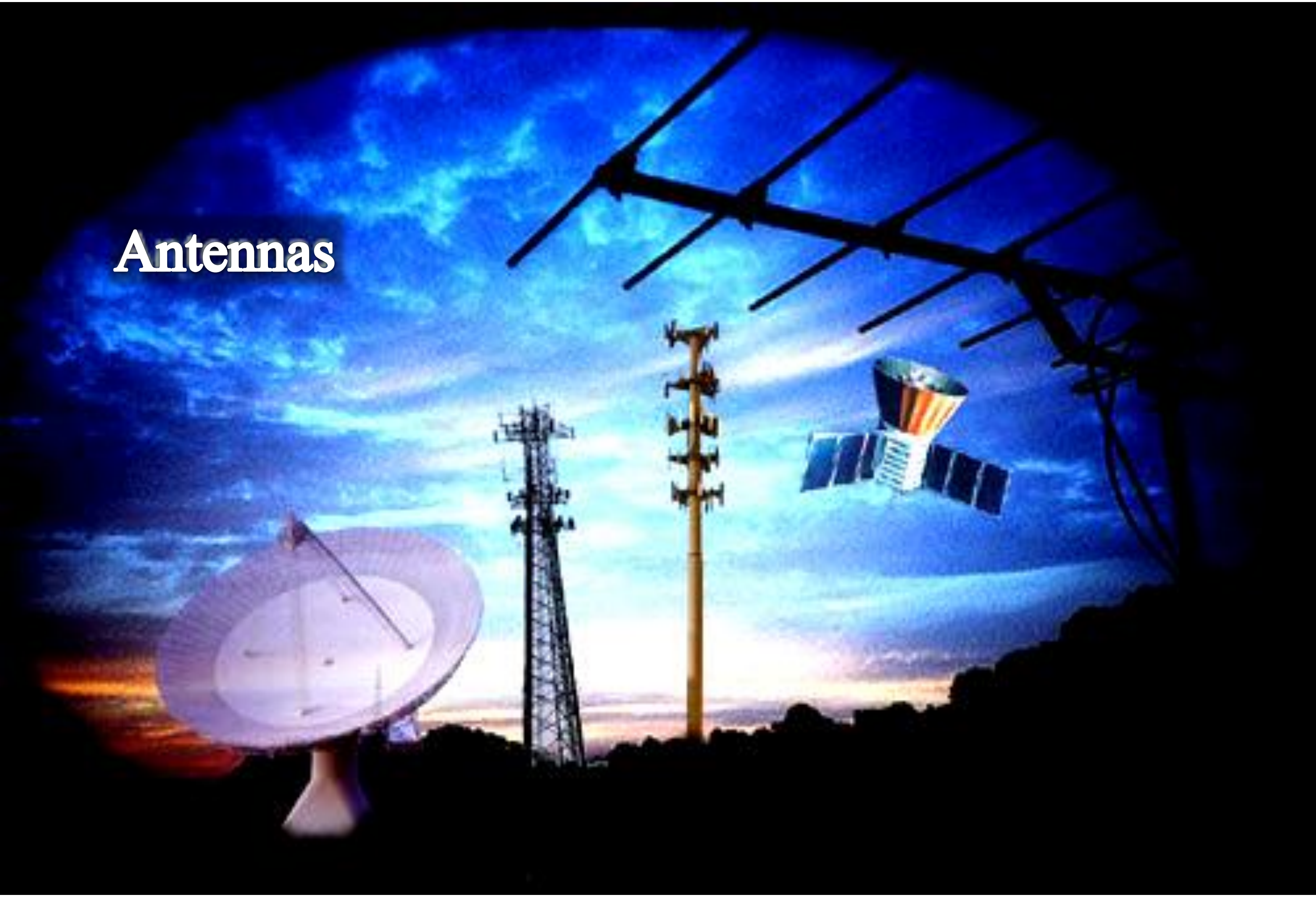

Antennas

Books:
Antenna theory analysis and design [3rd edition-Constantine A. Balanis]
Antenna theory and design[2nd edition- Warren L. Stutzman

Antenna is defined as

A transducer designed to transmit and receive electromagnetic waves, it converts signals on electric circuits (V&I) to EM waves (E&H) radiate in space and vise versa.

Types of Antennas

A good antenna would radiate almost the power delivered to it from the transmitter in a desired direction or directions. A receiver antenna does the reciprocal process, and delivers power received from a desired direction or directions.

Antenna can be categorized by:

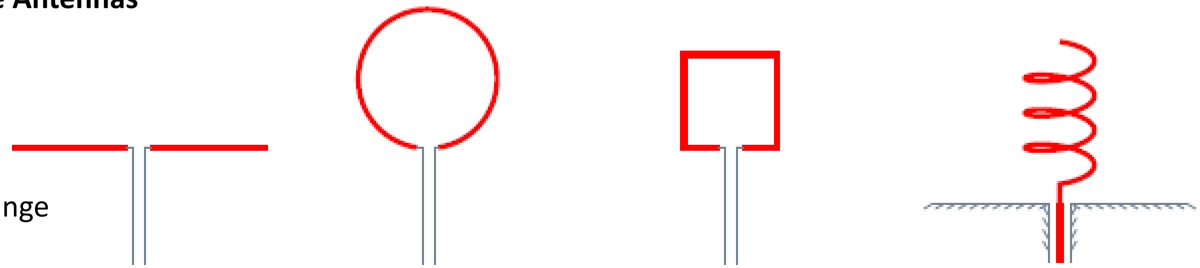
- ❑ Narrow band versus broadband
- ❑ Size in comparison to the wavelength (e.g., electrically small antennas)
- ❑ Omni-directional versus directional antennas
- ❑ Polarization (linear, circular, or elliptic)
- ❑ **Antenna Types by Physical Structure**
  - Wire antennas
  - Aperture antennas
  - Microstrip antennas
  - Antenna arrays
  - Reflector antennas

