Antenna: (Passive Device)

- The IEEE Standard defined antenna or areal as "a mean for radiating and Recieving of Radio wave"

- basically the antenna is a eyes for open space.
  it is impedance transformer because input impedance of is source is matched with open space. (Atmosphere).

- It is also called transducer because electric wave is converted in to Electromagnetic wave. (EM).

Principle

Mechenism

- 1. source must be time varying not static
  2. the length of the antenna must be the order of wavelength of the source.
  3. It must follows maximum transformer theorem.
     i.e. load (impedance) must be equal to source impedance.
  4. It must be follows Faraday's law $(\nabla \times E = -\frac{\partial B}{\partial t})$
  5. It must be follows Amper's law. $(\nabla \times H = J + \frac{\partial D}{\partial t})$

- Single wire
  - ↳ There is radiation if the wire is curved, bend, discontinous, terminated, or trunctaed.
  - ↳ If ~~wire is~~ charge is moving with uniform velocity there is no radiation.

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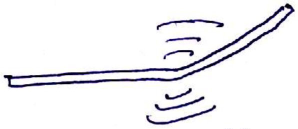
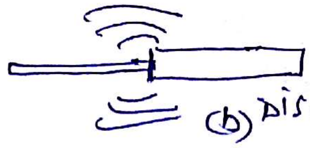
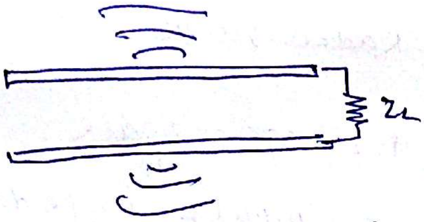


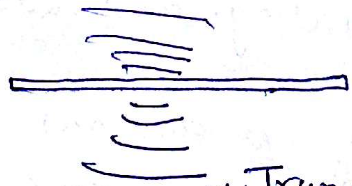
(a) curved/Bent



(b) Discontinous



(c) Terminated



(d) Truncted.

Basic Equation $\boxed{\tilde{I} L = Q \tilde{V}}$ $\left(\because I = \frac{dQ}{dt} \right)$

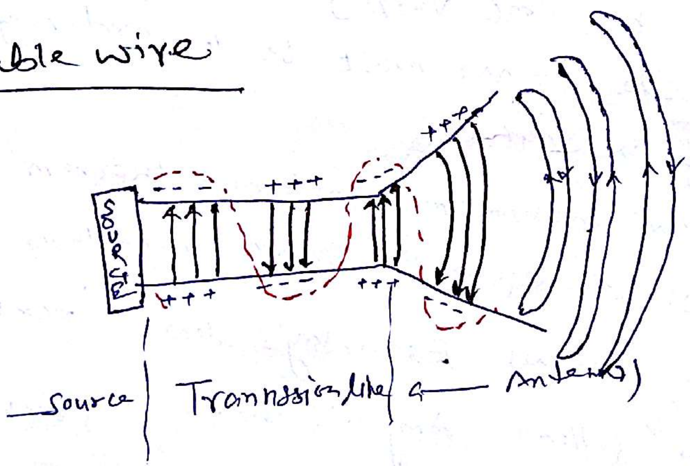
where $\tilde{I}$ = Time varying current

L = Length of the antenna

Q = charge

$\tilde{V}$ = Time varying velocity (It gives acceleration)

- **Double wire**

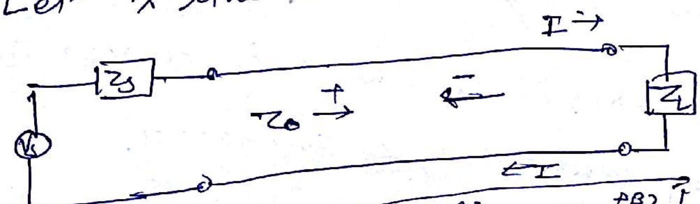


- When the transmission line Bent, and open at the end, it start radiating

Explanation

- Let Tx line is terminated with some load.

step I



- Not properly (Impedance) matched then reflection occurs)

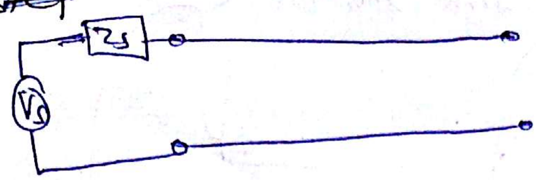
$$\boxed{V(z) = V_0^{+} e^{-\beta z} + V_0^{-} e^{+\beta z}} \text{ or } \boxed{I(z) = \frac{V_0^{+}}{Z_0} e^{-\beta z} - \frac{V_0^{-}}{Z_0} e^{+\beta z}}$$

Step 2 As Reflection coefficient

$$\left[\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \right]$$

Let Zero

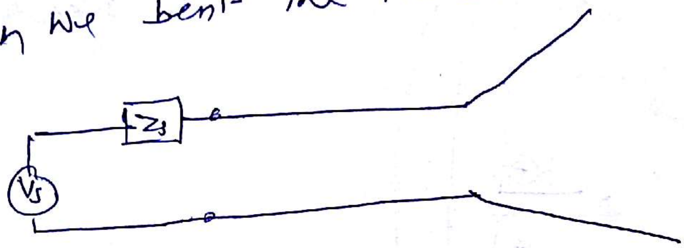
~~Step~~



* ~~A~~. Reflection coefficient is one, hence all power is reflected back, hence Standing wave created.

