

UEC747: ANTENNA AND WAVE PROPAGATION

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Lecture 3: How Antenna Radiates?

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First considerations

One of the first questions that may be asked concerning antennas would be "how is radiation accomplished?"

RADIATION MECHANISM

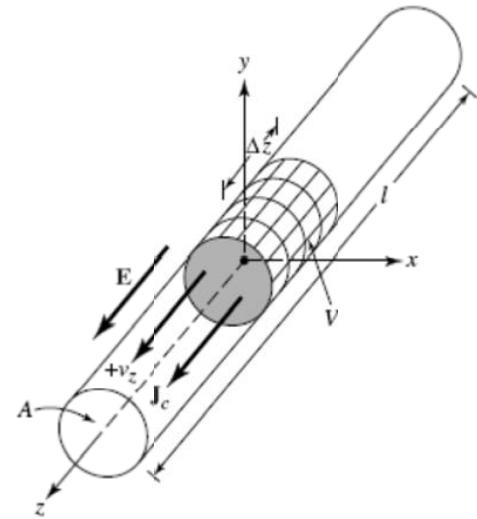


Fig 1.9 Charge uniformly distributed in a circular cross section cylinder wire

• Single Wire

Conducting wires are material whose prominent characteristics are the motion of electric charges and the creation of current flow.

Assume that an electric **volume charge density** q_v (coulombs/m³), is distributed uniformly in a circular wire of **cross-sectional area** A and **volume** V . The total charge Q within volume V is moving **in the z direction with a uniform velocity** V_z .

- The current density J_z (amperes/m²) over the cross section of the wire is

Current density over the cross section of the wire.

$$(1-1a) \quad J_z = q_z v_z \quad \frac{\text{amperes}}{\text{m}^2} = \frac{\text{coulombs/m}^3}{\text{meters/sec}}$$

If the wire is made of an ideal electric conductor.

$$(1-1b) \quad J_s = q_l v_z \quad \frac{\text{amperes}}{\text{m}} = \frac{\text{coulombs/m}^2}{\text{meters/sec}}$$

If the wire is very thin(ideally zero radius)

$$(1-1c) \quad I_z = q_l v_z \quad \text{amperes} = \frac{\text{coulombs/m}}{\text{meters/sec}}$$

If the current is time varying and the wire is of length l

Equation (1-3) is the basic relation between current and charge, and it also serves as the fundamental relation of electromagnetic radiation.

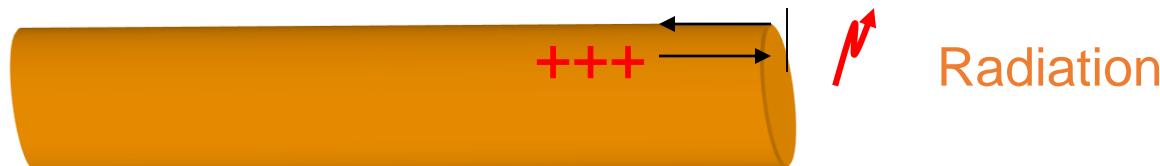
$$(1-3) \quad l \frac{dI_z}{dt} = l q_l \frac{dv_z}{dt} = l q_l a_z$$

Radiation mechanism

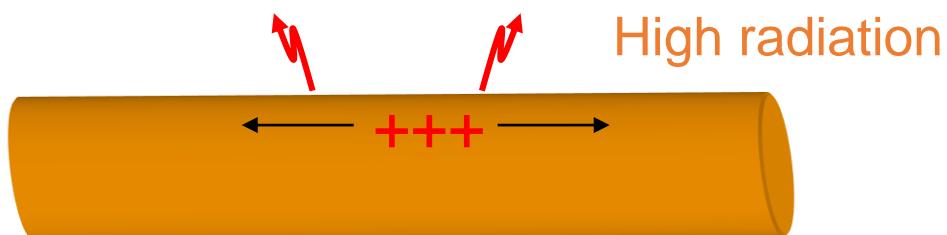
Charges transmitted over a straight metal at a constant speed do not produce radiation.



If the charges encountered a discontinuity (OC, bend ...) their speed changes, then there is radiation.

