CHAPTER 1: ANTENNA FUNDAMENTALS

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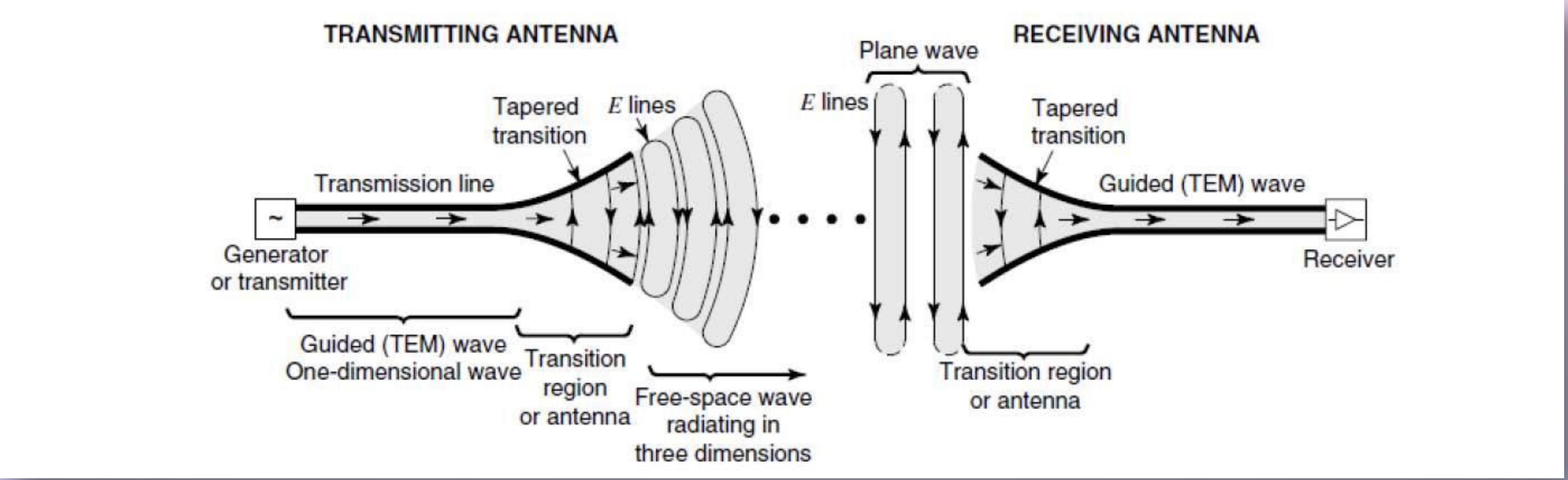
Introduction

- An antenna is defined by Webster's Dictionary as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves.
- " The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145-1983) defines the antenna or aerial as "a means for radiating or receiving radio waves.
- " In other words the antenna is the transitional structure between free-space and a guiding device.
- The guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), and it is used to transport electromagnetic energy from the transmitting source to the antenna or from the antenna to the receiver.
- In the former case, we have a transmitting antenna and in the latter a receiving antenna.



- An antenna is basically a transducer. It converts radio frequency (RF) signal into an electromagnetic (EM) wave of the same frequency.
- It forms a part of transmitter as well as the receiver circuits. Its equivalent circuit is characterized by the presence of resistance, inductance, and capacitance.
- The current produces a magnetic field and a charge produces an electrostatic field. These two in turn create an induction field.

Definition of antenna

An antenna can be defined in the following different ways:

1. An antenna may be a piece of conducting material in the form of a wire, rod or any other shape with excitation.
2. An antenna is a source or radiator of electromagnetic waves.
3. An antenna is a sensor of electromagnetic waves.
4. An antenna is a transducer.
5. An antenna is an impedance matching device.
6. An antenna is a coupler between a generator and space or vice-versa.

Radiation Mechanism

The radiation from the antenna takes place when the Electromagnetic field generated by the source is transmitted to the antenna system through the Transmission line and separated from the Antenna into free space.

Radiation from a Single Wire

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

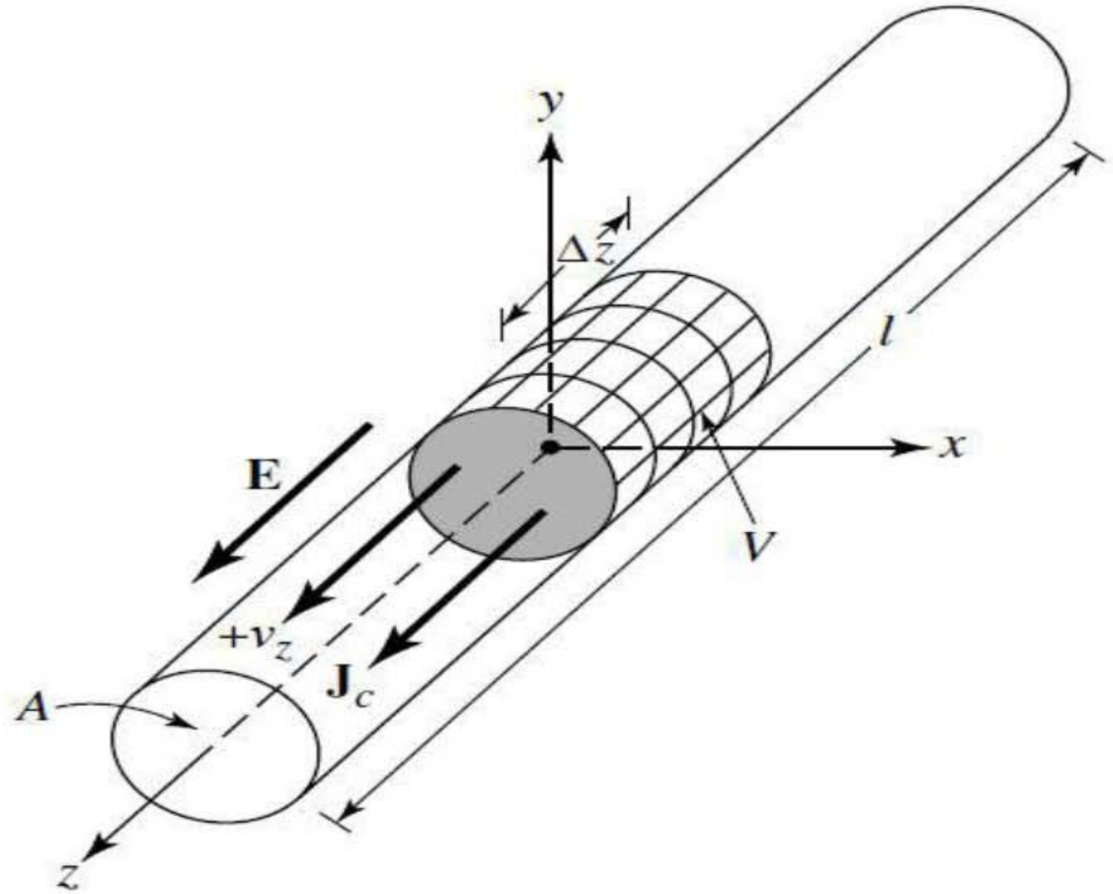


Figure: Charge uniformly distributed in a circular cross section cylinder wire.

Current density in a volume with volume charge density qv (C/m^3)

Jz = qv Vz (A/m^2) (1)

Surface current density in a section with a surface charge density qs (C/m^2)

$J_s = q_s V_z$ (A/m) (2)

Current in a thin wire with a linear charge density q_1 (C/m):

$I_z = q_1 V_z$ (A) (3)

To accelerate/decelerate charges, one needs sources of electromotive force and/or discontinuities of the medium in which the charges move. Such discontinuities can be bends or open ends of wires, change in the electrical properties of the region, etc.

In summary:

It is a fundamental single wire antenna. From the principle of radiation there must be some time varying current. For a single wire antenna,

1. If a charge is not moving, current is not created and there is no radiation.
2. 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, as shown in Figure.

