天线与电波传播
ANTENNAS AND WAVE PROPAGATION

LECTURE 7

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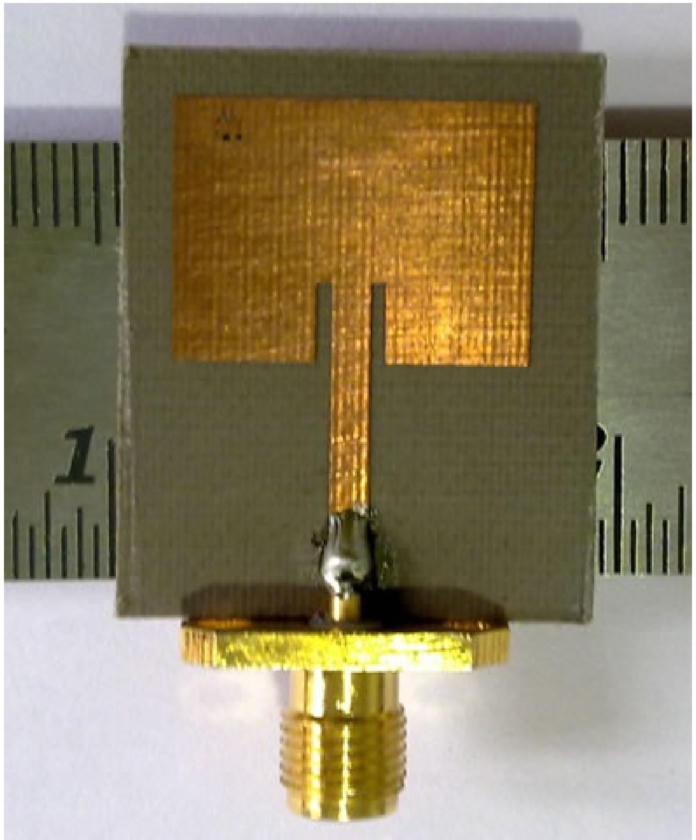
Last week

- ❖ Overview of microstrip antennas
- ❖ Feeding methods
- ❖ Basic principles of operation
- ❖ General characteristics
- ❖ CAD Formulas
- ❖ Radiation pattern
- ❖ Input Impedance
- ❖ Polarization



Travelling Wave, Broadband, and Frequency Independent Antennas

Outline

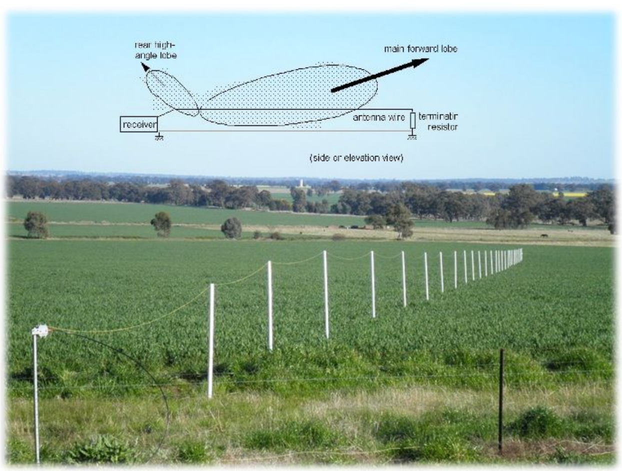
- Traveling Wave Antennas
  - Introduction
  - Traveling Wave Antennas: Long Wire, V Antenna, Rhombic Antenna
  - Yagi-Uda Array
- Broadband Antennas: Helical Antenna
- Frequency Independent Antennas
  - Introduction
  - Theory
  - Frequency Independent Antennas: Equiangular
    Spiral, Log-Periodic Dipole Array

Traveling Wave Antennas

Traveling Wave Antennas-Introduction

So far the antennas discussed: **resonant or standing-wave** antennas:
Standing waves form on an antenna due to the impedance mismatch at the open end of the antenna (pattern changes with frequency)

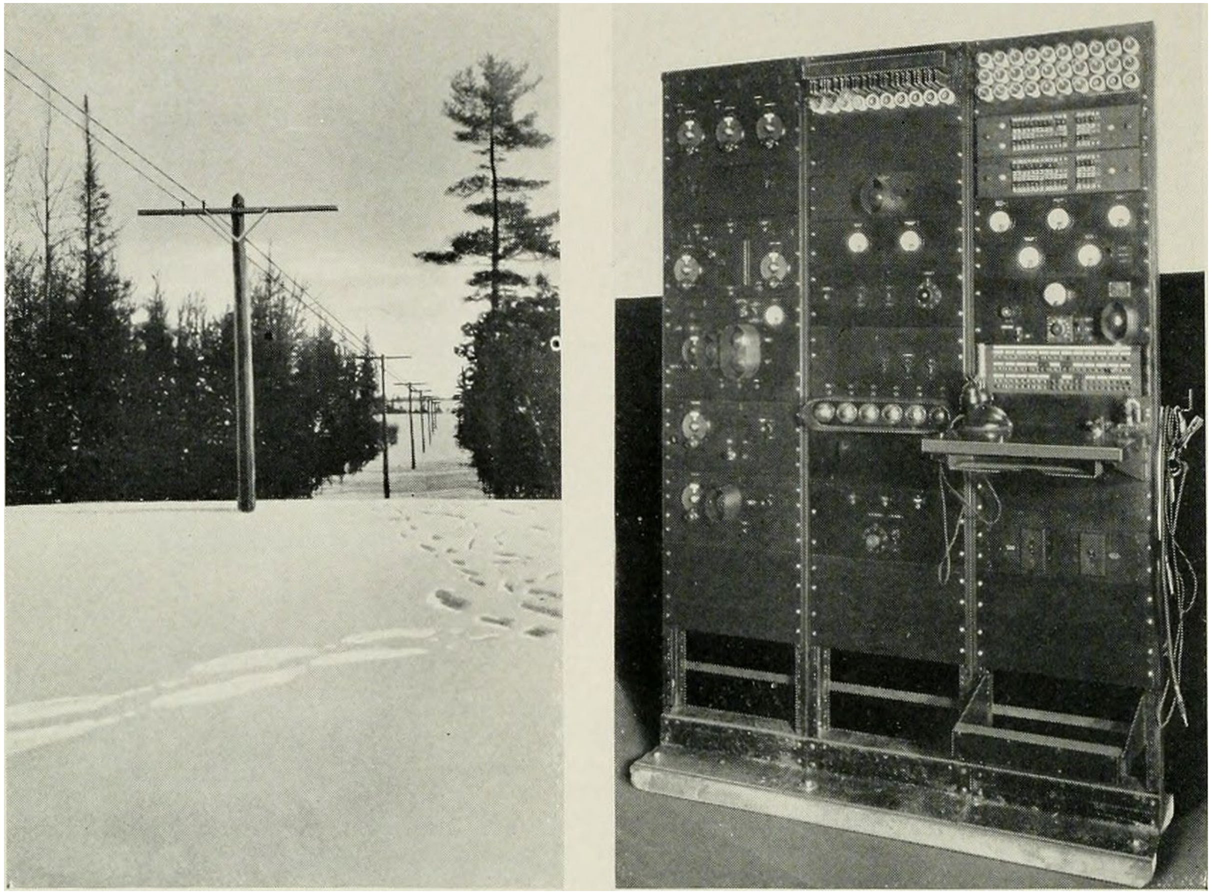
Antennas that have uniform patterns in current and voltage are **traveling wave, non-resonant** antennas:
Achieved by properly terminating the antenna wire so that the reflections are minimized or completely eliminated.



Traveling Wave Antennas-Introduction

An example of this traveling wave antenna is called the **beverage** antenna.

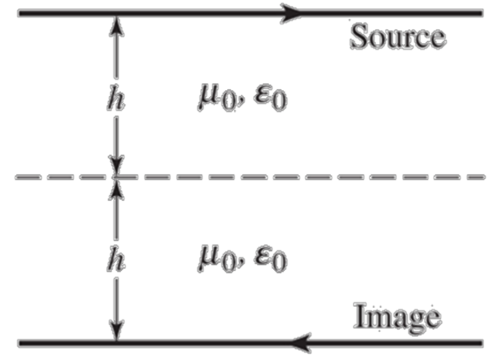
Invented by Harold H. Beverage

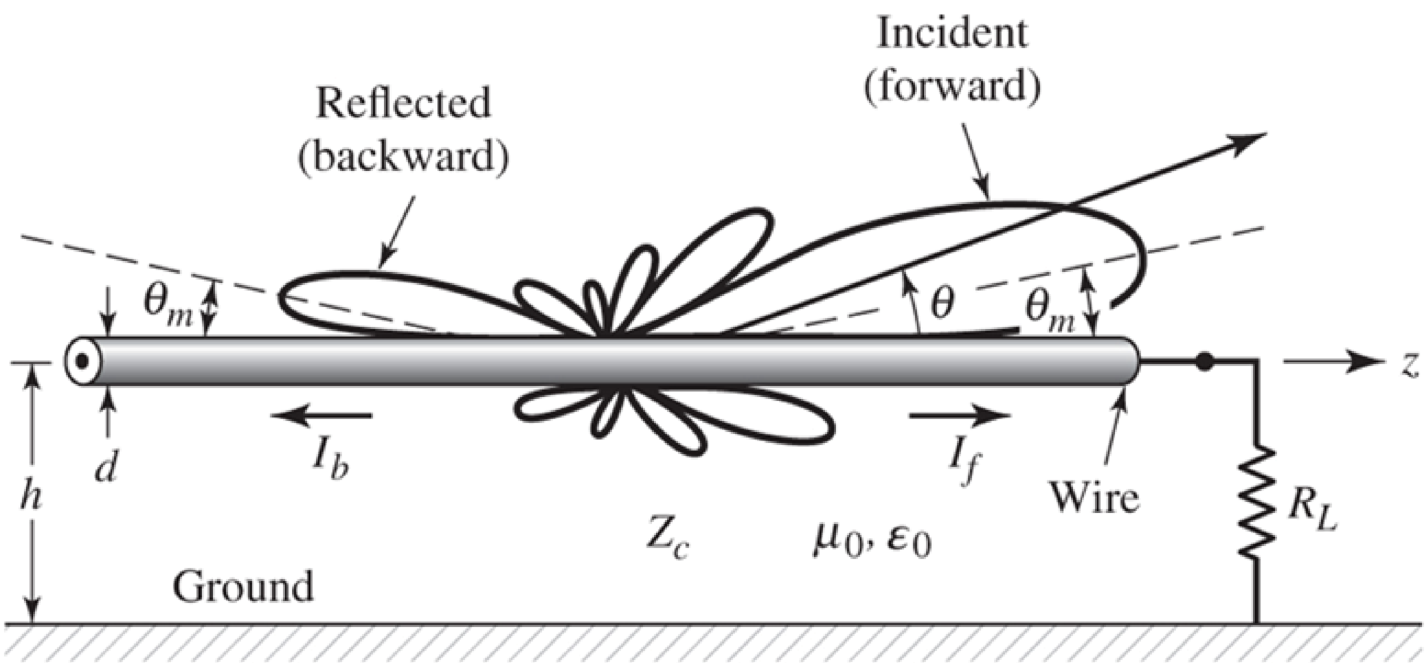


The AT&T receiving Beverage antenna (left) and radio receiver (right) at Houlton, Maine, from a 1920s magazine

Traveling Wave Antennas-Introduction

An example of this traveling wave antenna is called the **beverage** antenna.



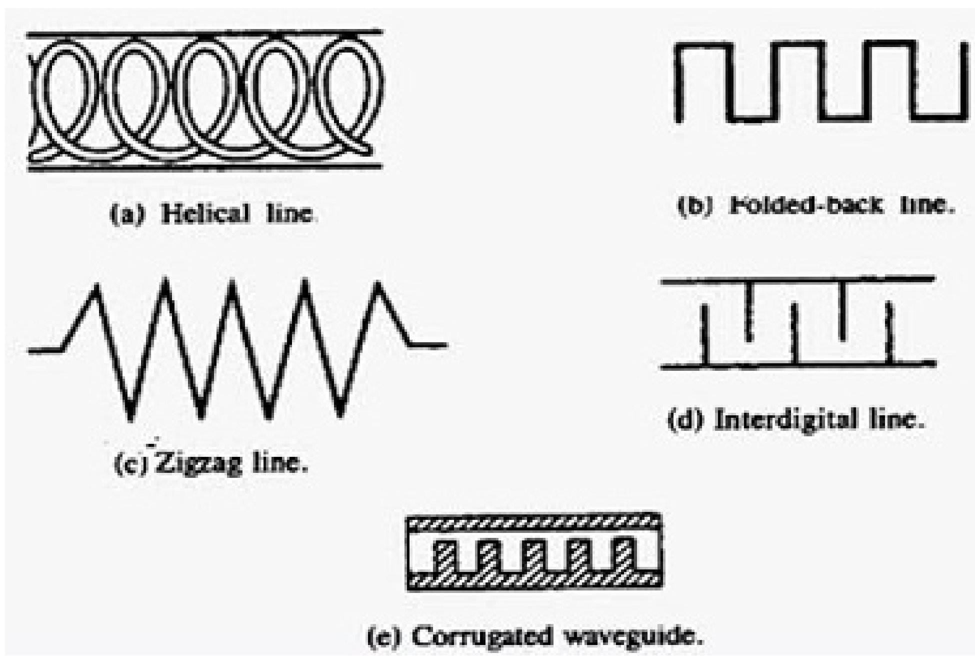


(a) Long wire above ground and radiation pattern

Traveling Wave Antennas-Introduction

A traveling wave can be classified as a slow wave if its phase velocity is equal or smaller than the speed of light, as opposed to fast waves, which the phase velocity is larger than the speed of light.

Slow wave structures:



Traveling Wave Antennas-Introduction

Traveling wave antennas can be classified in two types:

- Surface Wave Antenna: A slow wave structure that radiates power from discontinuities in the structure. (Compact design)
- Leaky-Wave Antenna: A fast wave structure that couples power from a traveling wave structure to free space. (Frequency steering)
- Beverage Antenna: A long-wire structure receiving near-vertical wave. (Receiving directional low-frequency wave).

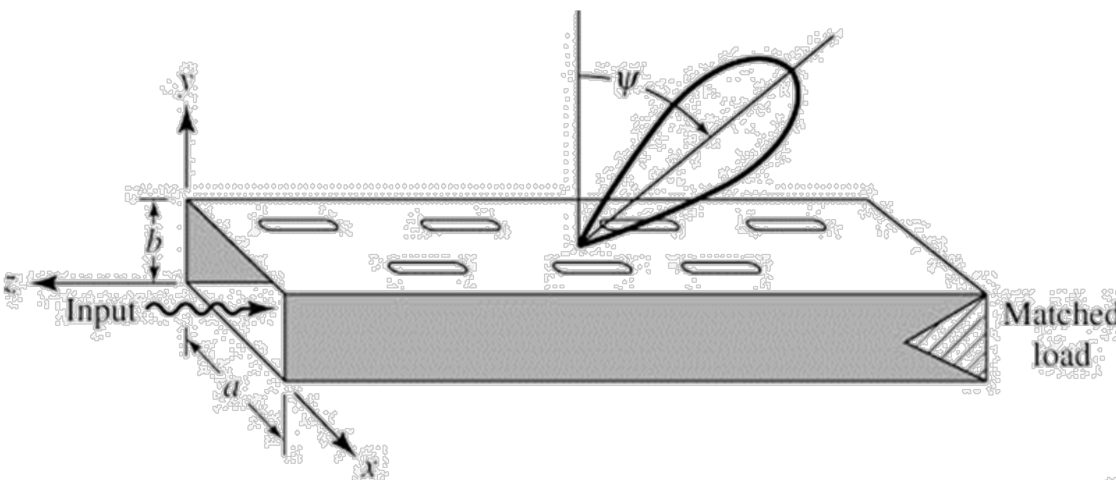


Fig. 10.2(a)

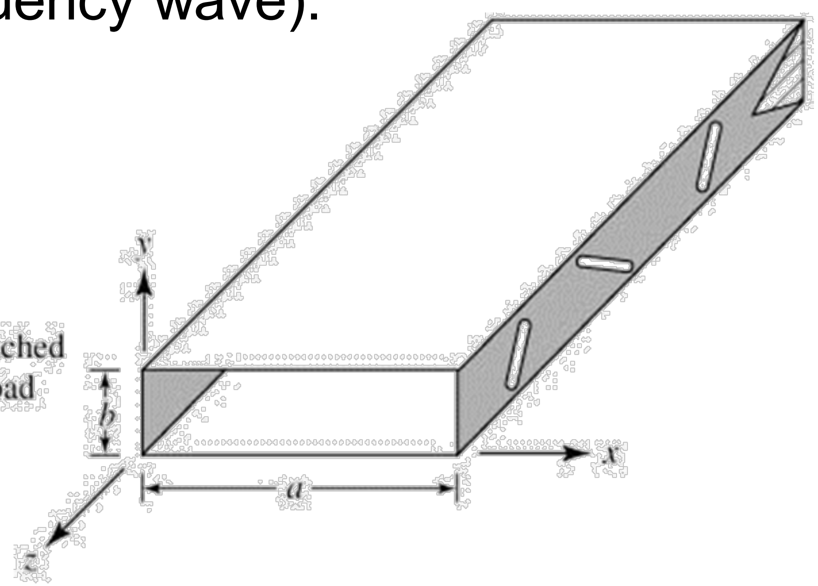
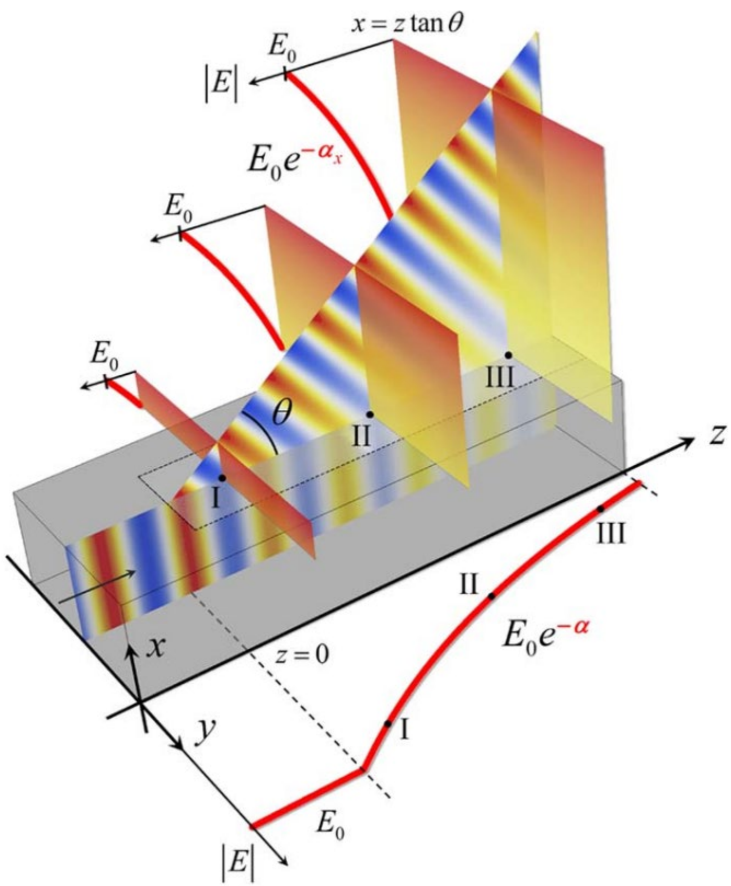


Fig. 10.2(b)

Chapter 10
Traveling Wave, Broadband Antennas

Traveling Wave Antennas-Introduction

- Leaky-Wave Antenna: A fast wave structure that couples power from a traveling wave structure to free space. (Frequency steering)



1. **Transition from Guided to Leaky Waves**: Illustrates how a wave transitions from being guided within a waveguide to leaking and radiating into open space as it propagates along the structure.
2. **Exponential Attenuation and Growth**: Shows the exponential attenuation of the wave along the propagation direction (z) and exponential growth in the transverse direction (x) within the leaky region, demonstrating the leakage mechanism.
3. **Field Distribution**: Depicts the field distribution on the xz plane, highlighting how the amplitude of the electromagnetic field varies in space as the wave becomes leaky.
4. **Radiation Angle**: Defines the radiation angle (θ), showing how the radiation is confined within a specific angular region, creating a wedge-like pattern of radiation.
5. **Amplitude Levels on the Aperture**: Marks different amplitude levels at the aperture for varying values of z, providing insights into how the field strength changes along the waveguide and as it radiates away.
6. **Spatial Confinement**: Emphasizes the spatial confinement of radiation within a region defined by $x < z\tan(\theta)$, indicating that radiation is directed within this wedge-like region and no radiation reaches beyond it.
7. **Interplay of Phase and Attenuation Constants**: The figure underscores the importance of the complex longitudinal wavenumber ($k_z = \beta - i\alpha$) in determining the behavior of leaky waves, including the direction and efficiency of radiation.

$$\theta = \arcsin\left(\frac{\beta}{k_0}\right)$$

where:

- θ is the radiation angle relative to the normal (perpendicular) to the antenna axis.
- β is the real part of the propagation constant k_z along the antenna, indicating the phase change per unit length.
- $k_0 = \frac{2\pi}{\lambda_0}$ is the free-space wave number, with λ_0 being the wavelength in free space and is given by $\lambda_0 = \frac{c}{f}$, where c is the speed of light in vacuum, and f is the frequency of the wave.

Long Wire (Beverage) Antenna

Invented in 1921 by H.H. Beverage. It is a straight conductor with a length from one to many wavelengths, above and parallel to the lossy earth. The height of the antenna must be chosen so that the reflected wave (wave from the image) is in phase with the direct wave.

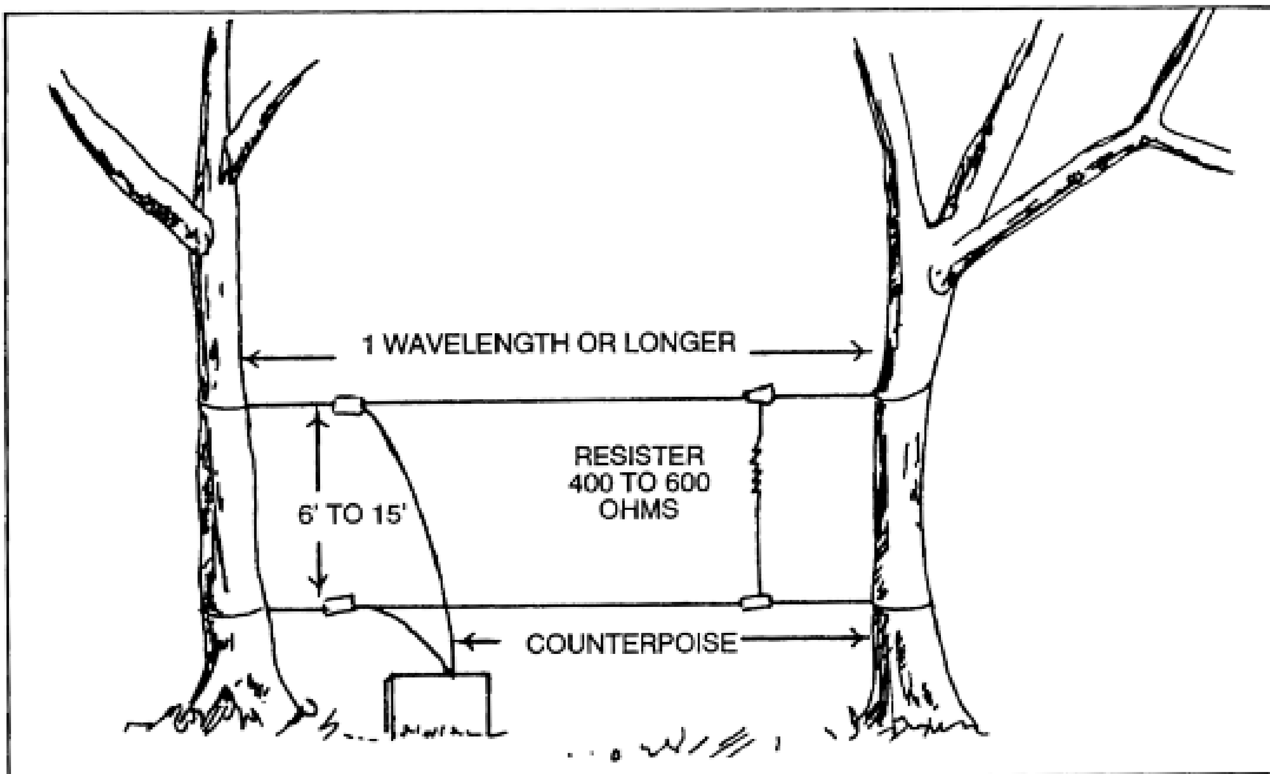
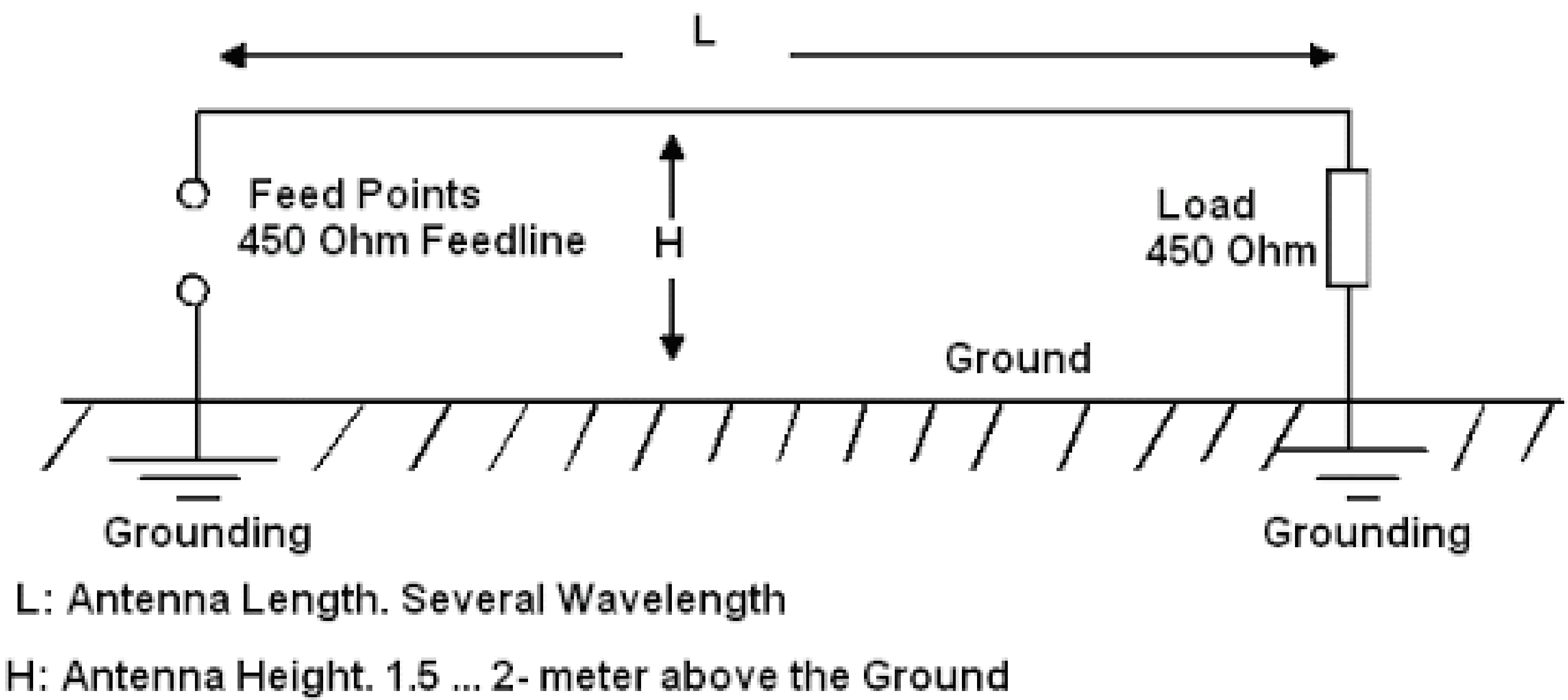


Figure D-11. Long-wire antenna.

Long Wire (Beverage) Antenna

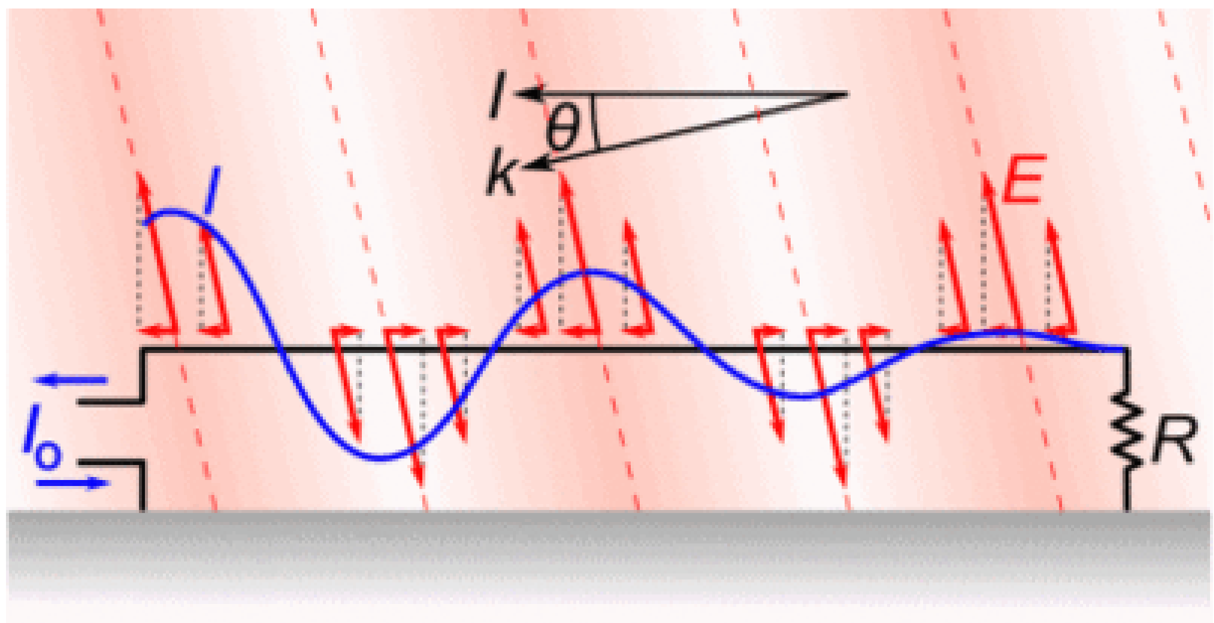
It is primarily used as a directive receiving antenna because losses at load are big (inefficient).



