# 3.1 Wire Antennas - long wire, loop antenna - helical antenna

## Module:3 HF, UHF and Microwave Antennas

**Course: BECE305L – Antenna and Microwave Engineering**

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CHENNAI

# Module:3 HF, UHF and Microwave Antennas
# 7 hours

Wire Antennas - long wire, loop antenna - helical antenna. Yagi-Uda antenna, Frequency independent antennas - spiral and log periodic antenna - Aperture antennas – Horn antenna, Parabolic reflector antenna - Microstrip antenna

- Source of the contents: Constantine A. Balanis - Antenna theory analysis and design (2016)

# 1. Introduction

1. constant for infinitesimal dipoles ($l \leq \lambda/50$)
2. linear (triangular) for short dipoles ($\lambda/50 < l \leq \lambda/10$)
3. sinusoidal for long dipoles ($l > \lambda/10$)

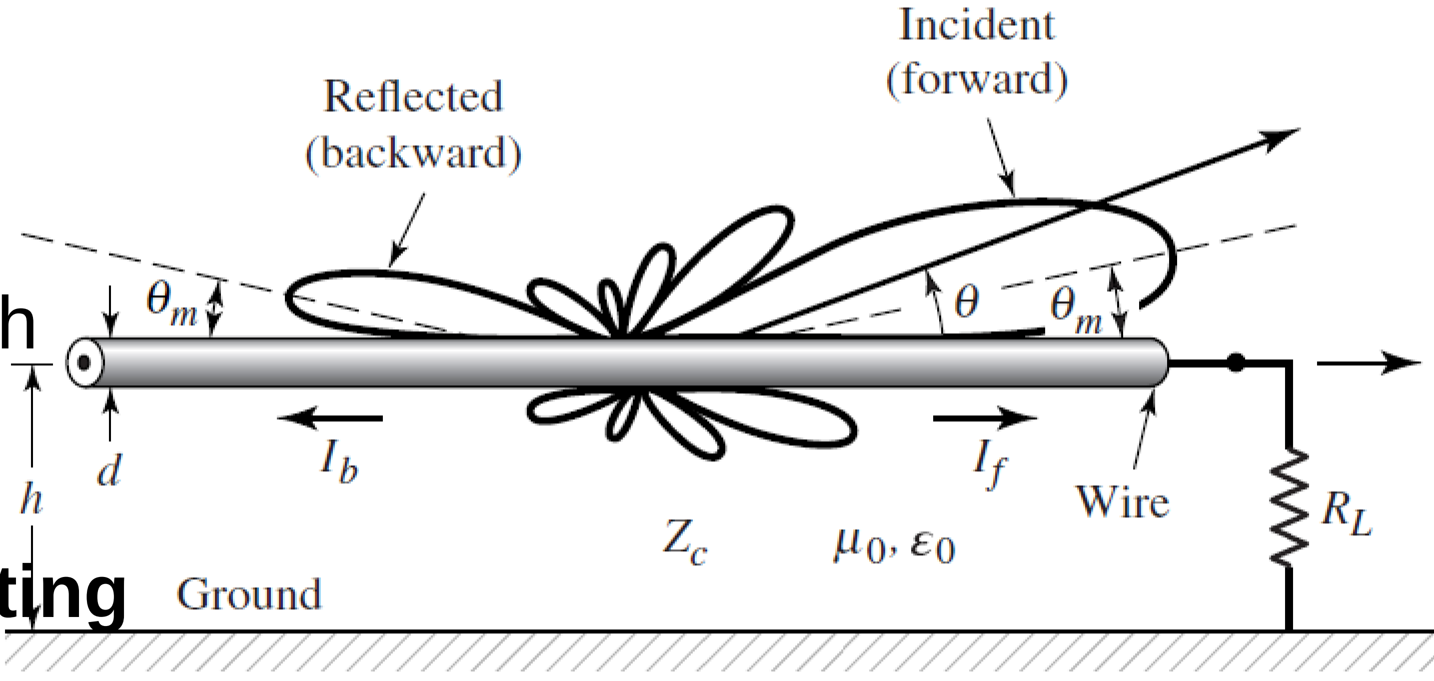
In all cases the phase distribution was assumed to be constant.

- The sinusoidal current distribution of long open-ended linear antennas is a standing wave constructed by **two waves of equal amplitude** and **180◦ phase difference at the open end traveling in opposite directions along its length**.
- The **voltage distribution has also a standing wave pattern** except that it has **maxima (loops) at the end of the line** instead of nulls (nodes) as the current.

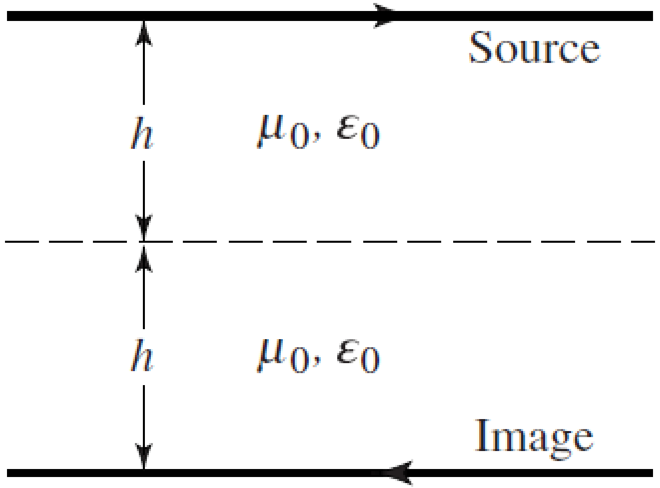
# 1. Introduction

- In each pattern, **the maxima and minima repeat every integral number of half wavelengths**.
  There is also a **λ/4 spacing between a null and a maximum** in each of the wave patterns.
- The current and voltage distributions on open-ended wire antennas are similar to the *standing wave patterns on open-ended transmission lines*.
- Linear antennas that exhibit current and voltage standing wave patterns formed by reflections from the open end of the wire are referred to as ***standing wave* or *resonant* antennas**.

- Antennas can be designed which have traveling wave (uniform) patterns in current and voltage.
- **Achieved by properly terminating the antenna wire so that the reflections are minimized** if not completely eliminated.
- example of such an antenna is <u>a long wire that runs  horizontal to the earth</u>
- ***Beverage or wave antenna***: input terminals consist of the ground and one end of the wire

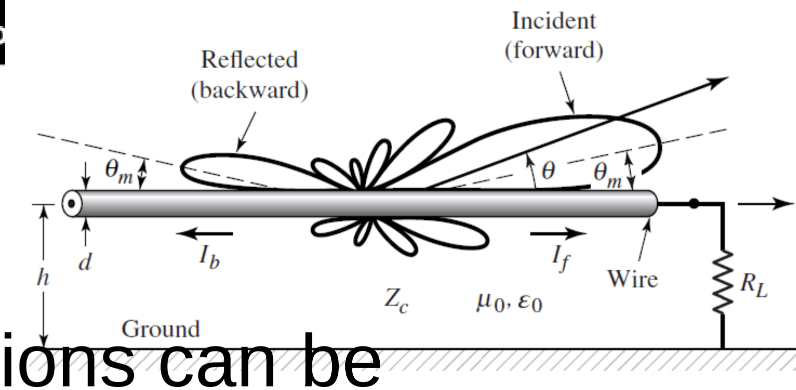



(a) Long wire above ground and radiation pattern



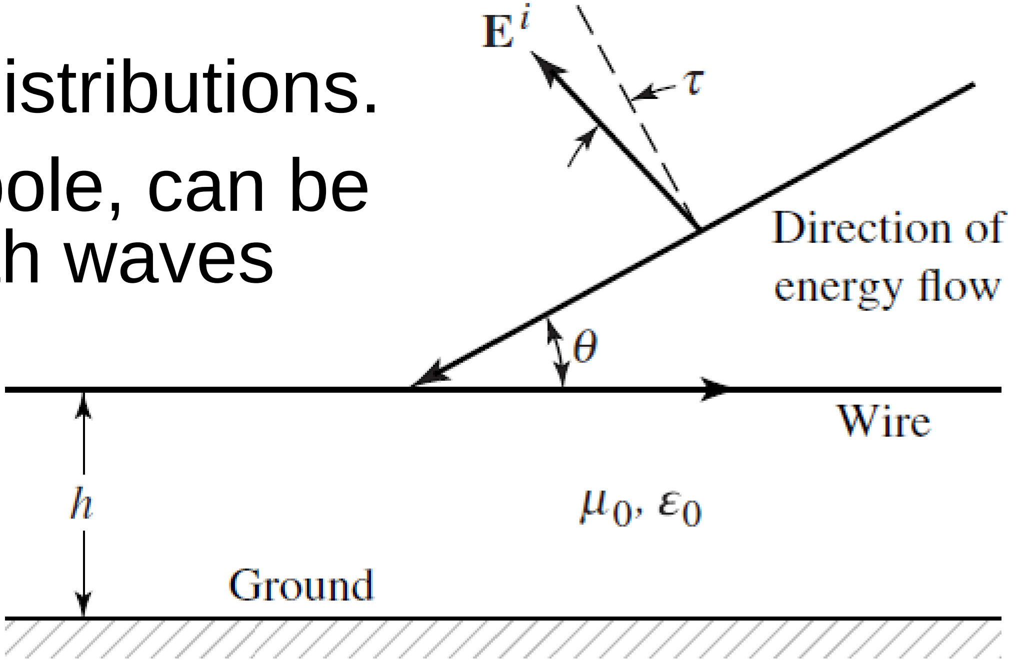

(b) Equivalent: Source and image

# 1. Introduction




(a) Long wire above ground and radiation pattern

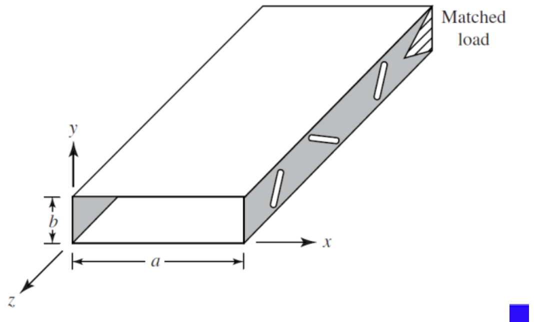
- all antennas whose current and voltage distributions can be represented by one or more traveling waves, usually in the same direction, are referred to as ***traveling wave*** or ***nonresonant antennas***.
- A progressive phase pattern is usually associated with the current and voltage distributions.
- Standing wave antennas, such as the dipole, can be |analyzed as traveling wave antennas with waves propagating in opposite directions (forward and backward) and represented by traveling wave currents *If* and *Ib*



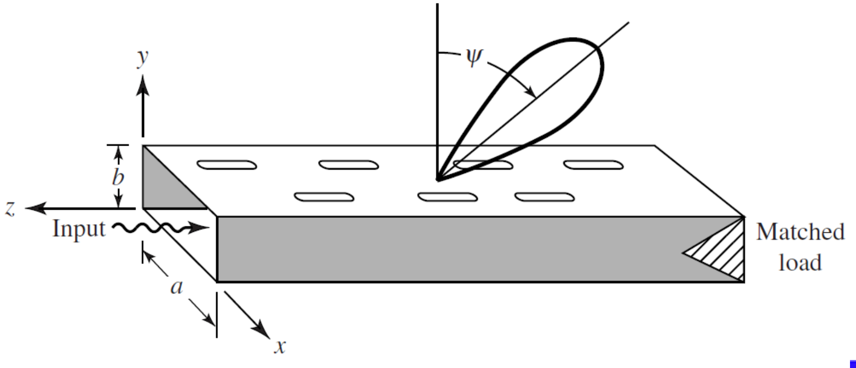

(c) Wave tilt

# 1. Introduction

- Other examples of traveling wave antennas: **dielectric rod (polyrod), helix, and various surface wave antennas**.
- **arrays of closely spaced radiators** (usually less than λ/2 apart) can also be analyzed as traveling wave antennas by approximating their current or field distribution by a continuous traveling wave.
- **Yagi-Uda**, **log-periodic**, and **slots in a waveguide** are some examples of discrete element traveling wave antennas.
- a traveling wave antenna is usually one that is associated with radiation from a continuous source.