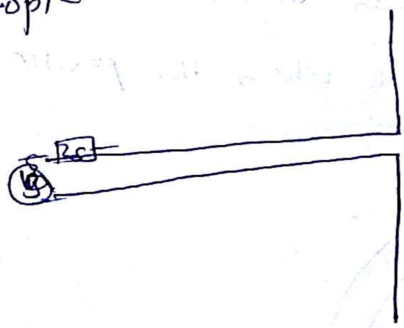
Step-3

When we bent the transmission line the Radiation starts.



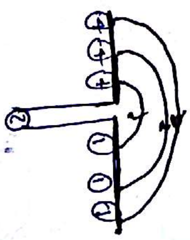
Step-4.

Let bent is 90° and length of the Antenna (bent portion) is equivalent to $\lambda/4$ (each side) or overall $\lambda/2$. called isotropic radiator or called dipole Antenna



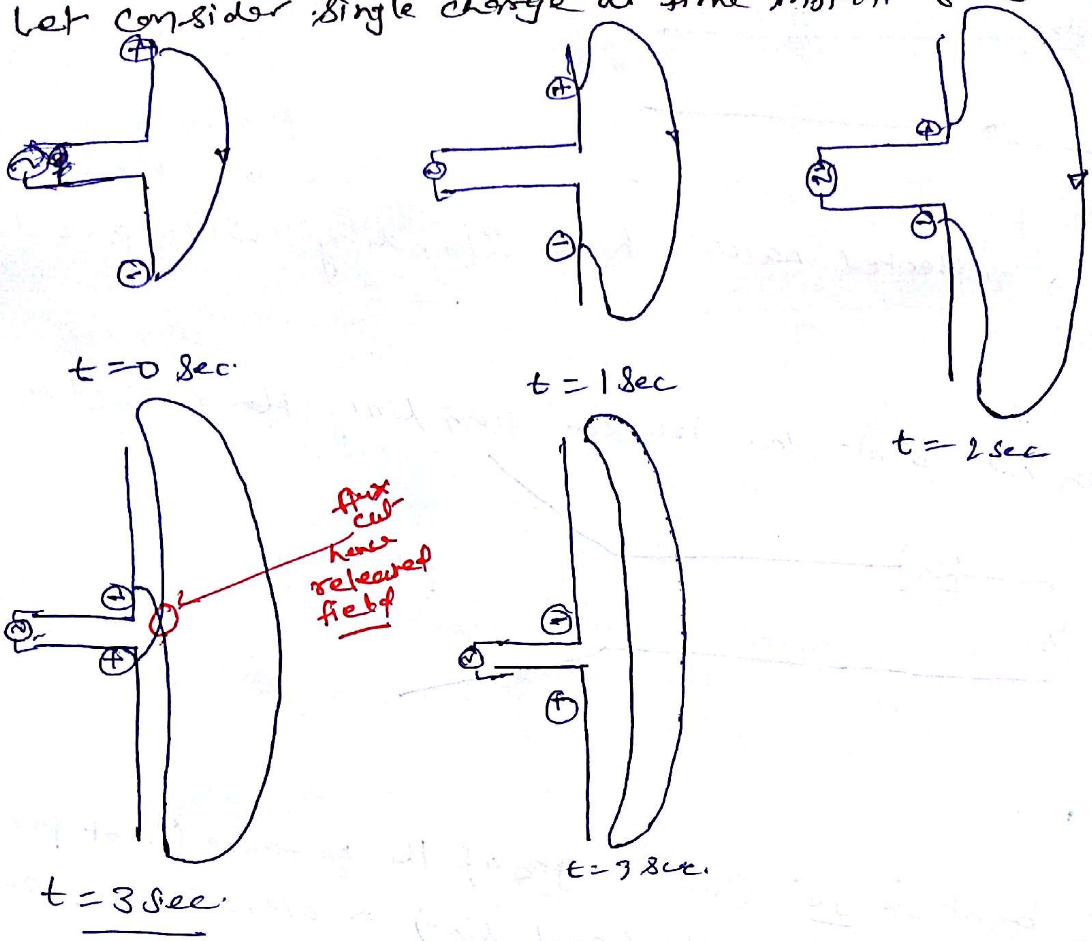
* As source is Time varying ~~it~~, ~~movi~~ charges are moving up & down in each cycle.

