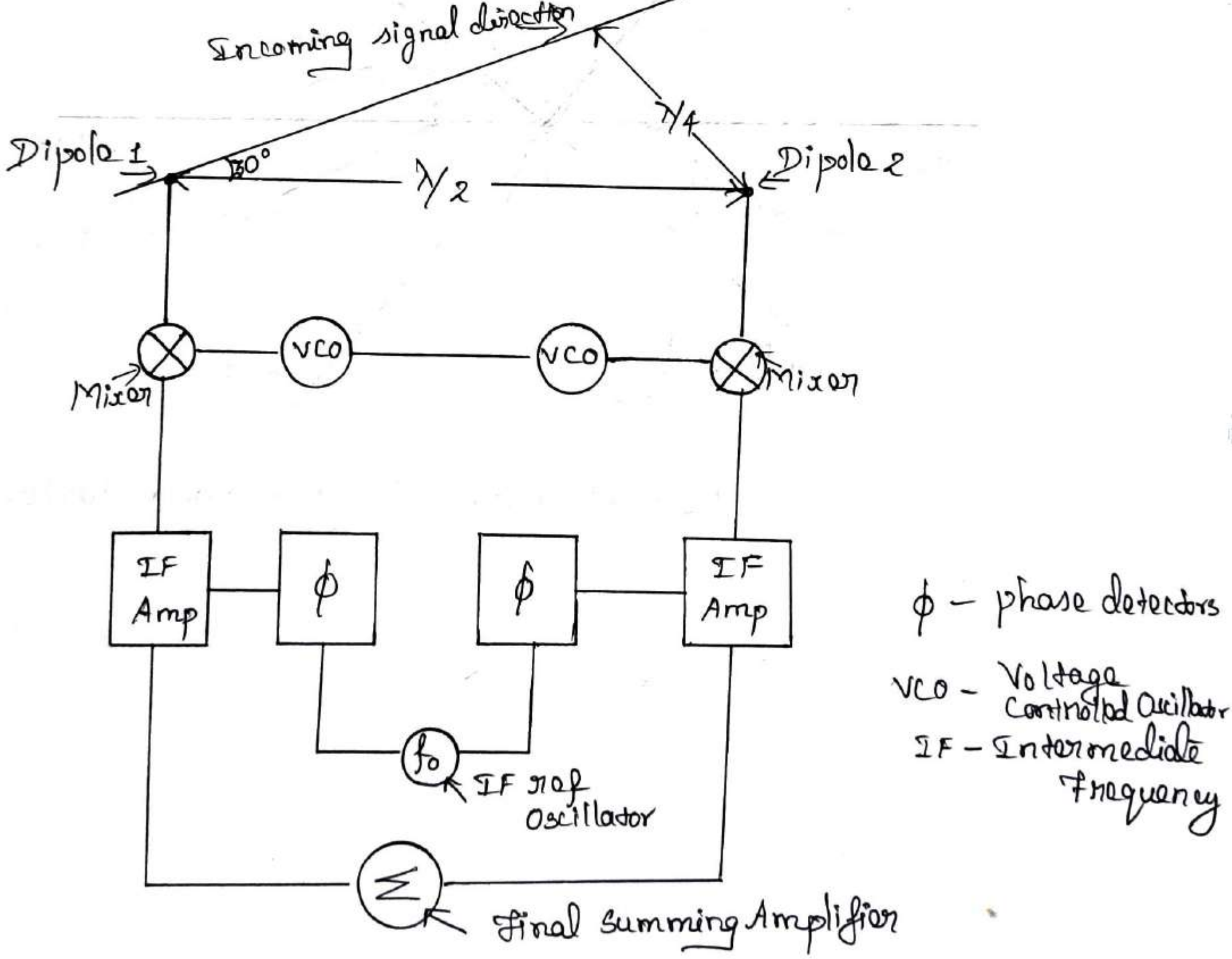


Fig: Two Element Adaptive Array

* spacing between the dipole element is $\lambda/2$

* each dipole element equipped with its own mixer, VCO, IF amp & phase detector

By suitable signal processing, performance of adaptive arrays further enhanced giving simulated patterns of higher resolution and lower side lobes in addition to appropriate sampling and digitizing the signals at the terminals of each element and processing then with a computer. This type of antenna is known as smart antenna.

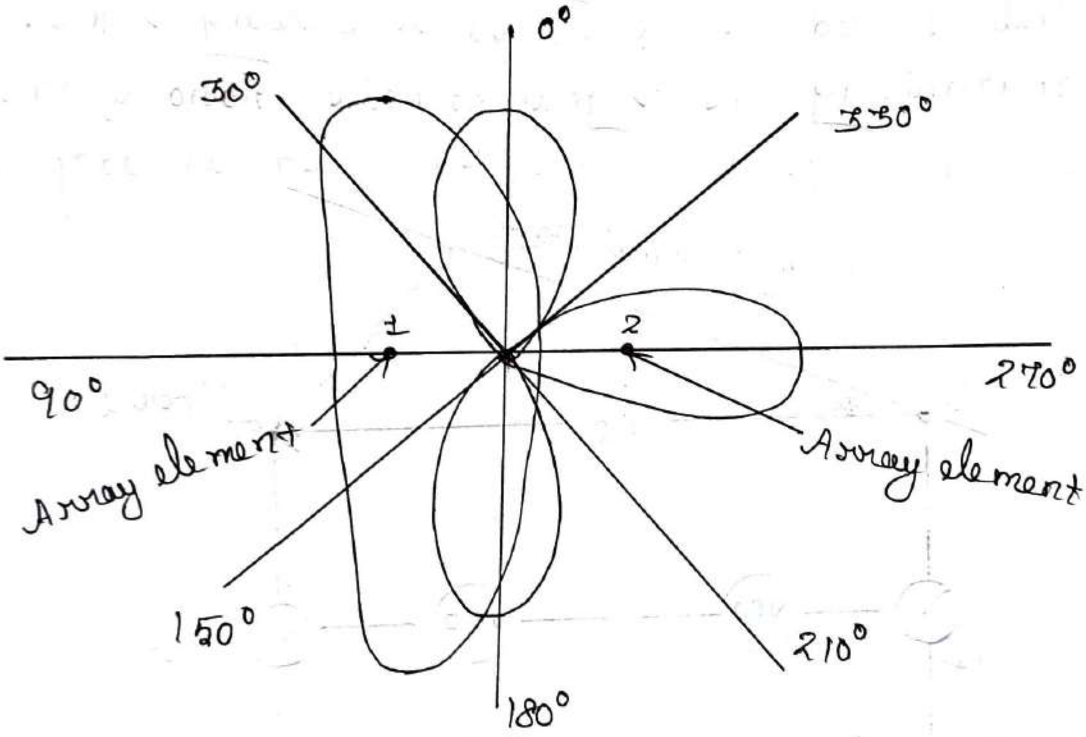


Fig: Adaptive Array Radiation Pattern

Basic Principle of Antenna Synthesis

Antenna analysis determines the radiation pattern for a given input distribution. Antenna synthesis is the inverse process. In antenna synthesis, input or source distribution is determined for a specified radiation pattern.

In the analysis problem an antenna model is chosen and it is analyzed for its radiation characteristics, such as pattern, directivity, impedance, beamwidth, efficiency, polarization and bandwidth. This is accomplished by initially specifying the current distribution of the antenna and then analysing it using standard procedures.

In practice, it is necessary to design an antenna system that will yield desired radiation characteristics. For example, a common request is to design an antenna whose far-field pattern possesses nulls in certain directions. Other common requests are for the pattern to exhibit a desired distribution, narrow beam width, low side lobes, decaying minor lobes and so forth. The task, in general, is to find not only the antenna configuration but also its geometrical dimensions and excitation distribution. The designed system should yield, either exactly or approximately, an acceptable radiation pattern and it should satisfy other system constraints. This method of design is referred to as synthesis. It is also referred to as antenna pattern synthesis.

Antenna pattern synthesis requires,

- an approximate analytical model is chosen to represent, either exactly or approximately, the desired pattern.
- to realize the analytical model by an antenna model.

→ Antenna pattern synthesis classified into three categories.

I Category

- requires that the antenna patterns possess nulls in desired directions
- accomplished using the Schelkunoff method

II Category

- requires that the patterns exhibit a desired distribution in the entire visible region
- accomplished using the Fourier transform and the Woodward - Lawson methods

III Category

- includes techniques that produce patterns with narrow beams and low side lobes
- accomplished using Binomial method and the Dolph - Tschebyscheff method

The synthesis methods will be utilized to design line sources and linear arrays whose space factors and array factors will yield desired far-field radiation patterns.

Binomial Array

Binomial array – linear array of n-isotropic sources of non-uniform amplitudes

In a uniform linear array, to increase the directivity, the array length has to be increased. But when the array length increases, the secondary or side lobes appear in the pattern. For special applications, it is desired to have single main lobe with no minor lobes.

To reduce the side lobes (or minor lobes), the amplitudes of the radiating sources are arranged according to the co-efficients of successive terms of the binomial series.

i.e., radiating sources have amplitudes proportional to the co-efficients of the binomial series

The binomial series,

$$(a+b)^{n-1} = a^{n-1} + (n-1)a^{n-2}b + \frac{(n-1)(n-2)}{2!}a^{n-3}b^{2} + \cdots$$

where,

n – number of sources

The array is arranged in such a way that radiating sources in the centre of the broadside array radiated more strongly than the radiating sources at the edges.