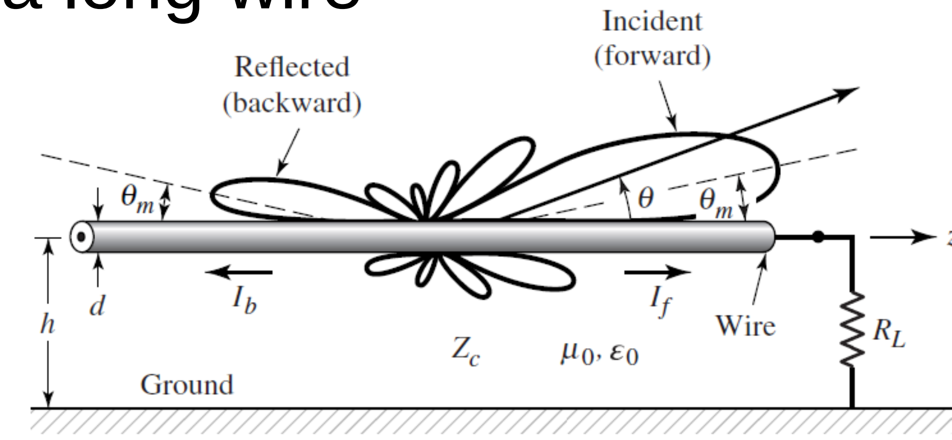
(b) Sidewall—inclined



(a) Upper wall—longitudinal

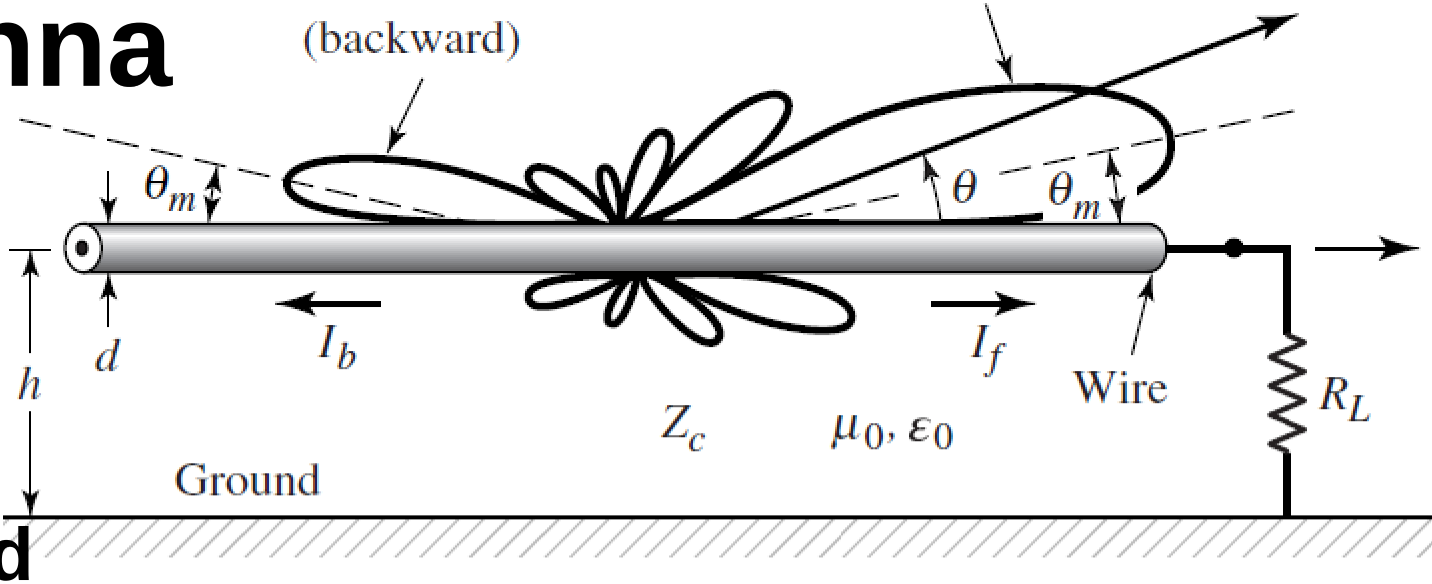
# 2. Long wire antenna

- A traveling wave may be classified as a **slow wave** if its phase velocity $v_p (v_p = \omega / k, \omega$ = wave angular frequency, *k* = wave phase constant) is equal or smaller than the velocity of light *c* in free-space ($v_p / c \leq 1$).
  A **fast wave** is one whose phase velocity is greater than the speed of light ($v_p / c > 1$).
- Example of slow wave traveling antenna is a long wire
- "if it is a straight conductor with a length from one to many wavelengths



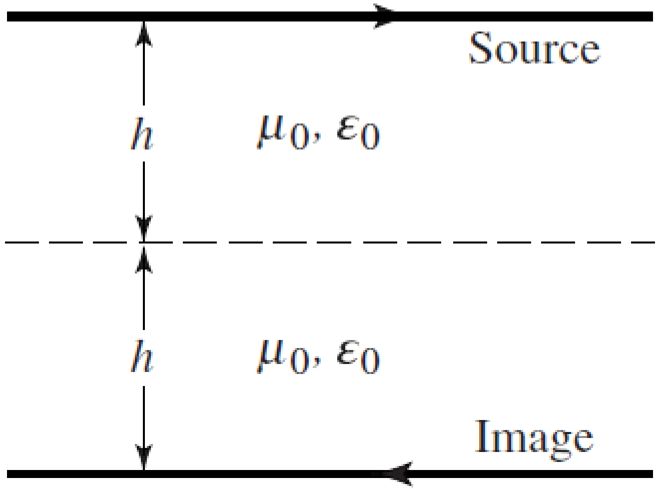

(a) Long wire above ground and radiation pattern

# 2. Long wire antenna




(a) Long wire above ground and radiation pattern

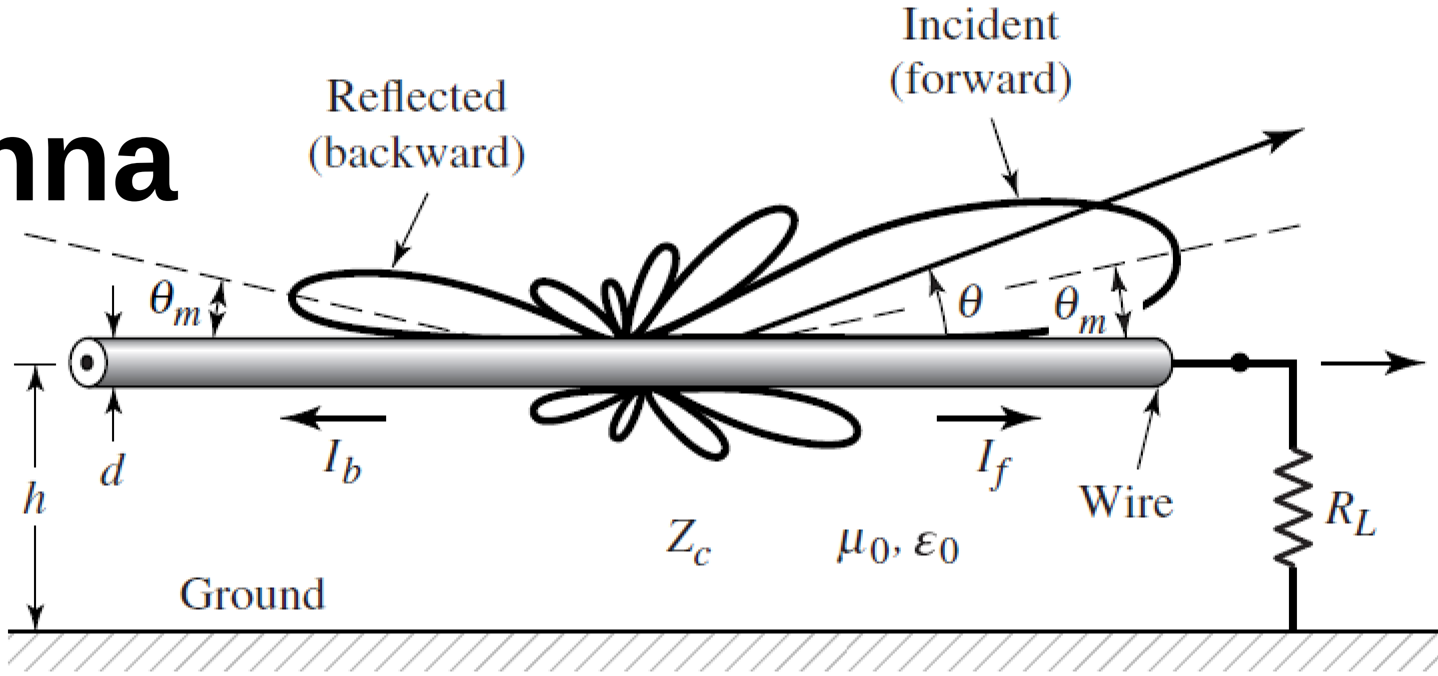
- in the presence of the ground, long wire antenna can be analyzed approximately using the equivalent where **an image is introduced to take into account the presence of the ground**.
- **The magnitude and phase of the image are determined using the reflection coefficient for horizontal polarizatio**



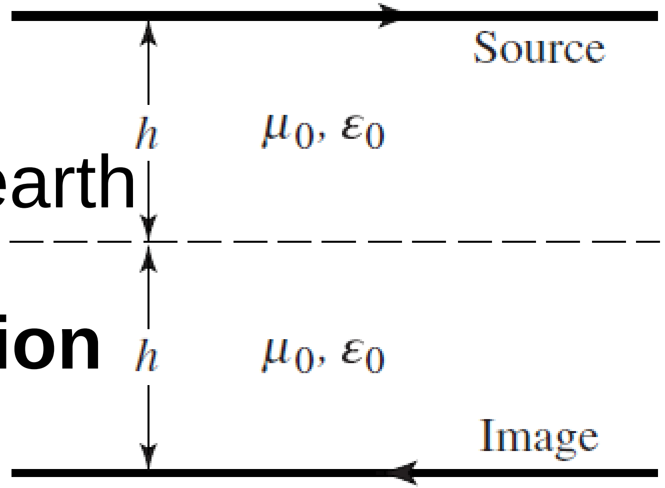

(b) Equivalent: Source and image

# 2. Long wire antenna

- The **height *h* of the antenna above the ground** must be chosen so that the **reflected wave** (or wave from the image), which includes the phase due to reflection **is in phase with the direct wave at the angles of desired maximum radiation**
- for typical electrical constitutive parameters of the earth especially **for observation angles near grazing**, the **reflection coefficient for horizontal polarization is approximately −1.**




(a) Long wire above ground and radiation pattern



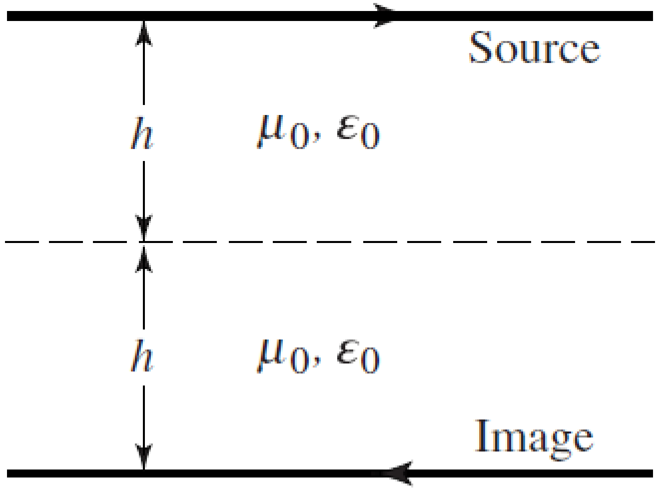

(b) Equivalent: Source and image

# 2. Long wire antenna

- Therefore **the total field radiated by the wire in the presence of the ground** can be found by **multiplying the field radiated by the wire in free space** by the **array factor of a two-element array**
- objective : to find the field radiated by the long wire in free space
- As the wave travels along the wire from the source toward the load, it **continuously leaks energy**. This can be **represented by an attenuation coefficient**.
- current distribution of the forward traveling wave

$$\mathbf{I}_f = \hat{\mathbf{a}}_z I_z(z')e^{-\gamma(z')z'} = \hat{\mathbf{a}}_z I_0 e^{-[\alpha(z')+jk_z(z')]z'}$$

- propagation coefficient $\gamma(z') = \alpha(z') + jk_z(z')$



(b) Equivalent: Source and image

$$\mathbf{I}_f = \hat{\mathbf{a}}_z I_z(z')e^{-\gamma(z')z'} = \hat{\mathbf{a}}_z I_0 e^{-[\alpha(z')+jk_z(z')]z'}$$

$$\gamma(z') = \alpha(z') + jk_z(z')$$

- $k_z(z')$ is the phase constant (radians/meter)
  $\alpha(z')$ is the attenuation constant (nepers/meter): Can also include **ohmic losses of wire**(very small and for simplicity are neglected) and **ground losses**
- radiating medium is air, the loss of energy in a long wire ($l \gg \lambda$) due to leakage is also usually very small, and it can also be neglected.

$$\mathbf{I} = \hat{\mathbf{a}}_z I(z')e^{-jk_z z'} = \hat{\mathbf{a}}_z I_0 e^{-jk_z z'}$$

$$I(z') = I_0$$

# 2. Long wire antenna

$$\mathbf{I} = \hat{\mathbf{a}}_z I(z')e^{-jk_z z'} = \hat{\mathbf{a}}_z I_0 e^{-jk_z z'}$$