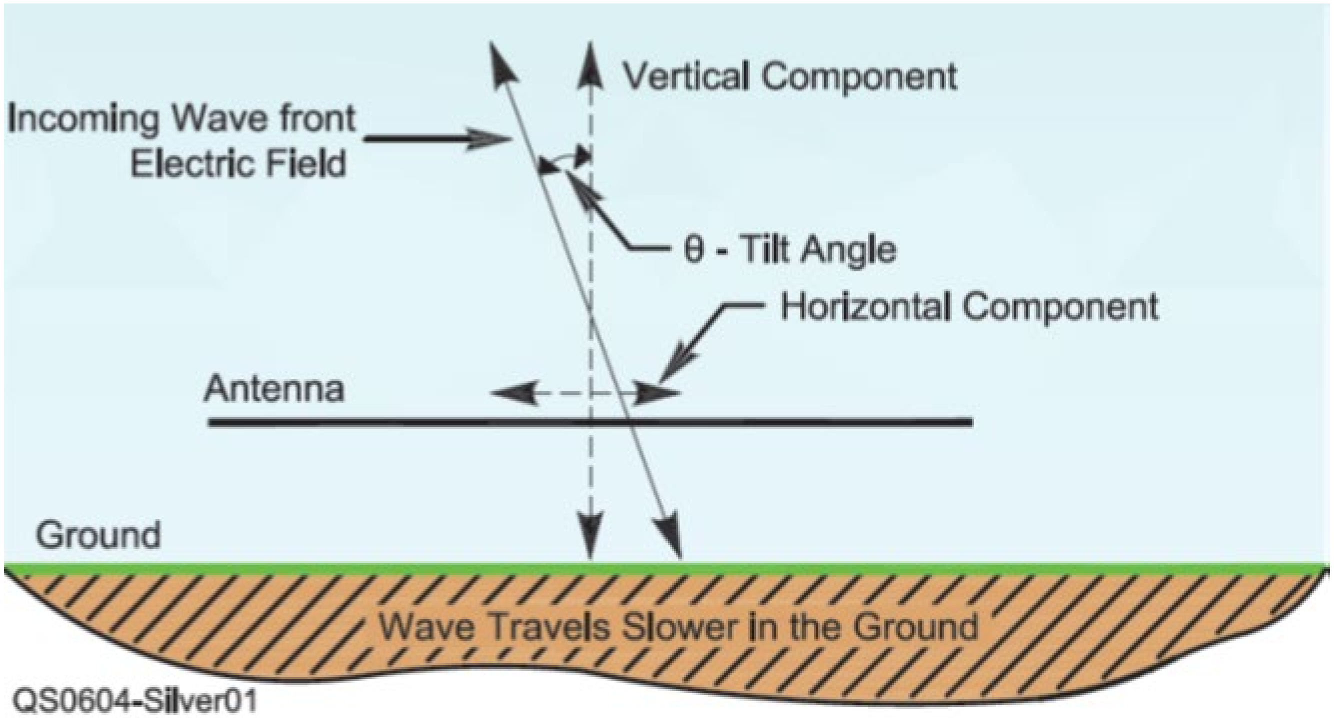
Long Wire (Beverage) Antenna

Animation showing how the antenna works. Due to ground resistance the electric field of the radio wave *(E, big red arrows)* is at an angle *θ* to the vertical, creating a horizontal component parallel to the antenna wire *(small red arrows)*. The horizontal electric field creates a traveling wave of oscillating current *(I, blue line)* and voltage along the wire, which increases in amplitude with distance from the end. When it reaches the driven end *(left)*, the current passes through the transmission line to the receiver. Radio waves in the other direction, toward the terminated end, create traveling waves which are absorbed by the terminating resistor *R*, so the antenna has a unidirectional pattern.

terminating resistor
R=400~600 Ohm

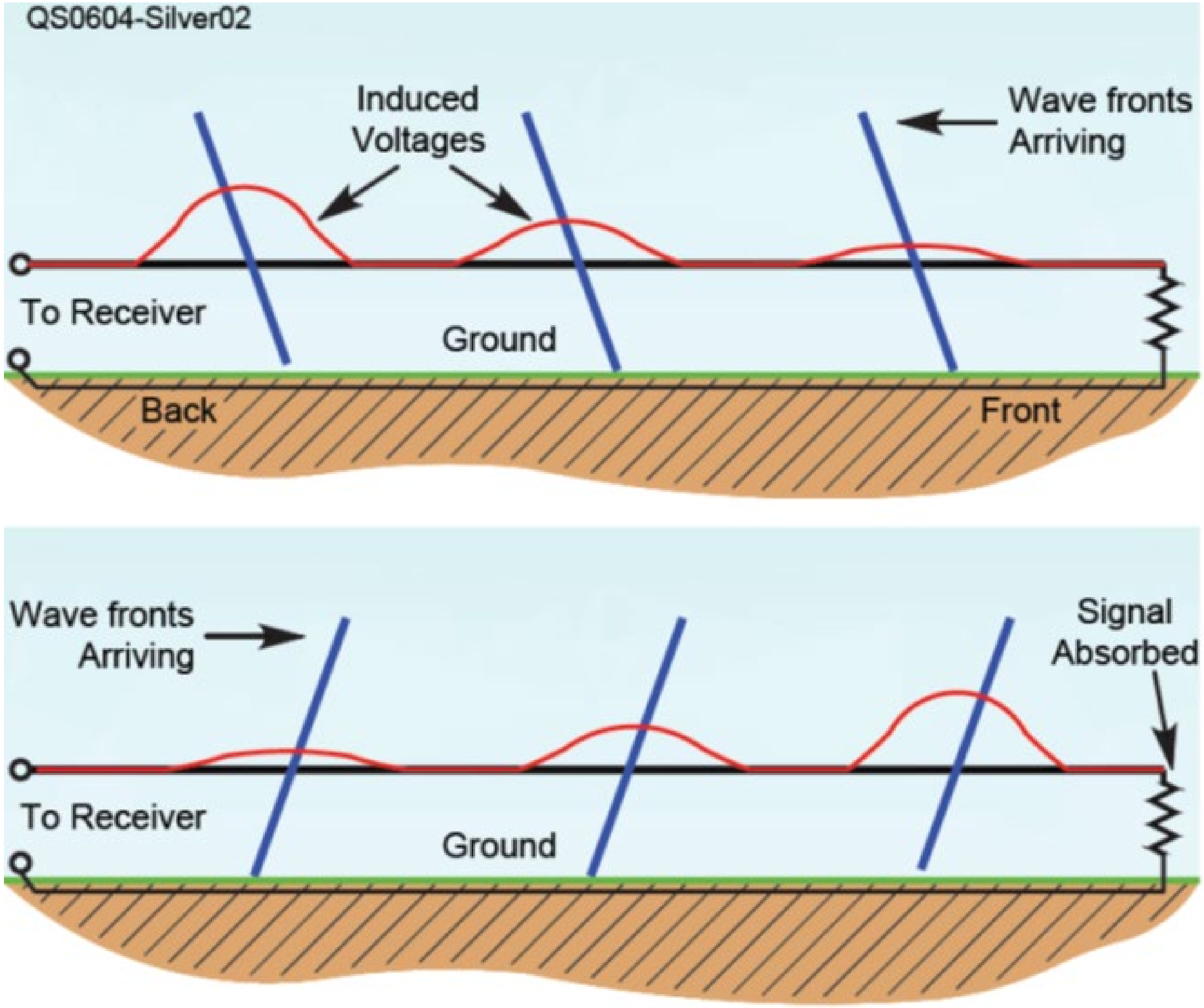


Long Wire (Beverage) Antenna



An incoming wavefront is tilted primarily because of reflection in the ionosphere. The wave also travels slightly slower along the ground at low frequencies.

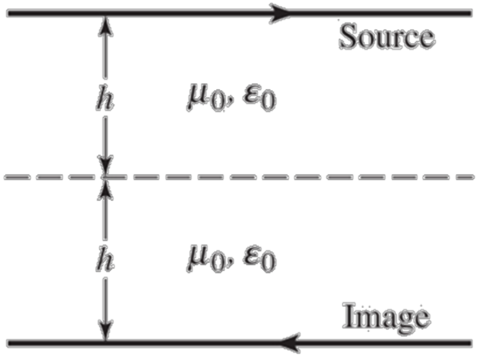
Long Wire (Beverage) Antenna

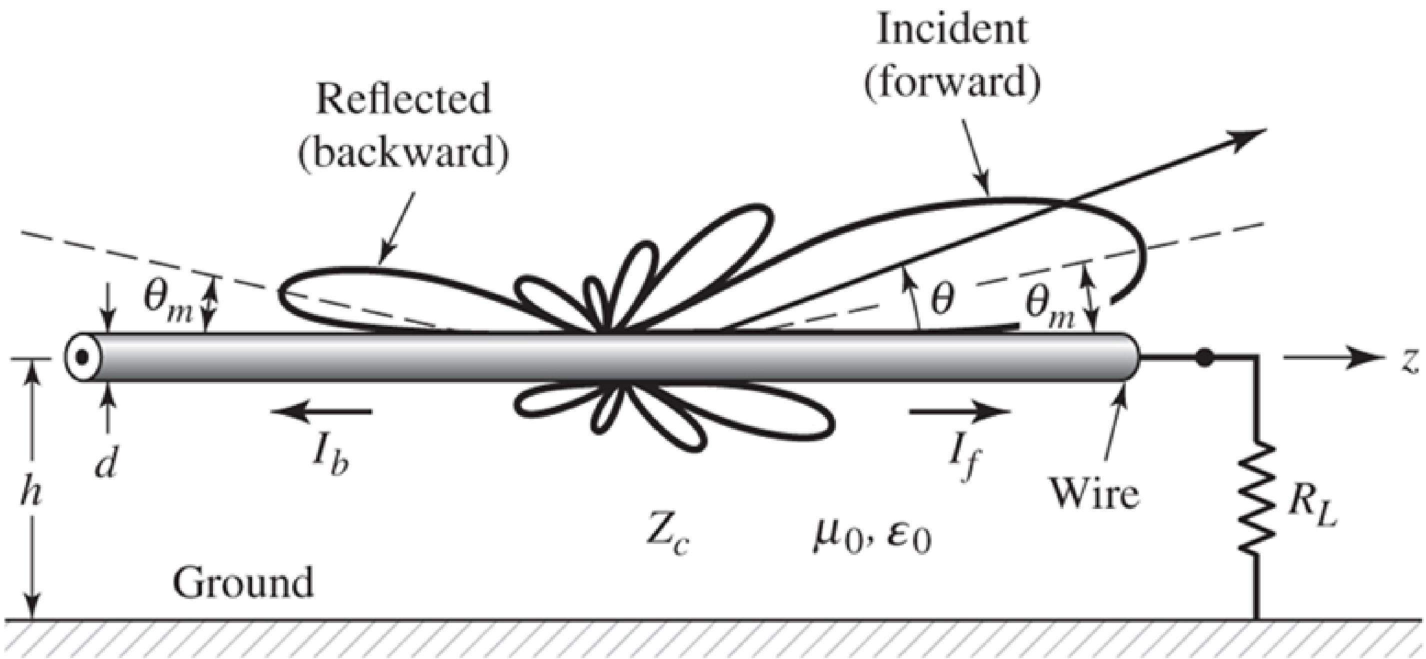


The incoming signal's E-field builds up a voltage wave along the antenna wire. The resulting signal is either absorbed or transferred to a feed line to the receiver.

Long Wire (Beverage) Antenna

can be analyzed as a rectangular loop, according to image theory. However, the effects of an imperfect ground may be significant and can be included using the reflection coefficient approach. [ref]





(a) Long wire above ground and radiation pattern

Beverage Antenna – Radiation Pattern

$$\theta_{\max} = \arccos\left(1 - \frac{\lambda}{2L}\right),$$

where

L is the length of the antenna wire,
λ is the wavelength.

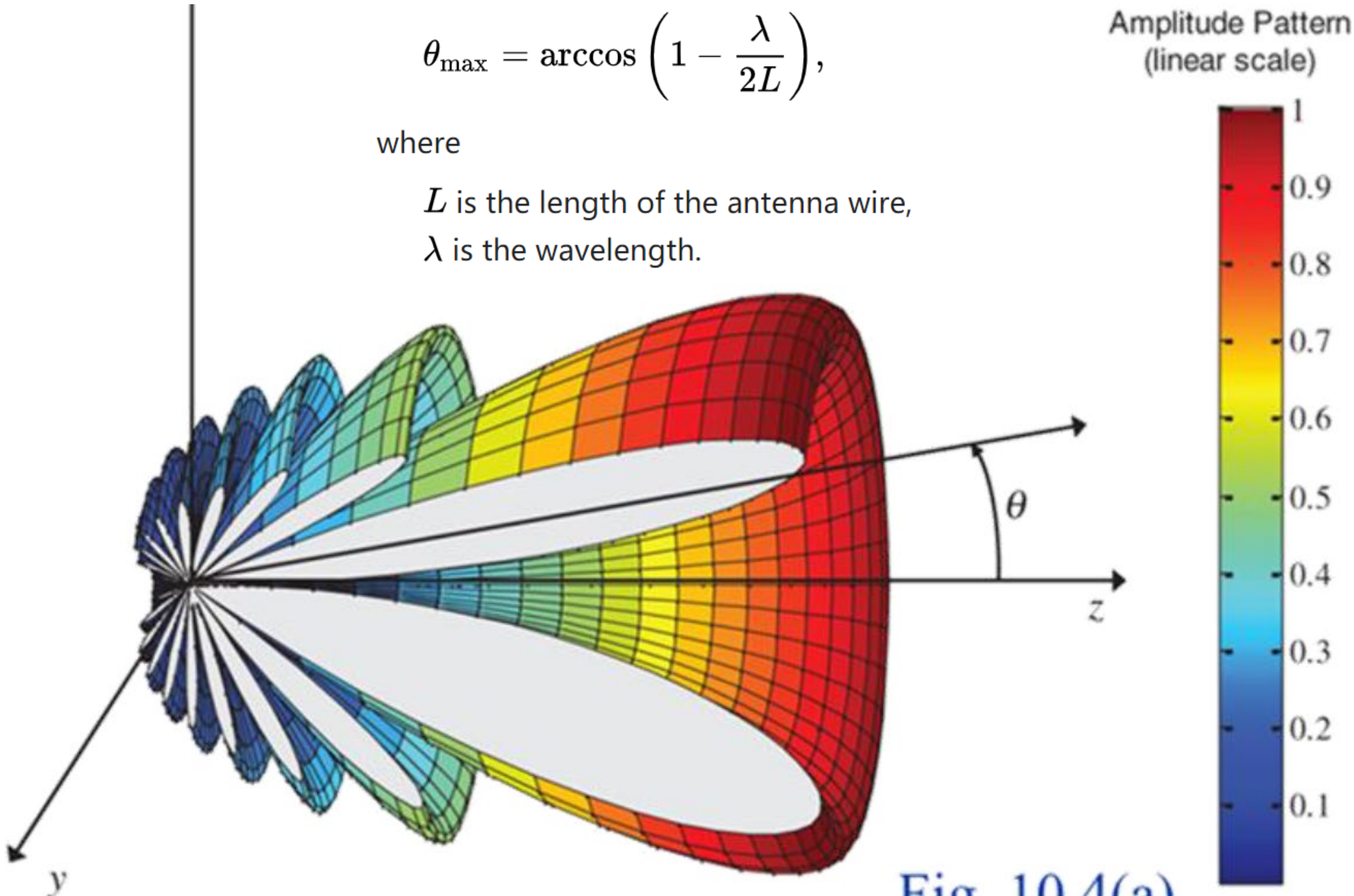
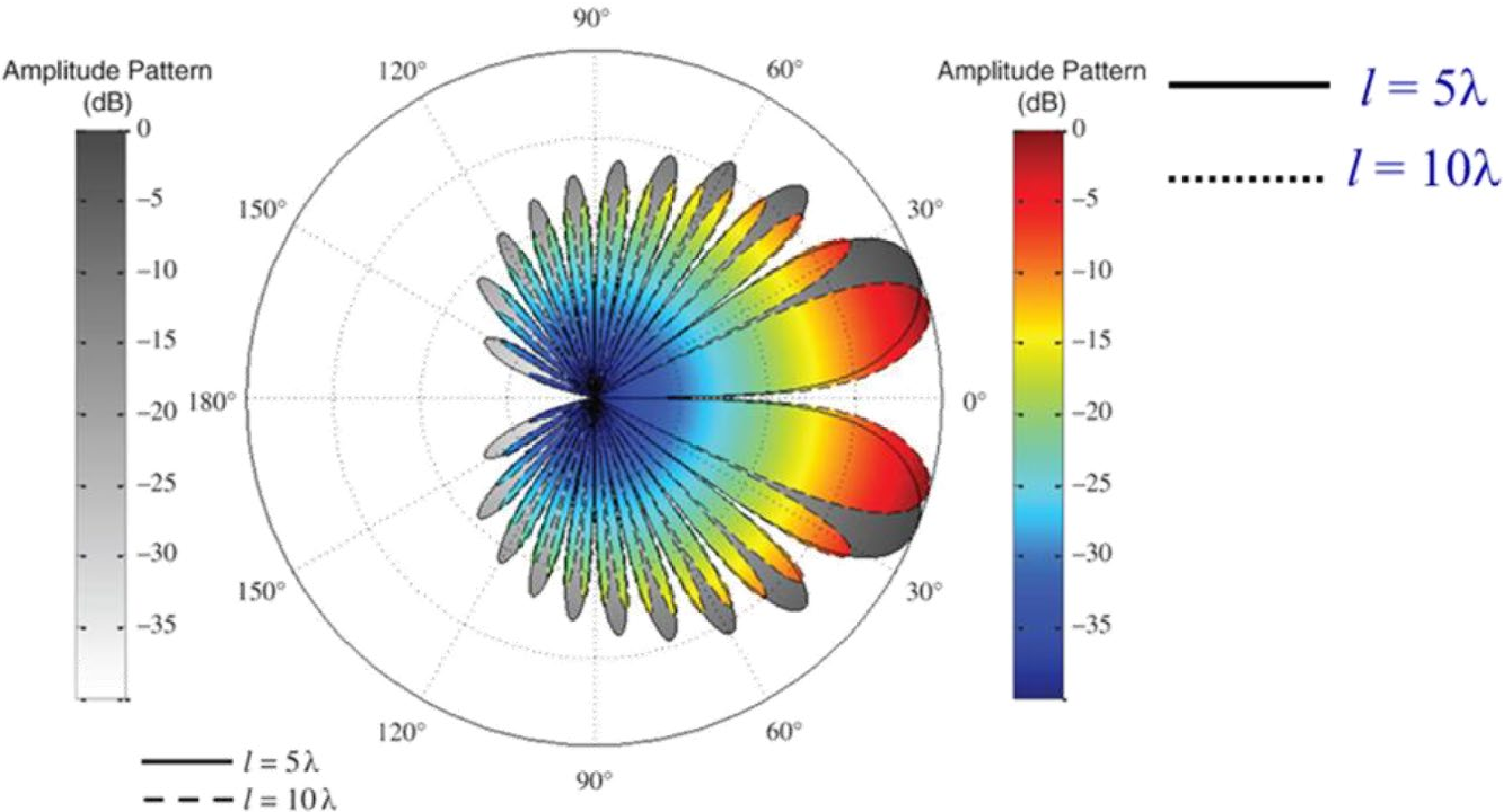


Fig. 10.4(a)

Beverage Antenna – Radiation Pattern



V Antenna

One very practical array of long wires is the symmetrical V antenna formed by using two wires with one of its ends connected to a feed line.

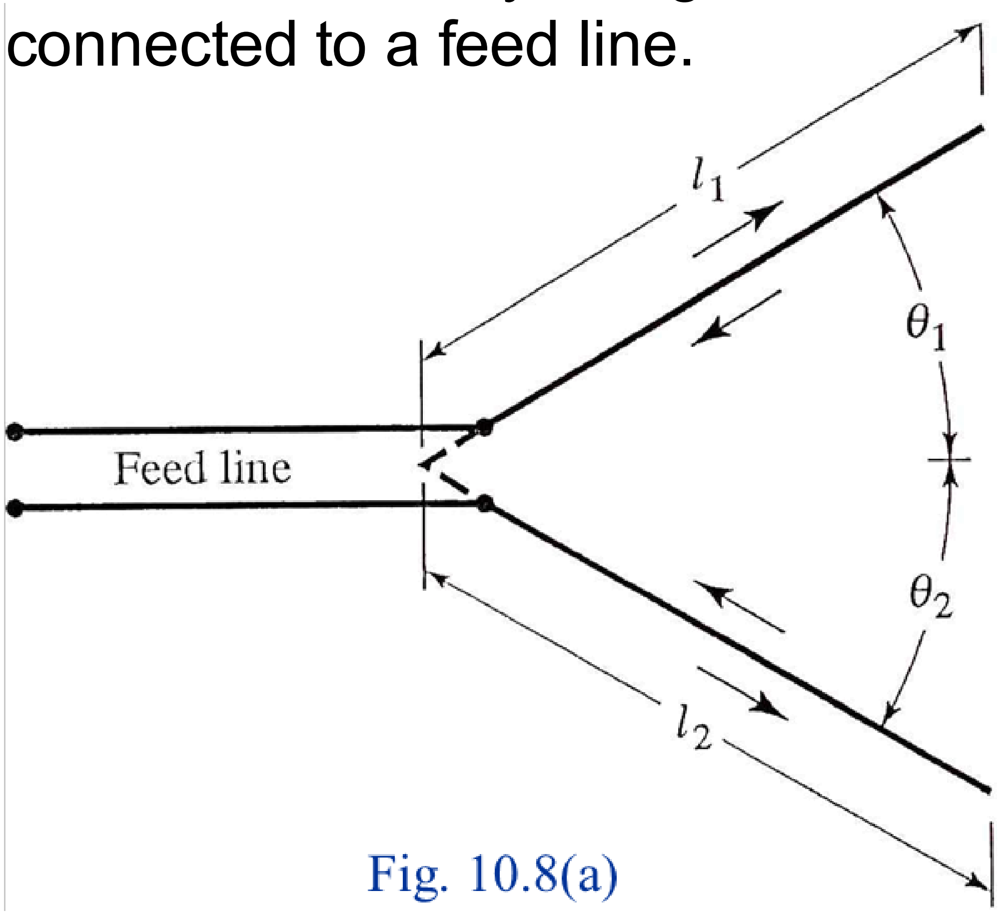
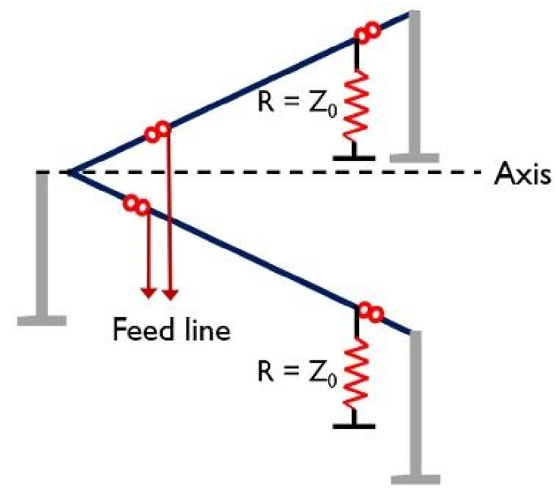


Fig. 10.8(a)



Non-resonant V antenna

Electronics Desk

V Antenna

Adjusting the angle (θ_1 and θ_2) to obtain greater directivity and smaller side lobes. The patterns on each wire are conical in form and inclined at an angle.

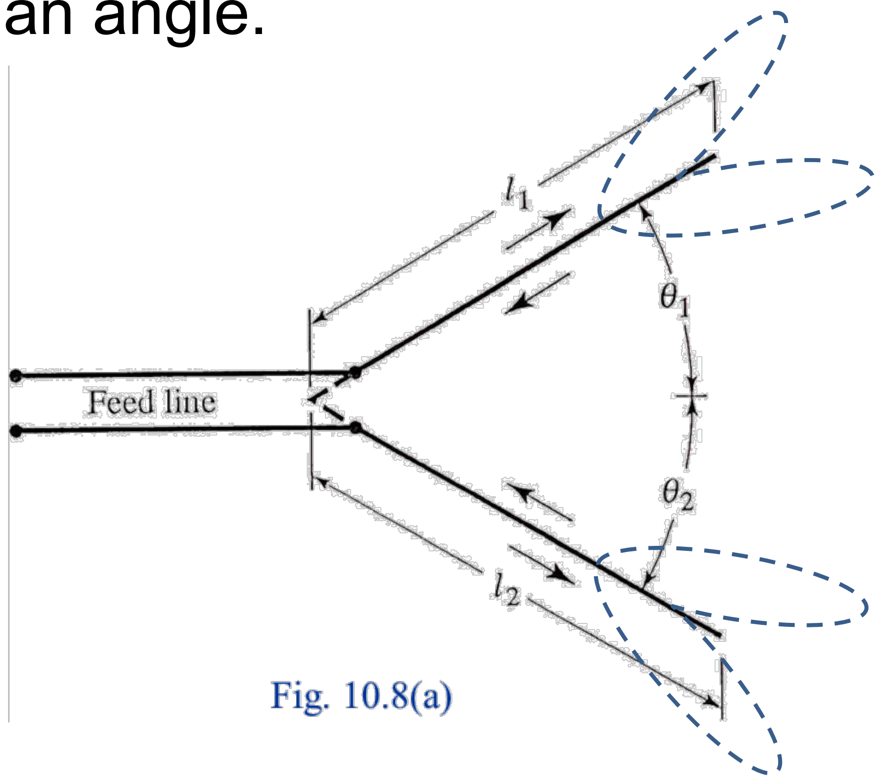
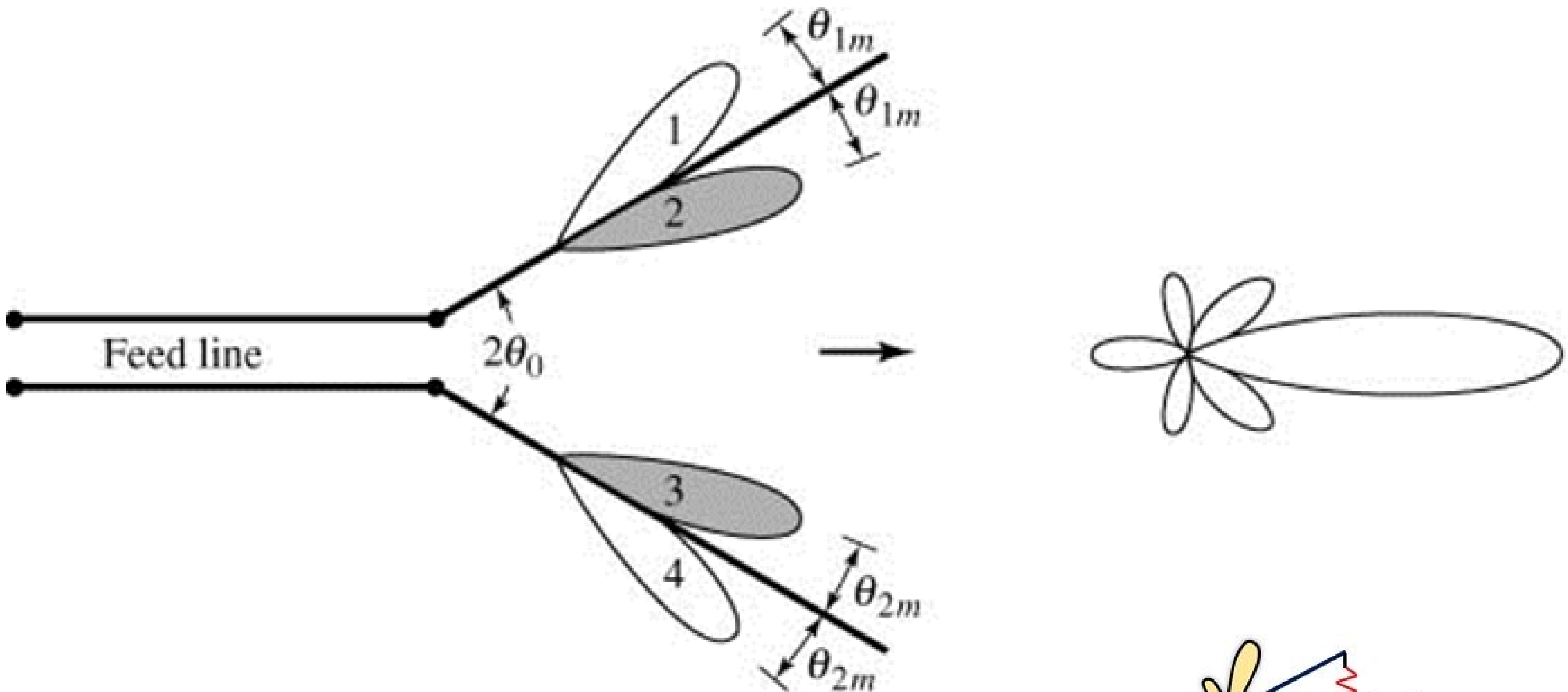
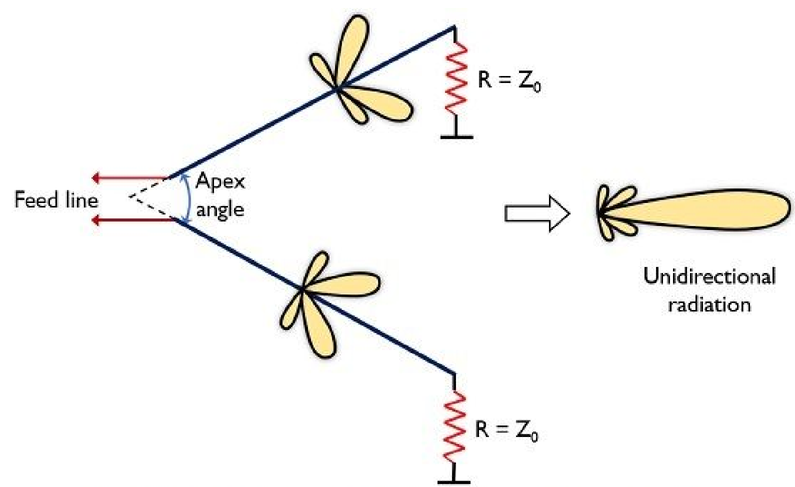


Fig. 10.8(a)

V Antenna – Pattern Beams



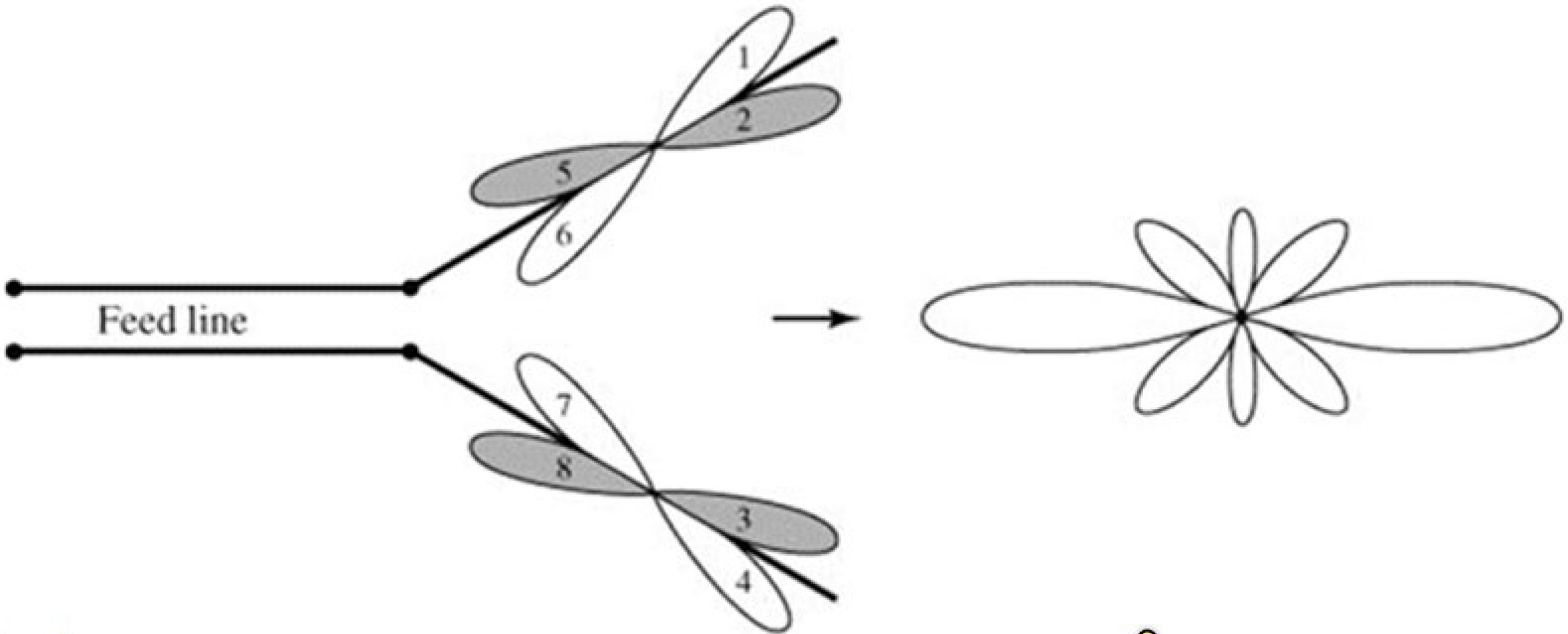


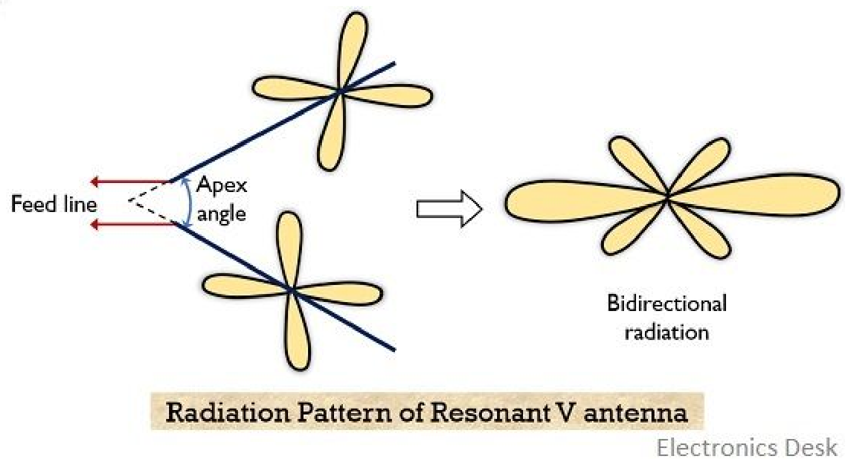
Radiation Pattern of Non-Resonant V antenna

Electronics Desk

When the correct arrangements are made, the patterns are aligned and add constructively. There is an **optimum angle** which leads to the **largest directivity**.