(a)

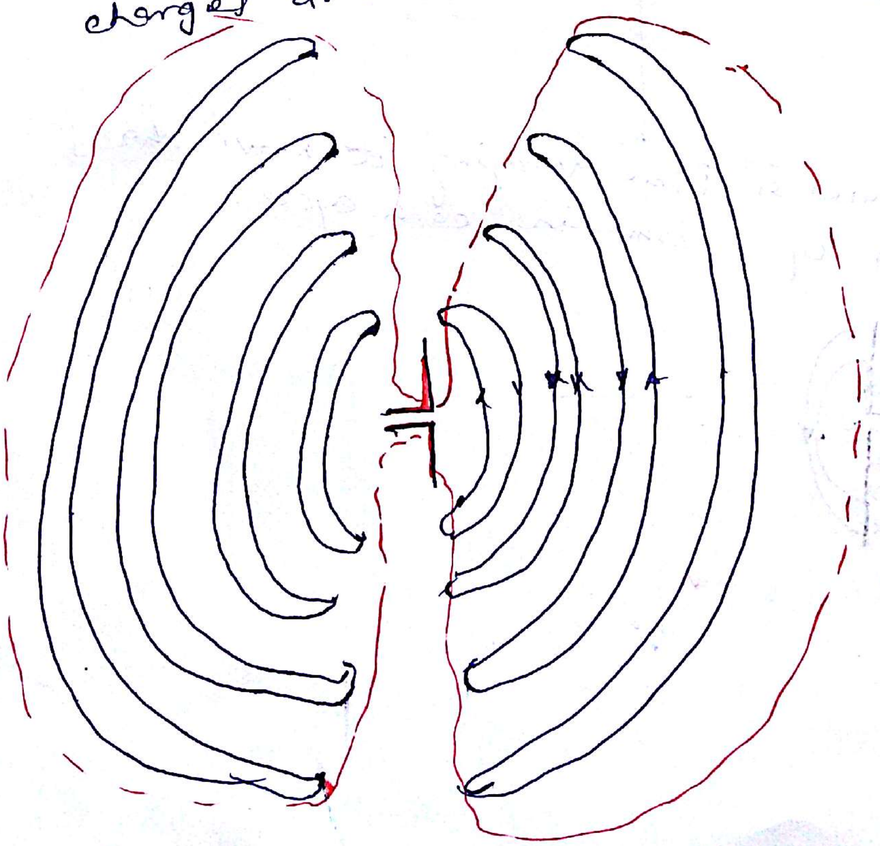


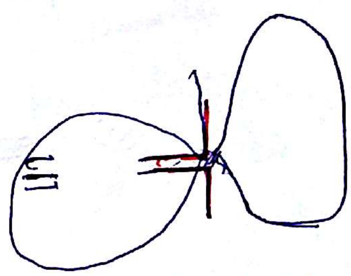
(E).

Let consider single charge at time instant t=0



- As charge is moving at every instant hence electric field is behaviour is shown in above Diagram.
- the first field is genrated when the positive & negative charges are reversed.





~~Field is Divided by Two categories~~

* If the generated Electric field is time varying the it produces Time varying magnetic field.

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

* And Hence generated magnetic field produced time varying Electric field.

- By these way EM Wave propogated in the atomosphere.

Field Types

① Near field. → Reactive near field
→ Radiating near field

② Far field or Radiating far field.

Antenna characteristics

1. Physical parameters
   (a) Antenna size
   (b) material used.
   (c) Temperature etc.

2. Circuit parameter
   (a) Input Impedance
   (b) Bandwidth
   (c) Radiation Resistance
   (d) Gain etc.

3. Transition parameter

ⓐ Antenna losses
ⓑ Attenuation
ⓒ mismatched

4. Space Parameter

ⓐ Radiation pattern
ⓑ Banwidth
ⓒ Directivity
ⓓ Radiation intensity
ⓔ Polarization

Classification of Antenna

1. Wavelength frequency Antenna

ⓐ Low freqn (LF)
ⓑ High freqn (HF)
ⓒ Medium freq (MF)
ⓓ Very High freq (VHF)
ⓔ Ultra high freqn (UHF)
ⓕ microwave freqn (MW)
ⓖ millimeter wave freqn (mmW)

2. Freqn Range of operation

ⓐ Narrow Band Antenna
ⓑ Broad band / wide band Antenna
ⓒ Ultra wide band Antenna

3. Shape of Antenna

(a) Wire Antenna
(b) Helical Antenna
(c) Aperature Antenna
(d) Lense Antenna
(e) planner / microstrip Antenna

4. Pattern classification

(a) Omnidirectional Antenna
(b) Isotropic Antenna
(d) Directional Antenna
(e) Pencil Beam Antenna
(f) Broadside Antenna
(g) End fire.