3. If charge is oscillating in a time-motion, it radiates even if the wire is straight.

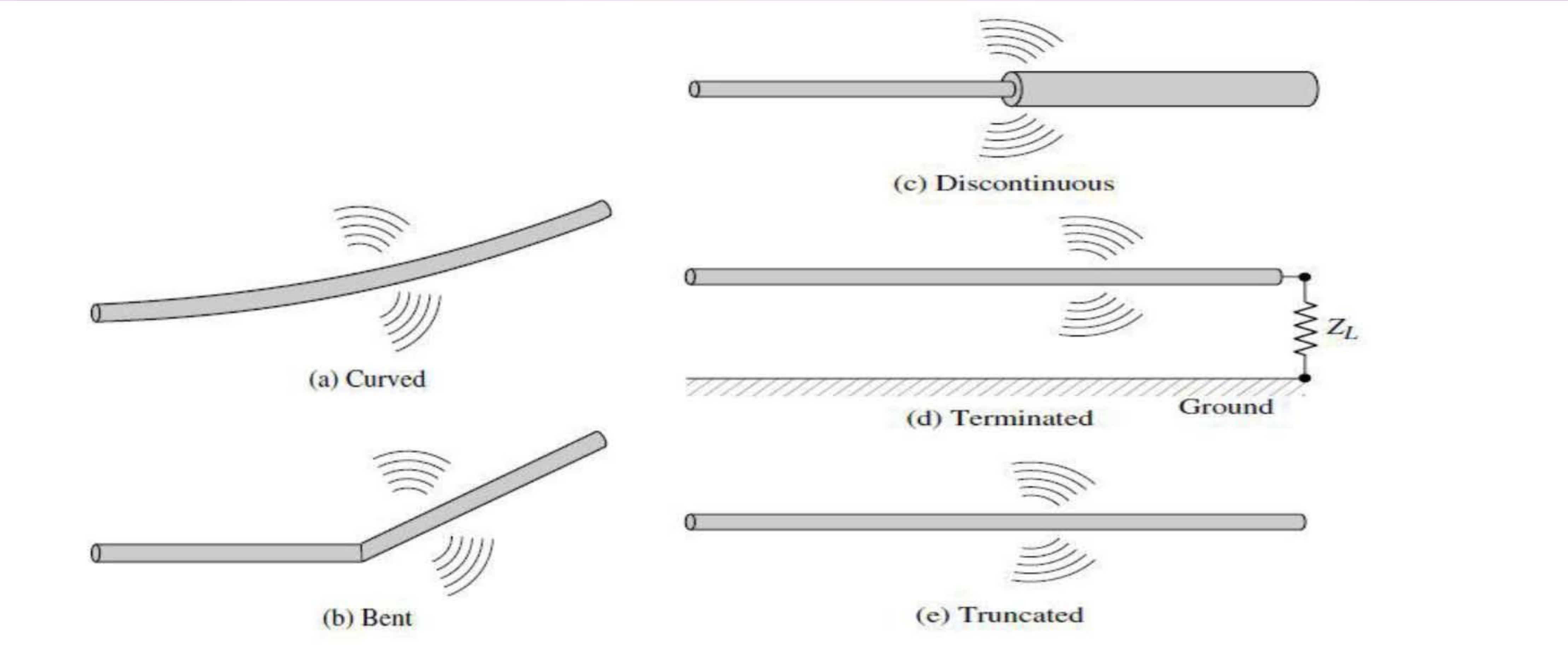


Figure: Wire Configurations for Radiation

Radiation from a Two Wire

- Let us consider a voltage source connected to a two-conductor transmission line which is connected to an antenna. This is shown in Figure (a).
- Applying a voltage across the two conductor transmission line creates an electric field between the conductors.
- The electric field has associated with it electric lines of force which are tangent to the electric field at each point and their strength is proportional to the electric field intensity.
- The electric lines of force have a tendency to act on the free electrons (easily detachable from the atoms) associated with each conductor and force them to be displaced.
- The movement of the charges creates a current that in turn creates magnetic field intensity.
- Associated with the magnetic field intensity are magnetic lines of force which are tangent to the magnetic field. We have accepted that electric field lines start on positive charges and end on negative charges.
- They also can start on a positive charge and end at infinity, start at infinity and end on a negative charge, or form closed loops neither starting or ending on any charge.
- Magnetic field lines always form closed loops encircling current-carrying conductors because physically there are no magnetic charges.
- In some mathematical formulations, it is often convenient to introduce equivalent magnetic charges and magnetic currents to draw a parallel between solutions involving electric and magnetic sources.

- The electric field lines drawn between the two conductors help to exhibit the Distribution of charge.
- If we assume that the voltage source is sinusoidal, we expect the electric field between the conductors to also be sinusoidal with a period equal to that of the applied source.
- The relative magnitude of the electric field intensity is indicated by the density (bunching) of the lines of force with the arrows showing the relative direction (positive or negative).
- The creation of time- varying electric and magnetic fields between the conductors forms electromagnetic waves which travel along the transmission line, as shown in Figure 1.11(a).
- The electromagnetic waves enter the antenna and have associated with them electric charges and corresponding currents.
- If we remove part of b the antenna structure, as shown in Figure (b), free-space waves can be formed by "connecting" the open ends of the electric lines (shown dashed).
- The free-space waves are also periodic but a constant phase point P0 moves outwardly with the speed of light and travels a distance of $\lambda/2$ (to P1) in the time of one-half of a period.
- It has been shown that close to the antenna the constant phase point P0 moves faster than the speed of light but approaches the speed of light at points far away from the antenna (analogous to phase velocity inside a rectangular waveguide).

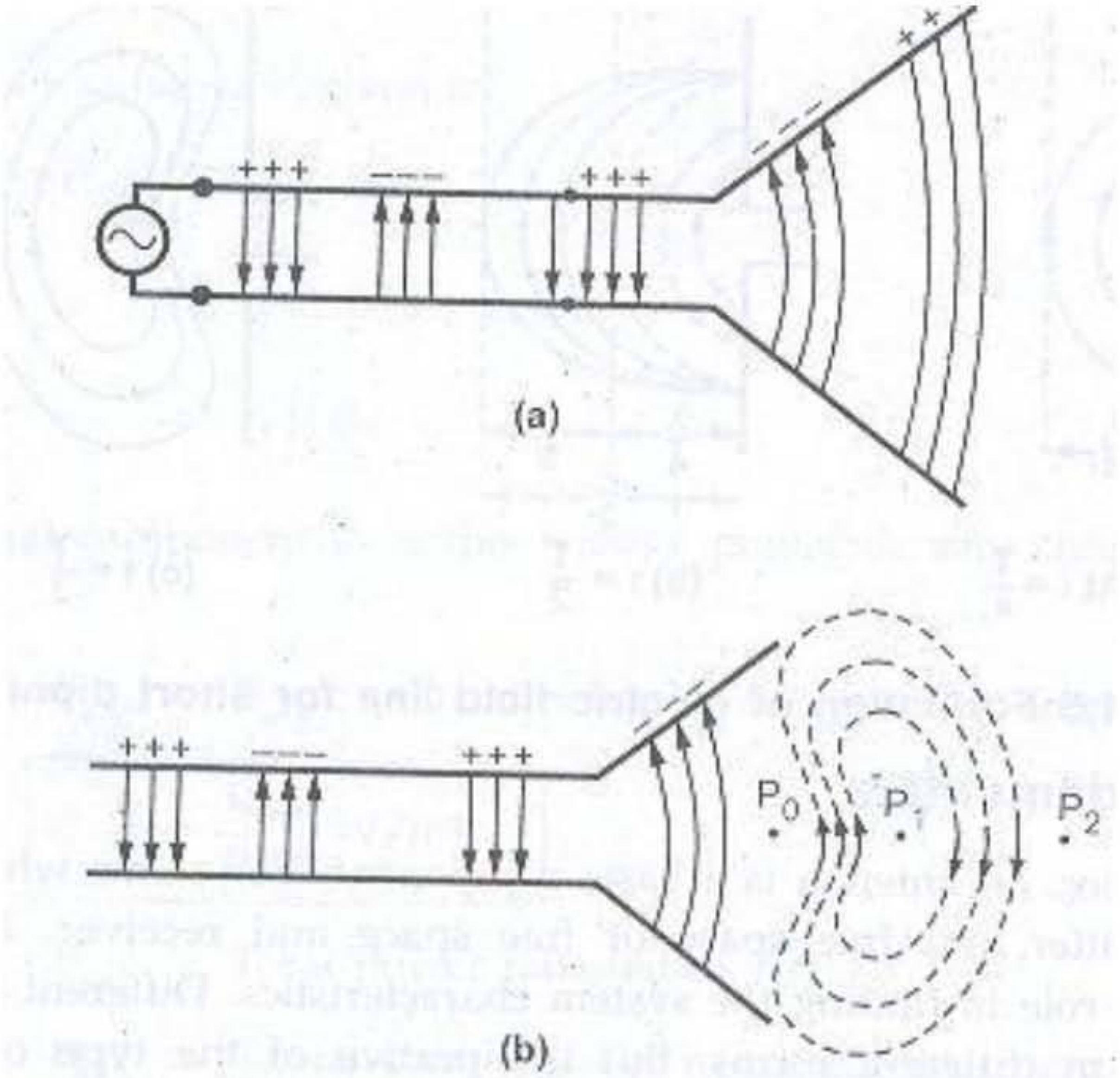


Fig. Radiation from two wire antennas

Radiation from a Dipole

- Now let us attempt to explain the mechanism by which the electric lines of force are detached from the antenna to form the free-space waves.
- This will again be illustrated by an example of a small dipole antenna where the time of travel is negligible.
- This is only necessary to give a better physical interpretation of the detachment of the lines of force. Although a somewhat simplified mechanism, it does allow one to visualize the creation of the free-space waves.
- Figure(a) displays the lines of force created between the arms of a small center-fed dipole in the first quarter of the period during which time the charge has reached its maximum value (assuming a sinusoidal time variation) and the lines have traveled outwardly a radial distance $\lambda/4$.
- For this example, let us assume that the number of lines formed is three.
- During the next quarter of the period, the original three lines travel an additional $\lambda/4$ (a total of $\lambda/2$ from the initial point) and the charge density on the conductors begins to diminish.
- This can be thought of as being accomplished by introducing opposite charges which at the end of the first half of the period have neutralized the charges on the conductors.