V Antenna – Pattern Beams





When the correct arrangements are made, the patterns are aligned and add constructively. There is an optimum angle which leads to the largest directivity.

Resonant - Open ended for both legs

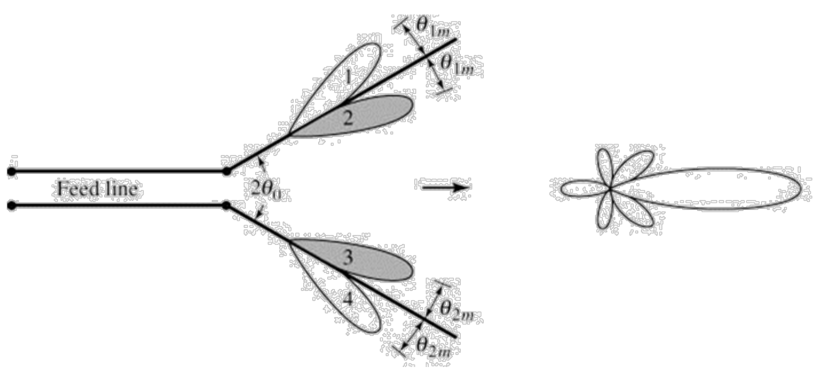
V Antenna – Parameters

Optimum angles for maximum directivity:

$$2\theta_0 = \begin{cases} -149.3\left(\frac{l}{\lambda}\right)^3 + 603.4\left(\frac{l}{\lambda}\right)^2 - 809.5\left(\frac{l}{\lambda}\right) + 443.6, & 0.5 \le \frac{l}{\lambda} \le 1.5 \\ 13.39\left(\frac{l}{\lambda}\right)^2 - 78.27\left(\frac{l}{\lambda}\right) + 169.77, & 1.5 \le \frac{l}{\lambda} \le 3 \end{cases}$$

Directivity of the antenna:

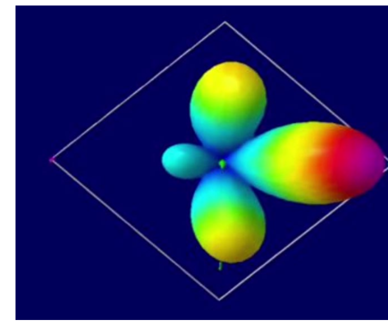
$$D_0 = 2.94\left(\frac{l}{\lambda}\right) + 1.15, \qquad 0.5 \le \frac{l}{\lambda} \le 3$$



Rhombic Antenna

The rhombic antenna are two V antennas connected in a diamond or rhombic shape, and terminated in the other end in a resistor to reduce or eliminate reflections.

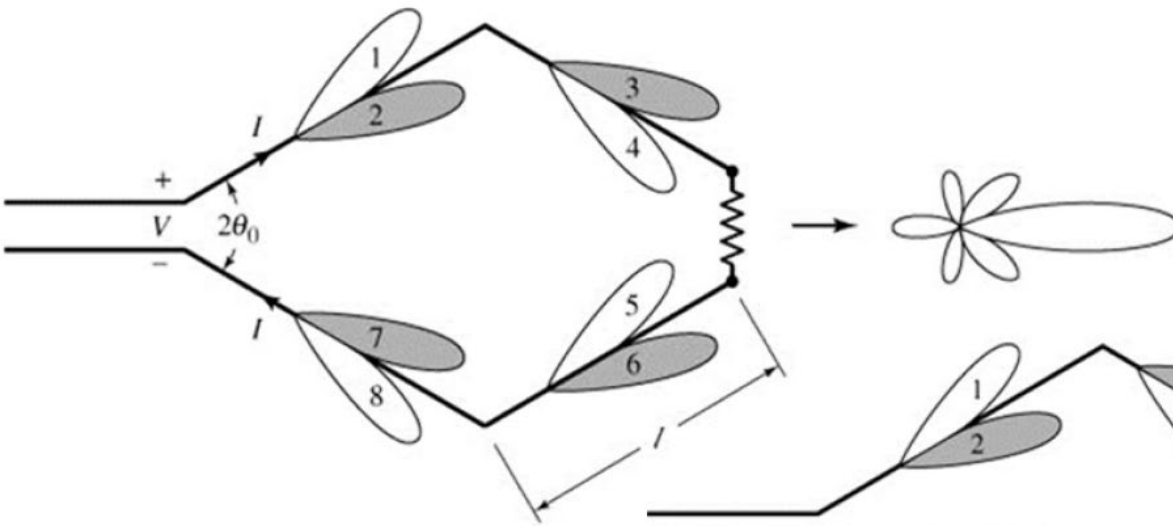
If the length of the legs is large enough, a resistor may not be needed, and has high radiation efficiency.

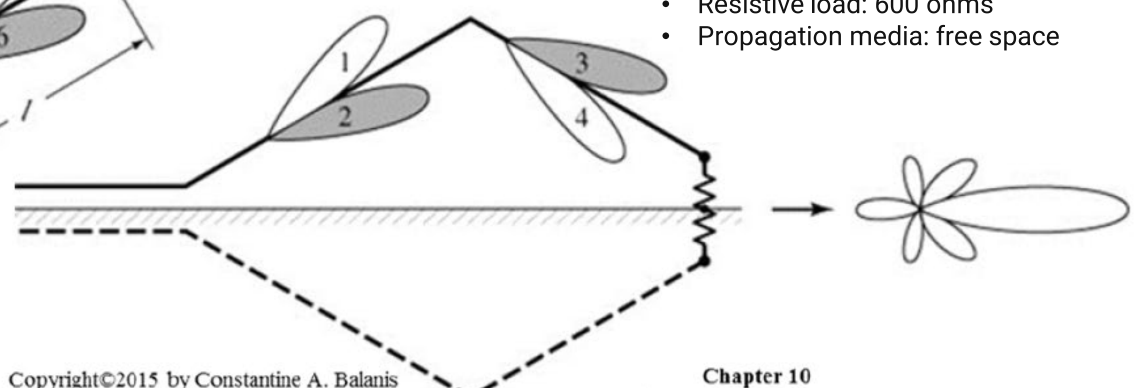


Variations of the acute angle

4Nec2 3D radiation pattern simulation

- Working frequency: 14 MHz
- Angle variations: 30 to 90 degree
- Length of leg: 21.42 m (2 wavelengths)
- Resistive load: 600 ohms
- Propagation media: free space





Chapter 10
Traveling Wave, Broadband Antennas

Rhombic Antenna

The rhombic antenna was designed in the 1931 by Edmond Bruce and **Harald Friis**, It was mostly commonly used in the high frequency (HF) or shortwave band as a broadband directional antenna. Prior to World War II, the rhombic was one of the most popular point-to-point high frequency antenna arrays.

Today it is still used by many radio Amateurs, also known as ham radio

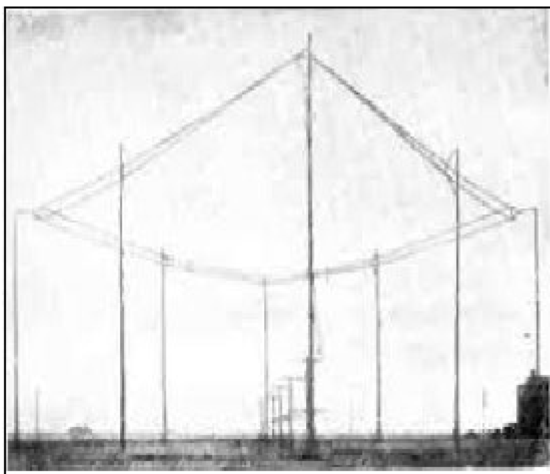


Figure 1

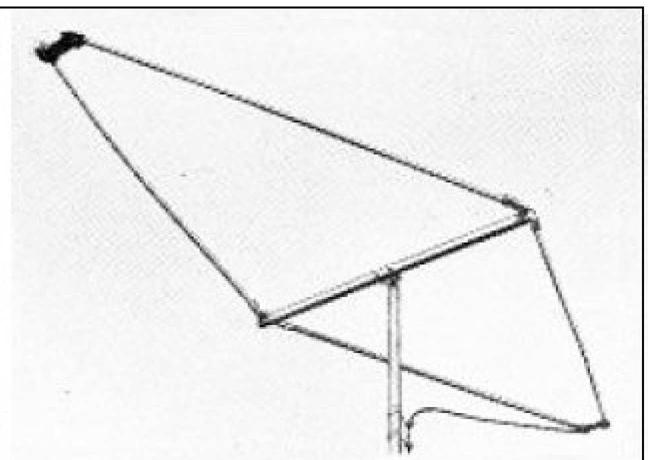
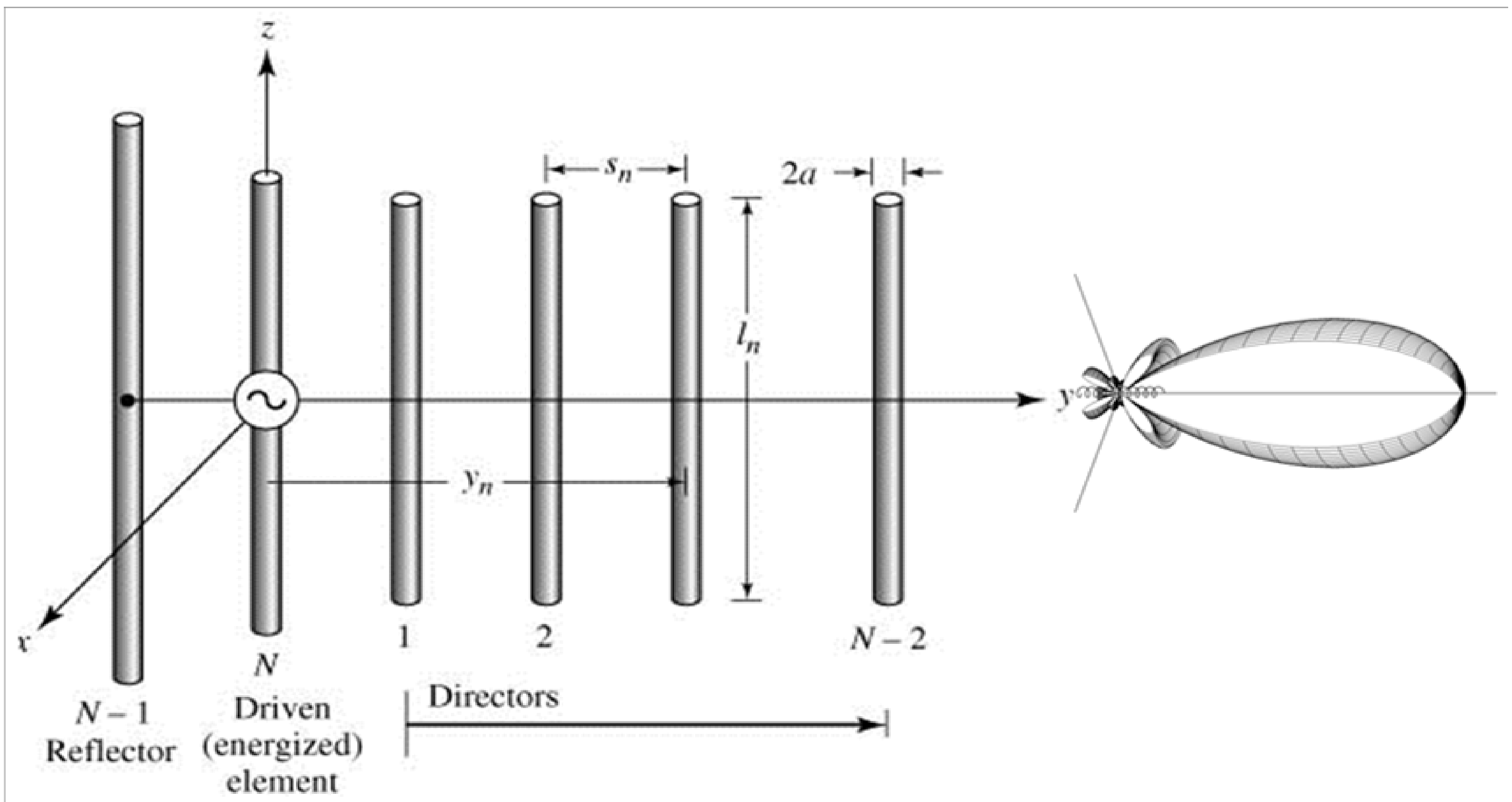


Figure 2

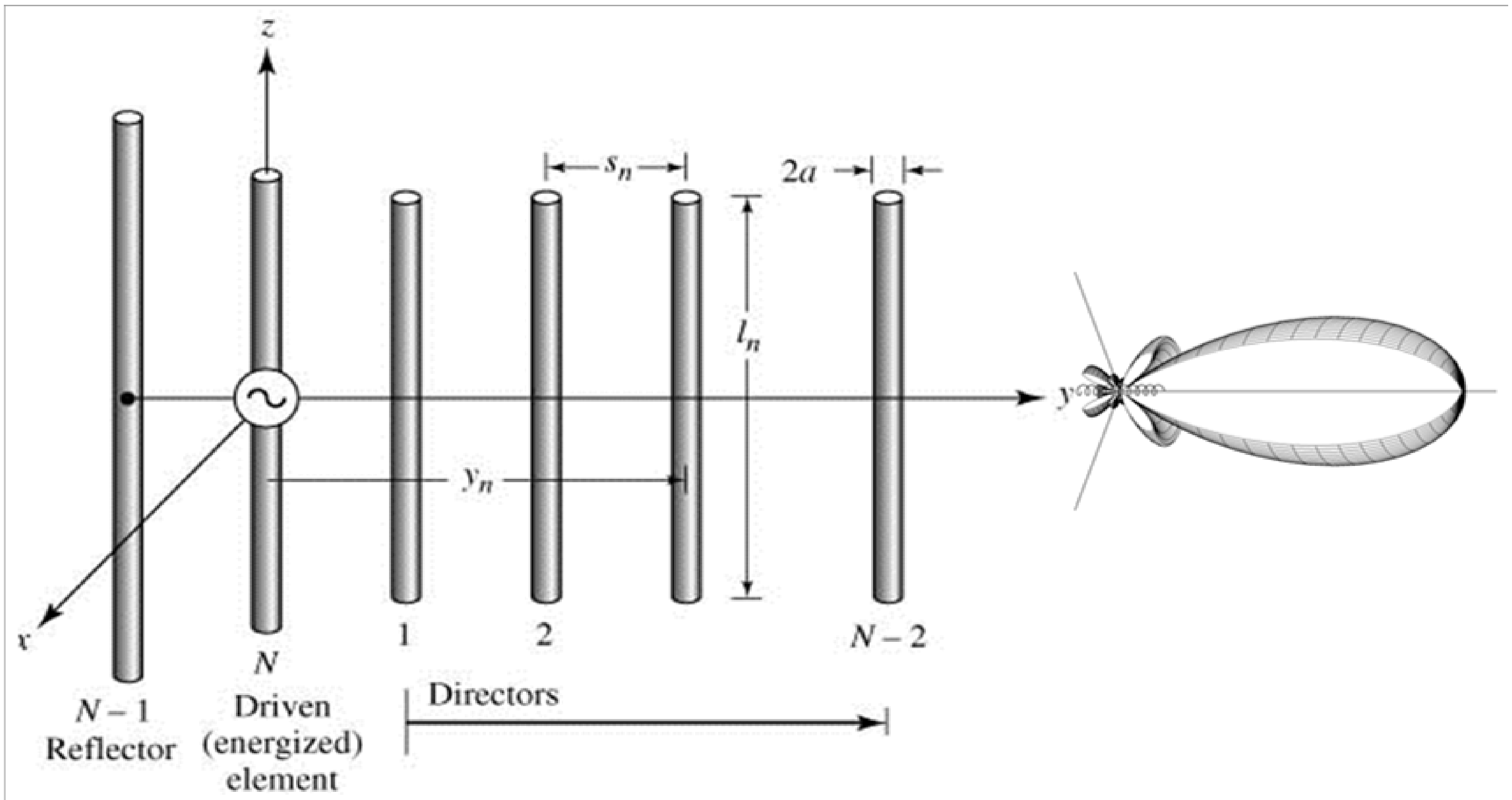
Yagi-Uda Array of Linear Elements (八木-宇田天线)

Yagi–Uda antenna, or simply Yagi antenna invented in 1926 by Hidetsugu Yagi (八木秀次) and Shintaro Uda (宇田新太郎) of Tohoku Imperial University (日本东北大学), Japan



Yagi-Uda Array of Linear Elements (八木-宇田天线)

An array consisting of a number of linear dipole elements. One of them is energized directly by a feed transmission line while the others act as parasitic radiators (directors and reflector) whose currents are induced by mutual coupling.

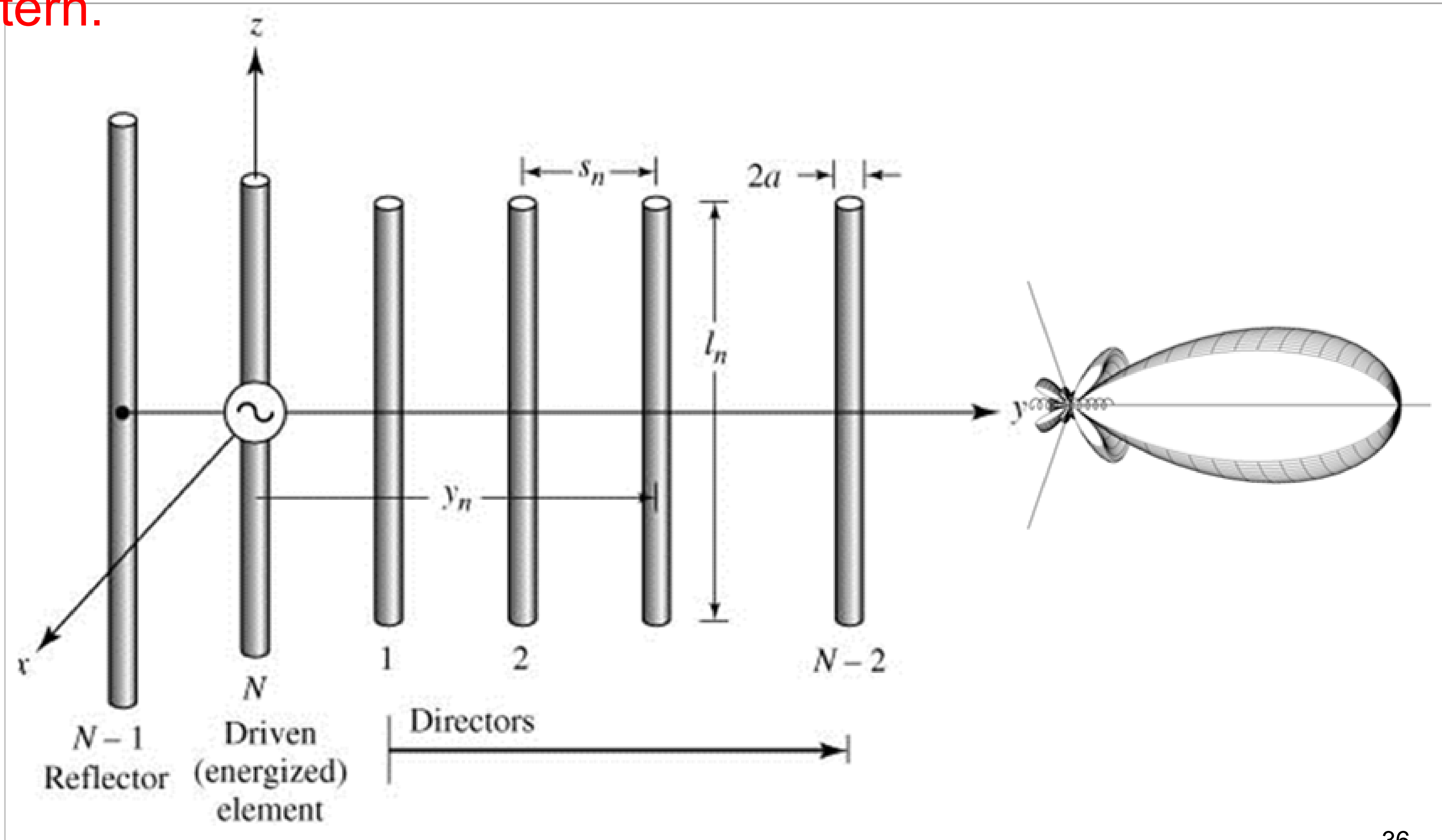


Yagi-Uda Array of Linear Elements

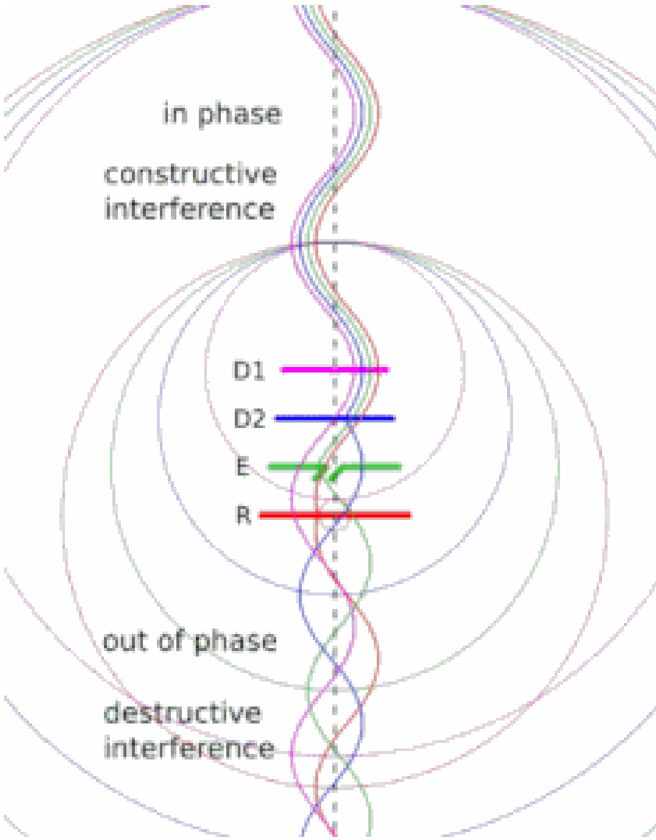
frequently used in practice because they are **lightweight**, **simple** to build, **low-cost**, and provide moderately **desirable characteristics** for many applications (e.g. Cable TV, Military)

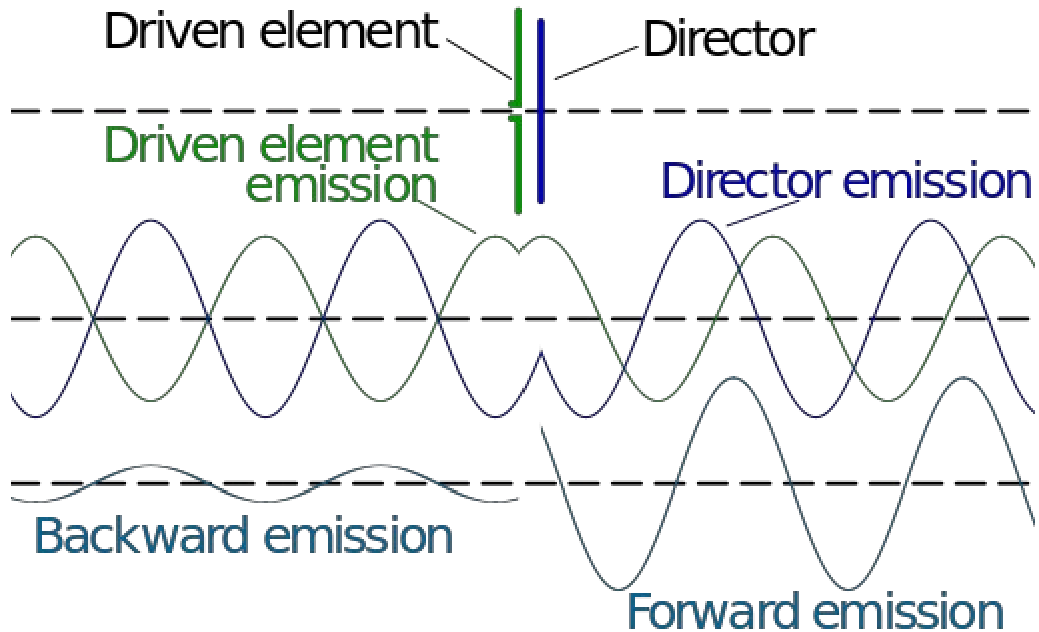
Yagi-Uda Array of Linear Elements

Yagi antennas use mutual coupling between standing-wave current elements to produce a traveling-wave unidirectional pattern.



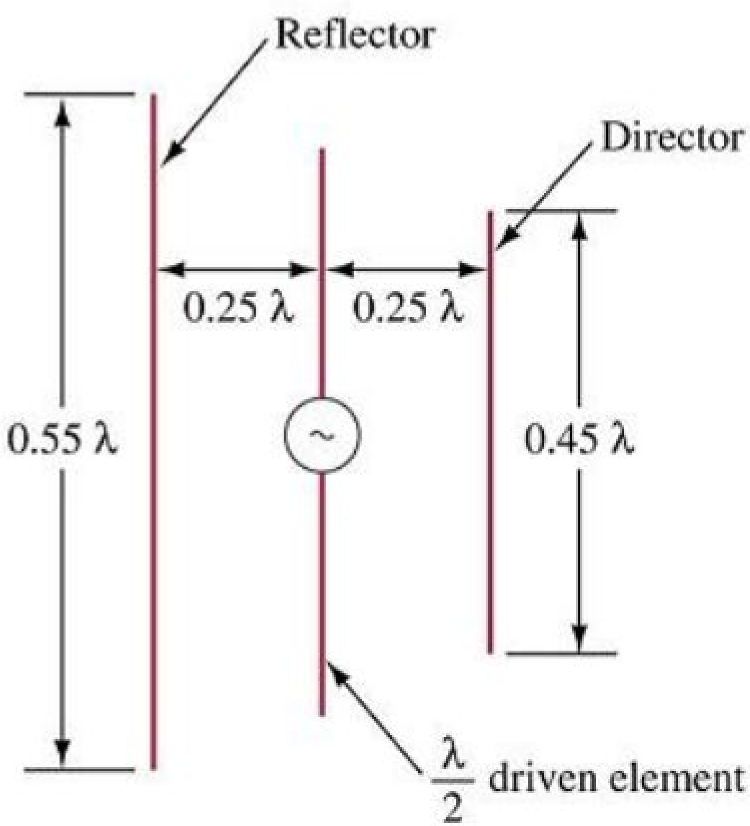
Yagi-Uda Array of Linear Elements



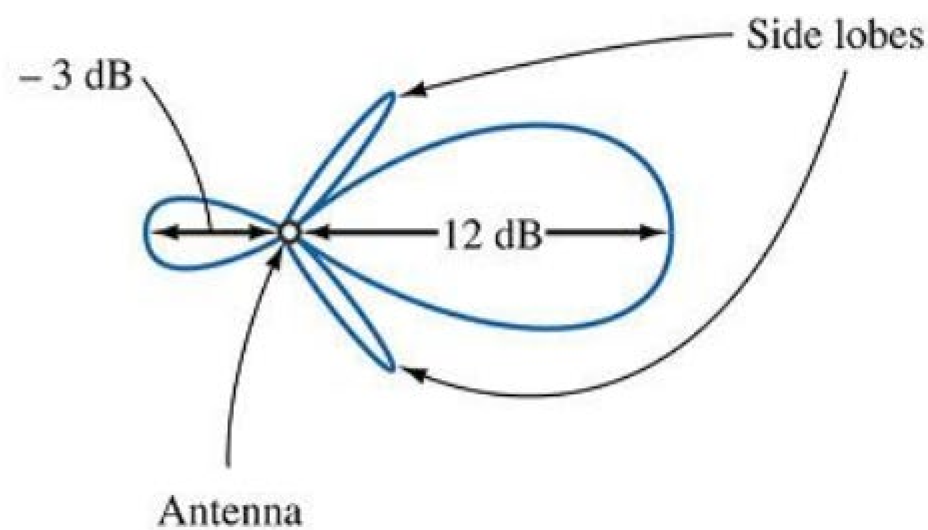


Yagi-Uda Array of Linear Elements

A 3 element Yagi



Associated radiation pattern



Yagi-Uda Array of Linear Elements

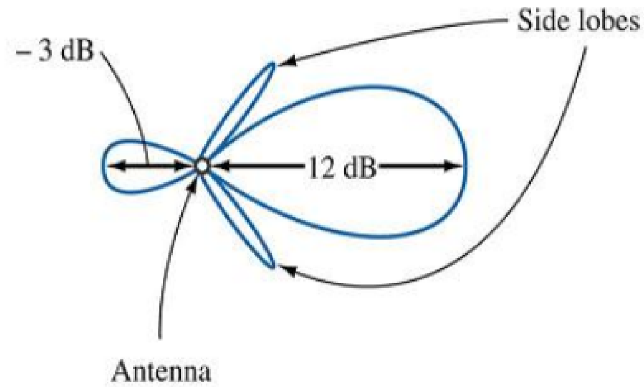
- The front-to-back ratio (F/B ratio) is the ratio of the power radiated in the forward direction to the power radiated in the backward direction.

$$F/B = 10\log\frac{P_f}{P_b} \quad \text{dB}$$

P_f = Forward power

P_b = Backward power

If the radiation patterns are plotted in decibels, the F/B ratio is simply the difference between the forward value and the backward value, in dB

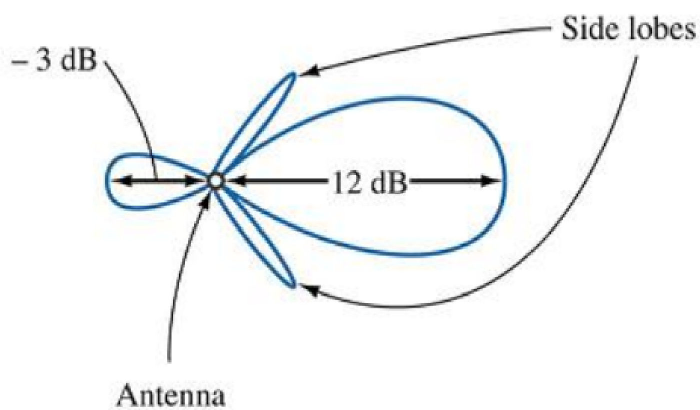


*Most Yagi antennas are designed to maximize F/B ratio rather than gain. This minimizes the radiation and reception from the rear of the antenna.

