17BEEC503 ANTENNAS AND WAVE PROPAGATION **L T P C**
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OBJECTIVES:

- To give an insight to antenna fundamentals and radiations.
- To create awareness about the different types antennas arrays and synthesis.
- To give a thorough understanding of the radiation characteristics of different types of antennas.
- To understand the propagation of radio waves in the atmosphere.

INTENDED OUTCOMES:

Upon completion of the course, students will be able to:

- Explain the various types of antennas and wave propagation.
- Write about the radiation from a current element.
- Analyze the antenna arrays and special antennas with introduction nto CAD modeling.

UNIT I ANTENNA FUNDAMENTALS AND RADIATION **9**

Definition and function of antennas – Antenna Theorems-Antenna parameters – Radiation Mechanism – Antenna field zones – Radiation from a small current element – Power radiated by a small current element and its radiation resistance – Hertzian dipole – Half wave dipole – Monopole – Current distributions.

UNIT II ANTENNA ARRAYS AND SYNTHESIS **9**

Linear arrays – Analysis of linear arrays – Phased arrays – Binomial arrays – Pattern multiplication – Method of excitation of antennas – Impedance matching techniques. Synthesis methods: Schelkunoff polynomial – Fourier transform – Wooden Lawson method.

UNIT III SPECIAL PURPOSE ANTENNAS **9**

Travelling wave – Loop – small loop – Dipole and Folded dipole antennas – Horn antenna – Reflector antenna – Yagi – Uda antenna – Log periodic antenna – Helical and Microstrip antennas. Introduction to CAD tools used for antenna modeling.

UNIT IV ANTENNA MEASUREMENTS **9**

Drawbacks in measurements of antenna parameters – Methods to overcome drawbacks in measurements –Measurement ranges – Impedance – Gain – Radiation pattern – Beam width – Radiation resistance – Antenna efficiency- Directivity-Polarization and Phase Measurements.

UNIT V RADIO WAVE PROPAGATION **9**

Basics of propagation-Ground wave propagation – Space wave propa gation- Considerations in space wave propagation – Super refraction – Ionospher ic wave propagation – Structure of ionosphere – Mechanism of ionospheric propagation – Effect of earth's Magnetic field on Radio wave propagation– Virtual height – MUF – Skip distance – OWF – Ionosphere abnormalities.

Total Hours: 45

TEXT BOOKS:

S.NO.	Author(s)Name	Titleof thebook	Publisher	Year of publication
1.	John D Kraus, Ronald J Marhefka, Ahmad S Khan	Antenna and Wave Propagation 4th Edition	Tata McGrawHill,	2010
2.	R.E. Collins	Antenna and Wave Propagation	McGraw-Hill,	1998

REFERENCES:

S.NO.	Author(s)Name	Titleof thebook	Publisher	Year of publication
1	ConstantineA. Balanis	AntennaTheory: Analysisand Design Third Edition	John WileyandSons	2012
2	G.S.N. Raju	Antennas and wave propagation	St Pearson Education	2012
3	RobertS.Elliott	Antenna Theory and Design Revised Edition	JohnWileyand Sons	2007
4	R.L. Yadava	Antennas and Wave Propagation	PHI	2011

WEBSITE:

1. https://youtu.be/6YssCB2pSUg

UNIT I

ANTENNA FUNDAMENTALS AND RADIATION

UNIT I-ANTENNA FUNDAMENTALS AND RADIATION

Definition and function of antennas – Antenna theorems-Antenna parameters – Radiation Mechanism – Antenna field zones – Radiation from a small current element – Power radiated by a small current element and its radiation resistance – Hertzian dipole – Half wave dipole – Monopole – Current distributions.

Retarded potentials

We are now in a position to solve Maxwell's equations. Recall that in steady-state, Maxwell's equations reduce to

$$\nabla^2\phi = -\frac{\rho}{\epsilon_0}, \tag{1}$$

$$\nabla^2\mathbf{A} = -\mu_0\,\mathbf{j}. \tag{2}$$

The solutions to these equations are easily found using the Green's function for Poisson's equation

$$\phi(\mathbf{r}) = \frac{1}{4\pi\,\epsilon_0}\int\frac{\rho(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|}\,d^3\mathbf{r}' \tag{3}$$

$$\mathbf{A}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int\frac{\mathbf{j}(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|}\,d^3\mathbf{r}'. \tag{4}$$

The time-dependent Maxwell equations reduce to

$$\Box^2\phi = -\frac{\rho}{\epsilon_0}, \tag{5}$$

$$\Box^2\mathbf{A} = -\mu_0\,\mathbf{j}. \tag{6}$$

We can solve these equations using the time-dependent Green's function From we find that

$$\phi(\mathbf{r},t) = \frac{1}{4\pi\,\epsilon_0}\int\int\frac{\delta(t-t'-|\mathbf{r}-\mathbf{r}'|/c)\,\rho(\mathbf{r}',t')}{|\mathbf{r}-\mathbf{r}'|}\,d^3\mathbf{r}'\,dt', \tag{7}$$

with a similar equation for $\mathbf{A}$. Using the well-known property of delta-functions, these equations reduce to

$$\phi(\mathbf{r},t) = \frac{1}{4\pi\,\epsilon_0}\int\frac{\rho(\mathbf{r}',t-|\mathbf{r}-\mathbf{r}'|/c)}{|\mathbf{r}-\mathbf{r}'|}\,d^3\mathbf{r}' \tag{8}$$

$$\mathbf{A}(\mathbf{r},t) = \frac{\mu_0}{4\pi}\int\frac{\mathbf{j}(\mathbf{r}',t-|\mathbf{r}-\mathbf{r}'|/c)}{|\mathbf{r}-\mathbf{r}'|}\,d^3\mathbf{r}'. \tag{9}$$

These are the general solutions to Maxwell's equations. Note that the time-dependent solutions, (8) and (9), are the same as the steady-state solutions, (3) and (4), apart from the weird way in which time appears in the former. According to Eqs. (8) and (9), if we want to work out the potentials at position $\mathbf{r}$ and time t then we have to perform integrals of the charge density and current density over all space (just like in the steady-state situation). However, when we calculate the contribution of charges and currents at position $\mathbf{r}'$ to these integrals we do not use the values at time t, instead we use the values at some earlier time $t - |\mathbf{r} - \mathbf{r}'|/c$. What is this earlier time? It is simply the latest time at which a light signal emitted from position $\mathbf{r}'$ would be received at position $\mathbf{r}$ before time t. This is called the *retarded time*. Likewise, the potentials (8) and(9) are called *retarded potentials*. It is often useful to adopt the following notation

$$A(\mathbf{r}', t - |\mathbf{r} - \mathbf{r}'|/c) \equiv [A(\mathbf{r}', t)]\,. \tag{10}$$

The square brackets denote retardation (*i.e.*, using the retarded time instead of the real time). Using this notation Eqs. (8) and(9), become

$$\phi(\mathbf{r}) \quad = \quad \frac{1}{4\pi\,\epsilon_0}\int \frac{[\rho(\mathbf{r}')]}{|\mathbf{r} - \mathbf{r}'|}\, d^3\mathbf{r}', \tag{11}$$

$$\mathbf{A}(\mathbf{r}) \quad = \quad \frac{\mu_0}{4\pi}\int \frac{[\mathbf{j}(\mathbf{r}')]}{|\mathbf{r} - \mathbf{r}'|}\, d^3\mathbf{r}'. \tag{12}$$

The time dependence in the above equations is taken as read. We are now in a position to understand electromagnetism at its most fundamental level. A charge distribution ρ(r,t) can thought of as built up out of a collection, or series, of charges which instantaneously come into existence, at some point $\mathbf{r}'$ and some time t', and then disappear again. Mathematically, this is written

$$\rho(\mathbf{r}, t) = \int\!\!\int \delta(\mathbf{r} - \mathbf{r}')\,\delta(t - t')\,\rho(\mathbf{r}', t')\, d^3\mathbf{r}' dt'. \tag{13}$$

Likewise, we can think of a current distribution j(r,t) as built up out of a collection or series of currents which instantaneously appear and then disappear:

$$\mathbf{j}(\mathbf{r}, t) = \int\!\!\int \delta(\mathbf{r} - \mathbf{r}')\,\delta(t - t')\,\mathbf{j}(\mathbf{r}', t')\, d^3\mathbf{r}' dt'. \tag{14}$$

Each of these ephemeral charges and currents excites a spherical wave in the appropriate potential. Thus, the charge density at $\mathbf{r}'$ and t' sends out a wave in the scalar potential:

$$\phi(\mathbf{r}, t) = \frac{\rho(\mathbf{r}', t')}{4\pi\,\epsilon_0}\,\frac{\delta(t - t' - |\mathbf{r} - \mathbf{r}'|/c)}{|\mathbf{r} - \mathbf{r}'|}. \tag{15}$$

Likewise, the current density at $\mathbf{r}'$ and t' sends out a wave in the vector potential:

$$\mathbf{A}(\mathbf{r}, t) = \frac{\mu_0\,\mathbf{j}(\mathbf{r}', t')}{4\pi}\,\frac{\delta(t - t' - |\mathbf{r} - \mathbf{r}'|/c)}{|\mathbf{r} - \mathbf{r}'|}. \tag{16}$$

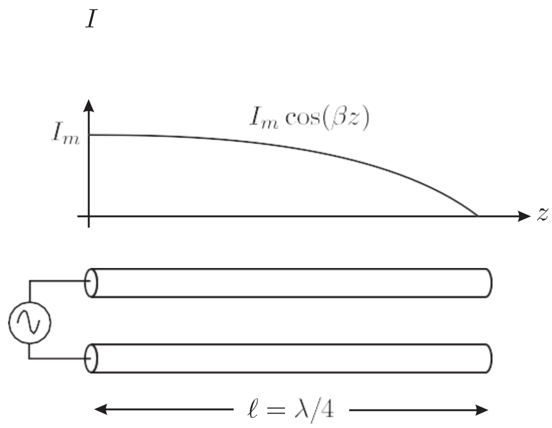
Half-wave Dipole

The dipole we have studied of aris not terribly useful, since it is not very efficiency and difficult to impedance –

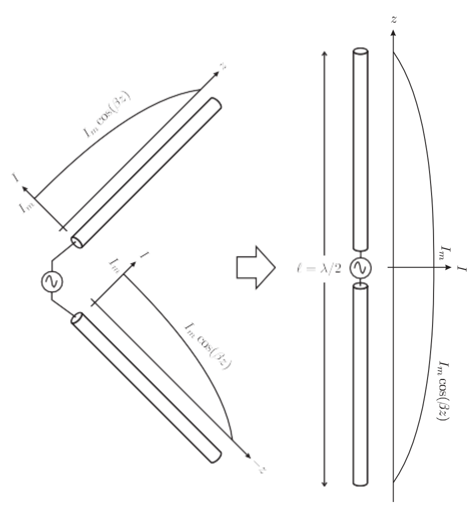
match to. Both these facts are a result of the electrically small nature of the antenna. A more practical dipole is the half-wave dipole (referring to the fact that it is $\lambda/2$long).The main reason for this, as we will see, is that the half-wave dipole has a real input impedance at resonance which is close to common system impedances.

Radiated Fields

Given the length of the dipole, it seems doubt full that the current distribution will be uniform as with the case of the Hertzian dipole. If we think about an open – circuited transmission line made of two wires, we imagine a sinusoidal current distribution set up by the standing wave along a quarter-wavelength length of line as follows:



Note that there is no current at $z=\lambda/4$ as required by the open circuit boundary condition. Now, if we "open" up the transmission line, we can essentially create a dipole that is half a wavelength long:



We can write the current distribution as

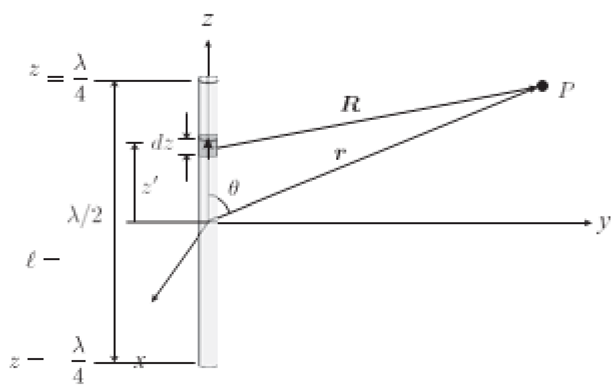
$$I(z) = I_m \cos(\beta z), \qquad (1)$$

Where β is the phase constant associated with the transmission line from which we have drawn the current distribution. Since we are in free space, $\beta=\omega/c=k$. Knowing the current distribution, our next question is how to find the electric field produced by the dipole? Well, we know that at in piece of dipole produces an electric field in the far field of

$$E_\theta = \frac{I\Delta z j\omega\mu}{4\pi}\frac{e^{-jkr}}{r}\sin\theta \qquad (2)$$

If excited with a current element of amplitude I at the origin. Using superposition, we can represent the half-wave dipole as a collection of Hertzian dipoles and add up all the responses of each dipole. Hence, each dipole "piece" contributes an electric field

$$dE_\theta = \frac{I(z')dz' j\omega\mu}{4\pi}\frac{e^{-jkR}}{R}\sin\theta. \qquad (3)$$



Now, since we are in the far field, the diagram above is not really correct. As the point P moves far from the source, the vectors R and r become parallel. This is known as the parallel ray approximation. Under this approximation,

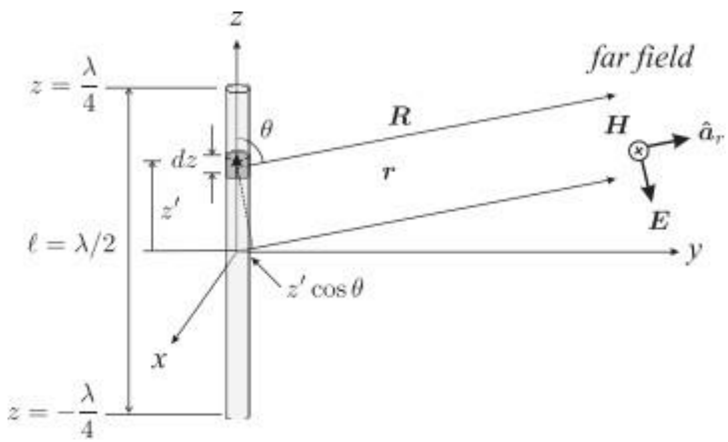
$$\begin{aligned} \frac{1}{R} &\approx \frac{1}{r} \text{ for amplitude variations} && (4)\\ \exp(-jkR) &\approx \exp[-jk(r - z'\cos\theta)] \text{ for phase variations} && (5) \end{aligned}$$

Where the latter approximation is evident by examining the geometry of the far-field situation.

Then,

$$dE_\theta = \frac{I(z')dz' j\omega\mu}{4\pi}\frac{e^{-jkr}}{r}e^{jkz'\cos\theta}\sin\theta \qquad (6)$$

$$\begin{aligned} E_\theta &= \int_{z'=-\lambda/4}^{z'=\lambda/4} \frac{I(z')j\omega\mu}{4\pi}\frac{e^{-jkr}}{r}e^{jkz'\cos\theta}\sin\theta dz' && (7)\\ &= \frac{j\omega\mu}{4\pi}\frac{e^{-jkr}}{r}\int_{z'=-\lambda/4}^{z'=\lambda/4} I_m\cos(\beta z')e^{jkz'\cos\theta}\sin\theta dz' && (8) \end{aligned}$$



NOTE:

$$\int \sin(a+bx)e^{cx} = \frac{e^{cx}}{b^2+c^2}[c\sin(a+bx) - b\cos(a+bx)] + C \tag{9}$$

$$\begin{aligned}
\int_{z'=-\lambda/4}^{z'=\lambda/4} \sin(\pi/2+kz')e^{jkz'\cos\theta} &= \frac{e^{jkz'\cos\theta}}{k^2+(jk\cos\theta)^2}\left[jk\cos\theta\sin(\pi/2+kz') - \beta\cos(\pi/2+kz')\right]\Big|_{-\lambda_4}^{\lambda/4} \\
&= \frac{e^{jk\frac{\lambda}{4}\cos\theta}}{k^2-k^2\cos^2\theta}\left[jk\cos\theta\cancel{\sin(\pi/2+k\lambda/4)} - \beta\cos(\pi/2+\beta\lambda/4)\right] - \\
&\quad \frac{e^{-jk\frac{\lambda}{4}\cos\theta}}{k^2-k^2\cos^2\theta}\left[jk\cos\theta\cancel{\sin(\pi/2-k\lambda/4)} - beta\cos(\pi/2-\beta\lambda/4)\right] \\
&= \frac{e^{j\frac{\pi}{2}\cos\theta}}{\beta^2\sin^2\theta}\beta + \frac{e^{-j\frac{\pi}{2}\cos\theta}}{\beta^2\sin^2\theta}\beta = 2\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\beta\sin^2\theta}
\end{aligned} \tag{10}$$

Therefore,

$$E_\theta = \underbrace{\frac{j\omega\mu I_m}{4\pi}\frac{e^{-jkr}}{r}\sin\theta}_{\text{Hertzian dipole E-field}} \cdot \underbrace{2\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\beta\sin^2\theta}}_{\text{space factor}} \tag{11}$$

and since $\beta = k$ and $\omega\mu/k = \eta$,

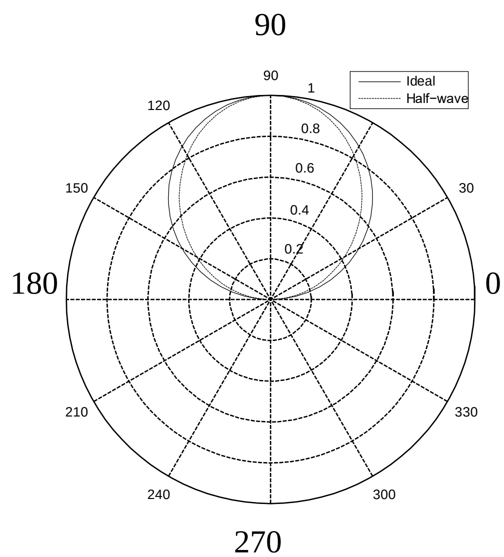
$$E_\theta = \frac{j\eta I_m}{2\pi}\frac{e^{-jkr}}{r}\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}. \tag{12}$$

H_ϕ follows as

$$H_\phi = \frac{E_\theta}{\eta} = \frac{jI_m}{2\pi}\frac{e^{-jkr}}{r}\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}. \tag{13}$$

Radiation Pattern

If we take a polar plot of the pattern indicated by the above expressions, and compare to the pattern from a Hertzian dipole, we notice that a half wave dipole has slightly less beam width than the Hertzian dipole. In fact, the HPBW of a Hertzian dipole is 90°, while that of a half-wave dipole is only 78°. Hence, we expect the half-wave dipole to exhibits lightly more directivity than its Hertzian counterpart.



Directivity and Input Impedance

Let's evaluate the directivity and input impedance of the half-wave dipole at the frequency where the dipole is exactly half a wave length long. We begin by calculating the radiation intensity produced by the dipole:

$$U(\theta) = \frac{1}{2} r^2 \frac{|E_\theta|^2}{\eta} = \frac{1}{2} \frac{\eta I_m^2}{(2\pi)^2} \frac{\cos^2(\pi/2 \cos\theta)}{\sin^2\theta}. \tag{14}$$

The radiated power produced by the dipole is

$$W_{rad} = \int_0^{2\pi} \int_0^{\pi} U(\theta) \sin\theta d\theta d\phi \tag{15}$$

$$= \frac{1}{2}(2\pi) \frac{\eta I_m^2}{(2\pi)^2} \underbrace{\int_0^{\pi} \frac{\cos^2(\frac{\pi}{2}\cos\theta)}{\sin\theta} d\theta}_{\text{1.2188 numerically}} \tag{16}$$

$$= 30(1.2188) I_m^2 = 36.5640 I_m^2. \tag{17}$$

The directivity relative to an isotropic radiator is then calculated as

$$D_m = \frac{4\pi U_m}{W_{rad}} = \frac{4\pi}{8\pi^2} \eta I_m^2 \cdot \frac{1}{36.5640 I_m^2} = 1.64 \tag{18}$$

Therefore,

$$D_{dipole} = 1.64 = 2.15 \text{ dBi} = 0 \text{ dBd}. \tag{19}$$

Notice that the dBd unit expresses the directivity with respect to a half-wave dipole, and hence compared to itself, a half-wave dipole has 0dBd of gain.

For the input impedance, we anticipate both are a land imaginary part, since the near-fields of the dipole will contribute to are active component. The input resistance can be found as follows: Then,

$$R_{rad} = \frac{2W_{rad}}{I_m^2} = 73.1280\ \Omega \tag{20}$$

The calculation of the reactive part of the input impedance is much more involved and beyond the scope of the discussion here. The final result for the dipole's input impedance is

$$Z_{dipole} = 73 + j42.5\ \Omega. \tag{21}$$

That is, the input impedance of the dipole is slightly inductive. However, there exists a "resonance" frequency where the imaginary part of the dipole's input impedance goes to zero. This occurs at a slightly lower frequency and produces

$$Z_{dipole} = 70 + j0\ \Omega, \tag{22}$$

Which is a useful operating point for the antenna. Common coaxial lines, such as RG-59U, have a characteristic impedance of 75Ω and hence can readily be connected to a dipole without impedance matching, although usually one cannot feed dipoles directly from coaxial line (more on that later).
Finally, the ohmic loss in a half-wave dipole is

$$R_{ohmic} = \frac{R_s}{2\pi a}\frac{\lambda}{4}. \tag{23}$$

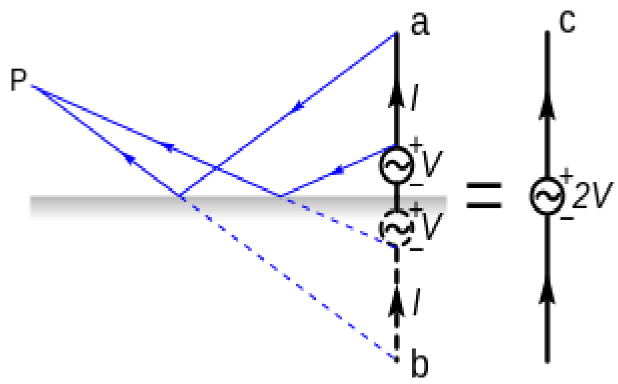
The details of this calculation have been omitted, but this is not the same expression as a Hertzian dipole. There as on for this is that the ohmic losses area function of position because the current is not uniformly distributed along the length of the dipole. In fact, if one plugs in $L = \lambda/4$ in to the expression for the Hertzian dipole and compare to the above expression, the ohmic loss is twice that predicted by (23), suggesting that only half of the dipole effectively contributes to significant ohmic losses.

Monopole antenna:

A monopole antenna is a class of radio antenna consisting of a straight rod-shaped conductor, often mounted perpendicularly over some type of conductive surface, called a ground plane. The driving signal from the transmitter is applied, or for receiving antennas the output signal to the receiver is taken, between the lower end of the monopole and the ground plane. One side of the antenna feed line is attached to the lower end of the monopole, and the other side is attached to the ground plane, which is often the Earth. This contrasts with a dipole antenna which consists of two identical rod conductors, with the signal from the transmitter applied between the two halves of the antenna.

Radiation pattern

Like a dipole antenna, a monopole has an omni directional radiation pattern. That is it radiates equal power in all azimuthally directions perpendicular to the antenna, but the radiated power varies with elevation angle, with the radiation dropping off to zero at the zenith, on the antenna axis. It radiates vertically polarized radio waves.



Showing the monopole antenna has the same radiation pattern over perfect ground as a dipole in free space with twice the voltage. Radiation pattern of 3/2 wavelength monopole. Monopole antennas up to 1/4 wavelength long have a single "lobe", with field strength declining monotonically from a maximum in the horizontal direction, but longer monopoles have more complicated patterns with several conical "lobes" (radiation maxima) directed at angles into the sky.

The ground plane used with a monopole may be the actual earth; in this case the antenna is mounted on the ground and one side of the feedline is connected to an earth ground at the base of the antenna. This design is used for the mast radiator antennas employed in radio broadcasting at low frequencies, as well as other low frequency antennas such as the T-antenna and umbrella antenna. At VHF and UHF frequencies the size of the ground plane needed is smaller, so artificial ground planes are used to allow the antenna to be mounted above the ground. A common type of monopole antenna at these frequencies consists of a quarter-wave whip antenna with a ground plane consisting of several wires or rods radiating horizontally or diagonally from its base; this is called a ground-plane antenna. At gigahertz frequencies the metal surface of a car roof or airplane body makes a good ground plane, so car cell phone antennas consist of short whips mounted on the roof, and aircraft communication antennas frequently consist of a short conductor in an aerodynamic fairing projecting from the fuselage; this is called a blade antenna. The most common antenna used in mobile phones is the inverted-F antenna, which is a variant of the inverted-L monopole. Bending over the antenna saves space and keeps the it within the bounds of the mobile's case but the antenna then has a very low impedance. To improve the match the antenna is not fed from the end, rather some intermediate point, and the end is grounded instead. The quarter-wave whip and rubber ducky antennas used with handheld radios such as walkie-talkies and cell phones are also monopole antennas. These don't use a ground plane, and the ground side of the transmitter is just connected to the ground connection on its circuit board. The hand and body of the person holding them may function as a rudimentary ground plane. Sometimes, monopole antennas are printed on a dielectric substrate to make it less fragile and they may be fabricated easily using the printed circuit board technologies. Such antennas are known as printed monopole antennas. They are suitable for various applications such as RFID, WLAN.VHF ground plane antenna, a type of monopole antenna used at high frequencies. The three conductors projecting downward are the ground plane

Monopole broadcasting antennas

When used for radio broadcasting, the radio frequency power from the broadcasting transmitter is fed across the base insulator between the tower and a ground system. The ideal ground system for AM broadcasters comprises at least 120 buried copper or phosphor bronze radial wires at least one-quarter wavelength long and a ground-screen in the immediate vicinity of the tower. All the ground system components are bonded together, usually by welding, brazing or using coin silver solder to help reduce corrosion. Monopole antennas that use guy-wires for support are called masts in some countries. In the United States, the term “mast” is generally used to describe a pipe supporting a smaller antenna, so both self-supporting and guy-wire supported radio antennas are simply called monopoles if they stand alone. If multiple monopole antennas are used in order to control the direction of radio frequency (RF) propagation, they are called directional antenna arrays. This impedance is periodically measured to verify the stability of the antenna and ground system. Normally, an impedance matching network matches the impedance of the antenna to the impedance of the transmission line feeding it.
Examples of monopole antennas are:

- the whip antenna
- the mast radiator (when isolated from the ground and bottom-fed)

Monopole antennas have become one of the components of mobile and internet networks across the globe. Their relative low cost and fast installation makes them an obvious choice for developing countries.

Directivity

Directivity (*D*) - the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

$$D(\theta,\phi) = \frac{U(\theta,\phi)}{U_{avg}} = \frac{4\pi\, U(\theta,\phi)}{P_{rad}}$$

The directivity of an isotropic radiator is $D(\theta , \phi) = 1$. The maximum directivity is defined as

$[D(\theta ,\phi)]_{max} = D_O$. The directivity range for any antenna is 0 $D(\theta, \phi)$ D_O. Directivity in dB

$$D(\theta,\phi)[dB] = 10\log_{10} D(\theta,\phi)$$

Directivity in terms of Beam Solid Angle

We may define the radiation intensity as

$$U(\theta,\phi) = B_o F(\theta,\phi)$$

where B_O is a constant and $F(\theta , \phi)$ is the radiation intensity pattern function. The directivity then becomes

$$D(\theta,\phi) = 4\pi \frac{U(\theta,\phi)}{P_{rad}} = 4\pi B_o \frac{F(\theta,\phi)}{P_{rad}}$$

and the radiated power is

$$P_{rad} = \int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta\, d\theta\, d\phi = B_o \int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi$$

Inserting the expression for P_{rad} into the directivity expression yields

$$D(\theta,\phi) = \frac{4\pi}{\int_0\int_0 F(\theta,\phi)\sin\theta\, d\theta\, d\phi}$$

The maximum directivity is

$$D(\theta,\phi) = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} F(\theta,\phi)\sin\theta\, d\theta\, d\phi} = \frac{4\pi}{\Omega_A}$$

where the term Ω_A in the previous equation is defined as the beam solid angle and is defined by Radiation Intensity

Radiation Intensity - radiated power per solid angle (radiated power normalized to a unit sphere).

$$P_{rad} = \oint_S \boldsymbol{P}_{avg} \cdot \mathrm{ds}$$

In the far field, the radiation electric and magnetic fields vary as $1/r$ and the direction of the vector power density ($\boldsymbol{P}_{avg}$) is radically outward. If we assume that the surface S is a sphere of radius r, then the integral for the total time-average radiated power becomes

$$\boldsymbol{P}_{avg} = P_{avg}\,\hat{\boldsymbol{r}}$$

$$\boldsymbol{ds} = \hat{\boldsymbol{s}}\,ds = \hat{\boldsymbol{r}}\,r^2 \sin\theta\, d\theta\, d\phi$$

$$P_{rad} = \int_0^{2\pi}\int_0^{\pi} P_{avg}\, r^2 \sin\theta\, d\theta\, d\phi$$

If we defined $P_{avg} r^2 = U(\theta, \phi)$ as the radiation intensity, then

$$P_{rad} = \int_0^{2\pi}\int_0^{\pi} U(\theta,\phi) \sin\theta\, d\theta\, d\phi = \int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\, d\Omega$$

Where d = sinθ dθ dϕ defines the differential solid angle. The units on the radiation intensity are defined as watts per unit solid angle. The average radiation intensity is found by dividing the radiation intensity by the area of the unit sphere (4) which gives

$$U_{avg} = \frac{\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\, d\Omega}{4\pi} = \frac{P_{rad}}{4\pi}$$

Theaverageradiationintensityforagivenantennarepresentstheradiation intensity of a point source producing the same amount of radiated power as the antenna.

PART B

1. Define an antenna.

Antenna is a transition device or a transducer between a guided wave and a free space waveor vice versa. Antenna is also said to be an impedance transforming device.

2. What is meant by radiation pattern?

Radiation pattern is the relative distribution of radiated power as a function of distance in space .It is a graph which shows the variation in actual field strength of the EM wave at all points which are at equal distance from the antenna. The energy radiated in a particular direction by an antenna is measured in terms of FIELD STRENGTH.(E Volts/m)

3. Define Radiation intensity?

The power radiated from an antenna per unit solid angle is called the radiation intensity U (watts per steradian or per square degree). The radiation intensity is independent of distance.

4. Define Beam efficiency?

The total beam area (WA) consists of the main beam area (WM) plus the minor lobe area (Wm) . Thus WA = WM+ Wm .

The ratio of the main beam area to the total beam area is called beam efficiency. Beam efficiency = SM = WM / WA.

5. Define Directivity?

The directivity of an antenna is equal to the ratio of the maximum power density P(q,f)max to its average value over a sphere as observed in the far field of an antenna.

D = P(q,f)max / P(q,f)av. Directivity from Pattern. D = 4p / WA. . Directivity from beam area(WA).

6**.What are the different types of aperture.?**

i) Effective aperture.

ii) Scattering aperture.

iii)Loss aperture.

iv) collecting aperture.

v). Physical aperture.

7. **Define different types of aperture.? Effective aperture**(Ae).

It is the area over which the power is extrated from the incident wave and delivered to the load is called effective aperture.

Scattering aperture(As.)

It is the ratio of the reradiated power to the power density of the incident wave.

Loss aperture. (Ae).

It is the area of the antenna which dissipates power as heat.

Collecting aperture. (Ae).

It is the addition of above three apertures.

Physical aperture. (Ap).

This aperture is a measure of the physical size of the antenna.

8. Define Aperture efficiency?

The ratio of the effective aperture to the physical aperture is the aperture efficiency. i.e Aperture efficiency = hap = Ae / Ap (dimensionless).

9. What is meant by effective height?

The effective height h of an antenna is the parameter related to the aperture.It may be defined as the ratio of the induced voltage to the incident field.i.e H= V / E

10. What are the field zone?

The fields around an antenna may be divided into two principal regions.

i. Near field zone (Fresnel zone)

ii. Far field zone (Fraunhofer zone)

11. What is meant by Polarization.?

The polarization of the radio wave can be defined by direction in which the electric vector E is aligned during the passage of atleast one full cycle.Also polarization can also be defined the physical orientation of the radiated electromagnetic waves in space.The polarization are three types. They are Elliptical polarization ,circular polarization and linear polarization.

12. What is meant by front to back ratio.?

It is defined as the ratio of the power radiated in desired direction to the power radiated in the opposite direction. i.e FBR = Power radiated in desired direction / power radiated in the opposite direction.

13. Define antenna efficiency.?

The efficiency of an antenna is defined as the ratio of power radiated to the total input power supplied to the antenna.

Antenna efficiency = Power radiated / Total input power

14. What is radiation resistance ?

The antenna is a radiating device in which power is radiated into space in the form of electromagnetic wave.

W' = I2 R

Rr = W'/ I2 Where Rr is a fictitious resistance called called as radiation resistance.

15. What is meant by antenna beam width?

Antenna beamwidth is a measure of directivity of an antenna. Antenna beam width is an angular width in degrees, measured on the radiation pattern (major lobe) between points where the radiated power has fallen to half its maximum value .This is called as "beam width" between half power points or half power beam width.(HPBW).

16. What is meant by reciprocity Theorem.?

If an e.m.f is applied to the terminals of an antenna no.1 and the current measured at the terminals of the another antenna no.2, then an equal current both in amplitude and phase will be obtained at the terminal of the antenna no.1 if the same emf is applied to the terminals of antenna no.2.

17. What is meant by isotropic radiator?

A isotropic radiator is a fictitious radiator and is defined as a radiator which radiates fields uniformly in all directions. It is also called as isotropic source or omni directional radiator or simply unipole.

18. Define self impedance

Self impedance of an antenna is defined as its input impedance with all other antennas are completely removed i.e away from it.

19 . Define mutual impedance

The presence of near by antenna no.2 induces a current in the antenna no.1 indicates that presence of antenna no.2 changes the impedance of the antenna no.1.This effect is called mutual coupling and results in mutual impedance.

20. What is meant by cross field.?

Normally the electric field E is perpendicular to the direction of wave propagation. In some situation the electric field E is parallel to the wave propagation that condition is called Cross field.