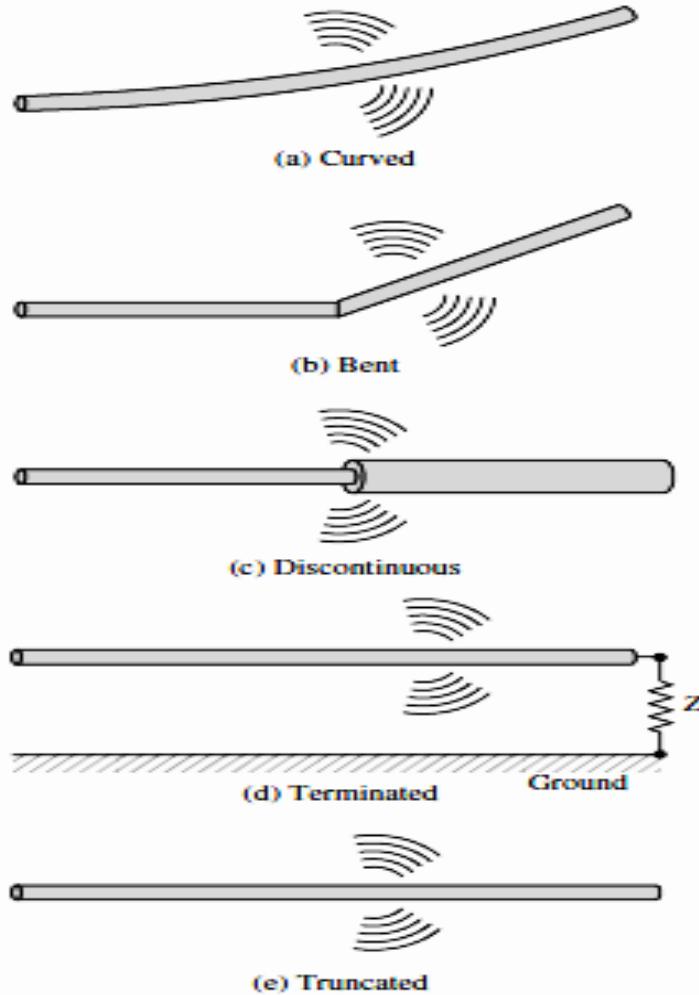


In a resonant structure, charges continuously oscillate, creating a continuous stream of radiation.



$$(1-3) \quad l \frac{dI_z}{dt} = lq_l \frac{dv_z}{dt} = lq_l a_z$$

To create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge. To create charge acceleration the wire must be curved, bent, discontinuous or terminated



Therefore,

1. charge is not moving

->No current, no radiation

2. Charge is moving uniform velocity

->Wire is straight , and infinite , no radiation

->Wire is curved, bent, discontinuous, terminated or truncated it makes radiation.

3. Charge is oscillating

->It radiates even if wire is straight.

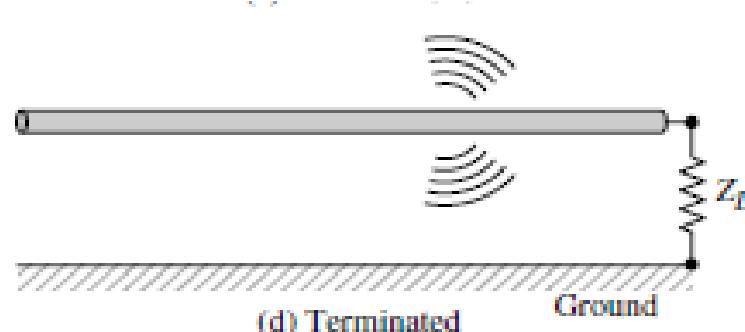
The internal forces receive energy from the charge buildup as its velocity is reduced to zero at the ends of the wire.
Charge acceleration is due to an exciting electric field and deceleration is due to impedance discontinuities or smooth curves of the wire.

Figure 1.24 Wire configurations for radiation.

A qualitative understanding of the radiation mechanism

For example, considering a pulse source attached to an open-ended conducting wire, which may be connected to the ground through a discrete load at its open end, as shown in Figure

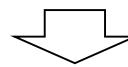
Figure 1.24 (d).



1. The acceleration of the charges is accomplished by the external source



2. Accelerated charges produces the associated field radiated.



3. Charges are accelerated in the source-end of the wire and decelerated during reflection from its end.



4. The deceleration of the charges at the end of the wire is accomplished by the internal forces due to the buildup of charge concentration at the ends of the wire.

<Maxwell Equations>

$$\nabla \times \vec{E} = -\frac{d\vec{B}}{dt}$$

$$\nabla \times \vec{H} = \vec{J} + \frac{d\vec{D}}{dt}$$

$$\nabla \cdot \vec{D} = q$$

$$\nabla \cdot \vec{B} = 0$$

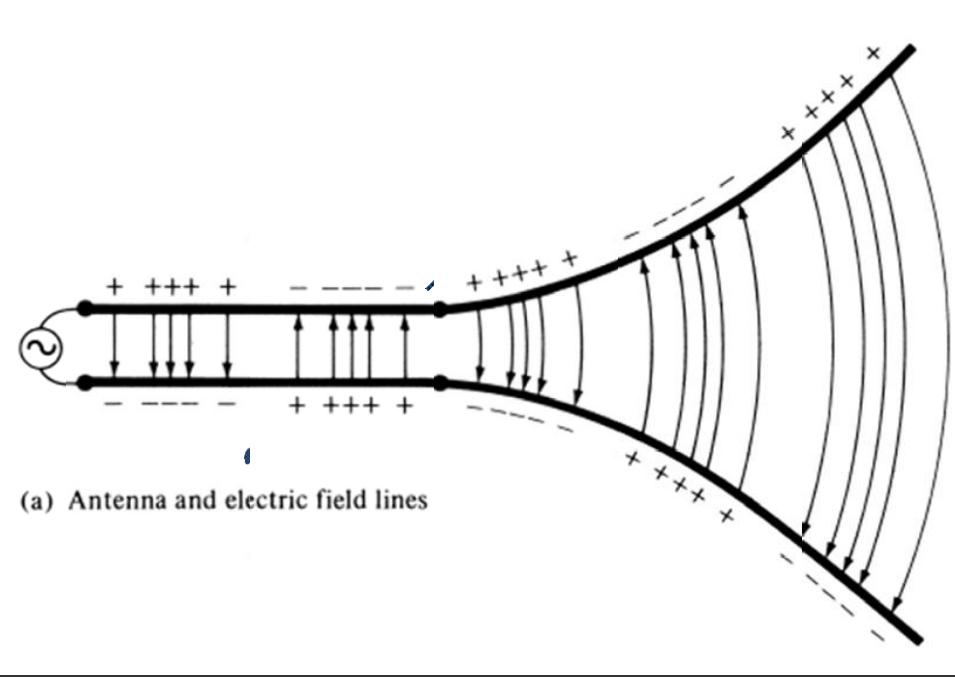
Charge is viewed as a more fundamental quantity, especially for transient fields.