Yagi-Uda Array of Linear Elements

Example Problem (Solution)

1. What is the front to back ratio for the radiation pattern shown below?
2. What is the power ratio?



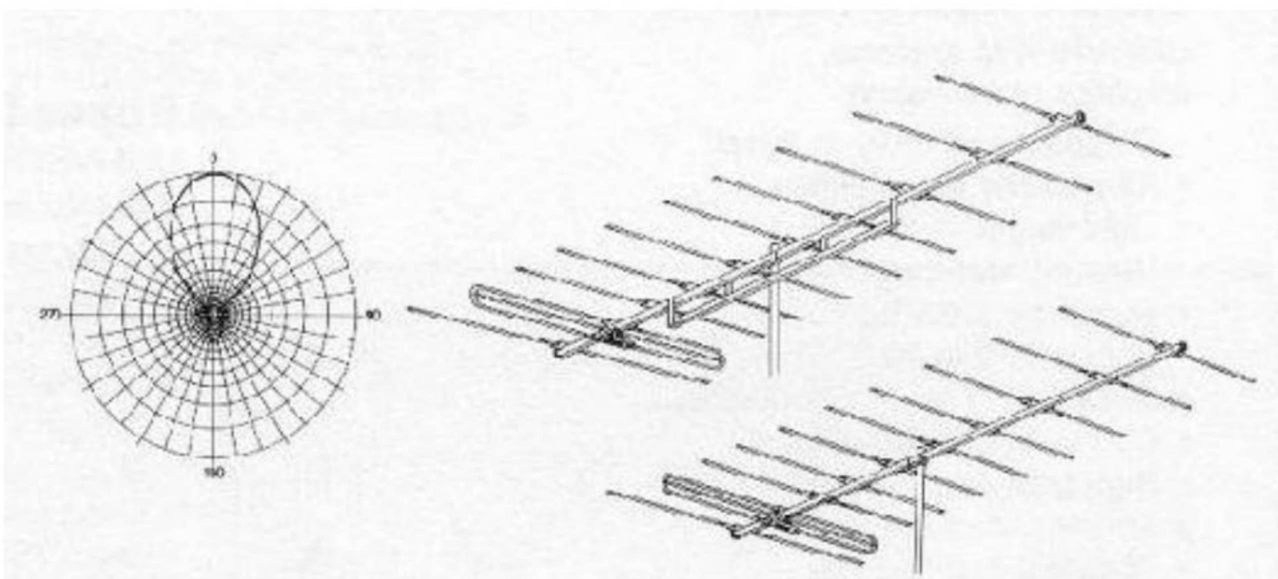
1. F/B Ratio = 12 dB – (-3 dB) = 15 dB

2. Start with $F/B = 10\log\frac{P_f}{P_b}$

$$\frac{P_f}{P_b} = 10^{\frac{F/B}{10}} = 10^{\frac{15}{10}} = 31.6$$

Yagi-Uda Array of Linear Elements

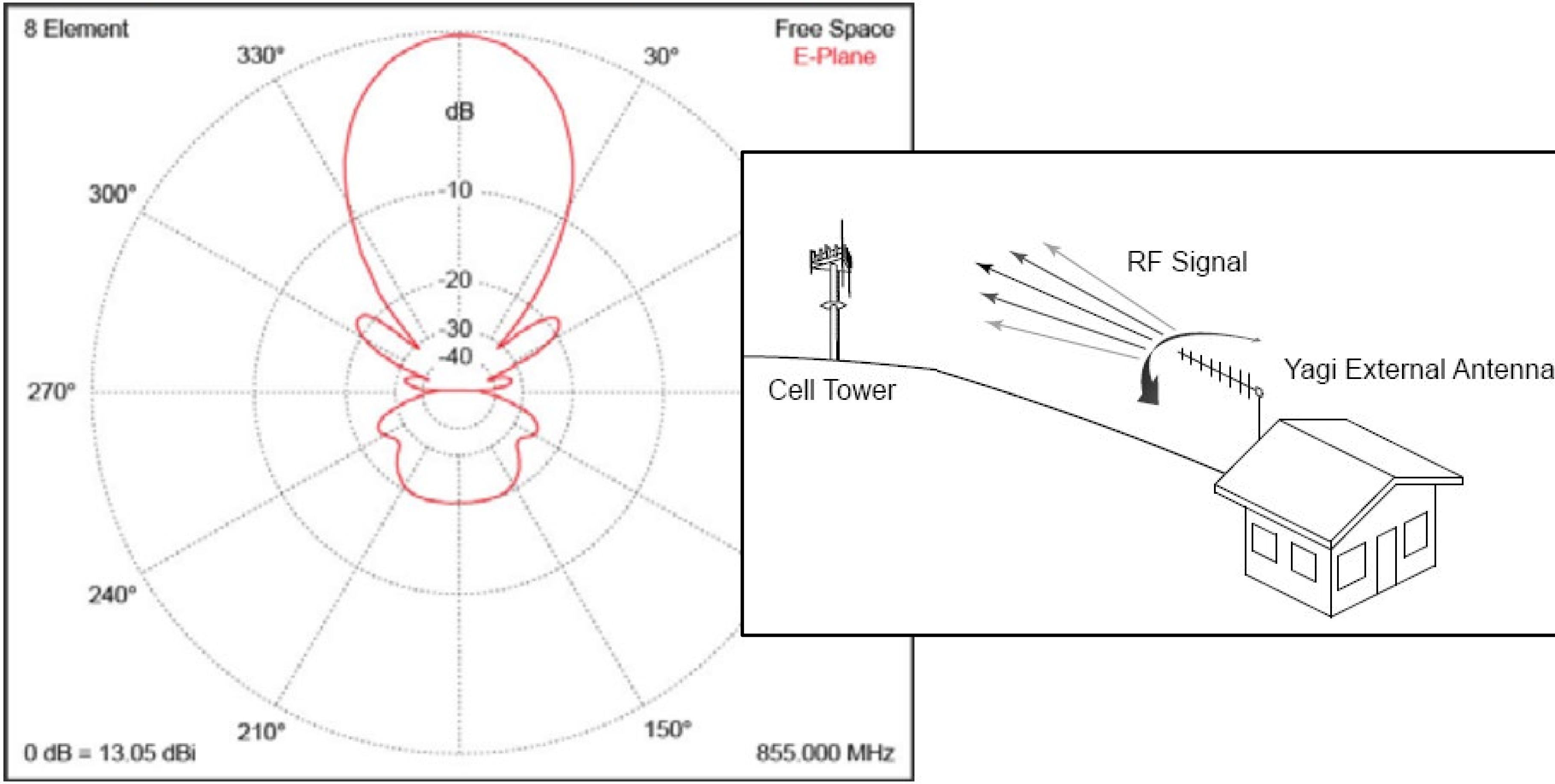
- More complicated Yagi-Uda antennas consist of a reflector and many directors to improve gain.
- This type antenna design is common of HF transmitting antennas and VHF/UHF television receiving antennas.



10 element Yagi VHF-TV antenna (10 dB gain)

Yagi-Uda Array of Linear Elements

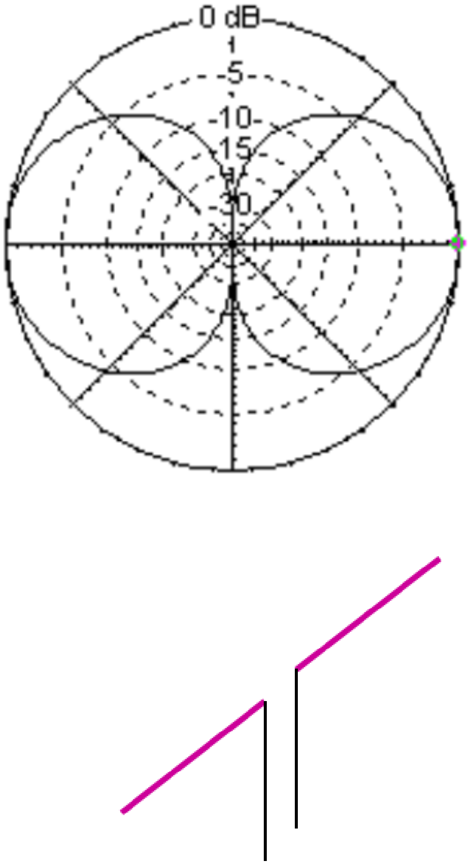
Slightly different radiation pattern plot



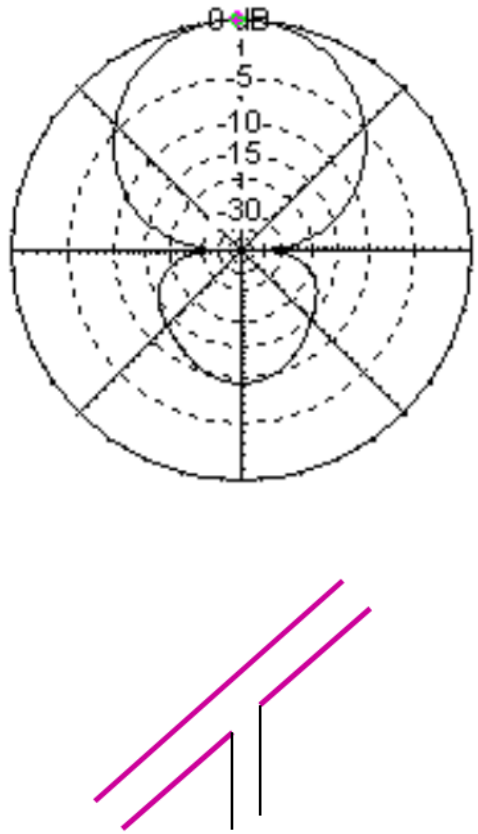
13dbi Yagi 806-939 MHz Cellular Antenna

Yagi-Uda Array of Linear Elements

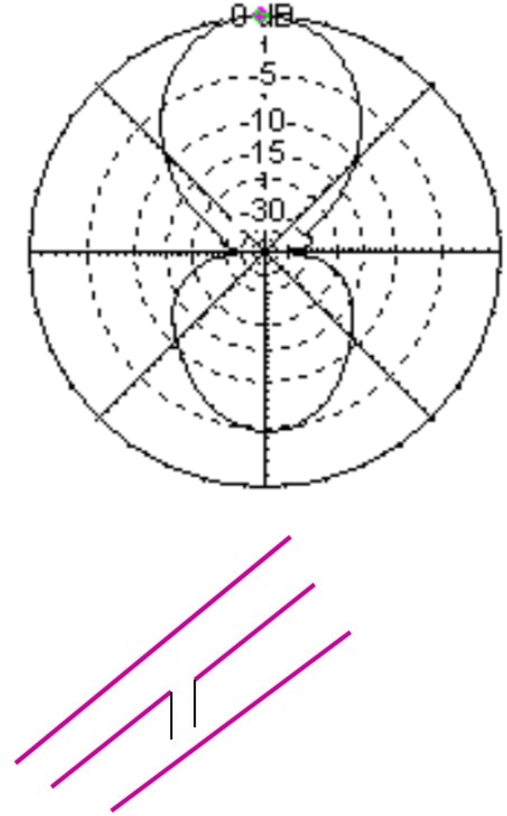
Impact of Reflector and Director



Dipole (2.16dBi)



2 Element Yagi (5.37dBi)



3 Element Yagi (7.94dBi)

Yagi-Uda Array of Linear Elements

Impact of Reflector and Director

APPROXIMATE YAGI-UDA ANTENNA GAIN LEVELS

NUMBER OF ELEMENTS	APPROX ANTICIPATED GAIN DB OVER DIPOLE
2	5
3	7.5
4	8.5
5	9.5*
6	10.5*
7	11.5*

* In practice around 8dB

Yagi-Uda Array of Linear Elements

Impact of Reflector and Director (impedance matching)
A 3-element yagi has a resistive impedance of between 10 ohms (Ω) and 40 Ω

Element spacing: There is a level of impedance variation that can be provided by altering the spacing between the elements. However it is not possible to bring the feed impedance back up to 50Ω needed for most feed applications. .
Balun: A balun is an impedance matching transformer and can be used to match a great variety of impedance ratios, provided the impedance is known when the balun is designed.
Folded dipole: One method which can effectively be implemented to increase the feed impedance is to use a folder dipole. In its basic form ***it raises the impedance four fold***, although by changing various parameters it is possible to raise the impedance by different factors.
Delta match: This method of Yagi impedance matching involves "fanning out" the feed connection to the driven element.
Gamma match: The gamma match solution to Yagi matching involves connecting the out of the coax braid to the centre of the driven element, and the centre via a capacitor to a point away from the centre, dependent upon the impedance increase required.

Yagi-Uda Array of Linear Elements

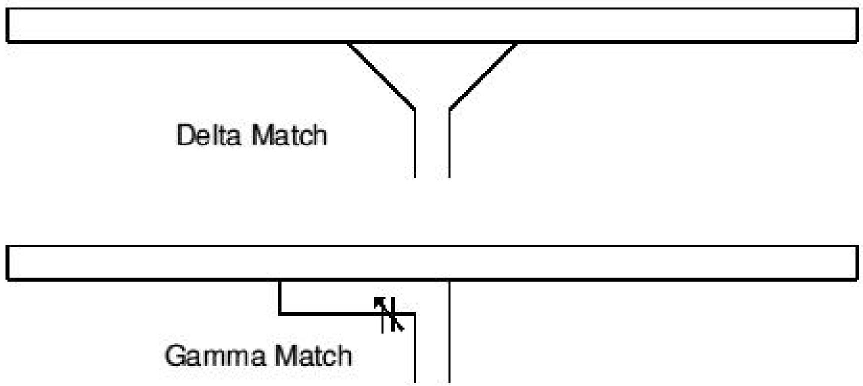
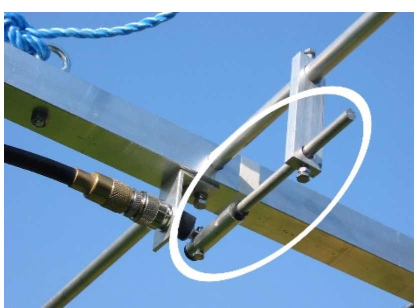
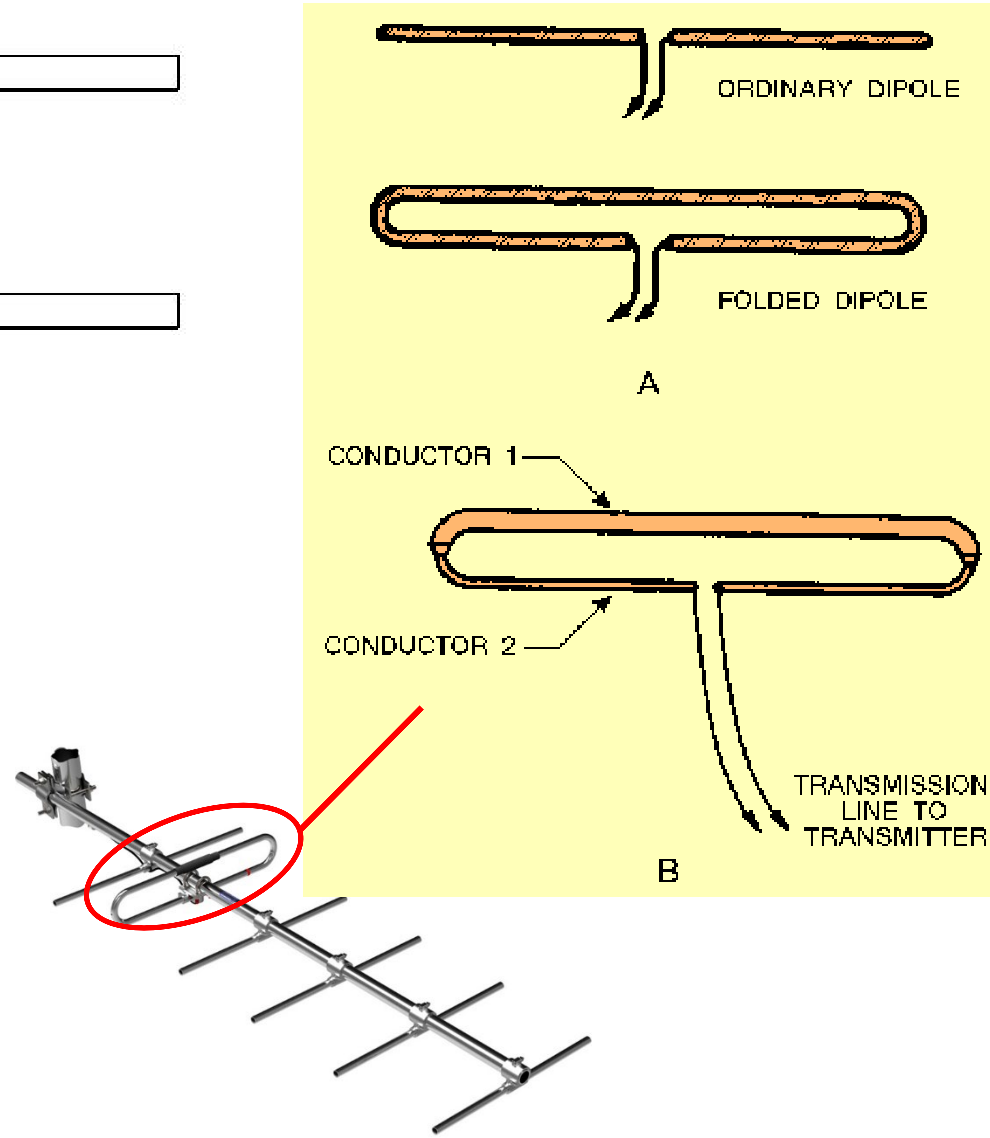


fig 1





Yagi-Uda Array of Linear Elements

Pros:
- Easy to construct
- Relatively good gain (6-9 dB)
- Good front to back ratio

Cons:
- Gain not high enough
- Narrow bandwidth (2-3%)

Broadband Antennas

An **antenna** whose main parameters and characteristics do not vary substantially over a rather wide frequency band.

Broadband antennas are used to transmit, receive, or transmit and receive radio signals with a wide frequency spectrum, for example, in television, radar, or radio astronomy.

Usually bandwidth (f_H/f_L) >=2 (for return loss, VSWR, gain, impedance etc.)

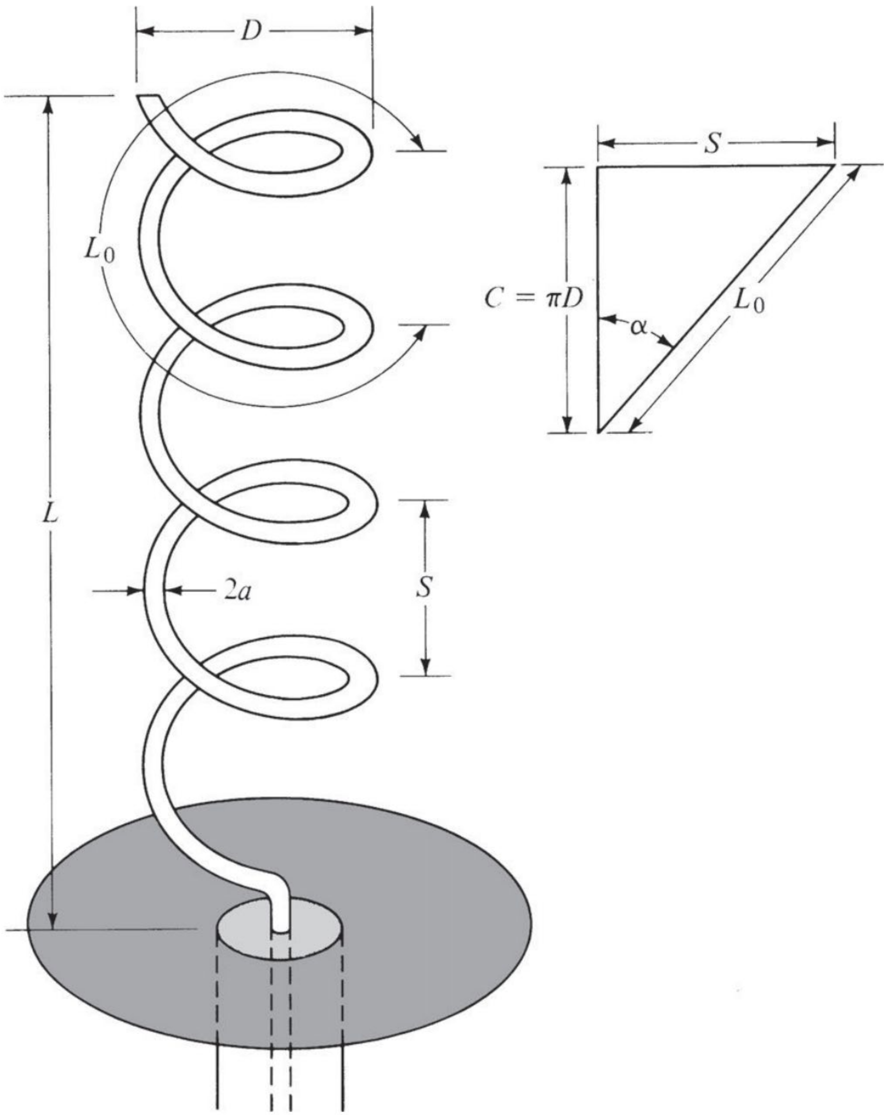
Some well-known examples of broadband antennas

Helical / Spiral / Log-Periodic Dipole (directional wire antennas) and the Conical / Asymptotical Conical Dipole (omnidirectional antennas).

Helical Antenna

- a travelling wave antenna
- wide bandwidth
- easily constructed
- real input impedance
- can produce circularly polarized fields
- invented by Kraus in 1946

Helical Antenna



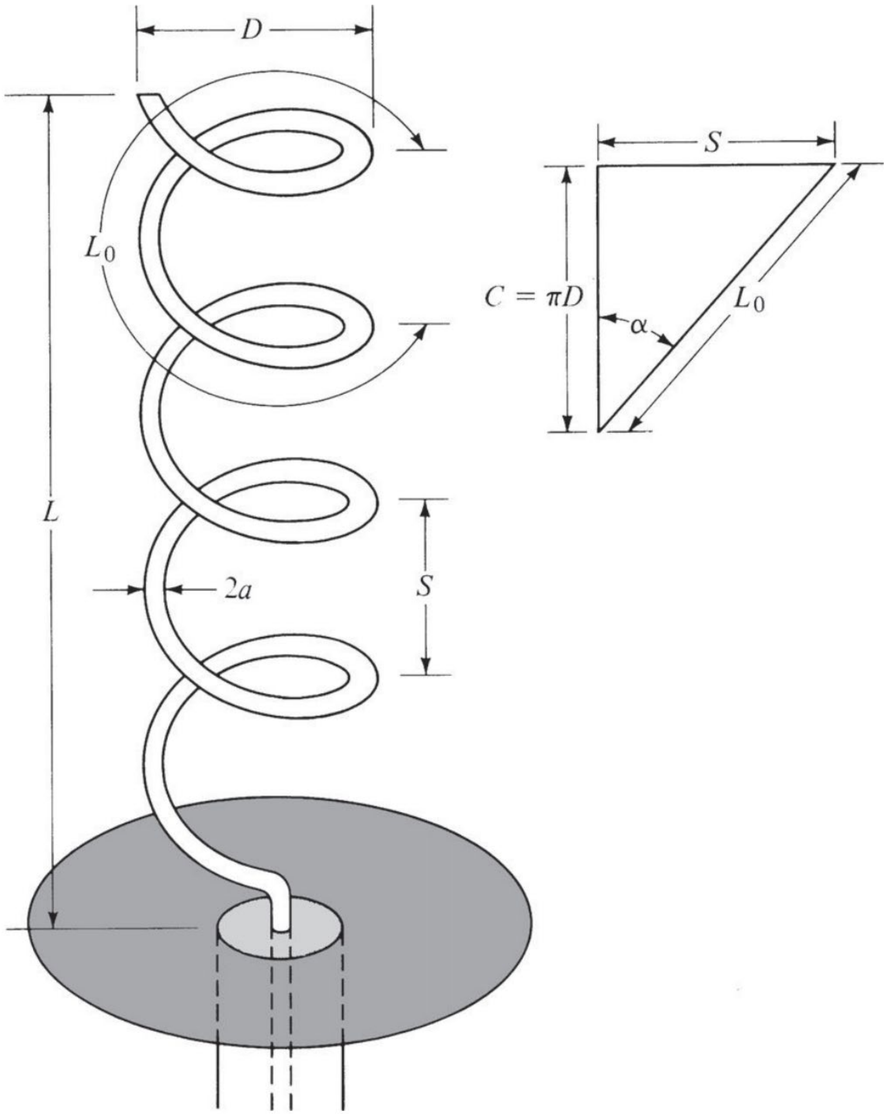
S: The spacing or pitch between the turns of the helix.
C: The circumference of one turn, equal to ***πD***.
D: The diameter of the helix, the width of one complete turn.
L_0: The length of wire used for one complete turn of the helix, which can be different from the circumference if the wire is not a perfect circle.
α: The pitch angle, the angle between the helix wire at any point and the plane perpendicular to the helical axis.
L: The total length of the helix along the axis, from base to top.

$$\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{S}{C}\right)$$

C=πD

Total Length of wire $L_{Total} = nL_0$
Total axial length $L = nS$

Helical Antenna



Special Cases

Case 1:

α = 0° ⇒

pitch S = 0 ⇒

Loop Antenna

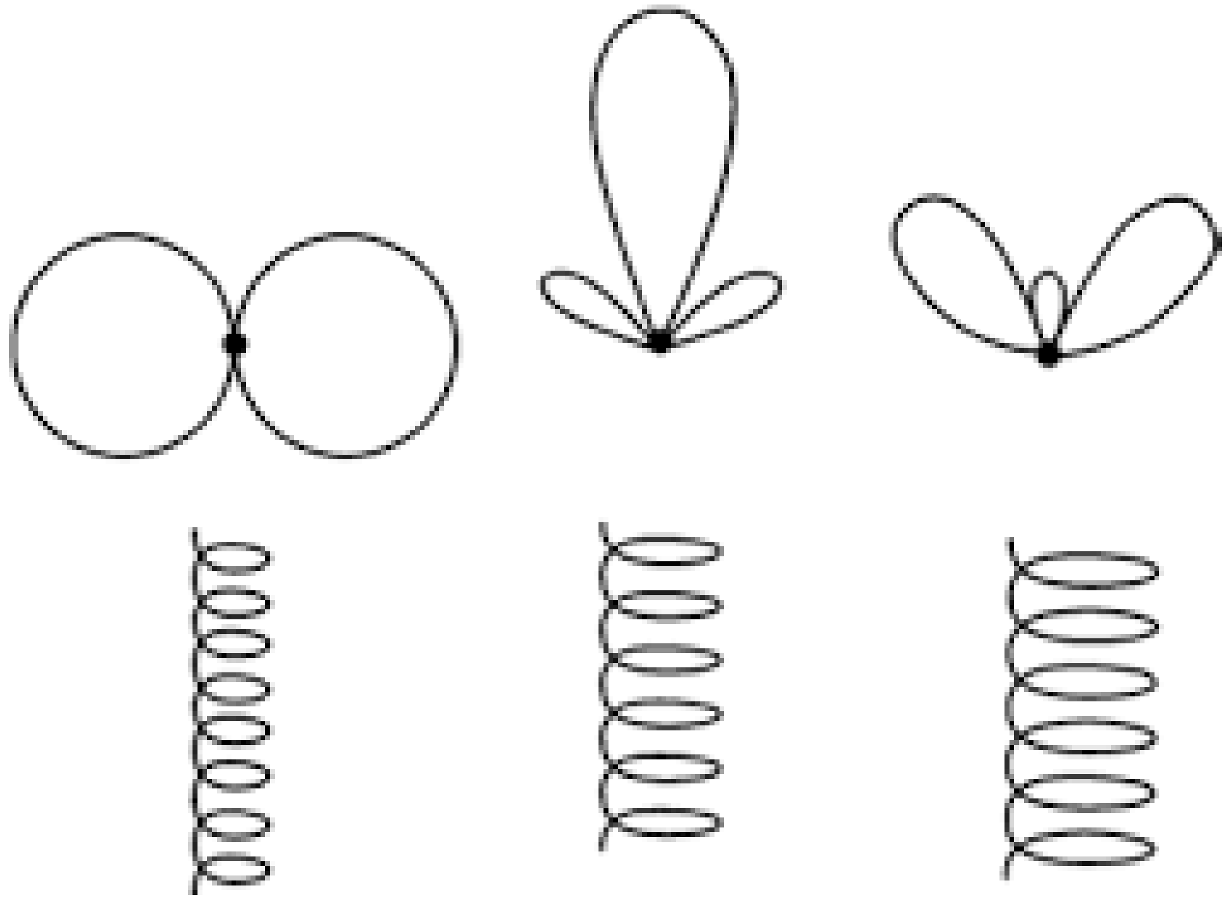
Case 2:

α = 90° ⇒

diameter D = 0 ⇒

Linear Antenna

Modes in Helical Antenna



Normal Mode	Axial Mode	Conical Mode
$\mathbf{C = \pi D << \lambda}$	$\mathbf{C \approx \lambda}$	$\mathbf{C \approx n\lambda, n = 2, 3..}$

Modes in Helical Antenna

Normal mode

- the radiation field **normal to the helix axis** and **circularly polarized**
- dimensions of helix are **small** compared to the wavelength $(C = \pi D \ll \lambda)$
- the radiation pattern combining **short dipole** and **loop antenna**.

