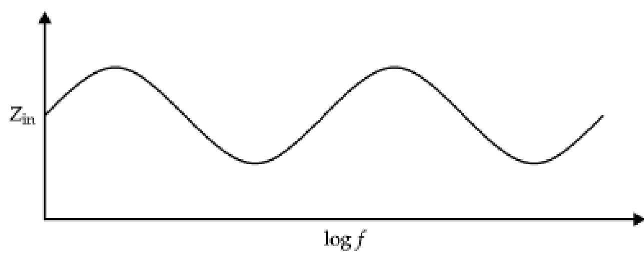
ANTENNA AND WAVE PROPAGATION

MODULE 5

Log-periodic Antenna

Log Periodic Antenna (LPA) is an antenna array of the same type of dipole elements but the length of these elements increases with a common ratio. All elements are excited by a common input with the same phase..

The structural geometry of LPA is so chosen that the electrical properties of the antenna must repeat periodically with the logarithm of the frequency. It is basically called a frequency-independent antenna because the impedance of the antenna depends upon the logarithmic of frequency. So, this Log Periodic Antenna is also called as "Frequency Independent Antenna".



Impedance Characteristics of Log-Periodic Antenna

It can be used to receive a good number of TV channels without any deterioration of the received field strength.

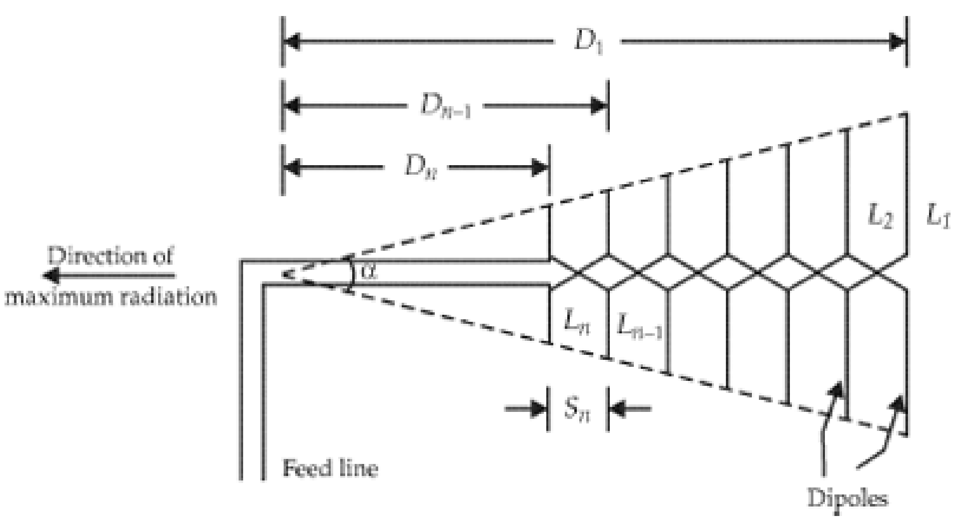


Fig. Log Periodic Antenna

Scale Factor,

$$\tau = \frac{D_n}{D_{n-1}} = \frac{L_n}{L_{n-1}}, n = 1, 2, 3, ...$$

Where

- τ is the design ratio or scale factor.
- R is the distance between the feed and the dipole
- l is the length of the dipole.

$\sigma = S_n/2L_n = S_n/S_{n-1}$
where**, α =*included angle*=$2\tan^{-1}[(1-\tau)/4\sigma]$**

The range of scale factor (τ) is from 0 to 1 for a specific wedge angle, α. If the value of α is large, then the scale factor (τ) is small. It means the wedge angle and scale factor are inversely proportional to each other. If τ is small and α is large, the performance of the antenna in terms of gain is improved.

Regions of Log Periodic Antenna

Inactive Transmission Line region (L≤λ/2)

In this region, the antenna elements are short with the resonant length (L≤λ/2), therefore the elements present a relatively high capacitance impedance. So this region is also called a capacitive region. S, the current leads with respect to the applied voltage by 90° in this region. These elements produce small backward radiation. The dipole element distance in this antenna is very small as compared with the wavelength.