1.3.2 Two-Wires

Consider a voltage source connected to a two-conductor transmission line which is connected to an antenna and creates an electric field between the conductors.

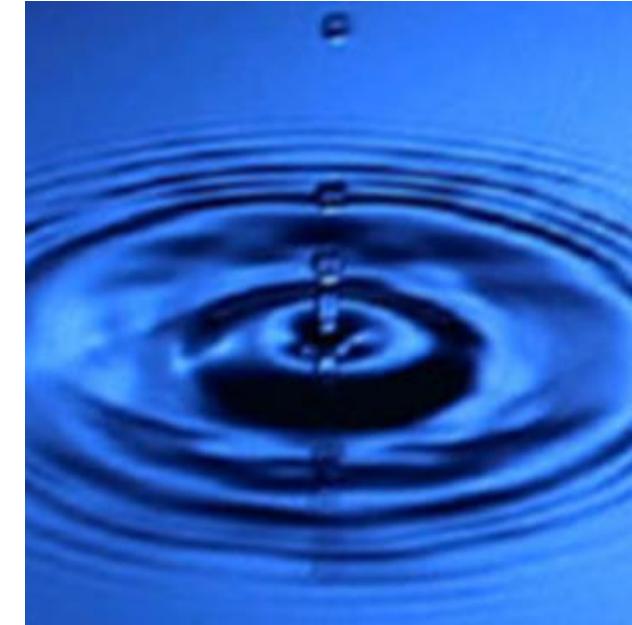
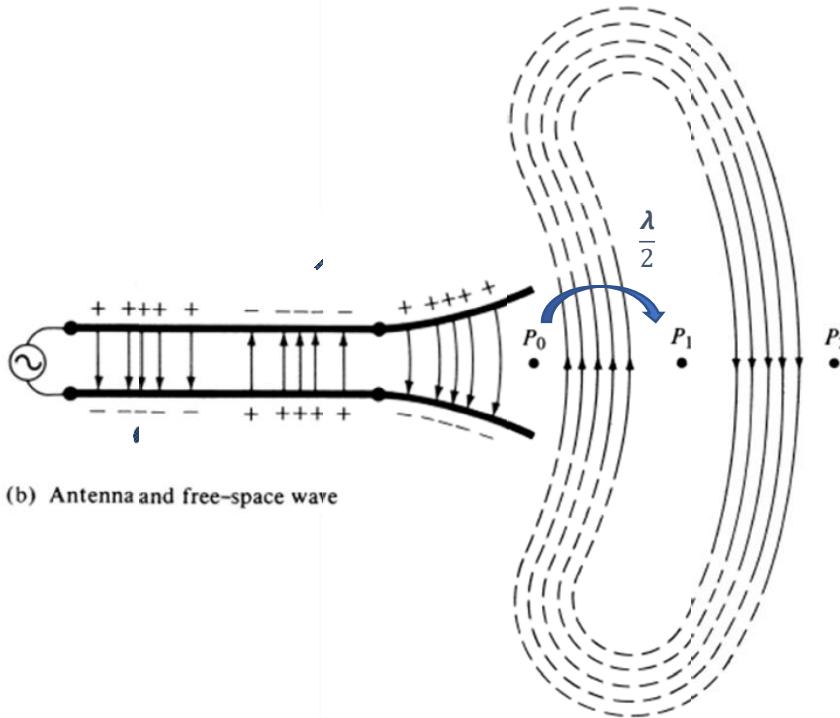
- The electric force lets the free electrons to be displaced. The movement of the charges creates a current that in turn creates magnetic field.

● If the voltage source is sinusoidal, the electric field between the conductors is sinusoidal with the same period. The relative magnitude and direction of the electric field the intensity indicated by density of the fines of force with the arrows.



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

- The electromagnetic waves enter the antenna and have associated with them electric charges and corresponding currents.
- Remove part of the antenna structure; as shown in Figure 1.11(b), free-space waves can be formed by "connecting" the open ends of the electric lines.



The free-space waves move outwardly with the speed of light.

Electric charges are required to excite the fields but are not needed to sustain them and may exist in their absence. This is in direct analogy with water waves.

<Conclusion>

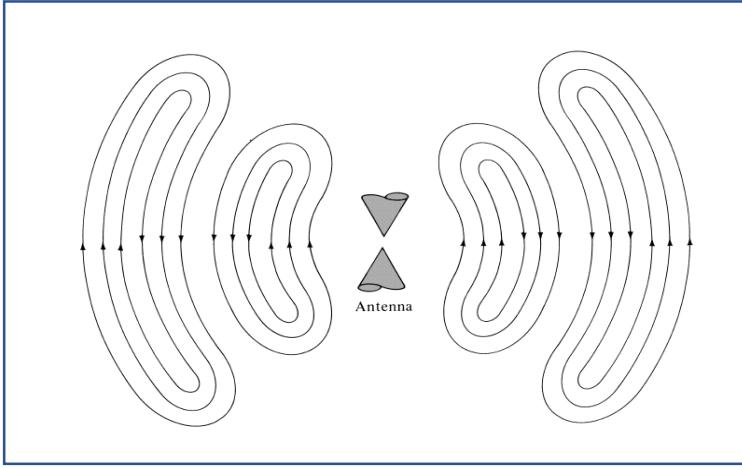


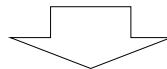
Figure 1.25 Electric field lines of free-space wave for biconical antenna.