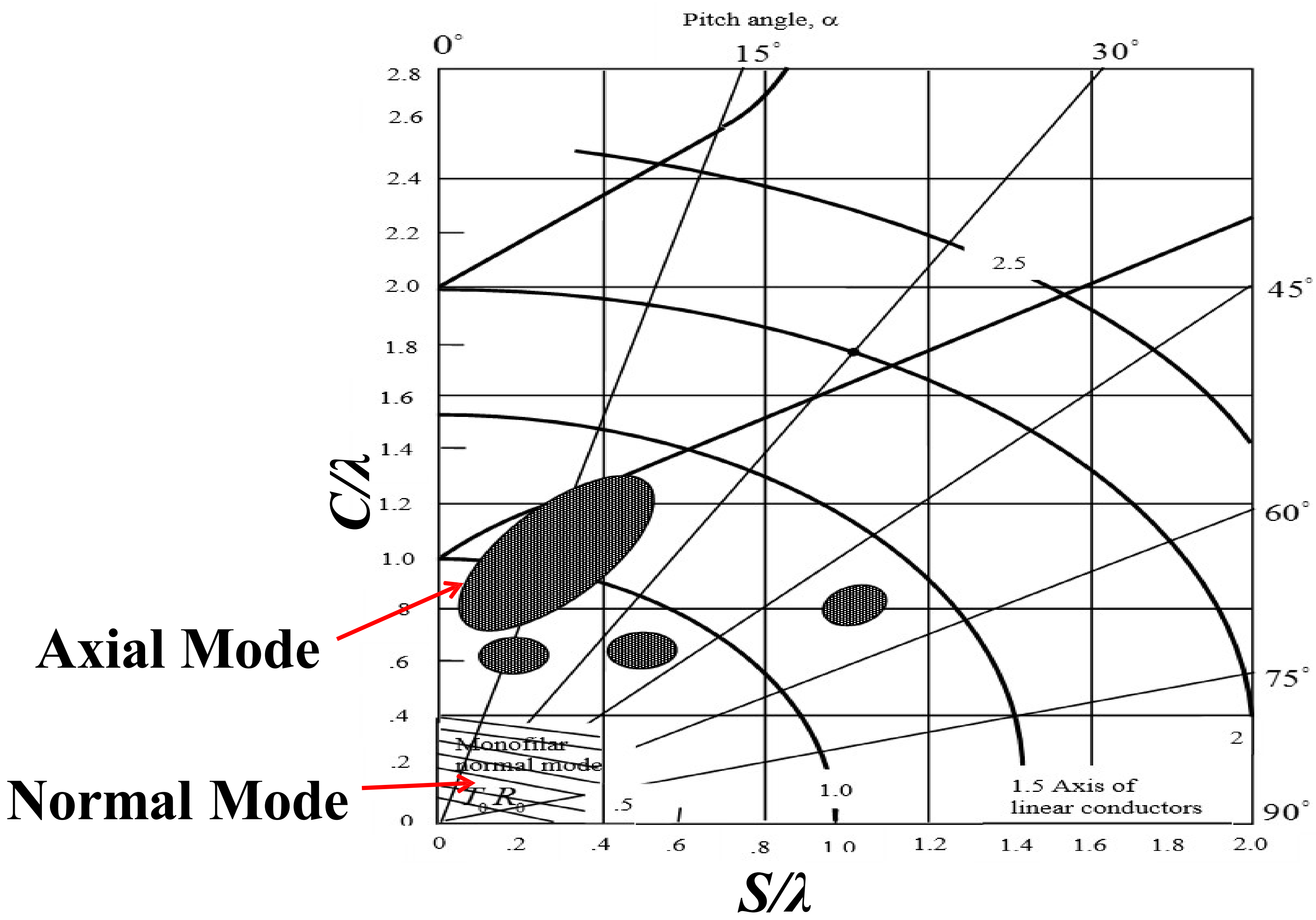
Axial Mode

- the radiation field is **along the axis of the helix** (non-resonant traveling wave mode)
- helix circumference is **near** the wavelength of operation $(C \approx \lambda)$
- **circularly polarized**

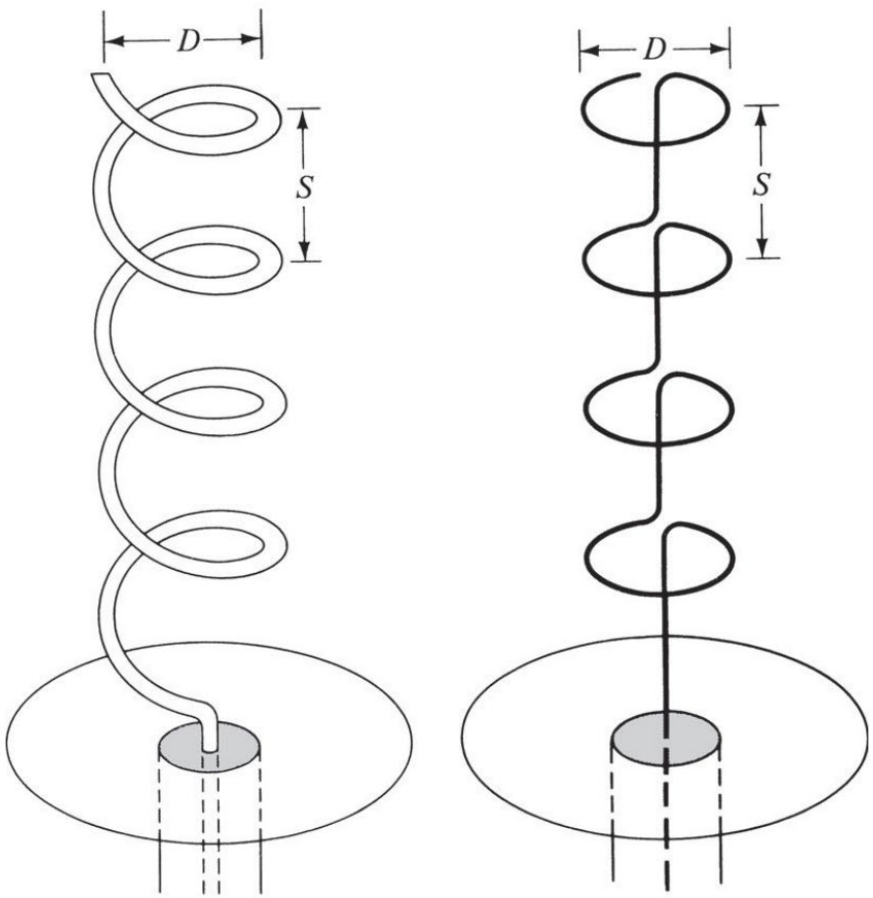
Conical Mode

- the radiation field forming a **conical beam** with **circular polarization**.
- existing a **helical-turn region** in which the input impedance shows a relatively constant value $(C \approx n\lambda,\ n = 2, 3..)$

Helical Antenna Modes Chart



Normal Mode



(a) Normal mode (b) Equivalent

E-Field from a **short dipole** of length S and constant current I_0

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

E-Field of radiated by a **loop**

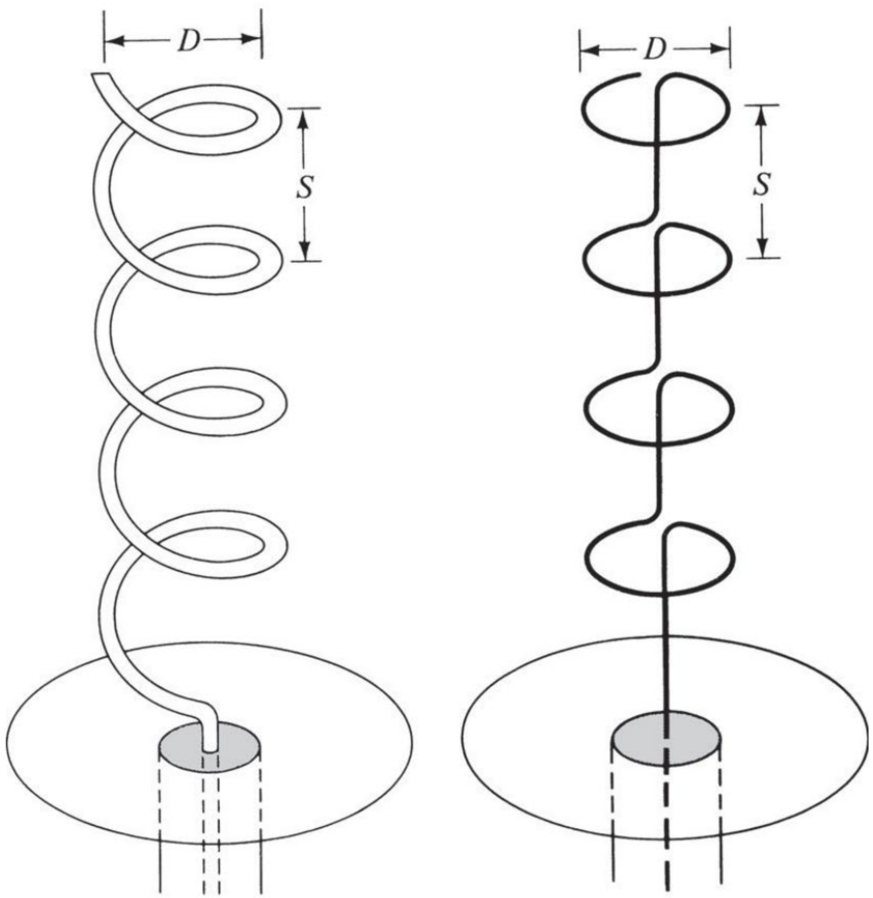
$$E_\phi = \eta \frac{k^2 (D/2)^2 I_0 e^{-jkr}}{4r} \sin\theta$$

Axial Ratio

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

Circular Polarization $\Longrightarrow \dfrac{2\lambda_0 S}{(\pi D)^2} = 1 \Longrightarrow \boxed{C = \pi D = \sqrt{2S\lambda_0}}$

Normal Mode



(a) Normal mode (b) Equivalent

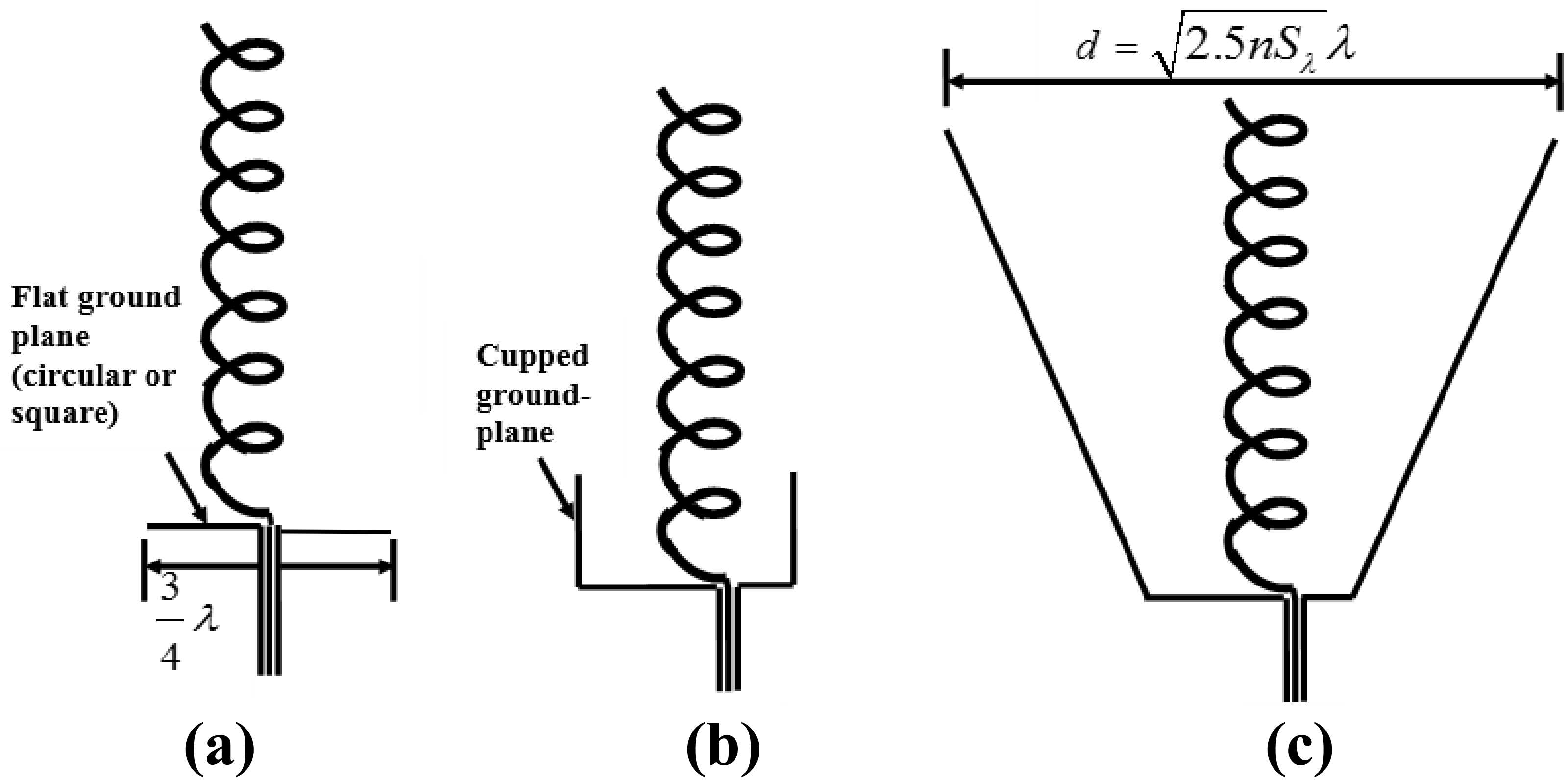
By varying the D and/or S the axial ratio attains values of 0 ≤ AR ≤ ∞

AR = 0 and E_θ = 0:
a linearly polarized wave of horizontal polarization (the helix is a loop)

AR = ∞, E_ϕ = 0:
linearly polarized with vertical polarization (the helix is a vertical dipole).

AR = 1:
circularly polarized in all directions other than $\theta = 0^\circ$ where the fields vanish

Axial Mode Helical Antenna: Ground Plane



Monofilar Axial Mode Helical Antenna

a) Flat Ground Plane

b) Shallow Cupped Ground Plane

c) Deep Conical Ground Plane Enclosure

Axial Mode Helical Antenna: Ground Plane

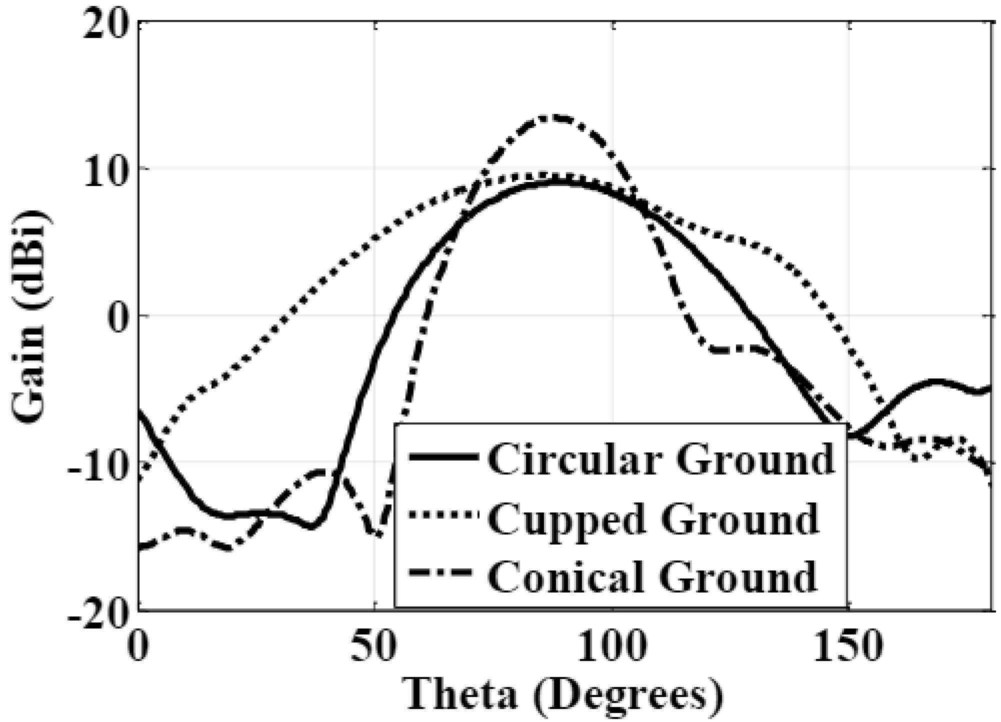
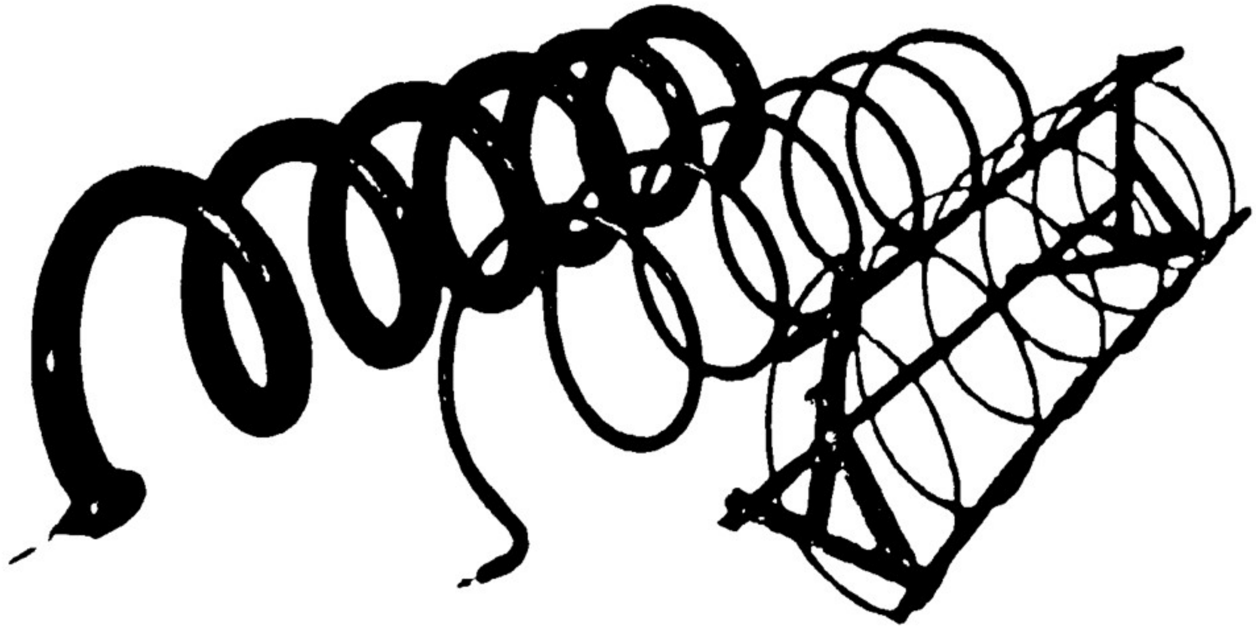


Fig. 7. Measured gain pattern of a helical antenna over different ground plane : circular, cupped with the height of 0.85λ and conical.

Using the **truncated conical ground plane**, the gain of the helical antenna can increase up to 4 dB for optimum cone dimensions.

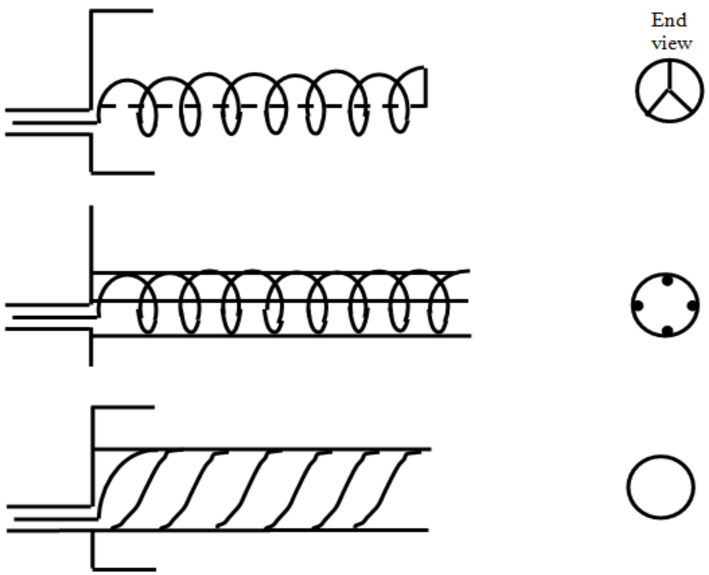
(15) (PDF) Helical Antenna Over Different Ground Planes. Available from: https://www.researchgate.net/publication/283329110_Helical_Antenna_Over_Different_Ground_Planes [accessed Mar 29 2021].

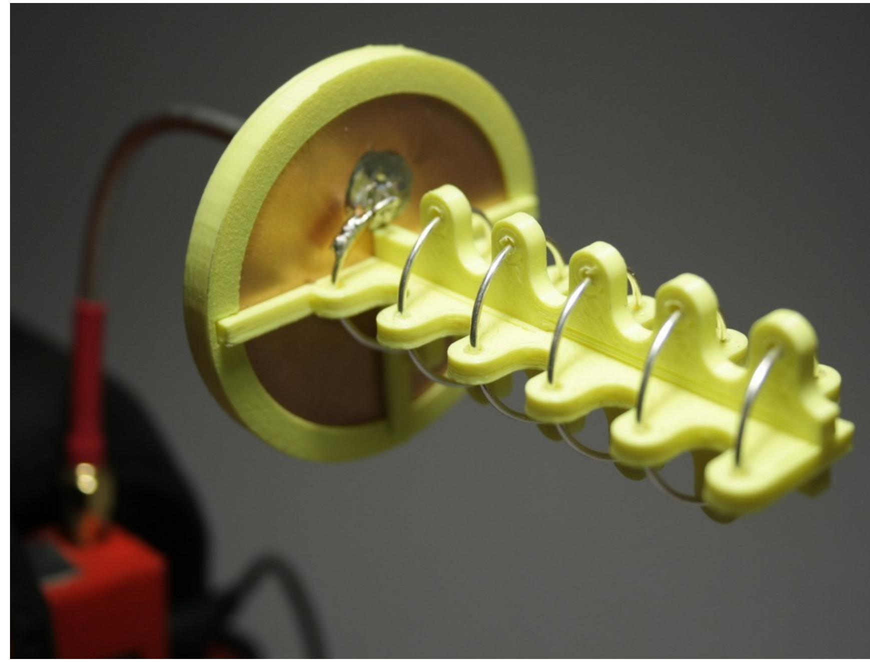
Conductor Size of Helical Antenna



- Monofilar axial-mode helical antennas with wire diameter of 0.055λ, 0.017λ and 0.0042λ at center frequency of 400 MHz
- Effect of conductor diameter on helical antenna performance - only minor changes

Helical Antenna Support





Material Type: Metal supports should be avoided as they can interfere with the antenna's radiation pattern. Dielectric materials are preferred due to their minimal effect on the electromagnetic field.
Dielectric Constant: Lower dielectric constants are generally preferable to minimize the impact on the antenna's resonant frequency and bandwidth.
Strength and Durability: The material should be mechanically robust to support the helix, especially in outdoor environments.
Weight: Lighter materials are beneficial for ease of installation and maintaining structural integrity.
Weather Resistance: Outdoor antennas benefit from materials resistant to environmental conditions like UV exposure and moisture.

Axial Mode Helical Antenna - Input Impedance

For Axial Feed: $R = 140 * C_\lambda \ \Omega$

For Peripheral or Circumferential Feed:

$$R \approx 150 / \sqrt{C_\lambda} \quad \Omega$$

Restrictions:

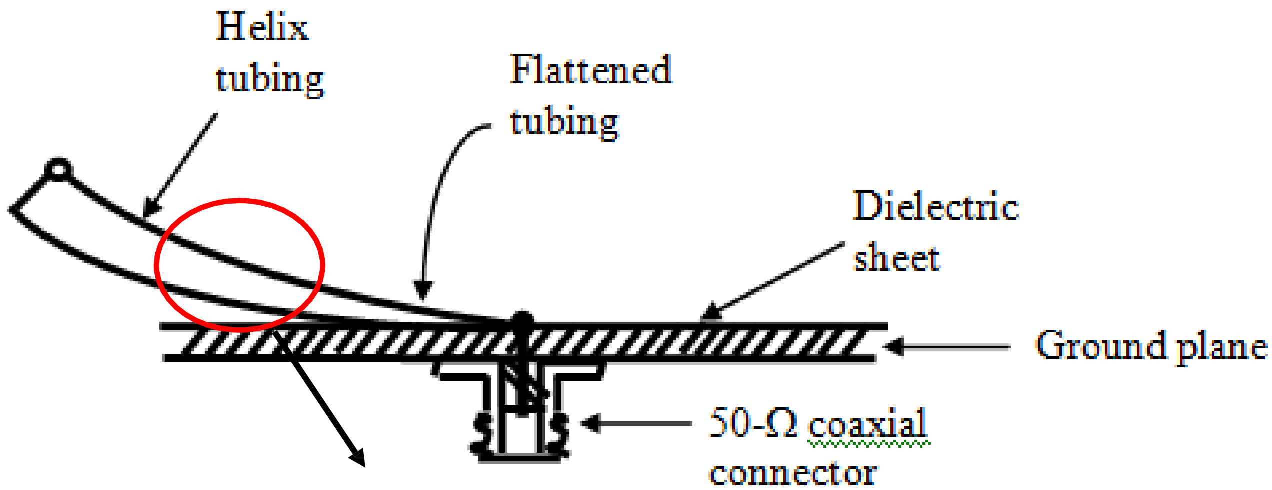
(a) $0.8 \leq C_\lambda \leq 1.2$

(b) $12° \leq \alpha \leq 14°$

(c) $n \geq 4$

Input Impedance Matching

1. Tapered Transition from helix to coaxial line

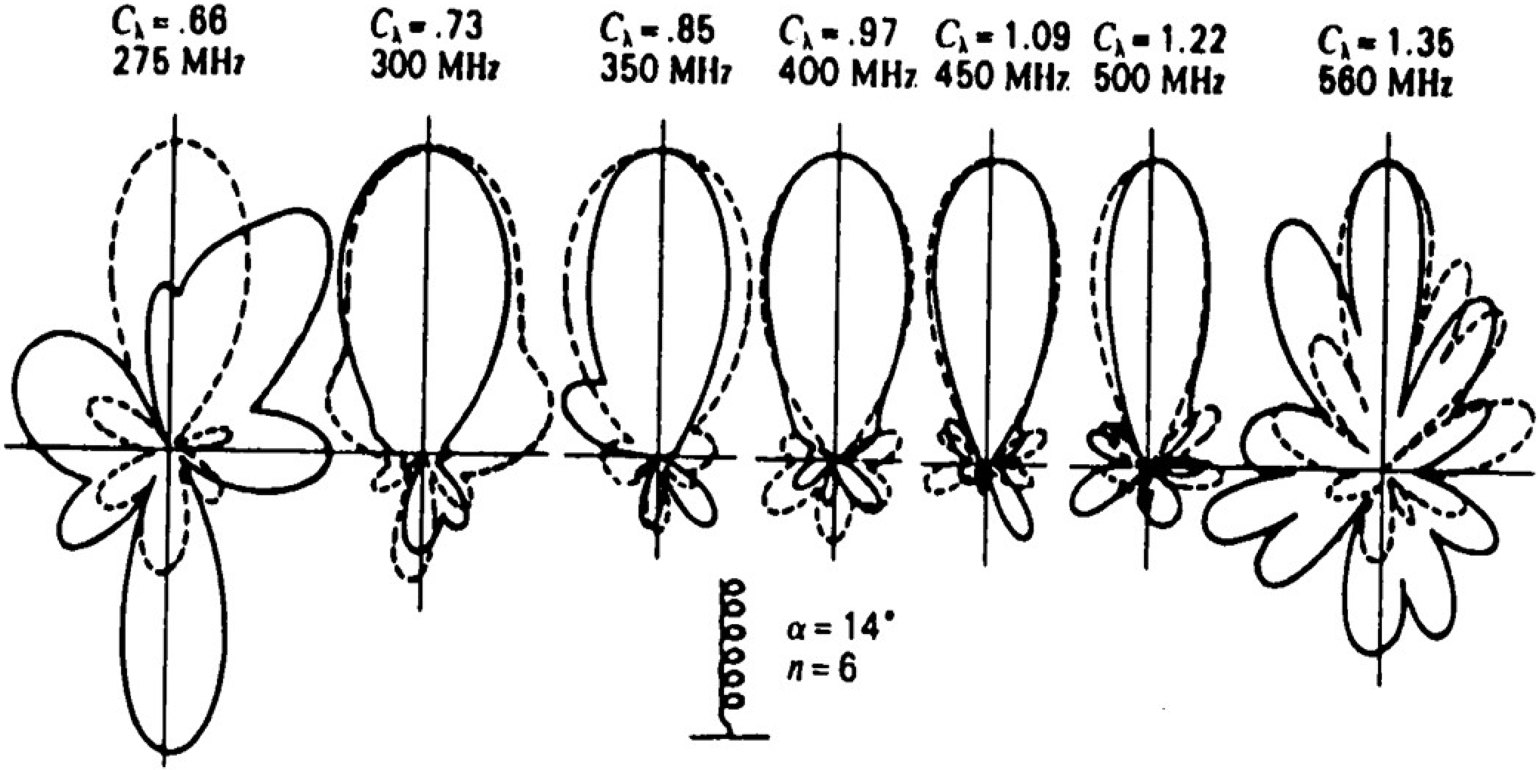


***w* = width of conductor at termination**

2. Tapered Microstrip Transition

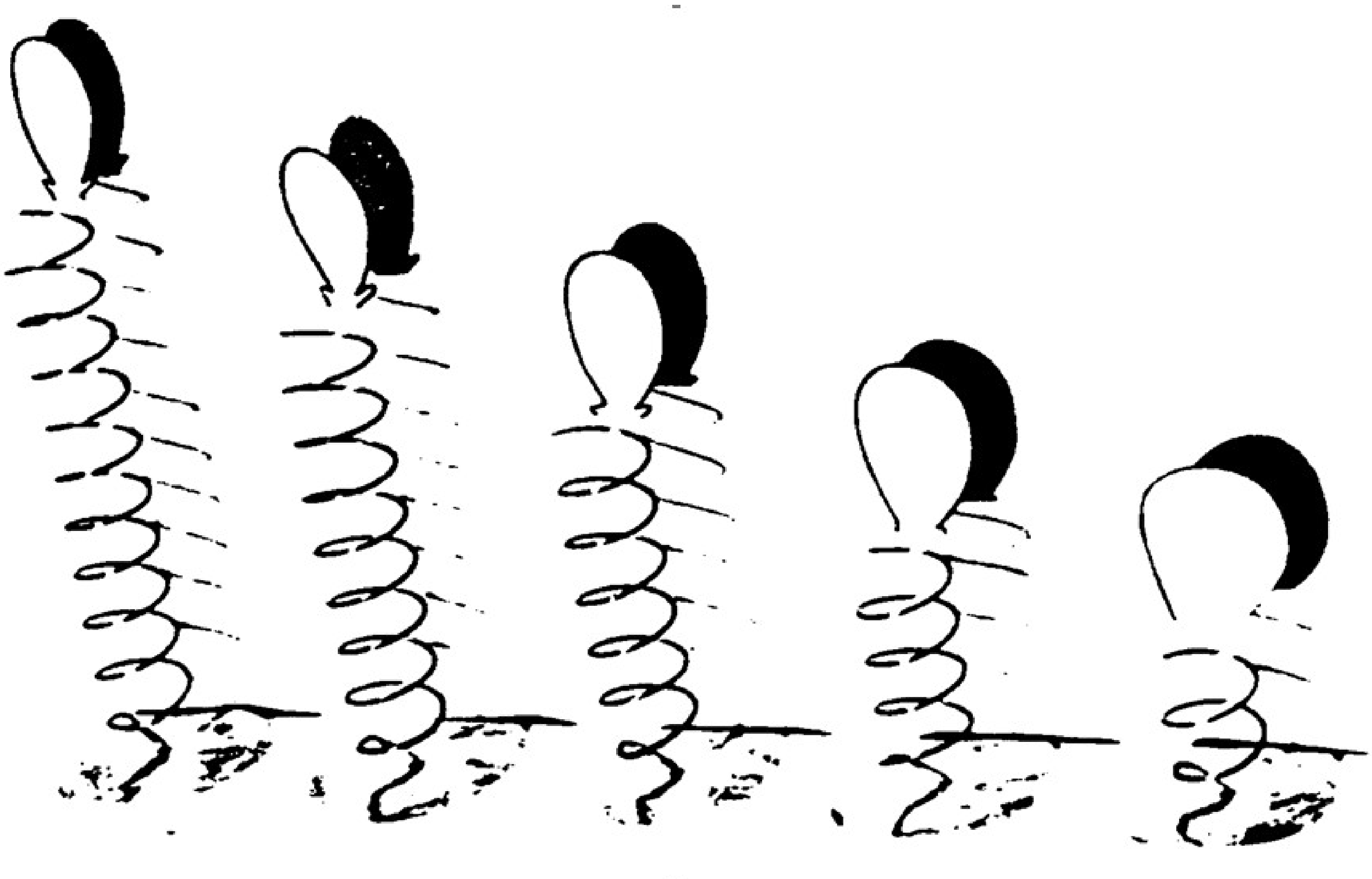
$$h = \frac{w}{[377/(\sqrt{\varepsilon_r} Z_0)] - 2}$$