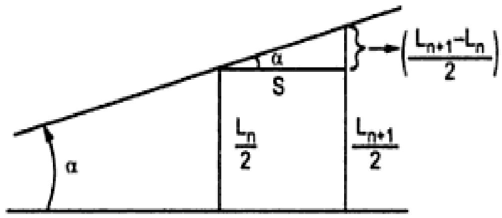
Active Region (Lλ/2)

In the region, the dipole length is an approximately resonant length and hence the impedance offered by the dipoles of this region is resistive appreciably in nature. So this region is also called a resistive region. In this region, the current is large and in phase with the voltage. These elements produce considerable forward radiation. The distance between two dipole elements in the antenna is greater than the Inactive Transmission Line region.

Inactive Reflective region (L>λ/2)

In this region the length of the element is longer than resonant length, hence the impedance becomes inductive, causing the current in the elements to lag the base voltage. The currents lag the voltage by 90°. The dipole element of the antenna reflects the incident signal in the backward direction.

Design of Log periodic dipole array



$$\tan\alpha = \frac{\left(\frac{L_{n+1}-L_n}{2}\right)}{s}$$

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

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

But $\frac{L_{n+1}}{L_n} = k$, i.e. $\frac{L_n}{L_{n+1}} = \frac{1}{k}$,

$$\tan\alpha = \frac{\left(1-\frac{1}{k}\right)L_{n+1}}{2s}$$

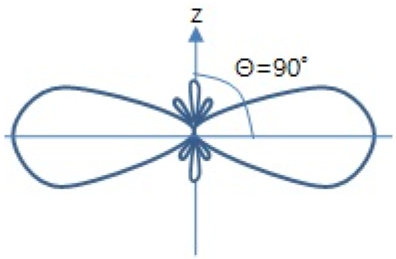
For active region $L_{n+1} = \frac{\lambda}{2}$

$$\tan\alpha = \frac{\left(1-\frac{1}{k}\right)\frac{\lambda}{2}}{2s}$$

$$\tan\alpha = \frac{1-\left(\frac{1}{k}\right)}{4\left(\frac{s}{\lambda}\right)}$$

$$\boxed{\tan\alpha = \frac{\left(1-\frac{1}{k}\right)}{4s_k}}$$

The Radiation pattern of log-periodic antenna can be of uni-directional or bi-directional, depending upon the log periodic structures. For **bi-directional Log-periodic antenna**, the maximum radiation is in broad side, which is normal to the surface of the antenna.



Advantages

- The antenna design is compact.
- Gain and radiation pattern are varied according to the requirements.

Disadvantages

- External mount.
- Installation cost is high.

Applications

- Used for HF communications.
- Used for particular sort of TV receptions.
- Used for all round monitoring in higher frequency bands.

Helical Antenna

Helical Antenna consists of a conducting wire wound in the form of a sc rew thread

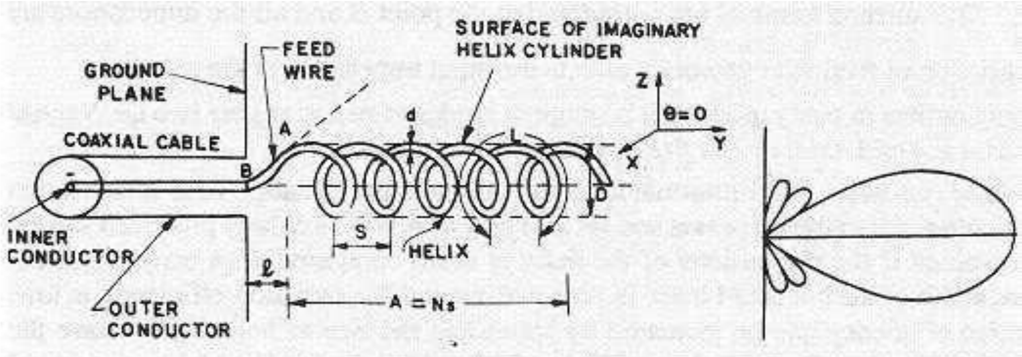
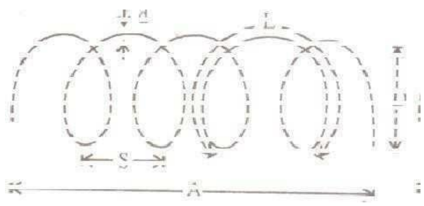