- The lines of force created by the opposite charges are three and travel a distance λ/4 during the second quarter of the first half, and they are shown dashed in figure (b).
- The end result is that there are three lines of force pointed upward in the first λ/4 distance and the same number of lines directed downward in the second λ/4.
- Since there is no net charge on the antenna, then the lines of force must have been forced to detach themselves from the conductors and to unite together to form closed loops.
- This is shown in figure(c). In the remaining second half of the period, the same procedure is followed but in the opposite direction.
- After that, the process is repeated and continues indefinitely and electric field patterns are formed.

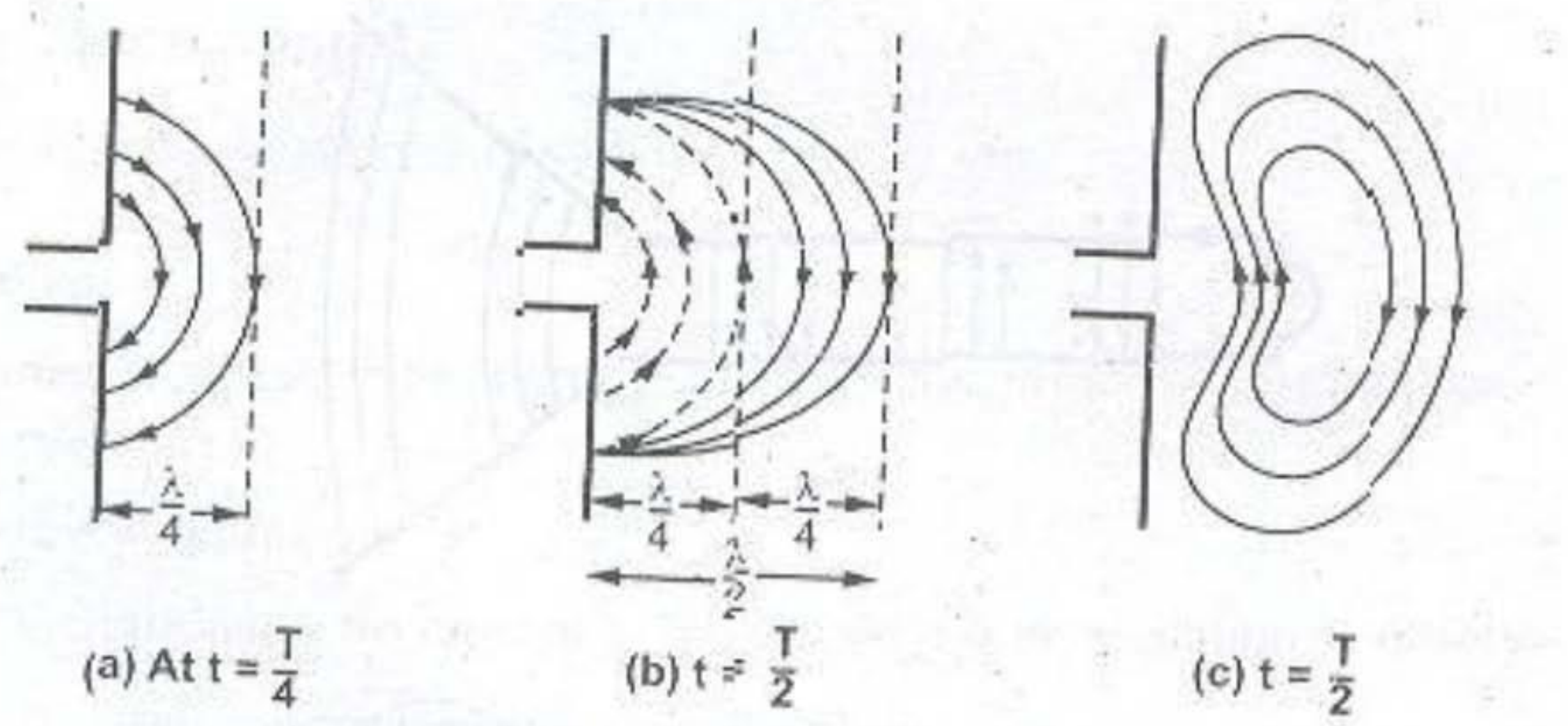
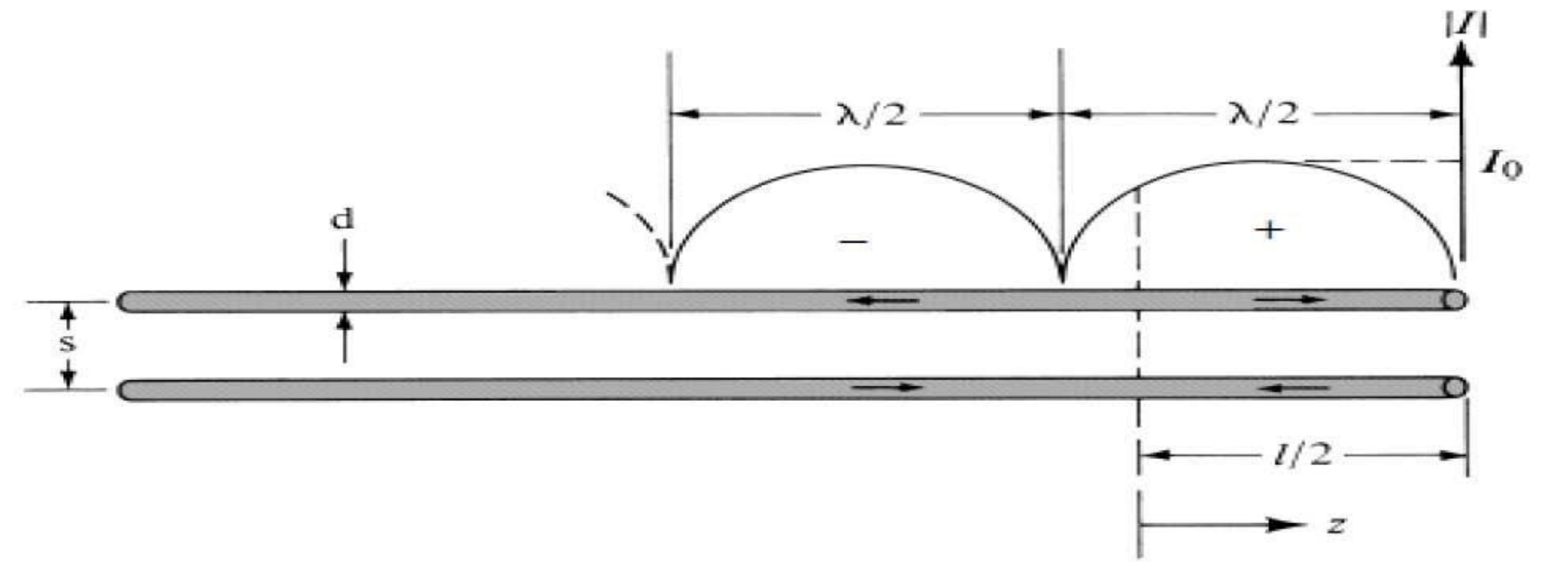


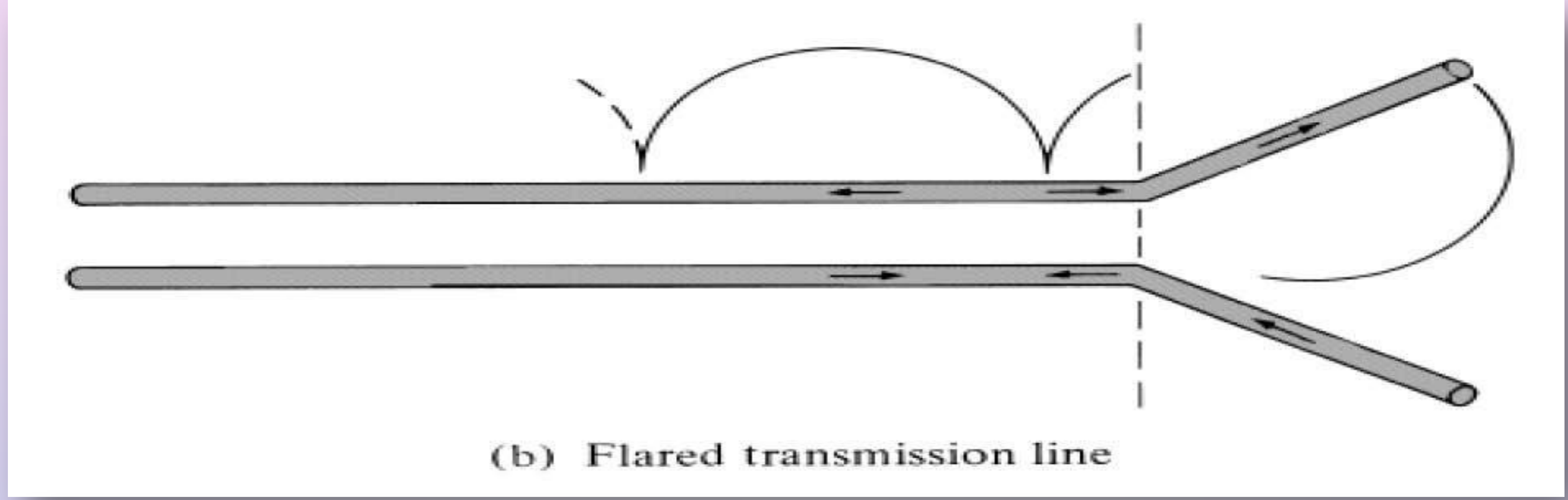
Figure : formation of electric field line for short dipole