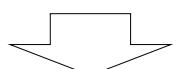
Figure 1.26 Water waves.

When the electromagnetic waves are **within the transmission line and antenna**, their existence is associated with the presence of the **charges inside the conductors**.

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 and may exist in their absence**.

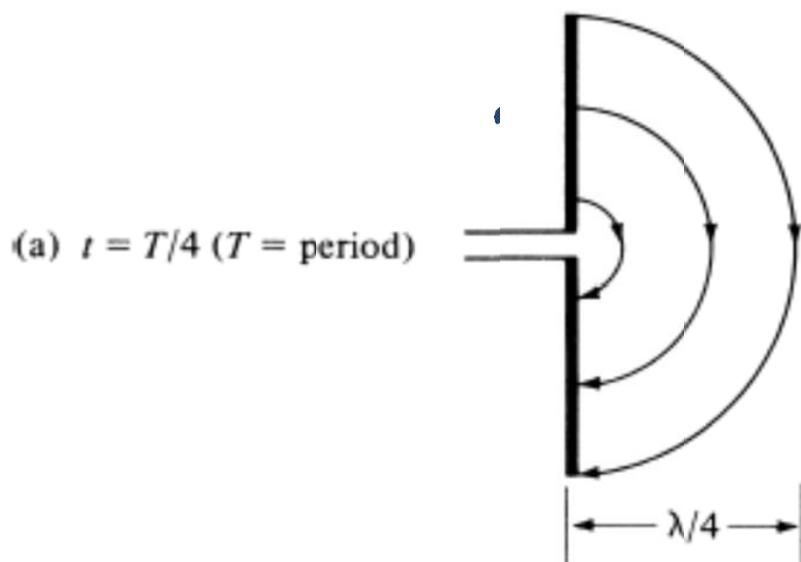


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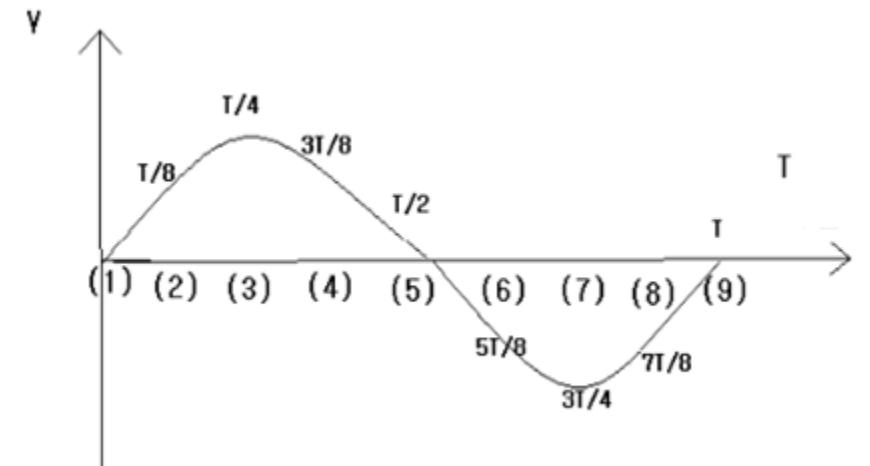
1.3.3 Dipole

Now we explain the mechanism by which the electric lines of force are detached from the antenna to form the free-space waves.

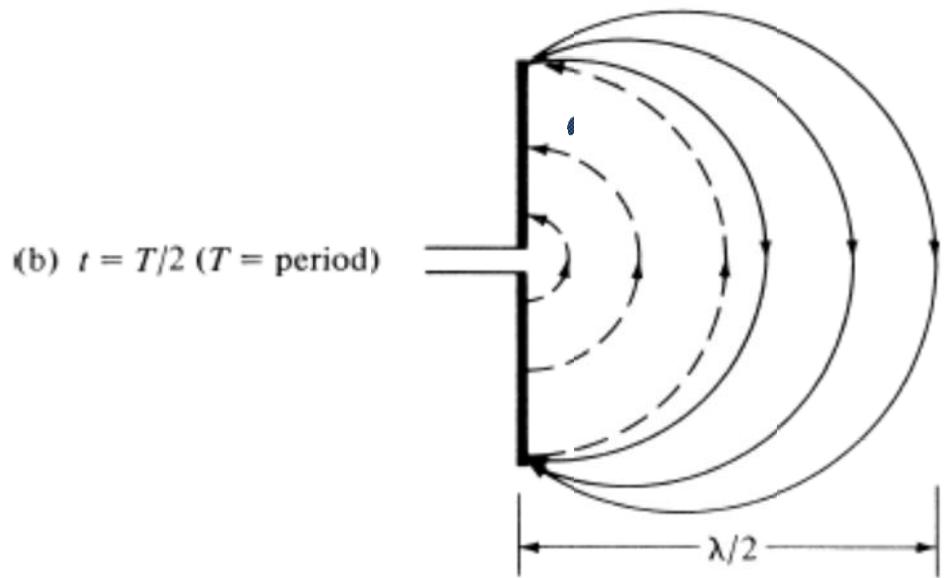
- Fig. displays the lines of force created between the arms of a small center-fed dipole in the first quarter of the period during which time the charge has reached its maximum value and the lines have traveled outwardly a radial distance $\lambda/4$