Fig 4.6.1 Helical antenna and its radiation pattern

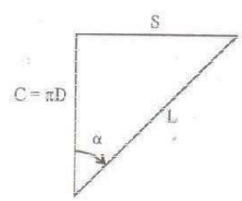
forming a helix. In the most cases the helix is used with a ground plane. The helix is usually connected to the center conductor of a co-axial transmission line and the outer conductor of the line is attached to the ground plane. Helical antenna is useful at very high frequency and ultra high frequencies to provide circular polarization.

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



N = Number of turns

D = Diameter of helix

C= circumference of helix(πD)

α = Pitch angle = $\tan^{-1}(\frac{S}{\pi D})$

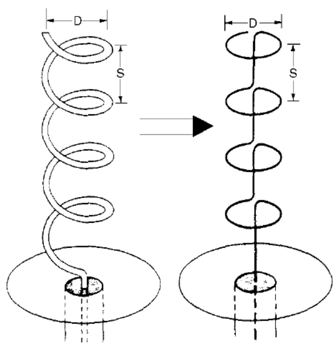
l = Distance between helix and ground plane.

The radiation characteristics of the antenna can be varied by controlling the size of its geometrical properties compared to the wavelength.

A helical antenna may radiate in many modes but prominent modes of radiations are two i.e. Normal or perpendicular mode of radiation and Axial or endfire or beam 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,

$$E_\Phi = \frac{120\,\pi 2\,[I]\,\sin\theta}{r} \cdot \frac{A}{\lambda^2}$$

Where,

r = Distance

[I] = Retarded current

A = Area of loop = $\pi D^2/4$
D = Diameter

λ = Operating wavelength.

Also far field of a short dipole is given by

$$E_\Theta = j\,\frac{60\,\pi 2\,[I]\,\sin\theta}{r} \cdot \frac{S}{\lambda}$$

S = L = length of dipole

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.

$$\text{Axial Ratio, AR} = \frac{|E\Theta|}{|E\Phi|} = \frac{\left|j\frac{60\,\pi 2\,[I]\sin\theta.S}{\lambda r}\right|}{\left|\frac{120\,\pi 2\,[I]\sin\theta A}{r.\lambda^2}\right|} = \frac{2S\lambda}{(\pi D)^2}$$

When the circumference is equal to

$$C = \pi D = \sqrt{2s\lambda}$$

the axial ratio becomes unity and the radiation is circularly polarised.

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.

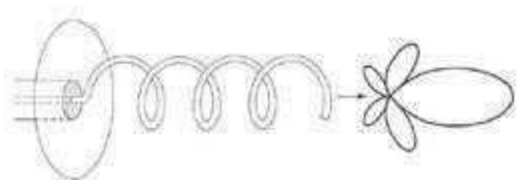


Fig 6.3: Axial mode of helix

General expression for terminal impedance is,

$$R = 140C/\lambda \text{ ohms}$$

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,

$$\textbf{HPBW} = \frac{52}{C}\sqrt{\frac{\lambda^3}{NS}} \text{ Degrees.}$$

Where,

λ = Wavelength

C = Circumference

N = Number of turns

S = Spacing.

$$\textbf{Axial Ratio, AR} = 1 + \frac{1}{2N}$$

Antennas for mobile base station and handsets.