Current distribution on a thin wire antenna

- Let us consider a lossless two wire transmission line in which the movement of charges creates a current having value I with each wire.
- This current at the end of the transmission line is reflected back, when the transmission line has parallel end points resulting in formation of standing waves in combination with incident wave.
- When the transmission line is flared out at 90º forming geometry of dipole antenna (linear wire antenna), the current distribution remains unaltered and the radiated fields not getting cancelled resulting in net radiation from the dipole.
- If the length of the dipole L< λ/2, the phase of current of the standing wave in each transmission line remains same.



(a) Two–wire transmission line



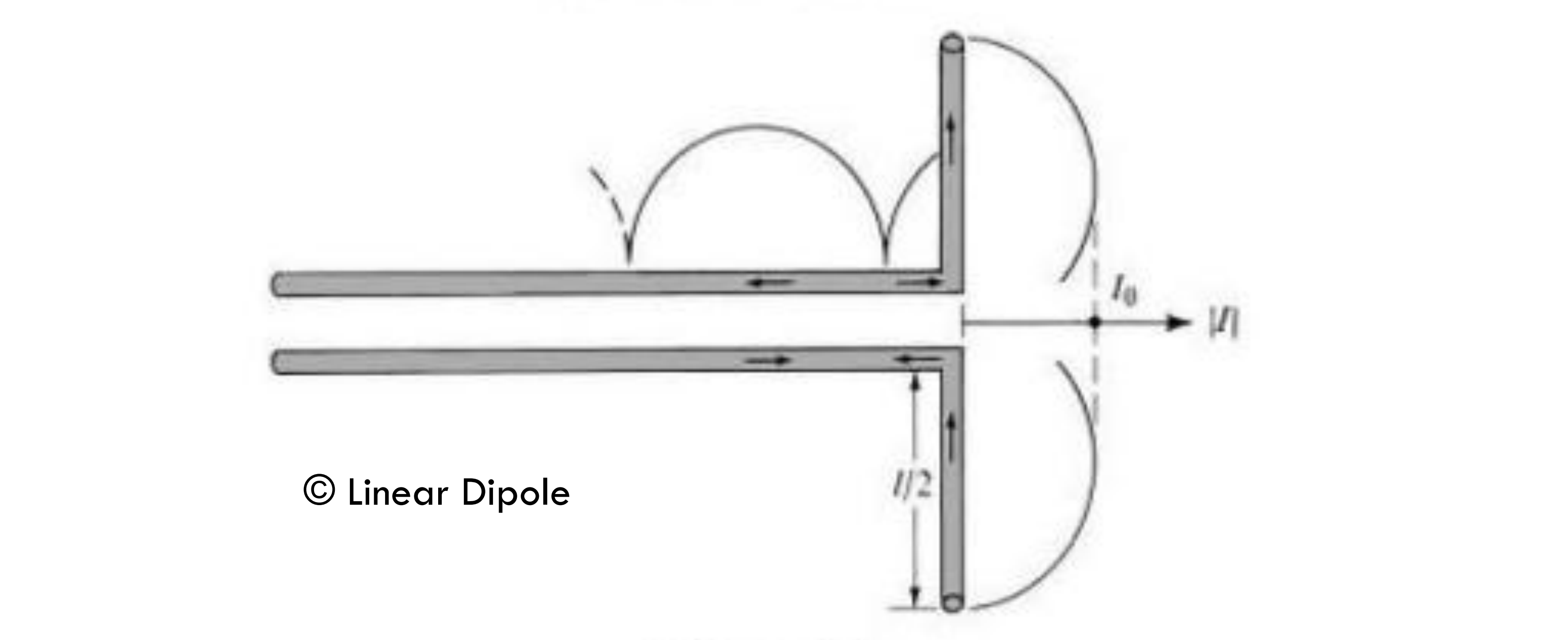
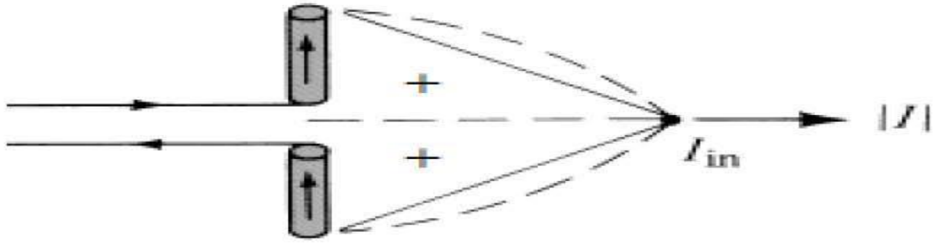


Fig. Current distribution on a lossless two-wire transmission line, flared transmission line, and linear dipole.

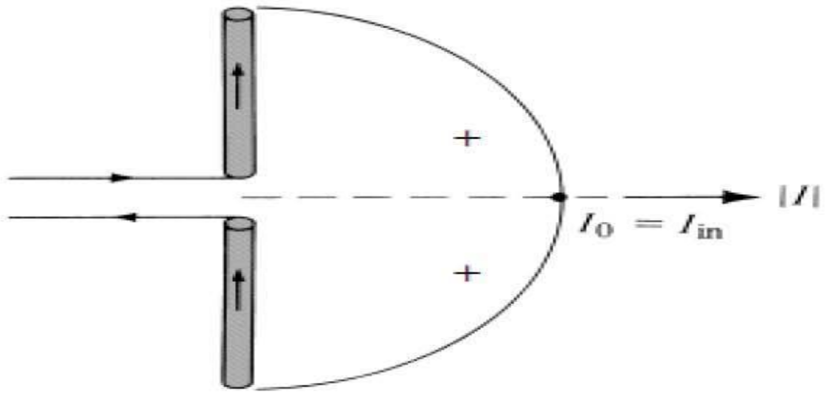
- If diameter of each line is small d<< λ/2, the current distribution along the lines will be sinusoidal with null at end but overall distribution depends on the length of the dipole (flared out portion of the transmission line).