		Wireless technology	Freuency band	Frequency	Free space λ	Range	Data rate	Deploy date	Comm Devices/Operation	Antenna Technology: traditional	Antenna Technology: Compact
Commercial		TACS Total Access Communication System		NTACS: Rx: 860–870 Tx: 915–925 ETACS Rx: 916–949 Tx: 871–904	32–35 cm	100–10,000 m	NA	1988 UK	TACS enabled cellular phones	Mono- Dipole	Patch Variant
	TV Broadcast	VHF TV	VHF	44–216 MHz	1.4–7 m	miles	NA	NA	6 VHF Ch, 7 FM Ch	Yagi	NA
		UHF TV	UHF	470–806 MHz	37–64 cm	miles	NA	NA	56 UHF Ch	Yagi	NA
	Wireless LAN Protocols	802.11a	C-band	5 GHz	6 cm	10–25 m indoors	54 Mbps	1999	Wireless internet access to Laptop computers, PDAs, cell phones	Mono-Dipole	Patch Variant
		802.11b Wi-Fi	S-band	2.4 GHz	12.5 cm	< 50 m	11 Mbps	1999	"	Mono-Dipole	Patch Variant
		802.11g		2.4 GHz	12.5 cm	< 50 m	54 Mbps	Jun-06	"	Mono-Dipole	Patch Variant
		802.11n		2.4 GHz	12.5 cm	10–100 m	540 Mbps	mid 2007	"	Mono-Dipole	Patch Variant
		802.15.1 Bluetooth		2.4 GHz	12.5 cm	<10 m	720 Kbps	May-99	Printers, Cameras, cell phones, PDAs, other peripherals	Mono-Dipole	Patch Variant
		802.15.4 ZigBee	ISM band Industrial scientific and medical	868 MHz, 915 MHz, 2.4 GHz	6 cm, 33 cm, 35 cm	< 50 m	100 Kbps	Jun-06	Bursts of power to extend battery for industrial data transfer, building and home automation	Mono-Dipole	Patch Variant
		(4G) 802.16 WiMax OFDM FDD/TDD	S-band C-band	2.5–2.69 GHz, 2.7–2.9 GHz, 3.4–3.6 GHz, 5.725–5.86 GHz	5–12 cm	1000–5000 m	70 Mbps	2004	Extended city/rural range wireless access w/ modem, PDA	Mono-Dipole	Patch Variant
		(4G) Broadway HIPERLAN/2 HIPERSPOT OFDM	C-band W-band	5 GHz 59–65 GHz	0.5 cm 6 cm	10–100 m	100s Mbps 1–5 Gbps	2007?	Unlicensed band worldwide	Mono-Dipole	Patch Variant
	Satellite Comm	Iridium	L-band	1.616–1.628 GHz	18 cm	Earth to LEO	2.4 kbps	Sep-98	Satellite phone	Helical Ant	Circ polar microstrip
		C-band Satcom	C-band	Uplink 5.925–6.425 GHz downlink: 3.7–4.2 GHz	4.7–8.1 cm	Earth to GEO	64 kbps – 1.5 Mbps	1960s	C-band Sat Comm System	Mech Dish Ant	Electronic Scan Phased Array
		Ku-band Satcom	Ku-band	Uplink: 11.2–11.7 Ghz downlink: 14–14.5 GHz	2–2.7 cm	Earth to GEO	.5–5 Mbps	Late 1970s	Ku-band Sat Comm System	Mech Dish Ant	Electronic Scan Phased Array
		Ka-band Satcom	Ka-band	Uplink: 27.5, 31 GHz downlink: 18.3, 18.8, 19.7,20.2 GHz	1–1.6 cm	Earth to GEO	Upload 2 Mbps down 30 Mbps	April 2005	Ka-band Sat Comm System	Mech Dish Ant	Electronic Scan Phased Array

FIGURE 2-4 Wireless technologies for commercial communication systems

Wire Antennas

Gain range
2dBi



Dipole | Circular loop | Rectangular loop | Helix

Aperture Antennas

Pyramidal horn

Conical horn

Horn antennas are very popular at UHF (300 MHz-3GHz)frequencies.
Horn antennas often have :
Directional [radiation pattern](#) (1.5 degree HPBW).
• [antenna gain](#) 10-20 dB (moderate gain)

Microstip Antennas

Mobile phone antenna

Antennas Arrays

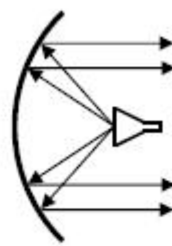
Reflector array

gain
10-20dBi

Yagi Uda

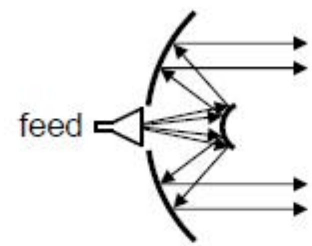
Reflector Antennas

Reflector



Parabolic reflector
(front feed)

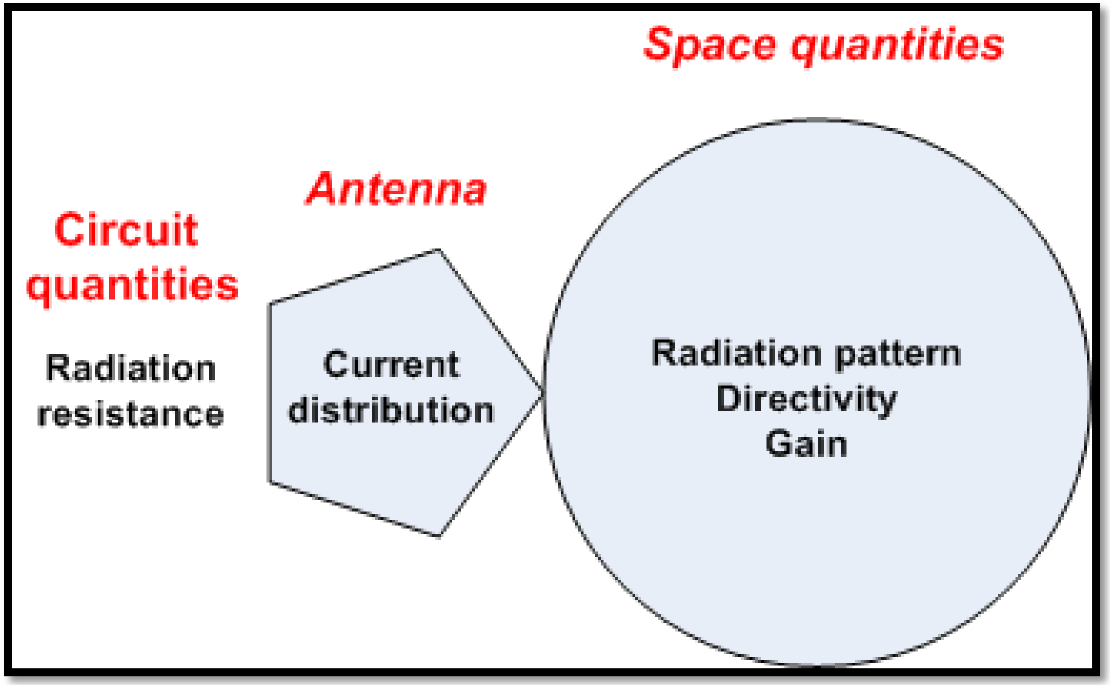
Reflector



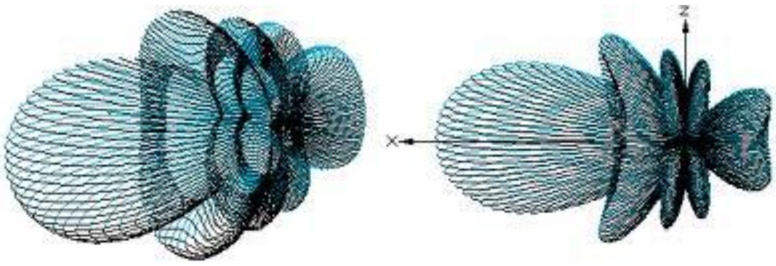
Parabolic reflector and
hyperbolic subreflector
(Cassegrain feed)