(a) $t = T/4$ (T = period)



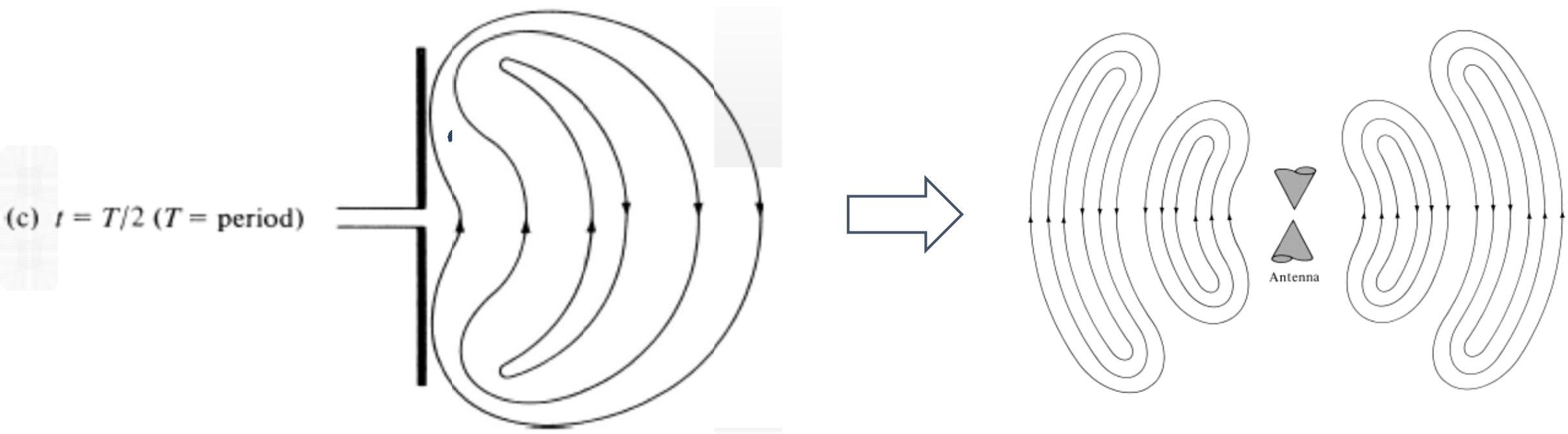
- During the next quarter of the period, the original three fines travel an additional $\lambda/4$ and the charge density on the conductors begins to diminish. This can be thought of as being accomplished by introducing opposite charges which at the end of the first half of the period have neutralized the charges on the conductors. The lines of force created by the opposite charges are three and travel a distance $\lambda/4$ during the second quarter of the first half, and they are shown dashed in Figure .



- If the disturbance persists, new waves are continuously created which lag in their travel behind the others.

- The end result is that there are three lines of force pointed upward in the first $\lambda/4$ distance and the same number of lines directed downward in the second $\lambda/4$.

- 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).



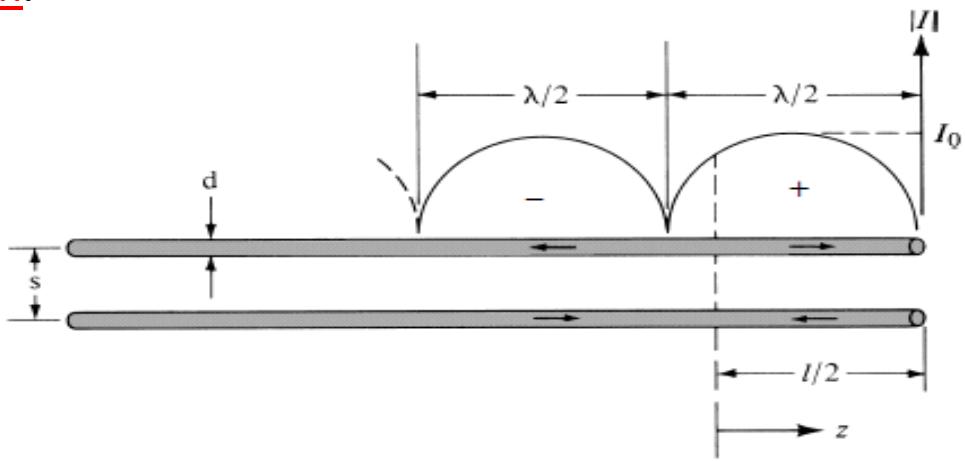
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- In the remaining second half of the period, the same procedure is followed but in the opposite direction. After that, the process is repeated and continues indefinitely and electric field patterns, similar to those of Figure, are formed

4.CURRENT DISTRIBUTION ON A THIN WIRE ANTENNA

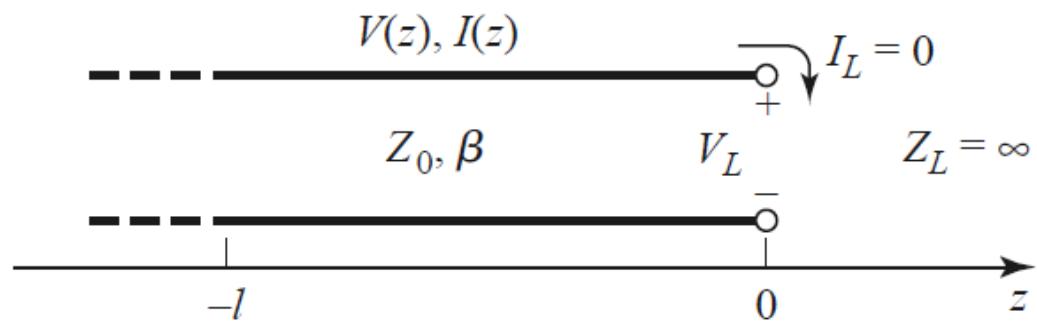
- Consider of a lossless two-wire transmission line, as shown in Figure. The movement of the charges creates a traveling wave current, of magnitude $\lambda/2$, along each of the wires.