- Using finite length dipole concept,

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

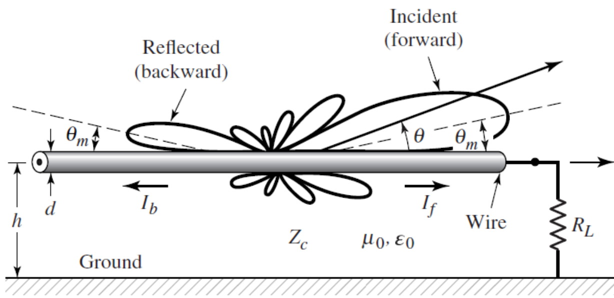
$$E_\theta \simeq j\eta \frac{klI_0 e^{-jkr}}{4\pi r} e^{-j(kl/2)(K-\cos\theta)} \sin\theta \frac{\sin[(kl/2)(\cos\theta - K)]}{(kl/2)(\cos\theta - K)}$$

$$H_\phi \simeq \frac{E_\theta}{\eta}$$

$$K = \frac{k_z}{k} = \frac{\lambda}{\lambda_g}$$

- *K* is used to represent the ratio of the phase constant of the wave along the transmission line $(k_z)$ to that of free-space (*k*)

$$\lambda_g = \text{wavelength of the wave along the transmission line}$$



(a) Long wire above ground and radiation pattern

# 2. Long wire antenna

- Assuming a perfect electric conductor for the ground the total field for Figure 10.1(a) is obtained by multiplying fields by the array factor $\sin(kh \sin\theta)$.
- Time averaged power density:

$$\mathbf{W}_{av} = \mathbf{W}_{rad} = \hat{\mathbf{a}}_r \eta \frac{|I_0|^2}{8\pi^2 r^2} \frac{\sin^2\theta}{(\cos\theta - 1)^2} \sin^2\left[\frac{kl}{2}(\cos\theta - 1)\right]$$

$$= \hat{\mathbf{a}}_r \eta \frac{|I_0|^2}{8\pi^2 r^2} \cot^2\left(\frac{\theta}{2}\right) \sin^2\left[\frac{kl}{2}(\cos\theta - 1)\right]$$

- power distribution of a wire antenna of length *l* is a multilobe pattern whose number of lobes depends upon its length

# 2. Long wire antenna

$$\mathbf{W}_{\text{av}} = \mathbf{W}_{\text{rad}} = \hat{\mathbf{a}}_r \eta \frac{|I_0|^2}{8\pi^2 r^2} \cot^2\left(\frac{\theta}{2}\right) \sin^2\left[\frac{kl}{2}(\cos\theta - 1)\right]$$

- For large values of l: $$\sin^2\left[\frac{kl}{2}(\cos\theta - 1)\right]_{\theta=\theta_m} = 1$$

$$\frac{kl}{2}(\cos\theta_m - 1) = \pm\left(\frac{2m+1}{2}\right)\pi, \quad m = 0, 1, 2, 3, \ldots$$

- **angles where the peaks occur** are given by

$$\theta_m = \cos^{-1}\left[1 \pm \frac{\lambda}{2l}(2m+1)\right], \quad m = 0, 1, 2, 3, \ldots$$

**maximum of the major lobe** occurs is given by $m = 0$ (or $2m + 1 = 1$).

- For large $l$: The angle of the maximum of the major lobe approaches zero degrees and the structure becomes a near-end-fire array.

# 2. Long wire antennas

- **the nulls of the pattern can be foun** $\sin^2\left[\frac{kl}{2}(\cos\theta - 1)\right]_{\theta=\theta_n} = 0$

$$\frac{kl}{2}(\cos\theta_n - 1) = \pm n\pi, \quad n = 1, 2, 3, 4, \ldots$$

- Angles where null occur: $$\theta_n = \cos^{-1}\left(1 \pm n\frac{\lambda}{l}\right), \quad n = 1, 2, 3, 4, \ldots$$

# 2. Long wire antenna

$$\mathbf{W}_{\text{av}} = \mathbf{W}_{\text{rad}} = \hat{\mathbf{a}}_r \eta \frac{|I_0|^2}{8\pi^2 r^2} \cot^2\left(\frac{\theta}{2}\right) \sin^2\left[\frac{kl}{2}(\cos\theta - 1)\right]$$

- total radiated power can be found by integrating power density over a closed sphere of radius *r*

$$P_{\text{rad}} = \oiint_S \mathbf{W}_{\text{rad}} \cdot ds = \frac{\eta}{4\pi}|I_0|^2 \left[1.415 + \ln\left(\frac{kl}{\pi}\right) - C_i(2kl) + \frac{\sin(2kl)}{2kl}\right]$$

- *Ci*(*x*) is the cosine integral

$$C_i(x) = -\int_x^\infty \frac{\cos y}{y}\, dy = \int_\infty^x \frac{\cos y}{y}\, dy$$

- The radiation resistance

$$R_r = \frac{2P_{\text{rad}}}{|I_0|^2} = \frac{\eta}{2\pi}\left[1.415 + \ln\left(\frac{kl}{\pi}\right) - C_i(2kl) + \frac{\sin(2kl)}{2kl}\right]$$

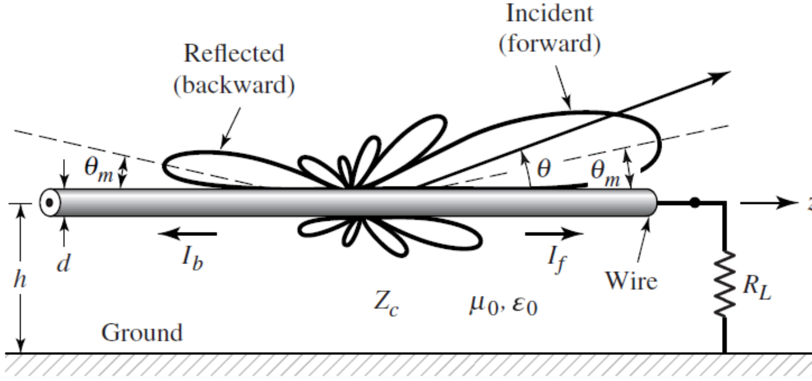
# 2. Long wire antenna

$$\mathbf{W}_{av} = \mathbf{W}_{rad} = \hat{\mathbf{a}}_r \eta \frac{|I_0|^2}{8\pi^2 r^2} \cot^2\left(\frac{\theta}{2}\right) \sin^2\left[\frac{kl}{2}(\cos\theta - 1)\right]$$

$$P_{rad} = \oiint_S \mathbf{W}_{rad} \cdot d\mathbf{s} = \frac{\eta}{4\pi}|I_0|^2 \left[1.415 + \ln\left(\frac{kl}{\pi}\right) - C_i(2kl) + \frac{\sin(2kl)}{2kl}\right.$$

- Directivity:

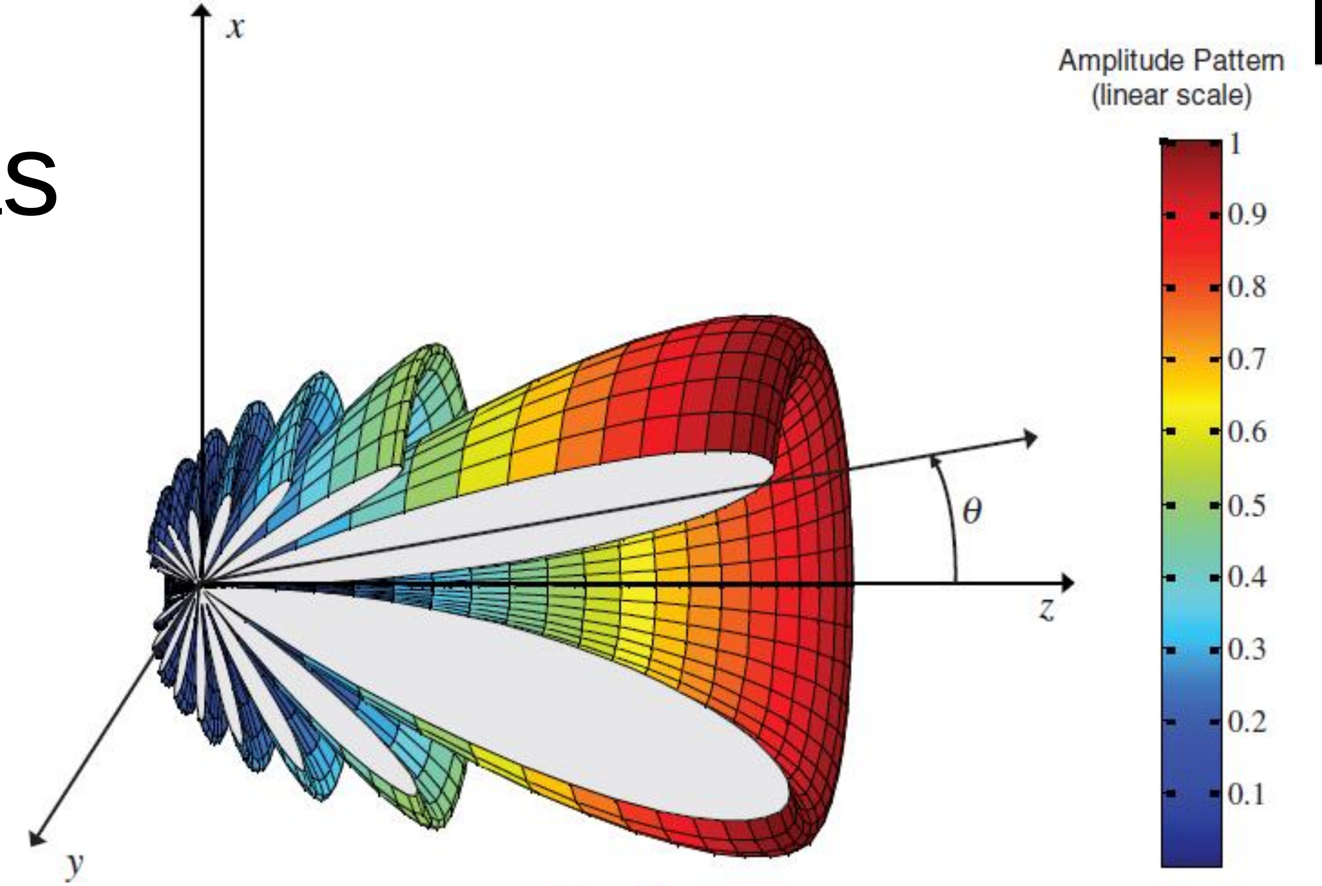
$$D_0 = \frac{4\pi U_{max}}{P_{rad}} = \frac{2\cot^2\left[\frac{1}{2}\cos^{-1}\left(1 - \frac{0.371\lambda}{l}\right)\right]}{1.415 + \ln\left(\frac{2l}{\lambda}\right) - C_i(2kl) + \frac{\sin(2kl)}{2kl}}$$




(a) Long wire above ground and radiation pattern

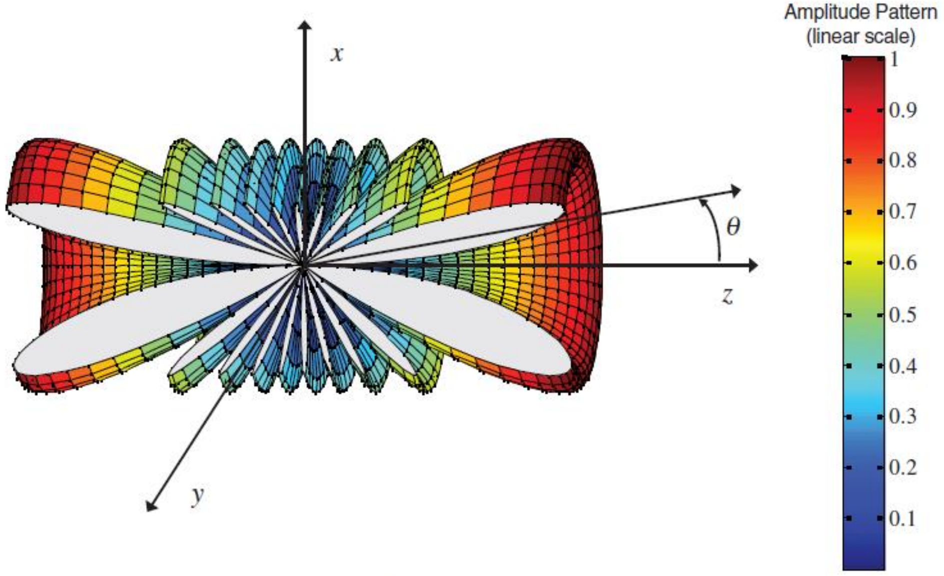
# 2. Long wire antennas

- three-dimensional pattern of a **traveling wire antenna** with length $l$ = 5λ --------->