Very good directivity (high gain)– Long distance communication

Basic antenna parameters



Example of
Radiation pattern

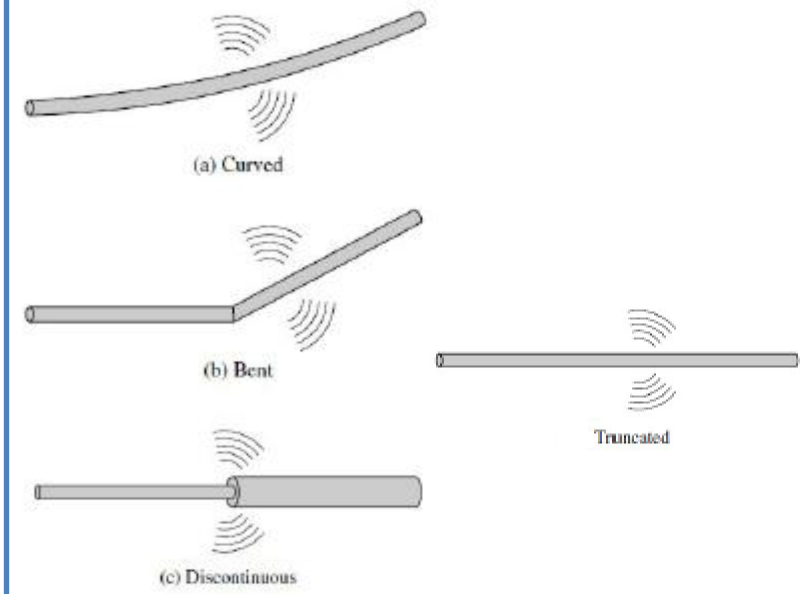


•**Radiation Mechanism**

○ **For single wire**

Current in a thin wire with a linear charge density q_l (C/m):

$$I_z = q_l v_z \quad \text{(A)}.$$



Thin Wire

If the current is time varying

$$\frac{dIz}{dt} = q_l \frac{dv_z}{dt} = q_l a_z$$

where a_z (m/s^2) is the acceleration. If the wire is of length l, then

$$l\frac{dIz}{dt} = lq_l \frac{dv_z}{dt} = lq_l a_z$$

this equation

is the basic relation between current and charge, and it also serves as the fundamental relation of electromagnetic radiation.

To create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge.

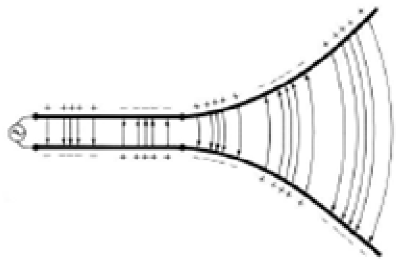
- To create charge acceleration (or deceleration) the wire must be curved, bent, discontinuous, or terminated.
- Periodic charge acceleration (or deceleration) or time-varying current is also created when charge is oscillating in a time-harmonic motion.

1. If charge is moving with a uniform velocity:
   (a) There is no radiation if the wire is straight, and infinite in extent.
   (b) There is radiation if the wire is curved, bent, discontinuous, terminated, or truncated.
2. If charge is oscillating in a time-motion, it radiates even if the wire is straight.

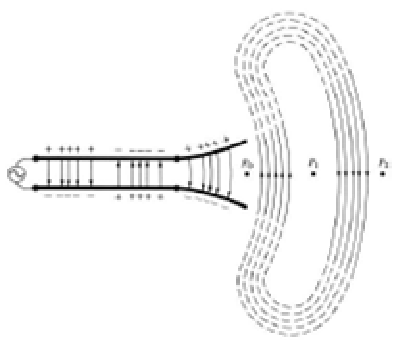
○ For two wires

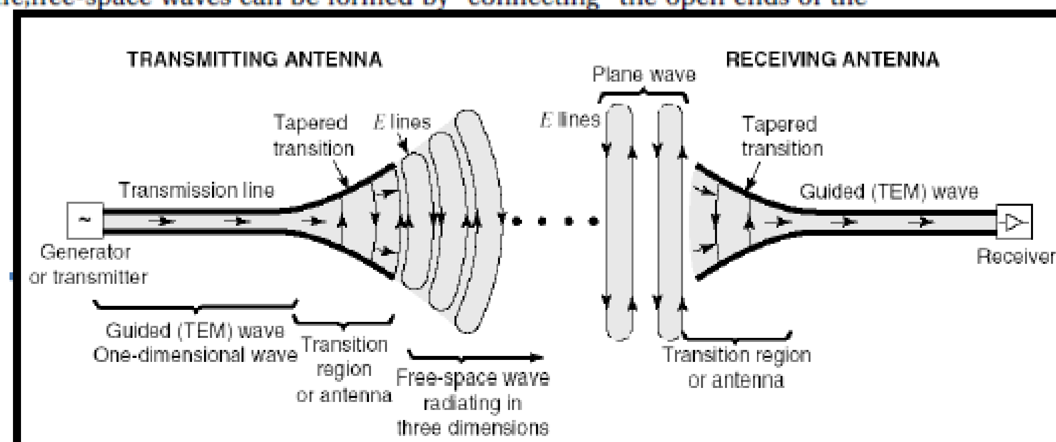
- Applying a voltage across the two-conductor transmission line creates an electric field between the conductors.
- The movement of the charges creates a current that in turn creates a magnetic field intensity.

- The creation of time-varying electric and magnetic fields between the conductors forms electromagnetic waves which travel along the transmission line.



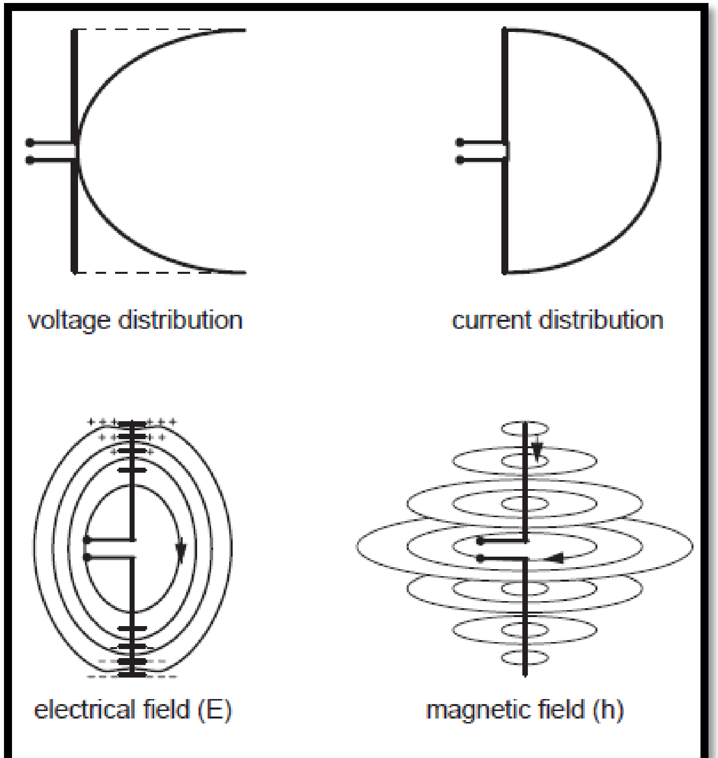
- If we remove part of the antenna structure,free-space waves can be formed by "connecting" the open ends of the electric lines.