Conditions

1. Spacing between the two consecutive radiating sources does not exceed $\lambda/2$
2. The current amplitudes in radiating sources are proportional to the coefficients of the successive terms of the binomial series.

Ex: Arrays of 1 to 10 radiating sources

Number of sources	Relative Amplitude
n = 1	1
n = 2	1 1
n = 3	1 2 1
n = 4	1 3 3 1
n = 5	1 4 6 4 1
n = 6	1 5 10 10 5 1
n = 7	1 6 15 20 15 6 1
n = 8	1 7 21 35 35 21 7 1
n = 9	1 8 28 56 70 56 28 8 1
n = 10	1 9 36 84 126 126 84 36 9 1

* co-efficients for any number of radiating sources can be obtained from Pascal's triangle

→ In Pascal's triangle – internal integer is the sum of the above adjacent integers

1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
1 5 10 10 5 1
1 6 15 20 15 6 1
1 7 21 35 35 21 7 1
1 8 28 56 70 56 28 8 1
1 9 36 84 126 126 84 36 9 1

Fig: Pascal's Triangle

- elimination of secondary lobes takes place at the cost of directivity
- Half Power Beam Width (HPBW) of Binomial array is more than that of uniform array for the same length of the array
- In uniform array secondary lobes appear but principal lobe is sharp and narrow
- In Binomial array width of beam widens but without secondary lobes.

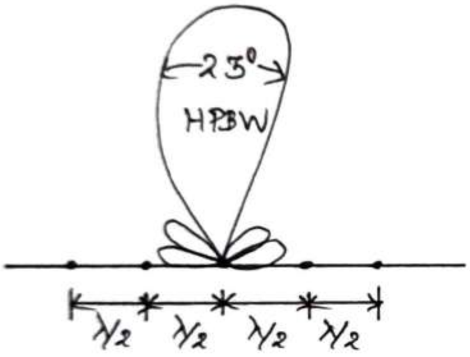


Fig: Uniform Array

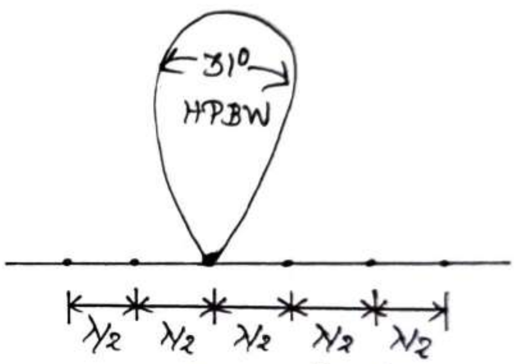


Fig: Binomial Array
[Amplitude ratio 1:4:6:4:1]

Disadvantages

1. HPBW increases and hence the directivity decreases
2. For design of a large array, larger amplitude ratio of sources is required.

UNIT - IV

Praise the Lord

MICROWAVE PASSIVE COMPONENTS

Directional Coupler

Directional coupler is a four port passive device used for coupling a known fraction of the microwave power to a port in the auxiliary line while flowing from input port to output port in the main line. The remaining port is ideally isolated port and matched terminated. Here, portions of the forward and reverse travelling waves on a line are separately coupled to two of the other ports.

Directional coupler can be designed to measure incident power, reflected power, SWR values, provide a signal path to a receiver or perform other desirable operations.

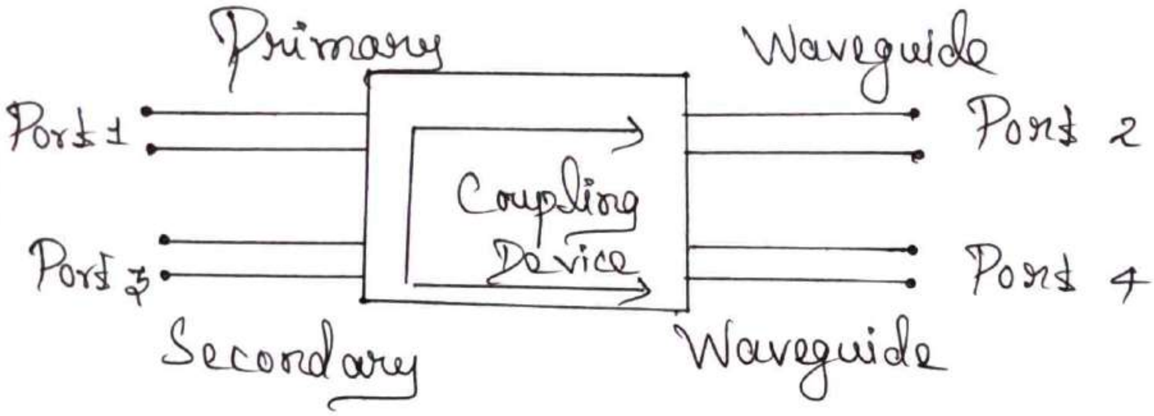


Fig: Schematic Diagram

Directional coupler can be unidirectional or bidirectional.

Unidirectional – measuring only incident power

Bi-directional – measuring both incident and reflected power

Properties

* Portion of power travelling from port 1 to port 2 is coupled to port 4 but not to port 3
* Portion of power travelling from port 2 to port 1 is coupled to port 3 but not to port 4
* Portion of power incident on port 3 is coupled to port 2 but not to port 1

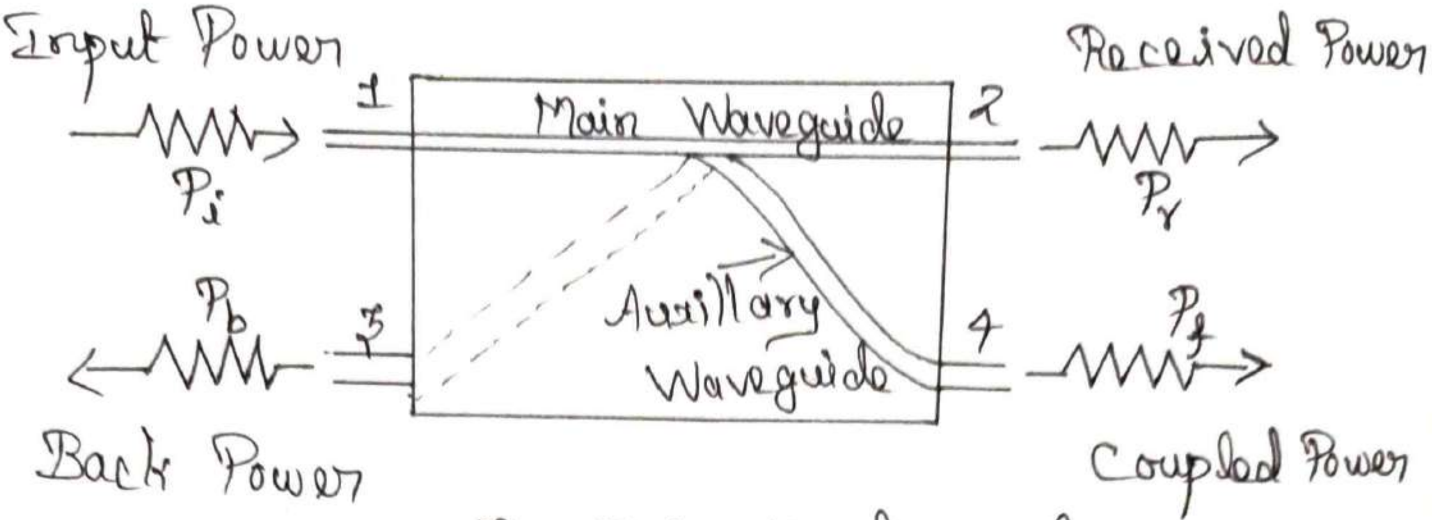


Fig: Directional Coupler Indicating Powers

where,

P_1 or P_i - Incident Power at port 1

P_2 or P_r - Received Power at port 2

P_3 or P_b - Back Power at Port 3

P_4 or P_f - Forward Coupled Power at Port 4

and a portion of the power incident on port 4 is coupled to port 1 but not to port 2. Also ports 1 and 3 are decoupled as port 2 and port 4.

Power Divider

Power divider is a passive microwave component which is used for power division as well as power combining in the microwave system.

Power dividers are used to divide the input power into a number of smaller amounts of power and the number of smaller amounts of input powers are combined to form a large output power which also act as power combiner.

Power divider may have three ports, four ports or more and may be lossless. Three port power divider can be a T-junctions while four port networks can be direction couplers, circulators and hybrids (Magic-T).