21. Define axial ratio

The ratio of the major to the minor axes of the polarization ellipse is called the Axial Ratio. (AR).

22. What is meant by Beam Area.?

The beam area or beam solid angle or WA of an antenna is given by the normalized power pattern over a sphere.

23. What is duality of antenna.?

It is defined as an antenna is a circuit device with a resistance and temperature on the one hand and the space device on the other with radiation patterns, beam angle ,directivity gain and aperture.

24. State Poynting theorem.

It states that the vector product of electric field intensity vector E and the magnetic filed intensity vector H at any point is a measure of the rate of energy flow per unit area at that point.The direction of power flow is perpendicular to both the electric field and magnetic field components.

PART C

1. Define the following parameters w.r.t antenna:
   i. Radiation resistance.
   ii. Beam area.
   iii. Radiation intensity.
   iv. Directivity.
   v. Gain.
   vi. Isotropic radiator.
   vii. Directive gain.
   viii. Hertzian dipole.
   ix. Power gain.
   x. Efficiency.
   xi. Power density.
   xii. Steradians & radians.
2. With the help of neat diagrams explain the principle of radiation in antennas.
3. Write a note on radiation pattern and radiation lobes.
4. Draw the radiation pattern of: (i) Directional antenna. (ii) Isotropic antenna.
5. Explain effective height of an antenna.
6. Derive an expression for power radiated by an isotropic antenna.
7. Derive the relation between directivity and beam solid angle.
8. Derive the relationship between radiation resistance and efficiency.
9. Derive an expression for field intensity at a distant point.
10. Write short notes on: (a) Fields of an oscillating dipole (b) Antenna field zones.
11. (i) Show that an isotropic radiator radiating 1 KW power gives a field of 173mv/m at a distance of 1 Km.

(ii) Find the directivity of an antenna having radiation resistance of 72 Ω and loss resistance of 12 Ω and a gain of 20.

(iii) What is the maximum effective aperture of a microwave antenna which has a directivity of900?

(iv) A radio station radiates a total power of 10KW and a gain of 30. Find the field intensity at a distance of 100Km from the antenna. Assume free space propagation.

12. Solve the wave equation for uniform plane waves in an infinitely extending conducting medium.
13. What are Hertzian dipoles? Derive the electric and magnetic field quantities of Infinitesimal dipole and radiation pattern.
14. Derive the electric and magnetic field components of Hertzian dipole.
15. Starting from the concepts of magnetic vector and electric scalar potentials derive the expressions for field components of short dipole.
16. Derive the expression for radiation resistance of Half wave dipole dipole.
17. Derive the field quantities and radiation resistance of a half wavelength dipole.
18. (i) The Radiation resistance of an antenna is 72Ω and loss resistance is 8Ω. What is it's the directive gain, if the power gain is 16?

    (ii) An Antenna has a loss resistance 10Ω, power gain of 20 and directive gain 22. Calculate its radiation resistance?

    (iii) Calculate the physical height of the half wave dipole having antenna Q of 30 and bandwidth 10MHz.

    (iv) Calculate the radiation resistance of an antenna which is drawing 15Ampere current and radiating 5KW.
19. Derive the fields radiated from a Symmetric antenna. Find the power radiated from the symmetric antenna.
20. Derive the expression for radiation from a small current element.
21. Explain in detail any eight antenna parameters.
22. Derive the expression for power radiation, radiation resistance of small current element.
23. Derive the fields radiated from a half wave dipole antenna. Find the power radiated from the half wave antenna.
24. (i) If the electric field strength of a plane wave is 1V/m, what is the strength of a magnetic field **H** in free space.

    (ii) A transmitting antenna having an effective height of 100 metres has s current at the base 100A at the frequency of 300KHz. Calculate

    (a) The value of radiation resistance (b) The power radiated

    (iii) An electric vector E of an electromagnetic wave in free space is given by this expression Ex = Ez = 0 ; Ey = A e $^{jw(t-z/v)}$ Using Maxwell's equation for free space condition determine expressions for the components of the magnetic vector **H**.
25. i) Derive the fields radiated from a quarter wave monopole antenna.

    ii) Discuss about assumed current distribution for wire antennas.

Unit –II
Antenna Array

UNIT II-ANTENNA ARRAYS AND SYNTHESIS: Linear arrays – Analysis of linear arrays – Phased arrays – Binomial arrays – Pattern multiplication –Method of excitation of antennas – Impedance matching techniques. Synthesis methods: Schelkunoff polynomial – Fourier transform – Wooden Lawson method.

Antenna array

The study of a single small antenna indicates that the radiation fields are uniformly distributed and antenna provides wide beam width, but low directivity and gain. For example, the maximum radiation of dipole antenna takes place in the direction normal to its axis and decreases slowly as one moves toward the axis of the antenna. The antennas of such radiation characteristic may be preferred in broadcast services where wide coverage is required but not in point to point communication. Thus to meet the demands of point to point communication, it is necessary to design the narrow beam and high directive antennas, so that the radiation can be released in the preferred direction. The simplest way to achieve this requirement is to increase the size of the antenna, because a larger-size antenna leads to more directive characteristics. But from the practical aspect the method is inconvenient as antenna becomes bulky and it is difficult to change the size later. Another way to improve the performance of the antenna without increasing the size of the antenna is to arrange the antenna in a specific configuration, so spaced and phased that their individual contributions are maximumin desired direction and negligible in other directions. This way particularly, we get greater directive gain. This new arrangement of multi-element is referred to as an array of the antenna. The antenna involved in an array is known as element. The individual element of array may be of any form (wire. dipole. slot, aperture. etc.). Having identical element in an array is often simpler, convenient and practical, but it is not compulsory. The antenna array makes use of wave interference phenomenon that occurs between the radiations from the different elements of the array. Thus, the antenna array is one of the methods of combining the radiation from a group of radiators in such a way that the interference is constructive in the preferred direction and destructive in the remaining directions. The main function of an array is to produce highly directional radiation. The field is a vector quantity with both magnitude and phase. The total field (not power) of the array system at any point away from its centre is the vector sum of the field produced by the individual antennas. The relative phases of individual field components depend on the relative distance of the individual clement and in turn depend on the direction.

ARRAY CONFIGURATIONS

Broadly, array antennas can be classified into four categories:

(a) Broadside array

(b) End-fire array

(c) Collinear array

(d) Parasitic array

Broadside Array- This is a type of array in which the number of identical elements is placed on a supporting line drawn perpendicular to their respective axes.

Elements are equally spaced and fed with a current of equal magnitude and all in same phase. The advantage of this feed technique is that array fires in broad side direction (i.e. perpendicular to the line of array axis, where there are maximum radiation and small radiation in other direction). Hence the radiation pattern of broadside array is bidirectional and the array radiates equally well in either direction of maximum radiation. In Fig. 1 the elements are arranged in horizontal plane with spacing between elements and radiation is perpendicular to the plane of array (i.e. normal to plane of paper.) They may also be arranged in vertical and in this case radiation will be horizontal. Thus, it can be said that broadside array is a geometrical arrangement of elements in which the direction of maximum radiation is perpendicular to the array axis and to the plane containing the array clement. Radiation pattern of a broad side array is shown in Fig. 2. The bidirectional pattern of broadside array can be converted into unidirectional by placing an identical array behind this array at distance of λ/4 fed by current leading in phase by90^0.

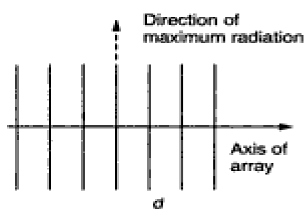


Fig. 1 Geometry of broad side array

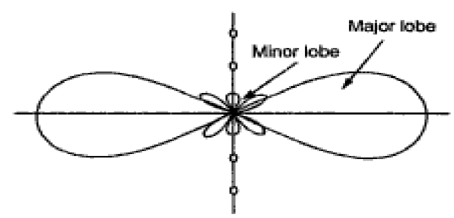


Fig. 2 Radiation pattern of broad side array

End Fire Array- The end fire array is very much similar to the broadside array from the point of view of arrangement. But the main difference is in the direction of maximum radiation.Inbroadsidearray,thedirectionofthemaximumradiationisperpendiculartothe axis of array; while in the end fire array, the direction of the maximum radiation is along the axis of array.

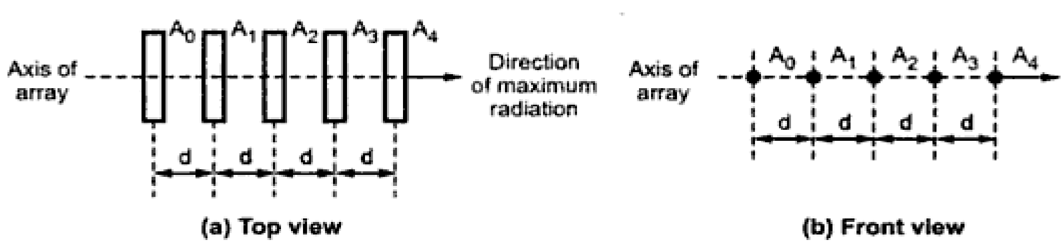


Fig. 3 End fire array

Thus in the end fire array number of identical antennas are spaced equally along a line. All the antennas are fed individually with currents of equal magnitudes but their phases vary progressively along the line to get entire arrangement unidirectional finally. i.e. maximum radiation along the axis of array. Thus end fire array can be defined as an array with direction of maximum radiation coincides with the direction of the axis of array to get unidirectional radiation.

Collinear Array-In collinear array the elements are arranged co-axially, i.e., antennas are either mounted end to end in a single line or stacked over one another. The collinear array is also a broadside array and elements are fed equally in phase currents. But the radiation pattern of a collinear array has circular symmetry with its main lobe everywhere normal to the principal axis.

This is reason why this array is called broadcast or Omni-directional arrays. Simple collinear array consists of two elements: however, this array can also have more than two elements (Fig. 4). The performance characteristic of array does not depend directly on the number of elements in the array. For example, the power gain for collinear array of 2, 3, and 4 elements are respectively 2 dB, 3.2 dB and 4.4 dB respectively. The power gain of 4.4 dB obtained by this array is comparatively lower than the gain obtained by other arrays or devices. The collinear array provides maximum gain when spacing between elements is of the order of 0.3λ to 0.5λ; but this much spacing results in constructional and feeding difficulties. The elements are operated with their ends are much close to each other and joined simply by insulator.

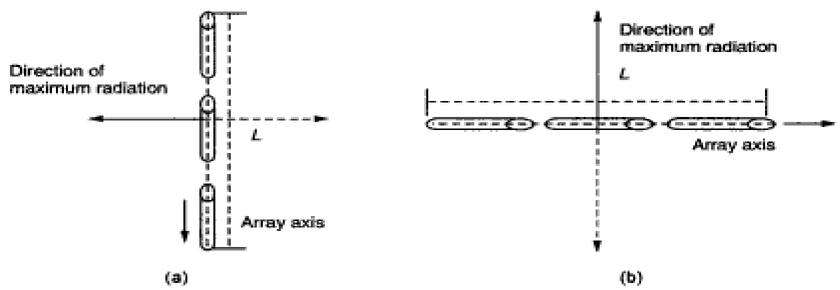


Fig. 4 (a) Vertical collinear antenna array (b) Horizontal collinear antenna array

Increase in the length of collinear arrays increases the directivity: however, if the number of elements in an array is more (3 or 4), in order to keep current in phase in all the elements, it is essential to connect phasing stubs between adjacent elements. A collinear array is usually mounted vertically in order to increase overall gain and directivity in the horizontal direction. Stacking of dipole antennas in the fashion of doubling their number with proper phasing produces a 3 dB increase in directive gain.

Parasitic Arrays-In some way it is similar to broad side array, but only one element is fed directly from source, other element arc electromagnetically coupled because of its proximity to the feed element. Feed element is called driven element while other elements are called parasitic elements. A parasitic element lengthened by 5% to driven element act as reflector and another element shorted by 5% acts as director. Reflector makes the radiation maximum in perpendicular direction toward driven element and direction helps in making maximum radiation perpendicular to next parasitic element. The simplest parasitic array has three elements: reflector, driven element and director, and is used, for example in Yagi-Uda array antenna. The phase and amplitude of the current induced in a parasitic element depends upon its tuning and the spacing between elements and driven element to which it is coupled. Variation in spacing between driven element and parasitic elements changes the relative phases and this proves to be very convenient. It helps in making the radiation pattern unidirectional. A distance of λ/4 and phase difference of π/2 radian provides a unidirectional pattern. A properly designed parasitic array with spacing 0.1λ to 0.15λ provides a frequency bandwidth of the order of 2%, gain of the order of 8 dB and FBR of about 20 dB. It is of great practical importance, especially at higher frequencies between 150 and 100 MHz, for Yagi array used for TV reception. The simplest array configuration is array of two point sources of same polarization and separated by a finite distance. The concept of this array can also be extended to more number of elements and finally an array of isotropic point sources can be formed.

Based on amplitude and phase conditions of isotropic point sources, there are three types of arrays:

(a) Array with equal amplitude and phases

(b) Array with equal amplitude and opposite phases

(c) Array with unequal amplitude and opposite phases

<u>Two Point Sources with Currents Equal in Magnitude and Phase</u>

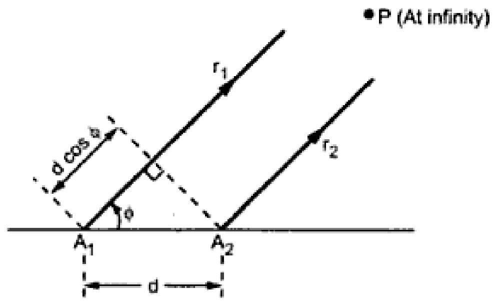


Fig. 5 Two element array

Consider two point sources A_1 and A_2, separated by distance d as shown in the Fig. 5. Consider that both the point sources are supplied with currents equal in magnitude and phase. Consider point P far away from the array. Let the distance between point P and point sources A_1 and A_2 be r_1 and r_2 respectively. As these radial distances are extremely large as compared with the distance of separation between two point sources i.e. d, we can assume,

$$r_1 = r_2 = r$$

The radiation from the point source A_2 will reach earlier at point P than that from point source A_1 because of the path difference. The extra distance is travelled by the radiated wave from point source A_1 than that by the wave radiated from point source A_2.
Hence path difference is given by,

Path difference=d cosυ **...(1)**

The path difference can be expressed in terms of wave length as,

Path difference = (d cos υ) /λ **...(2)**

Hence the phase angle υ is given by, Phase angle υ=2π(Path difference)

$$\therefore \quad \psi = 2\pi\left(\frac{d\cos\phi}{\lambda}\right)$$

$$\therefore \quad \boxed{\psi = \frac{2\pi}{\lambda} d\cos\phi \quad \text{rad}} \qquad \ldots(3)$$

But phase shift β = 2π/λ, thus equation (3) becomes,

$$\therefore \quad \boxed{\psi = \beta d\cos\phi \quad \text{rad}} \qquad \ldots(4)$$

Let E_1 be the far field at a distant point P due to point source A_l. Similarly let E_2 be the far field at point P due to point source A_2. Then the total field at point P be the addition of the two field components due to the point sources A_1 and A_2. If the phase angle between the two fields is υ = βd cosυ then the far field component at point P due to point source A_1 is given by,

$$E_1 = E_0 \cdot e^{-j\frac{\Psi}{2}} \qquad \ldots(5)$$

Similarly the far field component at point P due to the point source A_2 is given by,

$$E_2 = E_0 \cdot e^{j\frac{\Psi}{2}} \qquad \ldots(6)$$

The total field at point P is given by,

Note that the amplitude of both the field components is E_0 as currents are same and the point sources are identical.

$$E_T = E_1 + E_2 = E_0 \cdot e^{-j\frac{\Psi}{2}} + E_0 \cdot e^{j\frac{\Psi}{2}}$$

$$\therefore \quad E_T = 2E_0\left(\frac{e^{j\frac{\Psi}{2}} + e^{-j\frac{\Psi}{2}}}{2}\right) \qquad \ldots(7)$$

Rearranging the terms on R.H.S., we get,

By trigonometric identity,

$$\frac{e^{j\theta} + e^{-j\theta}}{2} = \cos\theta.$$

Hence equation (7) can be written as,

$$E_T = 2E_0 \cos\left(\frac{\Psi}{2}\right) \qquad \ldots(8)$$

Substituting value of Ψ from equation (4), we get,.

$$\therefore \quad \boxed{E_T = 2E_0 \cos\left(\frac{\beta d \cos\phi}{2}\right)} \qquad \ldots(9)$$

Above equation represents total field in intensity at point P. due to two point sources having currents of same amplitude and phase. The total amplitude of the field at point P is $2E_0$ while the phase shift is βd cosυ/2

The array factor is the ratio of the magnitude of the resultant field to the magnitude of the maximum field.

$$\therefore \quad \text{A.F.} = \frac{|E_T|}{|E_{max}|}$$

But maximum field is Ernax =$2E_0$

$$\therefore \quad \boxed{A.F. = \frac{|E_T|}{|2E_0|} = \cos\left(\pi \frac{d}{\lambda} \cos\phi\right)}$$

The array factor represents the relative value of the field as a function of υ defines the radiation pattern in a plane containing the line of the array.

Maxima direction

From equation (9), the total field is maximum when $\cos\left(\frac{\beta d \cos\phi}{2}\right)$ is maximum. As we know, the variation of cosine of a angle is ± 1. Hence the condition for maxima is given by,

$$\boxed{\cos\left(\frac{\beta d \cos\phi}{2}\right) = \pm 1}$$

Let spacing between the two point sources be λ/2. Then we can write,

$$\cos\left[\frac{\beta(\lambda/2)\cos\phi}{2}\right] = \pm 1 \qquad \ldots(10)$$

$$\text{i.e. } \cos\left[\frac{\frac{2\pi}{\lambda}\cdot\frac{\lambda}{2}\cos\phi}{2}\right] = \pm 1 \qquad \ldots \because \beta = \frac{2\pi}{\lambda}$$

$$\text{i.e. } \cos\left(\frac{\pi}{2}\cos\phi\right) = \pm 1$$

$$\text{i.e. } \frac{\pi}{2}\cos\phi_{max} = \cos^{-1}(\pm 1) = \pm n\pi, \text{ where } n = 0, 1, 2, \ldots\ldots$$

If n = 0, then

$$\frac{\pi}{2}\cos\phi_{max} = 0$$

$$\text{i.e. } \cos\phi_{max} = 0$$

$$\text{i.e. } \boxed{\phi_{max} = 90^\circ \text{ or } 270^\circ} \qquad \ldots(11)$$

Minima direction

Again from equation(9),total field strength is minimum when $\cos\left(\frac{\beta d \cos\phi}{2}\right)$ is minimum

i.e. 0 as cosine of angle has minimum value 0. Hence the condition for minima is given by,

$$\therefore \quad \boxed{\cos\left(\frac{\beta d \cos\phi}{2}\right) = 0} \quad \ldots(12)$$

Again assuming d = λ/2 and β=2π/λ, we can write

$$\cos\left(\frac{\pi}{2}\cos\phi_{min}\right) = 0$$

$$\therefore \quad \frac{\pi}{2}\cos\phi_{min} = \cos^{-1} 0 = \pm(2n+1)\frac{\pi}{2}, \text{ where } n = 0, 1, 2, \ldots\ldots\ldots$$

If n = 0, then,

$$\frac{\pi}{2}\cos\phi_{min} = \pm\frac{\pi}{2}$$

$$\text{i.e. } \cos\phi_{min} = \pm 1$$

$$\text{i.e. } \quad \boxed{\phi_{min} = 0^\circ \text{ or } 180^\circ} \quad \ldots(13)$$

Half power point direction:

When the power is half, the voltage or current is 1/√2 times the maximum value.

Hence the condition for half power point is given by,

$$\boxed{\cos\left(\frac{\beta d \cos\phi}{2}\right) = \pm\frac{1}{\sqrt{2}}} \quad \ldots(14)$$

Let d=λ/2 and β=2π/λ, then we can write,

$$\cos\left(\frac{\pi}{2}\cos\phi\right) = \pm\frac{1}{\sqrt{2}}$$

$$\text{i.e. } \frac{\pi}{2}\cos\phi = \cos^{-1}\left(\pm\frac{1}{\sqrt{2}}\right) = \pm(2n+1)\frac{\pi}{4}, \text{ where } n = 0, 1, 2, \ldots.$$

If n = 0, then

$$\frac{\pi}{2}\cos\phi_{HPPD} = \pm\frac{\pi}{4}$$

$$\text{i.e. } \cos\phi_{HPPD} = \pm\frac{1}{2}$$

$$\text{i.e. } \phi_{HPPD} = \cos^{-1}\left(\pm\frac{1}{2}\right)$$

$$\therefore \quad \boxed{\phi_{HPPD} = 60^\circ \text{ or } 120^\circ} \quad \ldots(15)$$

The field pattern drawn with E_T against ʋ for d=λ/2, then the pattern is bidirectional as shown in Fig 6. The field pattern obtained is bidirectional and it is a figure of eight.

If this pattern is rotated by 360^0 about axis, it will represent three dimensional doughnut shaped space pattern. This is the simplest type of broadside array of two point sources and it is called

Broadside couplet as two radiations of point sources are in phase.

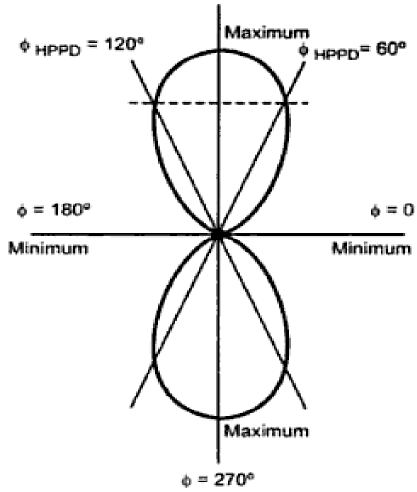


Fig. 6 Field pattern for two point source with spacing d=λ/2 and fed with currents equal in magnitude and phase.

<u>Two Point Sources with Currents Equal in Magnitudes but Opposite in Phase</u>

Consider two point sources separated by distance d and supplied with currents equal in magnitude but opposite in phase. Consider Fig. 5 all the conditions are exactly same except the phase of the currents is opposite i.e. 180°. With this condition, the total field at far point P is given by,

$$E_T = (-E_1) + (E_2) \quad \ldots(1)$$

Assuming equal magnitudes of currents, the fields at point P due to the point sources A_1 and A_2 can be written as,

$$E_1 = E_0 e^{-j\frac{\psi}{2}} \quad \ldots(2)$$

$$\text{and} \quad E_2 = E_0 e^{j\frac{\psi}{2}} \quad \ldots(3)$$

Substituting values of E_1 and E_2 in equation (1), we get

$$E_T = -E_0 \cdot e^{-j\frac{\psi}{2}} + E_0 \cdot e^{j\frac{\psi}{2}}$$

$$\therefore \quad E_T = E_0\left(-e^{-j\frac{\psi}{2}} + e^{j\frac{\psi}{2}}\right)$$

Rearranging the terms in above equation, we get,

$$\therefore \quad E_T = (j2)\, E_0\left(\frac{e^{j\frac{\psi}{2}} - e^{-j\frac{\psi}{2}}}{j2}\right) \quad \ldots(4)$$

By trigonometry identity,

$$\frac{e^{j\theta} - e^{-j\theta}}{2} = \sin\frac{\theta}{2}.$$

Equation (4) can be written as,

$$E_T = j2E_0 \sin\left(\frac{\psi}{2}\right) \quad \ldots(5)$$

Now as the condition for two point sources with currents in phase and out of phase is exactly same, the phase angle can be written as previous case.

Phase angle=βd cosʋ ...(6)

Substituting value of phase angle in equation (5), we get,

$$\boxed{E_T = j(2E_0)\sin\left(\frac{\beta d \cos\phi}{2}\right)} \quad \ldots(7)$$

Maxima direction

From equation (7), the total field is maximum when $\sin\left(\frac{\beta d \cos\phi}{2}\right)$ is maximum i.e. ±1 as the maximum value of sine of angle is ±1. Hence condition for maxima is given by,

$$\boxed{\sin\left(\frac{\beta d \cos\phi}{2}\right) = \pm 1} \quad \ldots(8)$$

Let the spacing between two isotropic point sources be equal to d=λ/2 Substituting d=λ/2 and β=2π/λ, in equation (8), we get,

$$\sin\left(\frac{\pi}{2}\cos\phi\right) = \pm 1$$

$$\text{i.e.} \quad \frac{\pi}{2}\cos\phi = \pm(2n+1)\frac{\pi}{2}, \text{ where } n = 0, 1, 2, \ldots\ldots$$

If n = 0. then

$$\frac{\pi}{2}\cos\phi_{max} = \pm\frac{\pi}{2}$$

$$\text{i.e. } \cos\phi_{max} = \pm 1$$

$$\text{i.e.} \quad \boxed{\phi_{max} = 0° \text{ and } 180°} \quad \ldots(9)$$

Minima direction

Again from equation(7),total field strength is minimum when $\sin\left(\frac{\beta d \cos\phi}{2}\right)$ isminimum

i.e. 0.

Hence the condition for minima is given by,

$$\boxed{\sin\left(\frac{\beta d \cos\phi}{2}\right) = 0} \quad \ldots(10)$$

Assuming d=λ/2 and β=2π/λ in equation (10), we get,

$$\sin\left(\frac{\pi}{2}\cos\phi\right) = 0$$

$$\text{i.e.}\quad \frac{\pi}{2}\cos\phi = \pm n\pi, \text{ where } n = 0, 1, 2, \ldots\ldots$$

If n = 0, then

$$\frac{\pi}{2}\cos\phi_{min} = 0$$

$$\text{i.e.}\quad \cos\phi_{min} = 0$$

$$\text{i.e.}\quad \boxed{\phi_{min} = +90^\circ \text{ or } -90^\circ} \qquad \ldots(11)$$

Half Power Point Direction (HPPD)

When the power is half of maximum value, the voltage or current equals to 1/√2 times the respective maximum value. Hence the condition for the half power point can be obtained from equation (7) as,

$$\boxed{\sin\left(\frac{\beta d\cos\phi}{2}\right) = \pm\frac{1}{\sqrt{2}}} \qquad \ldots(12)$$

Let d=λ/2 and β=2π/λ, we can write,

$$\sin\left(\frac{\pi}{2}\cos\phi\right) = \pm\frac{1}{\sqrt{2}}$$

$$\text{i.e.}\quad \frac{\pi}{2}\cos\phi = \pm(2n+1)\frac{\pi}{4}, \text{ where } n = 0, 1, 2.$$

If n = 0, we can write,

$$\frac{\pi}{2}\cos\phi_{HPPD} = \pm\frac{\pi}{4}$$

$$\text{i.e.}\quad \cos\phi_{HPPD} = \pm\frac{1}{2}$$

$$\therefore\quad \boxed{\phi_{HPPD} = 60^\circ \text{ or } 120^\circ} \qquad \ldots(13)$$

Thus from the conditions of maxima, minima and half power points, the field pattern can be drawn as shown in the Fig. 7.

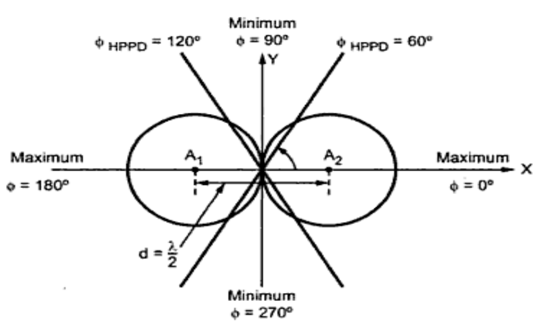


Fig. 7 Field pattern for two point sources with spacing d = d=λ/2 and fed with currents equal in magnitude but out of phase by 180^0.

As compared with the field pattern for two point sources with in phase currents, the maxima have shifted by 90° along X-axis in case of out-phase currents in two point source array. Thus the maxima are along the axis of the array or along the line joining two point sources. In first case, we have obtained vertical figure of eight. Now in above case, we have obtained horizontal figure of eight. As the maximum field is along the line joining the two point sources, this is the simple type of the end fire array.

Two point sources with currents unequal in magnitude and with any phase

Let us consider Fig. 5. Assume that the two point sources are separated by distance d and supplied with currents which are different in magnitudes and with any phase difference say α. Consider that source 1 is assumed to be reference for phase and amplitude of the fields E_1 and E_2, which are due to source 1 and source 2 respectively at the distant point P. Let us assume that E_1 is greater than E_2 in magnitude as shown in the vector diagram in Fig. 8.

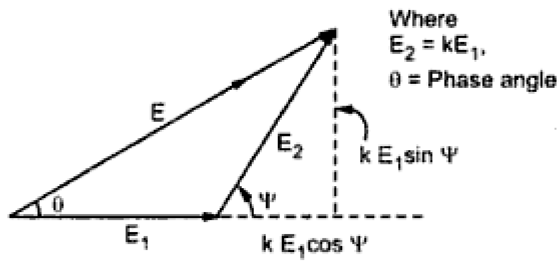


Fig. 8 Vector diagram of fields E_l and E_2

Now the total phase difference between the radiations by the two point sources at any far point P is given by,

$$\boxed{\Psi = \frac{2\pi}{\lambda}\cos\phi + \alpha} \qquad \dots (1)$$

where α is the phase angle with which current I_2 leads current I_l. Now if α = 0, then the condition is similar to the two point sources with currents equal in magnitude and phase. Similarly if α = 180", then the condition is similar to the two point source with currents equal in magnitude but opposite in phase. Assume value of phase difference as $0 < \alpha < 180^0$. Then the resultant field at point P is given by,

$$E_T = E_1 e^{j0} + E_2 e^{j\psi} \qquad \text{...(source 1 is assumed to be reference hence phase angle is 0)}$$

$$\therefore \quad E_T = E_1 + E_2 e^{j\psi}$$

$$\therefore \quad E_T = E_1\left(1 + \frac{E_2}{E_1} e^{j\psi}\right)$$

$$\text{Let} \quad \frac{E_2}{E_1} = k \qquad \dots(2)$$

Note that $E_1 > E_2$, the value of k is less than unity. Moreover the value of k is given by, $0 \le k$

≤ 1

$$\therefore \quad \boxed{E_T = E_1 \left[1 + k(\cos\psi + j\sin\psi)\right]} \qquad \dots (3)$$

The magnitude of the resultant field at point P is given by,

$$|E_T| = |E_1 [1 + k\cos\psi + j\,k\sin\psi]|$$

$$\therefore \quad \boxed{|E_T| = E_1\sqrt{(1+k\cos\psi)^2+(k\sin\psi)^2}} \quad \ldots (4)$$

The phase angle between two fields at the far point P is given by,

$$\therefore \quad \boxed{\theta = \tan^{-1}\frac{k\sin\psi}{1+k\cos\psi}} \quad \ldots (5)$$

n Element Uniform Linear Arrays

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 in the arrow from 2 to n say. An array of n elements is said to be linear array if all the individual elements are spaced equally along a line. An array is said to be uniform array if the elements in the array are fed with currents with equal magnitudes and with uniform progressive phase shift along the line. Consider a general n element linear and uniform array with all the individual elements spaced equally at distance d from each other and all elements are fed with currents equal in magnitude and uniform progressive phase shift along line as shown in the Fig.9.

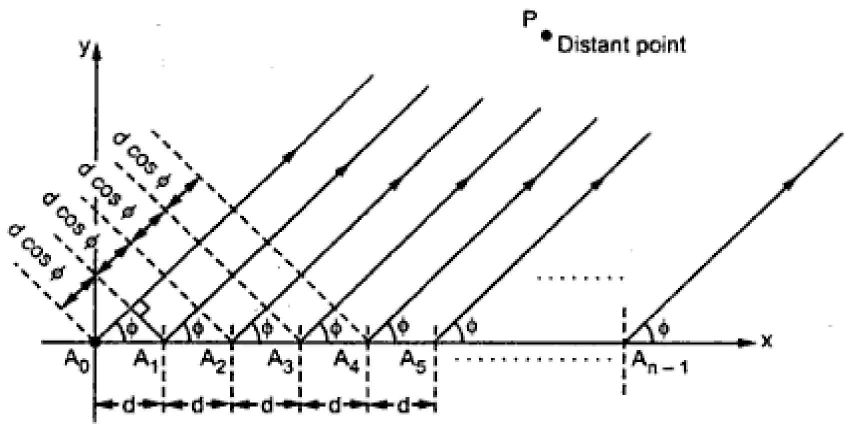


Fig. 9 Uniform, linear array of n elements

The total resultant field at the distant point P is obtained by adding the fields due to n individual sources vectorically. Hence we can write,

$$E_T = E_0 \cdot e^{j0} + E_0\, e^{j\psi} + E_0\, e^{2j\psi} + \ldots + E_0\, e^{j(n-1)\psi}$$

$$\therefore \quad \boxed{E_T = E_0\,[1 + e^{j\psi} + e^{j2\psi} + \ldots + e^{j(n-1)\psi}]} \quad \ldots (1)$$

Note that ʋ= (βd cosʋ + α) indicates the total phase difference of the fields from adjacent sourcescalculatedatpointP.Similarlyαistheprogressivephaseshiftbetweentwoadjacent point sources. The value of α may lie between 0^0 and 180^0. If α = 0^0 we get n element uniformlinearbroadsidearray.Ifα=180^0wegetnelementuniformlinearendfirearray.
Multiplying equation (1) by $e^{j\upsilon}$, we get,

$$E_T\, e^{j\psi} = E_0\,[e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \ldots + e^{jn\psi}] \quad \ldots (2)$$

Subtracting equation (2) from (1), we get,

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

$$E_T (1 - e^{j\psi}) = E_0 (1 - e^{jn\psi})$$

$$\therefore \quad \boxed{E_T = E_0 \left[\frac{1 - e^{jn\psi}}{1 - e^{j\psi}}\right]} \quad \ldots (3)$$

Simply mathematically, we get

$$E_T = E_0 \left[\frac{e^{j\frac{n\psi}{2}}\left(e^{-j\frac{n\psi}{2}} - e^{j\frac{n\psi}{2}}\right)}{e^{j\frac{\psi}{2}}\left(e^{-j\frac{\psi}{2}} - e^{j\frac{\psi}{2}}\right)}\right]$$

According to trigonometric identity,

$$e^{-j\theta} - e^{j\theta} = -2j \sin\theta,$$

The resultant field is given by,

$$E_T = E_0 \left[\frac{\left(-j2\sin\frac{n\psi}{2}\right)e^{j\frac{n\psi}{2}}}{\left(-j2\sin\frac{\psi}{2}\right)e^{j\frac{\psi}{2}}}\right]$$

$$\therefore \quad \boxed{E_T = E_0 \left[\frac{\sin n\frac{\psi}{2}}{\sin\frac{\psi}{2}}\right] e^{j\left(\frac{n-1}{2}\right)\psi}} \quad \ldots (4)$$

This equation (4) indicates the resultant field due to n element array at distant point P. The magnitude of the resultant field is given by,

$$\therefore \quad \boxed{E_T = E_0 \left[\frac{\sin n\frac{\psi}{2}}{\sin\frac{\psi}{2}}\right]} \quad \ldots (5)$$

The phase angle θ of the resultant field at point P is given by,

$$\therefore \quad \boxed{\theta = \frac{(n-1)}{2}\psi = \frac{(n-1)}{2}\beta d \cos\phi + \alpha} \quad \ldots (6)$$

Array of n elements with Equal Spacing and Currents Equal in Magnitude and Phase

•Broadside Array

Consider 'n' number of identical radiators carries currents which are equal in magnitude and in phase. The identical radiators are equispaced. Hence the maximum radiation occurs in the directions normal to the line of array. Hence such an array is known as Uniform broadside array. Consider a broadside array with n identical radiators as shown in the Fig.10.