- When the current arrives at the end of each of the wires, it undergoes a complete reflection. Forms a pure standing wave pattern.

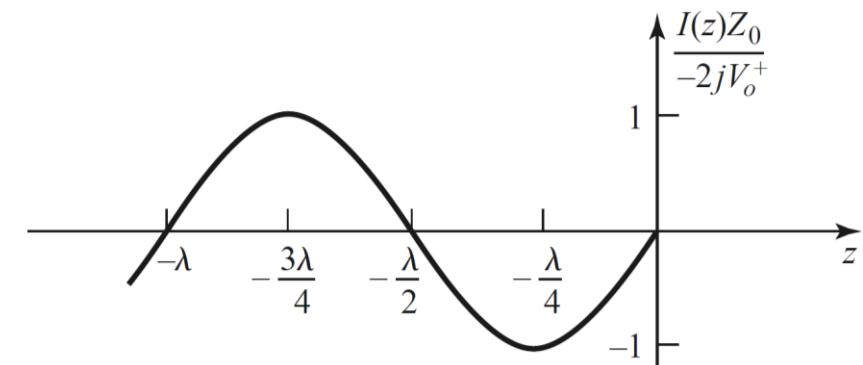


(a) Two-wire transmission line

- The current in a half cycle of one wire is of the same magnitude but 180° out-of-phase from that in the corresponding half-cycle of the other wire.
- the current of each wire are essentially cancelled by those of the other.



A transmission line terminated in an open circuit.



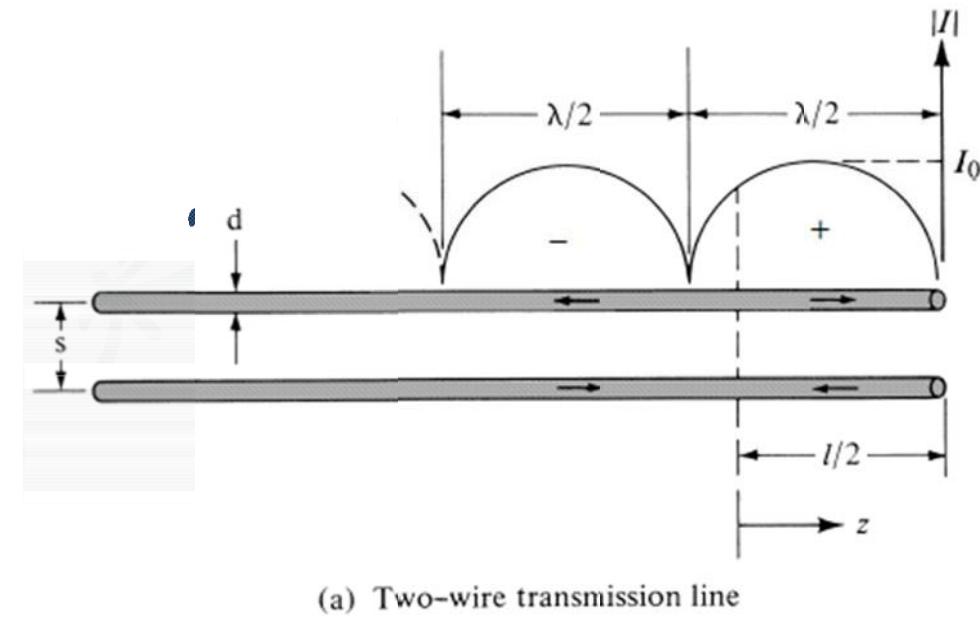
Current variation along an open circuited-transmission line.

$$I(z) = \frac{V_o^+}{Z_0} (e^{-j\beta z} - e^{j\beta z}) = \frac{-2jV_o^+}{Z_0} \sin \beta z$$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = 1$$