Three Port Power Divider

A simple power divider is a T-junction network. If three port T-junction is act as power divider, the port 1 ~~is~~ act as input po and ports 2 and 3 are act as an output port

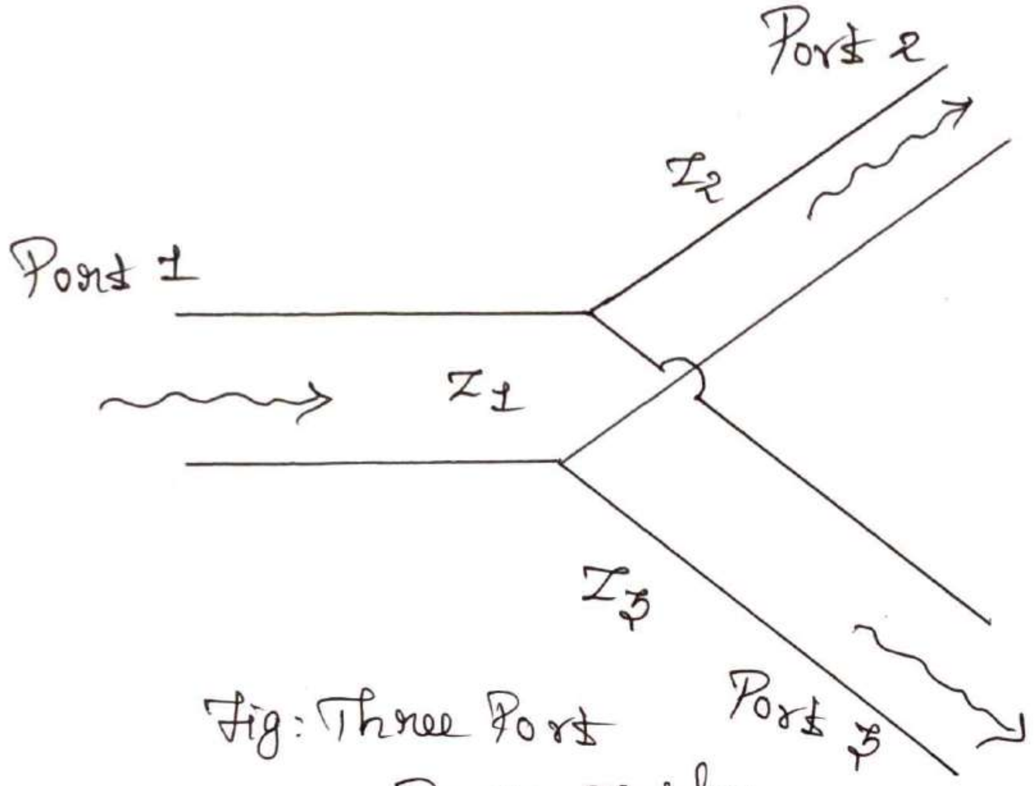


Fig: Three Port Power Divider

The power is divided among the ports equally and it is expressed in lossless as,

Input Power = Output Power

i.e., $P_1 = P_2 + P_3$

When used as power combiner, the port 1 is act as output port and port 2 and 3 are act as input ports and it is expressed as

$$P_2 + P_3 = P_1$$

The scattering matrix for an arbitrary three port network is,

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

For a lossless, reciprocal three port junction where all three ports can be perfectly matched, then $S_{11} = S_{22} = S_{33} = 0$ and its scattering matrix will be symmetric $(S_{ij} = S_{ji})$.

Now the scattering matrix becomes,

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

$|||^{ly}$ The scattering matrix for an arbitrary four port network is,

↓
Directional coupler

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

If all the ports are perfectly matched, then diagonal elements are zero.

$$\therefore S_{11} = S_{22} = S_{33} \; S_{44} = 0$$

$$\therefore [S] = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{21} & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

Applications

* Used in the radiating elements of an array antenna.
* Used in the balanced amplifiers both as power divider and power combiner.

Magic Tee [Hybrid-T or E-H Plane Tee or Magic-T]

Magic Tee is a four port passive device, in which a signal incident on any one of the port divides between two output ports with the remaining port being isolated.

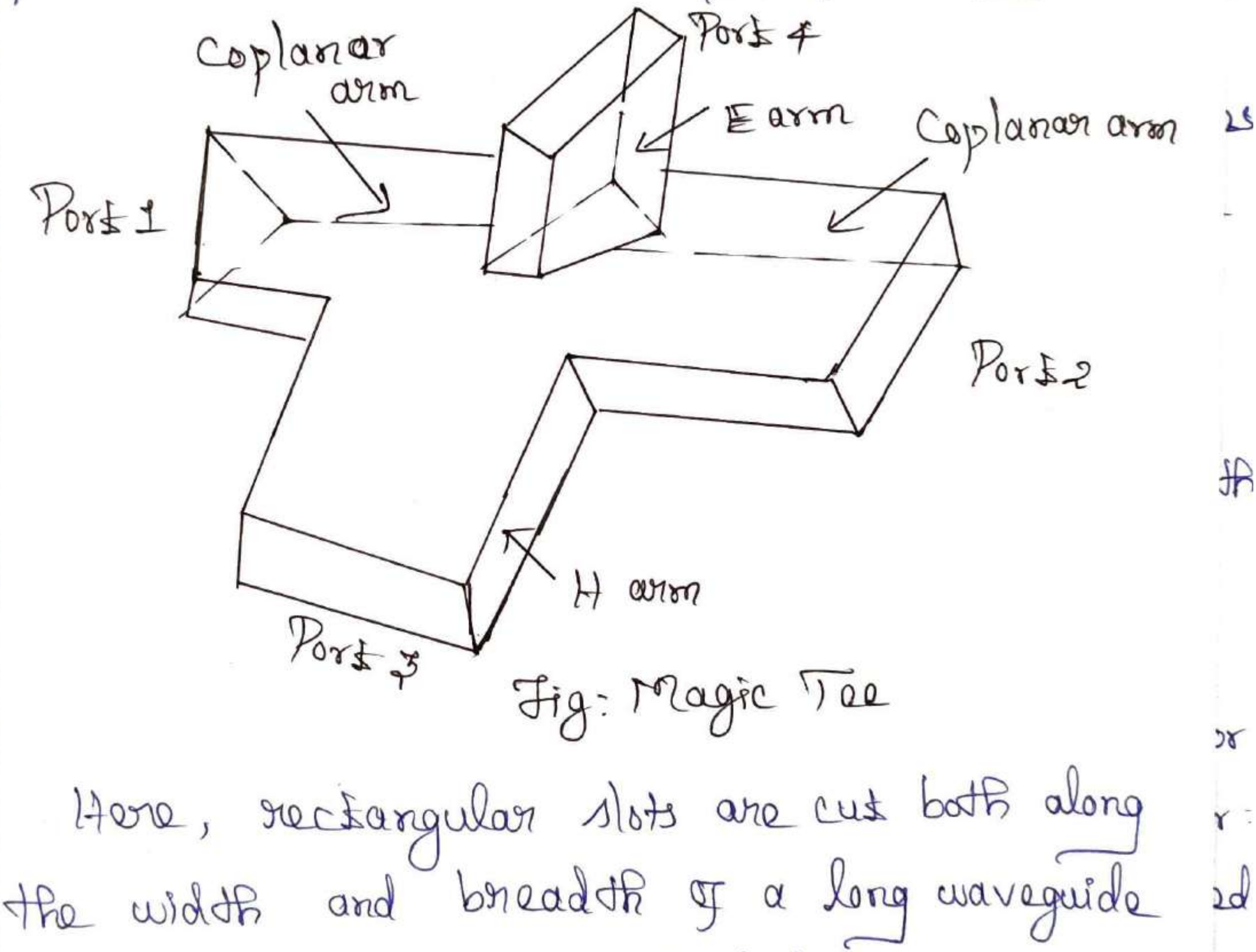


Fig: Magic Tee

Here, rectangular slots are cut both along the width and breadth of a long waveguide and side arms are attached. Magic Tee is a combination of the E-plane Tee and H-plane Tee. Ports 1 and 2 are colinear arms, and port 3 is the H-arm, and port 4 is the E-arm.

characteristics

- If two in phase waves of equal magnitude are fed into ports 1 and 2, the output at port 4 is subtractive and hence zero and the total output will appear additively at port 3. Hence, port 4 is called the difference or E-arm and port 3 is the sum or H-arm.

- A wave incident at port 4 (E-arm) divides equally between ports 1 and 2 but opposite in phase with no coupling port 3 (H-arm).

- A wave incident at port 3 (H-arm) divides equally between ports 1 and 2 are in phase with no coupling to port 4 (E-arm).

$$S_{43} = S_{34} = 0$$

- A wave (incident) fed into colinear port 1 or 2 will not appear in the other colinear port 2 or 1. Hence, two colinear ports 1 and 2 are isolated from each other.

$$S_{12} = S_{21} = 0$$

- A magic-T can be matched by putting screws suitably in the E and H arms without destroying the symmetry of the junction.

For an ideal, lossless magic-T matched at ports 3 and 4. [Diagonal elements zero]

$$S_{33} = S_{44} = 0$$

Resonator

Resonators are tunable circuits used in microwave oscillators amplifiers, wave meters and filters. At the tuned frequency the circuit resonates where the average energies stored in the electric field (W_e) and magnetic field (W_m) are equal and the circuit impedance becomes purely real.

$\therefore$ Total Energy = Twice the electric energy
or magnetic energy

ie, Total Energy = $2W_e$ or $2W_m$

The frequency at which the energy in the cavity attains maximum value is termed as resonant frequency.

Quality factor is a measure of the frequency selectivity of a cavity.

$$Q = 2\pi \times \frac{\text{Maximum Energy Stored}}{\text{Energy Dissipated per cycle}}$$

Attenuator

Attenuator is a passive device which control the amount of microwave power transferred from one point to another without causing a big distortion to its waveform on a microwave transmission system. In general, attenuator decreasing the power level of a microwave signal.

Attenuators control the flow of microwave power either reflecting it or absorbing it and it is expressed in decibels of relative power.

Attenuator which attenuates the RF signal) in a waveguide system is referred as waveguide attenuator.

Types

1. Fixed Attenuator
2. Variable Attenuator

PRINCIPLES OF MICROWAVE SEMICONDUCTOR DEVICES

Gunn Diode [Gunn Oscillator]

Gunn diode is a form of diode, a two terminal semiconductor electronic component, with negative resistance used in high frequency electronics. It is also known as transferred electron device (TED) or transferred electron oscillator or Gunn Oscillator.