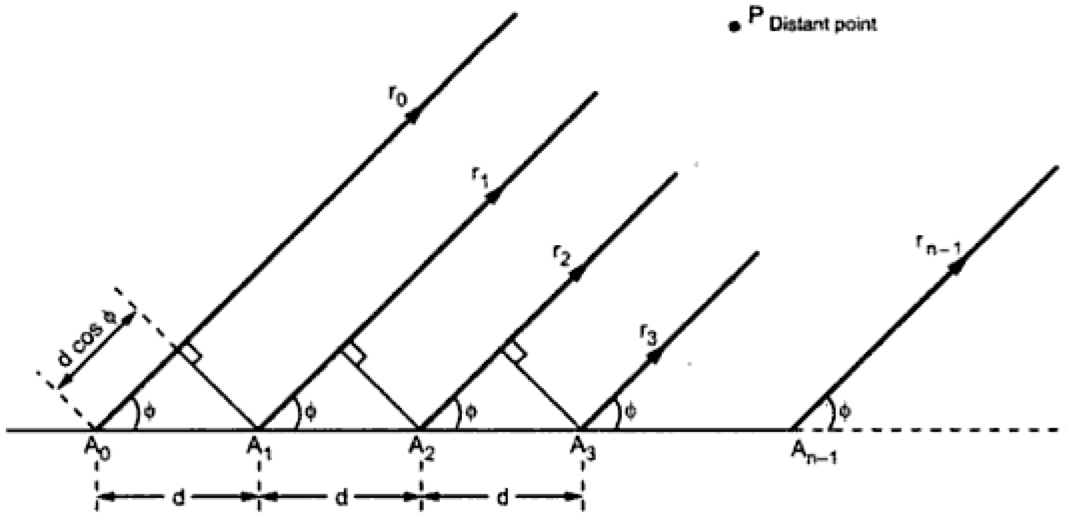


Fig 10 Array of n elements with Equal Spacing

The electric field produced at point P due to an element A_0 is given by,

$$E_0 = \frac{I\,dL\sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_0}\right] e^{-j\beta r_0} \qquad \ldots (1)$$

As the distance of separation d between any two array elements is very small as compared to the radial distances of point P from A_0, A_1, ...A_{n-1}, we can assume r_0, r_1, ...r_{n-1} are approximately same. Now the electric field produced at point P due to an element A_1 will differ in phase as r_0 and $r_1$arenotactuallysame. HencetheelectricfieldduetoA$_1$isgivenby,

$$E_1 = \frac{I\,dL\sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_1}\right] e^{-j\beta r_1}$$

But $\quad r_1 = r_0 - d\cos\phi$

$$\therefore \quad E_1 = \frac{I\,dL\sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_0}\right] e^{-j\beta(r_0 - d\cos\phi)} \qquad \ldots r_1 \approx r_0$$

$$\therefore \quad E_1 = E_0 \cdot e^{j\beta d\cos\phi} \qquad \ldots (2)$$

$$\therefore \quad E_1 = \frac{I\,dL\sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_0}\right] e^{-j\beta r_0}\; e^{j\beta d\cos\phi}$$

Exactly on the similar lines we can write the electric field produced at point P due to an element A_2 as,

$$E_2 = \frac{I\,dL\sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_2}\right] e^{-j\beta r_2}$$

$$\therefore \quad E_2 = \frac{I\,dL\sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_1}\right] e^{-j\beta(r_1 - d\cos\phi)} \qquad \ldots\; r_2 = r_1 - d\cos\phi$$

$$\therefore \quad E_2 = \left\{\frac{I\,dL\sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_1}\right] e^{-j\beta r_1}\right\} e^{j\beta d\cos\phi}$$

But the term inside the bracket represent E_1

$$\therefore \quad E_2 = E_1\, e^{j\beta d\cos\phi}$$

From equation (2), substituting the value of E_1, we get,

$$E_2 = \left[E_0\, e^{j\beta d\cos\phi}\right] e^{j\beta d\cos\phi}$$

$$\therefore \quad E_2 = E_0 \cdot e^{j2\beta d\cos\phi} \qquad \ldots (3)$$

Similarly, the electric field produced at point P due to element A_{n-1} is given by,

$$E_{n-1} = E_0 \cdot e^{j(n-1)\beta d\cos\phi} \qquad \ldots (4)$$

The total electric field at point P is given by,

$$E_T = E_0 + E_1 + E_2 + \ldots + E_{n-1}$$

$$\therefore \quad E_T = E_0 + E_0\, e^{j\beta d\cos\phi} + E_0\, e^{j2\beta d\cos\phi} + \ldots + E_0\, e^{j(n-1)\beta d\cos\phi}$$

Let βd cosυ = υ, then rewriting above equation,

$$E_T = E_0 + E_0\, e^{j\psi} + E_0\, e^{j2\psi} + \ldots + E_0\, e^{j(n-1)\psi}$$

$$\therefore \quad E_T = E_0\left[1 + e^{j\psi} + e^{j2\psi} + \ldots + e^{j(n-1)\psi}\right] \qquad \ldots (5)$$

Consider a series given by

$s = 1 + r + r^2 + \ldots\ldots + r^{n-1}$ ...(i)

where $r = e^{j\upsilon}$

Multiplying both the sides of the equation (i) by r,

$s \cdot r = r + r^2 + \ldots\ldots + r^n$ ...(ii)

Subtracting equation (ii) from (i), we get. $s(1-r) = 1-r^n$

$$\therefore \quad s = \frac{1-r^n}{1-r} \qquad \text{... (iii)}$$

Using equation (iii), equation (5) can be modified as,

$$E_T = E_0\left[\frac{1-e^{jn\psi}}{1-e^{j\psi}}\right]$$

$$\therefore \quad \frac{E_T}{E_0} = \frac{e^{jn\frac{\psi}{2}}\left[e^{-jn\frac{\psi}{2}} - e^{jn\frac{\psi}{2}}\right]}{e^{j\frac{\psi}{2}}\left[e^{-j\frac{\psi}{2}} - e^{j\frac{\psi}{2}}\right]} \qquad \text{... (6)}$$

From the trigonometric identities,

$$e^{-j\theta} = \cos\theta - j\sin\theta$$

$$e^{j\theta} = \cos\theta + j\sin\theta$$

$$\text{and} \quad e^{-j\theta} - e^{j\theta} = -j\,2\sin\theta$$

Equation (6) can be written as,

$$\frac{E_T}{E_0} = \frac{e^{jn\frac{\psi}{2}}\left[-j\,2\sin\left(\frac{n\psi}{2}\right)\right]}{e^{j\frac{\psi}{2}}\left[-j\,2\sin\left(\frac{\psi}{2}\right)\right]}$$

$$\therefore \quad \frac{E_T}{E_0} = e^{j\frac{(n-1)\psi}{2}}\left[\frac{\sin\left(\frac{n\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)}\right] \qquad \text{... (7)}$$

The exponential term in equation (7) represents the phase shift. Now considering magnitudes of the electric fields, we can write,

$$\left|\frac{E_T}{E_0}\right| = \frac{\sin\frac{n\psi}{2}}{\sin\frac{\psi}{2}} \qquad \text{... (8)}$$

Properties of Broadside Array

1. Major lobe

In case of broadside array, the field is maximum in the direction normal to the axis of the array. Thus the condition for the maximum field at point P is given by,

$$\psi = 0 \quad \text{i.e.} \quad \beta d\cos\phi = 0 \qquad \text{...(9)}$$

$$\text{i.e.} \quad \cos\phi = 0$$

$$\text{i.e.} \quad \boxed{\phi = 90^\circ \text{ or } 270^\circ} \qquad \text{...(10)}$$

Thus $\upsilon = 90^0$ and 270^0 are called directions of principle maxima.

2. Magnitude of major lobe

The maximum radiation occurs when ʋ=0. Hence we can write,

$$|\text{Major lobe}| = \left|\frac{E_T}{E_0}\right| = \lim_{\psi \to 0}\left\{\frac{\frac{d}{d\psi}\left(\sin n\frac{\psi}{2}\right)}{\frac{d}{d\psi}\left(\sin\frac{\psi}{2}\right)}\right\}$$

$$= \lim_{\psi \to 0}\left\{\frac{\left(\cos n\frac{\psi}{2}\right)\left(n\frac{\psi}{2}\right)}{\left(\cos\frac{\psi}{2}\right)\left(\frac{\psi}{2}\right)}\right\}$$

$$\therefore \quad \boxed{|\text{Major lobe}| = n} \quad \ldots(11)$$

where, n is the number of elements in the array.

Thus from equation (10) and (11) it is clear that, all the field components add up together to give total field which is 'n' times the individual field when ʋ = 90^0 and 270^0.

3. Nulls

The ratio of total electric field to an individual electric field is given by,

$$\left|\frac{E_T}{E_0}\right| = \frac{\sin n\frac{\psi}{2}}{\sin\frac{\psi}{2}}$$

Equating ratio of magnitudes of the fields to zero,

$$\therefore \quad \left|\frac{E_T}{E_0}\right| = \frac{\sin n\frac{\psi}{2}}{\sin\frac{\psi}{2}} = 0$$

The condition of minima is given by,

$$\therefore \quad \boxed{\sin n\frac{\psi}{2} = 0; \quad \text{but } \sin\frac{\psi}{2} \neq 0} \quad \ldots(12)$$

Hence we can write,

$$\sin n\frac{\psi}{2} = 0$$

$$\text{i.e.} \quad n\frac{\psi}{2} = \sin^{-1}(0) = \pm m\pi, \text{ where } m = 1, 2, 3, \ldots\ldots$$

$$\text{Now } \psi = \beta d\cos\phi = \frac{2\pi}{\lambda}(d)\cos\phi$$

$$\therefore \quad \frac{n}{2}\left(\frac{2\pi}{\lambda}d\right)\cos\phi_{min} = \pm m\pi$$

$$\therefore \quad \boxed{\phi_{min} = \cos^{-1}\left(\pm\frac{m\lambda}{nd}\right)} \quad \ldots(13)$$

i.e. $$\frac{nd}{\lambda}\cos\phi_{min} = \pm m$$

where, n= number of elements in the array d= spacing between elements in meter λ= wavelength in meter m= constant= 1, 2 , 3....

Thus equation (13) gives direction of nulls

4. Side Lobes Maxima

The directions of the subsidiary maxima or side lobes maxima can be obtained if in equation (8),

$$\sin\left(n\frac{\psi}{2}\right) = \pm 1$$

$$\therefore \quad \boxed{n\frac{\psi}{2} = \pm\frac{3\pi}{2}, \pm\frac{5\pi}{2}, \pm\frac{7\pi}{2}, \ldots\ldots} \qquad \ldots(14)$$

Hence sin(nυ/2), is not considered. Because if nυ/2=π/2 then sin nυ/2 =1 which is the direction of principle maxima.
Hence we can skip sin nυ/2 = ±π/2 value Thus, we get

$$\psi = \pm\frac{3\pi}{n}, \pm\frac{5\pi}{n}, \pm\frac{7\pi}{n}, \ldots\ldots\ldots\ldots$$

Now $$\psi = \beta d\cos\phi = \left(\frac{2\pi}{\lambda}\right)d\cos\phi$$

Now equation for υ can be written as,

$$\frac{2\pi}{\lambda}d\cos\phi = \pm\frac{3\pi}{n}, \pm\frac{5\pi}{n}, \pm\frac{7\pi}{n}, \ldots\ldots\ldots\ldots$$

$$\therefore \quad \cos\phi = \frac{\lambda}{2\pi d}\left[\pm\frac{(2m+1)}{n}\pi\right] \quad \text{where } m = 1, 2, 3, \ldots\ldots$$

$$\therefore \quad \boxed{\phi = \cos^{-1}\left[\pm\frac{\lambda(2m+1)}{2nd}\right]} \qquad \ldots(15)$$

The equation (15) represents directions of subsidiary maxima or side lobes maxima.

5. Beam width of Major Lobe

Beam width is defined as the angle between first nulls. Alternatively beam width is the angle equal to twice the angle between first null and the major lobe maximum direction. Hence beam width between first nulls is given by,

$$\therefore \quad \boxed{BWFN = 2\times\gamma, \quad \text{where } \gamma = 90-\phi} \qquad \ldots(16)$$

But $$\phi_{min} = \cos^{-1}\left(\pm\frac{m\lambda}{nd}\right), \quad \text{where } m = 1, 2, 3, \ldots\ldots$$

Also $$90-\phi_{min} = \gamma \quad \text{i.e. } 90-\gamma = \theta_{min}$$

Hence $$90-\gamma = \cos^{-1}\left(\pm\frac{m\lambda}{nd}\right)$$

Taking cosine of angle on both sides, we get

$$\cos(90-\gamma) = \cos\left[\cos^{-1}\left(\pm\frac{m\lambda}{nd}\right)\right]$$

$$\therefore \quad \sin\gamma = \pm\frac{m\lambda}{nd} \qquad \ldots(17)$$

If γ is very small, then $\sin\gamma \approx \gamma$. Substituting n above equation we get,

$$\gamma = \pm\frac{m\lambda}{nd} \qquad \ldots(18)$$

For first null i.e. m=1,

$$\gamma = +\frac{\lambda}{nd}$$

$$\therefore \quad BWFN = 2\gamma = \frac{2\lambda}{nd}$$

But nd≈ (n-1)d if n is very large. This L= (nd) indicates total length of the array.

$$\therefore \quad \boxed{BWFN = \frac{2\lambda}{L}\ rad = \frac{2}{\left(\frac{L}{\lambda}\right)}\ rad} \qquad \ldots(19)$$

$$\boxed{BWFN = \frac{114.6\lambda}{L} = \frac{114.6}{\left(\frac{L}{\lambda}\right)}\ degrees} \qquad \ldots(20)$$

BWFN in degree is written as,

Now HPBW is given by,

$$\boxed{HPBW = \frac{BWFN}{2} = \frac{1}{\left(\frac{L}{\lambda}\right)}\ rad} \qquad \ldots(21)$$

HPBW in degree is written as,

$$\therefore \quad \boxed{HPBW = \frac{57.3}{\left(\frac{L}{\lambda}\right)}\ degrees} \qquad \ldots(22)$$

6. Directivity

The directivity in case of broadside array is defined as,

$$G_{Dmax} = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}} = \frac{U_{max}}{U_{avg}} = \frac{U_{max}}{U_0} \quad \ldots(23)$$

where, U_0 is average radiation intensity which is given by,

$$U_0 = \frac{P_{rad}}{4\pi} = \frac{1}{4\pi}\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} |E(\theta,\phi)|^2 \sin\theta \; d\theta \, d\phi \quad \ldots(24)$$

From the expression of ratio of magnitudes we can write,

$$\left|\frac{E_T}{E_0}\right| = n$$

or $|E_T| = n|E_0|$

For the normalized condition let us assume $E_0 = 1$, then

$$|E_T| = n$$

Thus field from array is maximum in any direction θ when υ=0.Hencenormalized field pattern is given by,

$$E_{Normalized} = \left|\frac{E_T}{E_{Tmax}}\right| = \frac{|E_0|}{n|E_0|} = \frac{1}{n}$$

Hence the field is given by,

$$\therefore \quad E_{Normalized} = \frac{\sin n\frac{\psi}{2}}{n\left(\sin\frac{\psi}{2}\right)} \quad \ldots(25)$$

Where υ = βd cosυ

Equation (23) indicated array factor, hence we can write electric field due to n array as

$$E = \frac{1}{n}\left[\frac{\sin\frac{n\beta d\cos\phi}{2}}{\sin\frac{\beta d\cos\phi}{2}}\right]$$

Assuming d is very small as compared to length of an array,

$$\sin\frac{\beta d\cos\phi}{2} \approx \frac{\beta d\cos\phi}{2}.$$

Then,

$$E = \frac{1}{n}\left[\frac{\sin\frac{n\beta d\cos\phi}{2}}{\sin\frac{\beta d\cos\phi}{2}}\right] \quad \ldots(26)$$

Substituting value of E in equation (24) we get

Let

$$z = \frac{n}{2}\beta d \cos\theta$$

$$\therefore \quad dz = -\frac{n}{2}\beta d \sin\theta \, d\theta$$

$$U_0 = \quad \sin\theta \, d\theta \, d\phi$$

$$\therefore \quad \sin\theta \, d\theta = -\frac{dz}{\frac{n}{2}\beta d}$$

Also when $\theta = \pi, \quad z = -\frac{n}{2}\beta d$, and ...(27)

when $\theta = 0, \quad z = +\frac{n}{2}\beta d$

Rewriting above equation we get,

$$U_0 = \frac{1}{2}\int_{+\frac{n}{2}\beta d}^{-\frac{n}{2}\beta d}\left[\frac{\sin z}{z}\right]^2 \cdot \frac{dz}{-\frac{n}{2}\beta d}$$

$$\therefore \quad U_0 = -\frac{1}{n\beta d}\int_{\frac{n}{2}\beta d}^{-\frac{n}{2}\beta d}\left[\frac{\sin z}{z}\right]^2 dz$$

For large array, n is large hence nβd is also very large (assuming tending to infinity). Hence rewriting above equation.

$$U_0 = -\frac{1}{n\beta d}\int_{\infty}^{-\infty}\left[\frac{\sin z}{z}\right]^2 dz$$

Interchanging limits of integration, we get

$$U_0 = +\frac{1}{n\beta d}\int_{-\infty}^{\infty}\left[\frac{\sin z}{z}\right]^2 dz$$

By integration formula,

$$\int_{-\infty}^{\infty}\left[\frac{\sin z}{z}\right]^2 dz = \pi.$$

Using above property in above equation we can write,

$$\boxed{U_0 = \frac{1}{n\beta d}[\pi] = \frac{\pi}{n\beta d}} \quad \ldots(28)$$

From equation (23), the directivity is given by,

$$G_{Dmax} = \frac{U_{max}}{U_0}$$

But $U_{max} = 1$ at $\upsilon = 90°$ and substituting value of U_0 from equation (28), we get,

$$\boxed{G_{Dmax} = \frac{1}{\left(\frac{\pi}{n\beta d}\right)} = \frac{n\beta d}{\pi}} \quad \ldots(29)$$

But $\beta = 2\pi/\lambda$

Hence

$$\boxed{G_{Dmax} = \frac{2nd}{\lambda} = 2n\left(\frac{d}{\lambda}\right)} \quad \ldots(30)$$

The total length of the array is given by, $L = (n - 1)\, d \approx nd$, if n is very large. Hence the directivity can be expressed in terms of the total length of the array as, $\boxed{G_{Dmax} = 2\left(\frac{L}{\lambda}\right)}$

Array of n Elements with Equal Spacing and Currents Equal in Magnitude but with Progressive Phase Shift - End Fire Array

Consider n number of identical radiators supplied with equal current which are not in phase as shown in the Fig. 11. Assume that there is progressive phase lag of βd radians in each radiator.

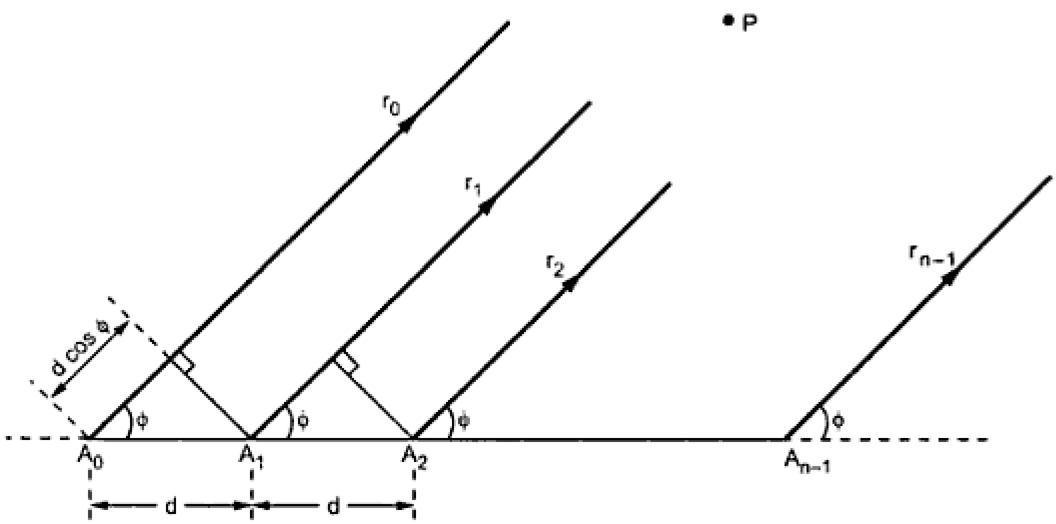


Fig.11 End fire array

Consider that the current supplied to first element A_0 be I_0. Then the current supplied to A_1 is given by,

$$I_1 = I_0 \cdot e^{-j\beta d}$$

Similarly the current supplied to A_2 is given by,

$$I_2 = I_1 \cdot e^{-j\beta d} = \left[I_0 \cdot e^{-j\beta d}\right] e^{-j\beta d} = I_0 \cdot e^{-j2\beta d}$$

Thus the current supplied to last element is

$$I_{n-1} = I_0\, e^{-j(n-1)\beta d}$$

The electric field produced at point P, due to A_0 is given by,

$$E_0 = \frac{I\, dL \sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_0}\right] e^{-j\beta r_0} \qquad \ldots (1)$$

The electric field produced at point P, due to A_1 is given by,

$$E_1 = \frac{I\, dL \sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_1}\right] e^{-j\beta r_1} \cdot e^{-j\beta d}$$

But $r_1 = r_0 - d\cos\upsilon$

$$\therefore \quad E_1 = \frac{I\, dL \sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_0}\right] e^{-j\beta(r_0 - d\cos\phi)} \cdot e^{-j\beta d}$$

$$\therefore \quad E_1 = \left[\frac{I\, dL \sin\theta}{4\pi\omega\varepsilon_0}\left[j\frac{\beta^2}{r_0}\right] e^{-j\beta r_0}\right] e^{j\beta d\cos\phi} \cdot e^{-j\beta d}$$

$$\therefore \quad E_1 = E_0 \cdot e^{j\beta d(\cos\phi - 1)} \qquad \ldots (2)$$

Let $\upsilon = \beta d\,(\cos\upsilon - 1)$

$$\therefore \quad E_1 = E_0\, e^{j\psi} \qquad \ldots (3)$$

The electric field produced at point P, due to A_2 is given by,

$$E_2 = E_0 \cdot e^{j2\psi} \qquad \ldots (4)$$

Similarly electric field produced at point P, due to A_{n-1} is given by,

$$E_{n-1} = E_0\, e^{j(n-1)\psi} \qquad \ldots (5)$$

The resultant field at point p is given by,

$$E_T = E_0 + E_1 + E_2 + \ldots + E_{n-1}$$

$$\therefore \quad E_T = E_0 + E_0\, e^{j\psi} + E_0\, e^{j2\psi} + \ldots + E_0\, e^{j(n-1)\psi}$$

$$\therefore \quad E_T = E_0\left[1 + e^{j\psi} + e^{j2\psi} + \ldots + e^{j(n-1)\psi}\right] \qquad \ldots (6)$$

$$E_T = E_0 \cdot \frac{1 - e^{jn\psi}}{1 - e^{j\psi}}$$

$$\therefore \quad \frac{E_T}{E_0} = \frac{\sin\frac{n\psi}{2}}{\sin\frac{\psi}{2}} \cdot e^{j\frac{(n-1)}{2}\psi} \qquad \ldots (7)$$

Considering only magnitude we get,

$$\therefore \qquad \boxed{\left|\frac{E_T}{E_0}\right| = \frac{\sin\frac{n\psi}{2}}{\sin\frac{\psi}{2}}} \qquad \ldots(8)$$

Properties of End Fire Array

1. Major lobe

For the end fire array where currents supplied to the antennas are equal in amplitude but the phase changes progressively through array, the phase angle is given by,

$\upsilon = \beta d(\cos\upsilon - 1)$ **...(9)**

In case of the end fire array, the condition of principle maxima is given by,

$\upsilon = = 0$ i.e.

$$\boxed{\beta d(\cos\phi - 1) = 0} \qquad \ldots(10)$$

i.e.

$\cos\upsilon = 1$

i.e. $\upsilon = 0^0$ **...(11)**

Thus $\upsilon = 0^0$ indicates the direction of principle maxima.

2.Magnitude of the major lobe

The maximum radiation occurs when $\upsilon = 0$. Thus we can write,

$$|\text{Major lobe}| = \lim_{\psi \to 0}\left\{\frac{\frac{d}{d\psi}\left(\sin n\frac{\psi}{2}\right)}{\frac{d}{d\psi}\left(\sin\frac{\psi}{2}\right)}\right\} = \lim_{\psi \to 0}\left\{\frac{\left(\cos n\frac{\psi}{2}\right)\left(n\frac{\psi}{2}\right)}{\left(\cos\frac{\psi}{2}\right)\left(\frac{\psi}{2}\right)}\right\}$$

$$\therefore \qquad \boxed{|\text{Major lobe}| = n} \qquad \ldots(12)$$

where, n is the number of elements in the array.

3. Nulls

The ratio of total electric field to an individual electric field is given by,

$$\left|\frac{E_T}{E_0}\right| = \frac{\sin n\frac{\psi}{2}}{\sin\frac{\psi}{2}}$$

Equating ratio of magnitudes of the fields to zero,

$$\therefore \quad \left|\frac{E_T}{E_0}\right| = \frac{\sin n\frac{\Psi}{2}}{\sin\frac{\Psi}{2}} = 0$$

The condition of minima is given by,

$$\boxed{\sin n\frac{\Psi}{2} = 0, \quad \text{but } \sin\frac{\Psi}{2} \neq 0} \qquad \ldots(13)$$

Hence we can write,

$$\sin n\frac{\Psi}{2} = 0$$

$$\text{i.e. } n\frac{\Psi}{2} = \sin^{-1}(0) = \pm m\pi, \text{ where } m = 1, 2, 3, \ldots\ldots$$

Substituting value of υ from equation (9), we get,

$$\therefore \frac{n\beta d(\cos\phi - 1)}{2} = \pm m\pi$$

But β= 2π/λ

$$\therefore \frac{nd}{\lambda}(\cos\phi - 1) = \pm m \qquad \ldots(14)$$

Note that value of (cosυ-1) is always less than 1. Hence it is always negative. Hence only considering -ve values, R.H.S., we get

$$\frac{nd}{\lambda}(\cos\phi - 1) = -m$$

$$\text{i.e. } \cos\phi - 1 = -\frac{m\lambda}{nd}$$

$$\boxed{\phi_{min} = \cos^{-1}\left[1 - \frac{m\lambda}{nd}\right]} \qquad \ldots(15)$$

where, n= number of elements in the array d= spacing between elements in meter λ= wavelength in meter m= constant= 1, 2 , 3....

Thus equation (15) gives direction of nulls Consider equation(14),

$$\cos\phi_{min} - 1 = \pm\frac{m\lambda}{nd}$$

Expressing term on L.H.S. in terms of half angles, we get,

$$2\sin^2\frac{\phi_{min}}{2} = \pm\frac{m\lambda}{nd} \qquad \ldots\left(\cos\theta - 1 = 2\sin^2\frac{\theta}{2}\right)$$

$$\therefore \quad \sin^2\frac{\phi_{min}}{2} = \pm\frac{m\lambda}{2nd}$$

$$\therefore \quad \boxed{\phi_{min} = 2\sin^{-1}\left[\pm\sqrt{\frac{m\lambda}{2nd}}\right]} \quad \ldots(16)$$

4. Side Lobes Maxima

The directions of the subsidiary maxima or side lobes maxima can be obtained if in equation (8),

$$\sin\left(n\frac{\psi}{2}\right) = \pm 1$$

$$\therefore \quad \boxed{n\frac{\psi}{2} = \pm\frac{3\pi}{2}, \pm\frac{5\pi}{2}, \pm\frac{7\pi}{2}, \ldots\ldots} \quad \ldots(17)$$

Hence sin(nυ/2), is not considered. Because if nυ/2=±π/2 then sin nυ/2 =1 which is the direction of principle maxima.
Hence we can skip sin nυ/2 = ±π/2 value Thus, we get

$$\frac{n\psi}{2} = \pm(2m+1)\frac{\pi}{2}, \text{ where } m = 1, 2, 3, \ldots\ldots$$

Putting value of υ from equation (9) we get

$$\frac{n\beta d(\cos\phi - 1)}{2} = \pm(2m+1)\frac{\pi}{2}$$

$$\therefore \; n\beta d(\cos\phi - 1) = \pm(2m+1)\pi$$

Now equation for υ can be written as, But β =2π/λ

$$n\left(\frac{2\pi}{\lambda}\right)d(\cos\phi - 1) = \pm(2m+1)\pi$$

$$\text{i.e. } \cos\phi - 1 = \pm(2m+1)\frac{\lambda}{2nd}$$

Note that value of (cosυ-1) is always less than 1. Hence it is always negative. Hence only considering -ve values, R.H.S., we get

$$\cos\phi - 1 = -(2m+1)\frac{\lambda}{2nd}$$

$$\text{i.e.} \quad \cos\phi = 1 - (2m+1)\frac{\lambda}{2nd}$$

$$\text{i.e.} \quad \boxed{\phi = \cos^{-1}\left[1 - \frac{(2m+1)\lambda}{2nd}\right]} \quad \ldots(18)$$

5. Beam width of Major Lobe

Beam width is defined as the angle between first nulls. Alternatively beam width is the angle equal to twice the angle between first null and the major lobe maximum direction.
From equation (16) we get,

$$\phi_{min} = 2\sin^{-1}\left[\pm\sqrt{\frac{m\lambda}{2nd}}\right] \quad ...(19)$$

$$\therefore \quad \sin\frac{\phi_{min}}{2} = \pm\sqrt{\frac{m\lambda}{2nd}}$$

υ_{min} is very low

Hence sin $\upsilon_{min}/2 \approx \upsilon_{min}/2$

$$\frac{\phi_{min}}{2} = \pm\sqrt{\frac{m\lambda}{2nd}}$$

$$\phi_{min} = \pm\sqrt{\frac{4m\lambda}{2nd}} = \pm\sqrt{\frac{2m\lambda}{nd}} \quad ...(20)$$

But nd≈ (n-1)d if n is very large. This L= (nd) indicates total length of the array. So equation (20) becomes,

$$\phi_{min} = \pm\sqrt{\frac{2m\lambda}{L}} = \pm\sqrt{\frac{2m}{L/\lambda}} \quad ...(21)$$

BWFN is given by,

$$\boxed{BWFN = 2\phi_{min} = \pm 2\sqrt{\frac{2m}{L/\lambda}}} \quad ...(22)$$

BWFN in degree is expressed as

$$BWFN = \pm 2\sqrt{\frac{2m}{L/\lambda}} \times 57.3 = \pm 114.6\sqrt{\frac{2m}{L/\lambda}} \text{ degree}$$

For m=1,

$$\boxed{BWFN = \pm 2\sqrt{\frac{2}{L/\lambda}} \text{ rad} = 114.6\sqrt{\frac{2}{L/\lambda}} \text{ degree}} \quad ...(23)$$

6. Directivity

The directivity in case of endfire array is defined as,

$$G_{Dmax} = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}} = \frac{U_{max}}{U_{avg}} = \frac{U_{max}}{U_0} \quad ...(23)$$

where, U_0 is average radiation intensity which is given by, For endfire array, U_{max} =1and $U_0 = \frac{\pi}{2n\beta d}$

$$\therefore \quad G_{Dmax} = \frac{1}{\frac{\pi}{2n\beta d}} = \frac{2n\beta d}{\pi}$$

$$\therefore \quad G_{Dmax} = 2n\left(\frac{2\pi}{\lambda}\right)\cdot\frac{d}{\pi}$$

$$\therefore \quad \boxed{G_{Dmax} = 4\left(\frac{nd}{\lambda}\right)} \qquad \ldots(24)$$

The total length of the array is given by, L = (n - 1) d ≈ nd, if n is very large. Hence the directivity can be expressed in terms of the total length of the array as,

$$\therefore \quad \boxed{G_{Dmax} = 4\left(\frac{L}{\lambda}\right)} \qquad \ldots(25)$$

Multiplication of patterns

In the previous sections we have discussed the arrays of two isotropic point sources radiating field of constant magnitude. In this section the concept of array is extended to non-isotropic sources. The sources identical to point source and having field patterns of definite shape and orientation. However, it is not necessary that amplitude of individual sources is equal. The simplest case of non-isotropic sources is when two short dipoles are superimposed over the two isotopic point sources separated by a finite distance. If the field pattern of each source is given by

$$E_0 = E_1 = E_2 = E' \sin\theta$$

Then the total far-field pattern at point P becomes

$$E_T = 2E_0 \cos\left(\frac{\psi}{2}\right) = 2E' \sin\theta \cos\left(\frac{\psi}{2}\right) \Rightarrow E_{Tn} = \sin\theta \cos\left(\frac{\psi}{2}\right) \qquad \ldots(1)$$

$$E_{Tn} = E(\theta) \times \cos\left(\frac{\psi}{2}\right)$$

where

$$\psi = \left(\frac{2\pi d}{\lambda} \cos\theta + \alpha\right)$$

Equation (1) shows that the field pattern of two non-isotropic point sources (short dipoles) is equal to product of patterns of individual sources and of array of point sources. The pattern of array of two isotropic point sources, i.e., cos υ/2 is widely referred as an array factor. That is

E_T= E (Due to reference source) x Array factor **...(2)**

This leads to the principle of pattern multiplication for the array of identical elements. In general, the principle of pattern multiplication can he stated as follows:

The resultant field of an array of non-isotropic hut similar sources is the product of the fields of individual source and the field of an array of isotropic point sources, each located at the phase centre of individual source and hating the relative amplitude and phase. The total phase is addition of the phases of the individual source and that of isotropic point sources. The same is true for their respective patterns also.