Radiation Pattern of Axial Mode Helical Antenna



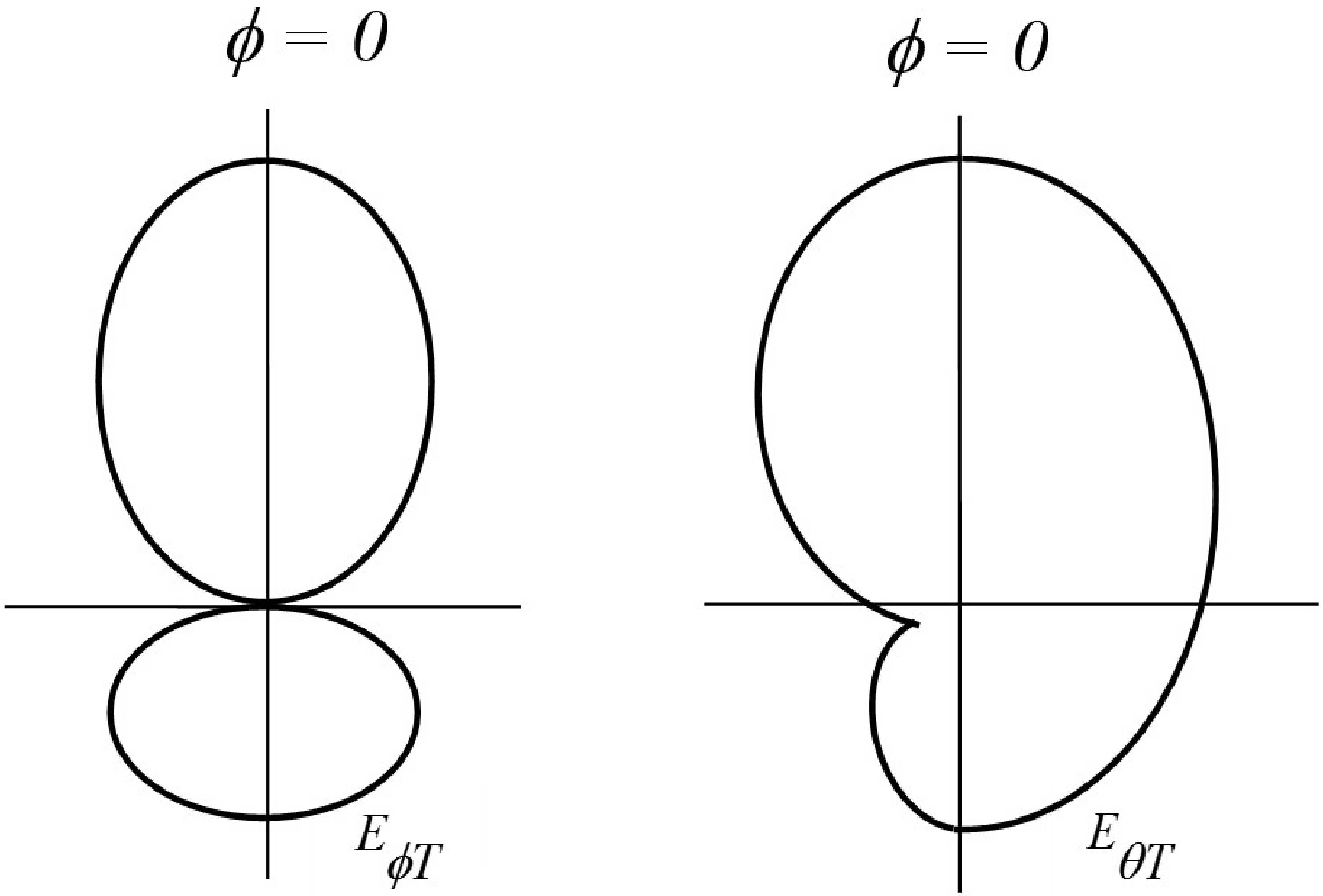
- Measured Field Patterns of Axial Mode Helical Antenna of 6 turns and pitch angle α = 14°.
- **CP Radiation Pattern for C/λ from 0.73 to 1.22**
- (—) Horizontally polarized field component and (---) Vertically polarized.

Effect of No. of Turns (n)



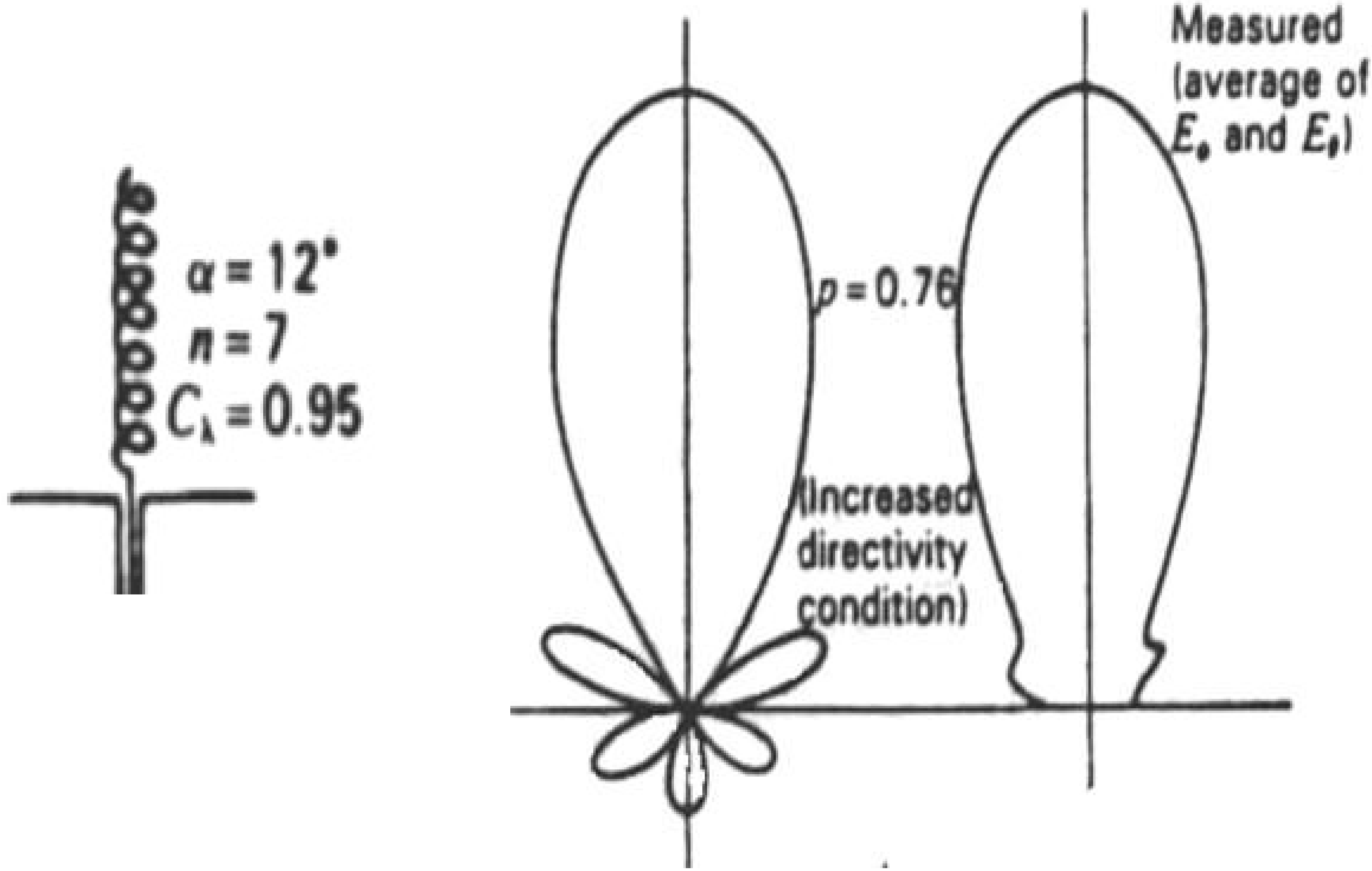
Helical Antennas: α =12.2° and 10, 8, 6, 4, 2 turns.

Pattern of Single Turn Helical Antenna



$\alpha = 12°, \mathrm{n} = 1$

Axial Mode Helical Antenna - Increased Directivity Endfire Array



Gain of Axial Mode Helical Antenna

HPBW (Half-Power Beamwidth) $\cong \dfrac{\mathbf{52}}{C_\lambda \sqrt{n\, S_\lambda}}\,\mathbf{(deg)}$

BWFN (Beamwidth Between First Nulls) $\cong \dfrac{\mathbf{115}}{C_\lambda \sqrt{n S_\lambda}}\,\mathbf{(deg)}$

Directivity = 32,400 / HPBW²

$$Directivity = 12\, C_\lambda^2\, nS_\lambda$$

Gain = η x Directivity,   η ≈ 60%

Design of Axial Mode Helical Antenna

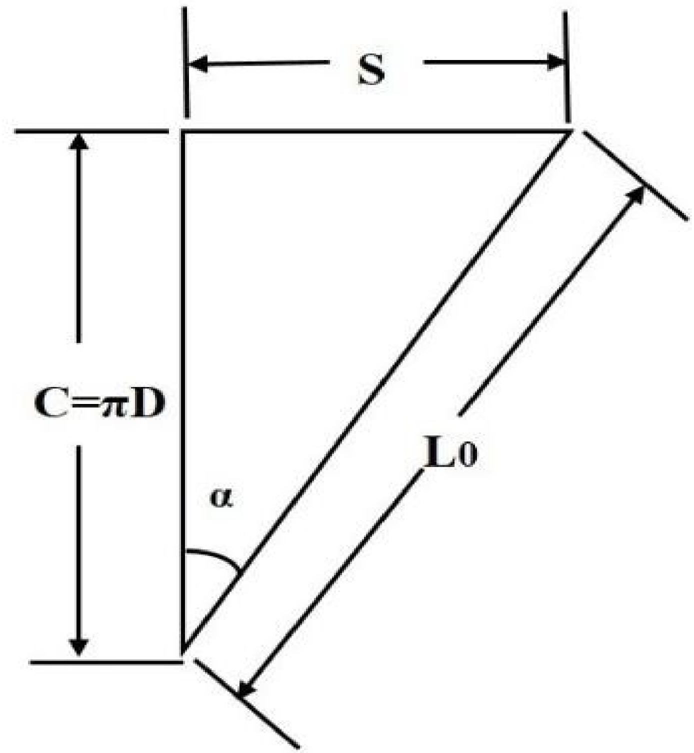
Desired: Directivity = 24 dB = 251.19

For Axial Mode Helical Antenna:

Assume: $C_\lambda = 1.05$ (0.8 to 1.2)

$\alpha = 12.7°$ (12° to 14°)

Calculate: $S_\lambda = C_\lambda \tan\alpha = 0.2366$



$$Directivity = 12\, C_\lambda^2\, n S_\lambda$$

$$n = \frac{251.19}{12(0.2366)(1.05)^2} = 80$$

2x2 Helical Antenna Array

Instead of single 80-turns helical antenna, four 20-turns helical antennas can be used

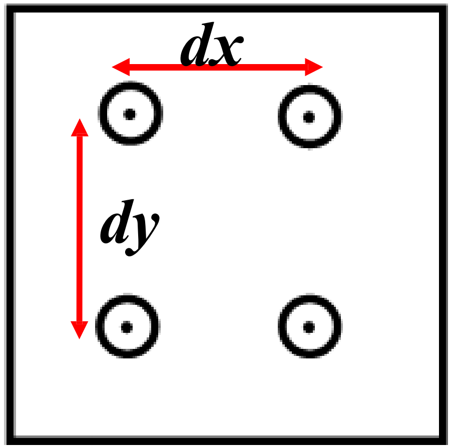
Directivity of each 20-turns helical antenna

$$= 251.19/4 = \color{red}{62.8}$$

Effective Aperture $= D_o \dfrac{\lambda^2}{4\pi} \approx 5\,\lambda^2$

Assuming Square Aperture

Side Length $= \sqrt{5}\lambda = 2.236\,\lambda$

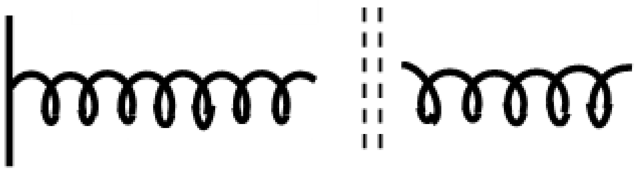


2x2 Array

Each Helix is placed at the center of its aperture.

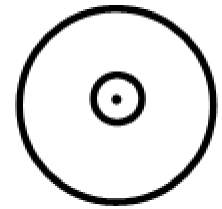
Helical Antenna and Arrays

Side View

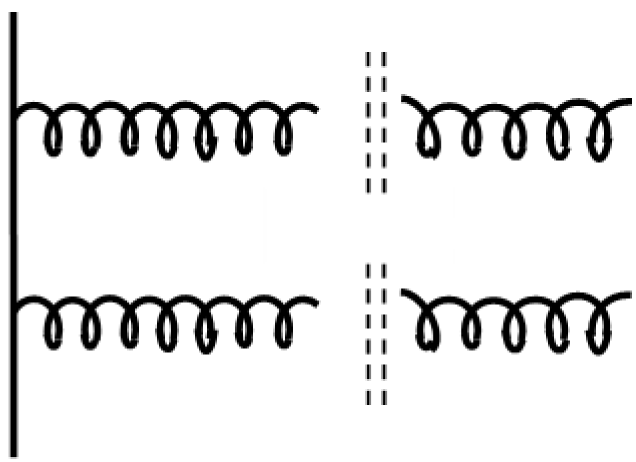


n = 80

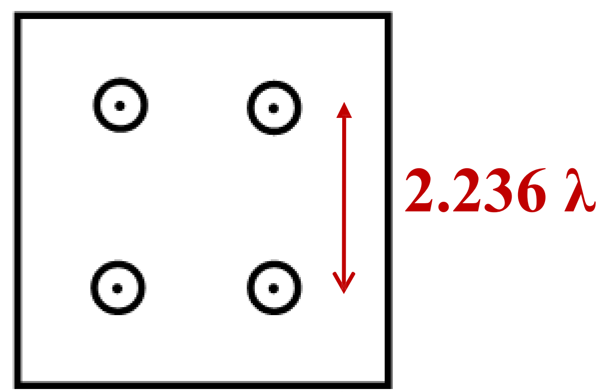
Front View



1 Helix

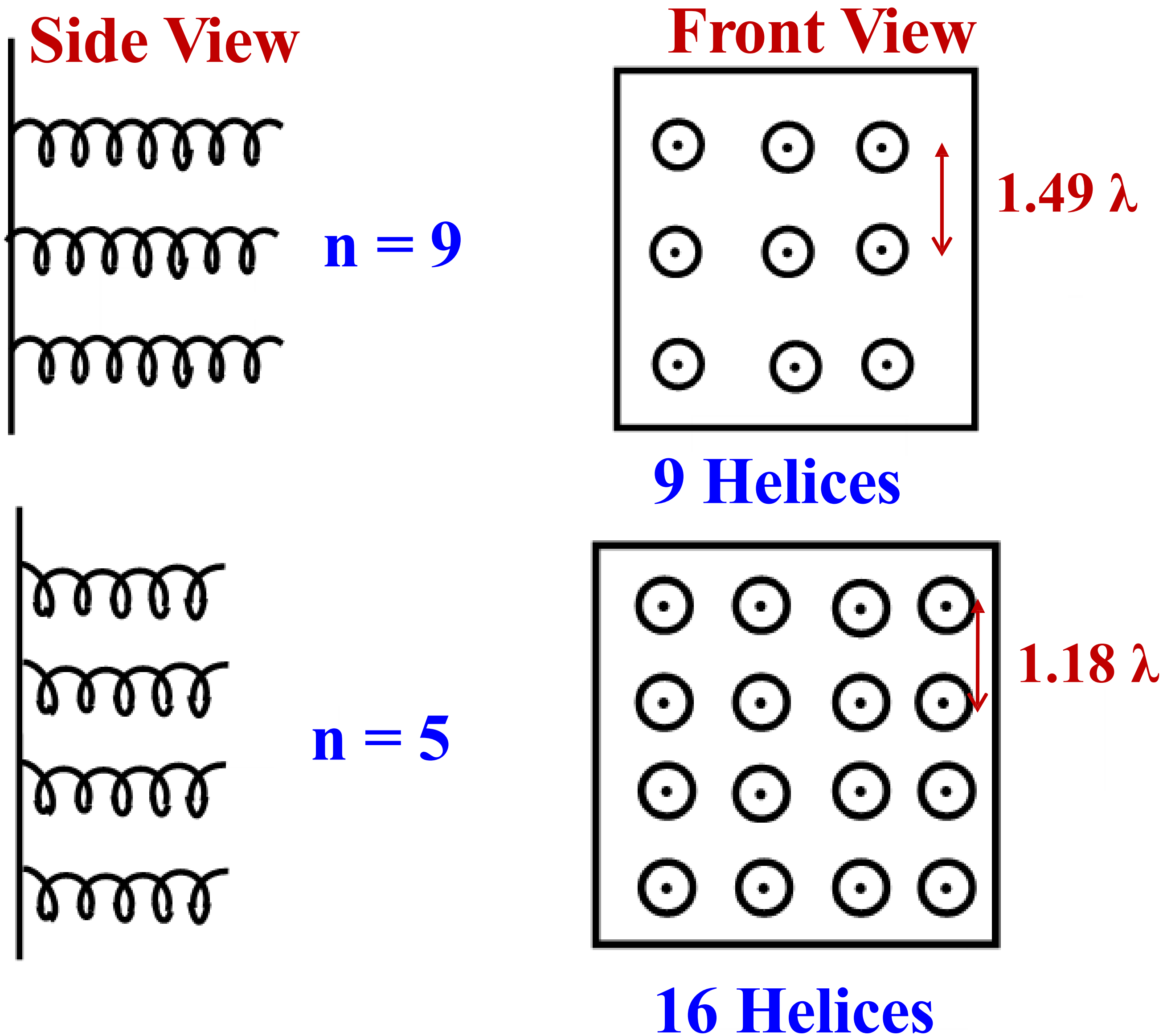


n = 20

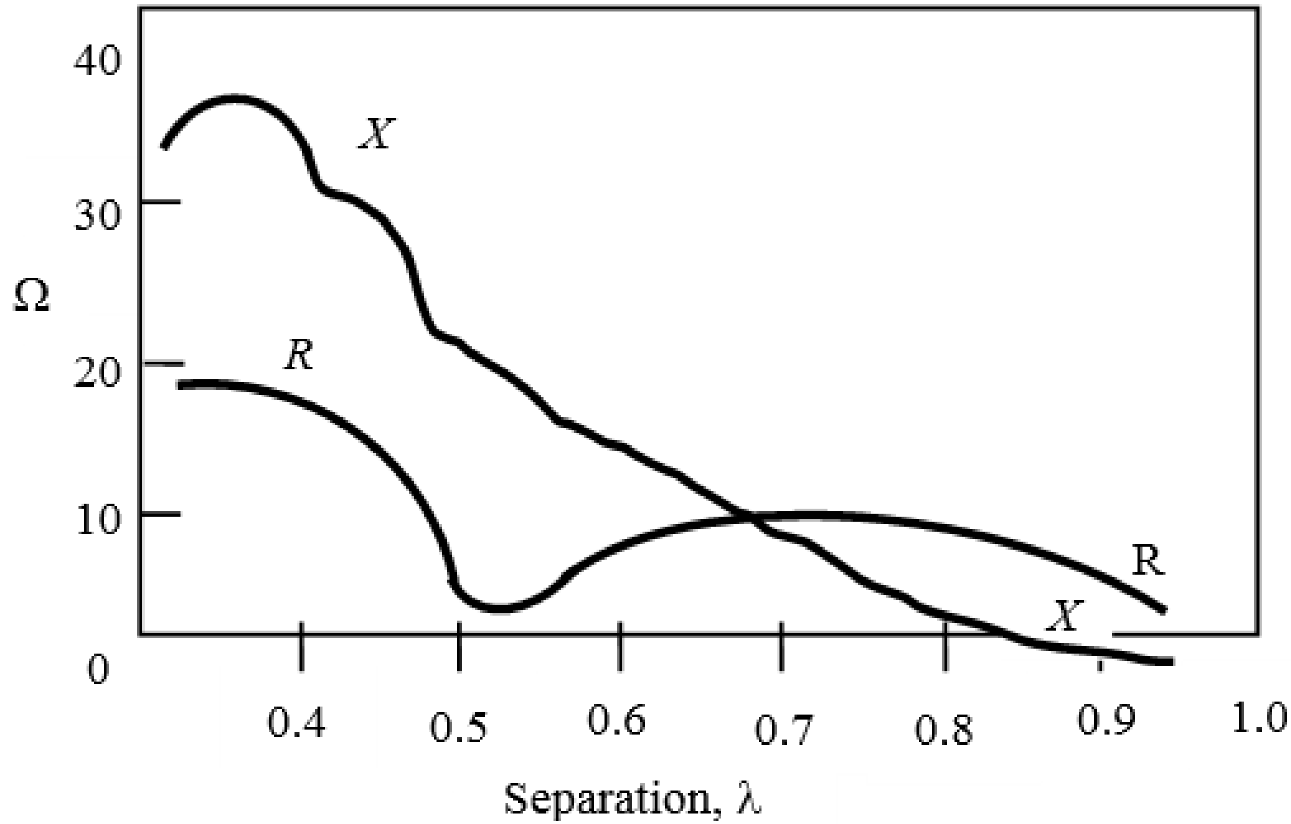


4 Helices

Arrays of Helical Antenna

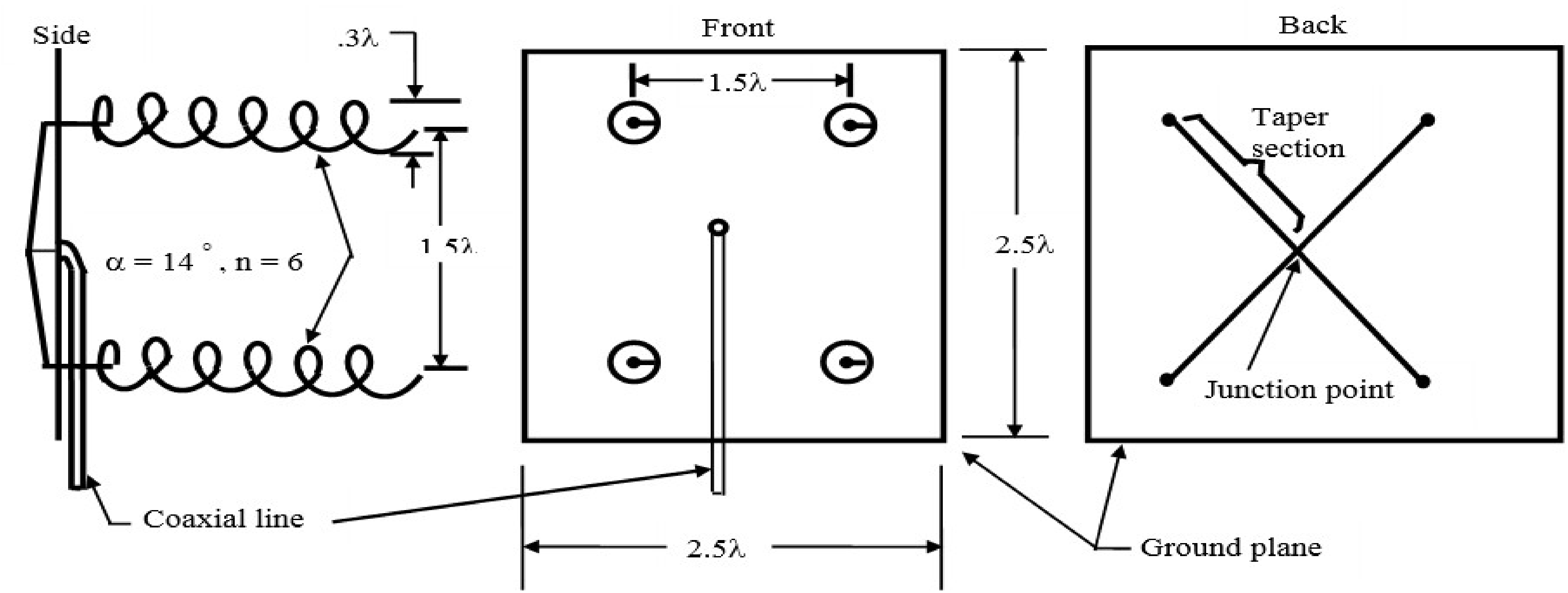


Mutual Impedance between Arrays of

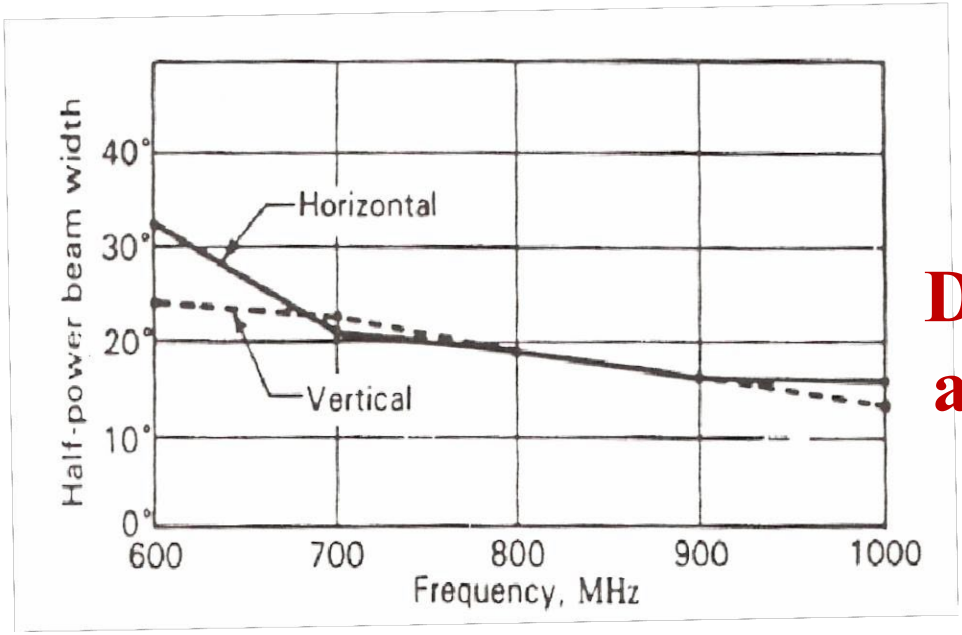


Resistive (R) and Reactive (X) components of the mutual impedance of a pair of same-handed 8-turn axial-mode helical antennas of 12° pitch angle