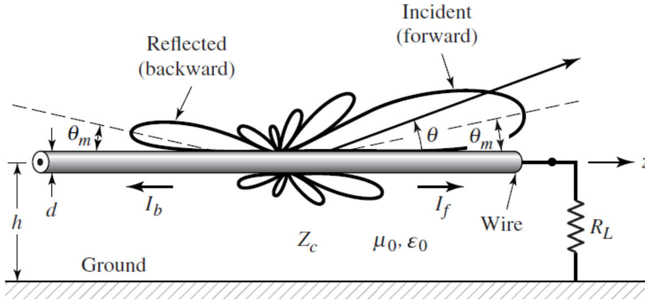



(a) Traveling wave

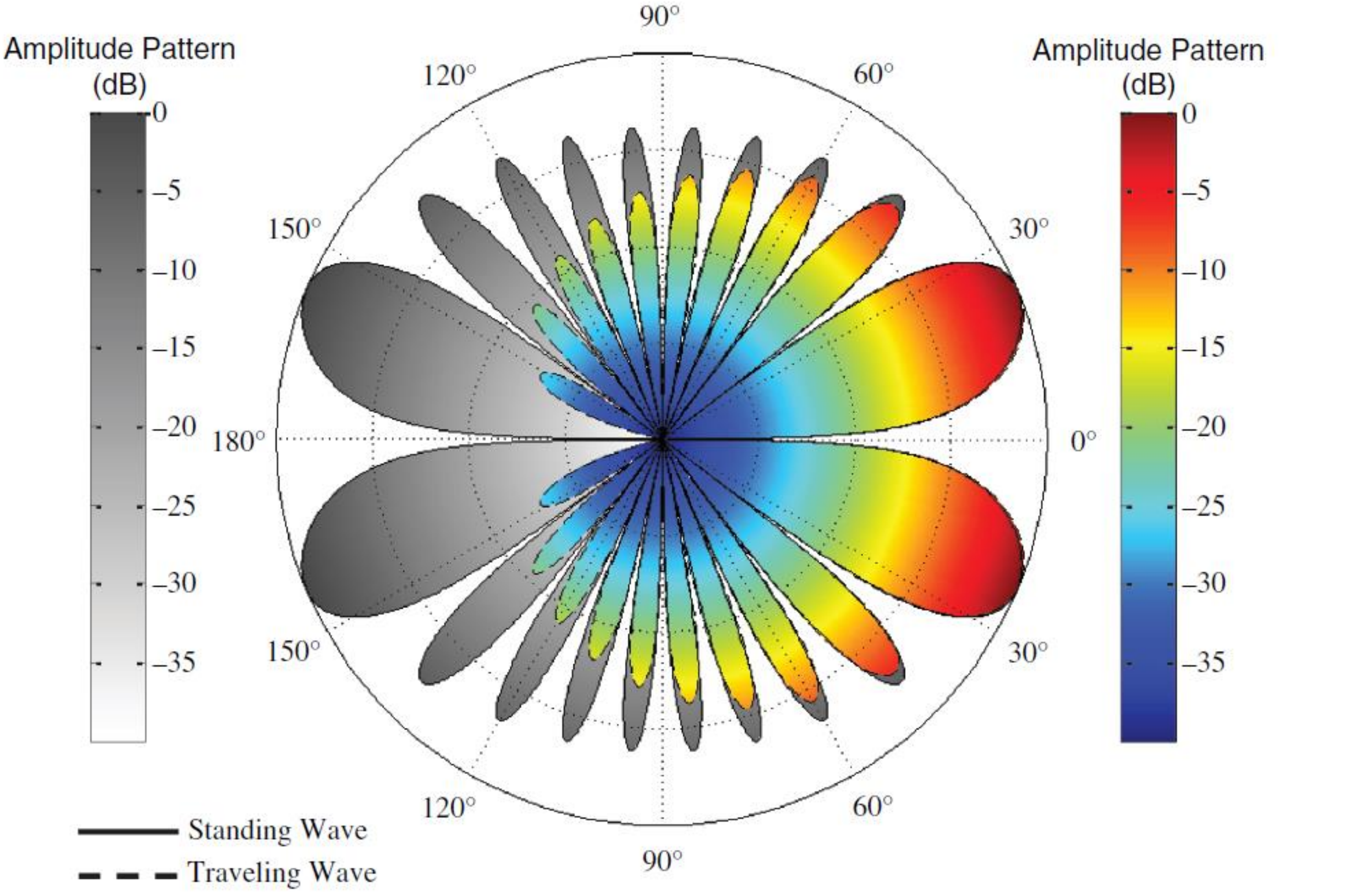
- **Standing wave wire antenna** is given below(length $l$ = 5λ)




(b) Standing wave




(a) Long wire above ground and radiation pattern



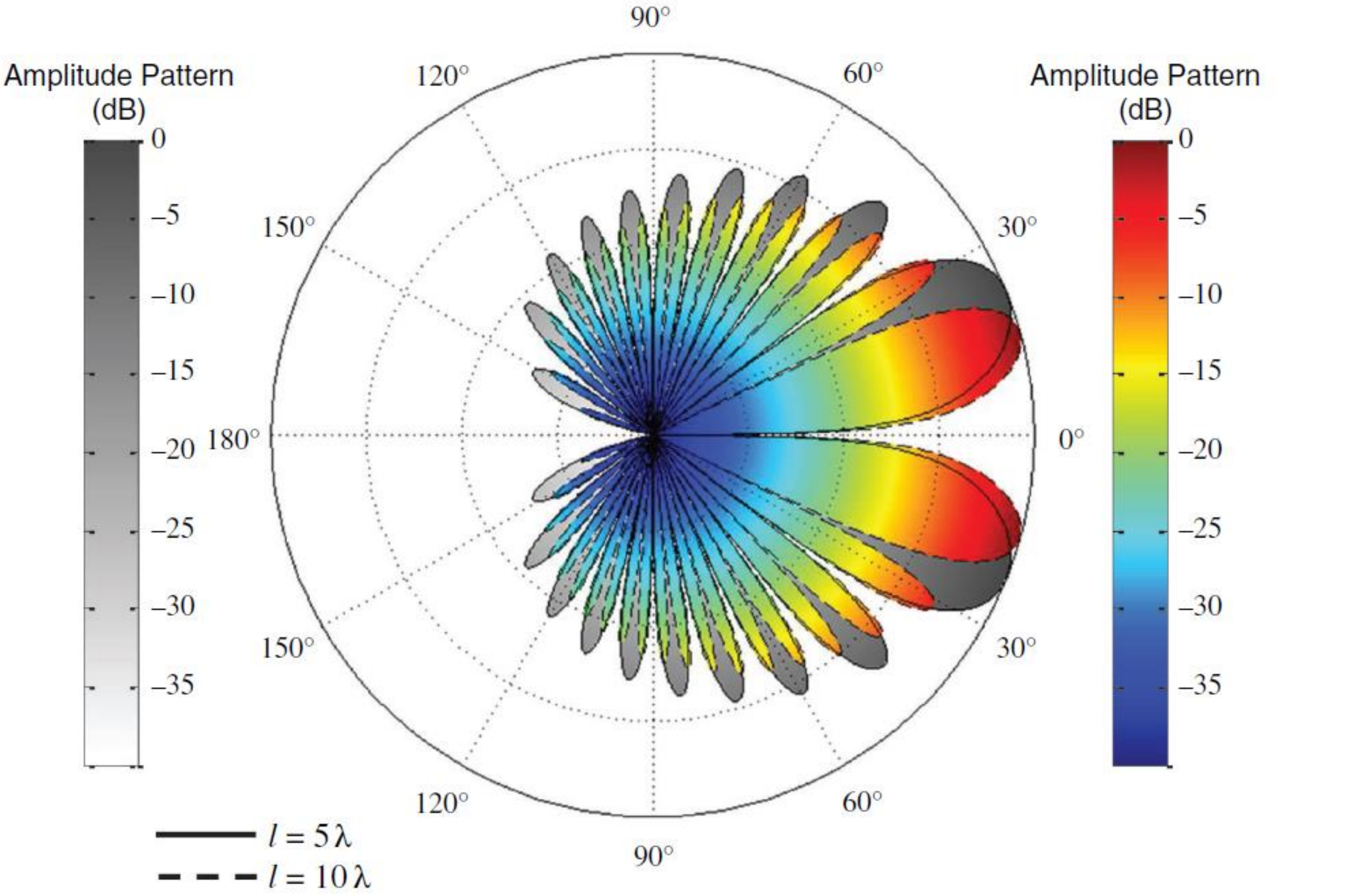

re 10.5 Two-dimensional free-space amplitude pattern for traveling and standing wave wire antennas of

- The two currents *If* and *Ib* together form a standing wave

$$I_s = I_f + I_b = I_1 e^{-jkz} - I_2 e^{+jkz} = -2jI_0 \sin(kz) \text{ when } I_2 = I_1 = I_0.$$

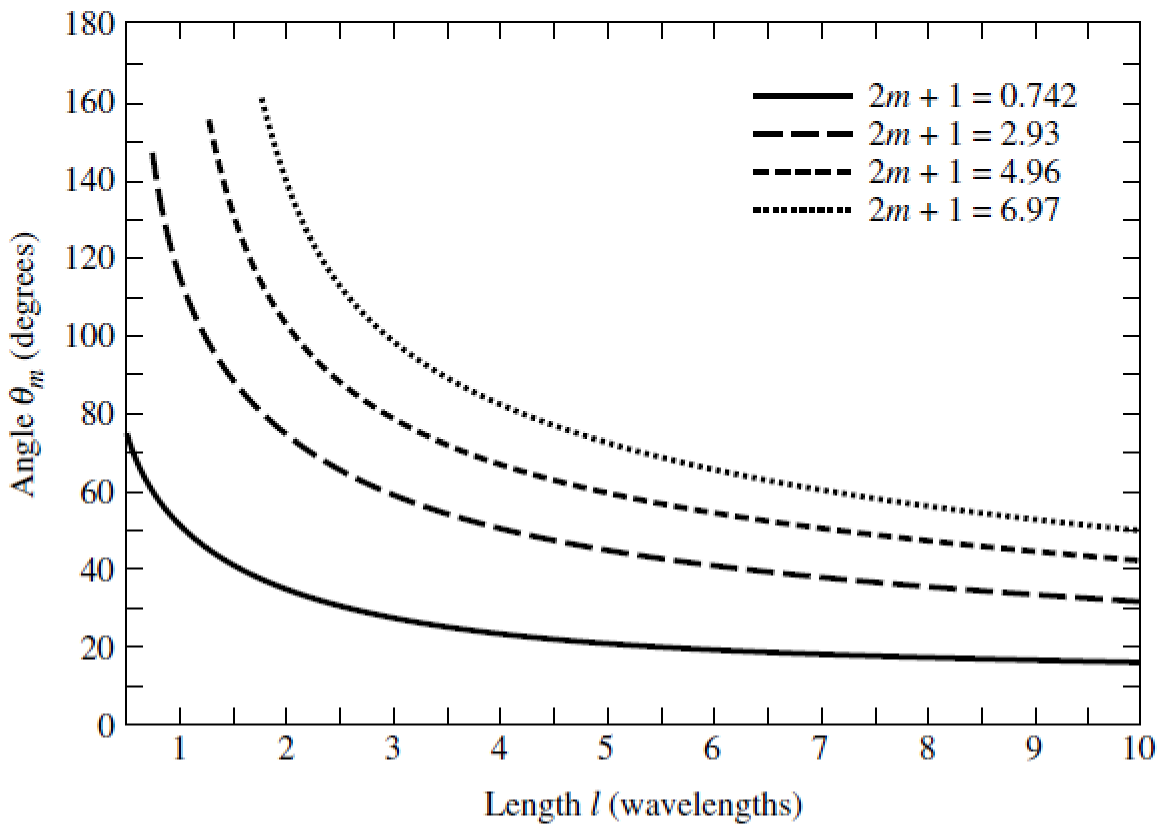
- **Traveling wave antenna**: maximum radiation in the forward direction
- **standing wave antenna**: maximum radiation in the forward and backward directions.
- The lobe near the axis of the wire in the directions of travel is the largest. The magnitudes of the other lobes from the main decrease progressively, with an envelope proportional to $\cot^2(\theta/2)$, toward the other direction.

- Comparison of lengths for a traveling wave wire antenna with $l$ = 5λ and 10λ.