The current distribution for dipole of length $l << \lambda$



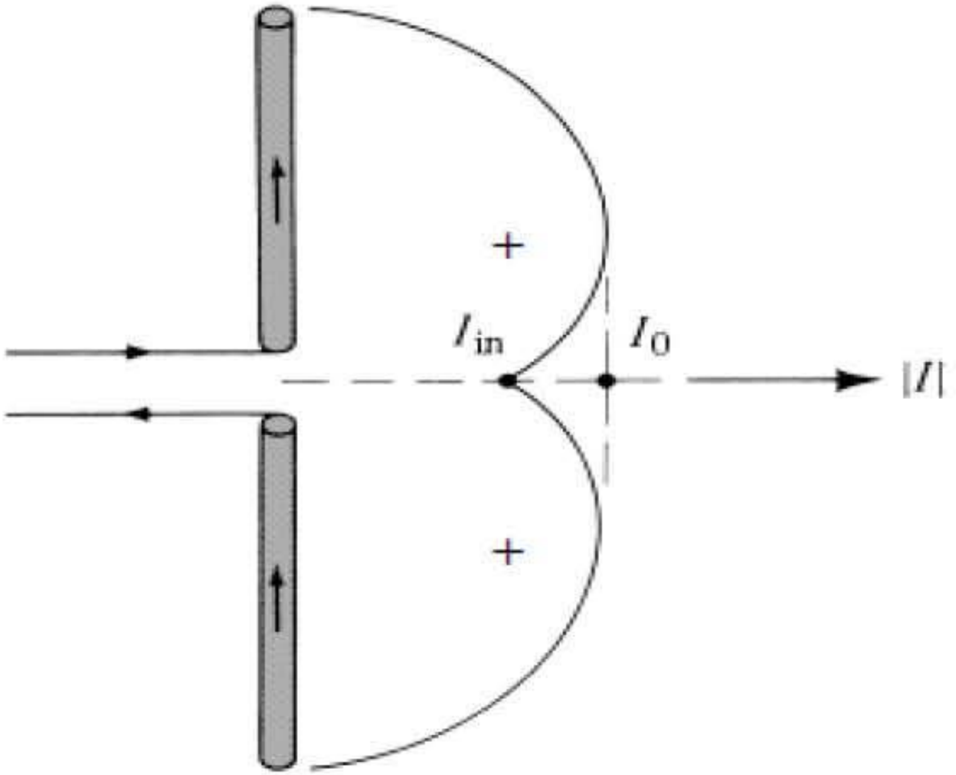
(a) $l << \lambda$

For $l = \lambda/2$



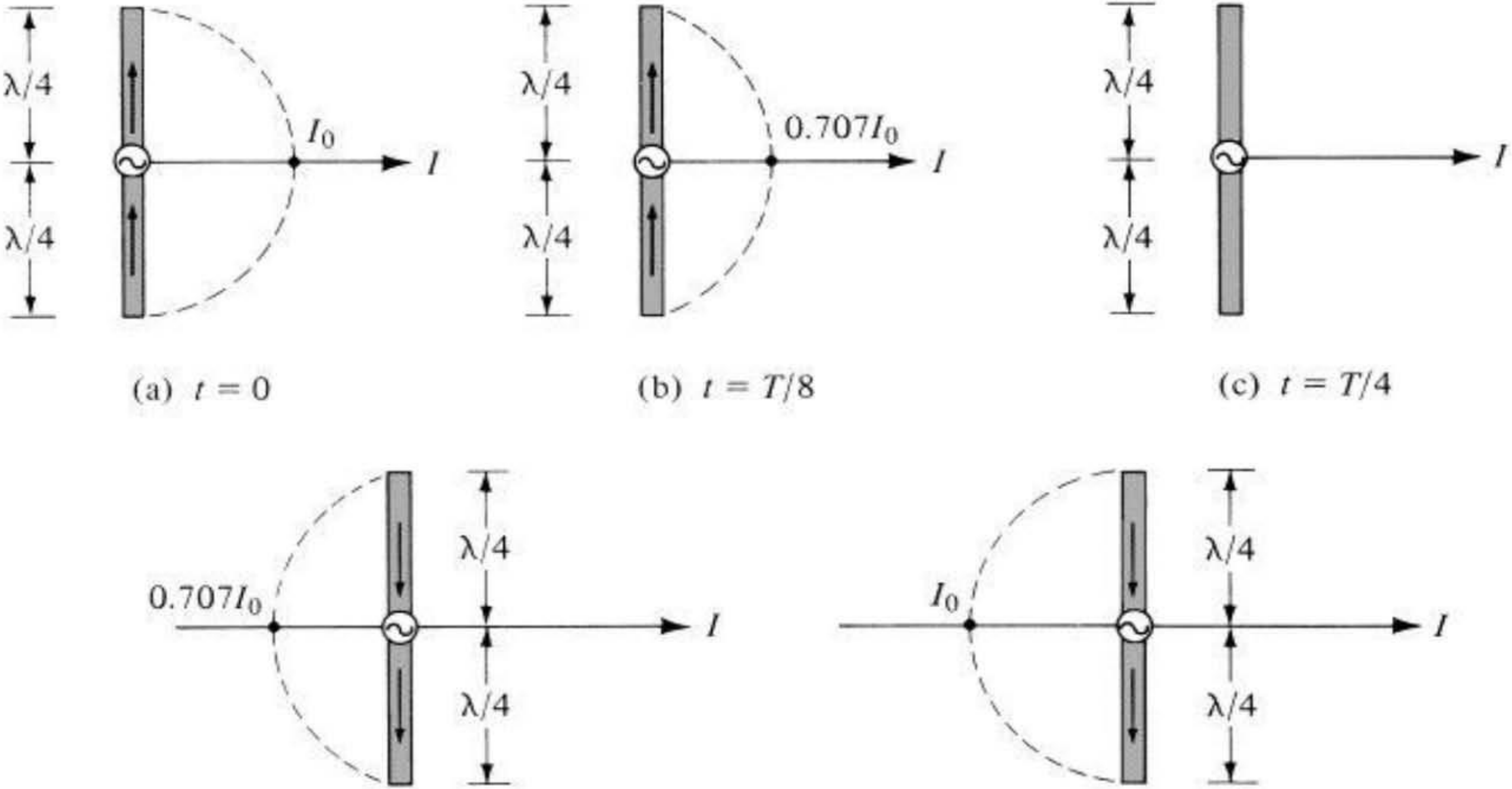
(b) $l = \lambda/2$

For $\lambda/2 < l < \lambda$



(c) $\lambda/2 < l < \lambda$

- When L> λ, the current goes phase reversal between adjoining half-cycles. Hence, current is not having same phase along all parts of transmission line.
- This will result into interference and canceling effects in the total radiation pattern.
- The current distributions we have seen represent the maximum current excitation for any time.
- The current varies as a function of time as well.



(a) $t = 0$ (b) $t = T/8$ (c) $t = T/4$

(d) $t = 3T/8$ (e) $t = T/2$

Linear antenna:-

These are broadly categorized into 2 parts:-

(i) Standing wave linear antenna dipole.

(ii) Traveling wave linear antenna dipole.

1.8.1 The Standing Wave Linear Antennas

- When a piece of open transmission line is considered, there exists a standing wave as illustrated in Figure 1.9(a).
- Because the conductors are very close to each other, the fields (the electric the magnetic) produced by the individual conductor therefore cancel with each other.
- Hence there will not be any radiation from the line However, if a portion of the line at the open end slowly bent outward, the cancellation of the fields gradually decreased.