5. Polarization classification

(a) Linear polaried Antenna
(b) circular —"— —"—
(c) Elliptical —"—
(d) Dual polarization. — " —

6. Application based classification

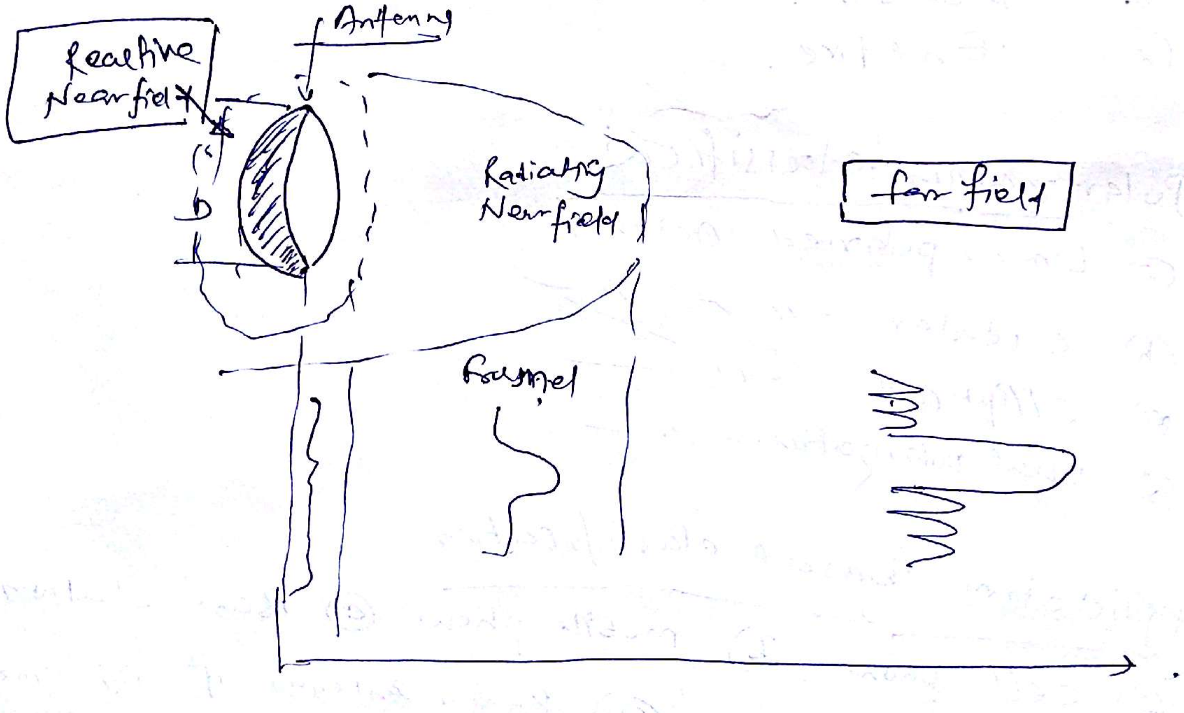
(a) cell phone (b) mobile phone (c) Base station
(d) Radar Antenna (f) Bio-medical
(e) satellite Antenna
(g) Radio astronomy Antenna

~~Definitions~~ ANTENNA TERMINOLOGY

- Reactive Near field : that portion of the near field region immediatly sourrounding the antenna.

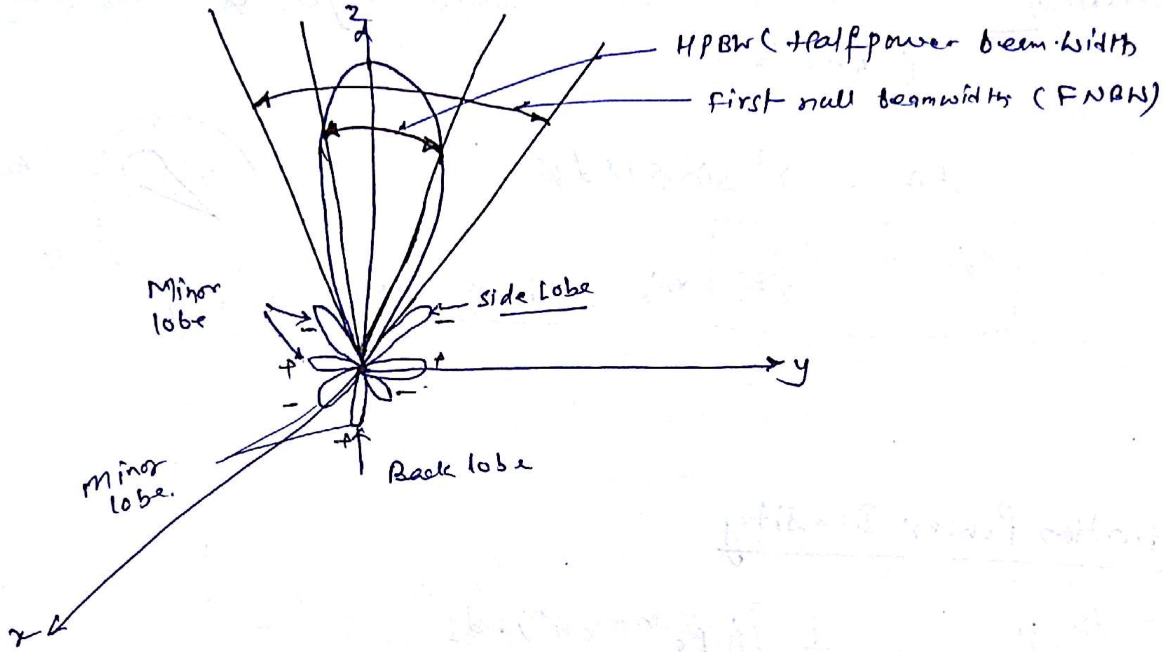
- Radiating near-field (fresnel) region : That region of the field between near field and far field.