Transferred Electron (Gunn) Effect

Some materials like gallium arsenide (GaAs) exhibit a negative differential mobility when biased above a threshold value of the electric field. The electrons in the lower energy band will be transferred into the higher energy band. The behaviour is called transferred electron effect or Gunn effect and the device is called Gunn Oscillator.

Negative Differential Mobility – a decrease in the carrier velocity with an increase in the electric field.

Working Principle

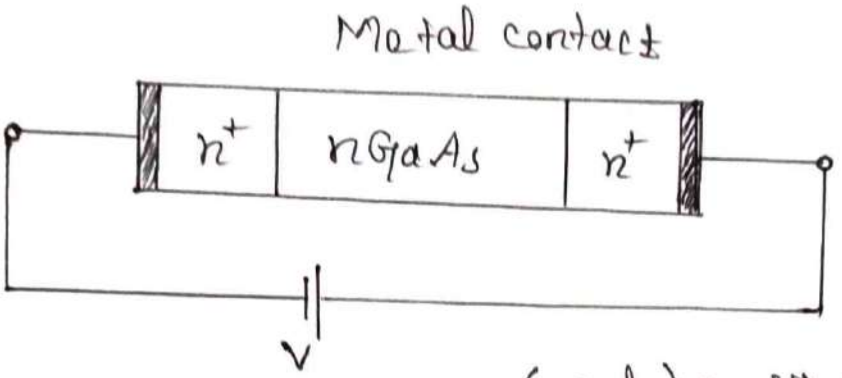


Fig: Gunn (Diode) Oscillator

The basic structure of a Gunn diode consists of n-type GaAs semiconductor with regions of high doping (n^+). Eventhough there is no junction this is called a diode with reference to the +ve end (anode) and -ve end (cathode) of the dc voltage applied across the device.

If a dc voltage / diode voltage /or electric field at low level is applied to the GaAs, an electric field is established across it. Initially, the current will increase with a rise in the voltage. At low E-field in the material, most of the electrons will be located in the lower energy band.

When the diode voltage exceeds a certain threshold value (V_{th}), a high electric field (3.2 KV/m for GaAs) is produced across the active regions and electrons are excited

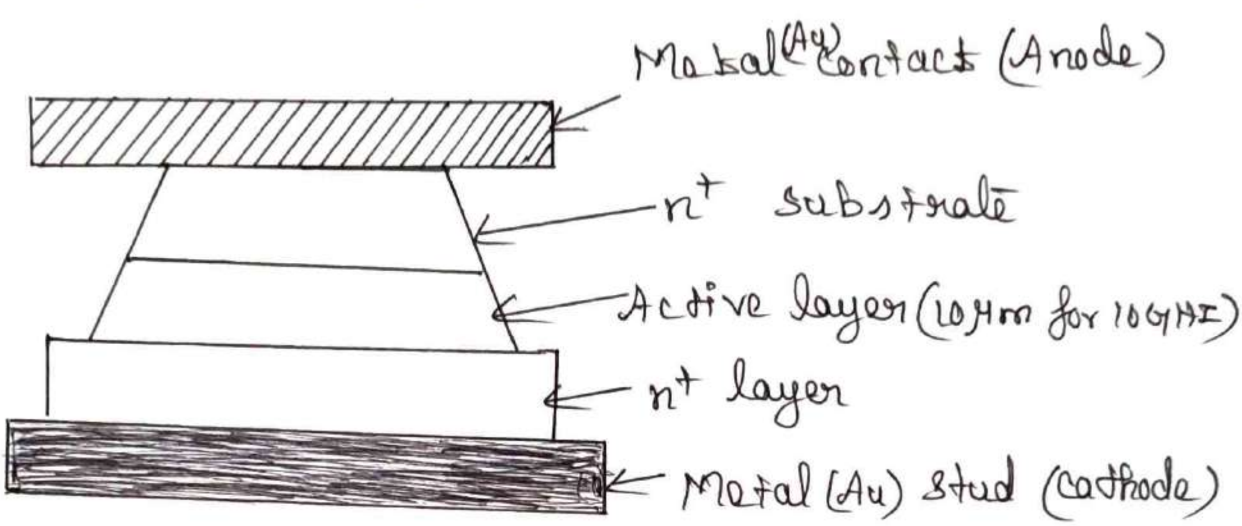


Fig: Construction Gunn Diode

from their initial lower valley to the higher valley where they become virtually immobile. If the rate at which electrons are transferred is very high, the current will decrease an increase in voltage resulting in an equivalent negative resistance effect.

Applications

Gunn diodes are used in,

- Low power oscillator at microwave frequencies
- Local oscillator in receiver front ends
- Parametric amplifiers as pump source
- Radar transmitters
- Broadband microwave amplifiers
- Fast combinational circuits
- Fast sequential circuits
- Low and medium power oscillator in microwave receivers

IMPATT DIODE

IMPATT - Impact Ionization Avalanche Transit Time

Impatt diode is a form of high power semiconductor diode used in high frequency microwave electronic devices. They have negative resistance and are used as oscillators and amplifiers at microwave frequencies. They operate at frequencies of about 3 GHz and 100 GHz or higher.

IMPATT diodes have many forms, n^+pip^+ or p^+nin^+ read device, p^+nn^+ abrupt junction and p^+in^+ diode. These diodes employ impact ionization and transit time properties of semiconductor structure to produce negative resistance at microwave frequencies.

Construction

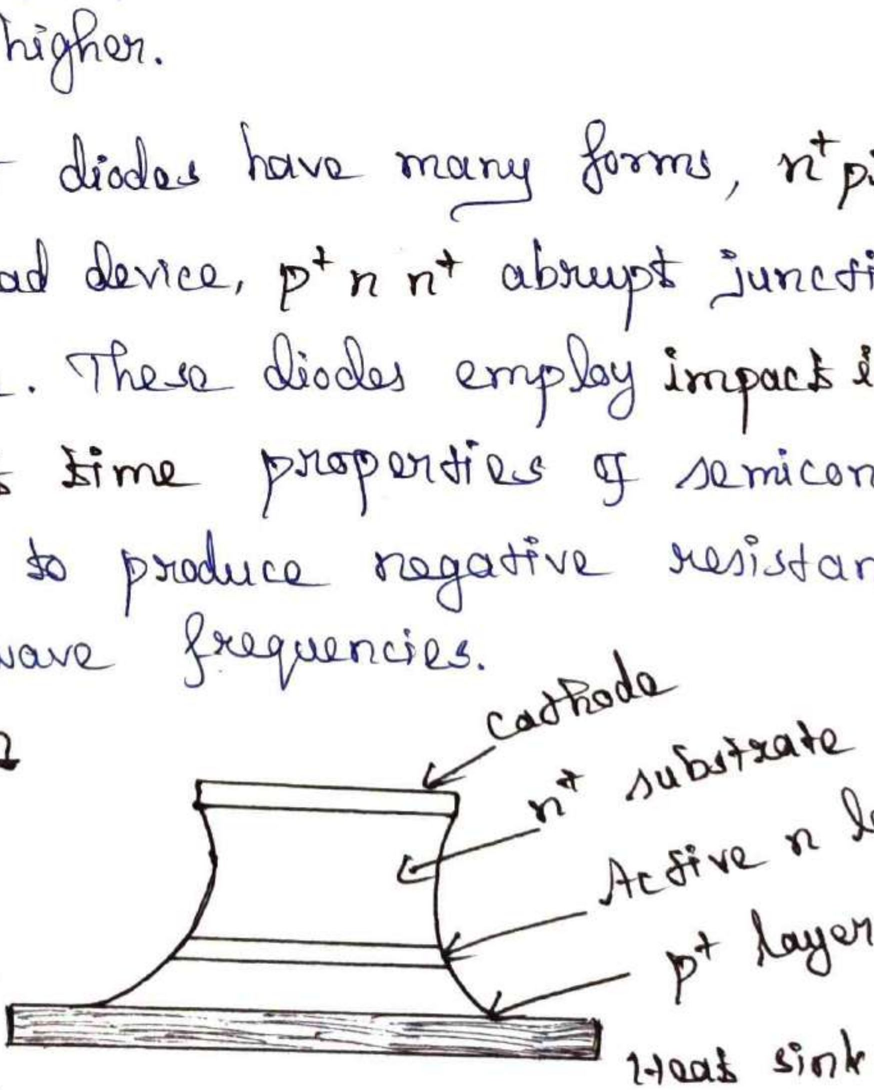


Fig: p^+nn^+ IMPATT Diode

An n-type epitaxial layer is formed over the n^+ substrate. On top of this, is the diffused p^+ layer. A metallised cathod and plated heat sink as anode are also included.