The normalized total field (i.e., E_{Tn}), given in Eq. (1), can re-written as

$$E = E_1(\theta) \times E_2(\theta)$$

where $E_1(\theta) = \sin\theta$ = Primary pattern of array

$$E_2(\theta) = \cos\left(\frac{2\pi d}{\lambda}\cos\theta + \alpha\right)$$ = Secondary pattern of array.

Thus the principle of pattern multiplication is a speedy method of sketching the field pattern of complicated array. It also plays an important role in designing an array. There is no restriction on the number of elements in an array; the method is valid to any number of identical elements which need not have identical magnitudes, phase and spacing between then). However, the array factor varies with the number of elements and their arrangement, relative magnitudes, relative phases and element spacing. The array of elements having identical amplitudes, phases and spacing provides a simple array factor. The array factor does not depend on the directional characteristic of the array elements; hence it can be formulated by using pattern multiplication techniques. The proper selection of the individual radiating element and their excitation are also important for the performance of array. Once the array factor is derived using the point-source array, the total field of the actual array can be obtained using Eq.(2).

Example(Beyond the Syllabus)

Using the concept of principle of pattern multiplication, find the radiation pattern of the four-element array separated at λ/2 as shown in Fig.12(a).

Fig. 12(a)

Solution: To solve this problem. we have to consider the case of binomial array. Let us consider that we have a linear array that consists of three elements which are physically placed away d = λ/2 and each element is excited in phase (δ= 0), the excitation of the centre element is twice as large as that of the outer two elements /see Fig. 12(b)

i.

Fig. 12(b)

The choice of this distribution of excitation amplitudes is based on the fact that 1:2:1 are the leading terms of a binomial series. Corresponding array which could be generalized to include more elements is called a binomial array. As the excitation at the centre element is twice that of the outer two elements, it can be assumed that this three-element array is equivalent to two-element array that are away by a distance d = λ/2 from each other. If so, equation

$$F(\theta, \phi) = \frac{\sin\left(\frac{N\psi}{2}\right)}{N \sin\left(\frac{\psi}{2}\right)}$$

can be used for N = 2, where it is interpreted to be the radiation pattern of this new element, i.e.,

$$F(\theta, \phi) = \frac{\sin\psi}{2\sin\left(\frac{\psi}{2}\right)} = \cos\left(\frac{\psi}{2}\right) = \cos\left(\frac{\beta d\cos\theta}{2}\right) = \cos\left(\frac{\pi\cos\theta}{2}\right)$$

i.e..the array factor of these elements is the same as the radiation pattern of one of the elements. Therefore from pattern multiplication principle, the magnitude of the far-field radiated electric field from this structure can be given by

$$F(\theta, \phi) = \cos^2\left(\frac{\pi\cos\theta}{2}\right)$$

Hence in general, for an array of n-elements:

$$F(\theta, \phi) = \cos^{n-1}\left(\frac{\pi\cos\theta}{2}\right)$$

Therefore, in given question, the array could be replaced by an array of two elements containing three sub-elements (1:2:1), each and new array will have the individual excitation (1:3:3:1), and

$$F(\theta, \phi) = \cos\left(\frac{\pi\cos\theta}{2}\right)\cos^2\left(\frac{\pi\cos\theta}{2}\right) = \cos^3\left(\frac{\pi\cos\theta}{2}\right)$$

Three patterns are possible:

(a) The element pattern: $\cos\left(\frac{\pi\cos\theta}{2}\right)$

(b) Array factor: $\cos^2\left(\frac{\pi\cos\theta}{2}\right)$

(c) The array pattern: $\cos^3\left(\frac{\pi\cos\theta}{2}\right)$

The radiation patterns are shown in Fig. 12(c).

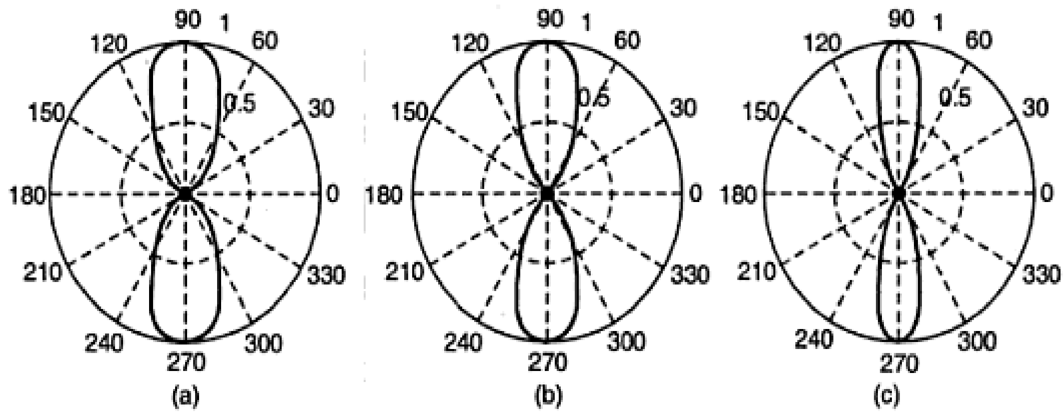
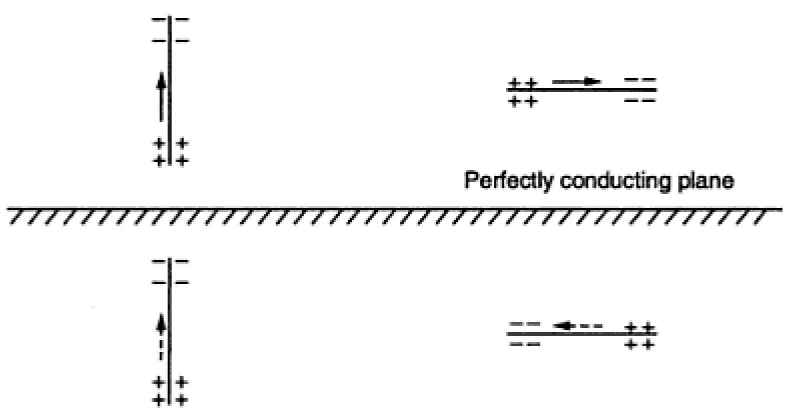


Fig. 12(c) Radiation pattern of 4-element array separated at a distance d = λ/2.

<u>Effect Of Ground On Antenna</u>

In general, it is assumed that radiators are fixed far away from the earth surface: but in practice they are erected right at or within a few λ off the earth surface. Under such situations, currents flow in the reflecting surface which magnitude and phase depends upon frequency, conductivity and dielectric constant of reflecting surface. These induced currents modify the radiation pattern of antenna accordingly. For the practical purposes, the resultant radiation fields are often computed on the assumption that reflecting surfaces are perfectly conducting. However, this computation is limited up to medium frequencies for the earth as reflecting surface, and radio frequency for the metallic reflector surface. The horizontal and vertical antennas located above perfect ground are shown in Fig. 13(a).



(i) Vertical antenna (ii) Horizontal antenna

FIG. 13(a) Actual and image charges and current of antennas.

According to boundary conditions the E_T and H_N must vanish, i.e., at the surface E is normal and H is tangential. Hence the charge distribution and currents flow on conducting surface would be in such a way that boundary condition is satisfied. Therefore, the total electric and magnetic fields will not be only due to charges and currents on the antenna, but also due to these induced charges and currents. The E and H above the conducting plane can be obtained by removing this plane and replacing it by suitably located images and currents; the image charges will be mirror images of actual charges. but are opposite nature. The currents in original and image antennas will have the same direction for vertical antennas, but opposite direction for horizontal antennas. The present case can be dealt with simple ray theory, where resultant field is considered as made up of direct and reflected waves. Actual antenna and image antenna will be the sources of direct and reflected waves. The vertical component of E for the incident wave is reflected without phase reversal, whereas horizontal component will have phase reversal of 180°. The phase delay due to path difference is automatically controlled.

Therefore, using image theory, it is simple to take into account the effect of earth on the radiation pattern. The earth is replaced by an image antenna, located at a distance below 2h, where h is the height of actual antenna above the earth. The field of image antenna is added to that of the actual antenna and obtain the resultant field. The shape of the vertical pattern is affected greatly, whereas horizontal pattern found remains unchanged (only the absolute value changes).The effect of the earth on the radiation pattern can also be explained using the principle of pattern multiplication of array theory [see Fig. 13(b)]. The vertical pattern of the antenna (or array) is multiplied by the vertical pattern of two non-directional radiations of equal amplitude and 2hspacing.

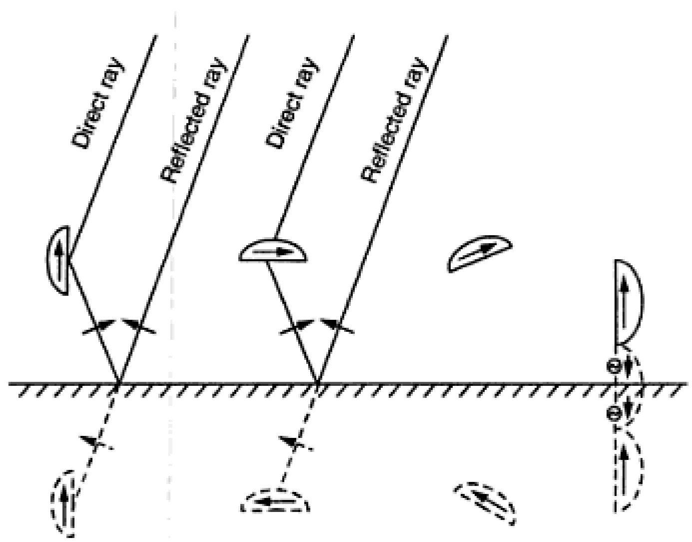


Fig. 13(b) Direct and reflected rays from actual and image antennas.

In case of vertical antenna pattern there will be equal phase, whereas there will be opposite phase for the horizontal antenna. That is, vertical antenna may be treated as broadside array and horizontal antenna array as end-fire array.

Binomial Array

In order to increase the directivity of an array its total length need to be increased. In this approach, number of minor lobes appears which are undesired for narrow beam applications. In has been found that number of minor lobes in the resultant pattern increases whenever spacing between elements is greater than λ/2. As per the demand of modern communication where narrow beam (no minor lobes) is preferred, it is the greatest need to design an array of only main lobes. The ratio of power density of main lobe to power density of the longest minor lobe is termed side lobe ratio. A particular technique used to reduce side lobe level is called tapering. Since currents/amplitude in the sources of a linear array is non-uniform, it is found that minor lobes can be eliminated if the centre element radiates more strongly than the other sources. Therefore tapering need to be done from centre to end radiators of same specifications. The principle of tapering are primarily intended to broadside array but it is also applicable to end-fire array. Binomial array is a common example of tapering scheme and it is an array of n-isotropic sources of non-equal amplitudes. Using principle of pattern multiplication, John Stone first proposed the binomial array in 1929, where amplitude of the radiatingsourcesarcarrangedaccordingtothebinomialexpansion.Thatis.ifminorlobes appearing in the array need to be eliminated, the radiating sources must have current amplitudes proportional to the coefficient of binomial series, i.e. proportional to the coefficient of binomial series, i.e.

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

where n is the number of radiating sources in the array.

For an array of total length nλ/2, the relative current in the nth element from the one end is given by

$$= \frac{n!}{r!(n-r)!}$$

where r = 0, 1, 2, 3, and the above relation is equivalent to what is known as Pascal's triangle. For example, the relative amplitudes for the array of 1 to 10 radiating sources are as follows:

No. of sources	*Pascal's triangle*
$n = 1$	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

Since in binomial array the elements spacing is less than or equal to the half-wave length, the HPBW of the array is given by

$$\text{HPBW} = \frac{10.6}{\sqrt{n-1}} = \frac{1.06}{\sqrt{\frac{2L}{\lambda}}} = \frac{0.75}{\sqrt{L_\lambda}}$$

and directivity

$$D_0 = 1.77\sqrt{n} = 1.77\sqrt{1+2L_\lambda}$$

Since in binomial array the elements spacing is less than or equal to the half-wave length, the HPBW of the array is given by

Using principle of multiplication, the resultant radiation pattern of an n-source binomial array is given by

$$E_n = \cos^{n-1}\left(\frac{\pi}{2}\cos\theta\right)$$

In particular, if identical array of two point sources is superimposed one above other, then three effective sources with amplitude ratio 1:2:1 results. Similarly, in case three such elements are superimposed in same fashion, then an array of four sources is obtained whose current amplitudes are in the ratio of 1:3:3:1.

The far-field pattern can be found by substituting n = 3 and 4 in the above expression and they take shape as shown in Fig. 14(a) and(b).

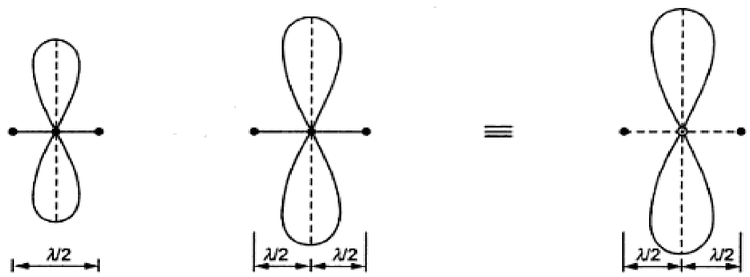


Fig. 14(a) Radiation pattern of 2-element array with amplitude ratio 1:2:1.

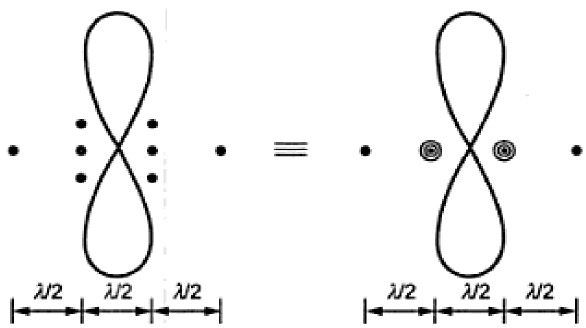


Fig 14(b) Radiation pattern of 3-element array with amplitude ratio 1:3:3:1.

It has also been noticed that binomial array offers single beam radiation at the cost of directivity, the directivity of binomial array is greater than that of uniform array for the same length of the array. In other words, in uniform array secondary lobes appear, but principle lobes are narrower than that of the binomial array.

Disadvantages of Binomial Array

(a) The side lobes are eliminated but the directivity of array reduced.

(b) As the length of array increases, larger current amplitude ratios are required.

phased array

In antenna theory, a phased array usually means an electronically scanned array; a computer-controlled array of antennas which creates a beam of radio waves which can be electronically steered to point in different directions, without moving the antennas. In an array antenna, the radio frequency current from the transmitter is fed to the individual antennas with the correct phase relationship so that the radio waves from the separate antennas add together to increase the radiation in a desired direction, while cancelling to suppress radiation in undesired directions. In a phased array, the power from the transmitter is fed to the antennas through devices called phase shifters, controlled by a computer system, which can alter the phase electronically, thus steering the beam of radio waves to a different direction. Since the array must consist of many small antennas (sometimes thousands) to achieve high gain, phased arrays are mainly practical at the high frequency end of the radio spectrum, in the UHF and microwave bands, in which the antenna elements are conveniently small.

Phased arrays were invented for use in military radar systems, to scan the radar beam quickly across the sky to detect planes and missiles. These phased array radar systems are now widely used, and phased arrays are spreading to civilian applications. The phased array principle is also used in acoustics, and phased arrays of acoustic transducers are used in medical imaging scanners (phased array ultrasonic), oil and gas prospecting(reflection seismology), and military sonar systems. The term is also used to a lesser extent for unsteered array antennas in which the phase of the feed power and thus the radiation pattern of the antenna is fixed.[6][9] For example, AM broadcast radio antennas consisting of multiple mast radiators fed so as to create a specific radiation pattern are also called "phased arrays".

Different Types of phased array:

There are two main types of beam formers. These are time domain beam formers and frequency domain beam formers. A graduated attenuation window is sometimes applied across the face of the array to improve side-lobe suppression performance, in addition to the phase shift. Time domain beam former works by introducing time delays. The basic operation is called "delay and sum". It delays the incoming signal from each array element by a certain amount of time, and then adds them together. The most common kind of time domain beam former is serpentine waveguide. Active phase array uses individual delay lines that are switched on and off. Yttrium iron garnet phase shifters vary the phase delay using the strength of a magnetic field.

There are two different types of frequency domain beam formers.

The first type separates the different frequency components that are present in the received signal into multiple frequency bins (using either an Discrete Fourier transform (DFT) or a filter bank). When different delay and sum beam formers are applied to each frequency bin, the result is that the main lobe simultaneously points in multiple different directions at each of the different frequencies. This can be an advantage for communication links, and is used with the SPS-48 radar.

The other type of frequency domain beam former makes use of Spatial Frequency. Discrete samples are taken from each of the individual array elements. The samples are processed using a DFT. The DFT introduces multiple different discrete phase shifts during processing. The outputs of the DFT are individual channels that correspond with evenly spaced beams formed simultaneously. A 1-dimensional DFT produces a fan of different beams. A 2-dimensional DFT produces beams with a pineapple configuration.

These techniques are used to create two kinds of phase array.

- Dynamic – an array of variable phase shifters are used to move the beam
- Fixed – the beam position is stationary with respect to the array face and the whole antenna is moved

There are two further sub-categories that modify the kind of dynamic array or fixed array.

- Active – amplifiers or processors in each phase shifter element
- Passive – large central amplifier with attenuating phase shifters

Dynamic phased array

Each array element incorporates an adjustable phase shifter that are collectively used to move the beam with respect to the array face. Dynamic phase array require no physical movement to aim the beam. The beam is moved electronically. This can produce antenna motion fast enough to use a small pencil-beam to simultaneously track multiple targets while searching for new targets using just one radar set (track while search).As an example, an antenna with a 2 degree beam with a pulse rate of 1 kHz will require approximately 8 seconds to cover an entire hemisphere consisting of 8,000 pointing positions. This configuration provides 12 opportunities to detect a 1,000 m/s (2,200 mph; 3,600 km/h) vehicle over a range of 100 km (62 mi), which is suitable for military applications.[citation needed]

The position of mechanically steered antennas can be predicted, which can be used to create electronic countermeasures that interfere with radar operation. The flexibility resulting from phase array operation allows beams to be aimed at random locations, which eliminates this vulnerability. This is also desirable for military applications.

Fixed phase array

An antenna tower consisting of a fixed phase collinear antenna array with four elements. Fixed phase array antennas are typically used to create an antenna with a more desirable form factor than the conventional parabolic reflector or cassegrain reflector. Fixed phased arrays incorporate fixed phase shifters. For example, most commercial FM Radio and TV antenna towers use a collinear antenna array, which is a fixed phased array of dipole elements.

In radar applications, this kind of phase array is physically moved during the track and scan process. There are two configurations.

- Multiple frequencies with a delay-line
- Multiple adjacent beams

The SPS-48 radar uses multiple transmit frequencies with a serpentine delay line along the left side of the array to produce vertical fan of stacked beams. Each frequency experiences a different phase shift as it propagates down the serpentine delay line, which forms different beams. A filter bank is used to split apart the individual receive beams. The antenna is mechanically rotated.

Semi-active radar homing uses monopulse radar that relies on a fixed phase array to produce multiple adjacent beams that measure angle errors. This form factor is suitable for gimbal mounting in missile seekers.

Active phase array

Active Electronically Scanned Arrays (AESA) elements incorporate transmit amplification with phase shift in each antenna element (or group of elements). Each element also includes receive pre-amplification. The phase shifter setting is the same for transmit and receive.

Active phase array do not require phase reset after the end of the transmit pulse, which is compatible with Doppler radar and Pulse-Doppler radar.

Passive phase array

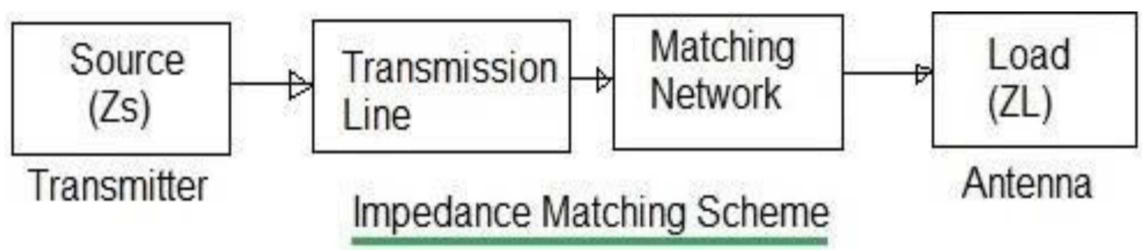
Passive phased arrays typically use large amplifiers that produce all of the microwave transmit signal for the antenna. Phase shifters typically consist of waveguide elements that contain phase shifters controlled by magnetic field, voltage gradient, or equivalent technology.

The phase shift process used with passive phase array typically puts the receive beam and transmit beam into diagonally opposite quadrants. The sign of the phase shift must be inverted after the transmit pulse is finished and before the receive period begins to place the receive beam into the same location as the transmit beam. That requires a phase impulse that degrades sub-clutter visibility performance on Doppler radar and Pulse-Doppler radar. As an example, garnet phase shifters must be changed after transmit pulse quench and before receiver processing starts to align transmit and receive beams. That impulse introduces FM noise that degrades clutter performance.

Whatisimpedance matching?

This topic covers impedance matching circuits, methods and devices. Impedance matching circuits are L network, pi network, split capacitor network, trans match circuit etc. Impedance matching devices include coaxial cable balun transformer, matching stubs, quarter wavelength transformer, series matching section etc.

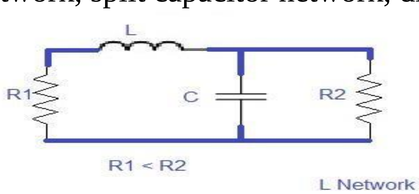
Let us understand **impedance matching** with the example of antenna used for radio frequency transmission. The common setup here is RF transmitter is connected with transmission line and transmission line is connected with RF antenna. In order to have maximum power transfer using this setup, output impedance of transmitter should match with transmission line impedance and transmission line impedance should match with the antenna feed impedance. In order to achieve impedance matching various circuits and methods are used.



As antenna impedance consists of both resistive and reactive components and hence matching network should have both of these elements in order to provide matching. In order to match resistive source with the complex load impedance matching network with complex conjugate of complex load impedance is needed. For example, if load impedance is R+j*X then matching network should have impedance of R-j*X and vice versa.

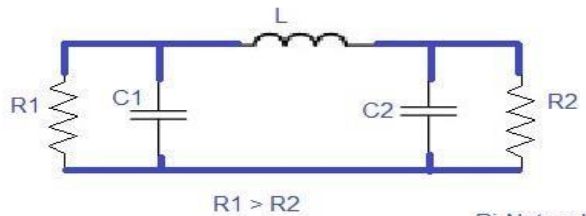
Impedance matching circuits

In this section, we will understand various **impedance matching circuits** such as L network, Pi network, split capacitor network, different transmatch circuits etc.



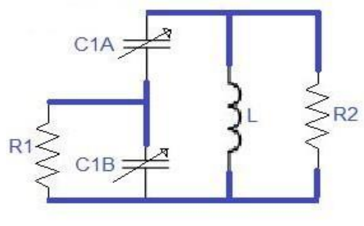
L Network:

The L network is one of the most commonly used antenna matching network. Different L sections exist such as inverted L section and reverse L section networks.



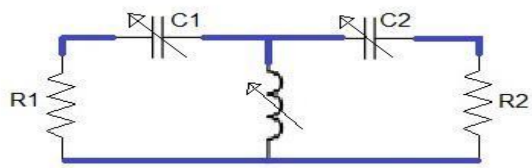
Pi-Network

Pi Network:
The Pi network is used to match high source impedance to the low load impedance. These circuits are commonly used in vacuum tube RF power amplifiers which requires to match with low value antenna impedances.



Split Capacitor N/W

Split Capacitor Network:
This network type is used to transform source impedance which is less than load impedance.



Transmatch network- Tee Type

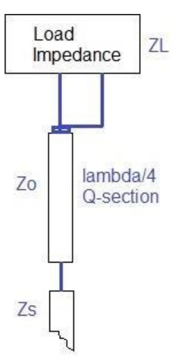
Transmatch Circuit:

This circuit is combination of split capacitor network and output tuning capacitor. This circuit is used for coaxial to coaxial impedance matching.

Matching stubs:

The shorted stub can be constructed which can produce reactance of any value. This can act as impedance matching device which cancels reactive part of complex impedance.

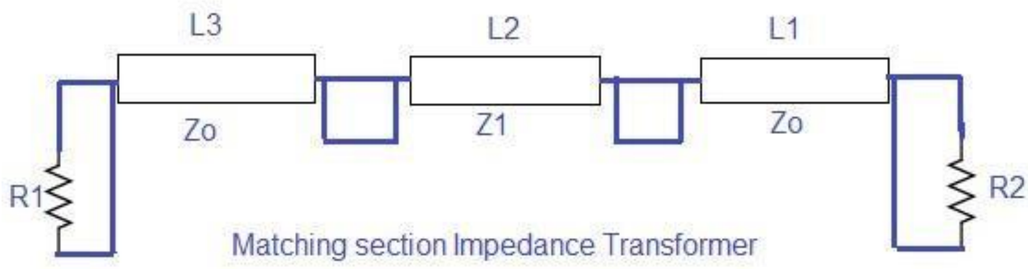
Example: If we have impedance of say Z=R+j*25 then we need stub with reactance value of -j25 Ohm to match it.



Impedance Transfomer

Quarter wavelength transformer:

The transformer as shown can be connected between transmission line and antenna load. This transformer is also known as Q-section. This transformer is capable of matching feedline impedance of Zs with antenna feed impedance of Zr. In order to have impedance matching, transmission line impedance of value Zo should be of value equal to $(Zs*Zr)^{0.5}$.



There are many disadvantages of quarter wavelength section as mentioned below.

• It should be located at the feed point of antenna.

• It must be of quarter wavelength long.

• Impedance value should be specified.

Series matching section:

This series matching section as shown in the figure overcomes the drawbacks mentioned above of the quarter wave transformer.

PART B

1. **What is meant by array.?**

An antenna is a system of similar antennas oriented similarly to get greater directivity in a desired direction.

2. **What is meant by uniform linear array.?**

An array is linear when the elements of the array are spaced equally along the straight line. If the elements are fed with currents of equal magnitude and having a uniform progressive phase shift along the line, then it is called uniform linear array .

3. **What are the types of array.?**

a. Broad side array.
b. End fire array
c. Collinear array.
d. Parasitic array.

4. **What is Broad side array.?**

Broad side array is defined as an arrangement in which the principal direction of radiation is perpendicular to the array axis and also the plane containing the array element

5. Define End fire array.?

End fire array is defined as an arrangement in which the principal direction of radiation is coincides with the array axis.

6. What is collinear array.?

In this array the antenna elements are arranged coaxially by mounting the elements end to end in straight line or stacking them one over the other with radiation pattern circular symmetry. Eg. Omnidirectional antenna.

7. What is Parasitic array.?

In this array the elements are fed parasitically to reduce the problem of feed line. The power is given to one element from that other elements get by electro magnetic coupling. Eg. Yagi uda antenna.

8. Define beam width of major lobe?

It is defined the angle between the first nulls (or) it is defined as twice the angle between the first null and the major lobe maximum direction.

9. What is the need for the Binomial array.?

The need for a binomial array is

i). In uniform linear array as the array length is increased to increase the directivity, the secondary lobes also occurs.

ii) For certain applications, it is highly desirable that secondary lobes should be eliminated completely or reduced to minimum desirable level compared to main lobes.

10. Define power pattern.?

Graphical representation of the radial component of the pointing vector Sr at a constant radius as a function of angle is called power density pattern or power pattern.

11. What is meant by similar Point sources.?

Whenever the variation of the amplitude and the phase of the field with respect to the absolute angle for any two sources are same then they are called similar point sources. The maximum amplitudes of the individual sources may be unequal.

12. What is meant by identical Point sources.?

Similar point sources with equal maximum amplitudes are called identical point sources.

13. What is the principle of the pattern multiplication?

The total field pattern of an array of non isotropic but similar sources is the product of the

i) individual source pattern and

ii) The array pattern of isotropic point sources each located at the phase center of the individual source having the same amplitude and phase. While the total phase pattern is the sum of the phase patterns of the individual source pattern and array pattern.

14. What is the advantage of pattern multiplication? ._

Useful tool in designing antenna ._It approximates the pattern of a complicated array without making lengthy computations

15. What is tapering of arrays?

Tapering of array is a technique used for reduction of unwanted side lobes .The amplitude of currents in the linear array source is non- uniform; hence the central source radiates more energy than the ends. Tapering is done from center to end.

16. What is a binomial array?

It is an array in which the amplitudes of the antenna elements in the array are arranged according to the coefficients of the binomial series.

17. What are the advantages of binomial array?

Advantage: ._No minor lobes

Disadvantages: ._Increased beam width ._Maintaining the large ratio of current amplitude in large arrays is difficult

18. What is the difference between isotropic and nonisotropic source ._

Isotropic source radiates energy in all directions but non-isotropic source radiates energy only in some desired directions. ._Isotropic source is not physically realizable but non-isotropic source is physically realizable.

19. Define Side Lobe Ratio

Side Lobe Ratio is defined as the ratio of power density in the principal or main lobe to the power density of the longest minor lobe.

20. List the arrays used for array tapering .

_Binomial Array:Tapering follows the coefficient of binomial series

_Dolph Tchebycheff Array: Tapering follows the coefficient of Tchebycheff polynomial

PART C

1. Write a note on antenna arrays. Mention the factors on which the resultant pattern of array depends.
2. Derive an expression for electric field intensity of array of n isotropic sources of equal amplitude and spacing and having a phase difference of 90 degree.
3. Explain the principle of pattern multiplication.
4. Obtain the electric field intensity of non isotropic but similar point sources.
5. Obtain the radiation pattern of 4 sources forming a uniform BSA with a spacing of $\lambda/2$.
6. 4 sources have equal magnitude & are spaced $\lambda/2$ apart. Maximum field is to be in line with sources. Plot the field pattern of the array
7. Find BWFN for uniform EFA & extended EFA. Given (i) n=4 (ii) d= $\lambda/2$.
8. The principle lobe width of uniform 10 elements of BSA was observed to be 30^{o} at a frequency of 30MHz. Estimate the distance between the individual elements of the array.
9. A uniform linear array consists of 16 isotropic sources with a spacing of $\lambda/4$ & phase

difference $\varphi = -90^{o}$. Calculate HPBW & effective aperture.

10. The main lobe width of 8 elements of BSA was observed to be 45^{o} at a frequency of 20MHz. Estimate the distance. N=8.
11. An EFA is composed of elements with the axis at right angles to the line of the array is required to have a power gain of 20. Calculate the array length and width of the major lobe between the nulls.
12. Calculate exact & approximate BWFN for BSA given n=4 & d= $\lambda/2$.
13. A BSA operating at 200cm wavelength consists of 4 dipoles spaced $\lambda/2$ apart & having $R_r = 73\Omega$. Each element carries radio frequency in same phase & of magnitude 0.5 A. Calculate (i) radiated power. (ii) HPBW.
14. Complete the field pattern & find BWFN & HPBW for a linear uniform array of 6 isotropic sources spaced $\lambda/2$ apart. The power is applied with equal amplitude and in phase.
15. An array of 4 isotropic antennas is placed along a straight line. Distance between the elements is $\lambda/2$. The peak is to be obtained in the direction from the axis of the array. What should be the phase difference between the adjacent elements? Compute the pattern and find BWFN & HPBW.
16. a)Obtain the Maxima, Minima and half power directions of radiated field of 2 identical isotropic point sources spaced 'd' apart and i) Fed with current of equal magnitude and same phase ii) fed with current of equal magnitude and opposite phase.
17. b) Find the direction of pattern maxima, pattern minima for an array of n sources with equal amplitude and spacing in broadside case.
    ii) Explain array of non uniform excitation with neat diagrams.
18. i)Explain the principle of pattern multiplication with neat diagrams.
    ii) Design a 4 element, broadside array of isotropic elements spaced $\lambda/2$ apart that has an array factor with all the side lobes 25 dB below the main lobe
19. An antenna array consists of two identical isotropic radiators spaced by a distance of $d=\lambda/4$ meters and fed with currents of equal magnitude but with a phase difference β. Evaluate the resultant radiation for $\beta=0^{o}$ and thereby identify the direction of maximum radiation.
20. Derive the expression for field pattern of end-fire array of n sources of equal amplitude and spacing
21. Expression for the radiation pattern of a broadside array with n-point sources.
22. Expression for the radiation pattern of a end fire array with n-point sources.
23. Explain the principle of pattern multiplication with two examples.
24. Derive the expression for the radiation pattern of a broadside array with two point sources.
25. Derive the expression for the radiation pattern of a end fire array with two point source

UNIT III

SPECIAL PURPOSE ANTENNAS

UNIT III-SPECIAL PURPOSE ANTENNAS

Travelling wave – Loop – small loop – Dipole and Folded dipole antennas – Horn antenna – Reflector antenna – Yagi–Uda antenna – Log periodic antenna – Helical and Micro strip antennas. Introduction to CAD tools used for antenna modeling.