- Far-field (Fraunhofer) region : That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna.



Radiation patterns

It is the graphical representation of radiation properties of antenna as a function of space coordinates.



Major lobe (main beam): is defined as " the radiation lobe containing the direction of maximum radiation.

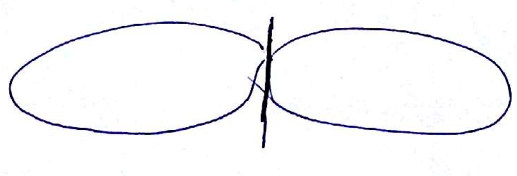
Minor lobes: Radiation is undesired direction.

Side lobe: A Radiation lobe in any direction, other than the intended lobe.

Omnidirectional pattern (Isotropic, radiator)

Radiation is uniformaly in all direction.

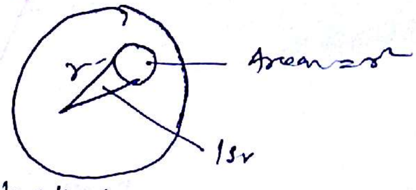
→ Having an essentially non directional pattern in a given plane and directional pattern in any orthogonal plane.



- **Radian** : The measure of a plane angle is a radian
$(2\pi r/r)$ ~~$dA=$~~

- **Steradian** The measure of a solid angle is a steradian.
$(4\pi r^2/r^2)$

$dA = r^2 \sin\theta \, d\theta \, d\phi$



$$\boxed{d\Omega = \frac{dA}{r^2}}$$ ← solid angle (1 steradian)

- **Radiation Power Density**

→ As $P_{rad} = \frac{1}{2} \oiint Re(E \times H^*) \cdot ds$

→ It is the EM field of an antenna in far-field region.

* Power density $$\boxed{W_0 = \frac{P_{rad}}{4\pi r^2}}$$ (Radiated power per unit Area)

Radiation Intensity

Radiation intensity in a given direction is defined as the power radiated from an antenna per unit solid angle

$$\boxed{U = r^2 W_{rad}}$$ U → radiation intensity

$$\boxed{U_0 = \frac{P_{rad}}{4\pi}}$$

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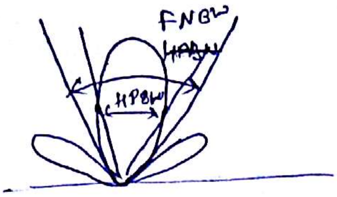
Beam width : Angular separation between two identical point on opposite side of the pattern maxima,

e.g. HPBW, FNBW, (Beam width of first null)



Directivity : the ratio of the radiation intensity in a given direction from antenna to the radiation intensity averaged over all direction

$$\boxed{D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}}}$$

Gain : $\boxed{G = 4\pi \cdot \frac{\text{Radiation intensity}}{\text{total input (accepted power)}}}$

BANDWIDTH : the range of freqn within which the performance of antenna confirmed to a specified standard.

Polarization : the property of an ~~em~~ electromagnetic wave describes the time-varying direction and direction of electric field vector with respect to ground.

⇒ Aperature Antenna.
⇒ Resonant antenna.
→ Broad band Antena

Types of Antenna

(Periodic) radiation patterns & Load isnot perfectly matched. Bidirectional travelling.

5. RESONANT ANTENNAS

A resonant antenna is a Standing Wave Antenna with zero input reactance at resonance and they have small bandwidths as % 8 or % 16.

5.1. Dipole Antenna

*Simple | Television
* monopole.