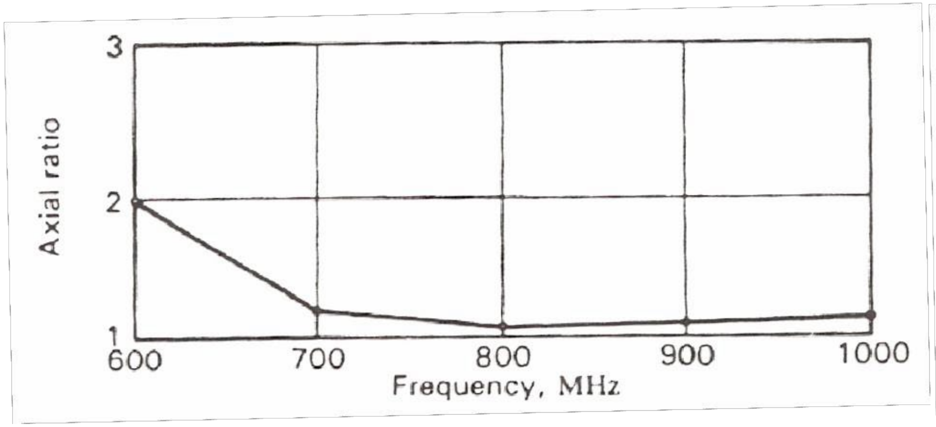
2x2 Array of Helical Antenna at 800 MHz

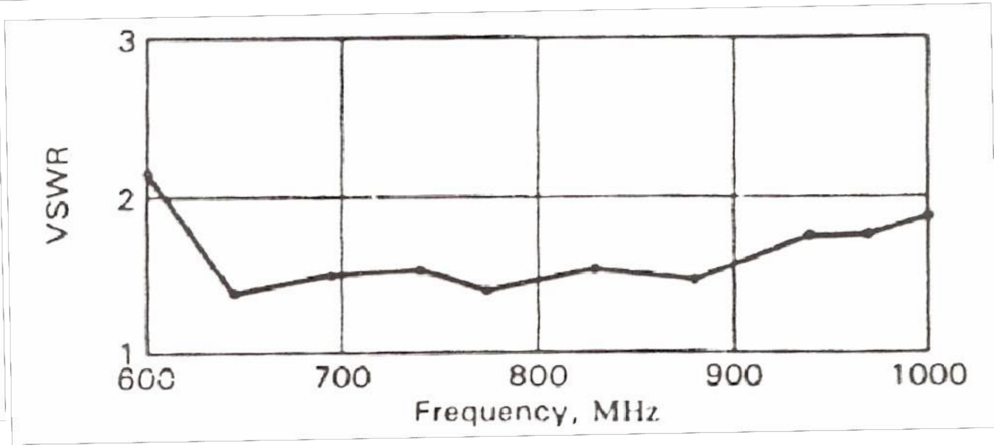


Results of 2x2 Array of Helical Antenna



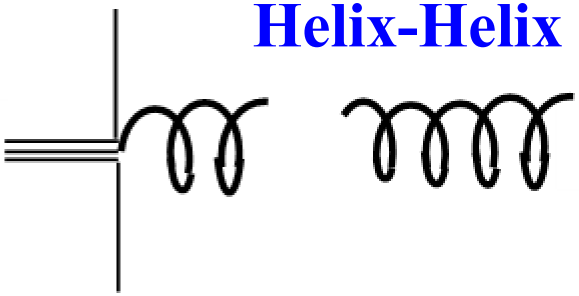
Directivity = 18.5 dB at 800 MHz



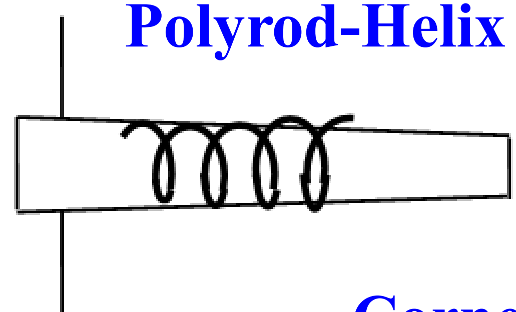


Helix as a Parasitic Element

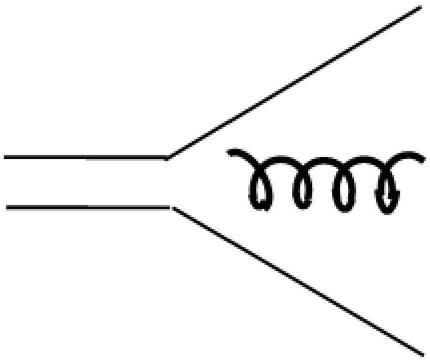
Helix-Helix



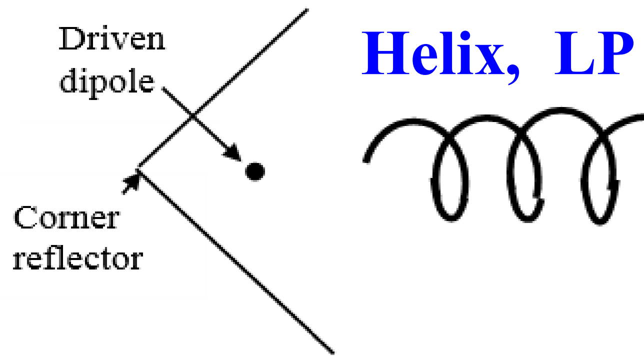
Polyrod-Helix LP to CP



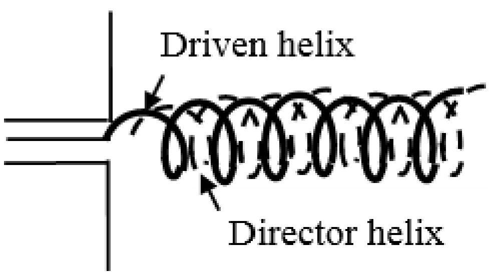
Horn-Helix LP to CP



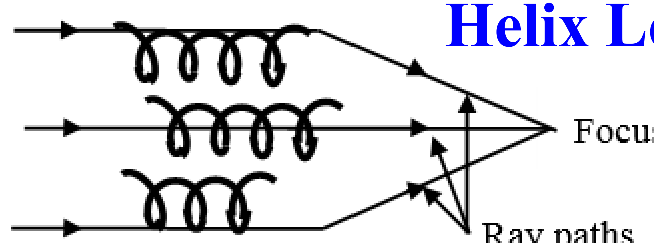
Corner-reflector Helix, LP to CP



Helix-Helix More Gain



Helix Lens



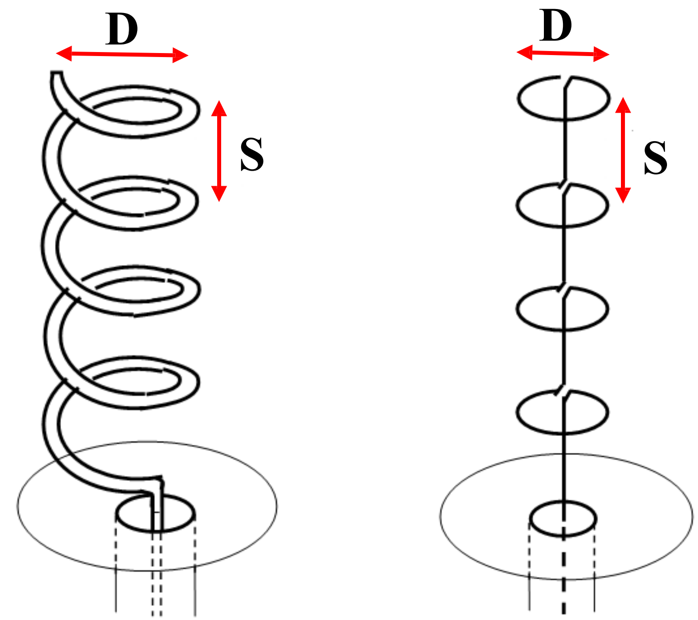
Normal Mode Helical Antenna

Small Dipole:

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

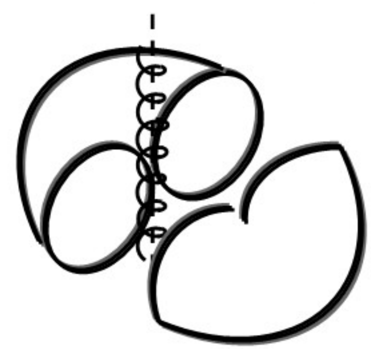
Small Loop:

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



Therefore, Axial Ratio is:

$$AR = \frac{|E_\theta|}{|E_\phi|} = \frac{2S\lambda}{C^2} = \frac{2S_\lambda}{C_\lambda^2}$$



For Circular Polarization, AR = 1 ⇒ $C_\lambda = \sqrt{2S_\lambda}$

Design of Normal Mode Helical Antenna

For Infinite Ground Plane:

Wire length ≈ λ / 4 – text book

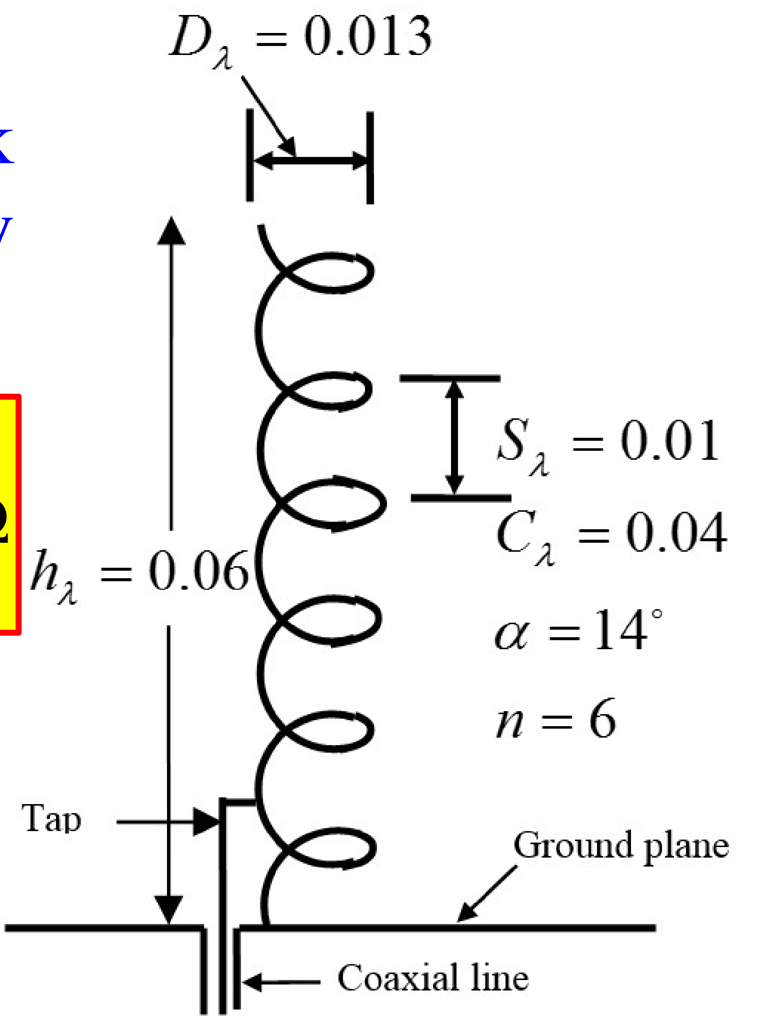
> λ / 4 – in reality

Radiation Resistance (R_s)

$$R_s = \frac{1}{2}(790)\left(\frac{I_{av}}{I_o}\right)^2 h_\lambda^2 \Rightarrow R_s = 0.6\ \Omega$$

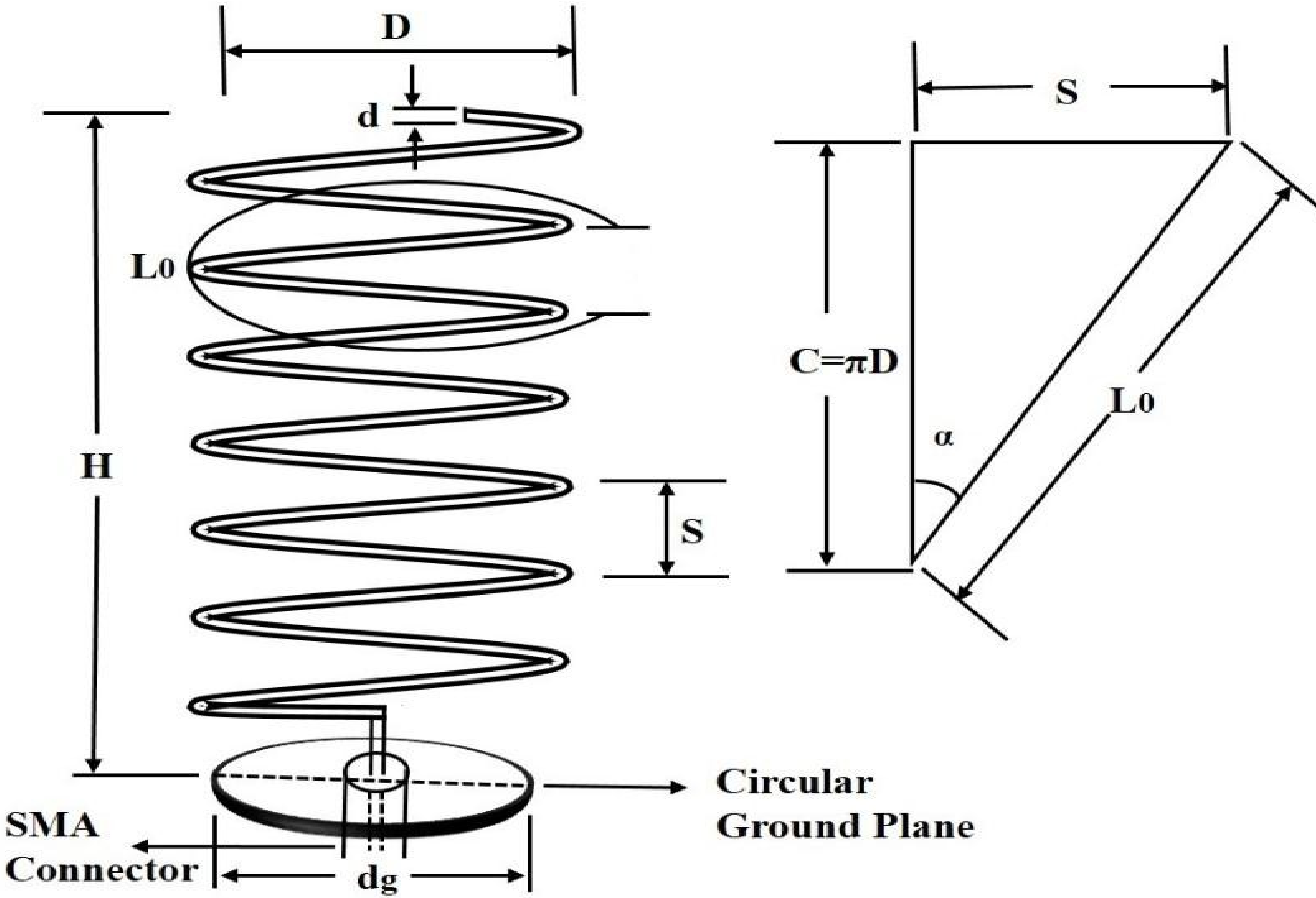
Axial Ratio (AR)

AR = 2 S_λ / C_λ^2
= 2x0.01/0.04 ^{2}
= 12.5 = 21.94 dB



Feed is tapped after one turn for impedance matching

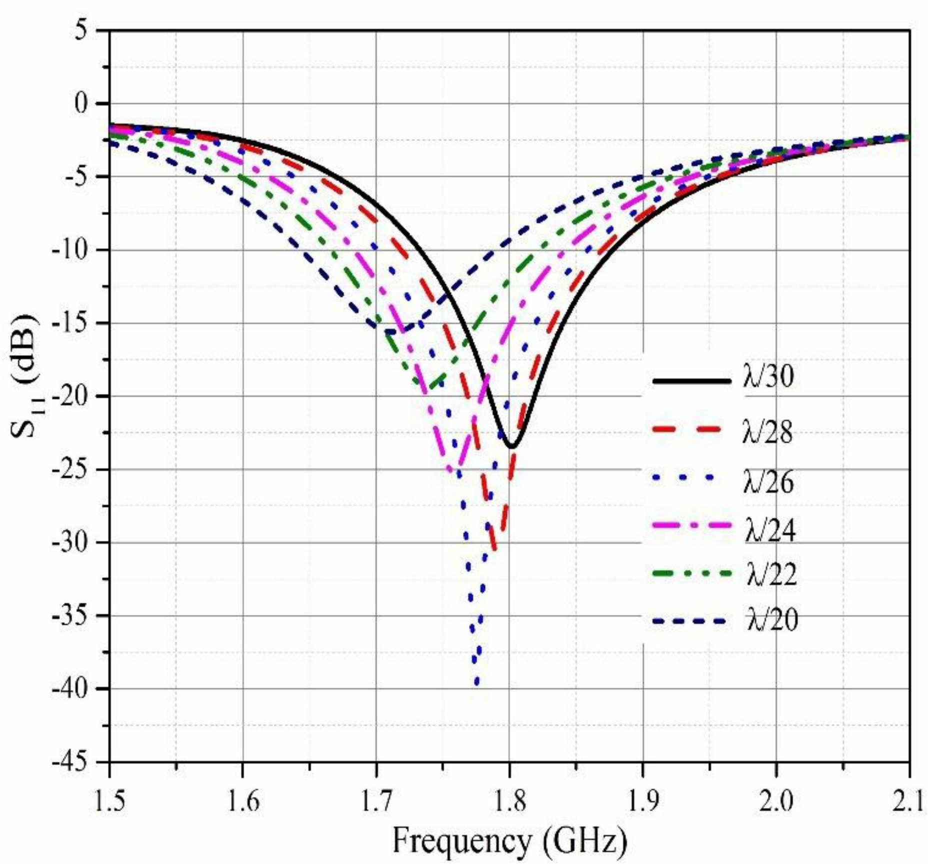
Normal Mode Helical Antenna (NMHA) on Small Circular

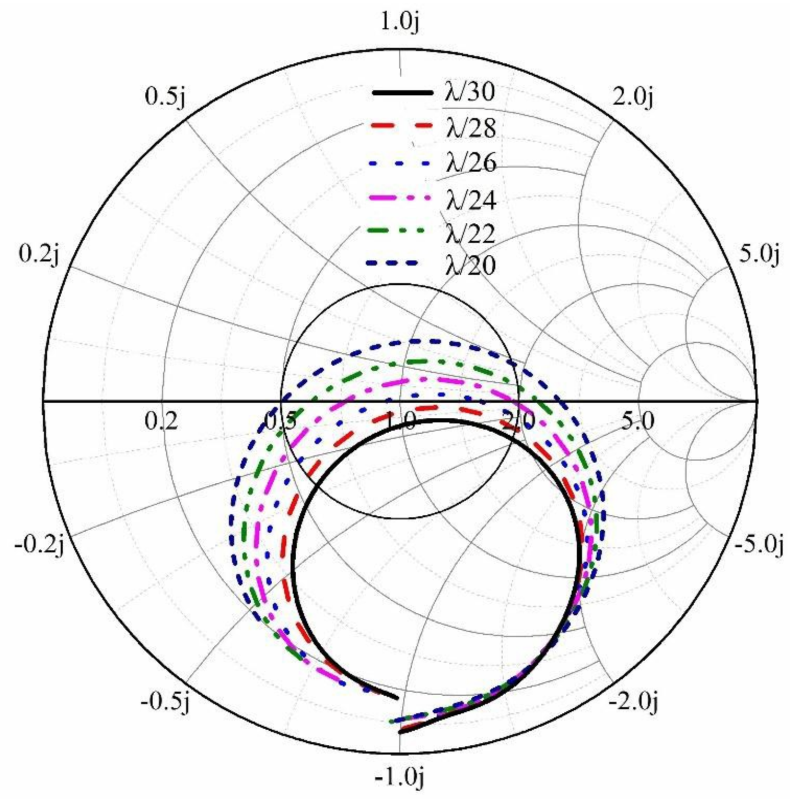


NMHA Design on Small Circular Ground Plane

Resonance Frequency	**1.8 GHz**
Wavelength	166 mm
Spacing = 0.027λ	4.5 mm
Diameter of Helix = 0.033λ	5.5 mm
No of Turns (N)	7
Pitch Angle (α)	14.6 Degree
Length of Wire = 0.75λ	124.5 mm

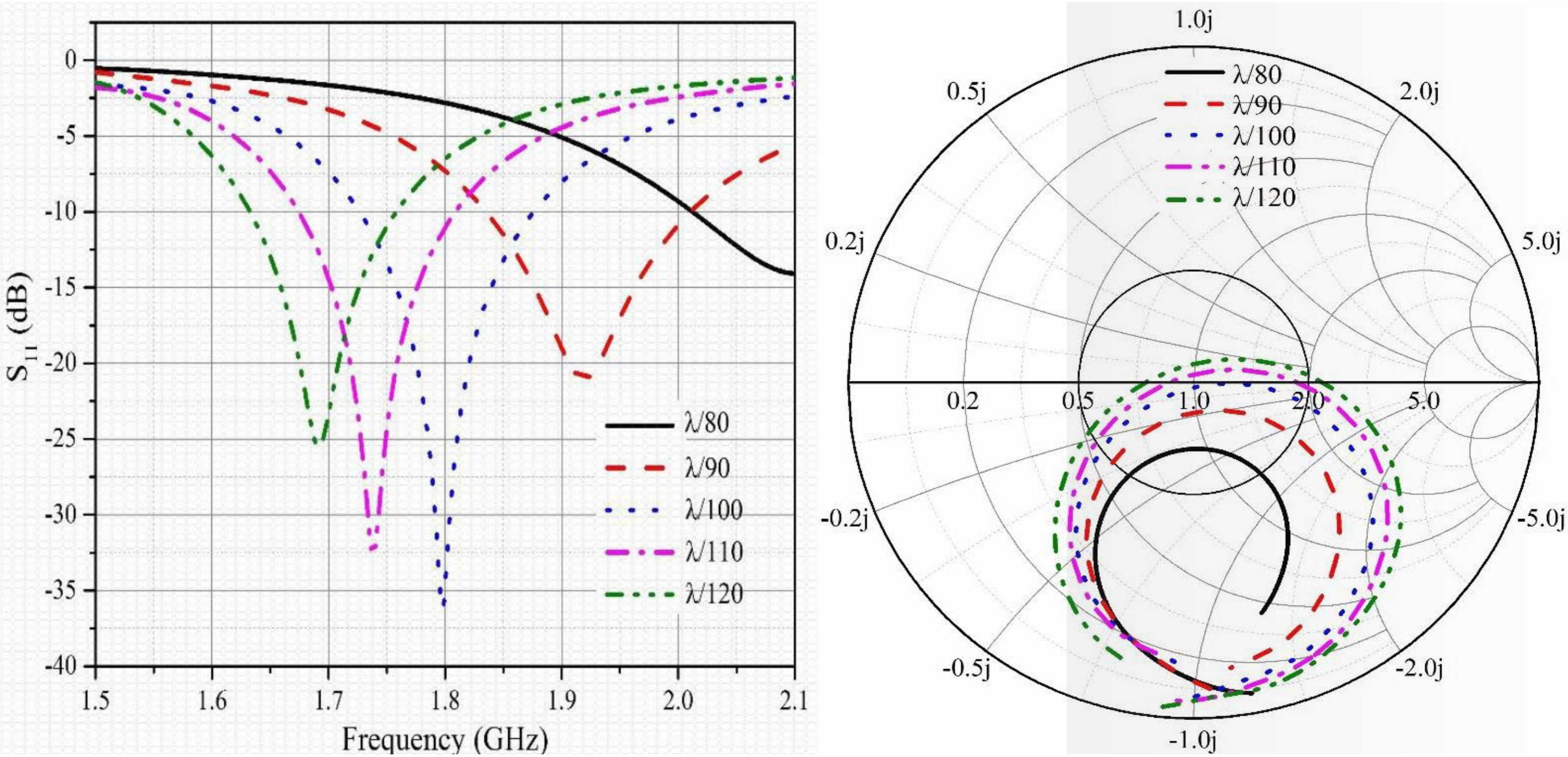
Effect of Ground Plane Size on NMHA





As ground plane radius increases from λ/30 to λ/20, resonance frequency decreases and the input impedance curve shifts upward. NMHA designed for 1.8 GHz and r_{wire} = 1.6 mm (λ/100)

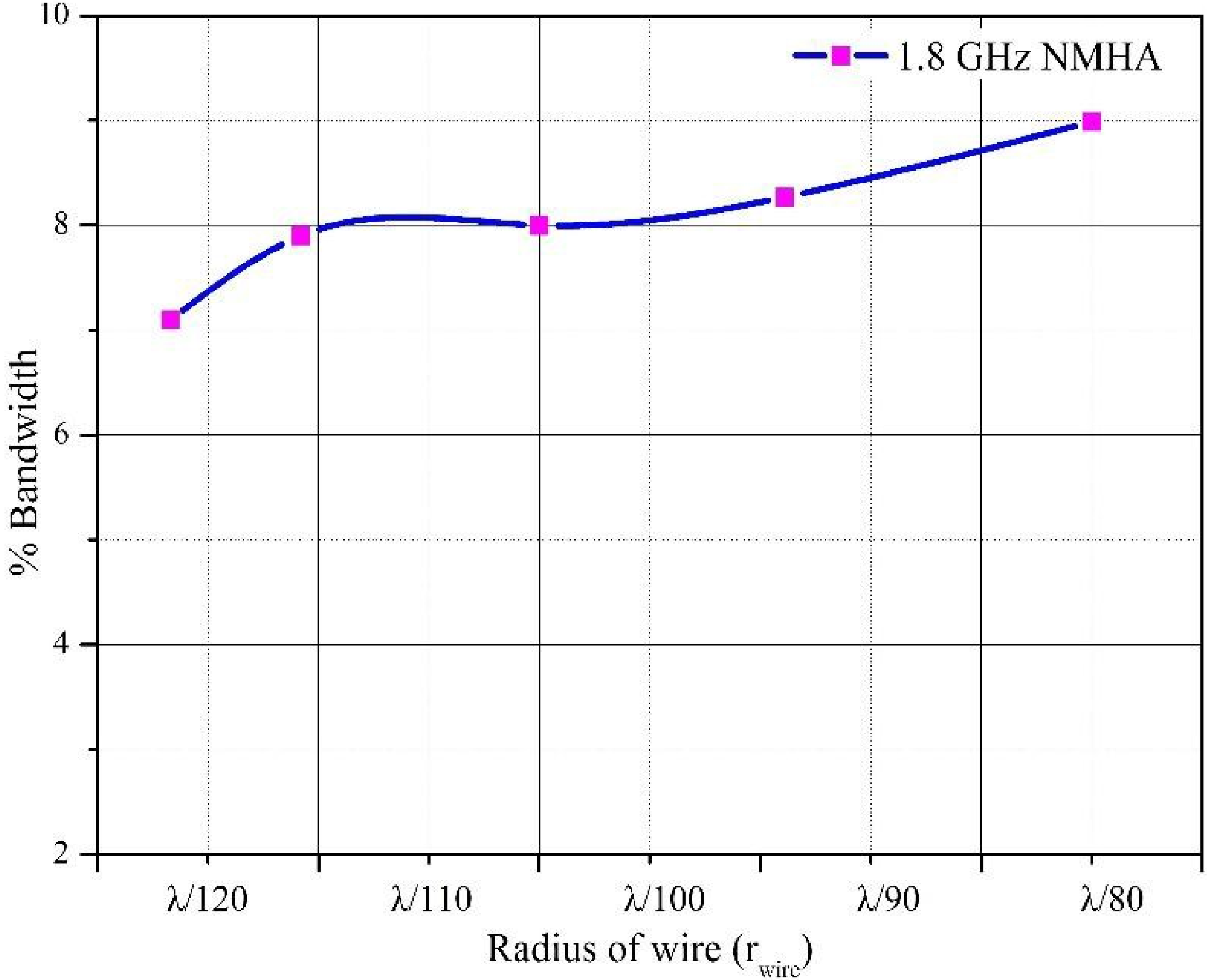
Effect of Wire Radius on NMHA



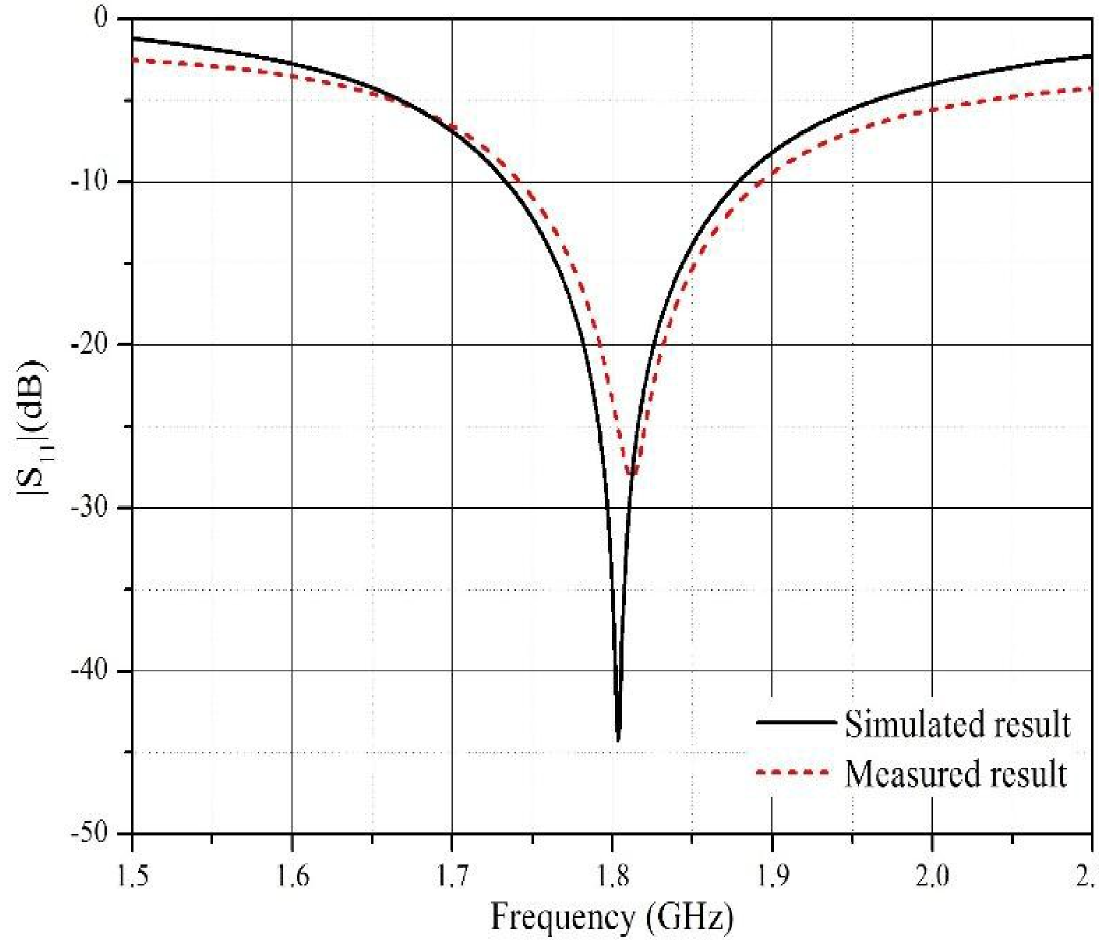
As radius of wire decreases from λ/80 to λ/120, its inductance increases so resonance frequency of NMHA decreases and its input impedance curve shifts upward (inductive region).

NMHA designed for 1.8 GHz and r_g = 5.5 mm (λ/30)

Effect of Wire Radius on Bandwidth of NMHA



Fabricated NMHA on Small Ground Plane and its Results



Helical Antenna Formula

Normal (broadside) mode

-Dimensions are small compared to wavelength $(NL_0 \ll \lambda_0)$

-The current throughout the antenna is assumed to be constant and its far-field independent of the number of loops and spacing.

- The fields radiate in θ and ϕ. The ratio between the magnitudes of
these fields is defined as the axial ratio:

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

$\mathrm{AR} = 0$ – Horizontal Polarization

$\mathrm{AR} = \infty$ – Vertical Polarization

$\mathrm{AR} = 1$ – Circular Polarization $\left(\mathrm{C} = \pi D = \sqrt{2S\lambda_0}, \tan\alpha = \frac{\pi D}{2\lambda_0}\right)$

Other values of AR – Elliptical Polarization

Helical Antenna Formula

Axial (end-fire) mode

- To achieve circular polarization, the circumference must be $\frac{3}{4} \leq \frac{C}{\lambda_0} \leq \frac{4}{3}$, and spacing about S $\cong \frac{\lambda_0}{4}$, pitch angle $12^{\circ} \leq \alpha \leq 14^{\circ}$, $\mathrm{N} > 3$.
- Input Resistance is around $R \cong 140\left(\frac{C}{\lambda_0}\right)$
- Half-Power Beamwidth is around

$$\mathrm{HPBW(degrees)} = \frac{52\lambda_0^{3/2}}{C\sqrt{NS}}$$

- Axial Ratio to achieve increased directivity

$$AR = \frac{2N+1}{2N}$$

- Directivity is given by

$$D_0(\mathrm{dimensionless}) = 15\mathrm{N}\,\frac{C^2 S}{\lambda_0^3}$$

Helical Antenna

Pro:

- It is simple in design.
- It uses circular polarized pattern.
- It can be used for broadband applications.
- It can be used at HF/VHF frequencies for transmission and reception.
- It offers higher directivity.
- It is very robust in construction.

Con:

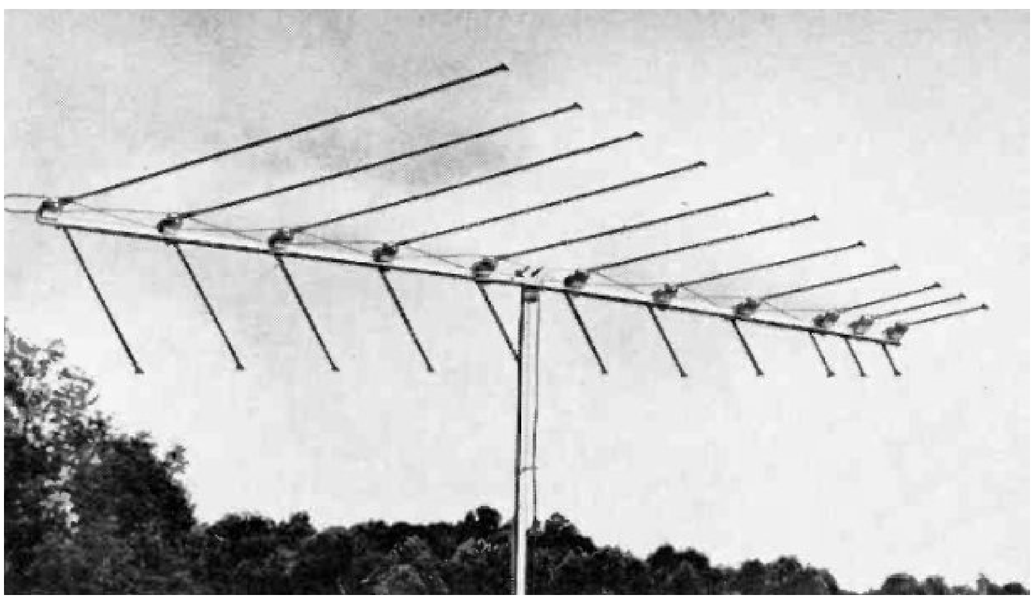
- It is large in size. This requires more space for installation.
- For higher number of turns its efficiency decreases. The maximum efficiency (~80%) achieved with the use of 3 to 4 turns.
- It is higher in cost.