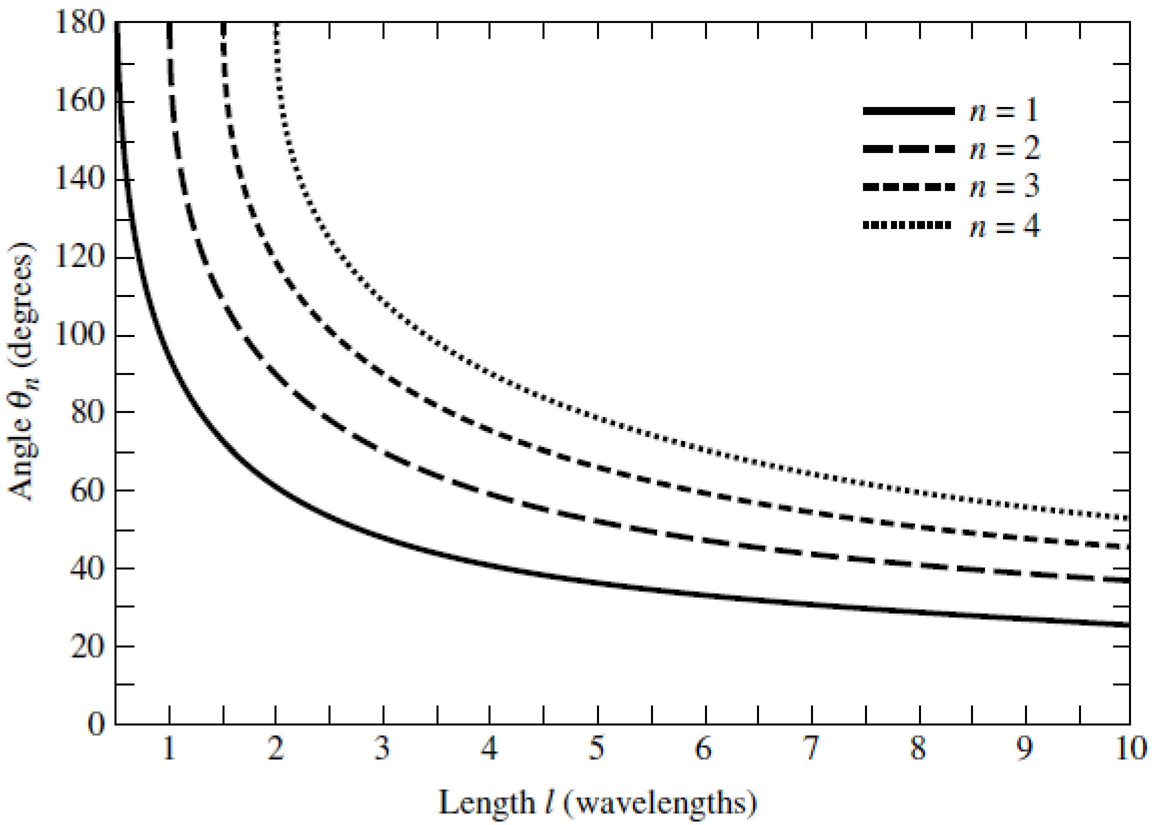



re 10.6 Two-dimensional free-space amplitude pattern for traveling wave wire antenna of $l$ = 5λ and 10λ.

- The **traveling wave antenna is used when it is desired to radiate or receive predominantly from one direction**
- As the **length of the wire increases**, **the maximum of the main lobe shifts closer toward the axis** and the **number of lobes increase**.




(a) Maxima




(b) Nulls

- Maxima angle and null angles as length of antenna is increased : For values of m(different maximas) and n(different nulls)
- These curves can be used effectively to design long wires when the direction of the maximum or nullis desired.

# 2.2 Input impedance of long wire antenna

- In **traveling wave wire antennas**, the **radiation in the opposite direction from the maximum is suppressed by reducing**, if not completely eliminating, **the current reflected from the end of the wire**.
- This is accomplished by **increasing the diameter of the wire** or more successfully by **properly terminating it to the ground**,
- **Ideally** a complete elimination of the reflections (perfect match) can only be accomplished if the antenna is **elevated only at small heights (compared to the wavelength) above the ground**, and **it is terminated by a resistive load**.

# 2.2 Input impedance of long wire antenna

- The value of the load resistor, to achieve the impedance match, is equal to the characteristic impedance of the wire near the ground (which is found using image theory)
- For a wire with diameter *d* and height *h* above the ground, **an approximate value of the termination resistance is obtained from**

$$R_L = 138 \log_{10}\left(4\frac{h}{d}\right)$$

- The **wave tilt increases with frequency and with ground resistivity**
- Therefore, for a Beverage wire antenna, shown in Figure in the receiving mode, reception is influenced by the tilt angle of the incident vertically polarized wavefront, which is formed by the losses of the
- local ground

- ANTENNAS To achieve a reflection-free termination, the load resistor can be adjusted about this value (usually about 200–300 ohms)
- Therefore the input impedance is the same as the load impedance or the characteristic impedance of the line,
- If not matched:

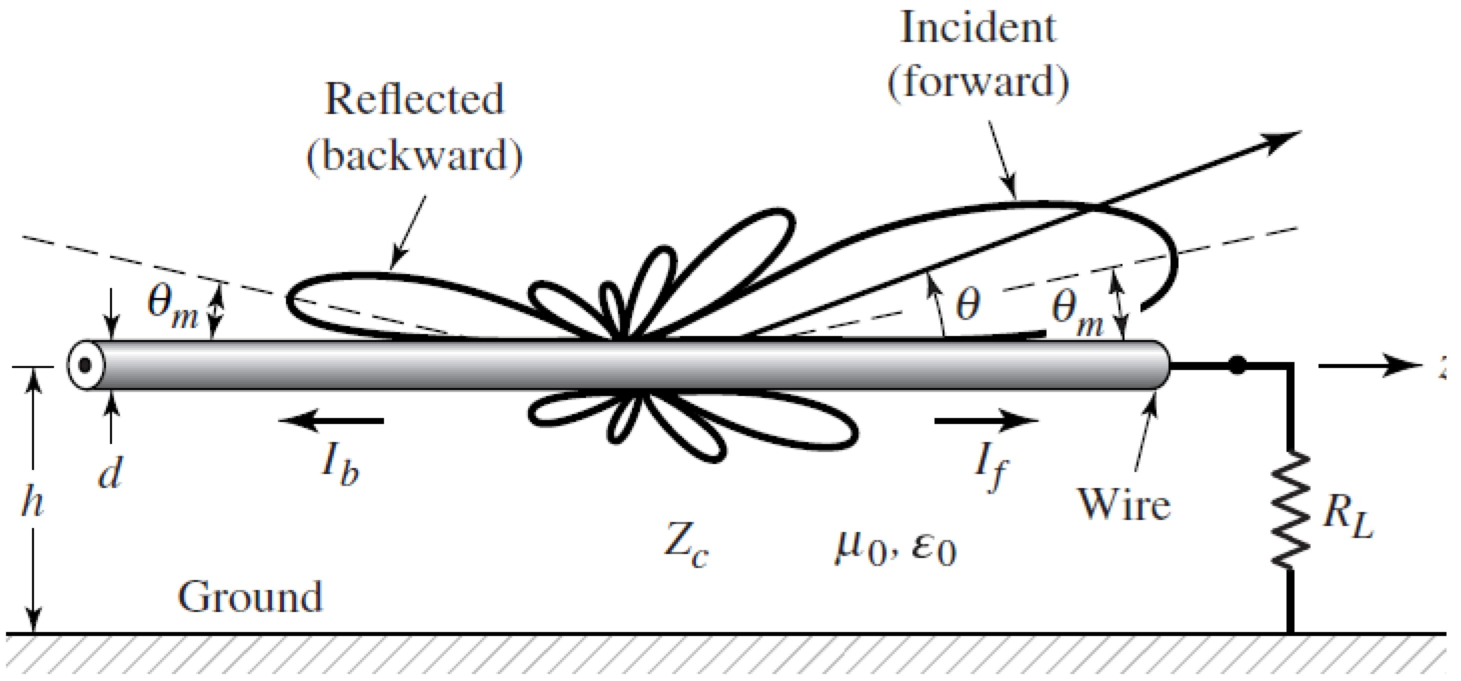
$$Z_{in}(l) = Z_c \left[ \frac{R_L + jZ_c \tan(\beta l)}{Z_c + jR_L \tan(\beta l)} \right]$$

# 2.3 Polarization of Wire antenna

- long-wire antenna is linearly polarized, and it is always parallel to the **plane formed by the <u>wire</u> and <u>radial vector from the center of the wire to the observation point</u>**
- **<u>Receiving mode:</u>** The electric-field vector of the incident wavefront produces an **electric force that is parallel to the wire**, which in turn **induces a current in the wire**.
- The current flows in the wire toward the receiver, and it is reinforced up to a certain point along the wire by the advancing wavefront.
- **The wave along the wire is transverse magnetic.**

# 2.4 Resonant Wires

- Resonant wire antennas are formed **when the load impedance is not matched to the characteristic impedance of the line**. This causes reflections which with the incident wave form **a standing wave**




(a) Long wire above ground and radiation pattern

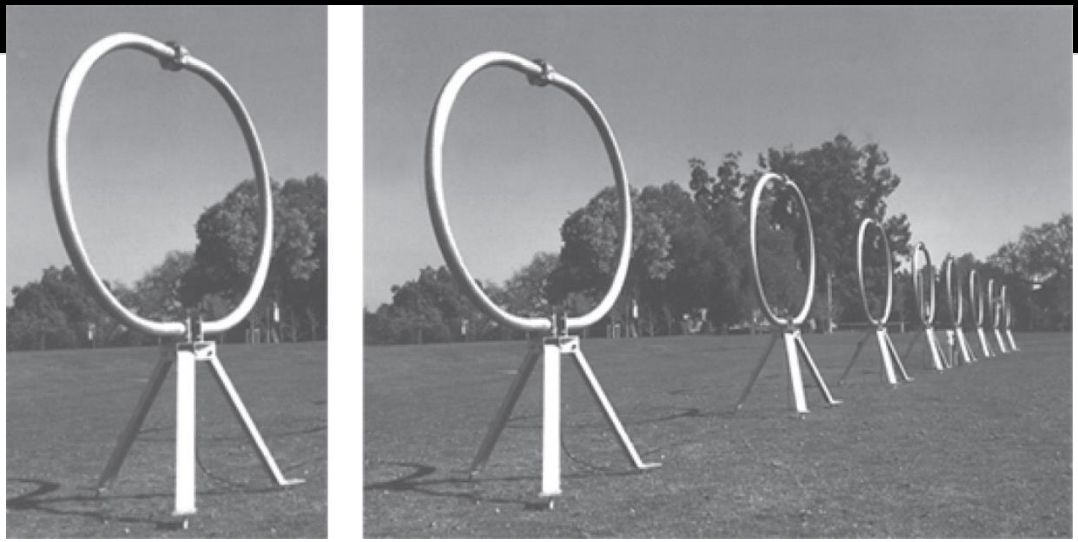
# 2.4 Resonant Wires

- Resonant antennas include the dipole.
- Resonant antennas are formed by using long wires with multiple of half wave lengths ( $l = n\lambda/2$, $n$ = 1, 3, 5,…),

$$R_r = 73 + 69\log_{10}(n)$$

$$\theta_{\max} = \cos^{-1}\left(\frac{n-1}{n}\right)$$

$$D_0 = \frac{120}{R_r \sin^2\theta_{\max}}$$



# 3. Loop antenna

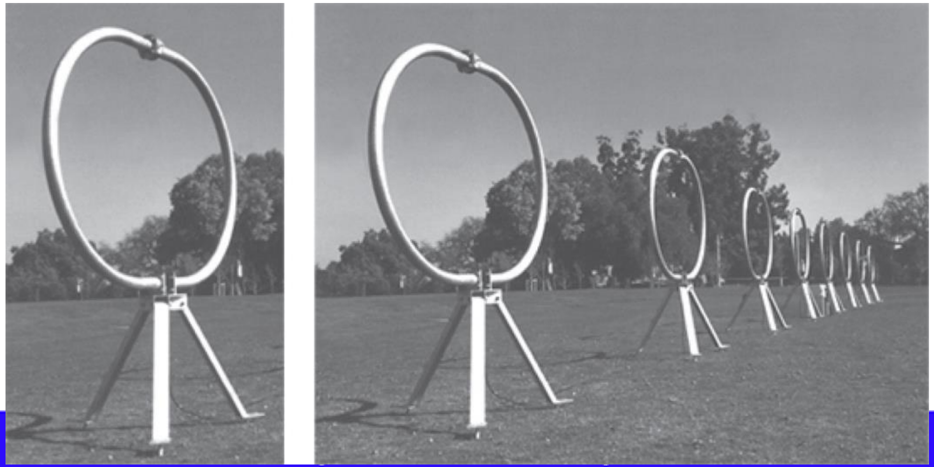
- Loop antennas are usually classified into two categories, electrically small and electrically large.
- **Electrically small antennas** are those whose overall length (circumference) is usually less than about one-tenth of a wavelength ($C < \lambda/10$).
- However, **electrically large loops** are those whose circumference is about a free-space wavelength ($C \sim \lambda$).
- Most of the applications of loop antennas are in the HF (3–30 MHz), VHF (30–300 MHz), and UHF (300–3,000 MHz) bands.
- When used as field probes, they find applications even in the microwave frequency range.