- Straight Wire Dipole: The assumed current distribution

$$I(z) = I_m sin\left[k\left(\frac{L}{2} - |z|\right)\right] \ , \ -\frac{L}{2} < z < \frac{L}{2}$$

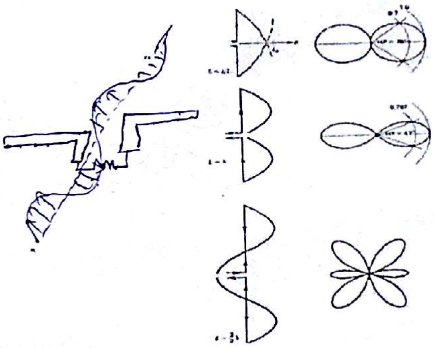
Then, $F(\theta)$ for a straight wire dipole is

$$F(\theta) = \frac{cos\left(\frac{kl}{2}cos\theta\right) - cos\left(\frac{kl}{2}\right)}{sin\theta}$$

In case of a half wave straight wiredipole, $L = \lambda/2$:

$$F(\theta) = \frac{cos\left(\frac{\pi}{2}cos\theta\right)}{sin\theta}$$

Different lengths of dipole produce different $F(\theta)$ means different radiation patterns as below:



We can see that the dipoles longer than one wavelength, the currents on the antenna are not all in the same direction. Over a half wave section, the current is in phase and adjacent half wave sections are of opposite phase will lead large canceling effects in radiation pattern.

- $L = m\lambda/2 \quad \Rightarrow \ X_A \cong 0$, Resonate (m odd number) integer
- $L < \lambda/2 \quad \Rightarrow \ X_A < 0$, Capacitive
- $\lambda/2 < L < \lambda \ \Rightarrow \ X_A > 0$, Inductive

$L = n\frac{\lambda}{4}$

- *Vee Dipole:* Whenever the directivity is bigger than straight dipole, input impedance is smaller than straight one.

- *Folded Dipole:* The folded dipoles (FM receiving antenna) are two parallel dipoles connected at the ends forming a half narrow loop with ease of rigidity reconstruction, impedance properties and wider bandwidth than ordinary HW dipole. The feed point is at the center of one side. It is an unbalanced transmission line with unequal currents (two closely spaced equal in one) and can be analyzed as transmission line (the currents cancel each other) and antenna mode (current reinforce each other).

$$Z_{HW\ folded} = 4Z_{dipole}^{\lambda/2}$$

5.2. Yagi-Uda Antenna

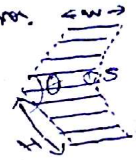
1) directional Antenna
2) consist multiple parallel elements in line.

UHF Television Antenna

Yagi-Uda antenna is used for HF, VHF, UHF bands with the advantages of high gain, simplicity, low weight, low cost, relatively narrow bandwidth. Using folded dipole, Yagi-Uda will show higher input impedance. The gain may be increased by stacking. It is a *Parasitic Array* means that a few elements are fed directly, the other elements receive their excitation by near field coupling. The longer parasitic element behaves as a reflector and changes the pattern through feed. The shorter parasitic element behaves as a director and changes the pattern through the parasitic element. Metal boom is used at the center in which the currents are zero. It is Travelling Wave Antenna supporting the surface wave of slow type. folded dipole.

5.3. Corner Reflector Antenna

directional Antenna.



A practical gain standard antenna at HF band having a gain of 10 to 12 dB over a HW dipole. Method of Images and AF are used to analyze it. The finite extend of plates result broader pattern and feed driving impedance is negligible. (VHF, UHF)

5.4. Large Loop Antenna

The large loop antennas have the loop's perimeter are sizable fraction of a wavelength or greater means that the current and phase of the loop are vary with position around the loop chancing the antenna performance. This also shows the similar effect whenever different frequencies are applied to the same loop antenna.

5.5. Microstrip Antenna

Microstrip antennas can be produced as a kind of printed antennas (patches) and were conceived in the 1950's. These are popular because of low profile, low cost, specialized geometries. The main challenge in microstrip patch antenna is to achieve adequate bandwidth in which conventional one has as low as a few percent. Because of resonance behavior of microstrip patches, they become excessively large below UHF and typically used from 1 to 100 GHz. They have loosely bound fields extending into space, but the fields tightly bound to the feeding circuitry. The patches geometry are generally rectangular but square and pentagonal patches are also possible for circular polarizations. Microstrip arrays can also be constructed for using advantages of printed circuit feed network with microstrip on the same single layer.

5.6. Wire Antennas above a Ground Plane

- Imperfect Real Ground Plane: Especially in low frequencies, electric field of an antenna penetrates into the earth causing the conductivity current due to the low conductivities. This gives rise of ohmic losses means increasing of input ohmic resistance lowering the radiation efficiency. Approximate pattern can be obtained using Method of Images combining the reflection coefficients. The pattern is different from free space antenna pattern.

These lecture notes are heavily based on the book of *Antenna Theory and Design* by W.L. Stutzman and G. A. Thilie. For future version or any proposals, please contact with *Dr. Serkan Aksoy* (saksoy@gyte.edu.tr).