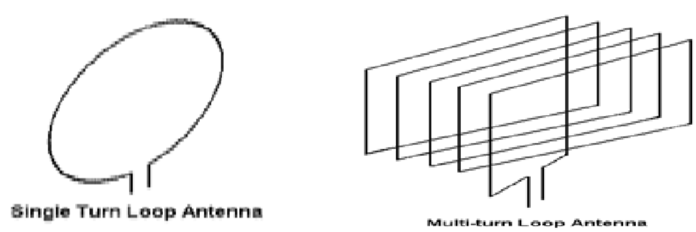
LOOP ANTENNAS

All antennas have used radiating elements that were linear conductors. It is also possible to make antennas from conductors formed into closed loops. There are two broad categories of loop antennas:

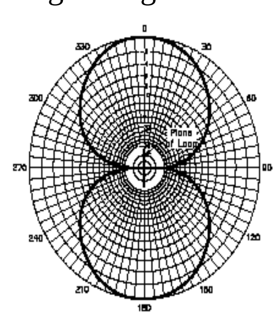
1. Small loops, which contain no more than 0.085 wavelengths of wire
2. Large loops, which contain approximately 1 wavelength of wire.

SMALL LOOP ANTENNAS

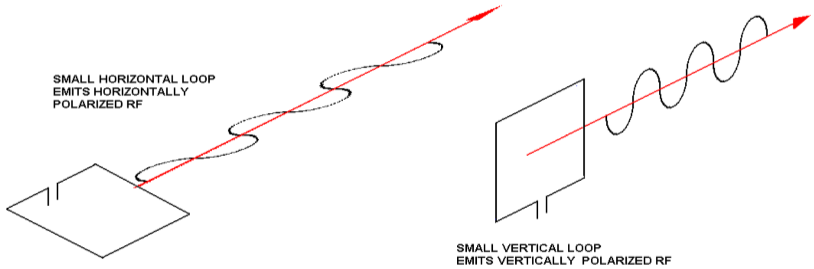
A small loop antenna is one whose circumference contains no more than 0.085 wavelengths of wire. In such a short conductor, we may consider the current, at any moment in time to be constant. This is quite different from a dipole, whose current was a maximum at the feed point and zero at the ends of the antenna. The small loop antenna can consist of a single turn loop or a multi-turn loop as shown below:



The radiation pattern of a small loop is very similar to a dipole. The figure below shows a 2-dimensional slice of the radiation pattern in a plane perpendicular to the plane of the loop. There is no radiation from a loop along the axis passing through the center of the loop, as shown below.



When the loop is oriented vertically, the resulting radiation is vertically polarized and vice versa:



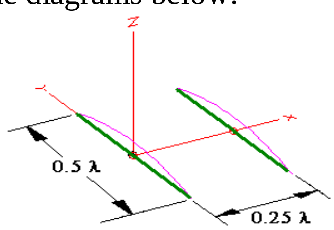
The input impedance of a small loop antenna is inductive, which makes sense, because the small loop antenna is actually just a large inductor. The real part of the input impedance is very small, on the order of 1 ohm, most of which is loss resistance in the conductor making up the loop. The actual radiation resistance may be 0.5 ohms or less. Because the radiation resistance is small compared to the loss resistance, the small loop antenna is not an efficient antenna and cannot be used for transmitting unless care is taken in its design and manufacture.

While the small loop antenna is not necessarily a good antenna, it makes a good receiving antenna, especially for LF and VLF. At these low frequencies, dipole antennas are too large to be easily constructed (in the LF range, a dipole's length ranges from approximately 1600 to 16,000 feet, and VLF dipoles can be up to 30 miles long!) making the small loop a good option. The small loop responds to the magnetic field component of the electromagnetic wave and is deaf to most man-made interference, which has a strong electric field. Thus the loop, although it is not efficient, picks up very little noise and can provide a better SNR than a dipole. It is possible to amplify the loop's output to a level comparable to what one might receive from a dipole.

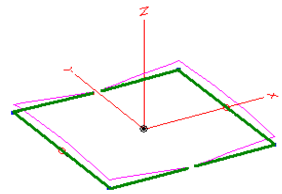
When a small loop is used for receiving, its immunity and sensitivity may be improved by paralleling a capacitor across its output whose capacitance will bring the small loop to resonance at the desired receive frequency. Antennas of this type are used in AM radios as well as in LF and VLF direction finding equipment used on aircraft and boats.

LARGE LOOP ANTENNAS

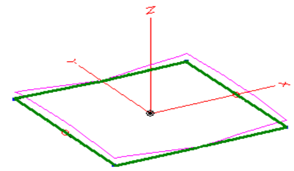
A large loop antenna consists of approximately 1 wavelength of wire. The loop may be square, circular, triangular or any other shape. Because the loop is relatively long, the current distribution along the antenna is no longer constant, as it was for the small loop. The current distribution and radiation pattern of a large loop can be derived by folding two half wave dipoles and connecting them as shown in the diagrams below:



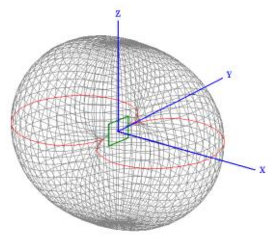
We begin with two λ/2 dipoles separated by λ/4. RF is fed into the center of each dipole. The resulting current distribution is shown below as a pink line. Note that the current is zero at the dipoles' ends. Now each dipole is folded in towards the other in a "U" shape as shown below. The current distribution has not changed - the antenna current is still zero at the ends.



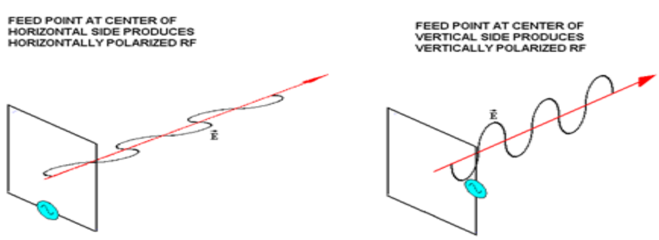
Since the current at the ends is zero, it would be OK to connect the ends to make a loop as shown below.



We have now created a square loop of wire whose circumference is 1 wavelength. From an electrical point of view, we have just shown that the large loop is equivalent to two bent dipole antennas. The radiation pattern of a loop antenna is shown below:



It is possible to create either horizontally or vertically polarized radiation with a large loop antenna. The polarization is determined by the location of the feed point as shown below. If the feed point is in a horizontal side of the loop, the polarization is horizontal. If the feed point is in a vertical side of the loop, the polarization is vertical.



So far we have looked at square loop antennas. One of the interesting things about the large loop antenna is that the shape is not important. As long as the perimeter of the antenna is approximately 1 wavelength, the loop antenna will produce a radiation pattern very similar to the one shown above. The shape of the loop may be circular, square, triangular, rectangular, or any other polygonal shape. While the shape of the radiation pattern is not dependent on the shape of the loop, the gain of the loop does depend on the shape. In particular, the gain of the loop is dependent on the area enclosed by the wire. The enclosed area are increased gain also increased. The circular loop has the largest gain and the triangular loop has the least.

Loop antennas may be combined to form arrays in the same manner as dipoles. Arrays of loop antennas are called "quad arrays" because the loops are most often square. The most common type of quad array is a Yagi-Uda array using loops rather than dipoles as elements. This type of array is very useful at high elevations, where the combination of high voltage at the element tips of the dipoles in a standard Yagi array and the lower air pressure lead to corona discharge and erosion of the element

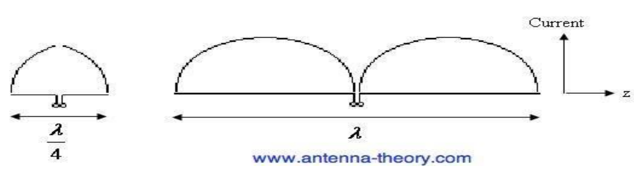
The input impedance of a loop depends on its shape. It ranges from approximately 100 ohms for a triangular loop to 130 ohms for a circular loop. Unlike the dipole, whose input impedance presents a good match to common 50 or 75 ohm.

Dipole Antenna

The dipole antenna with a very thin radius is considered. The dipole antenna is similar to the short dipole except it is not required to be small compared to the wavelength. For a dipole antenna of length L oriented along the z-axis and centered at z=0, the current flows in the z-direction with amplitude which closely follows the following function:

$$I(z) = \begin{cases} I_0 \sin\left[k\left(\frac{L}{2} - z\right)\right], & 0 \le z \le \frac{L}{2} \\ I_0 \sin\left[k\left(\frac{L}{2} + z\right)\right], & -\frac{L}{2} \le z \le 0 \end{cases}$$

Note that this current is also oscillating in time sinusoidal at frequency f. The current distributions for the quarter-wavelength (left) and full-wavelength (right) dipole antennas are given in Figure. Note that the peak value of the current IO is not reached along the dipole unless the length is greater than half a wavelength.



Current distributions on finite-length dipole antennas.

Before examining the fields radiated by a dipole antenna, consider the input impedance of a dipole as a function of its length, plotted in Figure 2 below. Note that the input impedance is specified as Z=R + jX, where R is the resistance and X is the reactance.

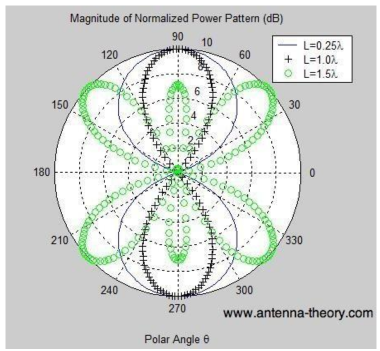
Radiation Patterns for Dipole Antennas

The far-fields from a dipole antenna of length L are given by

$$E_\theta = \frac{j\eta I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kL}{2}\cos\theta\right)-\cos\left(\frac{kL}{2}\right)}{\sin\theta}\right]$$

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

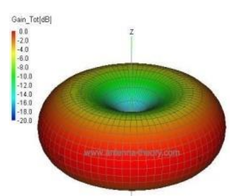
The normalized radiation patterns for dipole antennas of various lengths are shown in below Figure.



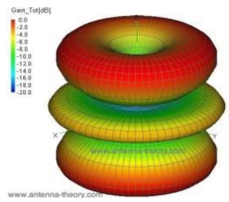
The full-wavelength dipole antenna is more directional than the shorter quarter-wavelength dipole antenna. This is a typical result in antenna theory: it takes a larger antenna in general to increase directivity. However, the results are not always obvious. The 1.5-wavelength dipole pattern is also plotted in Figure. Note that this pattern is maximum at approximately +45 and -45degrees.

The dipole antenna is symmetric when viewed azimuthally as a result the radiation pattern is not a function of the azimuthal angle ϕ. Hence, the dipole antenna is an example of an omni directional antenna. Further, the E-field only has one vector component and consequently the fields are linearly polarized. When viewed in the x-y plane (for a dipole oriented along the z-axis), the E-field is in the -y direction, and consequently the dipole antenna is vertically polarized.

The 3D pattern for the 1-wavelength dipole antenna is shown in below Figure. This pattern is similar to the pattern for the quarter- and half-wave dipole antenna.

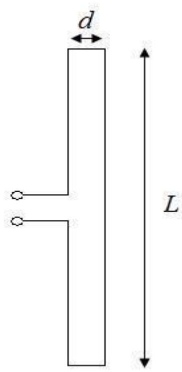


The 3D radiation pattern for the 1.5-wavelength dipole antenna is significantly different, and is shown in below Figure.



Folded dipole

A folded dipole is a dipole antenna with the ends folded back around and connected to each other, forming a loop as shown in Figure 1.



A Folded Dipole Antenna of length L.

Typically, the width d of the folded dipole antenna is much smaller than the length L. Because the folded dipole forms a closed loop, one might expect the input impedance to depend on the input impedance of a short-circuited transmission line of length L. However, you can imagine the folded dipole antenna as two parallel short-circuited transmission lines of length L/2 (separated at the midpoint by the feed in Figure 1). It turns out the impedance of the folded dipole antenna will be a function of the impedance of a transmission line of length L/2.

Also, because the folded dipole is "folded" back on itself, the currents can reinforce each other instead of cancelling each other out, so the input impedance will also depend on the impedance of a dipole antenna of length L. Letting Zd represent the impedance of a dipole antenna of length L and Zt represent the impedance of a transmission line impedance of length L/2, which is given by:

$$Z_t = jZ_0 \tan\frac{\beta L}{2}$$

The input impedance ZA of the folded dipole is given by:

$$Z_A = \frac{4Z_t Z_d}{Z_t + 2Z_d}$$

Horn antenna

Pyramidal microwave horn antenna, with a bandwidth of 0.8 to 18 GHz. A coaxial cable feed line attaches to the connector visible at top. This type is called a ridged horn; the curving fins visible inside the mouth of the horn increase the antenna's bandwidth.

A horn antenna or microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. Horns are widely used as antennas at UHF and microwave frequencies, above 300 MHz. They are used as feed antennas (called feed horns) for larger antenna structures such as parabolic antennas, as standard calibration antennas to measure the gain of other antennas, and as directive antennas for such devices as radar guns, automatic door openers, and microwave radiometers. Their advantages are moderate directivity, low standing wave ratio (SWR), broad bandwidth, and simple construction and adjustment.

An advantage of horn antennas is that since they have no resonant elements, they can operate over a wide range of frequencies, a wide bandwidth. The usable bandwidth of horn antennas is typically of the order of 10:1, and can be up to 20:1 (for example allowing it to operate from 1 GHz to 20 GHz). The input impedance is slowly varying over this wide frequency range, allowing low voltage standing wave ratio (VSWR) over the bandwidth. The gain of horn antennas ranges up to 25 dBi, with 10 - 20 dBi being typical.

Description

Pyramidal horn antennas for a variety of frequencies. They have flanges at the top to attach to standard waveguides. A horn antenna is used to transmit radio waves from a waveguide (a metal pipe used to carry radio waves) out into space, or collect radio waves into a waveguide for reception. It typically consists of a short length of rectangular or cylindrical metal tube (the waveguide), closed at one end, flaring into an open-ended conical or pyramidal shaped horn on the other end. The radio waves are usually introduced into the waveguide by a coaxial cable attached to the side, with the central conductor projecting into the waveguide to form a quarter-wave monopole antenna. The waves then radiate out the horn end in a narrow beam. In some equipment the radio waves are conducted between the transmitter or receiver and the antenna by a waveguide; in this case the horn is attached to the end of the waveguide. In outdoor horns, such as the feed horns of satellite dishes, the open mouth of the horn is often covered by a plastic sheet transparent to radio waves, to exclude moisture.

working Principle

Corrugated conical horn antenna used as a feed horn on a Hughes Direcway home satellite dish. A transparent plastic sheet covers the horn mouth to keep out rain. A horn antenna serves the same function for electromagnetic waves that an acoustical horn does for sound waves in a musical instrument such as a trumpet. It provides a gradual transition structure to match the impedance of a tube to the impedance of free space, enabling the waves from the tube to radiate efficiently into space. If a simple open-ended waveguide is used as an antenna, without the horn, the sudden end of the conductive walls causes an abrupt impedance change at the aperture, from the wave impedance in the waveguide to the impedance of free space, (about 377 ohms). When radio waves travelling through the waveguide hit the opening, this impedance-step reflects a significant fraction of the wave energy back down the guide toward the source, so that not all of the power is radiated. This is similar to the reflection at an open-ended transmission line or a boundary between optical mediums with a low and high index of refraction, like at a glass surface. The reflected waves cause standing waves in the waveguide, increasing the SWR, wasting energy and possibly overheating the transmitter. In addition, the small aperture of the waveguide (less than one wavelength) causes significant diffraction of the waves issuing from it, resulting in a wide radiation pattern without much directivity.

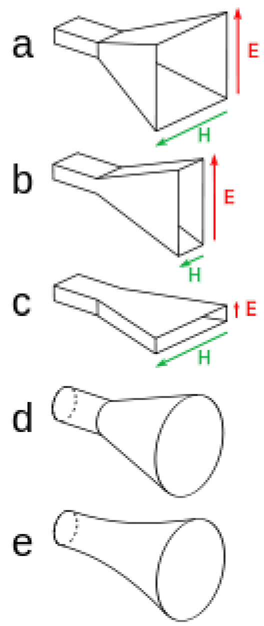
To improve these poor characteristics, the ends of the waveguide are flared out to form a horn. The taper of the horn changes the impedance gradually along the horn's length. This acts like an impedance matching transformer, allowing most of the wave energy to radiate out the end of the horn into space, with minimal reflection. The taper functions similarly to a tapered transmission line, or an optical medium with a smoothly varying refractive index. In addition, the wide aperture of the horn projects the waves in a narrow beam. The horn shape that gives minimum reflected power is an exponential taper. Exponential horns are used in special applications that require minimum signal loss, such as satellite antennas and radio telescopes. However conical and pyramidal horns are most widely used, because they have straight sides and are easier to design and fabricate.

Radiation pattern

The waves travel down a horn as spherical wave fronts, with their origin at the apex of the horn, a point called the phase center. The pattern of electric and magnetic fields at the aperture plane at the mouth of the horn, which determines the radiation pattern, is a scaled-up reproduction of the fields in the waveguide. Because the wave fronts are spherical, the phase increases smoothly from the edges of the aperture plane to the center, because of the difference in length of the center point and the edge points from the apex point. The difference in phase between the center point and the edges is called the phase error. This phase error, which increases with the flare angle, reduces the gain and increases the beam width, giving horns wider beam widths than similar-sized plane-wave antennas such as parabolic dishes.At the flare angle, the radiation of the beam lobe is down about -20 dB from its maximum value.

As the size of a horn (expressed in wavelengths) is increased, the phase error increases, giving the horn a wider radiation pattern. Keeping the beamwidth narrow requires a longer horn (smaller flare angle) to keep the phase error constant. The increasing phase error limits the aperture size of practical horns to about 15 wavelengths; larger apertures would require impractically long horns. This limits the gain of practical horns to about 1000 (30 dBi) and the corresponding minimum beam width to about 5 - 10°.

Types



Below are the main types of horn antennas. Horns can have different flare angles as well as different expansion curves (elliptic, hyperbolic, etc.) in the E-field and H-field directions, making possible a wide variety of different beam profiles. Pyramidal horn (a, right) – a horn antenna with the horn in the shape of a four-sided pyramid, with a rectangular cross section. They are a common type, used with rectangular waveguides, and radiate linearly polarized radio waves.

Sectorial horn(a)– A pyramidal horn with only one pair of sides flared and the other pair parallel. It produces a fan-shaped beam, which is narrow in the plane of the flared sides, but wide in the plane of the narrow sides. These types are often used as feed horns for wide search radar antennas.

E-plane horn (b) – A sectorial horn flared in the direction of the electric or E-field in the waveguide.

H-plane horn (c) – A sectorial horn flared in the direction of the magnetic or H-field in the waveguide.

Conical horn (d) – A horn in the shape of a cone, with a circular cross section. They are used with cylindrical waveguides.

Exponential horn (e) – A horn with curved sides, in which the separation of the sides increases as an exponential function of length. Also called a scalar horn, they can have pyramidal or conical cross sections. Exponential horns have minimum internal reflections, and almost constant impedance and other characteristics over a wide frequency range. They are used in applications requiring high performance, such as feed horns for communication satellite antennas and radio

telescopes.
Corrugated horn – A horn with parallel slots or grooves, small compared with a wavelength, covering the inside surface of the horn, transverse to the axis. Corrugated horns have wider bandwidth and smaller side lobes and cross-polarization, and are widely used as feed horns for satellite dishes and radio telescopes.
Dual-mode conical horn – (The Potter horn [15]) This horn can be used to replace the corrugated horn for use at sub-mm wavelengths where the corrugated horn is lossy and difficult to fabricate.
Diagonal horn – This simple dual-mode horn superficially looks like a pyramidal horn with a square output aperture. On closer inspection, however, the square output aperture is seen to be rotated 45° relative to the waveguide. These horns are typically machined into split blocks and used at sub-mm wavelengths.[16]
Ridged horn – A pyramidal horn with ridges or fins attached to the inside of the horn, extending down the center of the sides. The fins lower the cutoff frequency, increasing the antenna's bandwidth.
Septum horn – A horn which is divided into several sub horns by metal partitions (septums) inside, attached to opposite walls.
Aperture-limited horn – a long narrow horn, long enough so the phase error is a negligible fraction of a wavelength,[13] so it essentially radiates a plane wave. It has an aperture efficiency of 1.0 so it gives the maximum gain and minimum beam width for a given aperture size. The gain is not affected by the length but only limited by diffraction at the aperture.[13] Used as feed horns in radio telescopes and other high-resolution antennas.

Optimum horn

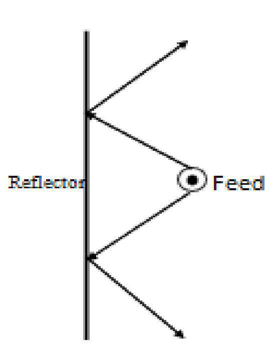
Corrugated horn antenna with a bandwidth of 3.7 to 6 GHz designed to attach to SMA waveguide feed line. This was used as a feed horn for a parabolic antenna on a British military base.

Gain

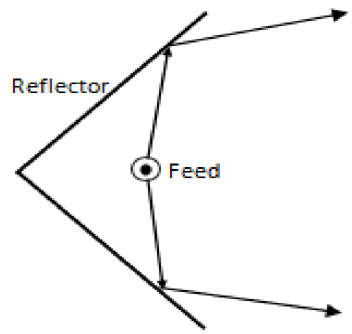
Horns have very little loss, so the directivity of a horn is roughly equal to its gain. The gain G of a pyramidal horn antenna (the ratio of the radiated power intensity along its beam axis to the intensity of an isotropic antenna with the same input power).The aperture efficiency ranges from 0.4 to 0.8 in practical horn antennas. For optimum pyramidal horns, e_A = 0.511., while for optimum conical horns e_A = 0.522. So an approximate figure of 0.5 is often used. The aperture efficiency increases with the length of the horn, and for aperture-limited horns is approximately unity.

REFLECTOR ANTENNAS

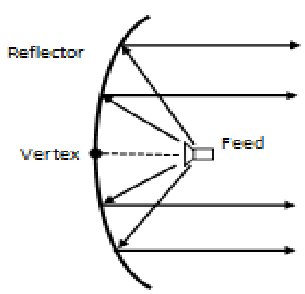
The radiation pattern of a radiating antenna element is modified using reflectors. A simple example is that the backward radiation from an antenna may be eliminated with a large metallic plane sheet reflector. So, the desired characteristics may be produced by means of a large, suitably shaped, and illuminated reflector surface. The characteristics of antennas with sheet reflectors or their equivalent are considered in this chapter. Some reflectors are illustrated in below Figure. The arrangement in Figure (a) has a large, flat sheet reflector near a linear dipole antenna to reduce the backward radiation. With small spacing between the antenna and sheet this arrangement also yields an increase in substantial gain in the forward radiation. The desirable properties of the sheet reflector may be largely preserved with the reflector reduced in size as long as its size is greater than that of the antenna.



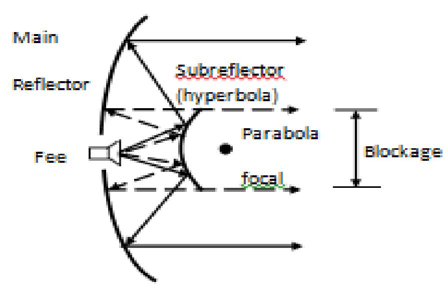
(a) Plane



(b) Corner



(c) Curved (front-fed)



(d) Curved (Cassegrain-feed)

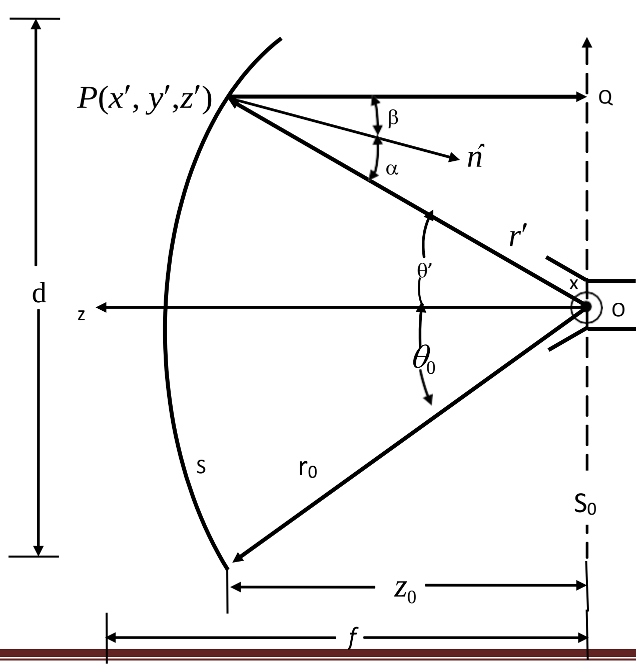
With two flat sheets intersecting at an angle α (<180°) as in Figure (b), a sharper radiation pattern than from a flat sheet reflector (α=180°) can be obtained. This arrangement, called corner reflector antenna, is most practical where apertures of 1 or 2 are of convenient size. A corner reflector without an exciting antenna can be used as a passive reflector or target for radar waves. In this application the aperture may be many wavelengths, and the corner angle is always 90 . Reflectors with this angle have the property that an incidence wave is reflected back toward its source, the corner acting as a retro reflector.

When it is feasible to build antennas with apertures of many wavelengths, parabolic reflectors can be used to provide highly directional antennas. A parabolic reflector antenna is shown in Figure (c). The parabola reflects the waves originating from a source at the focus into a parallel beam, the parabola transforming the curved wave front from the feed antenna at the focus into a plane wave front. A front fed and a cassegrain –feed parabolic reflectors are depicted in Figures (c) and (d). Many other shapes of reflectors can be employed for special applications. For instance, with an antenna at one focus, the elliptical reflector produces a diverging beam with all reflected waves passing through the second focus of the ellipse. Examples of reflectors of other shapes are the hyperbolic and the spherical reflectors.

The plane sheet reflector, the corner reflector, the parabolic reflector and other reflectors are discussed in more detail in the following sections. In addition, feed systems, aperture blockage, aperture efficiency, diffraction, surface irregularities, gain and frequency-selective surfaces are considered.

Front-Fed Parabolic Reflector

Parabolic cylinders have widely been used as high-gain apertures fed by line sources. The analysis of a parabolic cylinder (single curved) reflector is similar, but considerably simpler than that of a paraboidal (double curved) reflector. The surface of a paraboloidal reflector is formed by rotating a parabola about its axis. Its surface must be a paraboloid of revolution so that rays emanating from the focus of the reflector are transformed into plane waves. The design is based on optical techniques, and it does not take into account any deformations (diffractions) from the rim of the reflector. Referring to Figure 3.15 and choosing a plane perpendicular to the axis of the reflector through the focus, it follows that



Two-dimensional configuration of a paraboloidal reflector.

CASSEGRAINREFLECTORS

The disadvantage of the front-fed arrangement is that the transmission line from the feed must usually be long enough to reach the transmitting or the receiving equipment, which is usually placed behind or below the reflector. This may necessitate the use of long transmission lines whose losses may not be tolerable in many applications, especially in low-noise receiving systems. In some applications, the transmitting or receiving equipment is placed at the focal point to avoid the need for long transmission lines. However, in some of these applications, especially for transmission that may require large amplifiers and for low-noise receiving systems where cooling and weatherproofing may be necessary, the equipment may be too heavy and bulky and will provide un desirable blockage.

The arrangement that avoids placing the feed (transmitter and/or receiver) at the focal point is that shown in Figure (d) and it is known as the Cassegrain feed. Through geometrical optics, Cassegrain, a famous astronomer (N. Cassegrain of France, hence its name), showed that incident parallel rays can be focused to a point by utilizing two reflectors. To accomplish this, the main (primary) reflector must be a parabola, the secondary reflector (Sub reflector) a hyperbola, and the feed placed along the axis of the parabola usually at or near the vertex. Cassegrain used this scheme to construct optical telescopes, and then its design was copied for use in radio frequency systems. For this arrangement, the rays that emanate from the feed illuminate the Sub reflector and are reflected by it in the direction of the primary reflector, as if they originated at the focal point of the parabola (primary reflector). The rays are then reflected by the primary reflector and are converted to parallel rays, provided the primary reflector is a parabola and the sub reflector is a hyperbola. Diffraction occurs at the edges of the sub reflector and primary reflector and they must be taken into account to accurately predict the overall system pattern, especially in regions of low intensity. Even in regions of high intensity, diffraction must be included if an accurate formation of the fine ripple structure of the pattern is desired. With the Cassegrain-feed arrangement, the transmitting and/or receiving equipment can be placed behind the primary reflector. This scheme makes the system relatively more accessible for servicing and adjustments.

Cassegrain designs, employing dual reflector surfaces, are used in applications where pattern control is essential, such as in satellite ground-based systems, and have efficiencies of 65-80%. They supersede the performance of the single-reflector front-fed arrangement by about 10%. Using geometrical optics, the classical Cassegrain configuration, consisting of a paraboloid and hyperboloid, is designed to achieve a uniform phase front in the aperture of the paraboloid. By employing good feed designs, this arrangement can achieve lower spillover and more uniform illumination of the main reflector. In addition, slight shaping of one or both of the dual-reflector‘s surfaces can lead to an aperture with almost uniform amplitude and phase with substantial enhancement in gain. These are referred to as shaped reflectors. Shaping techniques have been employed in dual-reflectors used in earth station applications.

In general, the Cassegrain arrangement provides a variety of benefits, such as the

1.ability to place the feed in a convenient location
2.reduction of spillover and minor lobe radiation
3.ability to obtain an equivalent focal length much greater than the physical length
4.capability for scanning and/or broadening of the beam by moving one of the reflecting surfaces

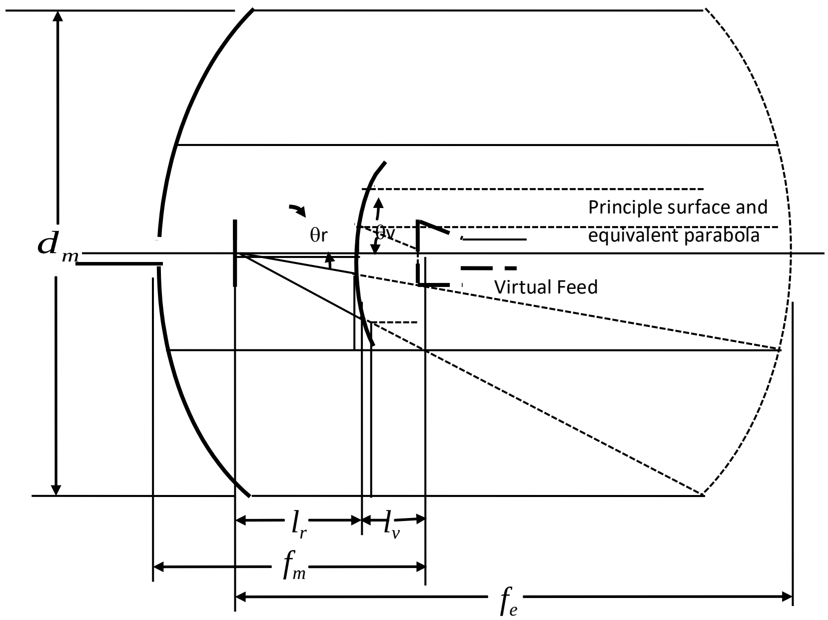


Figure 3.19 Equivalent parabola concepts.

To achieve good radiation characteristics, the sub reflector must be few wavelengths in diameter. However, its presence introduces shadowing which is the principle limitation of its use as a microwave antenna. The shadowing can significantly degrade the gain of the system, unless the main reflector is several wavelengths in diameter. Therefore the Cassegrain is usually attractive for applications that require gains of 40 dB or greater.

YAGI-UDA ANTENNA

The Yagi antenna sometimes called the Yagi-Uda RF antenna is widely used where specified gain and directivity are required.

INTRODUCTION

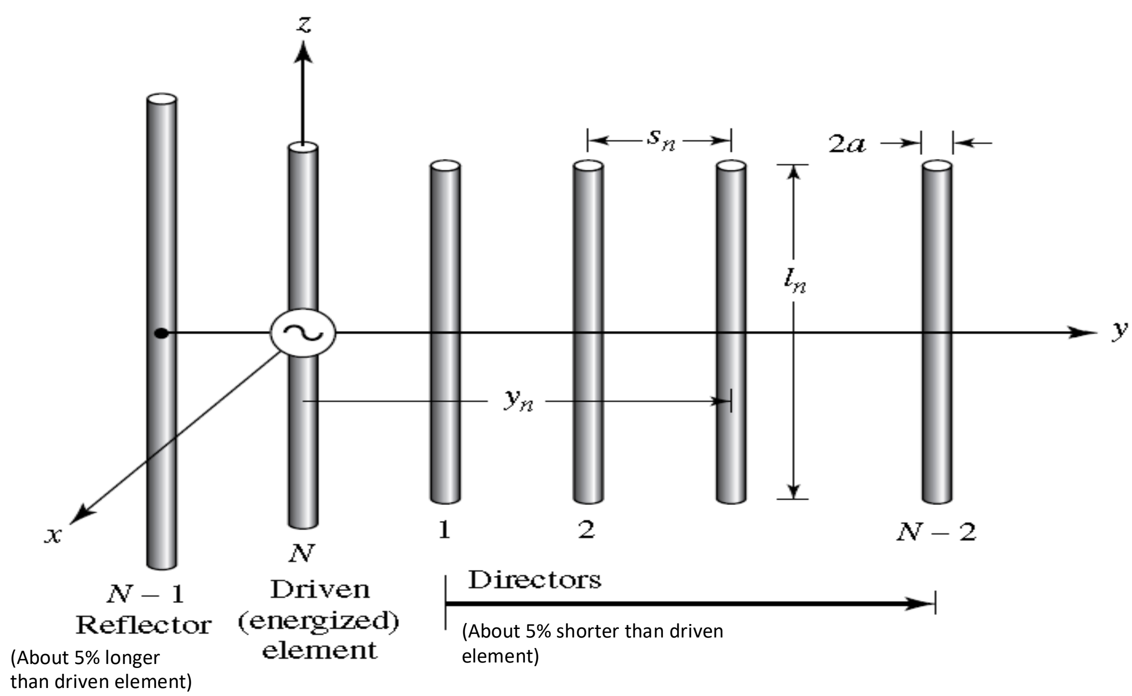
The Yagi-Uda antenna is one of the most successful RF antenna designs for directive antenna applications. This antenna is used in a wide variety of applications where an RF antenna design with gain and directivity is required. It has become particularly popular for television reception, but it is also used in many other domestic and commercial applications where an RF antenna is needed that has gain and directivity.

Not only is the gain of the Yagi-Uda antenna important as it enables better levels of signal to noise ratio to be achieved, but also the directivity can be used to reduce interference levels by focusing the transmitted power on areas where it is needed, or receiving signals best from where the source is present.