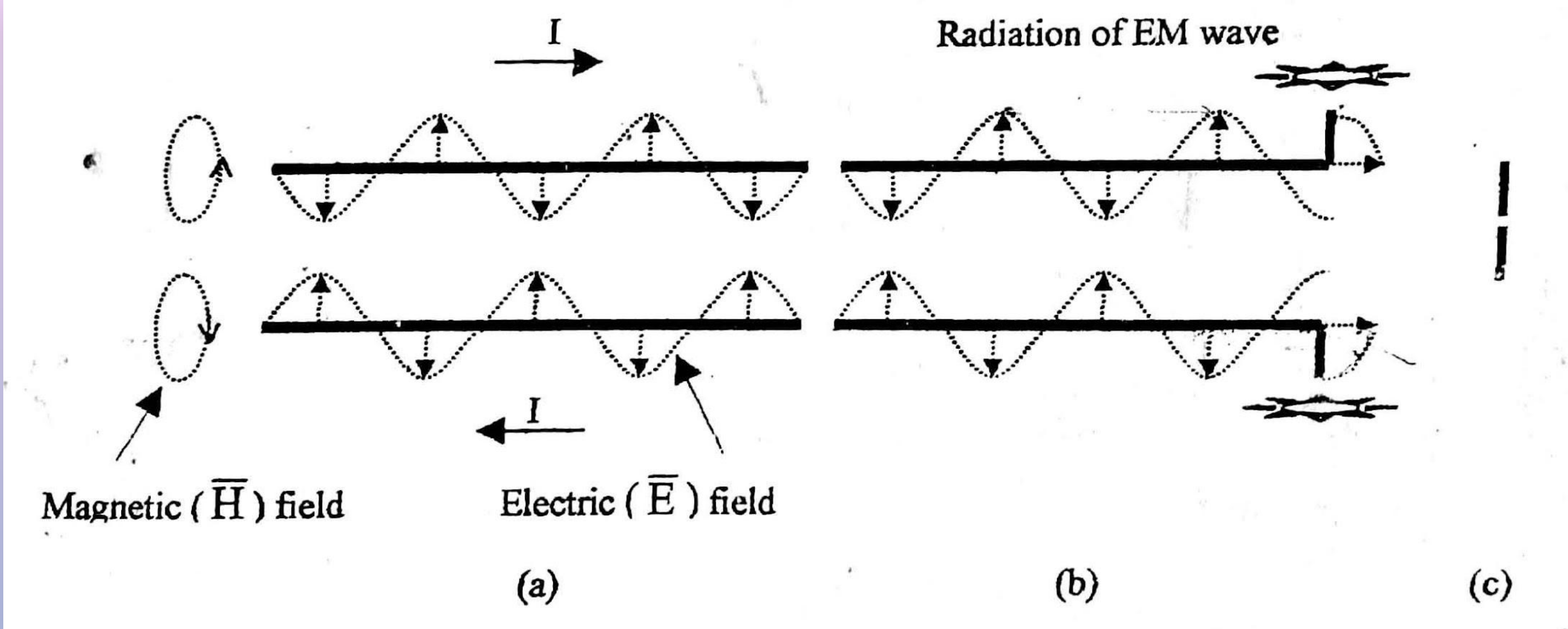


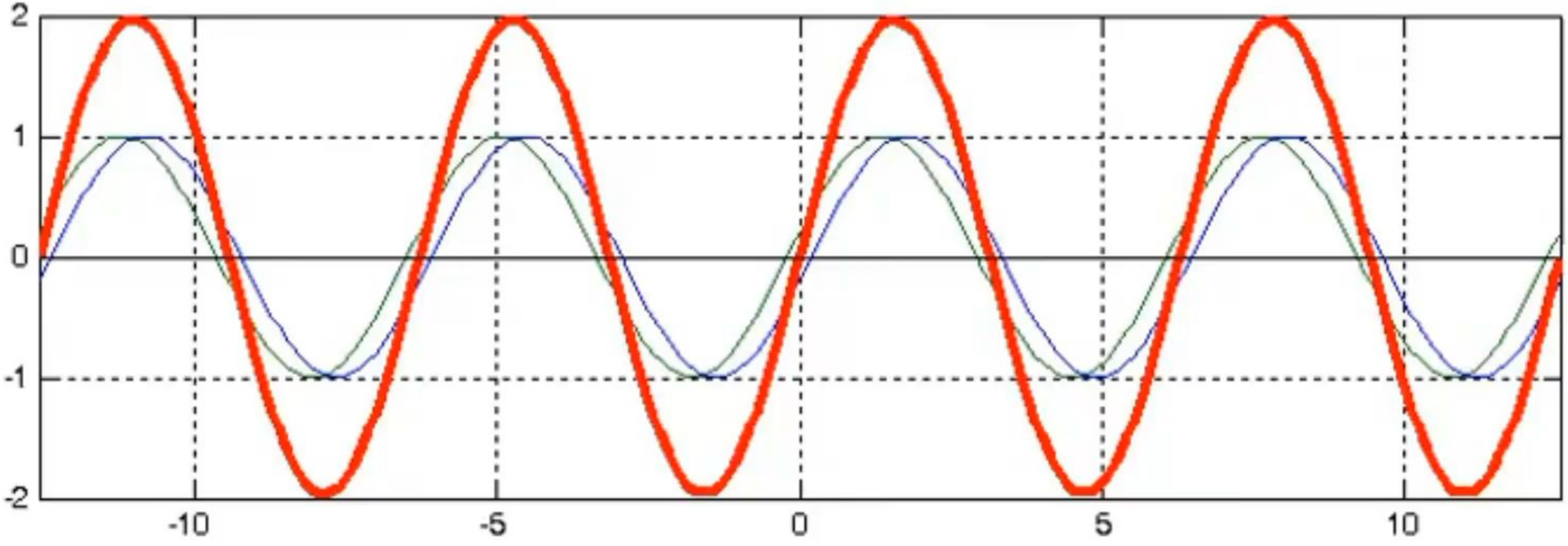
Figure 1.9 (a) The opposite electric and the magnetic fields with no radiation, (b) a standing wave linear dipole antenna with radiation, and (c) a representation of a dipole antenna.

- When the line finally takes the form as shown in Figure 1.9(b), no more cancellation occurs, and the construction radiates the EM waves out into the surrounding medium.
- The portion of the line, which has been bent, is the sanding wave linear antenna, and is popularly known as the dipole antenna.
- In practice such antennas are depicted as shown in Figure 1.9(c).
- Three types of such dipole antennas will be discussed next.

(i) Infinite small dipole
(ii) Short dipole
(iii) Long dipole

Standing wave

Two waves with the same frequency, wavelength and amplitude traveling in opposite directions will interfere and produce a standing wave or stationary wave

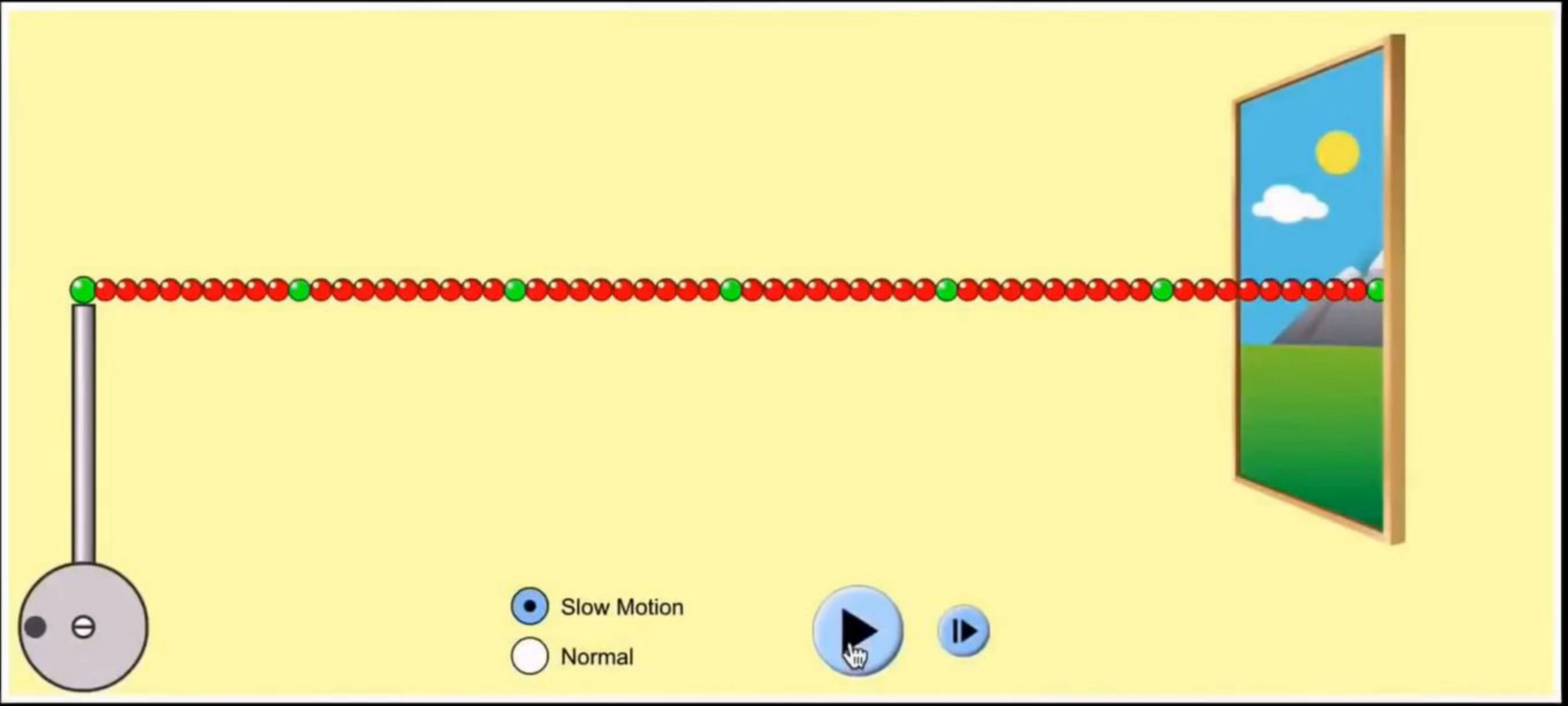


y1=Asin(kx-wt)
wave moving to the right

y2=Asin(kx+wt)
wave moving to the left

y1+y2
Standing wave

Traveling vs. Standing Waves



Infinitesimal dipole

An infinitesimal dipole antenna

(1) is a building block of practical linear antennas

(2) has length≤ λ /50 and

(3) carries the current, which varies as I=I_0Cos(wt -βz), but since the length of the antenna is very small, it is assumed that the current is uniform throughout the length at any time.

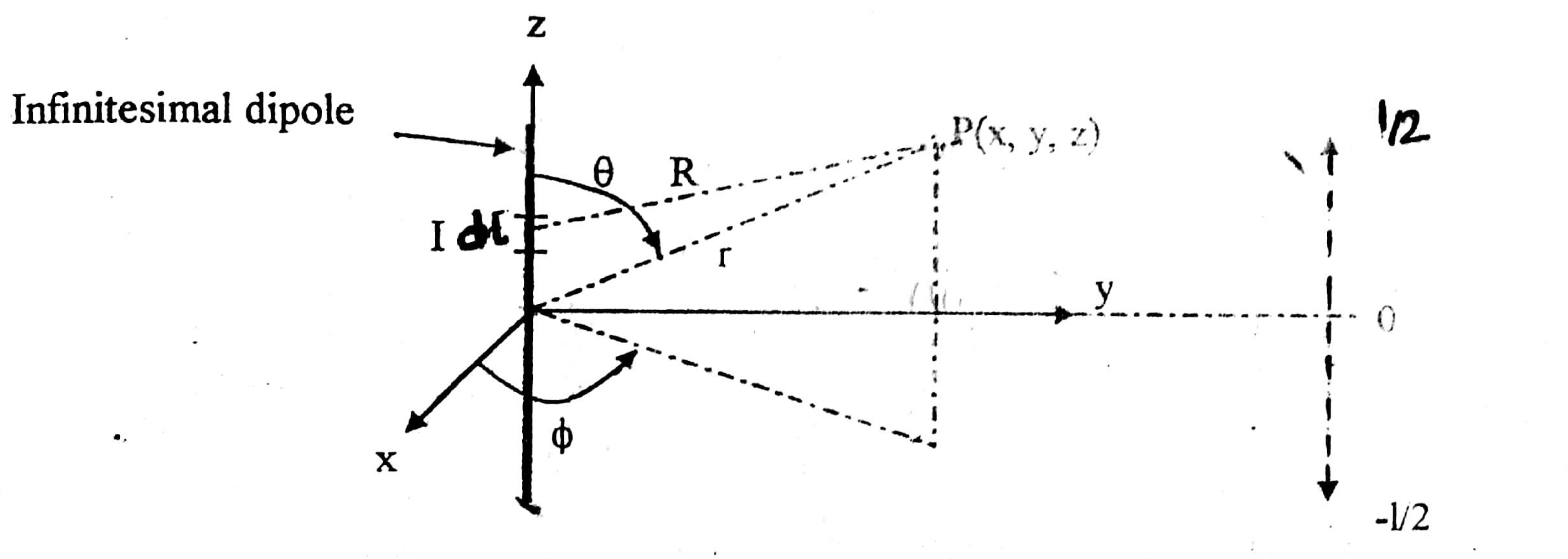


Figure 1.10 An infinitesimal dipole in Cartesian coordinate system.