Long wire Antenna / Resonant Antenna, Non-Resonant Antenna.

6. BROADBAND ANTENNAS

A broadband antenna can be defined as its impedance and pattern do not change significantly over about an octave or more. The bandwidths of the narrow and wideband broadband antenna are generally calculated as

$$BW_{narrow} = \frac{f_{upper} - f_{lower}}{f_{center}} \times 100\ \%$$

$$BW_{wide} = \frac{f_{upper}}{f_{center}}$$

The wire antennas are broadband, such as Traveling-Wave antennas, Helix and Log-Periodic.

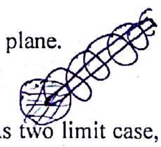
6.1. Traveling Wave Antenna, TWA

The reflected wave is not a strongly present with guiding EM waves. TWA can be created using very long antennas (or matched loads at the ends). Their bandwidth is broader than Standing Wave Antennas (SWA) and distinguishing with no second major lobe in reverse direction like SWA. Longer than one-half wavelength wire antenna is one of the *Travelling Wave Long Wire* antennas. Using some assumptions, the current of TWA

$$I(z) = I_m e^{ikz}.$$

TWA has real valued input resistance. Some types of TWA

- Travelling Wave Vee Antenna,
- Rhombic Antenna,
- Beverage Antenna: On the imperfect ground plane.



6.2. Helical Antenna

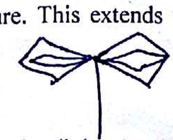
It has a helical shape as an uncoiled form. As two limit case, it reduces to loop or a linear antenna. Two forms of its operation are possible as

• *Normal Mode:* The radiated field is maximum in a direction normal to the helix axis. Because the dimension of the helix must be small compared to wavelength (electrically small antenna) for this mode, the efficiency is low (low radiation resistance) with emitting circularly polarized waves. The analysis may be done by using a small loop model with constant amplitude and phase variation. The depending on its orientation (such as quarter wave length with higher radiation resistance), vertical polarization may be dominant.

• *Axial Mode:* This mode is used when a moderate gain up to about 15 dB and circular polarization is required. Assuming the helix carries pure travelling wave, an approximate model can be used for analysis. The amplitude and phase of the antenna are not uniform.

6.3. Biconical Antenna

The conductors of the wire antenna can be flared to form biconical structure. This extends to increase bandwidth. The types are



- *Infinite Biconical Antenna:* The biconical structure is infinite and can be analyzed by Transmission Line Method.
- *Finite Biconical Antenna:* Practical one with less weight, less cost. Bow-Tie antenna is a favor example.
- *Discone Antenna:* One of the finite biconical antenna is replaced with a discone. Omnidirectional pattern is obtained.

6.4. Sleeve Antenna

The addition of a sleeve to a dipole or monopole antenna can increase bandwidth more than one octave and the frequency sensitivity is decreased. Types are

- *Sleeve Monopoles*: VSWR may be high and requires matching network feed.
- *Sleeve Dipoles*: VSWR is low over a wide bandwidth.

6.5. Frequency Independent Antenna

A bandwidth of an antenna about 10:1 or more is referred to as a *Frequency Independent Antenna*. The impedance, pattern and polarization should nearly remain constant over a broad frequency range. The following properties yield broadband behavior

- Emphasis on angles rather than lengths,
- Self complementary structures,
- Thick metal.

Two arm-Log Spiral Antenna.

6.5.1. Spiral Antenna

Either exactly or nearly self-complementary with a bandwidth of 40:1. Types are

- *Equiangular Spiral:* It has a bidirectional pattern with two wide beams broadside to the plane of the spiral.
- *Archimedean Spiral:* It has a broad main beam perpendicular to the plane of spiral. Unidirectional beam can also be created by a cavity backed feeding.
- *Conical Equiangular Spiral:* It has a single main beam is directed of the cone tip.

Spiral antennas can also have different configurations such as Sinuous Antenna offering flexible polarizations.

6.5.2. Log-Periodic Antenna

Log-Periodic antenna has a structural geometry such that its impedance and radiation characteristics repeat periodically as the logarithm of frequency. Because of this variability is minor, it is considered as a frequency independent antenna. Using parallel wire segments, Log-Periodic Dipole Arrays can also be constructed of different types are

- Log-Periodic Toothed Planar Antenna
- Log-Periodic Toothed Wedge Antenna
- Log-Periodic Toothed Trapezoid Antenna
- Log-Periodic Toothed Trapezoid Wedge Antenna
- Log-Periodic Toothed Trapezoid Wire Antenna
- Log-Periodic Toothed Trapezoid Wedge Wire Antenna
- Log-Periodic Zigzag Antenna.

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A variable-sized hole that controls the amount of light admitted to a camera.