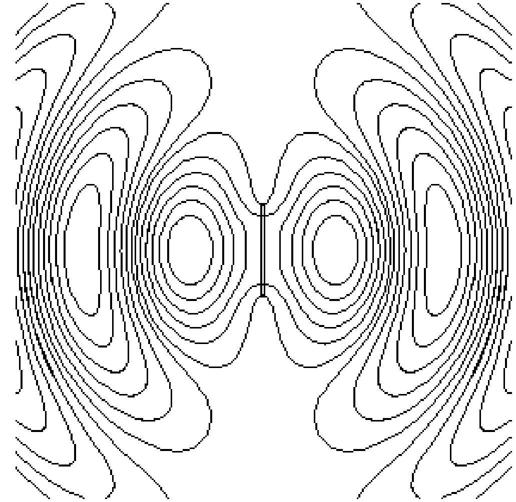


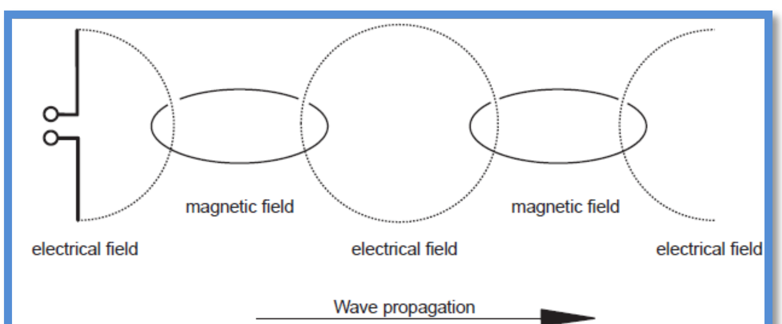
- If the initial electric disturbance by the source is of a short duration, the created electromagnetic waves travel inside the transmission line, then into the antenna, and finally are radiated as free-space waves, even if the electric source has ceased to exist.
- If the electric disturbance is of a continuous nature, electromagnetic waves exist continuously and follow in their travel behind the others.
- However, when the waves are radiated, they form closed loops and there are no charges to sustain their existence.
- Electric charges are required to excite the fields but are not needed to sustain them.

λ / 2 Dipole antenna



Field distribution on a λ/2 Dipole





Maxwell's Equations

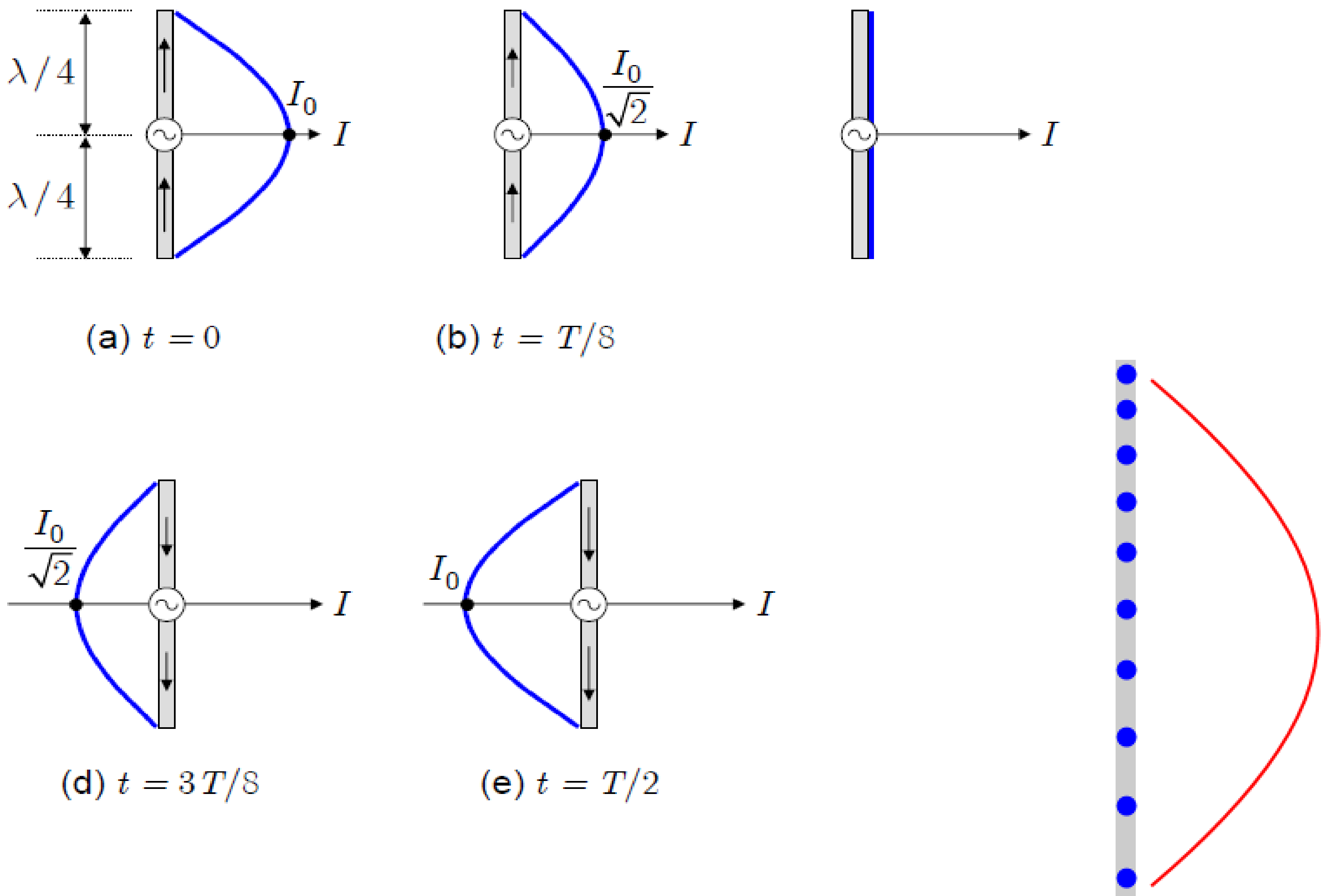
Differential (or point form)	Remarks
$\nabla \cdot \vec{D} = \rho_v$	*Gauss's* Law
$\nabla \cdot \vec{B} = 0$	Nonexistence of isolated Magnetic charge
$\nabla \times \vec{E} = -\dfrac{\partial \vec{B}}{\partial t}$	*Faraday's* Law
$\nabla \times \vec{H} = \vec{J} + \dfrac{\partial \vec{D}}{\partial t}$	*Ampere's* Circuit Law