ANTENNA BASICS

The Yagi antenna design has a dipole as the main radiating or driven element. Further 'parasitic' elements are added which are not directly connected to the driven element. These parasitic elements pick up power from the dipole and re-radiate it. The phase is in such a manner that it affects the properties of the RF antenna as a whole, causing power to be focused in one particular direction and removed from others.

The parasitic elements of the Yagi antenna operate by re-radiating their signals in a slightly different phase to that of the driven element. In this way the signal is reinforced in some directions and cancelled out in others. It is found that the amplitude and phase of the current that is induced in the parasitic elements is dependent upon their length and the spacing between them and the dipole or driven element.



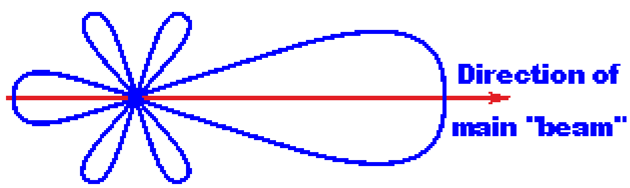
There are three types of element within a Yagi antenna:

(i) Driven element: The driven element is the Yagi antenna element to which power is applied. It is normally a half wave dipole or often a folded dipole.

(ii) Reflector : The Yagi antenna will generally only have one reflector. This is behind the main driven element, i.e. the side away from the direction of maximum sensitivity. Further reflectors behind the first one add little to the performance. However many designs use reflectors consisting of a reflecting plate, or a series of parallel rods simulating a reflecting plate. This gives a slight improvement in performance, reducing the level of radiation or pick-up from behind the antenna, i.e. in the backwards direction. Typically a reflector will add around 4 or 5 dB of gain in the forward direction.

(iii) Director: The director or directors are placed in front of the driven element, i.e. in the direction of maximum sensitivity. Typically each director will add around 1 dB of gain in the forward direction, although this level reduces as the number of directors increases.

The antenna exhibits a directional pattern consisting of a main forward lobe and a number of spurious side lobes. The main one of these is the reverse lobe caused by radiation in the direction of thereflector.Theantennacanbeoptimizedtoeitherreducethisorproducethemaximumlevelof forward gain. Unfortunately, these two do not coincide exactly, and a compromise on the performance has to be made depending upon the application.



Yagi-Uda antenna radiation pattern.

The Yagi-Uda antenna offers many advantages for its use in a number of applications:

- It has high gain allowing lower strength signals to be received.
- It has high directivity enabling interference levels to be minimized.
- This antenna allows all constructional elements to be made from rods simplifying construction.
- The construction enables the antenna to be mounted easily on vertical and other poles with standard mechanical fixings.

- The Yagi antenna is particularly useful in applications where an RF antenna design is required to provide required gain and directivity. In this way the optimum transmission and reception conditions can be obtained.

The Yagi antenna also has a number of disadvantages that need to be considered.

- For high gain levels the antenna becomes very long.
- Gain limited to around 20dB or so for a single antenna.

Yagi-Uda Array Advantages

- Lightweight
- Low cost
- Simple construction
- Unidirectional beam (front-to-back ratio)
- Increased directivity over other simple wire antennas
- Practical for use at HF (3-30 MHz), VHF (30-300 MHz), and UHF (300 MHz - 3 GHz)

LOG PERIODIC ANTENNA

A log-periodic antenna (LP), also known as a log-periodic array or log-periodic aerial, is a multi-element, directional, antenna designed to operate over a wide band of frequencies. The most common form of log-periodic antenna is the log-periodic dipole array or LPDA, The LPDA consists of a number of half-wave dipole driven elements of gradually increasing length, each consisting of a pair of metal rods. The dipoles are mounted close together in a line, connected in parallel to the feedline with alternating phase. Electrically, it simulates a series of two or three-element Yagi antennas connected together, each set tuned to a different frequency. LPDA antennas look somewhat similar to Yagi antennas, in that they both consist of dipole rod elements mounted in a line along a support boom, but they work in very different ways. Adding elements to a Yagi increases its directionality, or gain, while adding elements to a LPDA increases its frequency response, or bandwidth. One large application for LPDAs is in rooftop terrestrial television antennas, since they must have large bandwidth to cover the wide television bands of roughly 54–88 and 174–216 MHz in the VHF and 470–890 MHz in the UHF while also having high gain for adequate fringe reception. One widely used design for television reception combined a Yagi for UHF reception in front of a larger LPDA for VHF.

Designing Log Periodic Antennas

The Log periodic antenna exhibit relatively uniform input impedances, VSWR, and radiation characteristics over a wide range of frequencies. The design is so simple that in retrospect it is remarkable that it was not invented earlier. In essence, log periodic arrays are a group of dipole antennas of varying sizes strung together and fed alternately through a common transmission line. Still, despite its simplicity, the log periodic antenna remains a subject of considerable study even today. The log periodic antenna works the way one intuitively would expect. Its “active region,” -- that portion of the antenna which is actually radiating or receiving radiation efficiently -- shifts with frequency. The longest element is active at the antenna's lowest usable frequency where it acts as a half wave dipole. As the frequency shifts upward, the active region shifts forward. The upper frequency limit of the antenna is a function of the shortest elements.

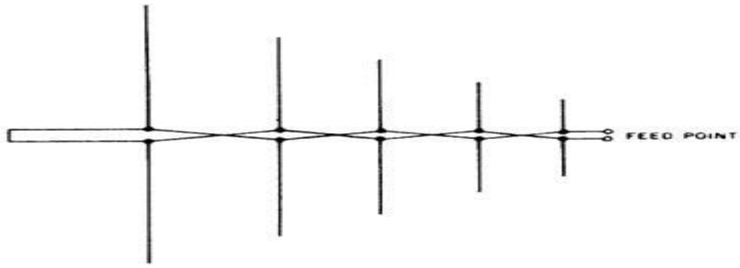


Figure 1. Basic arrangement of a Log Periodic Dipole Array (LPDA).

Log periodic designs vary, but the one most commonly used for EMC work is the Log Periodic Dipole Array (LPDA) of Figure. The LPDA covers a frequency range of 200 to 1000 MHz.

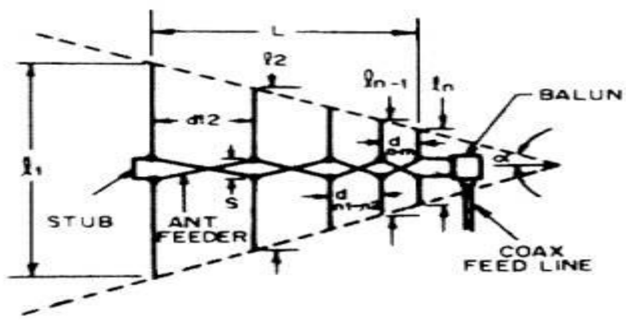


Figure 2: A closer look at the LPDA. Note that adjacent elements are fed out of phase.

The basic geometry is that shown in Figure 2.. Each element is shorter than the element to its left. Ratio of each element to each adjacent element is constant, and is referred to as tau (t). The other critical dimension is the spacing between elements, designated "d" in Figure 2. Distance $d_{1,2}$ for example, is the distance between the left most element and its nearest neighbor. The distance between two adjacent elements is equal to:

$$d_{1,2} = \frac{1}{2}[l_1 - l_2]\cot\alpha$$

Two factors, tau (t) and sigma (s), are for the most part the only factors we need to consider. Tau, as mentioned, is the ratio of the length of one element to its next longest neighbor. Sigma is known as the "relative spacing constant" and along with t determines the angle of the antenna's apex, a.

$$\cot\alpha = \frac{4\sigma}{1-\tau}$$

In operation, the LPDA works as follows. Referring to Figure 2, assume that we are operating at a frequency in which the third (middle) element is resonant. Elements 2 and 4 are slightly longer and shorter, respectively, than element 3. Their spacing, combined with the fact that the transmission line flips 180 degrees in phase between elements allows these two elements to be in phase and nearly (but not quite) resonant with element 3. Element 4, being slightly shorter that element 3 acts as a “director” shifting the radiation pattern slightly forward. Element 2, being slightly longer, acts as a “reflector” further shifting the pattern forward. The net result is an antenna with gain over a simple dipole. As the frequency shifts, the active region (those elements that are receiving or transmitting most of the power) shifts along the array.

Now comes the tricky part. We have to select the characteristic impedance of the transmission line that feeds the elements, a transmission line that also acts as the boom of the antenna. We will call this transmission line impedance Z_b (for boom) and Reference 1 tells us it should be:

$$Z_b = \frac{Z_i^{\,2}}{8\sigma' Z_d} + Z_i \sqrt{\left(\left(\frac{Z_i}{8\sigma' Z_d}\right)^2 + 1\right)}$$

Where :

$$Z_d = 120\left(\ln\left(\frac{l_n}{d_n}\right) - 2.25\right)$$

$$\sigma' = \frac{\sigma}{\sqrt{\tau}}$$

This equation deserves some explanation. Z_d is the average characteristic impedance of a simple dipole antenna. As stated previously, Z_b is the characteristic impedance of the boom, itself a transmission line (referred to as the “antenna feeder” line in Figure 2). Z_i is the impedance of the antenna as seen from its input terminals. Those terminals are usually connected to some kind of balun which performs the balanced to unbalanced transformation and steps down the impedance Z_i to match the impedance of the signal source (when transmitting) or receiver input (when receiving). The impedance is of this line, referred to as the “coax feed” line in Figure 2, is usually 50 ohms and we will refer to it as Z_0.

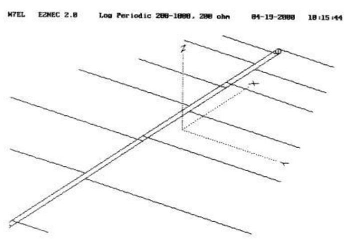


Figure 4: The antenna we have chosen to model uses two booms acting as a transmission line.

We have chosen to make the antenna elements from 1/4 inch rods. That makes the impedance Z_d of the longest element:

$$Z_d = 120\left(\ln\left(\frac{l_n}{d_n}\right) - 2.25\right) = 120\left(\ln\left(\frac{29.52}{.25}\right) - 2.25\right)$$

$$= 302 \text{ ohms}$$

Next we choose the spacing between the two booms. The booms will consist of one-quarter inch rods to which the left and right elements are alternately attached (Figure 4). Note that each element is fed 180 degrees out of phase with the elements adjacent to it. For reasons that will become apparent shortly, we will need to choose a relatively high impedance to feed the booms (Z_i). We will choose 200 ohms. This impedance is four times the characteristic impedance of our coaxial line (Z_0 = 50 ohms) and is readily produced through the use of a balun with a 2:1 ratio of windings. The spacing between the two booms needs to be (after Ref. 1):

$$S = \left(\frac{diam}{2}\right) \times 10^{\left(\frac{Z_i}{276}\right)} = .125 \times 10^{\left(\frac{302}{276}\right)} = 2.5\,\text{inches}$$

Where:

diam = diameter of each boom in inches.

S = center-to-center spacing between the booms in inches.

To get such a low impedance, we will have to use thick booms and antenna elements. For the purposes of our example, we will choose .75 inch diameter pipe. First we compute Z_d for .75 inch elements:

$$Z_d = 120\left(\ln\left(\frac{l_n}{d_n}\right) - 2.25\right) = 120\left(\ln\left(\frac{29.53}{.75}\right) - 2.25\right)$$

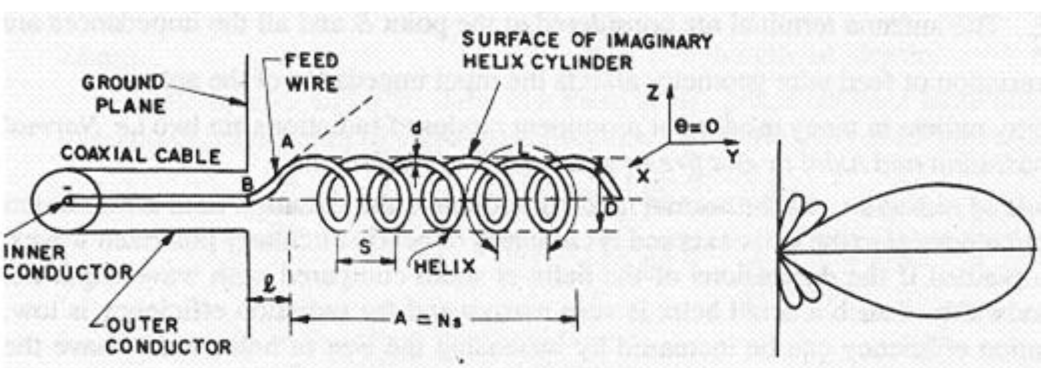
$$= 169.6\ \text{ohms}$$

Then we can calculate the boom center-to-center spacing:

$$S = \left(\frac{diam}{2}\right) \times 10^{\left(\frac{Z_i}{276}\right)} = .375 \times 10^{\left(\frac{169.6}{276}\right)} = 1.544\,\text{inches}$$

HELICAL ANTENNA

Helical antenna is useful at very high frequency and ultra high frequencies to provide circular polarization. Consider a helical antenna as shown below,



Here helical antenna is connected between the coaxial cable and ground plane. Ground plane is made of radial and concentric conductors. The radiation characteristics of helical antenna depend upon the diameter (D) and spacing S.

In the above figure,

L = length of one turn = $\sqrt{S^2+(\pi D)^2}$

N = Number of turns

D = Diameter of helix = πD

α = Pitch angle = tan-1($S/\pi D$)

l = Distance between helix and ground plane.

Helical antenna is operated in two modes. They are,

1. Normal mode of radiation
2. Axial mode of radiation.

1.Normal mode of radiation

Normal mode of radiation characteristics is obtained when dimensions of helical antenna are very small compared to the operating wavelength. Here, the radiation field is maximum in the direction normal to the helical axis. In normal mode, bandwidth and efficiency are very low. The above factors can be increased, by increasing the antenna size. The radiation fields of helical antenna are similar to the loops and short dipoles. So, helical antenna is equivalent to the small loops and short dipoles connected in series.

We know that, general expression for far field in small loop is, $E\Phi = \{120\ \pi 2[I]\ \sin\theta/r\}[A/\lambda 2]$

Where,

r = Distance

$I = I0 \sin \omega(t-r/C)$ = Retarded current

A = Area of loop = $\pi D2/4$

D = Diameter

λ = Operating wavelength.

The performance of helical antenna is measured in terms of Axial Ratio (AR). Axial ratio is defined as the ratio of far fields of short dipole to the small loop.

Axial Ratio, $AR = (E\varnothing)/(E\Phi)$

2.Axial mode of radiation

Helical antenna is operated in axial mode when circumference C and spacing S are in the order of one wavelength. Here, maximum radiation field is along the helical axis and polarization is circular. In axial mode, pitch angle lies between 12° to 18° and beam width and antenna gain depends upon helix length NS.

General expression for terminal impedance is, $R = 140C/\lambda$ ohms

Where,

R = Terminal impedance

C = Circumference.

In normal mode, beam width and radiation efficiency is very small. The above factors increased by using axial mode of radiation. Half power beam width in axial mode is,

$HPBW = 52/C\sqrt{\lambda 3/NS}$ Degrees. Where,

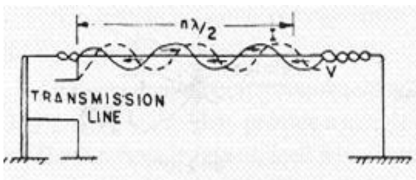
λ = Wavelength

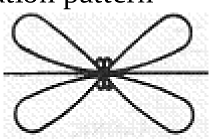
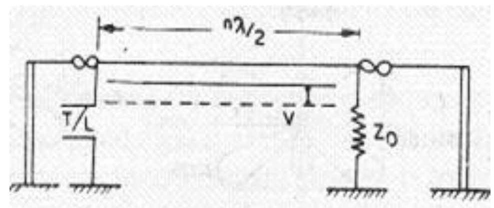
C = Circumference

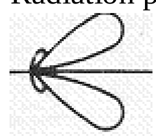
N = Number of turns

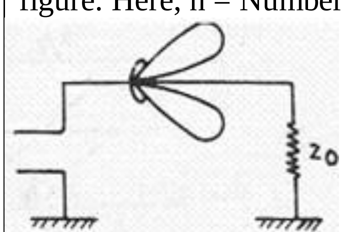
S =Spacing.

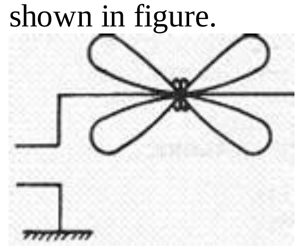
Axial Ratio, $AR = 1 + 1/2N$

<table>
<tr><th>Resonant Antenna</th><th>Non-resonant Antenna</th></tr>
<tr><td>1. These correspond to a resonant transmission line that is an exact number of half wave length long and is open at both ends.
2. Because of incident and reflected waves, standing waves exist.
3. The radiation pattern of this antenna is bi-directional.
4. These antennas are used for fixed frequency operations.
5. Resonant antenna


Long wire resonant antenna.
6.Radiation pattern

Bi-directional radiation pattern</td>
<td>1. These correspond to a transmission line that is exited at one end and terminated with characteristic impedance at the other end.
2. Due to the absence of reflected waves, standing waves do not exist.
3. The radiation pattern of this antenna is uni-directional.
4. These antennas are used for variable and wide frequency operations.
1. Non-resonant antenna


Long wire non-resonant antenna.
2. Radiation pattern

Uni-directional radiation pattern</td></tr>
</table>

<table>
<tr><th>Travelling Wave Antennas</th><th>Standing Wave Antennas</th></tr>
<tr><td>1.which standing waves does not exist.
2. Travelling wave antennas are also known as a periodic or non-resonant antenna.
3. Reflected wave does not appear in travelling wave antennas.
4. Radiation pattern of travelling wave antenna is uni-directional.
5. Uni-directional pattern for n = 4 is shown in figure. Here, n = Number of wave lengths.


6. Directivity is more.
7. The length of wire increases, major lobes get closer and narrower to the wire axis</td>
<td>1.In standing wave antenna, standing wave exists.
2. Standing wave antennas are also known as periodic or resonant antennas.
3. Reflected wave appears in standing wave antenna.
4. Radiation pattern of standing wave antenna is bi-directional.
5. Bi-directional pattern for n = 3 is shown in figure.

6. Directivity is less.
7. Length of wire does not depend upon the lobes</td></tr>
</table>

Narrow Band Antennas	Wide Band Antennas
1. Since, the bandwidth of receiving antenna is narrow, it is difficult for high-speed data communication. 2. These are bigger in size. 3. Because of the constitution of narrow band radio module, these are more expensive. 4. These antennas can realize stable long range communication. 5. These antennas lead to the high efficiency of radio wave use within same frequency band.	1. Since, the bandwidth of receiving antenna is very high, it is very easy for high-speed data communication. 2. These are small in size. 3. These are less expensive than narrow band antennas. 4. Because of large bandwidth, these are not suitable for long range communication. 5. These antennas lead to the less efficiency of radio wave use within same frequency band

PART B

1. What is Horn Antenna? Sketch the various types of Horn Antenna and explain its operation.
2. Describe the principle of operation and applications of parabolic reflectors and derive its necessary equations.
3. Explain Slot antenna and derive its field expressions.
4. Explain the methods of feeding Slot Antenna?
5. Describe Flat sheet and corner reflectors and derive their field equations.
6. Explain the following theorem in detail
   i. Uniqueness theorem
   ii. Field equivalence principle
   iii. Method of images
   iv. Huygenes principle
   v. Babinets principle
   vi. Duality principle
7. Explain the structure and operation of Slot antenna. Also derive the expression of its input impedance.
8. Explain the working operation of parabolic reflector antenna in detail.
9. Explain the operation of hyperbolic reflectors and derive its equation.
10. Explain the radiation mechanism of microwave Horn antenna with diagram.
11. Explain the special features of parabolic reflector antenna and discuss on different types of feed used with neat diagram.
12. Explain the radiation mechanism of slot antenna with diagram.
13. Explain the special features of reflector antenna and discuss on different types of feed used with neat diagram.
14. With field equivalence principle explain radiation mechanism
15. Describe the working of slot antenna. What is the terminal impedance of slot antenna
16. What is reflector antenna? With necessary diagrams, explain parabolic reflector antenna and its different types of feeding systems.
17. How is aperture blockage in reflector antennas avoided?
18. Explain the geometry of a log periodic antenna. Give the design equations and uses of log

periodic antenna.

19. Derive the expression for Horn antenna & HPBW and find its directivity.
20. Design a yagi-uda antenna& explain the features with example.
21. Discuss the radiation from a slot antenna.
22. Derive equation for Horn antenna & HPBW and find its directivity.
23. Write a note on helical antenna and helical geometry.
24. Derive the relation between circumference spacing turn lengths and pitch angle of a helix.
25. Explain helix modes of operation.

UNIT IV

ANTENNA MEASUREMENTS

UNIT IV-ANTENNA MEASUREMENTS

Drawbacks in measurements of antenna parameters – Methods to overcome drawbacks in measurements –Measurement ranges – Impedance – Gain – Radiation pattern – Beam width – Radiation resistance – Antenna efficiency- Directivity-Polarization and Phase Measurements.

Antenna Measurements

Basically, the most common and desired measurements are an antenna's radiation pattern including antenna gain and efficiency, the impedance or VSWR, the bandwidth, and the polarization.

The procedures and equipment used in antenna measurements are described in the following sections:

1. Required Equipment and Ranges

In this first section on Antenna Measurements, we look at the required equipment and types of "antenna ranges" used in modern antenna measurement systems.

2. Radiation Pattern and Gain Measurements

The second antenna measurements section discusses how to perform the most fundamental antenna measurement - determining an antenna's radiation pattern and extracting the antenna gain.

3. Phase Measurements

The third antenna measurements section focuses on determining phase information from an antenna's radiation pattern. The phase is more important in terms of 'relative phase' (phase relative to other positions on the radiation pattern), not 'absolute phase'.

4. Polarization Measurements

The fourth antenna measurements section discusses techniques for determining the polarization of the antenna under test. These techniques are used to classify an antenna as linearly, circularly or elliptically polarized.

5. Impedance Measurements

The fifth antenna measurement section illustrates how to determine an antenna's impedance as a function of frequency. Here the focus is on the use of a Vector Network Analyzer (VNA).

6. Scale Model Measurements

The sixth antenna measurement section explains the useful concept of scale model measurements. This page illustrates how to obtain measurements when the physical size of the desired test is too large (or possibly, too small).

7 SAR (Specific Absorption Rate)Measurements

The final antenna measurement section illustrates the new field of SAR measurements and explains what SAR is. These measurements are critical in consumer electronics as antenna design consistently needs altered (or even degraded) in order to meet FCC SAR requirements.

Required Equipment in Antenna Measurements

For antenna test equipment, we will attempt to illuminate the test antenna (often called an Antenna-Under-Test) with a plane wave. This will be approximated by using a source (transmitting) antenna with known radiation pattern and characteristics, in such a way that the fields incident upon the test antenna are approximately plane waves. More will be discussed about this in the next section. The required equipment for antenna measurements include:

- A source antenna and transmitter- This antenna will have a known pattern that can be used to illuminate the test antenna
- A receiver system- This determines how much power is received by the test antenna
- A positioning system - This system is used to rotate the test antenna relative to the source antenna, to measure the radiation pattern as a function of angle.

A block diagram of the above equipment is shown in Figure 1.

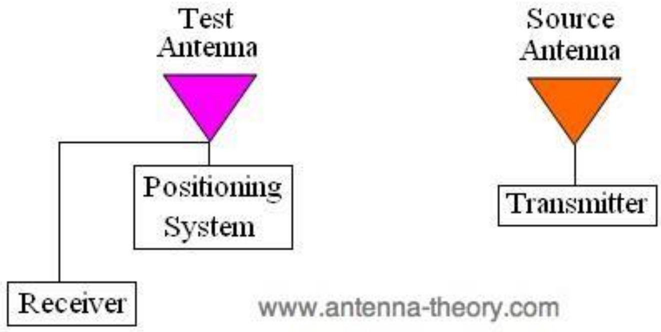


Figure 1.Diagram of required antenna measurement equipment.

These components will be briefly discussed. The Source Antenna should of course radiate well at the desired test frequency. It must have the desired polarization and a suitable beam width for the given antenna test range. Source antennas are often horn antennas, or a dipole antenna with a parabolic reflector.

The Transmitting System should be capable of out putting a stable known power. The output frequency should also be tunable (selectable), and reasonably stable (stable means that the frequency you get from the transmitter is close to the frequency you want).

The Receiving System simply needs to determine how much power is received from the test antenna. This can be done via a simple bolometer, which is a device for measuring the energy of incident electromagnetic waves. The receiving system can be more complex, with high quality amplifiers for low power measurements and more accurate detection devices.

The Positioning System controls the orientation of the test antenna. Since we want to measure the radiation pattern of the test antenna as a function of angle (typically in spherical coordinates), we need to rotate the test antenna so that the source antenna illuminates the test antenna from different angles. The positioning system is used for this purpose.

Once we have all the equipment we need (and an antenna we want to test), we'll need to place the equipment and perform the test in an antenna range, the subject of the next section.

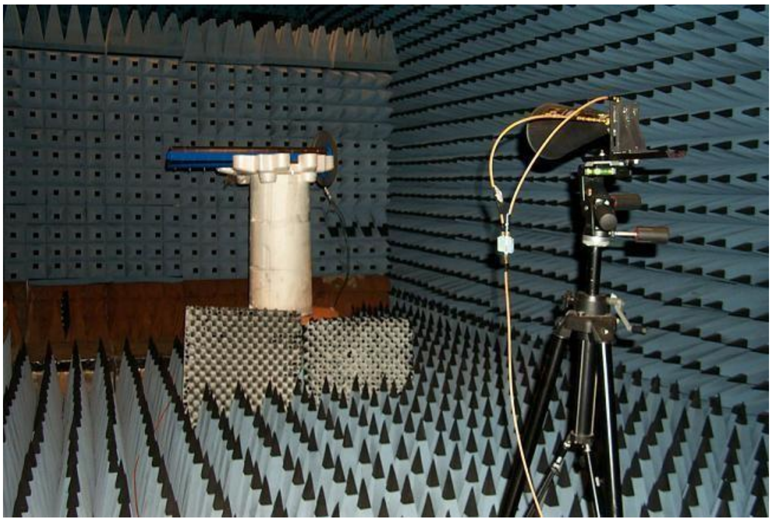
The first thing we need to do an antenna measurement is a place to perform the measurement. Maybe you would like to do this in your garage, but the reflections from the walls, ceilings and floor would make your measurements inaccurate. The ideal location to perform antenna measurements is somewhere in outer space, where no reflections can occur. However, because space travel is currently prohibitively expensive, we will focus on measurement places that are on the surface of the Earth. There are two main types of ranges, Free Space Ranges and Reflection Ranges. Reflection ranges are designed such that reflections add together in the test region to support a roughly planar wave. We will focus on the more common free space ranges.

Free Space Ranges

Free space ranges are antenna measurement locations designed to simulate measurements that would be performed in space. That is, all reflected waves from nearby objects and the ground (which are undesirable) are suppressed as much as possible. The most popular free space ranges are anechoic chambers, elevated ranges, and the compact range.

Anechoic Chambers

Anechoic chambers are indoor antenna ranges. The walls, ceilings and floor are lined with special electromagnetic wave absorbing material. Indoor ranges are desirable because the test conditions can be much more tightly controlled than that of outdoor ranges. The material is often jagged in shape as well, making these chambers quite interesting to see. The jagged triangle shapes are designed so that what is reflected from them tends to spread in random directions, and what is added together from all the random reflections tends to add incoherently and is thus suppressed further. A picture of an anechoic chamber is shown in the following picture, along with some test equipment:



The drawback to anechoic chambers is that they often need to be quite large. Often antennas need to be several wave length away from each other at a minimum to simulate far-field conditions. Hence, it is desired to have anechoic chambers as large as possible, but cost and practical constraints often limit their size. Some defense contracting companies that measure the Radar Cross Section of large airplanes or other objects are known to have anechoic chambers the size of basketball courts, although this is not ordinary. universities with anechoic chambers typically have chambers that are 3-5 meters in length, width and height. Because of the size constraint, and because RF absorbing material typically works best at UHF and higher, anechoic chambers are most often used for frequencies above 300 MHz. Finally, the chamber should also be large enough that the source antenna's main lobe is not in view of the side walls, ceiling or floor.

Elevated Ranges

Elevated Ranges are outdoor ranges. In this setup, the source and antenna under test are mounted above the ground. These antennas can be on mountains, towers, buildings, or wherever one finds that is suitable. This is often done for very large antennas or at low frequencies (VHF and below, <100 MHz) where indoor measurements would be intractable. The basic diagram of an elevated range is shown in Figure 2.

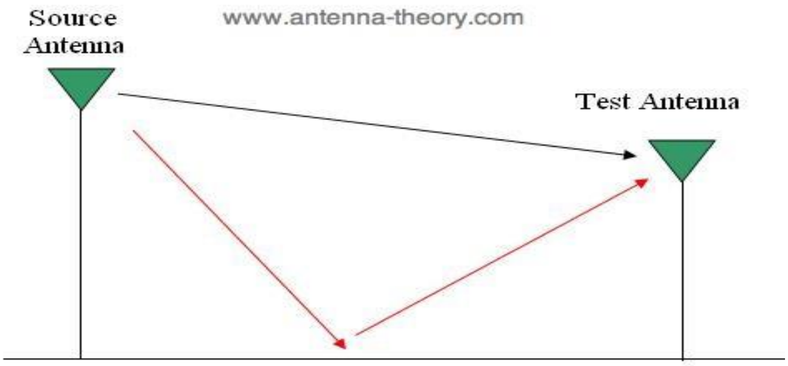


Figure 2.Illustration of elevated range.

The source antenna is not necessarily at a higher elevation than the test antenna, I just showed it that way here. The line of sight (LOS) between the two antennas (illustrated by the black ray in Figure 2) must be unobstructed. All other reflections (such as the red ray reflected from the ground) are undesirable. For elevated ranges, once a source and test antenna location are determined, the test operators then determine where the significant reflections will occur, and attempt to minimize the reflections from these surfaces. Often rf absorbing material is used for this purpose, or other material that deflects the rays away from the test antenna.

Compact Ranges

The source antenna must be placed in the far field of the test antenna. The reason is that the wave received by the test antenna should be a plane wave for maximum accuracy. Since antennas radiate spherical waves, the antenna needs to be sufficiently far such that the wave radiated from the source antenna is approximately a plane wave - see Figure 3.

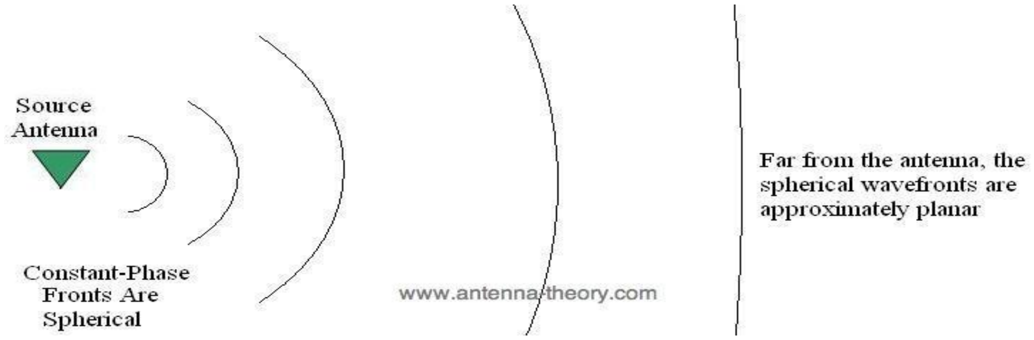


Figure 3. A source antenna radiates a wave with a spherical wave front.

However, for indoor chambers there is often not enough separation to achieve this. One method to fix this problem is via a compact range. In this method, a source antenna is oriented towards a reflector, whose shape is designed to reflect the spherical wave in an approximately planar manner. This is very similar to the principle upon which a dish antenna operates. The basic operation is shown in Figure 4.

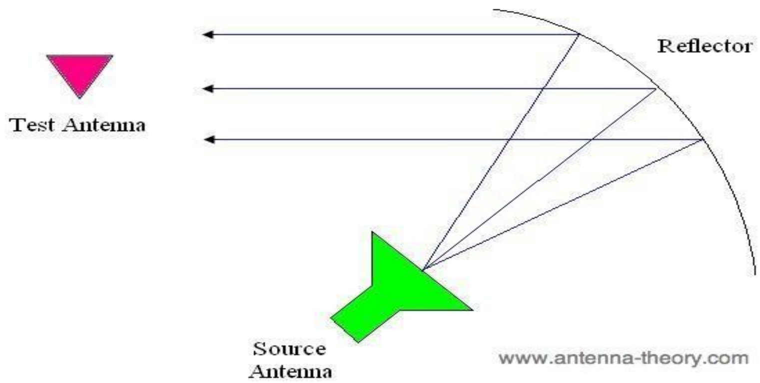


Figure 4. Compact Range - the spherical waves from the source antenna are reflected to be planar (collimated).

The length of the parabolic reflector is typically desired to be several times as large as the test antenna. The source antenna in Figure 4 is offset from the reflector so that it is not in the way of the reflected rays. Care must also be exercised in order to keep any direct radiation (mutual coupling) from the source antenna to the test antenna.

Antenna Impedance Measurement

For radio frequencies below 30 MC, it is usual to use bridge measurements. The fundamental Wheatstone-bridge shown in Fig. 15 is quite useful for this measurement. This bridge utilizes a null method, and is useful for measurements of impedance, resistive or reactive from dc to the lower VHF band.

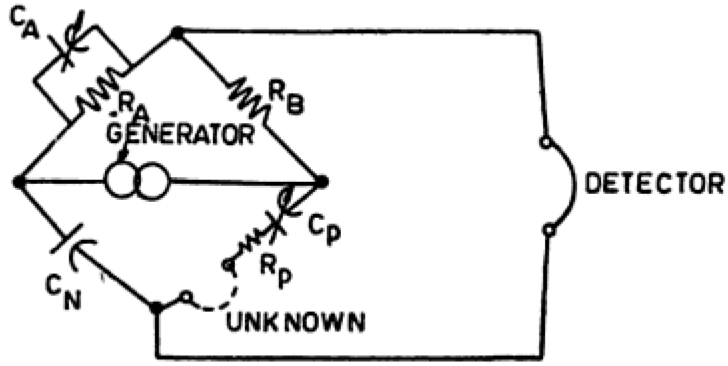


Fig. 5 Wheatstone-bridge.