# 3. Loop antenna: Electrically small

- Loop antennas with **electrically small** circumferences or perimeters have small radiation resistances that are usually smaller than their loss resistances.
- Thus they are **very poor radiators**, and they are seldom employed for transmission in radio communication.
- When they are used in any such application, **it is usually in the receiving mode**, such as in portable radios and pagers, where antenna efficiency is not as important as the signal-to-noise ratio.
- They are also **used as probes for field measurements and as directional antennas for radiowave navigation**.
- The **field pattern of electrically small antennas of any shape** (circular, elliptical, rectangular, square, etc.) **is similar to that of an infinitesimal dipole** with a **null perpendicular to the plane of the loop** and with its **maximum along the plane of the loop**.

# 3. Loop antenna: **Electrically large**

- As the **overall length of the loop increases** and its **circumference approaches one free-space wavelength**,
  the **maximum of the pattern shifts** from the plane of the loop **to the axis of the loop** which is perpendicular to its plane
- . The **radiation resistance of the loop can be increased**, and made comparable to the characteristic impedance of practical transmission lines,
  by **increasing (electrically) its perimeter and/or the number of turns.**



# 3. Loop antenna: **Electrically large**

- Another way **to increase the radiation resistance of the loop** is to insert, within its circumference or perimeter, **a ferrite core of very high permeability** which will raise the magnetic field intensity and hence the radiation resistance.
  This forms the so-called **ferrite loop**.
- **Electrically large loops** are used primarily in directional arrays, such as in **helical antennas,** Yagi-Uda arrays, quad arrays.
- For these and other similar applications, **the maximum radiation is directed toward the axis of the loop forming an end-fire antenna**.
- To achieve such directional pattern characteristics, **the circumference (perimeter) of the loop should be about one free-space wavelength**. The proper phasing between turns enhances the overall directional properties.

# 4. Helical antenna (Broadband loop antenna)

- There are numerous other antenna designs that exhibit greater broadband characteristics than those of the dipoles. **Some of these antenna can also provide circular polarization**, a desired extra feature for many applications.
- In most cases the helix is used with a ground plane. The ground plane can take different forms.
- Typically the **diameter of the ground plane should be at least 3λ/4**.
- **helix is usually connected to the center conductor** of a coaxial transmission line at the feed point with the **outer conductor of the line** attached to the **ground plane**

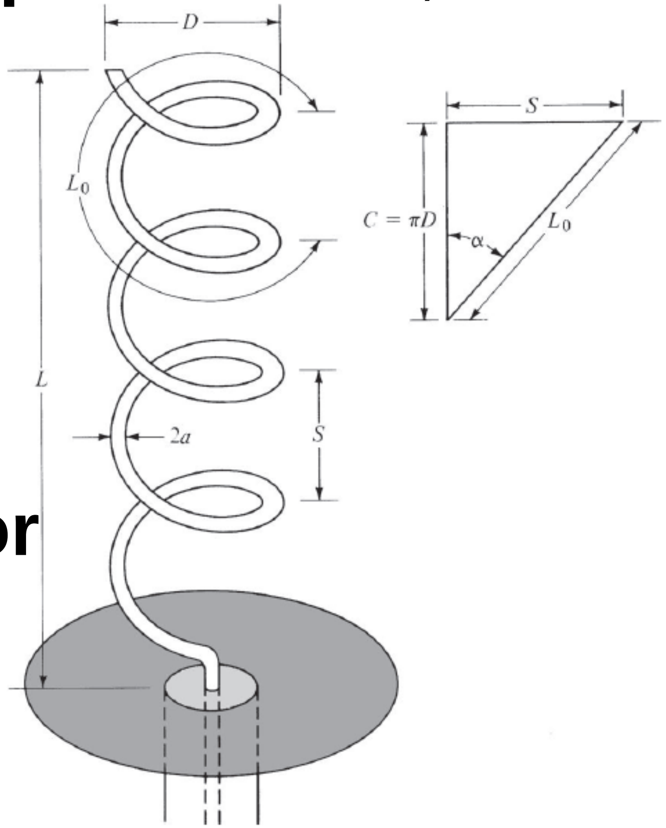



Figure 10.13 Helical antenna with ground plane.

# 4. Helical antenna

- *N* turns,
  diameter *D* and
  spacing *S* between each turn
- The total length of the antenna is *L* = *NS*
- *Length of one winding:* $L_0 = \sqrt{S^2 + C^2}$
  *Circumference:* $C = \pi D$
- total length of the wire is
  $L_n = NL_0 = N\sqrt{S^2 + C^2}$
- *Pitch angle:* $\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{S}{C}\right)$

  *If* $\alpha = 0$*: Flat : Loop antenna*
  *If* $\alpha = 90°$: *linear wire*
- $0 < \alpha < 90°$*: Helical antenna*

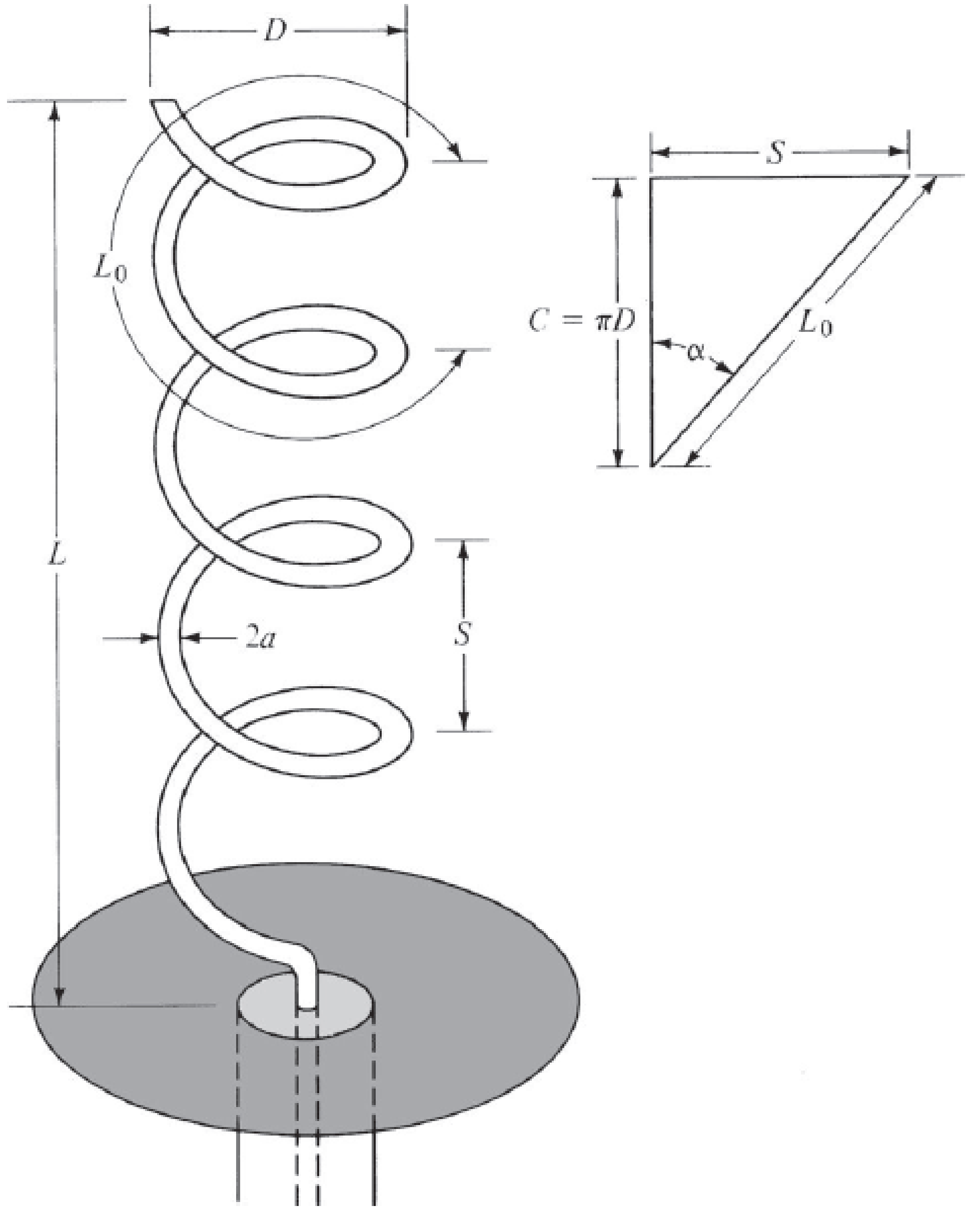



Figure 10.13 Helical antenna with ground plane.

# 4. Helical antenna

- **radiation characteristics** of the antenna can be **<u>varied by controlling the size</u>** of its geometrical properties compared to the wavelength.
- The **input impedance is critically dependent upon the pitch angle and the size of the conducting wire**, especially near the feed point, and it can be adjusted by controlling their values.
- The **general polarization of the antenna is elliptical**.
- However **circular and linear polarizations can be achieved** over different frequency ranges.

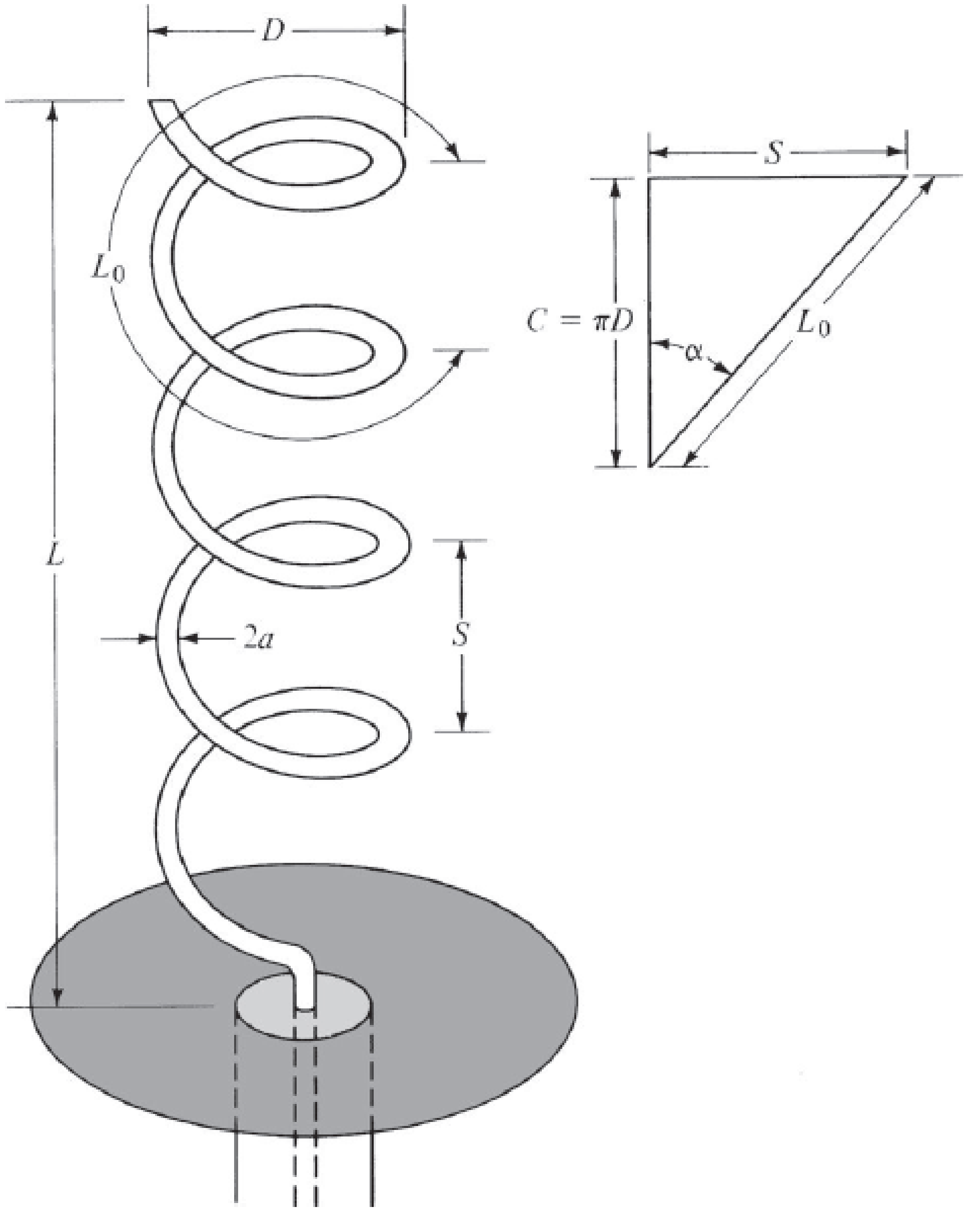
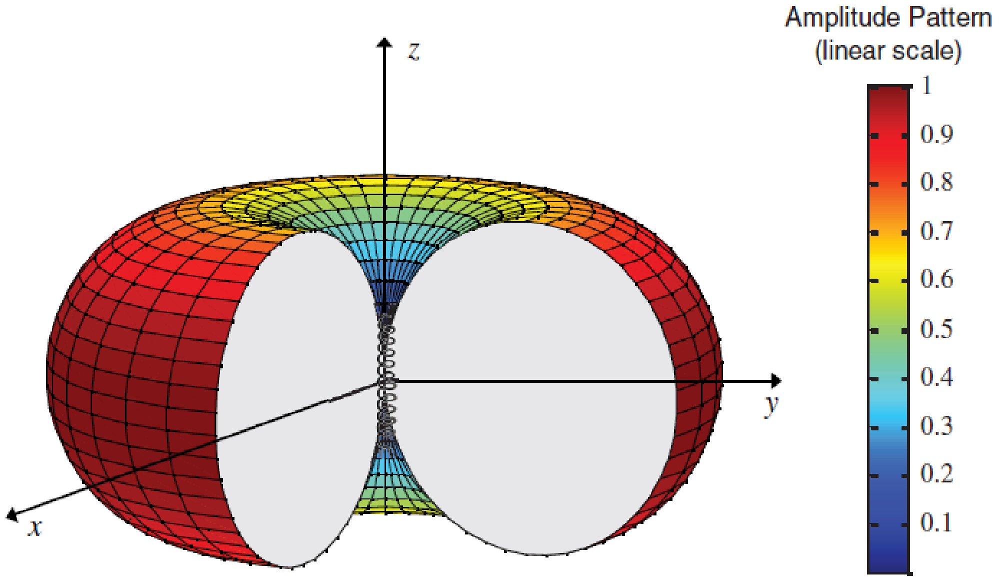