electric field intensity (V/m)

magnetic field intensity (H/m)

ma

Current distribution on a λ/2 wire antenna for different times



(a) $t = 0$

(b) $t = T/8$

(d) $t = 3T/8$

(e) $t = T/2$

Maxwell's equations

The physics of the fields radiated by an antenna are described by Maxwell's equations. For harmonic variations of the fields $(e^{j\omega t})$, we can write

$$\nabla \times \vec{H} = j\omega\varepsilon\vec{E} + \vec{J} \qquad (1)$$

with $\vec{J} \begin{cases} \neq 0 & \text{in source region} \\ = 0 & \text{elsewhere} \end{cases}$

$$\nabla \times \vec{E} = -j\omega\mu\vec{H} \qquad (2)$$

$$\nabla \cdot \vec{D} = \varepsilon \nabla \cdot \vec{E} = \rho \qquad (3)$$

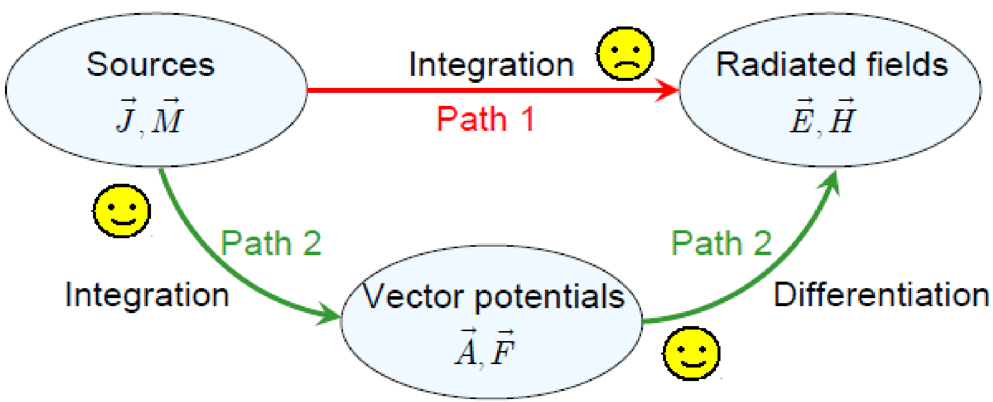
$$\nabla \cdot \vec{B} = \mu \nabla \cdot \vec{H} = 0 \qquad (4)$$

E, H: Electric and magnetic field
D: Dielectric displacement
B: Magnetic flux (induction)
J: Electric source current density
ρ: Charge density

$\nabla \times \vec{V} = \operatorname{curl} \vec{V}$
$\nabla \cdot \vec{V} = \operatorname{div} \vec{V}$
$\nabla \phi = \operatorname{grad} \phi$

Vector potentials

To analyze the fields radiated by sources, it is common practice to introduce auxiliary functions known as **vector potentials**, which will aid in the solution of Maxwell's equations.



- The two-step procedure usually involves simpler integrations than the direct path.
- The use of vector potentials basically permits to reduce the number of unknowns.

Useful identities from vector analysis

During the following mathematical treatment, we will make use of the following relations:

$\text{div curl} = 0$	or	$\nabla \cdot (\nabla \times \vec{V}) = 0$
$\text{curl grad} = 0$	or	$\nabla \times (\nabla \phi) = 0$

Reciprocally, it can then be demonstrated that

1) If the divergence of a vector field equals zero, then there exists a potential vector field so that the curl of the potential field equals the vector field

$$\nabla \cdot \vec{V} = 0 \quad \Rightarrow \quad \text{there exists } \vec{U} \text{ so that } \quad \vec{V} = \nabla \times \vec{U} \qquad (*)$$

2) If the curl of a vector field equals zero, then this vector field can be written as the gradient of a potential function

$$\nabla \times \vec{V} = 0 \quad \Rightarrow \quad \text{there exists } \phi \text{ so that } \quad \vec{V} = \nabla \phi \qquad (**)$$

2. Vector potential $\vec{A}$ for electric current source $\vec{J}$

- Since $\nabla \cdot \vec{B} = 0$, the magnetic flux $\vec{B}$ can be represented as the curl of another vector $\vec{A}$

$$\vec{B}_A = \nabla \times \vec{A} \qquad \left(\nabla \cdot \vec{B} = \nabla \cdot (\nabla \times \vec{A}) = 0 \quad \text{according to (*)}\right)$$

or

$$\boxed{\vec{H}_A = \frac{1}{\mu} \nabla \times \vec{A}} \qquad \left(\vec{B}_A = \mu \vec{H}_A\right)$$

The vector $\vec{A}$ is called ***magnetic vector potential***.

- The definition of $\vec{A}$ is put into Faraday's law (Maxwell equation (2))

$$\nabla \times \vec{E}_A = -j\omega\mu \vec{H}_A = -j\omega \nabla \times \vec{A} \quad \Rightarrow \quad \nabla \times \left(\vec{E}_A + j\omega \vec{A}\right) = 0$$

- We can now apply the identity (**) from the previous page to define the ***electric scalar potential*** ϕ_e

Since $\nabla \times \left(\vec{E}_A + j\omega \vec{A}\right) = 0$, there exists a scalar function ϕ_e so that $\left(\nabla \times (-\nabla \phi_e) = 0\right)$

$$\vec{E}_A + j\omega \vec{A} = -\nabla \phi_e \quad \Rightarrow \quad \boxed{\vec{E}_A = -\nabla \phi_e - j\omega \vec{A}}$$

The scalar function ϕ_e represents an arbitrary electric scalar potential which is a function of position.