The measurements are usually preceded by a calibration of the bridge in which the latter is balanced with the unknown impedance terminals short-circuited or open-circuited. There are many bridges, derived from Fig. 5, with many fixed known resistors, inductances and capacitances and with one or more variable calibrated elements. The generator signal source should give at least 1 mv output, and the detector should be a well-shielded receiver having at least a sensitivity of 5μv. At higher UHF frequencies and microwave frequencies, slotted-line measurements are more convenient. Figure 6 shows the set-up for slotted line impedance measurement.

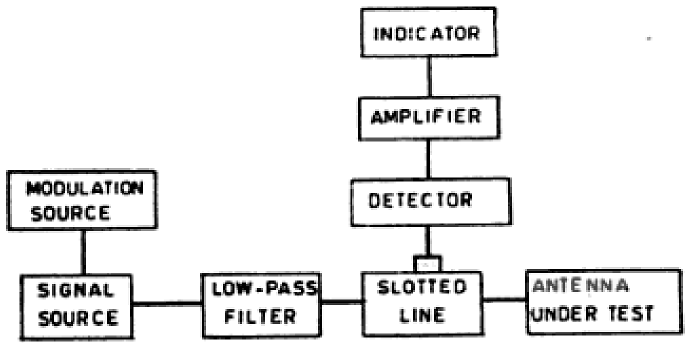


Fig. 6 Set-up for slotted-line impedance measurement.

Slotted-lines may be coaxial line, slab lines or waveguide lines. The characteristic impedance of coaxial or slab lines is usually 50 ohms, and waveguide slotted-lines are available in different sizes corresponding to different waveguide sizes for different bands. The standing wave patterns with the slotted-line shorted, and with the antenna as load arc drawn as shown in Fig. 7.

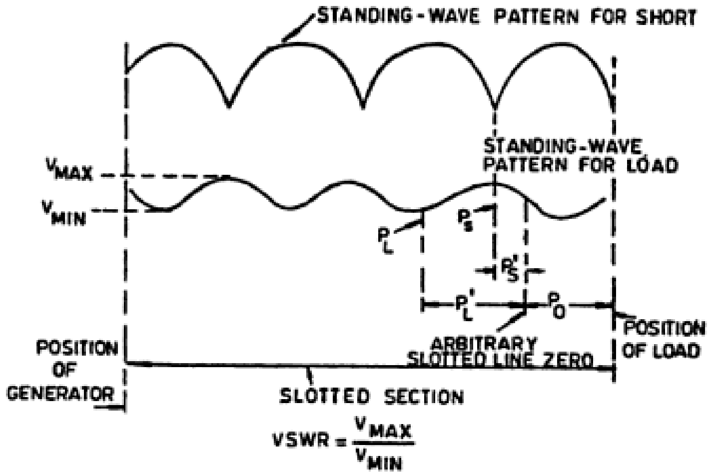


Fig. 7 Standing wave pattern

$$\mathbf{SWR} = 20 \log \mathbf{VSWR} = 20 \log \frac{V_{\mathrm{MAX}}}{V_{\mathrm{MIN}}}$$

The input impedance of the antenna is given by

$$Z_L = Z_0 \left\{ \frac{S}{\cos^2(\beta l) + S^2 \sin^2(\beta l)} + j \left[\frac{(S^2 - 1)\sin(\beta l)\cos(\beta l)}{\cos^2(\beta l) + S^2 \sin^2(\beta l)} \right] \right\}$$

where,

S = VSWR

$\beta = 2\pi/\lambda_g$

$\lambda_{g=}$ Guided wavelength

Z_0 = Characteristic Impedance of the line Z_L = Antenna Impedance

The antenna impedance, Z_L, is also found from the knowledge of reflection coefficient. That is,

$$Z_a = Z_0 \left[\frac{1 + |\rho| \angle\theta}{1 - |\rho| \angle\theta} \right] \Omega$$

Here, $|\rho|$ = reflection coefficient magnitude.

$$\theta = 720^\circ \left(\frac{d}{\lambda_g} - \frac{1}{4} \right)$$

d = distance of voltage minimum from antenna.

Measurement of mutual impedance between two antennas

Let Z_s, be the self impedance of antenna 1 or antenna 2 and Z_m be the mutual impedance between the two antennas. Let Z_1 be the measured terminal impedance of antenna 1, when antenna 2 is short circuited. Then,

$$Z_1 = Z_s + \frac{I_2}{I_1} Z_m$$

$$0 = Z_s + \frac{I_1}{I_2} Z_m$$

$$Z_m^2 = Z_S (Z_s - Z_1)$$

$$Z_m = \sqrt{Z_s (Z_s - Z_1)}.$$

Radiation Pattern Measurement

Antenna pattern is also known as radiation pattern. It is defined as the graphical presentation of the radiation properties as a function of space coordinates. In general, the radiation pattern is determined in the far-field region. The radiation properties include electric field strength, radiation intensity, phase and polarization. The antenna patterns consist of radiation lobes. The radiation lobe is only one for an ideal antenna. In fact, no antenna is ideal. Hence, the radiation lobe is defined stile portion of the radiation pattern bounded by the regions of relatively weak radiation intensity. The radiation pattern of any antenna consists of one major lobe and a set of minor or side lobes. Major lobe or main lobe: it is defined as the radiation lobe which contains direction of maximum radiation. Minor lobe: It is defined as any lobe other than the major lobe. Antenna patterns are of two types:

1. Field pattern: Field pattern is the variation of absolute field strength with θ in free space. That is, 1E| Vs θ is field pattern
2. Powerpattern:Power(proportionaltoE^2)patternisthevariationofradiatedpowerwithθ in free space. That is, P Vs θ or $|E|^2$Vs θ is power pattern.

Measurement procedure :

The set-up for measurement is shown in Fig. 18. The set-up consists of:

- Modulating source
- Transmitter
- Transmitting antenna
- Antenna under test
- Antenna mount
- Antenna driving unit
- Shaft for antenna rotation
- Antenna position indicating device
- Detector and
- Indicator

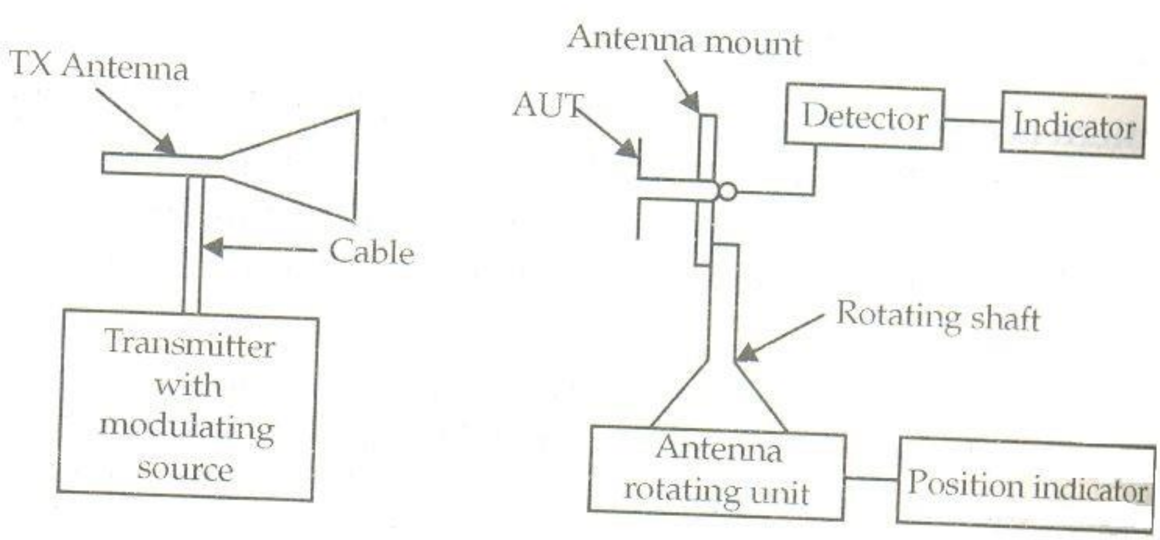


Fig. 8 Set up for pattern measurement

Here, transmitting antenna is fixed and antenna under test is rotated by the unit. For each position indicated by the position indicator, the received power is noted from the indicator. The indicator can be a power meter or a Ammeter. Then, from the results obtained, field (proportional to current) or power (proportional to I^2) is plotted as a function of θ. This gives the desired patterns of antenna under test. For pattern measurements, the following precautions should be taken.

Precautions in pattern measurements

1.Distance between the transmitting antenna and the receiving antenna must be

$$R \geq \frac{2D_a^2}{\lambda}$$

Here, D_a = maximum dimension of the aperture of AUT

λ = wavelength

2.AUT should be illuminated uniformly.

3.Ground and other reflections should be avoided.

4.Measurements should be taken in shielded chambers like anechoic chambers to eliminate the effect of external EMI.

5.Automatic range equipment should be used to avoid manual errors.

6.The transmitting antenna should be able to produce a uniform wave from to reduce phase error of AUT.

7.The TX antenna should have high gain.

8.The side lobe level of TX antenna should be very small.

9.Horns, paraboloids or arrays of dipoles may be used as TX antennas.

Gain Measurement by Direct Comparison Method

At high frequencies, the gain measurement is done using direct comparison method. In this method, the gain measurement is done by comparing the strengths of the signals transmitted or received by the antenna under test and the standard gain antenna. The antenna whose gain is accurately known and can be used for the gain measurement of other antennas is called standard gain antenna. At high frequency, the universally accepted standard gain antenna is the horn antenna. The set up of gain measurement by the comparison method is as shown in the Fig 19. This method uses two antennas termed as primary antenna and secondary antenna. The secondary antenna is arbitrary transmitting antenna.

The knowledge of gain of the secondary antenna is not necessary. The primary antenna consists two different antennas separated through a switch SW. The first primary antenna is the standard gain antenna (i.e. horn antenna in above case) and the subject antenna under test. The two primary antennas are located with sufficient distance of separation in between so as to avoid interference and coupling between the two antennas. While the primary are secondary antennas are separated with a distance greater than or equal to $2d^2/\lambda$), to minimize. the reflection between them to great extent.

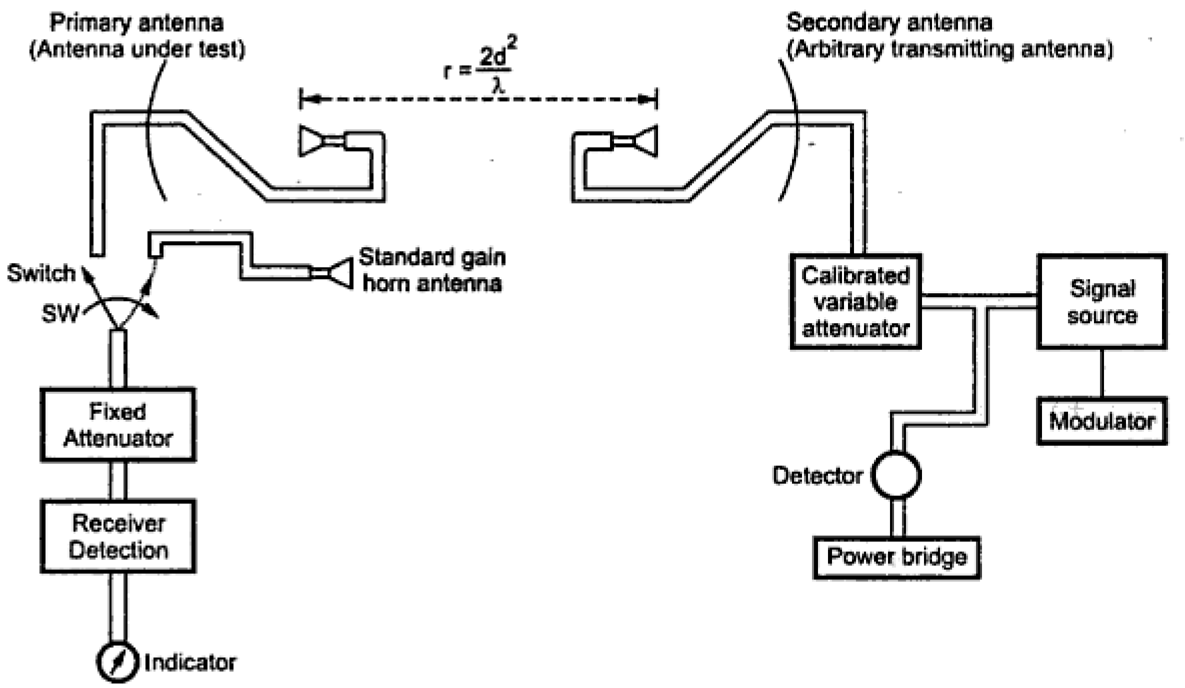


Fig 19 Set up for gain measurement by direct comparison method

At the input of receiver, attenuation pad i.e. fixed attenuator is inserted for matching load conditions. This method demands that throughout the gain measurement process the frequency of radiated power in the direction of the primary antenna should remain constant. To ensure almost frequency stability at the transmitter, the power bridge circuit is used.

The gain measurement by the gain-comparison method is two step procedure.

1) Through the switch SW, first standard gum antenna is connected to the receiver. The antenna is adjusted in the direction of the secondary antenna to have maximum signal intensity. The input connected to the secondary or transmitting antenna is adjusted to required level. For this input corresponding primary antenna reading at the receiver is recorded. Corresponding attenuator and power bridge readings are recorded as A_1 and P_1.

2) Secondly the antenna under test is connected to the receiver by changing the position of the switch SW. To get the same reading at the receiver (obtained with the standard gain antenna), the attenuator is adjusted. Then corresponding attenuator and power bridge readings are recorded as A_2 and P_2. Now consider two different case.

Case I : If $P_1 = P_2$, then no correction need to be applied and the gain of the subject antenna under test is given by,

$$\text{Power gain} = G_P = \frac{A_2}{A_1},$$

where A_1 and A_2 are relative power levels Taking logarithms on both the sides, we get,

$$\log_{10} G_P = \log_{10}\left(\frac{A_2}{A_1}\right) = \log_{10} A_2 - \log_{10} A_1$$

$$\text{i.e.} \qquad \boxed{\underset{(dB)}{G_P} = \underset{(dB)}{A_2} - \underset{(dB)}{A_1}}$$

Case II : If $P_1 \neq P_2$, then correction need to be applied

$$\text{Let} \qquad \frac{P_1}{P_2} = P, \text{ then}$$

$$\log_{10}\frac{P_1}{P_2} = P_{(dB)}$$

Hence power gain is given by

$$G = G_P \times \frac{P_1}{P_2} = \frac{A_2}{A_1} \cdot \frac{P_1}{P_2}$$

$$\text{i.e.} \qquad G = G_P \cdot \frac{P_1}{P_2}$$

Taking logarithms on both the sides, we get,

$$\log_{10} G = \log_{10}\left(G_P \cdot \frac{P_1}{P_2}\right) = \log_{10} G_P + \log_{10}\left(\frac{P_1}{P_2}\right)$$

i.e. $$\boxed{G_{(dB)} = G_{P(dB)} + P_{(dB)}}$$

Directivity measurement

The directivity, D of an antenna is its maximum directive gain. It is obtained from the field pattern of the antenna. From the measured pattems and their beam width in both the principal planes, D is obtained. The principal planes are E-plane and H-plane.

E-plane pattern: For a linearly polarized antenna, E-Plane pattern is defined as a pattern in the plane which contains the electric field and the direction of maximum radiation.

H-plane pattern: For a linearly polarized antenna, the H-plane pattern is defined as the pattern in the plane which contains the magnetic field and the direction of maximum radiation.

Procedure for the measurement of directivity

1. Obtain E and H-plane patterns of AUT
2. Find the half-power beam widths from the patterns of step1.
3. Find the directivity of AUT from

$$D = \frac{41{,}253}{(B.W)_E \times (B.W)_H}$$

Here, $(B.W)_E$ = half power beam width in E-plane (degrees) $(B.W)_H$ = half-power beam width in H-plane (degrees)

This method is accurate when the pattern consist of only one main lobe.

4. Asthefieldvarieswithbothθandυ,thedirectivityalsovarieswithθandυ.Thatis,

$$D_t = \frac{\partial D}{\partial \theta} + \frac{\partial D}{\partial \phi}$$

Here $$D_\theta = \frac{4\pi\,(RI_{max})_\theta}{(P_r)_\theta + (P_r)_\phi}$$

$$D_\phi = \frac{4\pi\,(RI_{max})_\phi}{(P_r)_\theta + (P_{rad})_\phi}$$

where,

$(RI_{max})_\theta$=maximum radiation intensity of θ component $(RI_{max})_\upsilon$=maximum radiation intensity of υ component $(P_r)_\theta$=radiated power in θ direction

$(P_r)_\upsilon$ = radiated power in υ direction

The pattern in elevation plane is obtained by varying θ over 0 to π for a fixed υ.

The pattern in azimuthally plane is obtained by varying υ over 0 to 2π for a fixed value of θ.

Measurement Of Polarization Of Antenna

Polarization of antenna is defined as the polarization of its radiated wave. The polarization of electromagnetic wave is the direction of its electric field. In general, the direction of electric field with time forms an ellipse. The ellipse has either clockwise or anticlockwise sense. When the ellipse becomes a circle, the polarization is circular. When the ellipse becomes a straight hint, the polarization is linear. The clockwise rotation of electric field with time is called right-hand polarization and anti-clockwise rotation of electric field is called left-hand polarization. The electric field consists of both 4 and E, components. The direction of rotation along the direction of propagation represents the sense of polarization. The axial ratio (AR) and tilt angle, α describe the ellipse. α is measured from the reference direction in the clockwise direction.

The methods of measurement of polarization are:

1. Polarization pattern method
2. Linear component method
3. Circular component method

1. Polarization method Procedure

(a) A rotatable half-wave dipole is connected to a calibrated receiver as in Fig.20.

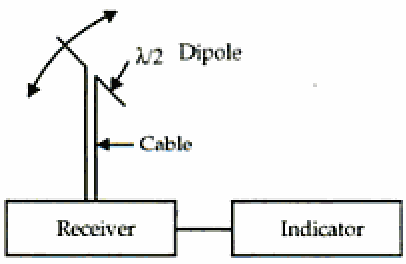


Fig. 20 Polarization measurement by polarization pattern method

(b) The dipole is rotated and incident field coming from AUT is measured. AUT is used in transmitting mode.

(c) If the variation of received signal forms an ellipse as in Fig. 21 the AUT is said to be elliptically polarized.

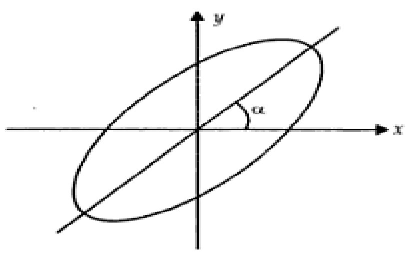


Fig. 21 Tilted ellipse

(d) The sense of polarization is obtained by using two antennas. Here one is right-hand circular polarized and the other left-hand circular polarized. The antenna which receives a large signal gives the sense of polarization.

2. <u>Linear component method</u> Procedure

(a) The AUT is used in transmitting mode.

(b) The signal coming from AUT is measured by a vertical antenna as in Fig. 22. Let the signal be E_v.

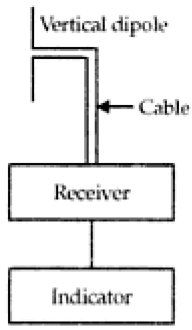


Fig. 22 Vertical dipole with receiver

(c) Now the vertical dipole is connected in horizontal position and the signal is measured. Let the signal be E_H.

Then,

$$E_x = E_v \sin(\omega t - \beta z)$$

$$E_y = E_H \sin(\omega t - \beta z + \alpha)$$

Here,

α = phase difference between the two signals

ω = angular frequency.

$\beta = 2\pi/\lambda$

The phase difference, α is measured by a phase comparative method.

(d) The signal from the vertical antenna is measured as in step 2. But the signal from the horizontal antenna is connected to a matched terminated slotted line. The probe in the slotted line is connected to the receiver as in Fig. 23.

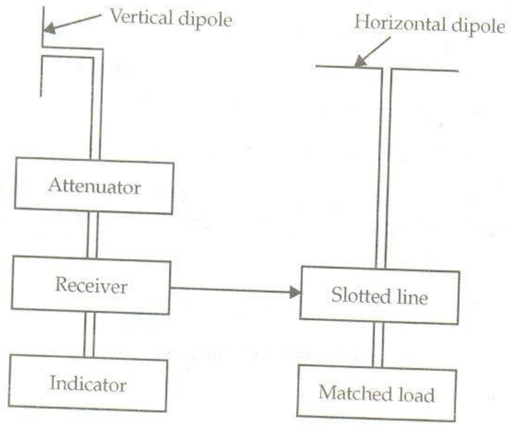


Fig. 23 Phase comparison

If α lies in $0 < \alpha < 180^0$, the direction of rotation is clockwise. If α lies in $0 < \alpha < -180^0$, the direction of rotation is anti-clockwise. The angle of tilt υ_t is given by

$$\phi_t = \frac{1}{2}\tan^{-1}\left(\frac{2E_1 E_2 \cos\alpha}{E_1^2 - E_2^2}\right)$$

3. Circular component method

In this method, two circularly polarized antennas of opposite sense, for example, left and right-hand helical antennas, are used to receive the signals E_L and E_R from AUT. The set-up for measurement using this method is shown in Fig. 24. The axial ratio is given by

$$AR = \frac{E_R + E_L}{E_R - E_L}$$

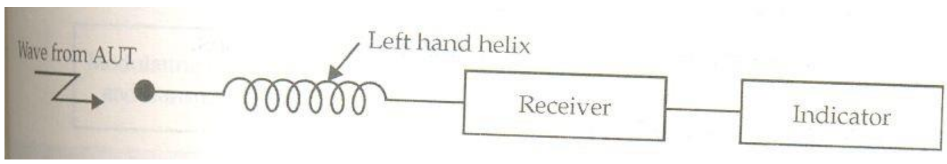


Fig. 24 Polarization measurement by circular component method

<u>Measurement of Phase of an Antenna</u>

The phase of an antenna is periodic quantity and it is defined in multiples of 36^0. Basically phase is a relative quantity. Hence for the measurement of a phase of an antenna, some reference is necessary so that the measurement of this relative quantity is carried out by the comparison with reference. The basic near field phase measurement system is as shown in the Fig. 25. For near-field phase pattern measurements, the reference signal is coupled from the transmission line. The received signal is compare with the reference signal using appropriate phase measurement circuit.

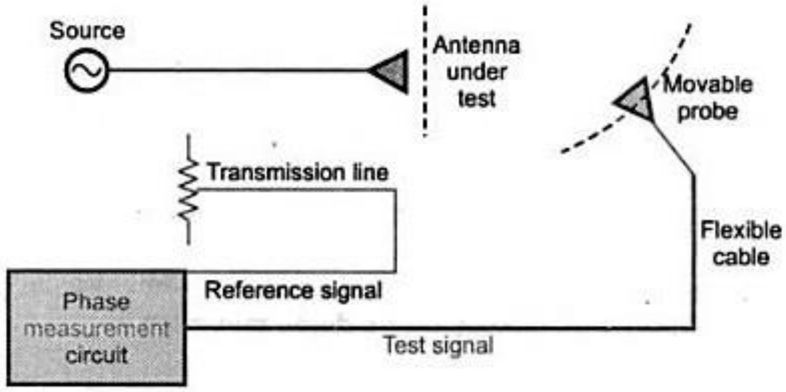


Fig. 25 Near-field phase pattern measuring system

Thus this method uses a technique in which direct of comparison of the phase of the receivedsignal with that of the reference is carried out. For far-field phase pattern measurement, this direct phase comparison technique is not possible. The far-field phase pattern measurement set up is as shown in the Fig. 26.

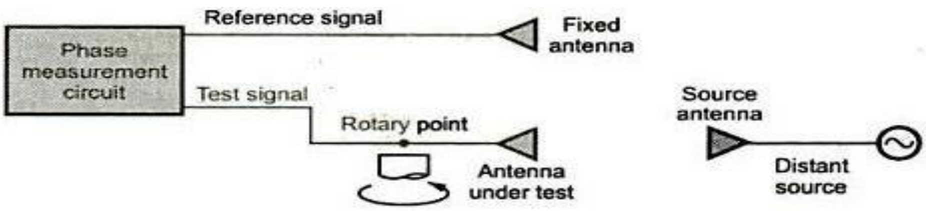


Fig. 26 Far-field phase pattern measuring system

The signal transmitted by the source antenna, fed with distant source, is received by the fixed antenna and the antenna under test simultaneously. Then the antenna under test is rotated but the fixed antenna is kept steady. This fixed antenna serves as a reference. Using dual channel heterodyne system as the phase measuring circuit, the phase pattern of the antenna under test is measured by comparing it with the reference phase pattern.

PART B

1 Explain the methods used to measure input impedance at high frequencies.

2 Explain the measurement of following antenna parameters

(i) Directivity

(ii) Radiation Resistance

3. Explain the two different methods used to measure gain of an antenna.

4. Explain the methods used to measure input impedance at low frequency.

5. Explain the measurement of following antenna parameters

(i) Antenna beam width

(ii) Radiation efficiency

(iii) Aperture efficiency

6. Discuss the radiation from a slot antenna

7. Write short notes on:

(i) Measurement of Antenna Polarization
(ii) Measurement of Antenna Directivity

8. Explain in detail about:

i). Directivity measurement
ii). Gain measurement

9. Explain the various ranges of antenna measurements in detail.

10. Explain absolute gain measurement and gain transfer method in detail.

11. Explain radiation pattern measurement in detail.

12. Explain in detail about:

i). Directivity measurement
ii). Gain measurement

UNIT V

UNITV-RADIO WAVE PROPAGATION

Basics of propagation-Ground wave propagation – Space wave propagation- Considerations in space wave propagation – Super refraction – Ionospheric wave propagation – Structure of ionosphere – Mechanism of ionospheric propagation – Effect of earth's Magnetic field on Radio wave propagation – Virtual height – MUF – Skip distance – OWF – Ionosphere abnormalities.

Modes of Propagation

Electromagnetic waves may travel from transmitting antenna to the receiving antenna in a number of ways.

Different propagations of electromagnetic waves are as follows,

(i) Ground wave propagation
(ii) Sky wave propagation
(iii) Space wave propagation
(iv) Tropospheric scatter propagation.

This classification is based upon the frequency range, distance and several other factors.

(i) Ground Wave Propagation

Ground wave propagation is also known as surface wave propagation. This propagation is practically important at frequencies up to 2 MHz. Ground wave propagation exists when transmitting and receiving antenna are very close to the earth's curvature.

Ground wave propagation suffers attenuation while propagating along the surface of the earth. This propagation can be subdivided into two types which are space wave and surface wave propagation

Applications

Ground wave propagation is generally used in TV, radio broadcasting etc.

(ii) Sky Wave Propagation

Sky wave propagation is practically important at frequencies between 2 to 30 MHz Here the electromagnetic waves reach the receiving point after reflection from an atmospheric layer known as ionosphere. Hence, sky wave propagation is also known as 'ionosphere wave propagation'.

It can provide communication over long distances.

Hence, it is also known as point-to-point propagation or point-to-point communication.

Disadvantage

Sky wave propagation suffers, from fading due to reflections from earth surface, fading can be reduced with the help of diversity reception.

Applications

1. Global communication is possible.

(iii) Space Wave Propagation

Space wave propagation is practically important at frequencies above 30 MHz It is also known as troposphere wave propagation because the waves reach the receiving point after reflections from tropospheric region.

In space wave propagation, signal at the receiving point is a combination of direct and indirect rays. It provides communication over long distances with VHF .UHF and microwave frequencies. Space wave propagation is also known as "line of sight propagation".

Applications

1. Space wave propagation is used in satellite communication.

2. It controls radio traffic between a ground station and a satellite.

(iv) Tropospheric scatter Propagation

Tropospheric scatter propagation is also known as forward 1 scatter propagation, it is practically important at frequencies above 300 MHz.. This propagation covers long distances in the range of 160 to 1600 km.

propagation characteristics of EM wave

Electromagnetic waves carry energy or momentum from one point in space to another by means of their electric and magnetic fields. It consists of electric and magnetic field components which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation.- Depending on the frequency of the EM waves they are classified into different types, such as radio waves, microwaves, visible light, ultraviolet radiation, x-rays and gamine rays.

Some of the significant characteristics of electromagnetic wave; are as follows.

1. Speed(c)

For most practical purposes the speed is taken as 3 x 10s m/s although the more exact value is 299792500 m/s. Although exceedingly fast, they still take a finite time to travel over a given distance.

2.Wavelength(λ)

This is distance between a given point on one cycle and the same point on the next cycle as shown in figure. It is denoted by 'λ'

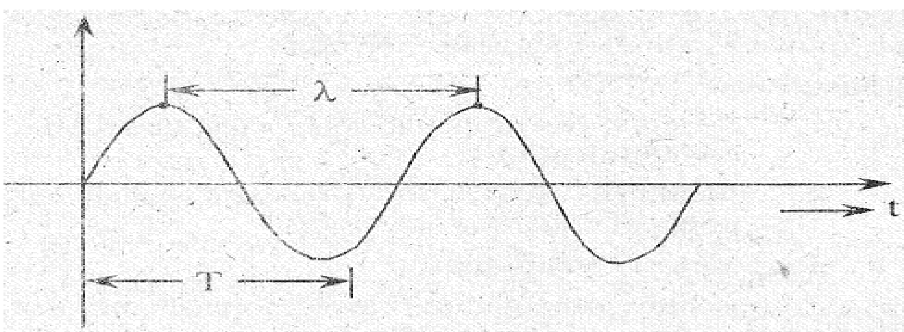


fig 10.1 EM Waves

The easiest points to choose are the peaks as these are the easiest to locate.

3. Frequency (f):

It is defined as the inverse of the time period of the wave. Time period of a wave is the time taken by a wave to repeat itself. Figure shows that the time taken by sinusoidal wave to repeat itself is T (seconds).

$$f = 1/T$$

The three characteristics of the wave are related by the equation.

$$C = f\lambda$$

Or

$$\lambda = C/f$$

ATMOSPHERIC PROPAGATION

Within the atmosphere, radio waves can be reflected, refracted, and diffracted like light and heat waves.

Reflection

Radio waves may be reflected from various substances or objects they meet during travel between the transmitting and receiving sites. The amount of reflection depends on the reflecting material. Smooth metal surfaces of good electrical conductivity are efficient reflectors of radio waves. The surface of the Earth itself is a fairly good reflector. The radio wave is not reflected from a single point on the reflector but rather from an area on its surface. The size of the area required for reflection to take place depends on the wavelength of the radio wave and the angle at which the wave strikes the reflecting substance.

When radio waves are reflected from flat surfaces, a phase shift in the alternations of the wave occurs. After reflection takes place, however, the waves are approximately 180 degrees out of phase from their initial relationship. The amount of phase shift that occurs is not constant. It depends on the polarization of the wave and the angle at which the wave strikes the reflecting surface.

Radio waves that keep their phase relationships after reflection normally produce a stronger signal at the receiving site. Those that are received out of phase produce a weak or fading signal. The shifting in the phase relationships of reflected radio waves is one of the major reasons for fading.

Refraction

Another phenomenon common to most radio waves is the bending of the waves as they move from one medium into another in which the velocity of propagation is different. This bending of the waves is called refraction. The change of medium, from hard surface to soft shoulder, causes a change in speed or velocity. This same principle applies to radio waves as changes occur in the medium through which they are passing. As an example, the radio wave is traveling through the Earth's atmosphere at a constant speed. As the wave enters the dense layer of electrically charged ions, the part of the wave that enters the new medium first travels faster than the parts of the wave that have not yet entered the new medium. This abrupt increase in velocity of the upper part of the wave causes the wave to bend back toward the Earth. This bending, or change of direction, is always toward the medium that has the lower velocity of propagation.

Radio waves passing through the atmosphere are affected by certain factors, such as temperature, pressure, humidity, and density. These factors can cause the radio waves to be refracted. This effect will be discussed in greater detail later in this chapter.

Diffraction

A radio wave that meets an obstacle has a natural tendency to bend around the obstacle. The bending, called diffraction, results in a change of direction of part of the wave energy from the normal line-of-sight path. This change makes it possible to receive energy around the edges of an obstacle as shown in view A or at some distances below the highest point of an obstruction, as shown in view B. Although diffracted rf energy usually is weak, it can still be detected by a suitable receiver. The principal effect of diffraction extends the radio range beyond the visible horizon. In certain cases, by using high power and very low frequencies, radio waves can be made to encircle the Earth by diffraction.

THE EFFECT OF THE EARTH'S ATMOSPHERE ON RADIO WAVES

This discussion of electromagnetic wave propagation is concerned mainly with the properties and effects of the medium located between the transmitting antenna and the receiving antenna. While radio waves traveling in free space have little outside influence affecting them, radio waves traveling within the Earth's atmosphere are affected by varying conditions. The influence exerted on radio waves bythe
Earth's atmosphere adds many new factors to complicate what at first seems to be a relatively simple problem. These complications are because of a lack of uniformity within the Earth's atmosphere. Atmospheric conditions vary with changes in height, geographical location, and even with changes in time (day, night, season, year). A knowledge of the composition of the Earth's atmosphere is extremely important for understanding wavepropagation.The Earth's atmosphere is divided into three separate regions, or layers. They are the TROPOSPHERE, the STRATOSPHERE, and the IONOSPHERE.

TROPOSPHERE

The troposphere is the portion of the Earth's atmosphere that extends from the surface of the

Earth to a height of about 3.7 miles (6 km) at the North Pole or the South Pole and 11.2 miles (18 km) at the equator. Virtually all weather phenomena take place in the troposphere. The temperature in this region decreases rapidly with altitude, clouds form, and there may be much turbulence because of variations in temperature, density, and pressure. These conditions have a great effect on the propagation of radio waves, which will be explained later in this chapter.

STRATOSPHERE

The stratosphere is located between the troposphere and the ionosphere. The temperature throughout this region is considered to be almost constant and there is little water vapor present. The stratosphere has relatively little effect on radio waves because it is a relatively calm region with little or no temperature changes.