7. APERTURE ANTENNAS
(hole, opening)

These (Horns, Reflectors etc.) are in common use at UHF and higher frequencies. These have very high gain increasing of f^2 and nearly real valued input impedance.

7.1. Rectangular Aperture

Many horn antennas and slots have rectangular apertures. If the aperture fields are uniform in phase and amplitude across the physical aperture, it is referred as a *Uniform Rectangular Aperture* having effective aperture equal to its physical aperture. Uniform excitation amplitude for an aperture gives the highest directivity. To reduce low side lobes, tapering the excitation of amplitude toward the edges of a line source (*Tapered Rectangular Apertures*) is a good way.

7.2. Circular Aperture

An antenna having a physical aperture opening with a circular shape is known as *a Circular Aperture*. If the aperture distribution amplitude is constant, it is referred to *Uniform Circiular Aperture*. To reduce low side lobes at the expense of wider bandwidth and reduced directivity, *Tapered Circular Apertures* such as parabolic taper (tapering the excitation of amplitude) is a good way.

7.3. Horn Antenna

They are popular at the frequencies above about 1 GHz having high gain, low VSWR, relatively wide bandwidth, low weight and easy to construct with theoretical analysis achieving to closing the experimental results. Types of the horn antennas as

- E Plane Sectoral Horn
- H Plane Sectoral Horn
- Pyramidal and Conical Horn

Pyramidal horn Antenna.

These horns are fed by a rectangular waveguide oriented its broad wall horizontal. Horn antenna emphasizes traveling waves leads to wide bandwidth and low VSWR. Because of longer path length from connecting waveguide to horn edge, phase delay across aperture causes phase error. Dielectric or metallic plate lens in the aperture are used to correct phase error. Those with metallic ridges increase the bandwidth. Horns are also used for a feed of reflector antennas.

7.4. Reflector Antenna

High gain for long distance radio communication and high resolution for radar applications need the reflector antenna. *A Parabolic Reflector Antenna* is a widely used one having a reflecting surface large relative to the wavelength with a smaller fed antenna. One of the fundamental problems is to match the feed antenna to the pattern of the parabolic reflector. GO/Aperture Distribution Method or PO/Surface Current Method are used to analyze the antenna with the principles of

- All reflected rays are colliminated at the focal point,
- All path lengths are the same. Phase of the waves at the focal point is constant means constant phase center.

It is inherently a very wide band antenna. Bandwidth is limited to the size of the reflector (low frequency limit) or smoothness of the reflector surface (high frequency limit). The bandwidth of the feed antenna is also another limit for overall system. Types:

• *Axisymmetric Parabolic Reflector:* Feed is located at the focal point. The main peak is directed toward reflector center.

• *Offset Parabolic Reflector:* It avoids blockage caused by the hardware in feed region created by a cluster of the feed horn.

• *Dual Parabolic Reflector:* Using a hyperbolic sub-reflector with parabolic main reflector (Gregorian or Cassegrain), the aperture amplitude and phase can be controlled by design. The advantages of this antenna

- Reduced support problem for feed hardware
- Avoids long transmission line currents and losses
- Fed radiation is directed toward the low noise sky region rather than more noisy ground region.

The other types of the reflector antenna are

- Parabolic Cylinder,
- Parabolic Torus,
- Non-Circular Parabolic,
- Spherical Reflector at all.

parabolic reflector.

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Classification of Antenna:

1) Wave Length frequency Antenna
a) Low freq (LF) b) medium freq (MF)
c) High freq (HF) d) VHF e) UHF
f) microwave freq. (MW)

2) Freq. range of operation
a) Narrow band antennas
b) Broad band/wide band Antenna
c) Ultra wide band antennas.

3) Shape of Antenna
a) Wire antenna
b) Helical Antenna
c) Aperture Antenna
d) Lense antenna
e) Planner/microstrip antenna

4) Pattern classification
a) Omni directional antennas
b) Isotropic antenna
c) Directional Antenna
d) pencil beam "
e) Broad side Antenna
f) End fire antenna.

5) polarization classification
a) Linear polaried antenna
b) circular " "
c) Elliptical
d) Dual polarization antenna.

6) Application based classification:
a) Cell phone b) Mobile Phone c) Base station
d) Satellite antenna e) Bio-medical
f) Radio astronomy antenna.

What is antenna?
1) All oscillating electric & Magnetic fields propagate
2) All circuits that create AC electric field and currents will radiate to some extent
3) Antenna is a device to ~~operate~~ optimize and control the emitted radiation so you can couple electrical energy from a circuit to free space and back again.

Design Factors:
1) Strength of the radiated field in different directions (antenna pattern)
2) Total power radiated compared to the driving power (radiation efficiency)
3) Impedance of the Antenna to match it to transmission Lines.
4) The radiation as a function of frequency (Bandwidth)
5) The voltage and current spatial distribution on the antenna to avoid heating or Breakdown