- **Relationship between $\vec{A}$ and ϕ_e**

We now consider Ampere's law (Maxwell equation (1)) $\nabla \times \vec{H}_A = j\omega\varepsilon\vec{E}_A + \vec{J}$

Introducing the defined vector and scalar potentials, we can write

$$\frac{1}{\mu}\nabla \times \nabla \times \vec{A} = j\omega\varepsilon(-\nabla\phi_e - j\omega\vec{A}) + \vec{J}$$

$$\longleftarrow \quad \nabla \times \nabla \times \vec{A} = \nabla\left(\nabla \cdot \vec{A}\right) - \nabla^2\vec{A}$$

$$\nabla\left(\nabla \cdot \vec{A}\right) - \nabla^2\vec{A} = -j\omega\varepsilon\mu\,\nabla\phi_e + \omega^2\varepsilon\mu\vec{A} + \mu\vec{J}$$

The vector potential $\vec{A}$ is defined through its curl.
Lorenz condition define its divergence.

$$\boxed{\nabla \cdot \vec{A} = -j\omega\varepsilon\mu\phi_e} \quad \Rightarrow \quad \boxed{\nabla^2\vec{A} + \omega^2\varepsilon\mu\vec{A} = -\mu\vec{J}}$$

Inhomogeneous wave equation for $\vec{A}$

The electromagnetic wave equation is a second-order partial differential equation that describes the propagation of electromagnetic waves through a medium or in a vacuum

- A solution for this inhomogeneous wave equation

$$\vec{A} = \frac{\mu}{4\pi} \iiint_V \vec{J} \frac{e^{-jkR}}{R} dv'$$

- In addition, using the Lorenz condition, once $\vec{A}$ is known, the fields $\vec{H}_A, \vec{E}_A$ can be determined

$$\vec{H}_A = \frac{1}{\mu} \nabla \times \vec{A}$$

$$\vec{E}_A = -\nabla \phi_e - j\omega \vec{A} = -j\omega \vec{A} - j \frac{1}{\omega \mu \varepsilon} \nabla(\nabla \cdot \vec{A})$$

$$\nabla \cdot \vec{A} = -j\omega\varepsilon\mu\phi_e$$

- Thus the electromagnetic field $\vec{H}_A, \vec{E}_A$ can be calculated from a single vector potential $\vec{A}$.

3. Similarly Vector potential $\vec{F}$ for magnetic current source $\vec{M}$

- $$\vec{F} = \frac{\varepsilon}{4\pi} \iiint_V \vec{M} \frac{e^{-jkR}}{R} dv'$$

- Using the Lorenz condition, once $\vec{F}$ is known, the fields $\vec{H}_F, \vec{E}_F$ can be determined

$$\vec{E}_F = -\frac{1}{\varepsilon} \nabla \times \vec{F}$$

$$\vec{H}_F = -\nabla \phi_m - j\omega \vec{F} = -j\omega \vec{F} - j \frac{1}{\omega \mu \varepsilon} \nabla(\nabla \cdot \vec{F})$$

$$\nabla \cdot \vec{F} = -j\omega\varepsilon\mu\phi_m$$

- Thus the electromagnetic field $\vec{H}_F, \vec{E}_F$ can be calculated from a single vector potential $\vec{F}$.

The total fields

The radiated fields will be the superposition of two contributions:

- fields generated by electric current sources $\vec{J}$
- fields generated by magnetic current sources $\vec{M}$

The total fields from these two contributions can be written in terms of $\vec{A}$ and $\vec{F}$

$$\vec{E} = \vec{E}_A + \vec{E}_F$$

$$\vec{H} = \vec{H}_A + \vec{H}_F$$

Summary of the analysis procedure

1) Specify the sources $\vec{J}$ and $\vec{M}$
2) Find the vector potential $\vec{A}$ and $\vec{F}$
3) Find the field contributions $\vec{E}$ and $\vec{H}$

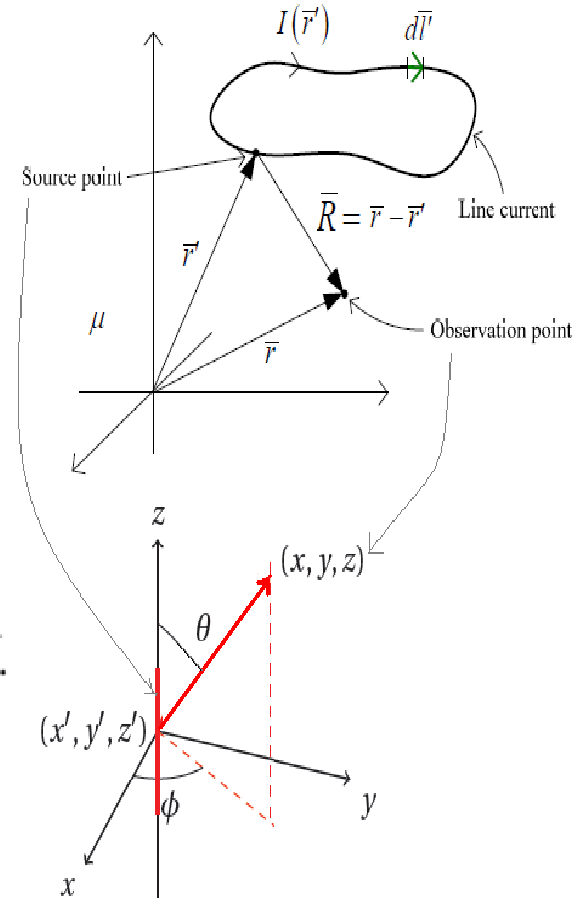
Infinitesimal Dipole

- An infinitesimal linear wire ($l \ll \lambda$) is positioned symmetrically at the origin of the coordinate system and oriented along the z axis.

- The spatial variation of the current is assumed to be constant and given by

$$\boldsymbol{I}(z') = \hat{\boldsymbol{a}}_z I_0$$

where I_0 is a constant.



- The source only carries an electric current $\boldsymbol{I}_e$. $\boldsymbol{I}_m$ and the potential function $\boldsymbol{F}$ are zero. To find $\boldsymbol{A}$ we write

$$\boldsymbol{A}(x, y, z) = \frac{\mu}{4\pi}\int_C \boldsymbol{I}_e(x', y', z')\frac{e^{-jkR}}{R}\,dl'.$$

where

(x, y, z) : Observation point coordinates.

(x', y', z') : Coordinates of the source.

R : The distance from any point on the source to the observation point.

C : Path along the length of the source.

$$\boldsymbol{I}_e(x', y', z') = \hat{\boldsymbol{a}}_z I_0.$$

$$x' = 0, y' = 0, z' = 0, \quad \text{for the infinitesimal dipole.}$$

$$R = \sqrt{(x - x')^2 + (y - y')^2 + (z - z')^2} = \sqrt{x^2 + y^2 + z^2} = r \quad \text{(constant).}$$

$$dl' = dz'.$$

$$\boldsymbol{A}(x,y,z) = \hat{\boldsymbol{a}}_z \frac{\mu I_0}{4\pi r} e^{-jkr} \int_{-l/2}^{l/2} dz' = \hat{\boldsymbol{a}}_z \frac{\mu I_0 l}{4\pi r} e^{-jkr}.$$

$$\boldsymbol{H}_A = \frac{1}{\mu} \nabla \times \boldsymbol{A} \quad \text{—} \quad \boldsymbol{E}_A: \nabla \times \boldsymbol{H}_A = \boldsymbol{J} + j\omega\epsilon \boldsymbol{E}_A \ .$$