At a point P(x, y, z),

$$\vec{A}(x,y,z) = \oint \frac{\mu[I]\overrightarrow{dL}}{4\pi R} = \oint \frac{\mu I_0 cos[w\left(t-\frac{R}{V}\right)]\overrightarrow{dL}}{4\pi R} = \oint \frac{\mu I_0 cos[wt-\beta R]\overrightarrow{dL}}{4\pi R}$$

$\vec{A}_s(x,y,z) = \oint \frac{\mu I_0 e^{-j\beta R}\overrightarrow{dL}}{4\pi R} \approx \oint \frac{\mu I_0 e^{-j\beta r}}{4\pi r}\ \hat{z}$, where $\overrightarrow{dL}$=dz$\hat{z}$, and R≈r

The $\vec{A}_s$ is usually expressed in spherical coordinate system to make it more realistic to the real life problems, in which the components take the following forms after performing the coordinate system transformations.

$$A_{rs} = \frac{\mu I_0 l e^{-j\beta r}}{4\pi r} cos\theta$$

$$A_{\theta s} = \frac{\mu I_0 l e^{-j\beta r}}{4\pi r} sin\theta$$

$$A_{\phi s} = 0$$

Using the relation $\vec{H}_s = \frac{1}{\mu}\nabla X\vec{A}$ the magnetic field components can be calculated as follows:

$$H_{\phi s} = j\frac{\beta I_0 l sin\theta}{4\pi r}\left[1 + \frac{1}{j\beta r}\right]e^{-j\beta r}$$

$$H_{rs} = H_{\theta s} = 0$$

And using $\vec{E}_s = \frac{1}{j\omega\varepsilon}\nabla X\vec{H}_s$, the electric field components will be as follows

$$E_{rs} = \eta\frac{I_0 l cos\theta}{2\pi r^2}\left[1 + \frac{1}{j\beta r}\right]e^{-j\beta r}$$

$$E_{\theta s} = j\eta\frac{\beta I_0 l sin\theta}{4\pi r}\left[1 + \frac{1}{j\beta r} + \frac{1}{(j\beta r)^2}\right]e^{-j\beta r}$$

$$E_{\theta s} = j\eta\frac{\beta I_0 l sin\theta}{4\pi r}\left[1 + \frac{1}{j\beta r} - \frac{1}{(\beta r)^2}\right]e^{-j\beta r}$$

$$E_{\phi s} = 0$$

It is found that the electric field and the magnetic field components change with a certain fashion within certain range of distance 'r' measured from the antenna to the point of interest. Therefore, The space surrounding the antenna is divided into three regions accordingly to make the calculation of the field components easier, They are:-

(a) Near or reactive field region ($r \ll \lambda$)

(b) Intermediate or Fresnel field region($r > \lambda$)

(c) Far or Fraunhofer field region($r \gg \lambda$)

(a) Near or Reactive Field Region r≪λ that is, $\frac{1}{Br}$>>1

The region in which the distance of the point of interest r, from the antenna is very small comparing to the operating wavelength is called the near or reactive field region. When r≪λ and $\frac{1}{Br}$>>1 is considered, the above Equations reduces to the following forms.

$$E_{rs} = \eta \frac{I_0 l cos\theta}{2\pi r^2}\left[\frac{1}{j\beta r}\right] e^{-j\beta r} = -j\eta \frac{I_0 l e^{-j\beta r}}{2\pi\beta r^3} cos\theta$$

$$E_{\theta s} = j\eta \frac{\beta I_0 l sin\theta}{4\pi r}\left[-\frac{1}{(\beta r)^2}\right] e^{-j\beta r} = -j\eta \frac{I_0 l e^{-j\beta r}}{4\pi\beta r^3} sin\theta$$

$$E_{\phi s} = 0$$

$$H_{\phi s} = j \frac{\beta I_0 l sin\theta}{4\pi r}\left[\frac{1}{j\beta r}\right] e^{-j\beta r} = \frac{I_0 l sin\theta}{4\pi r^2} sin\theta$$

$$H_{rs} = H_{\theta s} = 0$$

An interesting result will be observed if one looks at P_{av} within this field

$$\overrightarrow{P_{av}} = \frac{1}{2} Re\left[\overrightarrow{E_s}\ X\ \overrightarrow{H_s^*}\right] = \frac{1}{2} Re\left[(E_{rs}\hat{r} + E_{\theta s}\hat{\theta}) X H_{\phi s}^* \hat{\phi}\right] = \frac{1}{2} Re\left[(-E_{rs}H_{\phi s}^*\hat{\theta} + E_{\theta s}H_{\phi s}^*\hat{r})\right] = 0$$

No power is following within the near field region. As a matter of fact the energy changes from electric to magnetic forms and vice versa instead of propagating.

(b) Intermediate, or Fresnel Field Region (r>λ that is, $\frac{1}{\beta r} < 1$)

The region in which the distance of the point of interest r, from the antenna is greater than the operating wavelength is called the intermediate, or Fresnel field region. When r>λ or $\frac{1}{\beta r} < 1$ is considered, the Equations above reduces to the following forms.

$$E_{rs} = \eta \frac{I_0 l e^{-j\beta r}}{2\pi r^2} cos\theta$$

$$E_{\theta s} = j\eta \frac{\beta I_0 l e^{-j\beta r}}{4\pi r} sin\theta$$

$$E_{\phi s} = 0$$

$$H_{\phi s} = j \frac{\beta I_0 l e^{-j\beta r}}{4\pi r} sin\theta$$

$$H_{rs} = H_{\theta s} = 0$$

$$\overrightarrow{P_{av}} = \frac{1}{2} Re\left[\overrightarrow{E_s}\, X\, \overrightarrow{H_s^*}\right] = \frac{\eta}{2} \left(\frac{\beta I_0 l}{4\pi r} sin\theta\right)^2 \hat{r}$$

(c) Far, or Fraunhofer Field Region (r≫λ that is $\frac{1}{\beta r} \ll 1$)

The region in which the distance of the point of interest r, from the antenna is such that r≫λ to $\frac{1}{\beta r} \ll 1$, then it is called the far, or Fraunhofer field region. As seen in the intermediate field, E_{rs} is inversely proportional to r², and $E_{\theta s}$ is inversely proportional to r. Because r is comparable to λ (r>λ) both of the electric filed components were counted. But, for r≫λ, E_{rs} will be very small comparing to $E_{\theta s}$ and E_{rs} is therefore neglected resulting in the following components only.

$$E_{\theta s} = j\eta \frac{\beta I_0 l e^{-j\beta r}}{4\pi r} sin\theta$$

$$E_{rs} = E_{\phi s} = 0$$

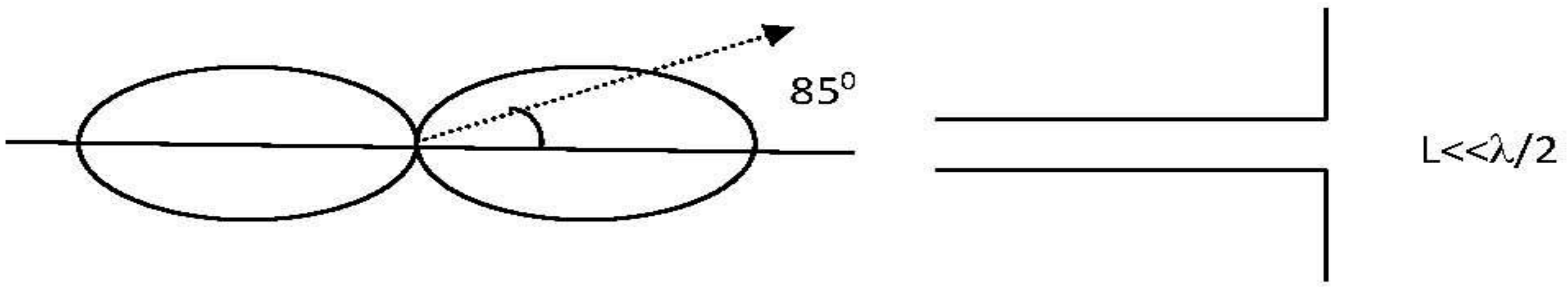
$$H_{\phi s} = j \frac{\beta I_0 l e^{-j\beta r}}{4\pi r} sin\theta$$