In a cellular mobile communications system, the same frequency is repeatedly used in different geographical areas to effectively utilize the limited number of frequencies. Because of this, the base station antenna must radiate the required radio waves within its cell while minimizing the emission of radio waves to other cells. Accordingly, the antenna is designed to control the main beam and direct it to the outer rim of its own cell by using beam tilt, while reducing side lobe emissions that can interfere with neighboring stations.

Portable telephone systems require compact, lightweight and high-performance antennas. In recent years, two types of antennas (the transmission/reception whip antenna and the receive-only built-in antenna) are being used more and more in mobile terminals, along with the diversity transmission system. The monopole antenna is commonly adopted as a whip antenna, while the board-shaped reverse-F antenna is widely used as a built-in antenna. Efforts are being concentrated on making these antennas more compact and lightweight, as well as improving their performance and broadband capabilities.

Future mobile communication systems should require very high-speed signal transmission techniques that can support bit rate of more than 10 times as fast as that offered by the IMT-2000 systems. Furthermore, in order to accommodate more users per MHz than the IMT-2000 systems, multiple users have to be able to use the same frequency- and time-slots simultaneously without spreading their signals in the frequency domain. For this purpose, technological breakthrough is required that can suppress effects of co-channel interference while keeping the desired signal's received strength higher than required to support acceptable communication quality. Adaptive array antennas have been considered most effective in achieving this goal.

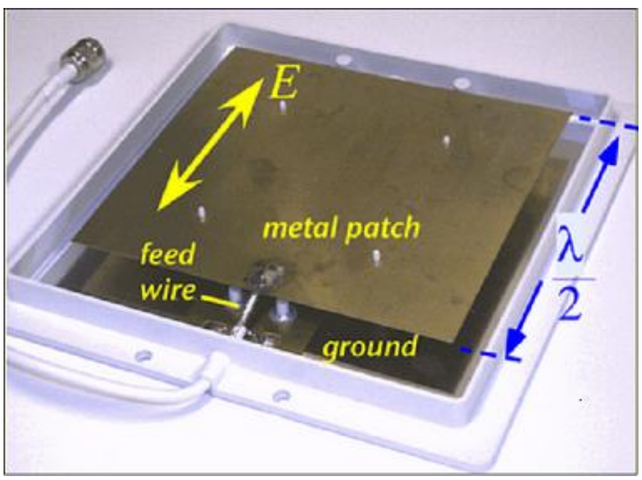
Adaptive array antennas control beam patterns by performing signal processing in the spatial domain so that deep nulls are formed towards interferer's incident angles, thereby desired signal components are received properly without being affected by the interferers. Unfortunately, however, adaptive array antenna is not effective in the presence of multiple propagation paths because it inevitably nullify the delayed desired signal components, even though they bear the desired user's transmitted information. A reasonable extension of the adaptive array antennas is space-time equalizers that combine adaptive array and adaptive equalizer concepts. The space-time equalizers perform signal processing in both spatial and temporal domains so that energies of delayed desired signal components can also be combined. This is quite effective in improving communication quality over the case where adaptive array antenna alone is used.

Micro strip antennas

Micro strip antennas are low-profile antennas. A metal patch mounted at a ground level with a di-electric material in-between constitutes a **Micro strip** or **Patch Antenna**. These are very low size antennas having low radiation. The patch antennas are popular for low profile applications at frequencies above **100MHz**.

Construction & Working of Micro strip Antennas

Micro strip antenna consists of a very thin metallic strip placed on a ground plane with a di-electric material in-between. The radiating element and feed lines are placed by the process of photo-etching on the di-electric material. Usually, the patch or micro-strip is chosen to be square, circular or rectangular in shape for the ease of analysis and fabrication. The following image shows a micro-strip or patch antenna.