Transformation from rectangular to spherical coordinates:

$$\begin{bmatrix} A_r \\ A_\theta \\ A_\phi \end{bmatrix} = \begin{bmatrix} \sin\theta\cos\phi & \sin\theta\sin\phi & \cos\theta \\ \cos\theta\cos\phi & \cos\theta\sin\phi & -\sin\theta \\ -\sin\phi & \cos\phi & 0 \end{bmatrix} \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix}$$

$A_x = 0, A_y = 0, A_z \neq 0.$

$$A_r = A_z \cos\theta = \frac{\mu I_0 l e^{-jkr}}{4\pi r} \cos\theta.$$

$$A_\theta = -A_z \sin\theta = -\frac{\mu I_0 l e^{-jkr}}{4\pi r} \sin\theta.$$

$$A_\phi = 0.$$

$$\nabla \times \boldsymbol{A} = \frac{\hat{\boldsymbol{a}}_r}{r\sin\theta} \left[\frac{\partial}{\partial\theta}(A_\phi \sin\theta) - \frac{\partial}{\partial\phi} A_\theta \right] + \frac{\hat{\boldsymbol{a}}_\theta}{r} \left[\frac{1}{\sin\theta} \frac{\partial}{\partial\phi} A_r - \frac{\partial}{\partial r}(r A_\phi) \right] + \frac{\hat{\boldsymbol{a}}_\phi}{r} \left[\frac{\partial}{\partial r}(r A_\theta) - \frac{\partial}{\partial\theta} A_r \right]$$

$$\boldsymbol{H} = \frac{1}{\mu}\frac{\hat{\boldsymbol{a}}_\phi}{r}\left[\frac{\partial}{\partial r}(r A_\theta) - \frac{\partial}{\partial \theta}A_r\right]$$

$$H_r = H_\theta = 0.$$

$$H_\phi = j\frac{kI_0 l \sin\theta}{4\pi r}\left[1 + \frac{1}{jkr}\right]e^{-jkr}.$$

$$\boldsymbol{E} = \boldsymbol{E}_A = \frac{1}{j\omega\epsilon}\nabla \times \boldsymbol{H}.$$

The Electric field generated from magnetic field in free space, thus J=0 and thus E and H components are valid every where except on the source itself

$$E_r = \eta\frac{I_0 l \cos\theta}{2\pi r^2}\left[1 + \frac{1}{jkr}\right]e^{-jkr}.$$

$$E_\theta = j\eta\frac{kI_0 l \sin\theta}{4\pi r}\left[1 + \frac{1}{jkr} - \frac{1}{(kr)^2}\right]e^{-jkr}.$$

$$E_\phi = 0.$$

Far Field $kr \gg 1$

$$E_\theta \simeq j\eta\frac{kI_0 l e^{-jkr}}{4\pi r}\sin\theta.$$

$$E_r \simeq E_\phi = H_r = H_\theta = 0.$$

$$H_\phi \simeq j\frac{kI_0 l e^{-jkr}}{4\pi r}\sin\theta.$$

E- and ***H***-field components are perpendicular to each other, transverse to the direction of propagation.

Power Density and Radiation Resistance

- For a lossless antenna, the real part of the input impedance is designated as the radiation resistance, that power is transferred from the guided wave to the free space wave.

$$\boldsymbol{W} = \frac{1}{2}\boldsymbol{E} \times \boldsymbol{H}^* = \frac{1}{2}(\hat{\boldsymbol{a}}_r E_r + \hat{\boldsymbol{a}}_\theta E_\theta) \times \left(\hat{\boldsymbol{a}}_\phi H_\phi^*\right).$$

$$= \frac{1}{2}\left(\hat{\boldsymbol{a}}_r E_\theta H_\phi^* - \hat{\boldsymbol{a}}_\theta E_r H_\phi^*\right).$$

$$W_r = \frac{\eta}{8}\left|\frac{I_0 l}{\lambda}\right|^2 \frac{\sin^2\theta}{r^2}\left[1 - j\frac{1}{(kr)^3}\right].$$

$$W_\theta = j\eta \frac{k|I_0 l|^2 \cos\theta \sin\theta}{16\pi^2 r^3}\left[1 + \frac{1}{(kr)^2}\right].$$

The complex power moving int eh radial direction

$$P = \oiint_S \boldsymbol{W} \cdot d\boldsymbol{s} = \int_0^{2\pi}\int_0^{\pi}(\hat{\boldsymbol{a}}_r W_r + \boldsymbol{a}_\theta W_\theta) \cdot \boldsymbol{a}_r r^2 \sin\theta d\theta d\phi$$

$$= \int_0^{2\pi}\int_0^{\pi} W_r r^2 \sin\theta d\theta d\phi$$

$$= \eta \frac{\pi}{3}\left|\frac{I_0 l}{\lambda}\right|^2\left[1 - j\frac{1}{(kr)^3}\right].$$

For large values of kr ($kr \gg 1$), the reactive power diminishes. For free space $\eta \simeq 120\pi$,

Time average power radiated is

$$p_{\text{rad}} = \eta\left(\frac{\pi}{3}\right)\left|\frac{I_0 l}{\lambda}\right|^2.$$

$$R_{\text{rad}} = \eta\left(\frac{2\pi}{3}\right)\left(\frac{l}{\lambda}\right)^2 = 80\pi^2.\left(\frac{l}{\lambda}\right)^2.$$

Example 4.1

Find the radiation resistance of an infinitesimal dipole whose overall length is $l = \lambda/50$.

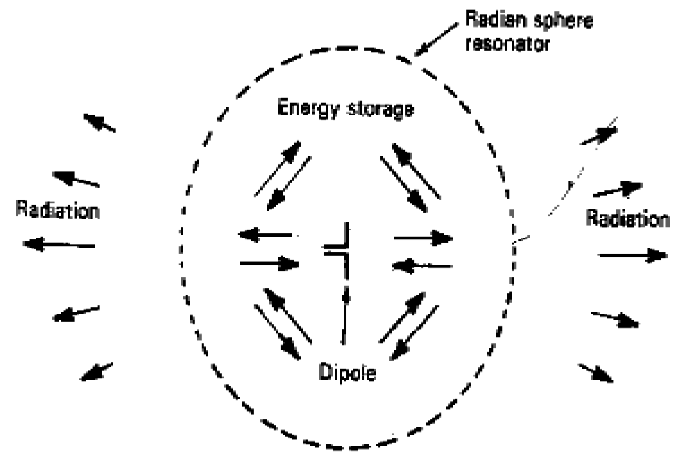
Solution:

$$R_r = 80\pi^2\left(\frac{l}{\lambda}\right)^2 = 80\pi^2\left(\frac{1}{50}\right)^2 = 0.316 \text{ ohms}$$

Since the radiation resistance of an infinitesimal dipole is about 0.3 ohms, it will present a very large mismatch when connected to practical transmission lines, many of which have characteristic impedances of 50 or 75 ohms. The reflection efficiency (e_r) and hence the overall efficiency (e_0) will be very small.