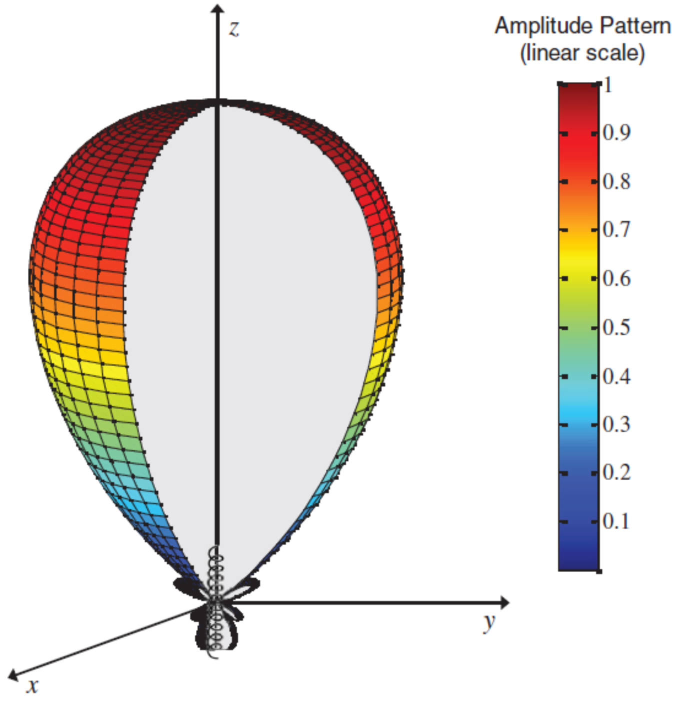

Figure 10.13 Helical antenna with ground plane.

# 4. Helical antenna

- two principal modes are the ***normal* (*broadside*) modes** and the ***axial* (*end-fire*) modes**.
- **Normal mode**: has its maximum in a plane normal to the axis and is nearly null along the axis.
- **Axial mode**: its maximum along the axis of the helix, and it is similar to that of an end-fire array.




(a) Normal (broadside) mode



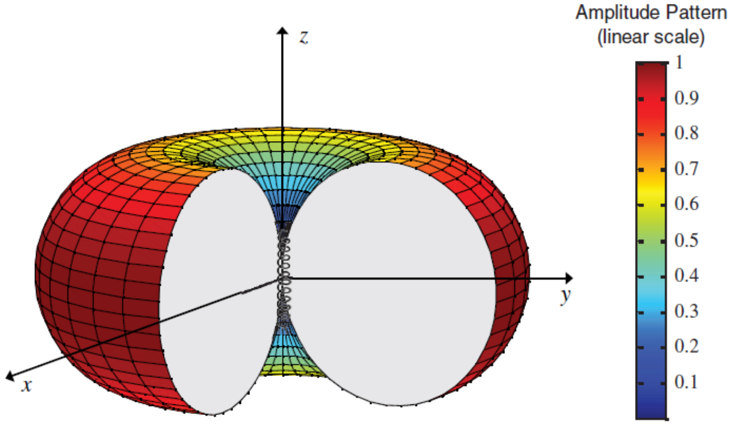

(b) End-fire (axial) mode

# 4. Helical antenna

- **elliptically polarized antenna** can be represented as the **sum of two orthogonal linear components in time-phase quadrature**, a **helix can always receive a signal transmitted from a rotating linearly polarized antenna**
- helices are usually positioned on the ground for
  **space telemetry applications of satellites**,
  **space probes**, and
  **ballistic missiles**

  to transmit or receive signals that have undergone Faraday rotation by traveling through the ionosphere.

# 4.1 Helical antenna: Normal mode



(a) Normal (broadside) mode

- **Normal mode**: field radiated by the antenna is **maximum in a plane normal to the helix axis and minimum along its axis**
- the dimensions of the helix are usually small compared to the wavelength (i.e., $NL_0 \ll \lambda_0$).
- far-zone electric field radiated by a short dipole of length *S*

$$E_\theta = j\eta \frac{kI_0 S e^{-jkr}}{4\pi r} \sin\theta$$

- electric field radiated by a loop

$$E_\phi = \eta \frac{k^2 (D/2)^2 I_0 e^{-jkr}}{4r} \sin\theta$$

- *N* turns, diameter *D* and spacing *S* between each turn
- The total length of the antenna is *L* = *NS*
- *Length of one winding:* $L_0 = \sqrt{S^2 + C^2}$ *Circumference:* $C = \pi D$
- total length of the wire is $L_n = NL_0 = N\sqrt{S^2 + C^2}$
- *Pitch angle:* $\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{S}{C}\right)$

  *If* $\alpha = 0$*: Flat : Loop antenna*
  *If* $\alpha = 90°$*: linear wire*
- $0 < \alpha < 90°$*: Helical antenna*

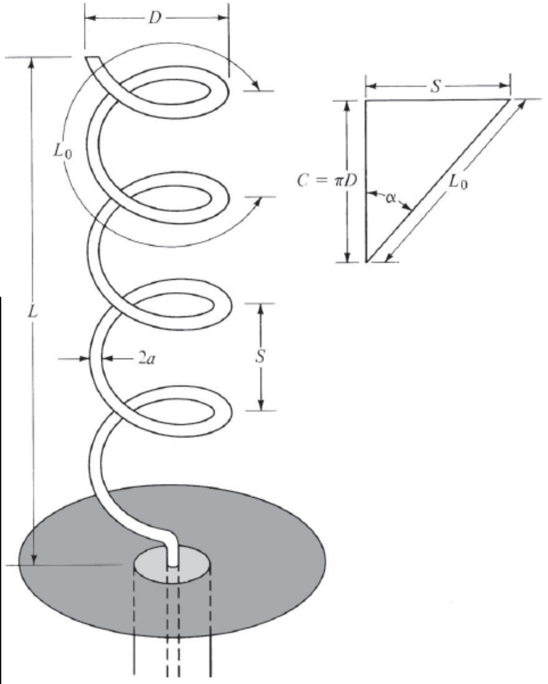


Figure 10.13 Helical antenna with ground plane.

# 4.1 Helical antenna: Normal mode

- the axial ratio (AR):

$$\mathrm{AR} = \frac{|E_\theta|}{|E_\phi|} = \frac{4S}{\pi k D^2} = \frac{2\lambda S}{(\pi D)^2}$$

- By varying the *D* and/or *S* the axial ratio attains values of $0 \leq \mathrm{AR} \leq \infty$.
- For $E_\theta = 0$, when $AR = 0$,
  **Linearly polarized wave of horizontal polarization (loop**
- For $E_\phi = 0$, when $AR = \infty$,
  **radiated wave is linearly polarized with vertical polarization** (the helix is a vertical dipole)
- Special case: $AR = 1 \; when \; E_\theta = E_\phi$
  **Circular polarized in all directions except $\theta = 0°$**

- *N* turns, diameter *D* and spacing *S* between each turn
- The total length of the antenna is *L* = *NS*
- *Length of one winding:* $L_0 = \sqrt{S^2 + C^2}$
  *Circumference:* $C = \pi D$
- total length of the wire is $L_n = NL_0 = N\sqrt{S^2 + C^2}$
- *Pitch angle:* $\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{S}{C}\right)$

*If* $\alpha = 0$*: Flat : Loop antenna*
*If* $\alpha = 90°$*: linear wire*

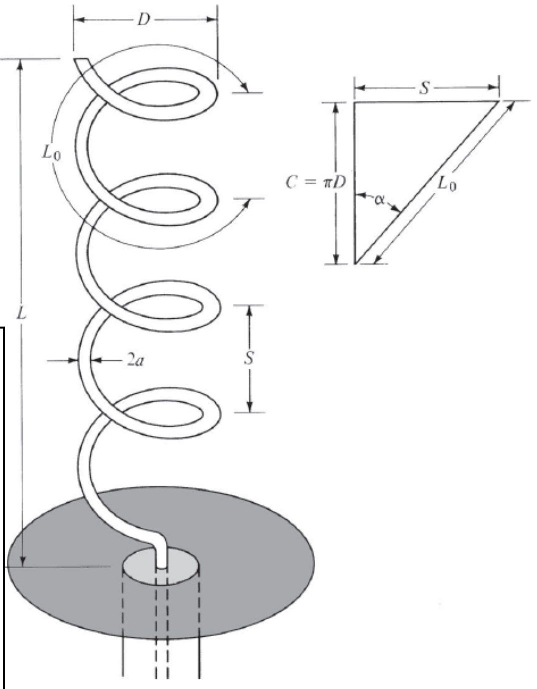



Figure 10.13 Helical antenna with ground plane.

# 4.1 Helical antenna: Normal mode

$$\mathrm{AR} = \frac{|E_\theta|}{|E_\phi|} = \frac{4S}{\pi k D^2} = \frac{2\lambda S}{(\pi D)^2}$$

- *N* turns, diameter *D* and spacing *S* between each turn
- The total length of the antenna is *L* = *NS*
- *Length of one winding:* $L_0 = \sqrt{S^2 + C^2}$ *Circumference:* $C = \pi D$
- total length of the wire is $L_n = NL_0 = N\sqrt{S^2 + C^2}$
- *Pitch angle:* $\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{S}{C}\right)$

  *If* $\alpha = 0$: *Flat : Loop antenna*
  *If* $\alpha = 90°$: *linear wire*
- $0 < \alpha < 90°$: *Helical antenna*

- Special case: $AR = 1\ when\ E_\theta = E_\phi$
  **Circular polarized in all directions** except $\theta = 0°$

$$\frac{2\lambda_0 S}{(\pi D)^2} = 1 \qquad C = \pi D = \sqrt{2S\lambda_0} \qquad \tan\alpha = \frac{S}{\pi D} = \frac{\pi D}{2\lambda_0}$$

- If above condition is not satisfied,
  $\alpha = 0°$: Linear horizontal polarized:
  $\alpha$ increased: elliptical polarized (with major axis horizontally polarized)
  $\alpha$ reaches such that $C = \sqrt{2S\lambda_0}$ : Circularly polarized
  $\alpha$ increased: elliptical polarized (with major axis vertically polarized)
  $\alpha = 90°$ Linear vertical polarized

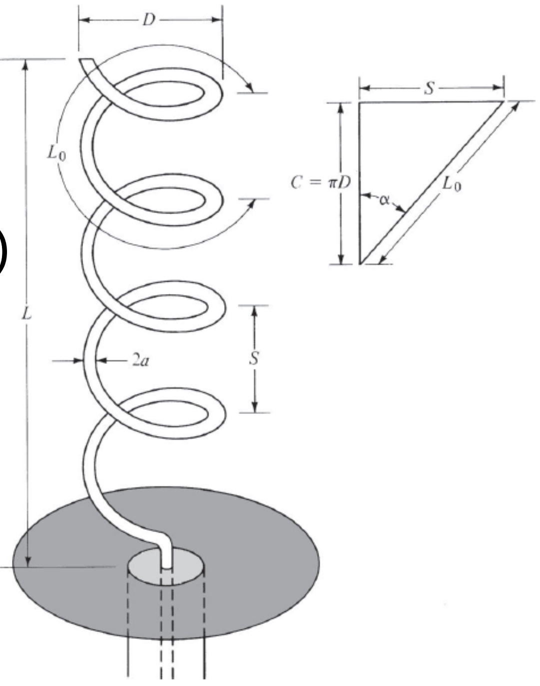



Figure 10.13 Helical antenna with ground plane.