Dimensions of a microstrip patch antenna depend on the resonant frequency and value of the dielectric constant. When the antenna is excited, the waves generated within the di-electric undergo reflections and the energy is radiated from the edges of the metal patch, which is very low.

The radiation pattern of microstrip or patch antenna is **broad**. It has low radiation power and narrow frequency bandwidth..

Design of patch antenna

For designing of a microstrip patch antenna, we have to select the resonant frequency and a dielectric medium for which antenna is to be designed. The parameters to be calculated are as under.

Width (W):

The width of the patch is calculated using the following equation

$$W = \frac{C_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Where,

W = Width of the patch

C_0= Speed of light

ε_r= value of the dielectric substrate

Effective refractive index:

The effective refractive index value of a patch is an important parameter in the designing procedure of a microstrip patch antenna. The radiations traveling from the patch towards the ground pass through air and some through the substrate (called as fringing). Bath the air and the substrates have different dielectric values, therefore in order to account this we find the value of effective dielectric constant. The value of the effective dielectric constant (ε_{reff}) is calculated using the following equation

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}, W/h > 1 \tag{2}$$

Length:

Due to fringing, electrically the size of the antenna is increased by an amount of (ΔL). Therefore, the actual increase in length (ΔL) of the patch is to be calculated using the following equation

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

Where 'h'= height of the substrate

The length (L) of the patch is now to be calculated using the below mentioned equation

$$L = \frac{C_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

Length (Lg) and widtg (Wg) of ground plane:

Now the dimensions of a patch are known. The length and width of a substrate is equal to that of the ground plane. The length of a ground plane (Lg) and the width of a ground plane (Wg) are calculated using the following equations [7]:

$$L_g = 6h + L \tag{5}$$

$$W_g = 6h + W \tag{6}$$

For feeding the microstrip patch antenna, there are different methods for example, feed line method, coaxial probe feeding method etc. But mostly coaxial probe method is used.

Feeding Techniques

1. Microstrip line technique

   It is a feeding technique, in which the microstrip patch is di- rectly connected with the conducting microstrip feed line. The dimensions of the feed line are different than microstrip patch. It is easy to fabricate and match.

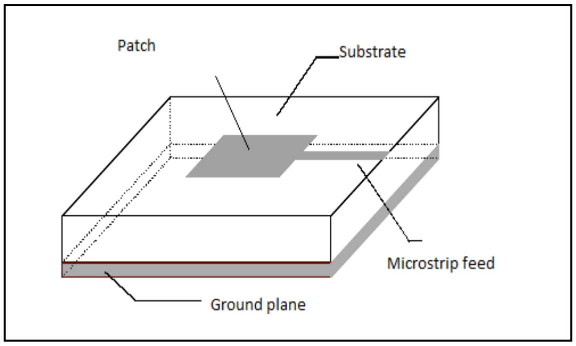


Fig . Microstrip line technique

2. Coaxial Probe Feeding Techniques

In this feeding method, inner conductor of coaxial cable is connected to the microstrip patch of an antenna and outer one is connected with ground plane. Mostly, the feed networks are isolated from the microstrip patch, but in this mechanism, it is not like that Spurious radiation minimization, easy fabrication and efficient feeding are the advantages of coaxial feeding method.

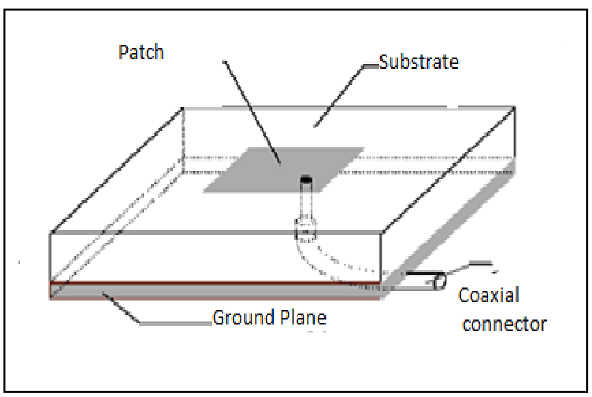


Fig. Coaxial Probe Feed

3. Feeding Techniques with Proximity coupled

The fabrication of this feeding method is bit complicated comparatively. Two dielectric substrates are used in this technique. The microstrip patch is there at the upper surface of the upper dielectric substrate and the feed line is there between two substrates. It provides highest bandwidth and avoids spurious radiation.