Operation

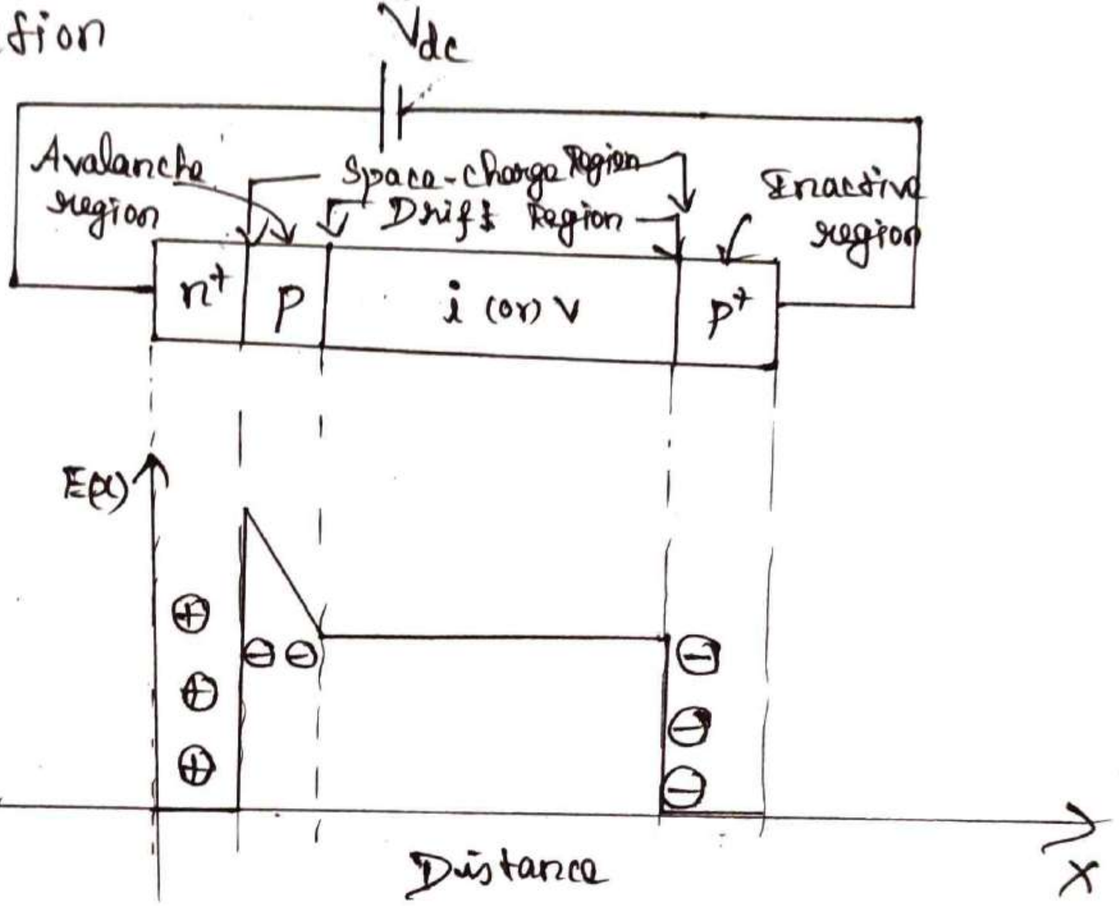


Fig: IMPATT Diode Operation

The thin 'p' region at which avalanche multiplication occurs. This region is also called the high field region or avalanche region.

The 'i' or 'v' region through which the generated holes must drift in moving to the p^+ contact. This region is also called as intrinsic region or drift region.

Advantages

IMPATT diode provides potentially reliable, compact, inexpensive and moderately efficiency microwave power sources.

Disadvantages

- Low efficiency
- It tends to be noisy due to avalanche process
- Requires high level of operating current
- Noise figure is 30dB, which is worse than that of Gunn diodes.

Applications

IMPATT Diode used in,

Microwave Generators
Modulated Output Oscillators
Receiver Local Oscillators
Parametric Amplifier as pumps
Negative resistance amplification

Schottky Barrier Diode (SBD)

Schottkey Barrier Diode is a simple metal semiconductor barrier diode that exhibiting a non-linear impedance. Basically it is an extension of the point contact diode.

Construction

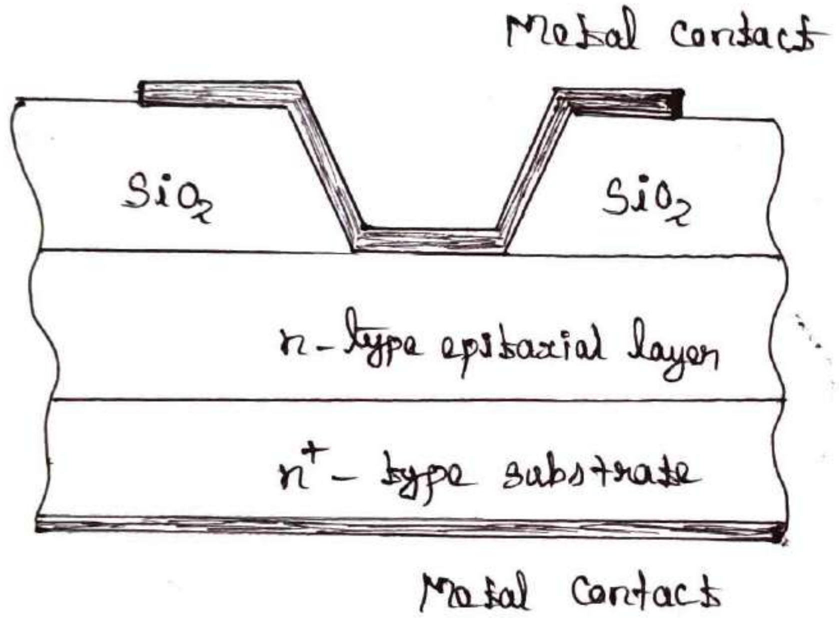


Fig: Schottky Diode

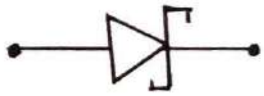


Fig: Symbol of SBD

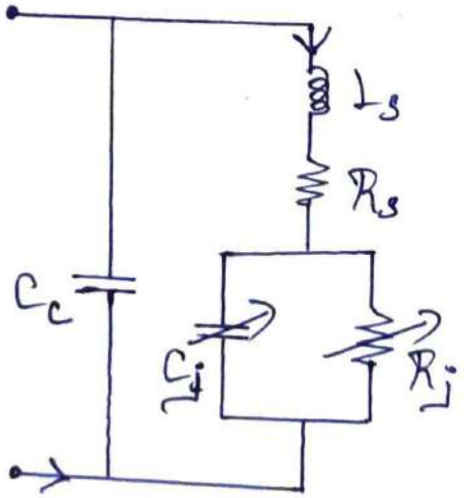
The diode is constructed on a thin silicon (n^+-type) substrate by growing epitaxially on n-type active layer of about 2-micron thickness. A thin SiO_2 layer is grown thermally over this active layer.

Metal semiconductor junction is formed by depositing metal over SiO_2. Schottky diodes also exhibit a square law characteristics and have a higher burn out rating, lower noise and better reliability that point contact diodes.

Operation

When the device is forward biased, the barrier height gets reduced. The major carriers (electrons) can be easily injected from the highly doped n-semiconductor material into the metal with an approximately exponential V-I characteristic.

When it is reverse biased, the barrier height, becomes too high for the electrons to cross and thus no conduction takes place.



where,

R_j - Resistance of metallic junction

C_j - Barrier Capacitance (0.3-0.5pF)

R_s - Bulk resistance of heavily doped Si Substrate (4-6 Ω)

L_s - Bond wire inductance (0.4-0.9nH)

C_c - Case Capacitance

Fig: Equivalent circuit of SBD

Applications

SBD is used as,

- Low Noise Mixer
- Balanced mixer in CW Radar
- Microwave Detector

PIN Diode

PIN Diode - Positive Intrinsic Negative Diode

PIN diode is a type of photo diode with a large, neutrally doped intrinsic region sandwiched between p-doped and n-doped semiconducting regions. ie, PIN diode consist of a high resistivity intrinsic semiconductor layer between two highly doped p^+ and n^+ 'Si' layers. (Si - Silicon)

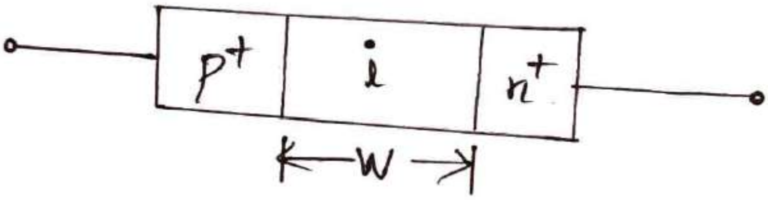


Fig: PIN Diode

PIN diode acts as electrically variable resistor which is related to the intrinsic layer. The intrinsic layer has a very large resistance in reverse bias and it decreases in forward bias. When mobile carriers from 'p' and 'n' regions are injected (from) into 'i' layer, carriers take time such that the diode ceases to act a rectifier at microwave frequency and appears as a linear resistance. This property is suitable as a variable attenuator at microwave frequencies.

Equivalent Circuit

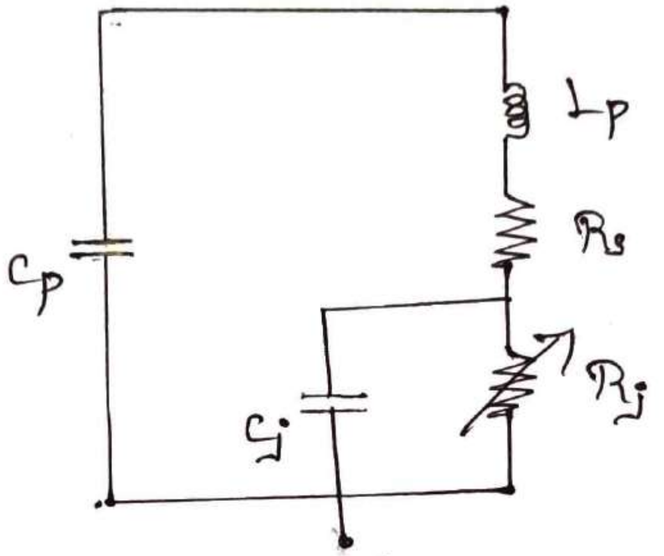


Fig: Equivalent circuit of PIN Diode

where,

$R_j C_j$ – Junction resistance, capacitance of 'i' layer

R_s – Bulk semiconductor (p^+ and n^+) layer and contact resistance

L_p, C_p – Package inductance, capacitance

Operation

* Zero bias, reverse bias, forward bias

Zero Bias

At zero bias, the diffusion of the holes and electrons across the junction causes space charge region of thickness which is inversely proportional to the impurity concentration.