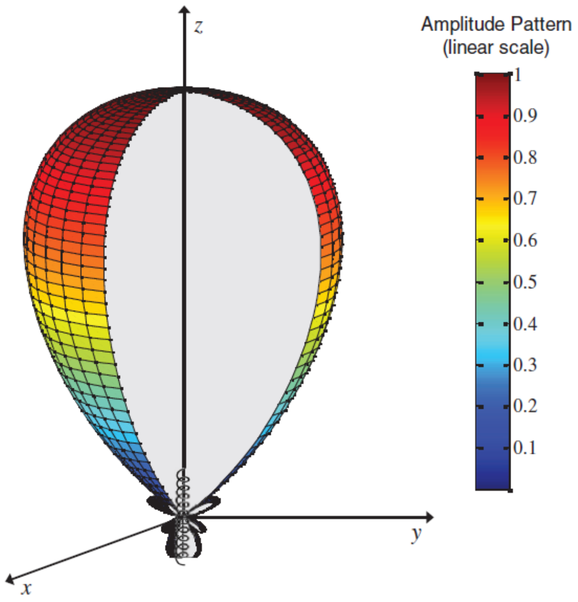
# 4.1 Helical antenna: Normal mode

- normal mode of operation,
  it has been assumed that the current throughout the length of the helix is of constant magnitude and phase.
- $NL_0$ is very small compared to the wavelength ($L_n \ll \lambda_0$)
- this mode of operation is very **narrow in bandwidth** and its **radiation efficiency is very small**.
- Normal mode is Rarely used

# 4.2 Helical antenna: End-Fire mode

- **there is only one major lobe and its maximum radiation intensity is along the axis of the helix**
- minor lobes are at oblique angles to the axis.
- **Very broad band antenna**
- diameter *D* and spacing *S* must be large fractions of the wavelength
- Circular polarization:
  $\frac{3}{4}\lambda_0 < C < \frac{4}{3}\lambda_0$ (Optimum: $C = \lambda_0$)
  Spacing: $S \approx \frac{\lambda_0}{4}$
  Pitch angle : $12° \leq \alpha \leq 14°$
  Ground plane diameter: atleast $\lambda_0/2$
- Feed: Coaxial

- *N* turns, diameter *D* and spacing *S* between each turn
- The total length of the antenna is *L* = *NS*
- *Length of one winding:* $L_0 = \sqrt{S^2 + C^2}$
  *Circumference:* $C = \pi D$
- total length of the wire is $L_n = NL_0 = N\sqrt{S^2 + C^2}$
- *Pitch angle:* $\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{S}{C}\right)$
  *If* $\alpha = 0$*: Flat : Loop antenna*
  *If* $\alpha = 90°$*: linear wire*
- $0 < \alpha < 90°$*: Helical antenna*



(b) End-fire (axial) mode

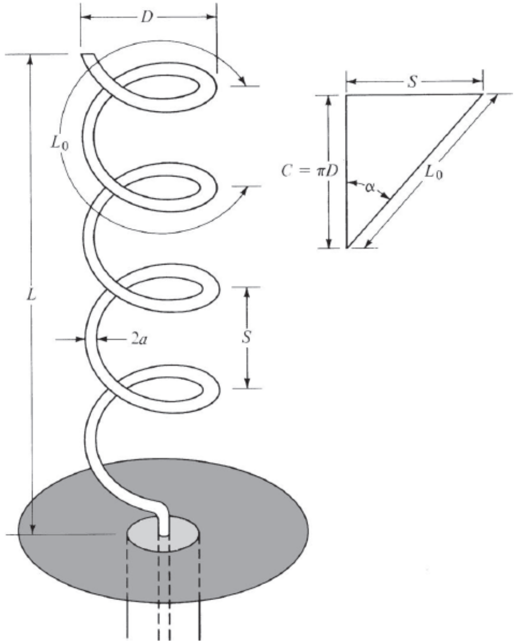


Figure 10.13 Helical antenna with ground plane.

# 4.2 Helical antenna: End-Fire mode

$$12° < \alpha < 14°, \ \frac{3}{4} < C/\lambda_0 < \frac{4}{3}, \text{ and } N > 3.$$

- Most preferred mode is End-fire
- input impedance (purely resistive) $R \simeq 140 \left(\frac{C}{\lambda_0}\right)$
- Half power beam width: $\text{HPBW (degrees)} \simeq \dfrac{52\lambda_0^{3/2}}{C\sqrt{NS}}$
- First null beam width: $\text{FNBW (degrees)} \simeq \dfrac{115\lambda_0^{3/2}}{C\sqrt{NS}}$
- Directivity: $D_0 \text{ (dimensionless)} \simeq 15N \dfrac{C^2 S}{\lambda_0^3}$
- Axial ratio $\text{AR} = \dfrac{2N+1}{2N}$

- *N* turns, diameter *D* and spacing *S* between each turn
- The total length of the antenna is *L* = *NS*
- *Length of one winding:* $L_0 = \sqrt{S^2 + C^2}$ *Circumference:* $C = \pi D$
- total length of the wire is $L_n = NL_0 = N\sqrt{S^2 + C^2}$
- *Pitch angle:* $\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{S}{C}\right)$

  *If* $\alpha = 0$*: Flat : Loop antenna*
  *If* $\alpha = 90°$*: linear wire*
- $0 < \alpha < 90°$*: Helical antenna*

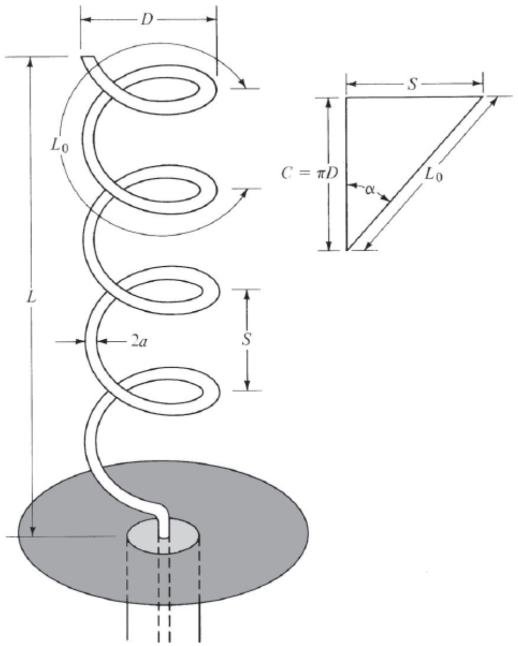



Figure 10.13 Helical antenna with ground plane.

# 4.2 Helical antenna: End-Fire mode

- Field pattern:

$$E = \sin\left(\frac{\pi}{2N}\right)\cos\theta\frac{\sin[(N/2)\psi]}{\sin[\psi/2]}$$

where

- relative phase $\psi$

$$\psi = k_0\left(S\cos\theta - \frac{L_0}{p}\right)$$

the relative wave velocity is:

$$p = \frac{L_0/\lambda_0}{S/\lambda_0 + 1}$$

For ordinary end-fire radiation

$$p = \frac{L_0/\lambda_0}{S/\lambda_0 + \left(\frac{2N+1}{2N}\right)}$$

For Hansen-Woodyard end-fire radiation

Design a 10-turn helix to operate in the axial mode. For an optimum design,

1. Determine the:
   a. Circumference (in $\lambda_o$), pitch angle (*in degrees*), and separation between turns (in $\lambda_o$)
   b. Relative (to free space) wave velocity along the wire of the helix for:
      (i) Ordinary end-fire design
      (ii) Hansen-Woodyard end-fire design
   c. Half-power beamwidth of the main lobe (*in degrees*)
   d. Directivity (in dB) using:
      (i) A formula
      (ii) The computer program **Directivity** of Chapter 2
   e. Axial ratio (*dimensionless* and in *dB*)

*Solution:*

1. a. For an optimum design

$$C \simeq \lambda_o, \alpha \simeq 13^\circ \Rightarrow S = C \tan \alpha = \lambda_o \tan(13^\circ) = 0.231\lambda_o$$

b. The length of a single turn is $L_o = \sqrt{S^2 + C^2} = \lambda_o \sqrt{(0.231)^2 + (1)^2} = 1.0263\lambda_o$

the relative wave velocity is:

Ordinary end-fire: $p = \dfrac{v_h}{v_o} = \dfrac{L_o/\lambda_o}{S_o/\lambda_o + 1} = \dfrac{1.0263}{0.231 + 1} = 0.8337$

Hansen-Woodyard end-fire: $p = \dfrac{v_h}{v_o} = \dfrac{L_o/\lambda_o}{S_o/\lambda_o + \left(\dfrac{2N+1}{2N}\right)} = \dfrac{1.0263}{0.231 + 21/20} = 0.8012$

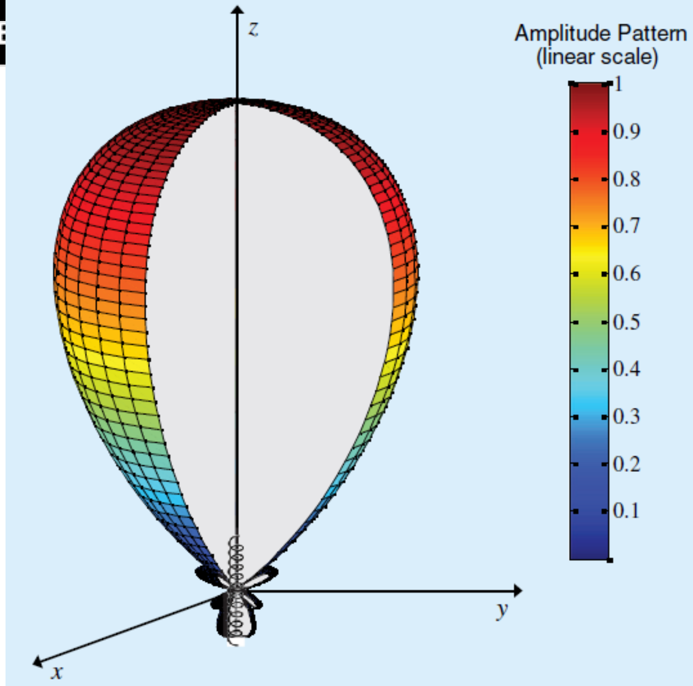
$$\text{HPBW} \simeq \frac{52\lambda_o^{3/2}}{C\sqrt{NS}} = \frac{52}{1\sqrt{10(0.231)}} = 34.2135^\circ$$

- Directivity:

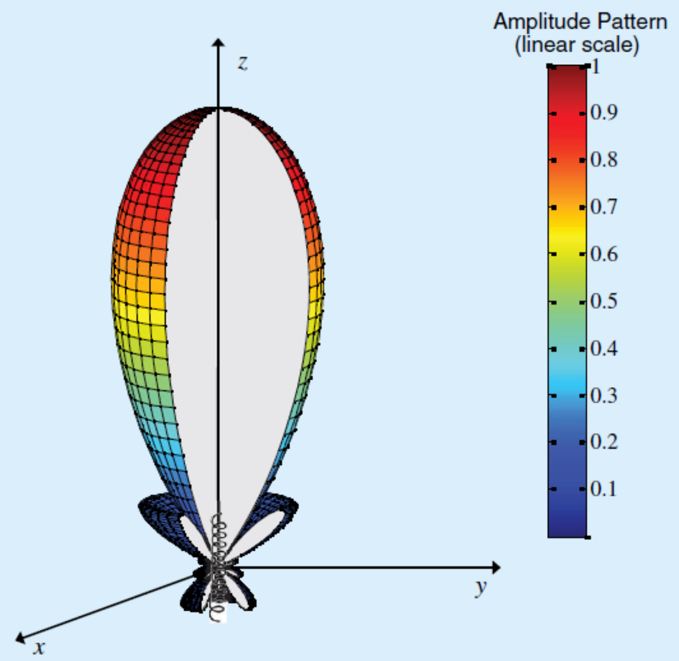
$$D_o \simeq 15N\frac{C^2 S}{\lambda_o^3} = 15(10)(1)^2(0.231) = 34.65\ (dimensionless)$$
$$= 15.397 \text{ dB}$$

- Axial ratio

$$\text{AR} = \frac{2N+1}{2N} = \frac{20+1}{20} = 1.05\ (dimensionless) = 0.21 \text{ dB}$$



(a) Ordinary end-fire



(b) Hansen-Woodyard end-fire