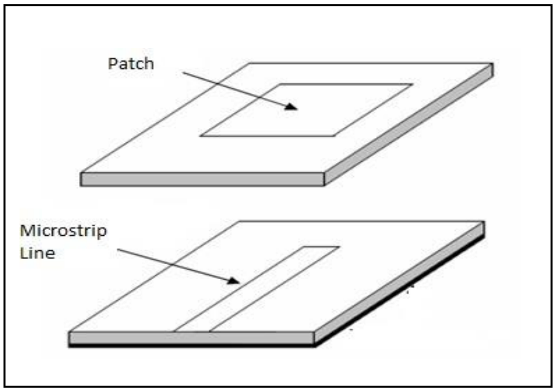


Fig. Proximity coupled Feed

4. Aperture coupled feed

   This feed is having two substrates, which are different from each other and are separated by a ground plane . In this method, the microstrip patch and feed line are coupled through a slot in the ground plane . Minimization in interference and pure polarization are the advantages of aperture coupled feeding method.

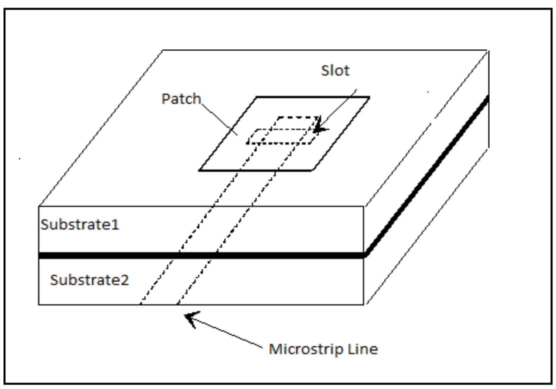


Fig.5.Aperture coupled feed

Advantages of Micro strip antenna

- Light weight
- Low cost
- Ease of installation

Disadvantages of Micro strip antenna

- Inefficient radiation
- Narrow frequency bandwidth

Applications of Micro strip antenna

- Used in Space craft applications
- Used in Air craft applications
- Used in Low profile antenna applications

Principle of smart antenna.

Smart Antennas, also known as adaptive array antennas is used to increase the efficiency in digital wireless communication systems. It works by taking the advantage of the diversity effect at the transceiver of the wireless system that is the source and the destination. The term diversity effect refers to the transmission and reception of multiple radio frequencies that are used to decrease the error during data communication and also to increase data speed between the source and the destination.

This type of technology has already found its significance in most of the wireless communication systems as special antenna arrays are used with signal processing algorithms which can easily locate and track the different wireless targets such as mobiles. It is also used to calculate the beam forming vectors and the direction of arrival (DOA) of the signal.

A smart antenna has mainly two basic functions.

1. Estimation of Direction of arrival (DOA)

In smart antennas various techniques like MUSIC (Multiple Signal Classification) and estimation of signal parameters via rotational invariance techniques (ESPRIT) algorithms are used to find the DOA of a signal. This method requires a lot of computations and algorithms. Even Matrix Pencil method is commonly used in smart arrays to find the DOA. Matrix Pencil method is more commonly used in real time systems as they are highly efficient than the other two. The antenna acts like a sensor in which a spatial spectrum of the array is selected and the DOA is found out from the peaks of this spectrum.