An ideal 'i' layer has no depletion region i.e., 'p' layer has a fixed negative charge and 'n' layer has a fixed positive charge under zero bias.

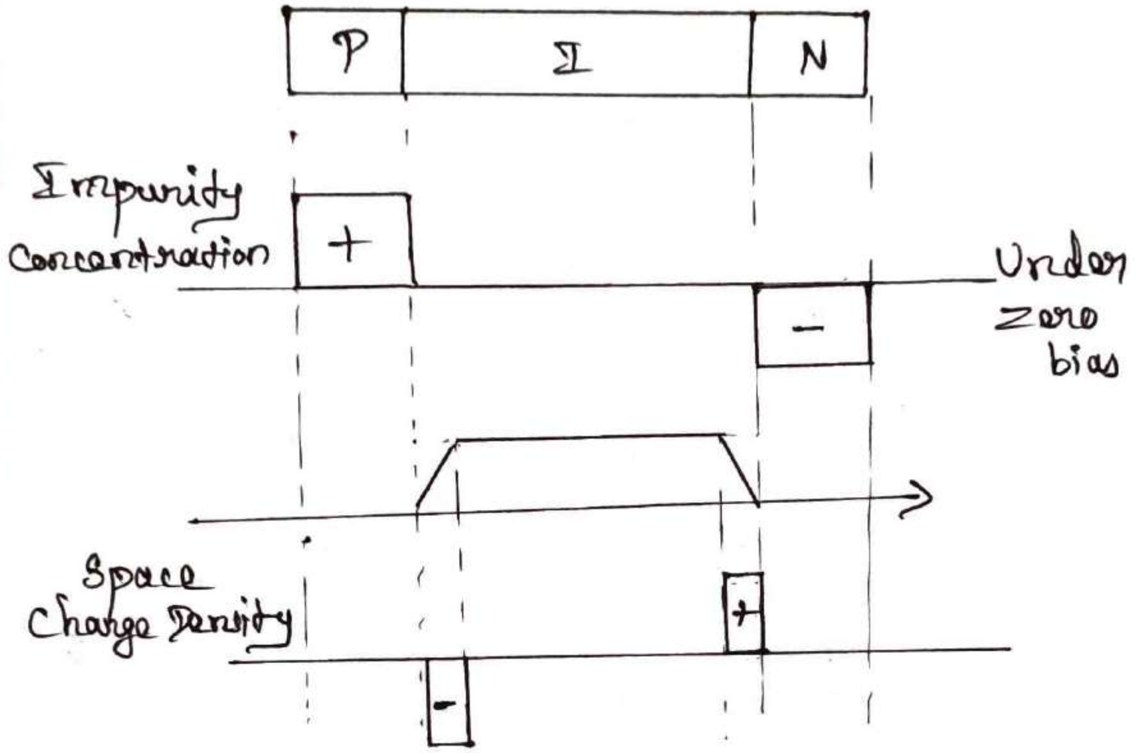


Fig: Operation of PIN Diode

Reverse Bias

As reverse bias is applied, the space charge regions in the 'p' and 'n' layers will become thicker. The reverse resistance will be very high and almost constant.

Forward Bias

With forward bias, carriers will be injected into the intrinsic (i) layer and the 'p' and 'n' space charge regions will become thinner i.e., electrons and holes are injected into the 'i' layer from 'p' and 'n' layers respectively. This results in the carrier concentration in the 'i' layer becoming raised above the equilibrium levels and the resistivity drops as the forward bias is increased. Thus, the low resistance is offered in the forward direction.

Applications

PIN diode is used as,

* switch
* Phase shifter
* Attenuator

MICROWAVE TUBES

Microwave tubes are constructed to overcome the limitations of conventional electronic vacuum tubes such as triodes, tetrodes and pentodes. These conventional electronic vacuum tubes fail to operate above 1GHz. In microwave tubes the electron transit time is used for microwave oscillation and amplification.

Transit Time

The transit time is the time taken for the electron to travel from cathode to anode.

The principle used in microwave tubes are an electron beam on which space charge waves interact with electromagnetic fields in the microwave cavities to transfer energy to the output circuit of the cavity (klystron or magnetrons) or interact with the electromagnetic fields in a slow wave structure to give amplification through the transfer of energy (TWT).

Klystron

Klystron is a vacuum tube that can be used either as a generator or as an amplifier of power at microwave frequencies operated by the principles of velocity and current modulation.

Basic Configurations

1. Reflex Klystron
   * It is used as low power microwave oscillator.
2. Two cavity or Multi cavity Klystron
   * It is used as low power microwave amplifier.

Two Cavity Klystron Amplifier

Two cavity klystron amplifier is a velocity modulated tube in which the velocity modulation process produces density modulated stream of electrons. It consists of two cavities namely, buncher (input) cavity and catcher (output) cavity.

The separation between buncher and catcher grids is called as drift space.

Operation

cathode emits an electron beam. This electrons beam first reaches the anode. The accelerating anode produces a high velocity electrons beam. The input RF signal to be amplified excites the buncher cavity with a coupling loop.

Bunching

The electrons beam passing the buncher cavity gap at zeros of the gap voltage V_g

passes through with an unchanged velocity.

V_g - Voltage between buncher grids

The electrons beam passing through the positive half cycles of the gap voltage undergoes an increase in velocity, those passing through the negative swings of the gap voltage undergoes a decrease in velocity. As a result of these actions, the electrons gradually bunch together as they travel down the drift space. This is called bunching.

The first cavity acts as the buncher and velocity modulates the beam. Thus the electron beam is velocity modulated to form bunches or under goes density modulation in accordance with the input RF signal cycle.

Characteristics

- Efficiency ≈ 40%
- Power output
    - i) Continuous wave average power ≈ 500 kW
    - ii) Pulsed Power 30 MW at 10 GHz
- Power gain ≈ 30 dB

Applications

- Used in Troposphere scatter transmitters
- Satellite communication ground stations
- Used in UHF TV transmitters
- Radar Transmitters

Magnetron

Magnetron is a high powered vacuum tube that works as a self excited microwave oscillator. Crossed electron and magnetic fields are used in the magnetron to produce the high power output required in the radar equipment. In magnetron, the flow of electrons is controlled by an applied magnetic field to generate power at microwave frequencies. In general, magnetron's job is to generate fairly short radio waves.

Applications

Magnetrons used for,

* Radar
* Microwave Ovens
* Lighting Systems

UNIT – V

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PRAISE THE LORD

IMPEDANCE TRANSFORMATION

The ratio of voltage to current is termed as impedance, which is represented as 'Z'.

$$Z = V/I , \Omega$$

Impedance is a complex quantity.

Impedance transformation is the process of transforming the impedance between the source and for maximum power deliver from source to load.

IMPEDANCE MATCHING

Impedance matching is the process of matching the value of source impedance to the value of load impedance.

In order to transfer maximum power from the source to load, impedance matching is must otherwise reflection from load will occur and power will be wasted, reducing transmission efficieny.

MICROWAVE FILTER DESIGN

Filter is a two port network used to control the frequency response at a certain point in an microwave system by providing transmission at frequencies with in the pass band of the filter and attenuation in the stop band of the filter.

Design Method

- Image Parameter Method
- Insertion Loss Method

Insertion Loss Method

The insertion loss method uses network synthesis techniques to design filters with a completely specified frequency response. It allows a high degree of control over the passband and stopband amplitude and phase characteristics, with a systematic way to synthesize a desired response.

The design is simplified by beginning with low pass filter prototypes that are normalized in terms of impedance and frequency.

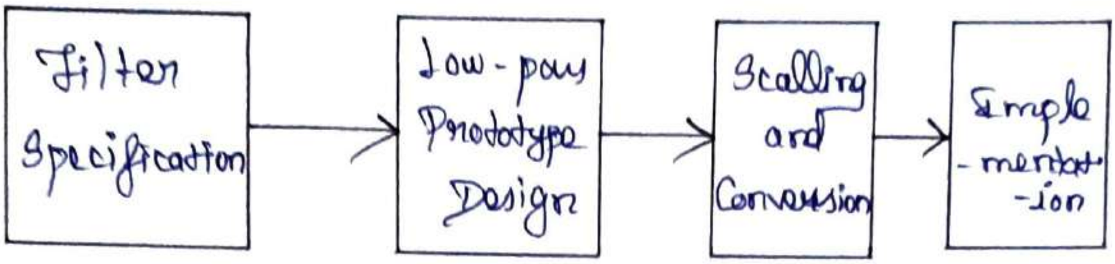

Fig: Process of Filter Design

Transformations are then applied to convert the prototype design to the desired frequency range and impedance level.