4. CURRENT DISTRIBUTION ON A THIN WIRE ANTENNA

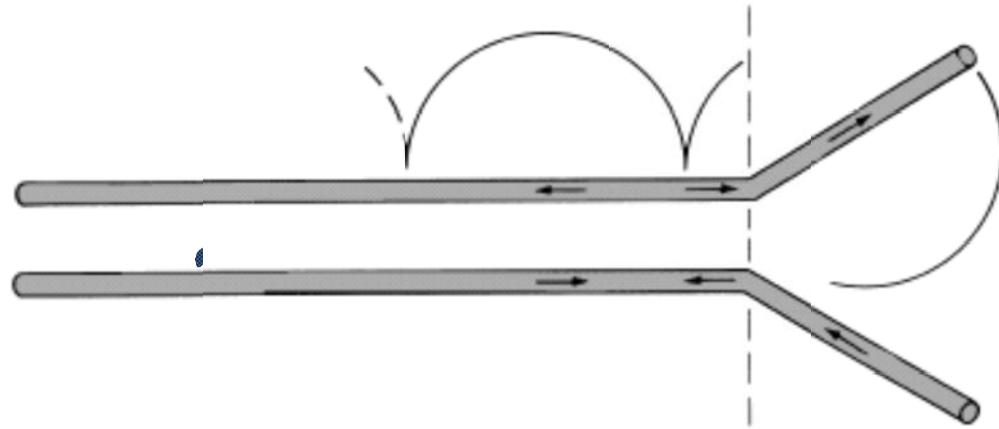
- The current in each wire undergoes a 180° phase reversal between adjoining half cycles indicated by the reversal of the arrow direction. Radiation from each wire individually occurs because of the time-varying nature of the current and the termination of the wire.
- For the two-wire balanced (symmetrical) transmission line, the current in a half-cycle of one wire is of the same magnitude but 180° out-of-phase.
- If in addition the spacing between the two wires is very small ($s \ll \lambda$), the fields radiated by the current of each wire are essentially cancelled.



● As the section of the transmission line between $0 \leq z \leq \lambda/2$

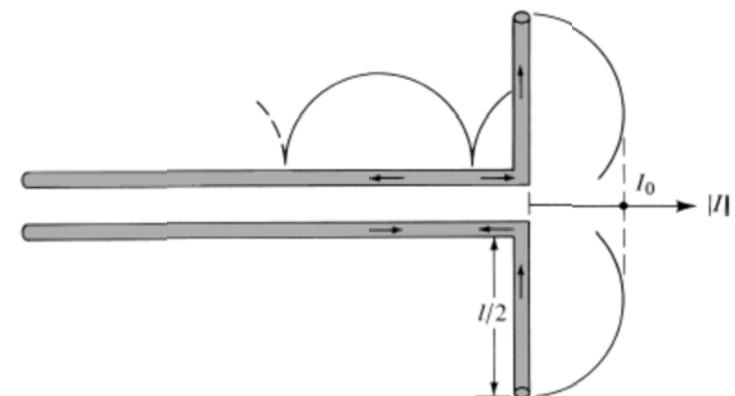
begins to flare, it can be assumed that the current

distribution is essentially unaltered. Because the two wires of the flared section are not close to each other, the fields radiated by one do not necessarily cancel those of the other. Therefore there is a net radiation by the transmission line system.



(b) Flared transmission line

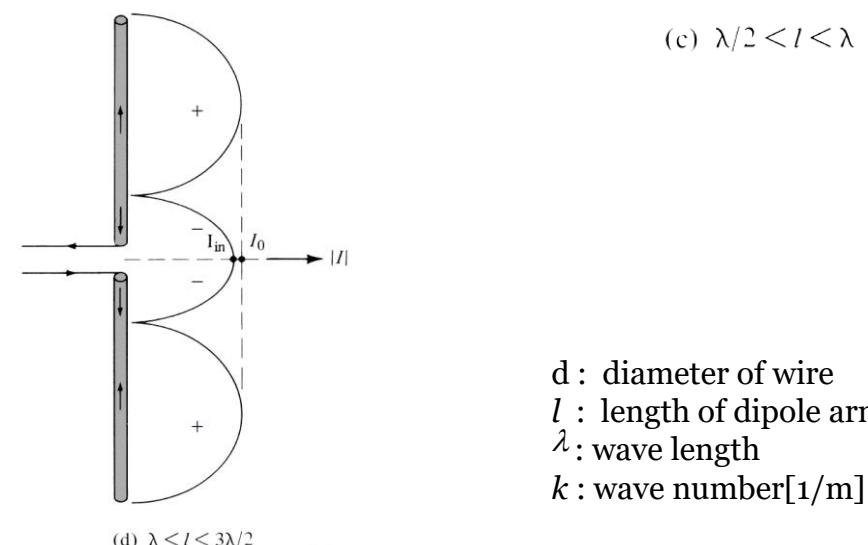
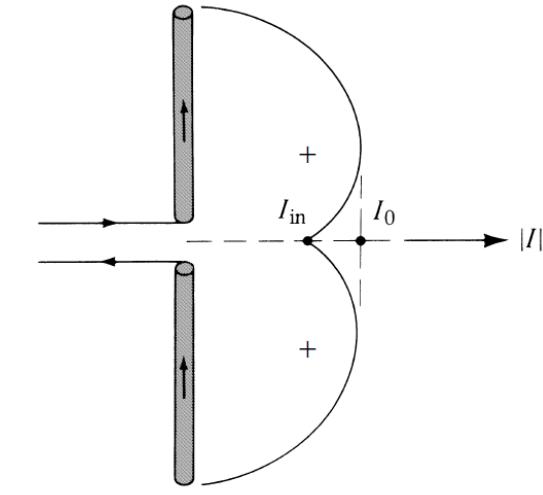
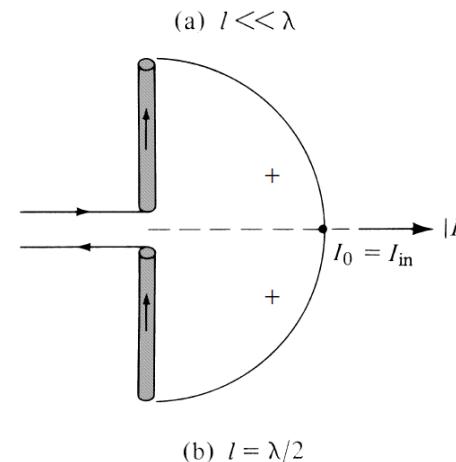
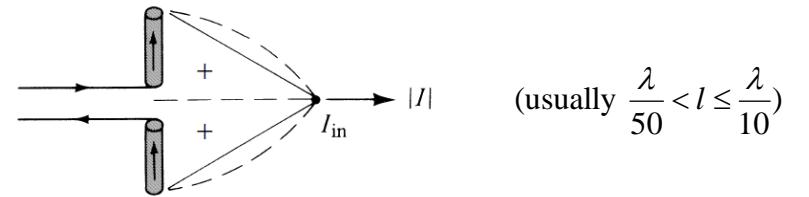
● Ultimately the flared section of the transmission line takes the form of dipole. If $l < \lambda$, the phase of the current standing wave pattern in each arm is the same. In addition, spatially it is oriented in the same direction. Thus the fields radiated by the two arms of the dipole will reinforce each other.