$$H_{rs} = H_{\theta s} = 0$$

Characteristics of different types of antenna:-

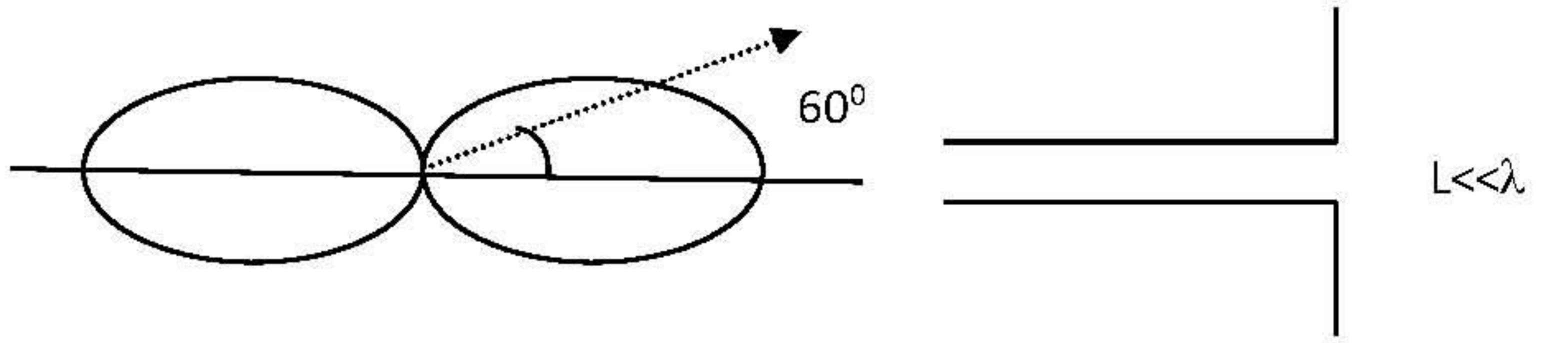
Short dipole:

- $L<<\lambda/2(\lambda/50<L<=\lambda/10)$.
- Self impedance is capacitive.
- SWR(2:1),bandwidth is quite small i.e 1% of design frequency.
- Directivity is 1.8dB
- Radiation pattern resemble to 8 or apple shape.
- Polarisation is vertical/horizontal.
- Beamwidth is 85^{o}x360



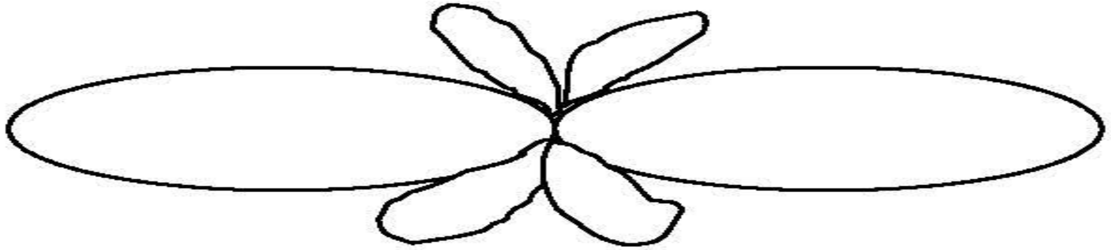
The Double zepp antenna:

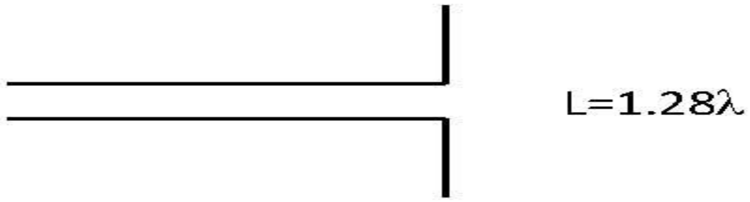
- L=1.λ.
- Self impedance is ~~ 3Ω.
- Radiation pattern resemble to 8 or apple shape.
- Polarisation is vertical/horizontal.
- Beamwidth is 60°x360



The Extended Double zepp antenna:

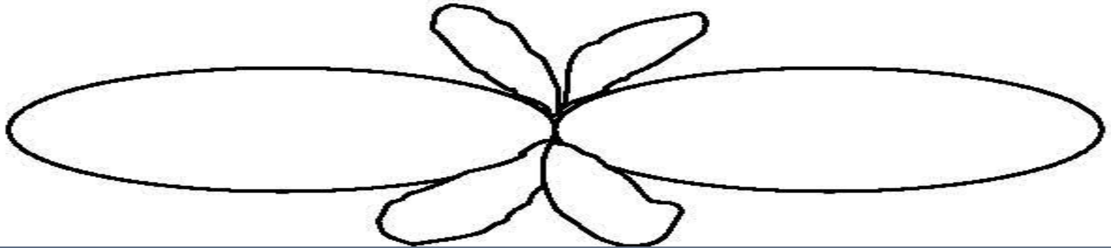
- L=1.28λ.
- Self impedance is ~~ 150-j800Ω.
- Radiation pattern spliting.
- Polarisation is vertical/horizontal.
- Diectivity 5db

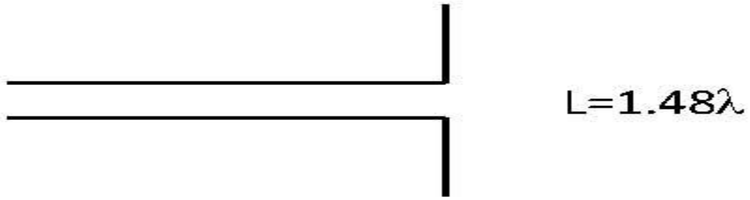




The 3λ/2 Dipole:

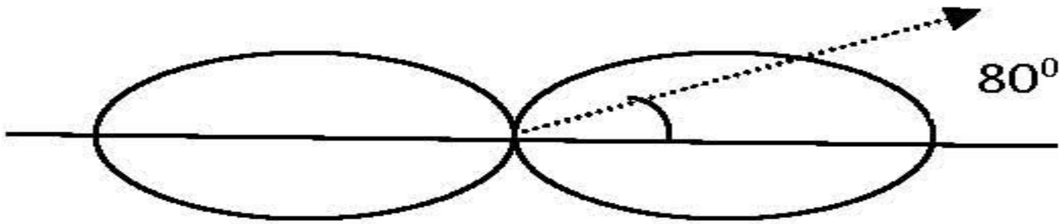
- L=1.48λ.
- Self impedance is ~~ 110Ω.
- Radiation pattern spliting.
- Polarisation is vertical/horizontal.
- Diectivity 3.2db

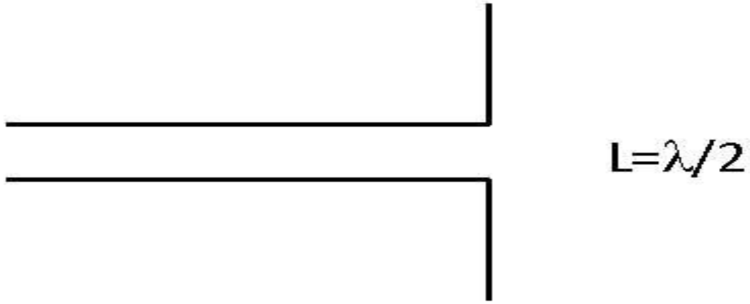




The Half wave (λ/2) Dipole:

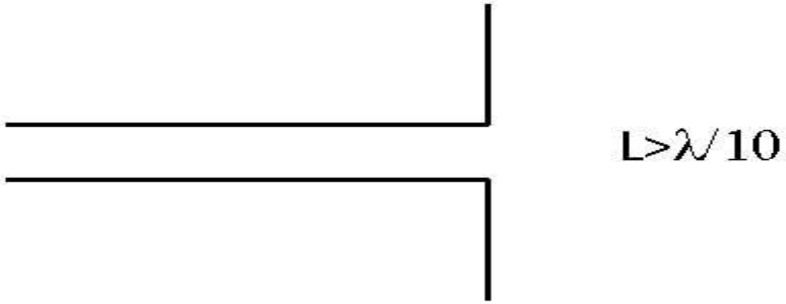
- L ~~λ/2 or 0.48λ.
- Self impedance is 40 – 80 Ω with no reactive components.
- SWR(2:1),bandwidth is 5% of design frequency.
- Directivity is 2.1dB
- Radiation pattern resemble to 8 or apple shape.
- Polarisation is vertical/horizontal.
- Beamwidth is 80°x360





Long Dipole Antenna:

- L >λ/10.
- Self impedance is 150Ω to 3kΩ .
- SWR(2:1),bandwidth is 5% of design frequency.
- Directivity is maximum when L=1.28 λ.
- Radiation pattern resemble is more complex.
- Polarisation is linear.



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