Power Loss Ratio

$$P_{LR} = \frac{\text{Power Incident at the Input}}{\text{Power Delivered to Load}}$$

$$\Rightarrow \quad P_{LR} = \frac{P_{in}}{P_{load}}$$

P_{LR} is unity – frequencies in pass band

P_{LR} is infinity – frequencies in stop band

Insertion Loss

Logarithmic value of power loss ratio is named as Insertion loss.

$$L = 10\log(P_{LR}) \text{ dB}$$

RF and MICROWAVE AMPLIFIER DESIGN

Microwave amplifiers combine active elements with passive transmission line circuits to provide functions critical to microwave systems and instruments.

Basic Concepts of RF Design

* RF Characteristics

All RF waves have characteristics that vary to define the wave. Some of these properties can be modified to modulate information onto the wave. These properties are wavelength, frequency, amplitude and phase.

* RF Behaviour

RF waves that have been modulated to contain information are called RF signals. These RF signals have behaviours that can be predicted and detected. They beome stronger and they become weaker. They react to different materials differently and they can interfere with other signals.

* Link Budget

Link budget used to describe the cumulative effects of gains and nonideal losses in a communication system. Link budgets become more common in their use for gain and loss analysis in any communication system.

Microwave Amplifier Power Design

RF source

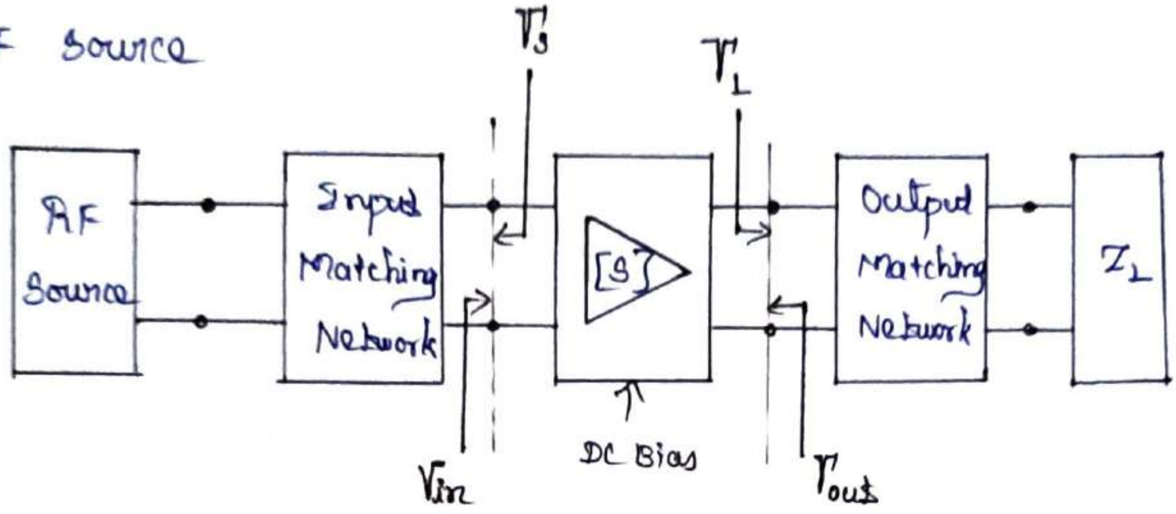

Fig: General Amplifier System

Assuming in terms of power flow relations, the two matching networks are included in the source and load impedances. The amplifier circuit is then reduced.

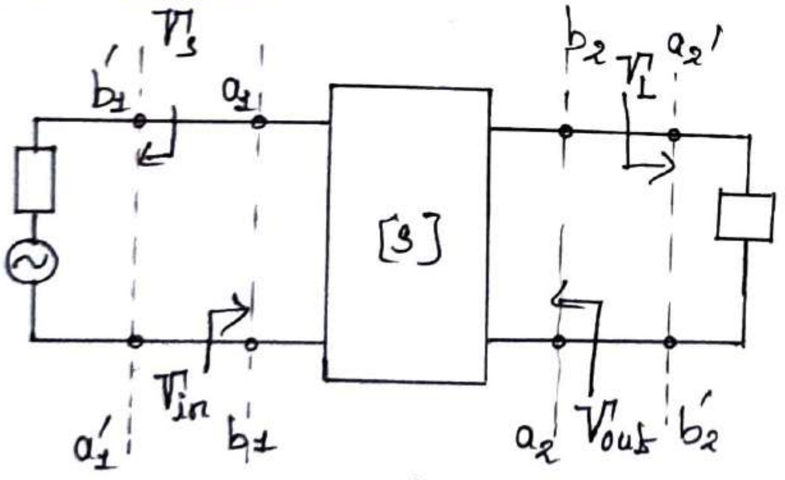

Fig: Simplified Diagram of single stage Amplifier

Incident Power

The incident power associated with b_1' is,

$$P_{inc} = \frac{1}{2}\left(\frac{Z_0}{Z_s+Z_0}\right)\cdot\frac{|V_s|^2}{|1-\Gamma_{in}\Gamma_s|}$$

The actual input power P_{in} is comprises of incident and reflected power waves.

$$P_{in} = P_{inc}\left[1 - |\Gamma_{in}|^2\right]$$

Available Power

Maximum power transfer condition exists when input impedance is complex conjugate matched with source impedance, ie., $Z_{in} = Z_s$. The maximum power transfer condition can also be expressed in terms of reflection co-efficient as, $\Gamma_{in} = \Gamma_s^*$.

The available power is,

$$P_A = P_{in}\Big|_{\Gamma_{in} = \Gamma_s^*}$$

$$= \frac{1}{2} \cdot \frac{|b_s|^2}{|1 - \Gamma_{in}\Gamma_s|^2}\Bigg|_{\Gamma_{in} = \Gamma_s^*}$$

$$P_A = \frac{1}{2} \frac{|b_s|^2}{1 - |\Gamma_s|^2}$$

$\Rightarrow$ available power is dependent on Γ_s. If. $\Gamma_{in} = 0$ and $\Gamma_s \neq 0$, then,

$$P_{inc} = \frac{|b_s|^2}{2}$$

Microwave Power Amplifier Design

High power amplifiers are typically used in transmitters. For design purposes, set of large-signal s-parameters is usually needed to characterise the device for power applications. However, the measurement of large signal s-parameters are not perfectly defined. Therefore alternative method is to obtain the source and load reflection coefficients in terms of output power and gain at its 1-dB gain compression point.

Gain Compression Point

* The 1 dB compression point is defined as the power gain at the non-linear region of the microwave devices reduces 1 dB power gain over the small signal linear power gain.

$$G_{1dB} = G_{sl}(dB) - 1\ dB$$

where, G_{sl} - small signal linear power gain

* The small signal power gain is,

$$G_p = \frac{P_{out}}{P_{in}} = P_{out}(dBm) - P_{in}(dBm)$$

$$\Rightarrow P_{out}(dBm) = P_{in}(dBm) + G_p(dB)$$

At 1 dB gain compression point, the output power can be expressed as,

$$P_{1dB}(dBm) = P_{in}(dBm) + G_p(dB) - 1(dB)$$

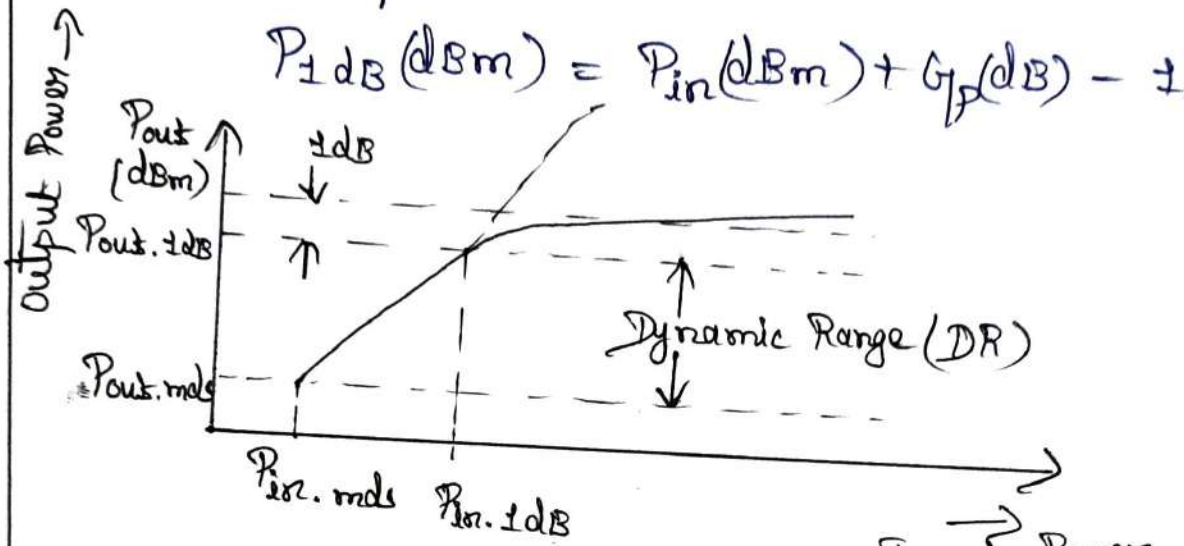

Fig: Power gain Compression Point

Dynamic Range (DR)

* The linear region is called as dynamic range. This range represents the power levels between the minimum detectable signal output power $P_{o,mds}$ and P_{1dB}.

* The low power level is limited by noise power level. A minimum detectable input signal $P_{in,mds}$ can be detectable only if its output power level $P_{out,mds}$ is above the noise power level.

Then dynamic range,

$$DR = P_{1dB} - P_{out,mds}$$

1 dB Compression Point

The point where the gain of amplifier deviates from the linear or small signal gain by 1 dB is called the 1 dB compression point. This point is used to characterise the power handling capabilities of the amplifier.