Radian Distance and Radian Sphere

- Distance r=1/K= λ/2π is called radian distance
- Radian sphere is spherical region of radius λ/2π around a small dipole antenna at which induction (imag.) and radiation(real) terms are equal in magnitude, inside radian sphere induction term dominate, outside radian sphere radiation term dominate.
- $$P = \eta\frac{\pi}{3}\left|\frac{I_0 l}{\lambda}\right|^2\left[1 - j\frac{1}{(kr)^3}\right].$$



For very short dipole

- Reactive Near field region: has r <1/K , power in this region basically stored.
- Far field region: region at r>>1/K , power in this region basically radiate.

For most antennas Reactive near field region outer boundaries are taken to exist at a distance $R < .62\sqrt{D^3/\lambda}$ from the antenna surface. Where D is the largest dimension of the antenna.

For all antennas this concept is applicable, the power density (Poynting vector w/m2) in regions closed to antennas are basically reactive (stored) and at faraway is basically real (radiated).

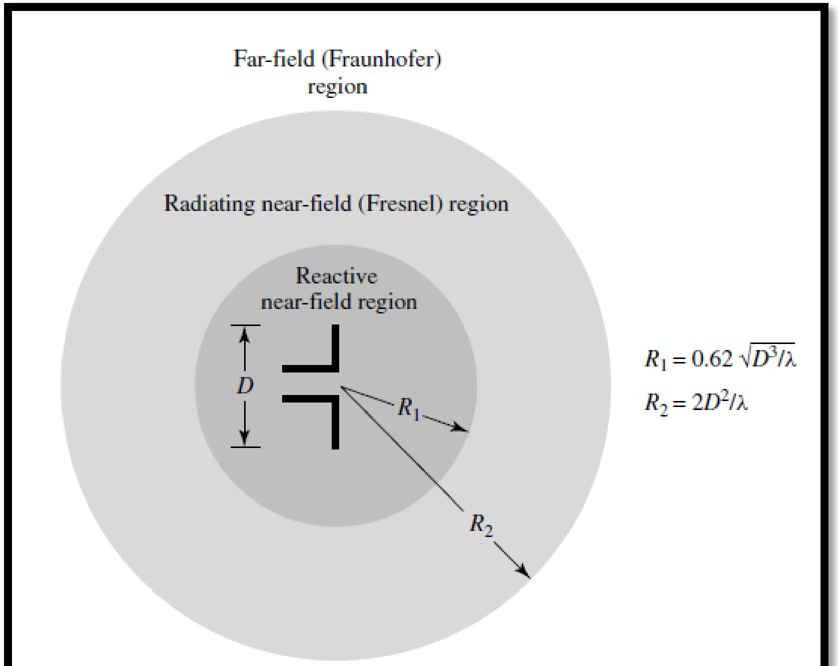
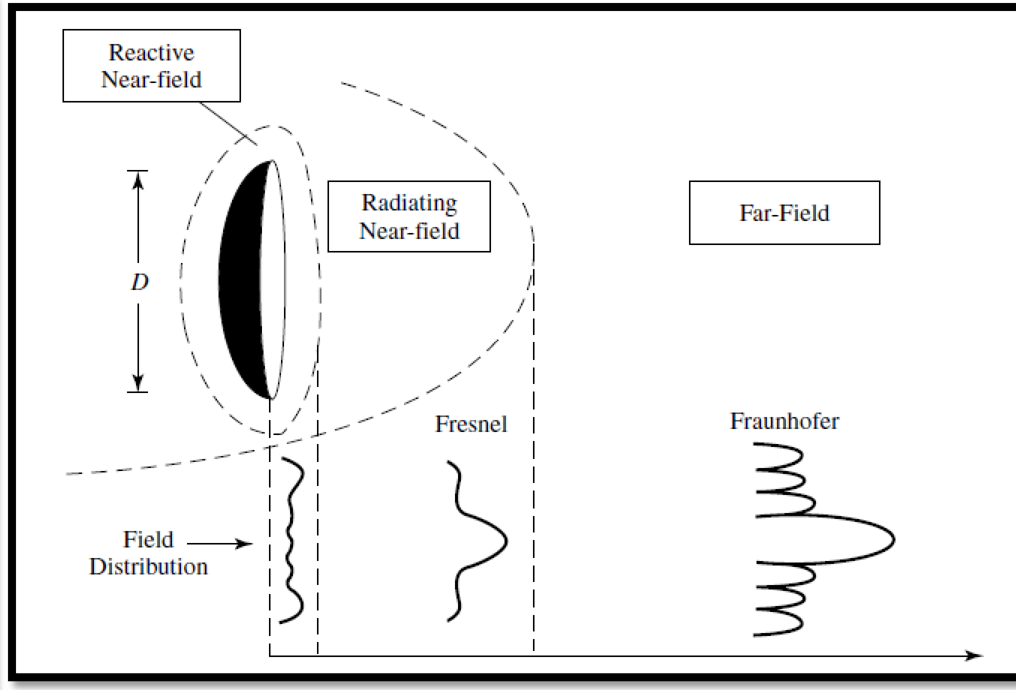


Figure 2.7 Field regions of an antenna.



- Far field zone:

1-field components are transverse to radial direction from antenna, and all power flow is directed radially outward.

2-shape of radiation pattern is independent on distance.

- *Near field zone:*

1-field components may not transverse to radial direction from antenna and power is not entirely radial.

2-shape of radiation pattern is dependent on distance.

Sheet (1)

1. **State different types of antenna**
2. **Describe radiation mechanism for single wire and two wires antenna.**
3. **Derive the wave equation described by magnetic vector potential.**
4. **A horizontal infinitesimal electric dipole of constant current I_0 is placed symmetrically about the origin and directed along the x-axis. Derive the far-zone fields radiated by the dipole.**
5. **Repeat Problem 4 for a horizontal infinitesimal electric dipole directed along the y-axis.**
6. **Why the infinitesimal electric dipole is not a practical antenna.**

- **The divergence of a continuously differentiable vector field F = *U* i + *V* j + *W* k is equal to the scalar-valued function:**

$$\operatorname{div}\,\mathbf{F} = \nabla\cdot\mathbf{F} = \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} + \frac{\partial W}{\partial z}.$$

The gradient (or gradient vector field) of a scalar function *f*

In the three-dimensional Cartesian coordinate system, this is given by

$$\nabla f = \frac{\partial f}{\partial x}\mathbf{i} + \frac{\partial f}{\partial y}\mathbf{j} + \frac{\partial f}{\partial z}\mathbf{k}$$

The Laplace operator is a second order differential operator in the *n*-dimensional Euclidean space, defined as the divergence ($\nabla\cdot$) of the gradient (∇f). Thus if f is a twice-differentiable real-valued function, then the Laplacian of f is defined by

$$\Delta f = \nabla^2 f = \nabla\cdot\nabla f$$

In Cartesian coordinates,

$$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2}.$$