(c) Linear dipole

If the diameter of each wire is very small ($d \ll \lambda$), the ideal standing wave pattern of the current along the arms is sinusoidal with a null at the end. However, its overall form depends on the length of each arm.

- The fields radiated by some parts of the dipole will not reinforce those of the others.
- As a result, significant interference and cancelling effects will be noted in the formation of the total radiation pattern.



d : diameter of wire
 l : length of dipole arm
 λ : wave length
 k : wave number [1/m]

Figure 1.16 Current distributions on linear dipoles

Current Distribution On A Thin Wire Antenna

The current variations, as a function of time, on a $\lambda/2$ center-fed dipole are shown in Figure 1.17 for $0 \leq t \leq T/2$ where T is the period. These variations can be obtained by multiplying the current standing wave pattern of Figure 1.16(b) by $\cos(\omega t)$.

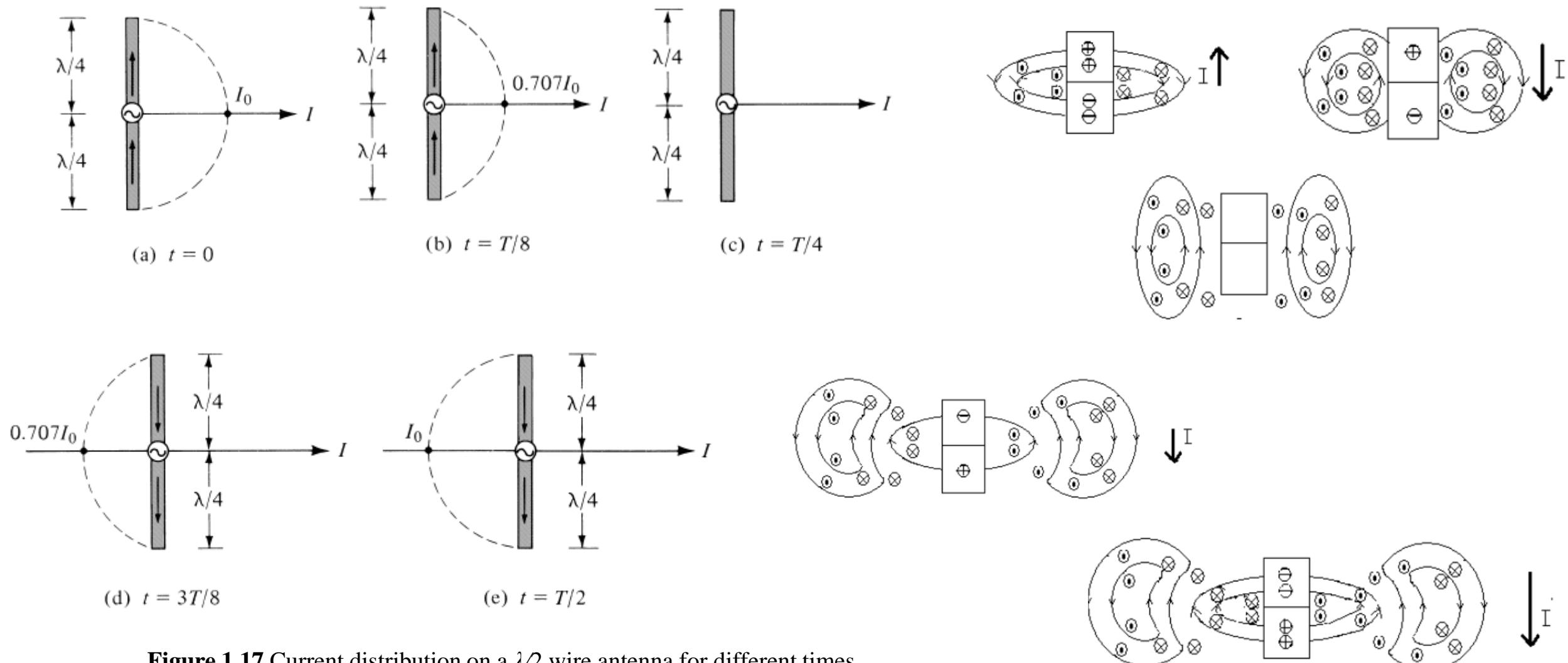


Figure 1.17 Current distribution on a $\lambda/2$ wire antenna for different times

THANKS