LOW NOISE AMPLIFIER DESIGN (LNA)

Low noise amplifier is a block that receives a weak signal and amplifies it right after the antenna. It is an electronic amplifier that amplifies a very low power signal without significantly degrading its signal to noise ratio.

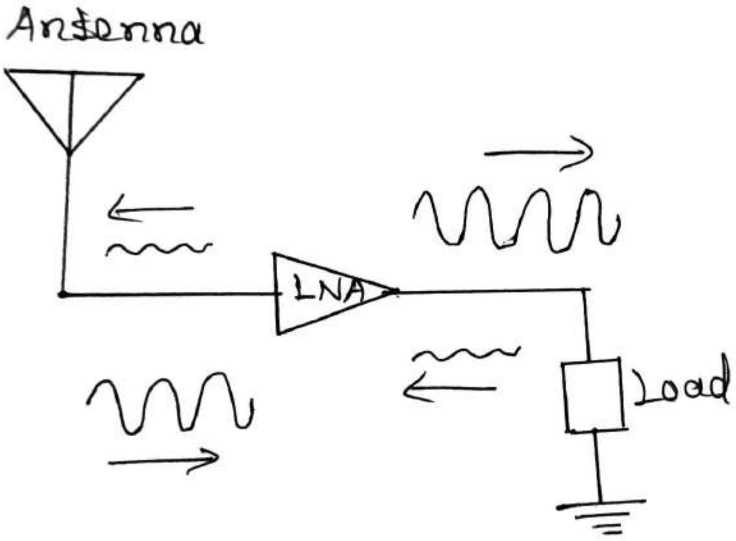

Fig: Low Noise Amplifier Design

The low noise amplifier is located right after the antenna before putting the signal in for processing. LNA is a critical stage which should provide enough gain without degrading the signal to noise ratio. As it is right after the antenna or a band pass filter it should be perfectly matched to ensure maximum power transfer. The purpose of placing the LNA into the first stage of circuit design to provide necessary gain and keep the noise figure optimized to a low level.

MICROWAVE MIXER DESIGN

Mixer is a three port device, which performs the task of frequency conversion. Mixers translate the frequency of an input signal to a different frequency.

The purpose of the microwave mixer is to provide either the sum or difference frequency of the two incoming signals at the output.

Frequency mixer is a 3-port electronic circuit. Two of the ports are input ports and the other port is an output port. The ideal mixer, mixes the two input signals such that the output signal frequency is either sum or difference frequency of the inputs.

In other words,

$$f_{out} = f_{in1} \pm f_{in2}$$

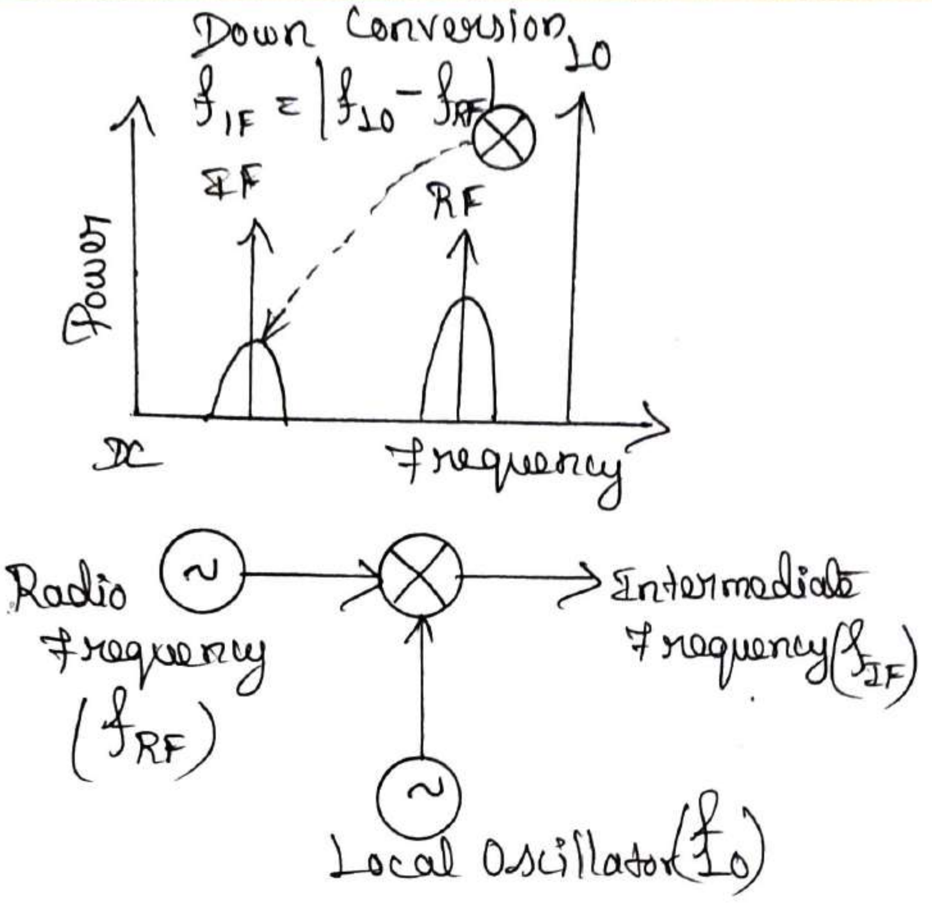

Fig: Mixer

Mixer is a three port device that uses a non linear or time varying element to achieve frequency conversion. An ideal mixer produces an output consisting of the sum and difference frequencies of its two input signals.

The ports of the mixer are,

- Local Oscillator (LO) port
- Radio Frequency (RF) port
- Intermediate Frequency (IF) port

The local oscillator port is typically driven with either a sinusoidal continuous wave (CW) signal or a square wave signal. Normally, the local oscillator signal acts as the gate of the mixer in the sense that the mixer can be considered ON when the local oscillator is a large voltage and OFF when the local oscillator is small voltage. The LO port is used as an input port.

MICROWAVE OSCILLATOR DESIGN

Microwave oscillators are used in all modern wireless communications, radars and remote sensing systems to provide signal sources for frequency conversion and carrier generation. At microwave frequencies negative resistance diodes or transistors are used to generate oscillations.

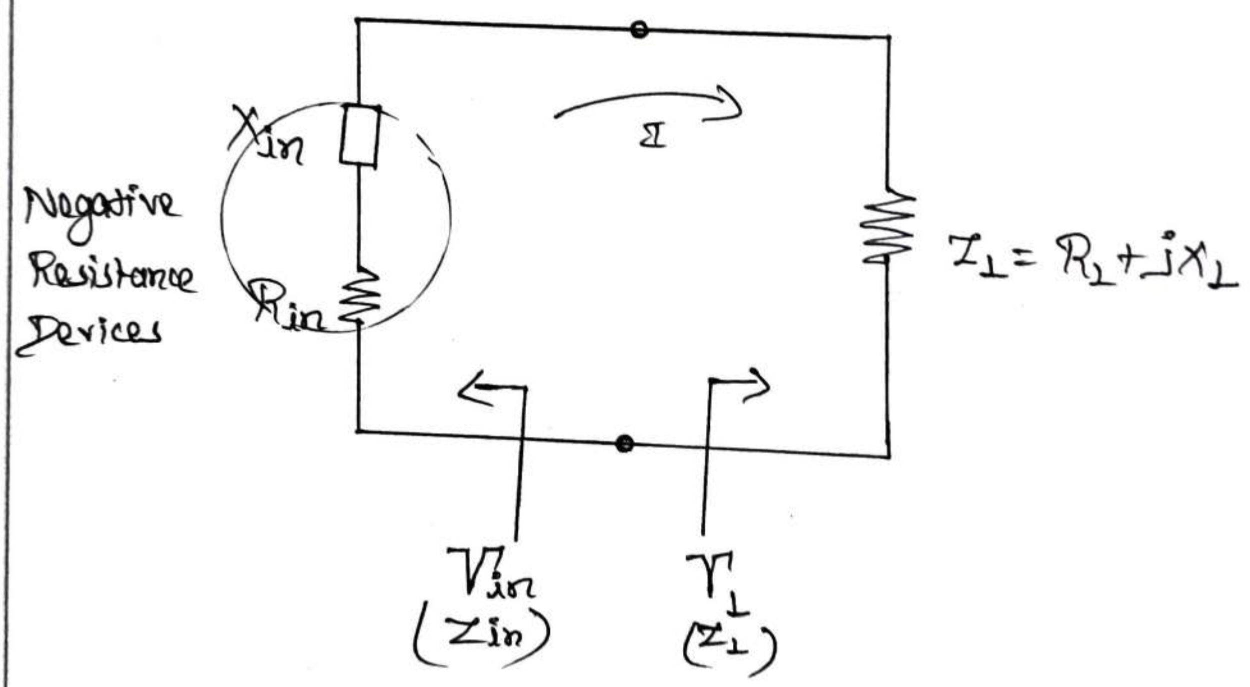

Fig: One Port Negative Resistance Oscillator

Here, $Z_{in} = R_{in} + jX_{in}$ is the input impedance of the active device.

Condition for steady state oscillation is,

$$Z_L = -Z_{in}$$

It implies the relation between reflection co-efficient Γ_L and Γ_{in},

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{-Z_{in} - Z_0}{-Z_{in} + Z_0} = \frac{Z_{in} + Z_0}{Z_{in} - Z_0} = \frac{1}{\Gamma_{in}}$$