2. Beamforming Method

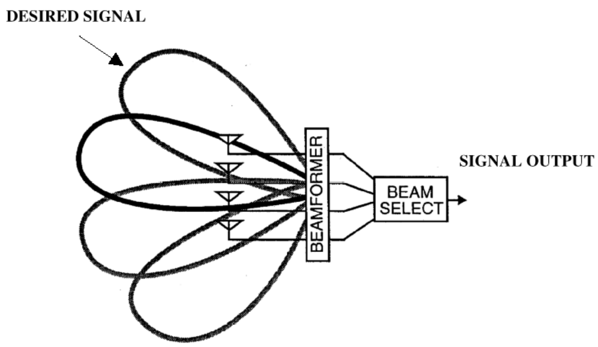
The mobiles or targets at which the signals are to be sent are first sought out and then a radiation pattern of the antenna array is created by adding the signal phases. At the same time the mobiles which will not need the signal will be out of pattern. Though this method may seem a little to complicated, it can be done easily with the help of a FIR tapped delay line filter. According to the signal used the weight of the FIR filter can also be changed accordingly. The filters will also be helpful in providing optical beamforming so as to decrease the MMSE between the actual and wanted beam pattern that is formed.

Types of Smart Antennas

The classification of Smart Antennas depends on the type of environment and the requirements of the system. There are mainly two types of Smart Antennas. They are

1. Phased Array/Beam Smart/Multi-beam Antenna

In this type of array, there will be numerous amount of fixed beams amongst which one beam will turn on or will be steered towards the wanted signal. This can be done only with the help of adjustment in the phase. In other words, as the wanted target moves, the beam will also be steered.

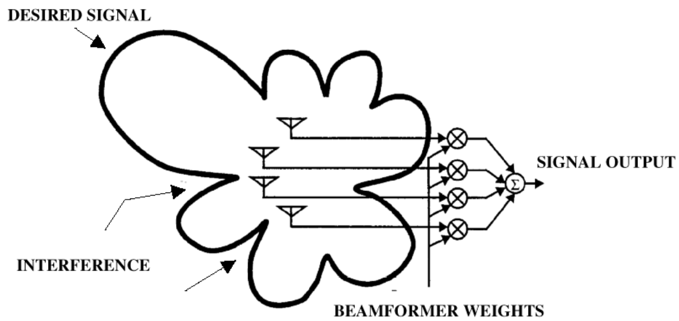


Phased Array Antenna

2. Adaptive Array Antenna

In this type of antenna, there will be a change in the beam pattern according to the movement of the wanted user and the movement of the interference. The signals that are received will be weighted and later combined to increase the wanted signal to interference in addition to the noise and power ratio [S/N]. Thus, the direction of interference will be balanced as the wanted signal will be in the direction of the main beam.

The antenna can easily steer the main beam to any direction, while at the same time nullifying the interfering signal. The direction of the beam can be calculated using the DOA method.



Adaptive Array Antennas

Another way of categorizing smart antennas is in the number of inputs and outputs that is used for the device

1. SIMO (Single Input – Multiple Output)

In this method one antenna will be used at the source and multiple antennas will be used at the destination.

2. MISO (Multiple Input – Single Output)

In this method, multiple antennas will be used at the source and only one antenna will be used at the receiver.

3. MIMO (Multiple Input – Multiple Output)

In this method multiple antennas will be used at both the source and the destination. This is the most efficient method amongst all. This method was extended recently in accordance to the IEEE 802.11n standard. This method clearly supports spatial information processing.

Advantages

- Both beam smart and adaptive arrays provide high efficiency and thus high power for the desired signal. When a large number of antenna elements are used at a higher frequency, Beam Smart antennas use narrow pencil beams. Thus high efficiency is obtained in the direction of the desired signal. If a fixed number of antenna elements are used the same amount times the power gain will be produced with the help of adaptive array antennas.
- Another advantage is in the amount of interference that is suppressed. Beam smart antennas suppress it with the narrow beam and adaptive array antennas suppress the interference by adjusting the beam pattern.

Disadvantages

- Smart Antenna System is complex in design
- Very expensive
- Larger size than traditional one