IONOSPHERE

The ionosphere extends upward from about 31.1 miles (50 km) to a height of about 250 miles (402 km). It contains four cloud-like layers of electrically charged ions, which enable radio waves to be propagated to great distances around the Earth. This is the most important region of the atmosphere for long distance point-to-point communications.

Skip Distance/Skip Zone

The SKIP DISTANCE is the distance from the transmitter to the point where the sky wave is first returned to Earth. The size of the skip distance depends on the frequency of the wave, the angle of incidence, and the degree of ionization present.

The SKIP ZONE is a zone of silence between the point where the ground wave becomes too weak for reception and the point where the sky wave is first returned to Earth. The size of the skip zone depends on the extent of the ground wave coverage and the skip distance. When the ground wave coverage is great enough or the skip distance is short enough that no zone of silence occurs, there is no skip zone. Occasionally, the first sky wave will return to Earth within the range of the ground wave. If the sky wave and ground wave are nearly of equal intensity, the sky wave alternately reinforces and cancels the ground wave, causing severe fading. This is caused by the phase difference between the two waves, a result of the longer path traveled by the sky wave.

PROPAGATION PATHS

The path that a refracted wave follows to the receiver depends on the angle at which the wave strikes the ionosphere. You should remember, however, that the RF energy radiated by a transmitting antenna spreads out with distance. The energy therefore strikes the ionosphere at many different angles rather than a single angle. After the RF energy of a given frequency enters an ionospheric region, the paths that this energy might follow are many. It may reach the receiving antenna via two or more paths through a single layer. It may also, reach the receiving antenna over a path involving more than one layer, by multiple hops between the ionosphere and Earth, or by any combination of these paths.

When the angle is relatively low with respect to the horizon (ray 1), there is only slight penetration of the layer and the propagation path is long.When the angle of incidence is increased (rays 2 and 3), the rays penetrate deeper into the layer but the range of these rays decreases. When a certain angle is reached (ray 3), the penetration of the layer and rate of refraction are such that the ray is first returned to Earth at a minimal distance from the transmitter. Notice, however, that ray 3 still manages to reach the receiving site on its second refraction (called a hop) from the ionospheric layer.

As the angle is increased still more (rays 4 and 5), the RF energy penetrates the central area of maximum ionization of the layer. These rays are refracted rather slowly and are eventually returned to Earth at great distances. As the angle approaches vertical incidence (ray 6), the ray is not returned at all, but passes on through the layer.

ABSORPTION IN THE IONOSPHERE

Many factors affect a radio wave in its path between the transmitting and receiving sites. The factor that has the greatest adverse effect on radio waves is ABSORPTION. Absorption results in the loss of energy of a radio wave and has a pronounced effect on both the strength of received signals and the ability to communicate over long distances.

Sky waves, on the other hand, suffer most of their absorption losses because of conditions in the ionosphere. Note that some absorption of sky waves may also occur at lower atmospheric levels because of the presence of water and water vapor. However, this becomes important only at frequencies above 10,000 megahertz. Most ionospheric absorption occurs in the lower regions of the ionosphere where ionization density is greatest. As a radio wave passes into the ionosphere, it loses some of its energy to the free electrons and ions. If these high-energy free electrons and ions do not collide with gas molecules of low energy, most of the energy lost by the radio wave is reconverted into electromagnetic energy, and the wave continues to be propagated with little change in intensity. However, if the high-energy free electrons and ions do collide with other particles, much of this energy is lost, resulting in absorption of the energy from the wave. Since absorption of energy depends on collision of the particles, the greater the density of the ionized layer, the greater the probability of collisions; therefore, the greater the absorption. The highly dense D and E layers provide the greatest absorption of radio waves.Because the amount of absorption of the sky wave depends on the density of the ionosphere, which varies with seasonal and daily conditions, it is impossible to express a fixed relationship between distance and signal strength for ionospheric propagation. Under certain conditions, the absorption of energy is so great that communicating over any distance beyond the line of sight is difficult.

FADING

The most troublesome and frustrating problem in receiving radio signals is variations in signal strength, most commonly known as FADING. There are several conditions that can produce fading. When a radio wave is refracted by the ionosphere or reflected from the Earth's surface, random changes in the polarization of the wave may occur. Vertically and horizontally mounted receiving antennas are designed to receive vertically and horizontally polarized waves, respectively. Therefore, changes in polarization cause changes in the received signal level because of the inability of the antenna to receive polarization changes Fading also results from absorption of the RF energy in the ionosphere. Absorption fading occurs for a longer period than other types of fading, since absorption takes place slowly.

Maximum Usable Frequency

As we discussed earlier, the higher the frequency of a radio wave, the lower the rate of refraction by an ionized layer. Therefore, for a given angle of incidence and time of day, there is a maximum frequency that can be used for communications between two given locations. This frequency is known as the MAXIMUM USABLE FREQUENCY (MUF).

Waves at frequencies above the MUF are normally refracted so slowly that they return to Earth beyond the desired location, or pass on through the ionosphere and are lost. You should understand, however, that use of an established MUF certainly does not guarantee successful communications between a transmitting site and a receiving site. Variations in the ionosphere may occur at any time and consequently raise or lower the predetermined MUF. This is particularly true for radio waves being refracted by the highly variable F2 layer. The MUF is highest around noon when ultraviolet light waves from the sun are the most intense. It then drops rather sharply as recombination begins to take place.

the refractive index given by.

$$n = \frac{\sin \phi_i}{\sin \phi_r} = \sqrt{1 - \frac{81N}{f^2}}$$

* for radio wave to return back to the earth angle of refraction must be 90° i.e $\phi_r = 90^\circ$

for this condition N becomes N_{max} and f becomes f_{muf}

$$\therefore \frac{\sin \phi_i}{\sin 90^\circ} = \sqrt{1 - \frac{81N_{max}}{f_{muf}^2}}$$

$$\therefore \sin \phi_i = \sqrt{1 - \frac{81N_{max}}{f_{muf}^2}}$$

Squaring both sides

$$\sin^2 \phi_i = 1 - \frac{81N_{max}}{f_{muf}^2}$$

$$\therefore \frac{81N_{max}}{f_{muf}^2} = 1 - \sin^2\phi_i = \cos^2\phi_i.$$

but $f_{cr} = \sqrt{81N_{max}}$

$$\therefore \frac{f_{cr}^2}{f_{muf}^2} = \cos^2\phi_i$$

$$\therefore f_{muf} = \frac{f_{cr}}{\cos\phi_i} = \sec\phi_i \, f_{cr}$$

$\therefore$ The f_{muf} is always greater than f_{cr} of the layer by the factor $\sec\phi_i$. This is called secant law.

Lowest Usable Frequency

As there is a maximum operating frequency that can be used for communications between two points, there is also a minimum operating frequency. This is known as the LOWEST USABLE FREQUENCY (LUF). As the frequency of a radio wave is lowered, the rate of refraction increases. So a wave whose frequency is below the established LUF is refracted back to Earth at a shorter distance than desired.

The transmission path that results from the rate of refraction is not the only factor that determines the LUF. As a frequency is lowered, absorption of the radio wave increases. A wave whose frequency is too low is absorbed to such an extent that it is too weak for reception. Likewise, atmospheric noise is greater at lower frequencies; thus, a low-frequency radio wave may have an unacceptable signal-to-noise ratio. For a given angle of incidence and set of ionospheric conditions, the LUF for successful communications between two locations depends on the refraction properties of the ionosphere, absorption considerations, and the amount of atmospheric noise present.

Optimum Working Frequency

Neither the MUF nor the LUF is a practical operating frequency. While radio waves at the LUF can be refracted back to Earth at the desired location, the signal-to-noise ratio is still much lower than at the higher frequencies, and the probability of multipath propagation is much greater. Operating at or near the MUF can result in frequent signal fading and dropouts when ionospheric variations alter the length of the transmission path. The most practical operating frequency is one that you can rely on with the least amount of problems. It should be high enough to avoid the problems of multipath, absorption, and noise encountered at the lower frequencies; but not so high as to result in the adverse effects of rapid changes in the ionosphere. A frequency that meets the above criteria has been established and is known as the OPTIMUM WORKING FREQUENCY.

RADIO WAVE TRANSMISSION

There are two principal ways in which electromagnetic (radio) energy travels from a transmitting antenna to a receiving antenna. One way is by GROUND WAVES and the other is by SKY WAVES.

Ground waves are radio waves that travel near the surface of the Earth (surface and space waves). Sky waves are radio waves that are reflected back to Earth from theionosphere.

Ground Waves The ground wave is actually composed of two separate component waves. These are known as the SURFACE WAVE and the SPACE WAVE. The determining factor in whether a ground wave component is classified as a space wave or a surface wave is simple. A surface wave travels along the surface of the Earth. A space wave travels over the surface.

SURFACE WAVE.—The surface wave reaches the receiving site by traveling along the surface of the ground. A surface wave can follow the contours of the Earth because of the process of diffraction. When a surface wave meets an object and the dimensions of the object do not exceed its wavelength, the wave tends to curve or bend around the object. The smaller the object, the more pronounced the diffractive action willbe. As a surface wave passes over the ground, the wave induces a voltage in the Earth. The induced voltage takes energy away from the surface wave, thereby weakening, or attenuating, the wave as it moves away from the transmitting antenna. To reduce the attenuation, the amount of induced voltage must be reduced. This is done by using vertically polarized waves that minimize the extent to which the electric field of the wave is in contact with the Earth. When a surface wave is horizontally polarized, the electric field of the wave is parallel with the surface of the Earth and, therefore, is constantly in contact with it. The wave is then completely attenuated within a short distance from the transmitting site. On the other hand, when the surface wave is vertically polarized, the electric field is vertical to the Earth and merely dips into and out of the Earth's surface. For this reason, vertical polarization is vastly superior to horizontal polarization for surface wave propagation.

The attenuation that a surface wave undergoes because of induced voltage also depends on the electrical properties of the terrain over which the wave travels. The best type of surface is one that has good electrical conductivity. The better the conductivity, lesser the attenuation.

Another major factor in the attenuation of surface waves is frequency. These high frequencies, with their shorter wavelengths, are not normally diffracted but are absorbed by the Earth at points relatively close to the transmitting site. You can assume, therefore, that as the frequency of a surface wave is increased, the more rapidly the surface wave will be absorbed, or attenuated, by the Earth. Because of this loss by attenuation, the surface wave is impractical for long-distance transmissions at frequencies above 2 megahertz. On the other hand, when the frequency of a surface wave is low enough to have a very long wavelength, the Earth appears to be very small, and diffraction is sufficient for propagation well beyond the horizon. In fact, by lowering the transmitting frequency into the very low frequency (VLF) range and using very high-powered transmitters, the surface wave can be propagated great distances. The Navy's extremely high-powered VLF transmitters are actually capable of transmitting surface wave signals around the Earth and can provide coverage to naval units operating anywhere atsea.

SPACE WAVE.—The space wave follows two distinct paths from the transmitting antenna to the receiving antenna—one through the air directly to the receiving antenna, the other reflected from the ground to the receiving antenna. The primary path of the space wave is directly from the transmitting antenna to the receiving antenna. So, the receiving antenna must be located within the radio horizon of the transmitting antenna. Because space waves are refracted slightly, even when propagated through the troposphere, the radio horizon is actually about one-third farther than the line-of-sight or natural horizon.

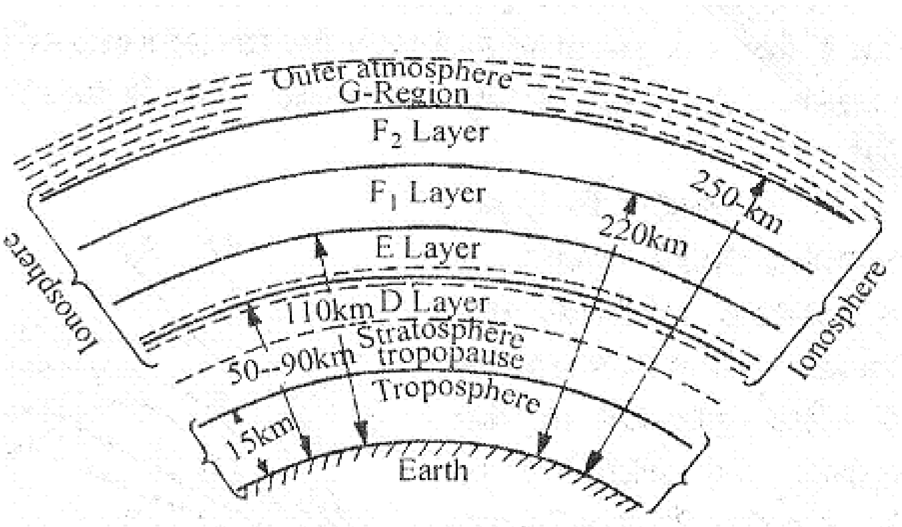
Although space waves suffer little ground attenuation, they nevertheless are susceptible to fading. This is because space waves actually follow two paths of different lengths (direct path and ground reflected path) to the receiving site and, therefore, may arrive in or out of phase. If these two component waves are received in phase, the result is a reinforced or stronger signal. Likewise, if they are received out of phase, they tend to cancel one another, which results in a weak or fading signal.

Sky Wave

The sky wave, often called the ionospheric wave, is radiated in an upward direction and returned to Earth at some distant location because of refraction from the ionosphere. This form of propagation is relatively unaffected by the Earth's surface and can propagate signals over great distances. Usually the high frequency (HF) band is used for sky wave propagation. The following in-depth study of the ionosphere and its effect on sky waves will help you to better understand the nature of sky wave propagation.

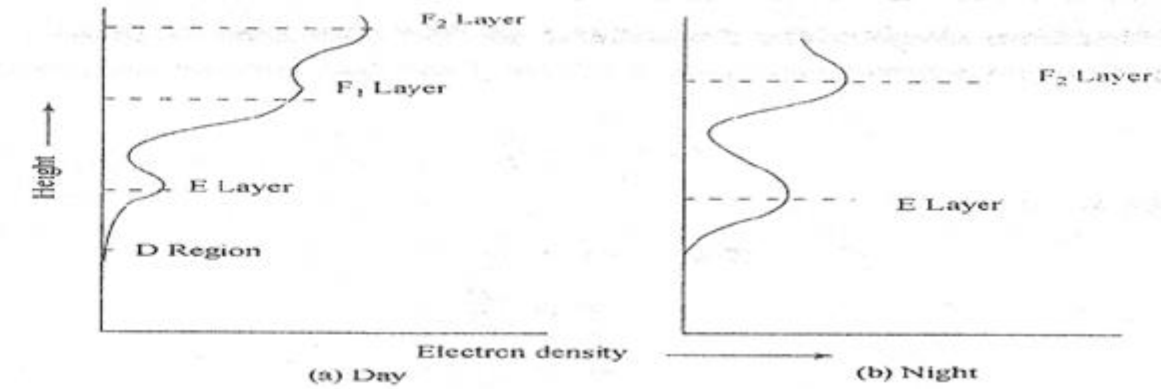
Structure of the ionosphere

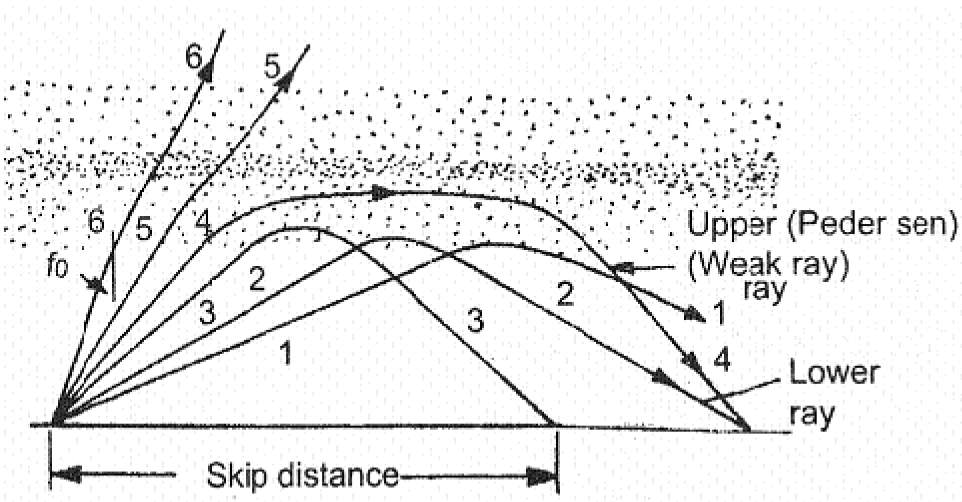
As the medium between the transmitting and receiving antennas plays a significant role, it is essential to study the medium above the earth, through which the radio waves propagate. The various regions above the earth's surface are illustrated in Fig.1



Structure of ionosphere

The portion of the atmosphere, extending up to a height (average of 15 Km) of about 16 to 18 Kms from the earth's surface, at the equator is termed as troposphere or region of change. Troposphere starts at the top of the troposphere and ends at the beginning of or region of calm. Above the stratosphere, the upper stratosphere parts of the earth's atmosphere absorb large quantities of radiant energy from the sun. This not only heats up the atmosphere, but also produces some ionization in the form of free electrons, positive and negative ions. This part of the atmosphere where the ionization is appreciable, is known as the ionosphere. The most important ionizing agents are ultraviolet UV radiation, ά , β and cosmic rays and meteors. The ionization tends to be stratified due to the differences in the physical properties of the atmosphere at different heights and also because various kinds of radiation are involved.





Effect of ionosphere on rays

The levels, at which the electron density reaches maximum, are called as layers. The three principal day time maxima are called E, F_1, and F_2 layers. In addition to these three regular layers, there is a region (below E) responsible for much of the day time attenuations of HF radio waves, called D region (ref. Fig. 4a). It lies between the heights of 50 and 90 Km (ref. Fig. 3). The heights of maximum density of regular layers E and $F_1$are relatively constant at about 110 Km and 220Km respectively. These have little or no diurnal variation, whereas the F_2layer is more variable, with heights in the range of 250 to 350Km.

At night F_1 and F_2 layers combine to form a single night time F_2 layer (Fig. 4b). The E layer is governed closely by the amount of UV light from the sun and at night tends to decay uniformly with time. The D layer ionization is largely absent during night

A sporadic E layer is not a thick layer. It is formed without any cause. The ionization is often present in the region, in addition to the regular E ionization. Sporadic E exhibits the characteristics of a very thin layer appearing at a height of about 90 to 130 Kms. Often, it occurs in the form of clouds, varying in size from 1 Km to several 100 Kms across and its occurrence is quite unpredictable. It may be observed both day and night and its cause is still uncertain.

Characteristics of F1 Layer:

1. F1 layer is the lower end region of F-layer and which will be situated at an average height of 220 km. (generally, 140 km to 250km).
2 . The behavior of F1 layer is similar to that of E-region (normal) and obeys the Chapman's law of variations.
3. Its critical frequency ranges from 5 MHz to 7 MHz at noontime.
4. The value of electron density varies from 2 x 105 to 4.5 x105.
5. F1 layer is formed by the ionization of oxygen atoms, due to an accepted view.
6. Maximum HF waves are penetrated through the F1 layer, even though some of them are reflected back.
7. The main function of F1 layer is to provide more absorption for HF waves.
8. The density of F1 layer is lowers in winter than summer, even though no great variations in height.

Characteristics of F2 Layer

F2 layer is the upper end region of F-layer and which will be situated at a height range of 250 km to 400 km.

Its critical frequency ranges from 5 MHz to 12 MHz (basically 10 MHz) and may be even more at low altitude stations.

The electron density of F2 layer may varies from 3 x 105 to 2 x 106.

Being the upper most regions, the air density is very low due to which ionization disappears very slowly. F2 layer is formed by ionization of UV, X-rays and corpuscular radiations.

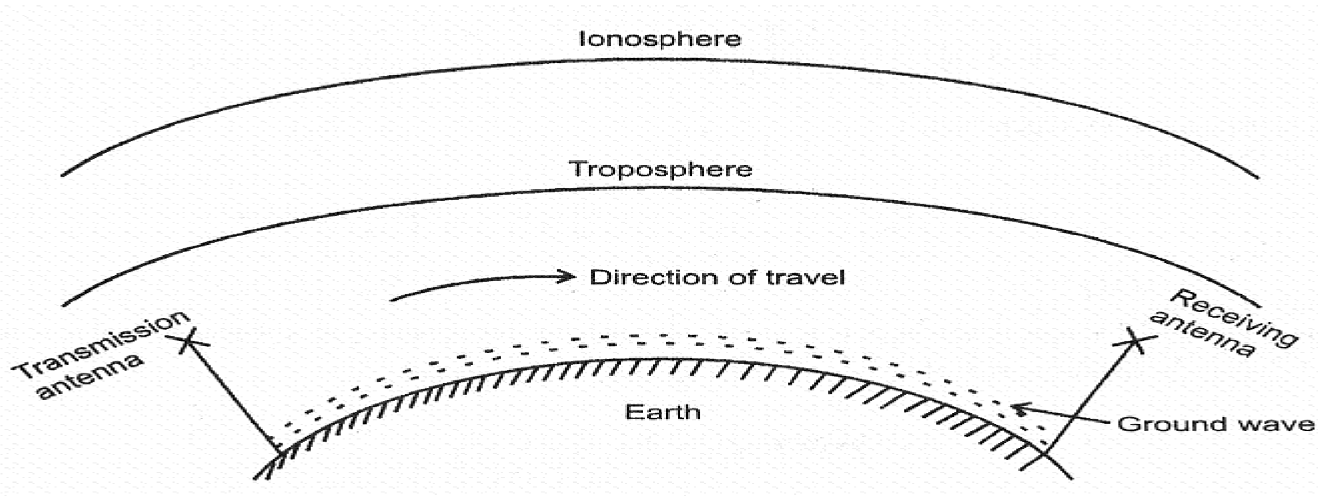
The earth's magnetic field, atmospheric, ionosphere storms and other geomagnetic disturbances have large effect on the ionization in F2 layer.

This layer does not follow Chapman's law of variations.

This is the most important reflecting medium for high frequency radio waves.

Ground Wave Propagation

The ground wave is a wave that is guided along the surface of the earth just as an electromagnetic wave is guided by a wave guide or transmission line. This ground wave propagation takes place around the curvature of the earth in the frequency bands up to 2 MHz This also called as surface wave propagation.



The ground wave is vertically polarized, as any horizontal component of the E field in contact with the earth is short-circuited by it. In this mode, the wave glides over the surface of the earth and induces charges in the earth which travel with the wave, thus constituting a current, (see Fig.1). While carrying this current, the earth acts as a leaky capacitor. Hence it can be represented by a resistance or conductance shunted by a capacitive reactance. Thus, the characteristics of the earth as a conductor can be described in terms of conductivity (a) and dielectric constant (e).

As the ground wave passes over the surface of the earth, it is weakened due to the absorption of its energy by the earth. The energy loss is due to the induced current flowing through the earth's resistance and is replenished partly, by the downward diffraction of additional energy, from the portions of the wave in the immediate vicinity of the earth's surface.

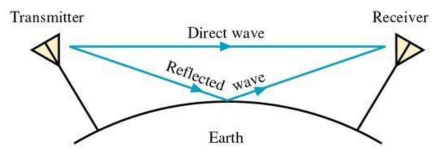
SPACE (DIRECT) WAVE PROPAGATION

Space Waves, also known as direct waves, are radio waves that travel directly from the transmitting antenna to the receiving antenna. In order for this to occur, the two antennas must be able to –see each other; that is there must be a line of sight path between them. The diagram on the next page shows a typical line of sight. The maximum line of sight distance between two antennas depends on the height of each antenna. If the heights are measured in feet, the maximum line of sight, in miles, is given by:

$$d = \sqrt{2h_T} + \sqrt{2h_R}$$

Because a typical transmission path is filled with buildings, hills and other obstacles, it is possible for radio waves to be reflected by these obstacles, resulting in radio waves that arrive at the receive antenna from several different directions. Because the length of each path is different, the waves will not arrive in phase. They may reinforce each other or cancel each other, depending on the phase differences. This situation is known as multipath propagation. It can cause major distortion to certain types of signals. Ghost images seen on broadcast TV signals are the result of multipath – one picture arrives slightly later than the other and is shifted in position on the screen. Multipath is very troublesome for mobile communications. When the transmitter and/or receiver are in motion, the path lengths are continuously changing and the signal fluctuates wildly in amplitude. For this reason, NBFM is used almost exclusively for mobile communications. Amplitude variations caused by multipath that make AM unreadable are eliminated by the limiter stage in an NBFM receiver.

An interesting example of direct communications is satellite communications. If a satellite is placed in an orbit 22,000 miles above the equator, it appears to stand still in the sky, as viewed from the ground. A high gain antenna can be pointed at the satellite to transmit signals to it. The satellite is used as a relay station, from which approximately ¼ of the earth‘s surface is visible. The satellite receives signals from the ground at one frequency, known as the uplink frequency, translates this frequency to a different frequency, known as the downlink frequency, and retransmits the signal. Because two frequencies are used, the reception and transmission can happen simultaneously. A satellite operating in this way is known as a transponder. The satellite has a tremendous line of sight from its vantage point in space and many ground stations can communicate through a single satellite.



Ionospheric Abnormalities

Various problems associated with skyways propagation are due to abnormalities in ionosphere and are of two types.

3. Normal
4. Abnormal

Normal variations include seasonal, height as thickness variation, noise.

Abnormal variation includes tides and winds, sunspot cycle, fading, whistles. Some of the

important variations are as follows.

Tides and Winds

Atmosphere experiences tidal pulls of the sun and moon. As the free period of isolation of the atmosphere coincides with the solve tidal period of 12 hours, it results in resonance phenomenon. This becomes more important and complicated by thermal heating of the atmosphere by the sun rays which have a 24 hours time period, which is twice that of tidal period.

The F_2layer has the highest speed of tidal motion with lowest particle density sighted at the height level.

Hence, F_2 layer suffers maximum from effect of tides and result in irregularities in its layer and causes a small peak of maximum ionization density in F_2layer at midnight.

Sudden Ionospheric Disturbances

Sudden appearance of height spot on solar disc increases the ionization density of D-region. This intern causes increased absorption of high frequency signals resulting in a complete blackout of all high frequency. It is known as Sudden Ionospheric Disturbance (SID).

Sunspot Cycle

SID are measured by sunspot cycle. In the graph below, critical frequency of the ionosphere are highest during sunspot maxima and lowest during sunspot minima.

Critical frequency of F_2layer is minimum at 6 MHz and maximum at 10MHz.

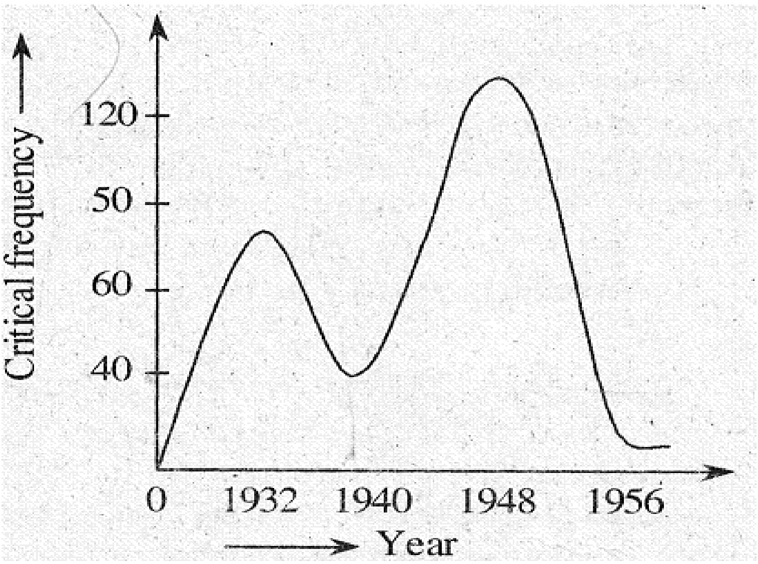


fig 8.1 (a) Sun Spot Number

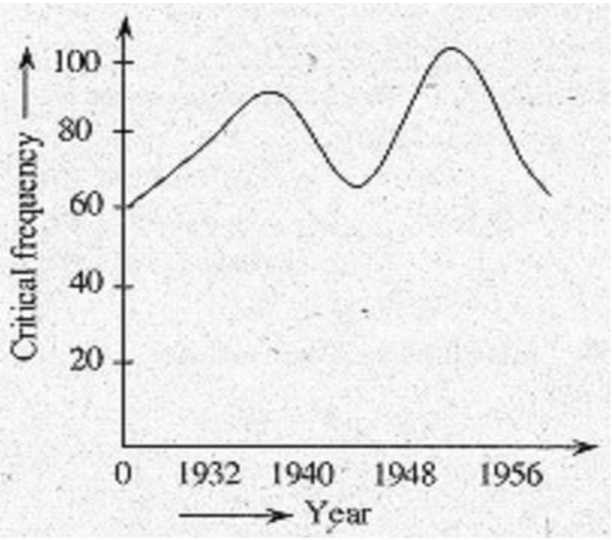


fig 8.2 Critical Frequency of F2 layer

Fading

Sky wave propagation largely suffers from fading variations or a fluctuation in the received signal strength is defined as fading. Wherever the signals that are propagated through sky wave propagation, at the receiver end the signals or wave follow different paths due to variations in the height and density of the ionization layer.

Fading is one of the important parameter in sky wave propagation and occurs due to reflections from the earth.
The values of fading are very small when the variation in signal strength is 20 to 30 dB. Fading can be reduced by using diversity reception.

Sudden Ionospheric Disturbances

With the sudden appearance of strong solar flares i.e., bright spot on the solar disc, there occurs an intense increase in *D* layer ionization. 'An increase in the D-layer, causes increased absorption of high frequency signals resulting in a complete blackout of all high frequencies. It is known as "sudden ionospheric disturbances".

IonosphericStorms

Ionospheric storms are the disturbances which occur with the rapid and excessive fluctuations associated with magnetic storms in ionosphere. These disturbances are dependent on the magnetic storms that occur in earth's magnetic field. Ionospheric storm disturbance causes absorption of sky waves and change in critical frequency of $F_2$and ***E*** layers.

These ionospheric storms occur throughout the day and night and may extend up to two or more days. During ionospheric storms, the ionosphere loses its layered structure. In order to establish communication in this situation, we have to lower the working frequency. The virtual height of F_2layer increases because of sudden decrease in critical frequency due to ionospheric storm.

Ionospheric storm is caused by α and β ray particles that are emitted from sun. The ionosphere storm effect decreases as one moves from poles to equator. The ionospheric effect causes narrowing of range of frequencies on radio transmission.

Sudden Ionosphere Disturbances(SID)

Sudden Ionospheric Disturbances (SIDs) are also called as Mongel-Dellinger effect. SID is caused due to appearance of bright spots on solar disc suddenly. These bright spots are caused due to large emission of hydrogen from the sun. The X-rays along with bright spot causes a tremendous increase in the ionization electron density till the D-layer.

This causes increase in absorption, reflection and atmospheric noise. Hence, the value of LUF increases and exceeds MUF, causing complete blackout of sky wave communication over ionosphere. This blackout effect is known as sudden ionospheric disturbance. SID is high at noon and at equator position SID doesn't occur during nights. SID takes place for a very less duration and it will depend on the sunlit portions of globe. It doesn't affect ***E,*** $F_1$and F_2layers. SID is caused due to UV radiation intensity from solar flares (bright spot on solar disk), that penetrates through ***E,*** F_1 F_2 layers and cause tremendous increase in ionization density in D-layer.

Reduction of Field Strength in Sky Wave Propagation

The low frequency radio signals lie in the band of 30-300 kHz. The electric field strength of three low frequency broadcasting stations, CLT, MCO and CZE has been monitored by a sampling frequency. The low frequency signals are characterized by the ground wave and the sky wave propagation modes.

The daytime electric field strength is lower than at night because the sky wave is greatly attenuated by the lower ionosphere and the ground wave alone is providing the signal which is faint. At nighttime, the low attenuation of the lower ionosphere permits an increase of 10-15 dB in the sky wave signal such that the received signal is practically all due to the sky wave propagation. The decrease in CLT radio- signal is mainly due to a reduction of electric field strength of the ground wave.

PART B

1. Discuss about the ground wave propagation.
2. Derive the expression for calculating field strength at a distance in space wave propagation.
3 . Write short notes an
   (a) MUF
   (b) Virtual Height
   (c) Skip distance
4. Explain in detail about Ionospheric Abnormalities
5.Explain the Structure of Ionosphere in detail.
6.Explain the Structure of atmosphere in detail.
7. Write short notes on:
   a. Surface wave tilting.
   b. Space wave propagation.
   c. Ionosphere propagation.
   d. Structure of ionosphere.
   e. Sky wave propagation.
   f. Duct propagation.
8. Obtain an expression for space wave field component taking into account a direct wave field component and a reflected wave from the earth surface.
9. Derive an expression for refractive index of ionosphere.
10. Explain the following and derive the relevant expressions:
   a. Critical frequency.
   b. Maximum usable frequency.
   c. Virtual height.
   d. Skip distance.
11. Briefly explain characteristics of different ionized layers in ionospheric propagation.
12. Calculate the critical frequency for a medium at which the wave reflects if the maximum electron density is 1.24×10^{6} electrons/cm^3.
13. Which propagation will aid the following frequencies and why. (a) 120KHz. (b) 10MHz.

(c) 300 MHz. (d) 30GHz.

14. Estimate the surface wave tilt in degrees over an earth of 12mm conductivity and relative permittivity 20 at a wave length of 300m.
15. A transmitter radiates 100Wof power at a frequency of 50MHz, so that space wave propagation takes place. The transmitting antenna has a gain of 5 and its height is 50m. The receiving antenna height is 2m. It is estimated that field strength of 100 V/m is required to give a satisfactory result. Calculate the distance between transmitter and receiver.
16. Explain the electrical properties of Ionosphere.
17. Explain the effect of earth's magnetic field.
18. Explain Faraday rotation and whistlers. Also explain wave propagation in complex environment.
19. Explain the mechanism of ionosphere propagation.
20. How does the earth affect ground wave propagation?
21. Explain the terms
    i). Optimum working frequency. ii). Duct propagation.
    iii). Virtual height iv). Skip distance
22. Discuss the effects of Earth's magnetic field on ionosphere radio wave propagation
23. Explain the important features of ground wave propagation.
24. Describe the structure of the atmosphere and specify the factors affecting the radio wave propagation.
25. Explain in detail about effect of earth's magnetic field on radio wave propagation.