Frequency Independent Antennas

History of Frequency-Independent Antenna

Frequency independent antennas had their beginning in research conducted in the late 1950s

An early nonmilitary application of frequency-independent antennas was the log-periodic dipole TV antenna that was used on houses around the world starting in the 1960s.



VHF TV antenna 1963

What is the difference between a Yagi and LPDA antenna? 4’12” Video

Principle of Frequency-Independent Antenna

the pattern of an antenna remaining constant over a very wide range of frequencies

An antenna with a bandwidth of about 10:1 or more is referred to as a frequency-independent antenna.

The ideal form of a frequency-independent antenna
- constant pattern
- constant impedance
- constant polarization
- constant phase center

Over large frequency band.

Few antennas meet all these criteria.

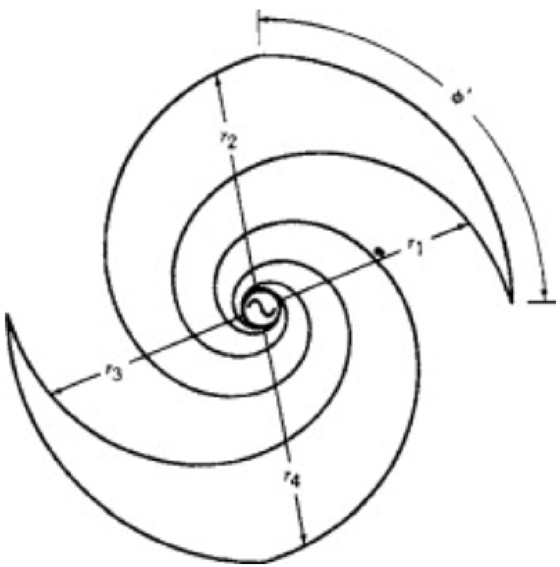
Characteristics that Produce Broadband Behavior

Emphasis on angles rather than lengths: [Rumsey, 1957]

Rumsey's principle states that the impedance and pattern properties of an antenna will be frequency-independent if the antenna shape is specified only in terms of angles.

$$KF(\theta, \phi) = F(\theta, \phi + C)$$

K is frequency scale factor
C is radiation angle



$$r = F(\theta, \phi) = e^{a\phi} f(\theta)$$

where $$a = \frac{1}{K}\frac{dK}{dC}$$

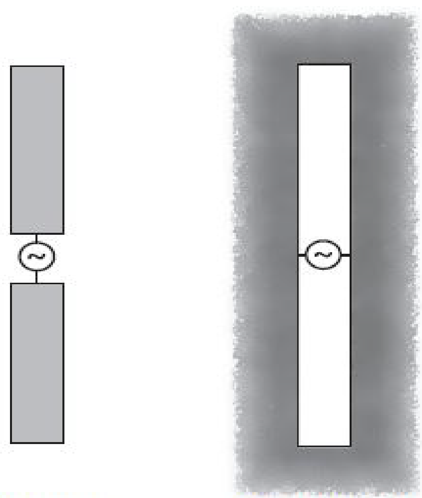
any antenna to have frequency independent characteristics, its surface must be described by (11-8) in Balanis Book.

Characteristics that Produce Broadband Behavior

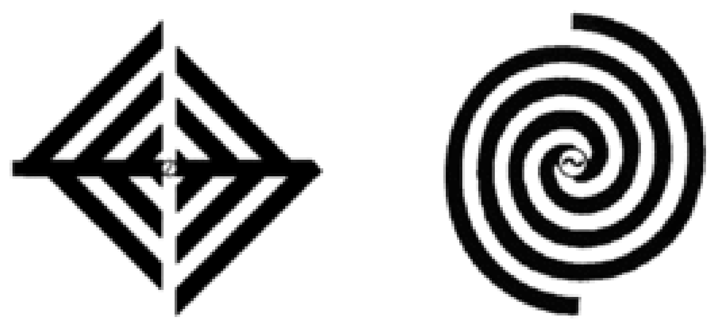
Self-complementary structures: [Prof. Yasuto Mushiake, 1948]

self-complementarity: Consider a metal antenna with input impedance Z_{metal}. A dual structure can be formed by replacing the metal with air and replacing air with metal. The resulting complementary antenna has input impedance Z_{air}.

An example is a ribbon dipole and its complement, the slot antenna, shown in Fig. 7-27.



(a) Ribbon dipole. (b) Slot antenna.



self-complementary antennas

Characteristics that Produce Broadband Behavior

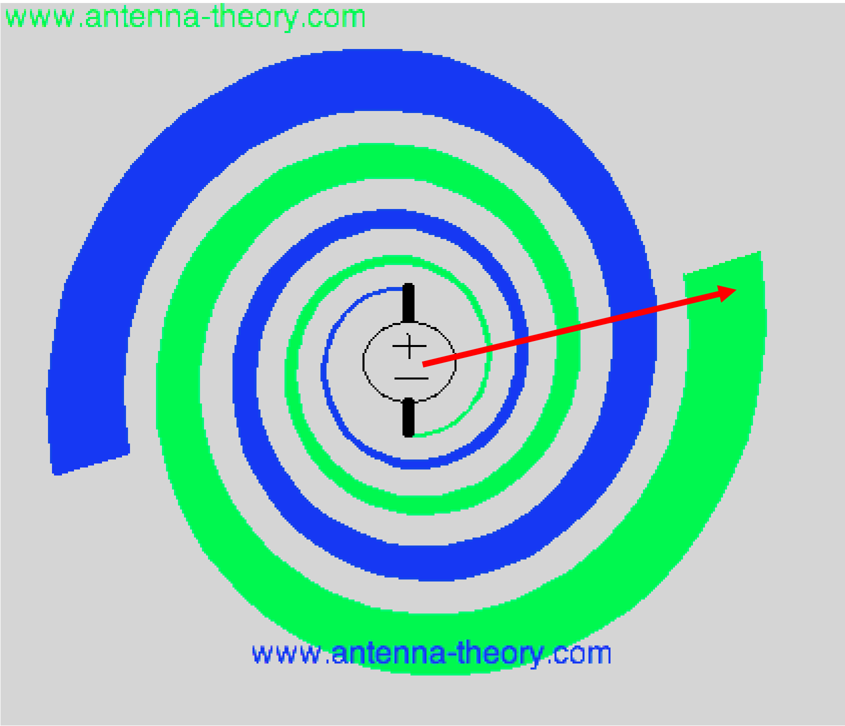
Thick metal—"fatter is better."

Increasing the wire diameter of even resonant antennas such as a dipole widens its bandwidth.

Ideally, frequency-independent antennas should display all three of these properties. It is found in practice that successful wide bandwidth designs emphasize these properties, but in many cases strict adherence is not required.

SPIRAL ANTENNAS

Spiral antennas and their variations are usually constructed to be either exactly or nearly self-complementary. This yields extremely wide bandwidths of up to 40:1.

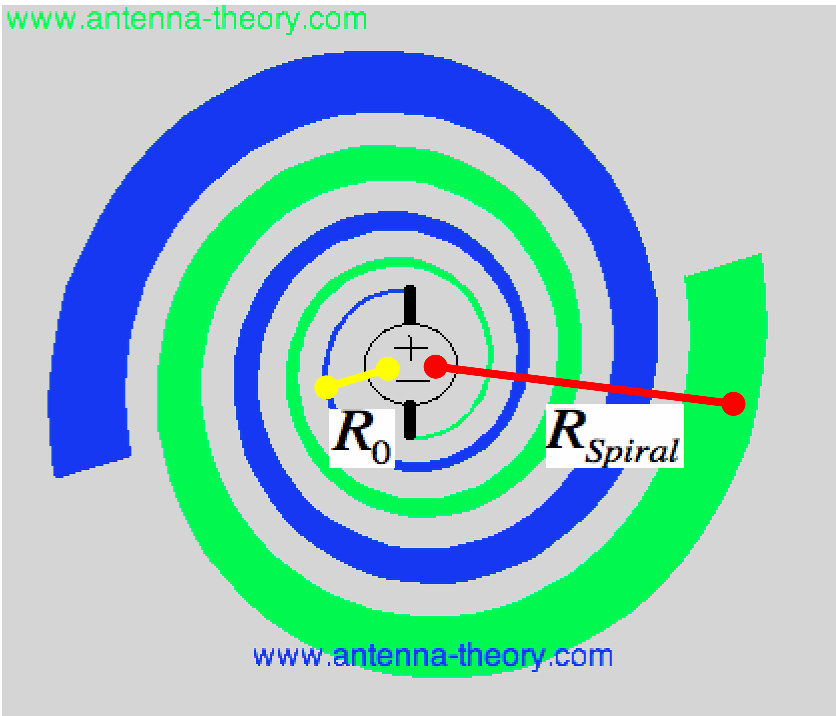


$$r = R_0 e^{a\phi}$$

where R_0 is the radius for $\emptyset = 0$ and α is a constant controlling the flare rate of the spiral.

SPIRAL ANTENNAS

Spiral antennas and their variations are usually constructed to be either exactly or nearly self-complementary. This yields extremely wide bandwidths of up to 40:1.

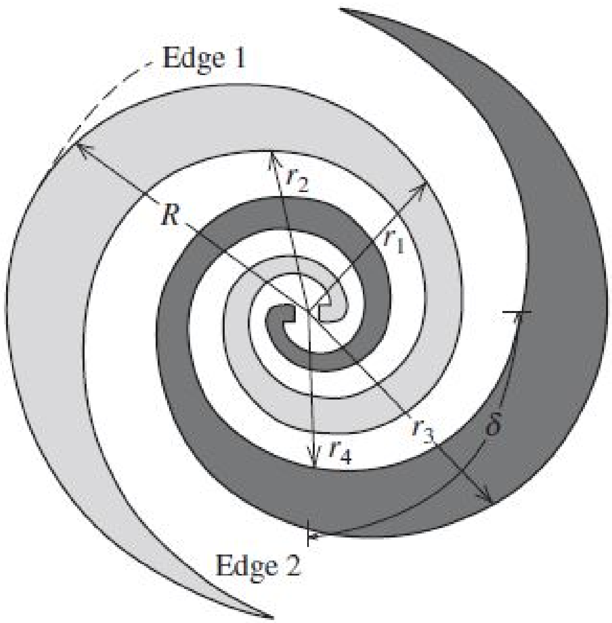


$$f_{Low} = \frac{c}{\lambda_{Low}} = \frac{c}{2\pi R_{Spiral}}$$

$$f_{Upper} = \frac{c}{\lambda_{Upper}} = \frac{c}{4R_0}$$

Planar Equiangular Spiral Antenna

The equiangular spiral curve is used to create the antenna which is referred to as the planar equiangular spiral antenna.
The structure is self-complementary, so $\delta = {}^{\pi}/_{2}$. It does not have to be constructed this way, but pattern symmetry is best for the **self-complementary** case.



$$r = r_0 e^{a(\theta+\delta)}$$

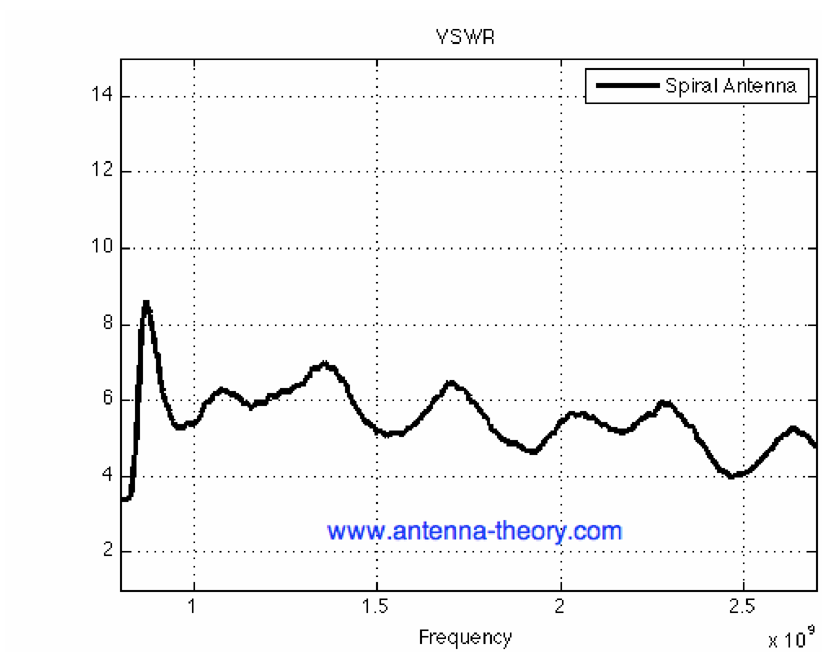
a determines the increasing rate of radius r, θ is the variable angle and δ determines rotation of the curve. $\delta = 0$ for outer curve, $\delta = {}^{\pi}/_{2}$ for inner curve.

Figure 7-29 Planar equiangular spiral antenna for the self-complementary case with $\delta = 90^\circ$.

Planar Equiangular Spiral Antenna

The impedance, pattern, and polarization of the planar equiangular spiral antenna remain **nearly constant** over a **wide range of frequencies**.

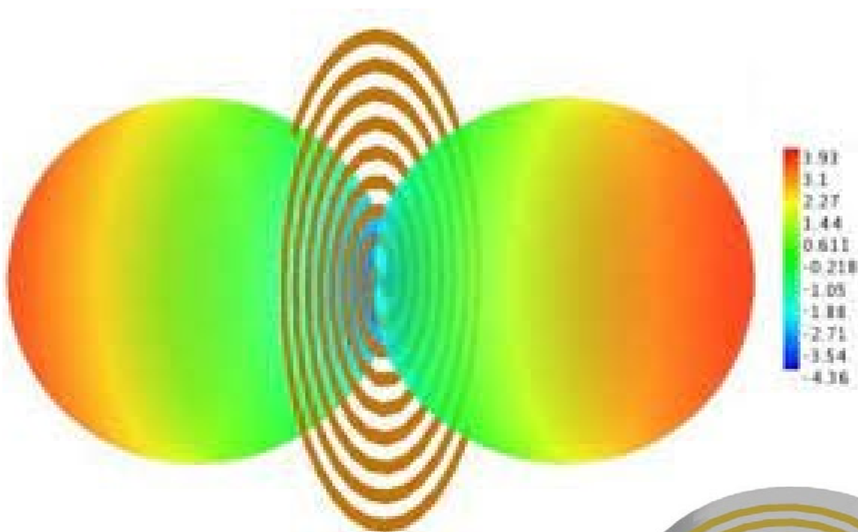
The feed point at the center, the overall radius, and the flare rate affect the performance.

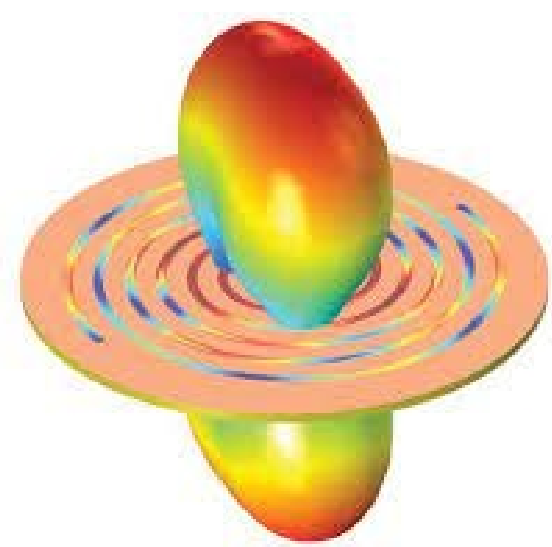


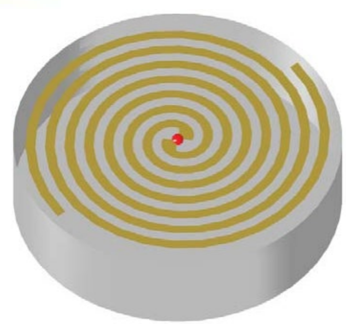
- VSWR=6, a little less than 50% mismatch power loss across the band
- VSWR almost constant, desirable property of broadband antennas
- VSWR further improved via optimization of the feed structure, increasing the number of turns and optimizing the shape (how quickly the spiral winds, or using the Log-Periodic Spiral Shape).

Planar Equiangular Spiral Antenna

The radiation pattern of the self-complementary planar equiangular spiral antenna is bidirectional with two wide beams broadside to the plane of the spiral.







Log-Periodic Antenna

known as a **log-periodic array** or **log-periodic aerial**, is a multi-element, directional antenna designed to operate over a wide band of frequencies. It was invented by John Dunlavy in 1952.

Not truly frequency independent, but very broadband.

the **sizes** and **spacing** of the different elements satisfy

$$\sigma = \frac{L_{n+1}}{L_n} \quad \text{and} \quad \sigma = \frac{d_{n+1}}{d_n}$$

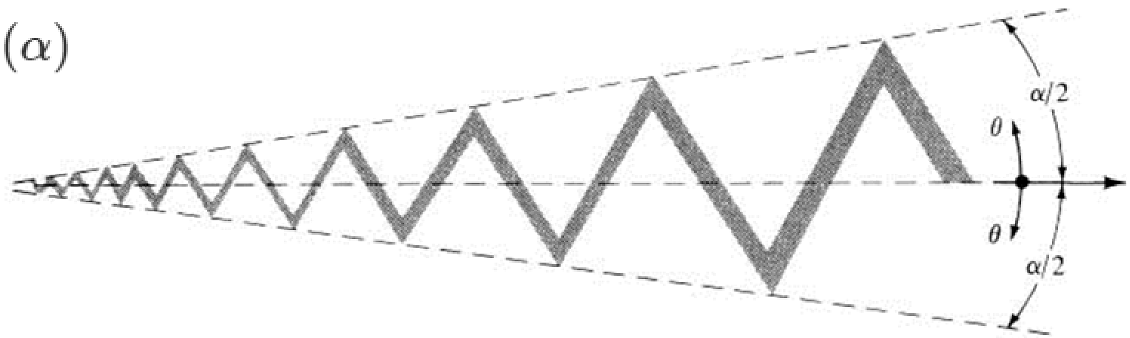
ratios of the logarithm (of frequency) will be **constant**

$$\log(\sigma) = \frac{\log(f_{n+1})}{\log(f_n)}$$

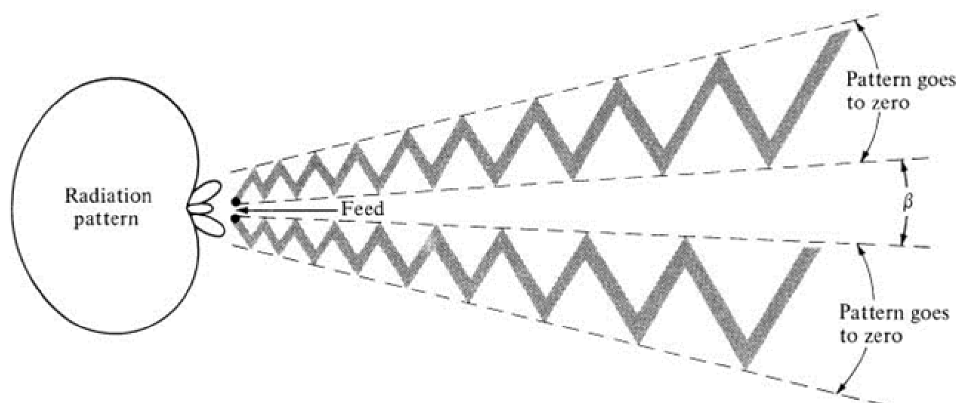
Log-Periodic Antenna

Also possible to relate the distance between two elements and the length of each one using the angle that the element lengths form at the apex within the formula below.

$$d_{x,y} = \frac{1}{2}(L_x - L_y)\cot(\alpha)$$

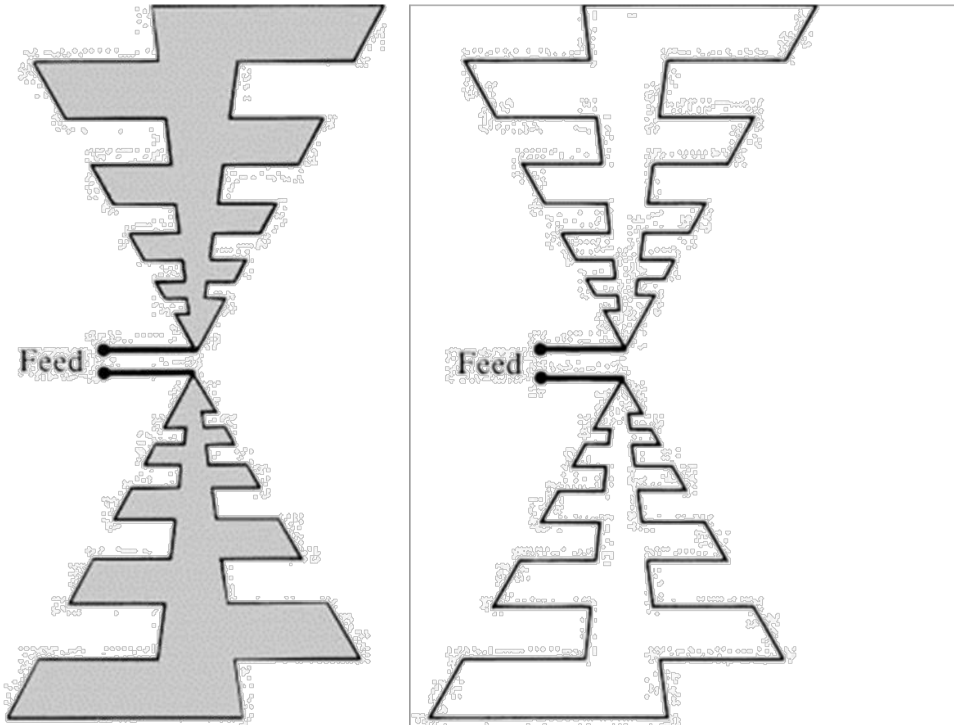


(a) Metal Strip Log-Periodic Configuration

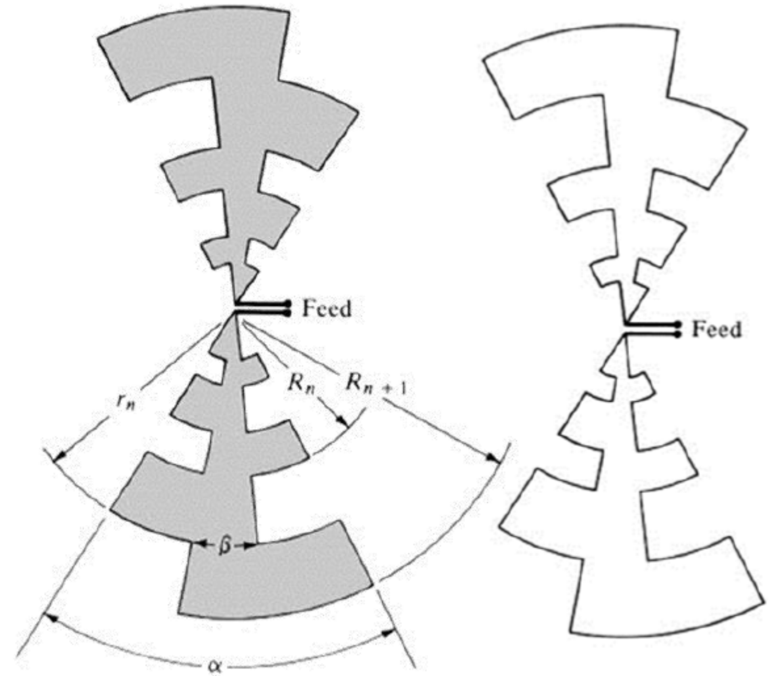


(b) Log-Periodic Metal Strip Antenna

Log-Periodic Antenna



DuHamel & Isbell- Planar and wire trapezoidal toothed log-periodic antennas [Balanis, Figure 11.7, p. 553]



DuHamel & Isbell- (a) Planar and (b) wire logarithmically periodic antennas [Balanis, Figure 11.6, p. 552]

(The removal of the inner surface of the antenna does not significantly impact the radiation characteristics.)

Log-Periodic Antenna

Geometric Ratio τ (defines period):

$$\tau = \frac{R_n}{R_{n+1}} < 1 \qquad (11\text{-}23)$$

Width of Slot:

$$\chi = \frac{r_n}{R_{n+1}} < 1 \qquad (11\text{-}24)$$

$$\tau = \frac{f_1}{f_2} < 1,\ f_2 > f_1 \qquad (11\text{-}25)$$

f_1 and f_2 are one period apart.

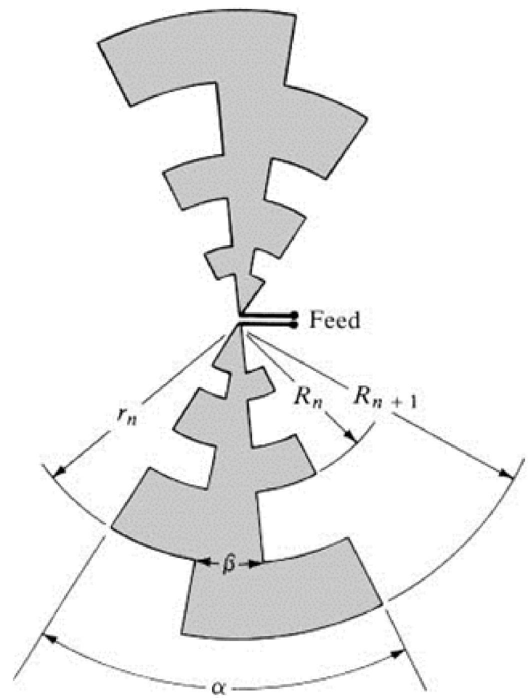
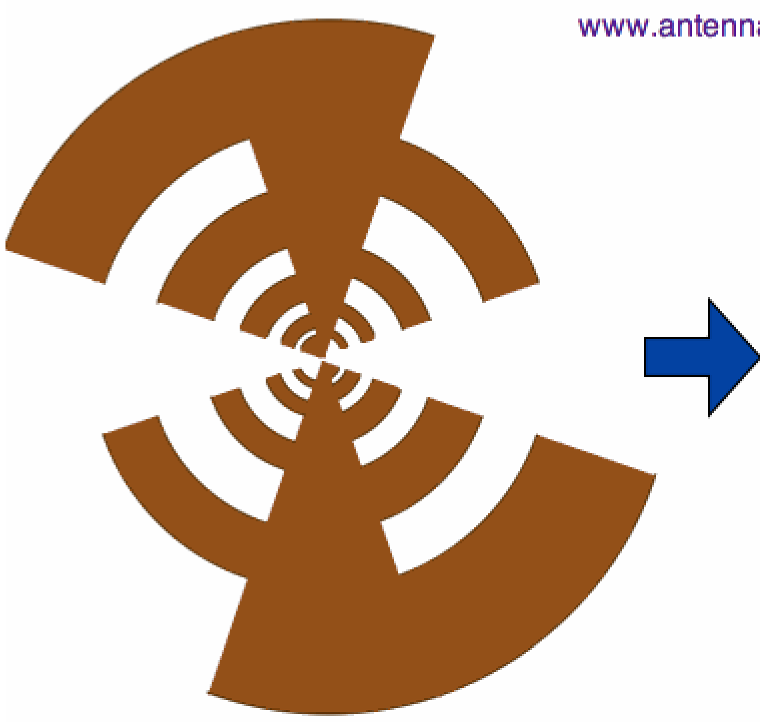


Fig. 11.6(a)

Log-Periodic Antenna (Self-Complimentary)

replace the metallic areas of the structure with air and vice versa, and we end up with the result as shown. If we then feed across the metallic gap as shown on the right. It is a log periodic tooth slot antenna. The properties of this slot antenna will be very similar to the standard dipole version of the antenna (same approximate radiation pattern, antenna gain, but the polarization will be changed).

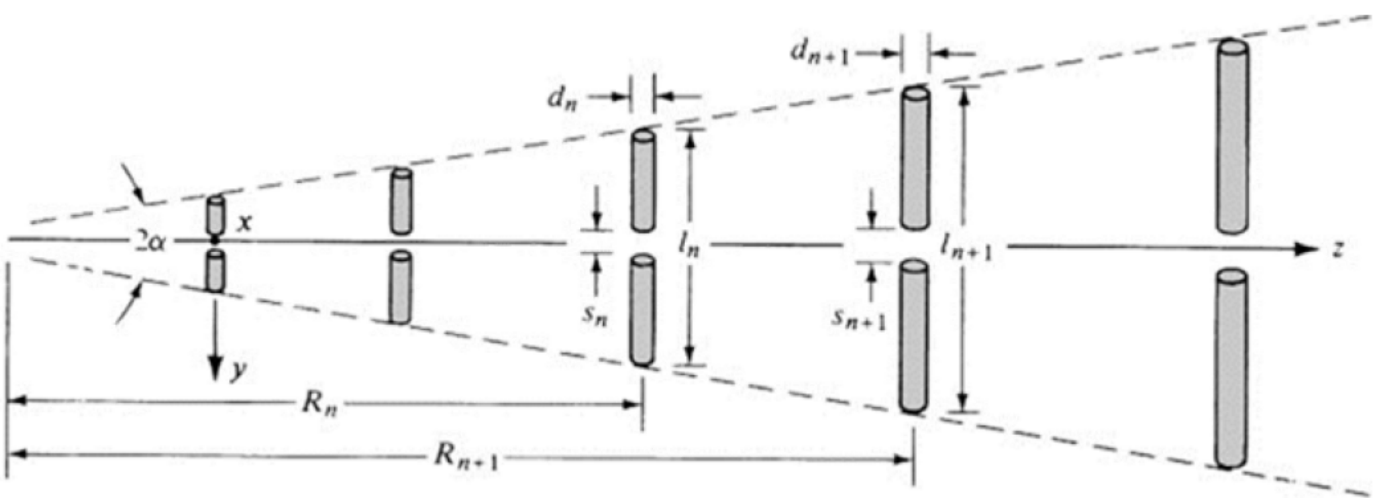


Standard LP Tooth

The Complement - The LP Tooth Slot Antenna

Log-Periodic Dipole Array

1. The Log-Periodic Dipole Array (LPDA) is the most commonly used VHF antenna for TV that supports all channels
2. It is capable of constant gain and input impedance over a bandwidth of 30:1
3. Has a gain range from 6.5-10.5 dB for half-wave dipole
4. The dipoles are connected to a central transmission line with phase reversal between dipoles, so that radiation is back-fire



Chapter 11
Frequency Independent Antennas, Antenna Miniaturization

Log-Periodic Dipole Array

Scale Factor τ:

$$\frac{1}{\tau}=\frac{\ell_2}{\ell_1}=\frac{\ell_{n+1}}{\ell_n}=\frac{R_2}{R_1}=\frac{R_{n+1}}{R_n}$$

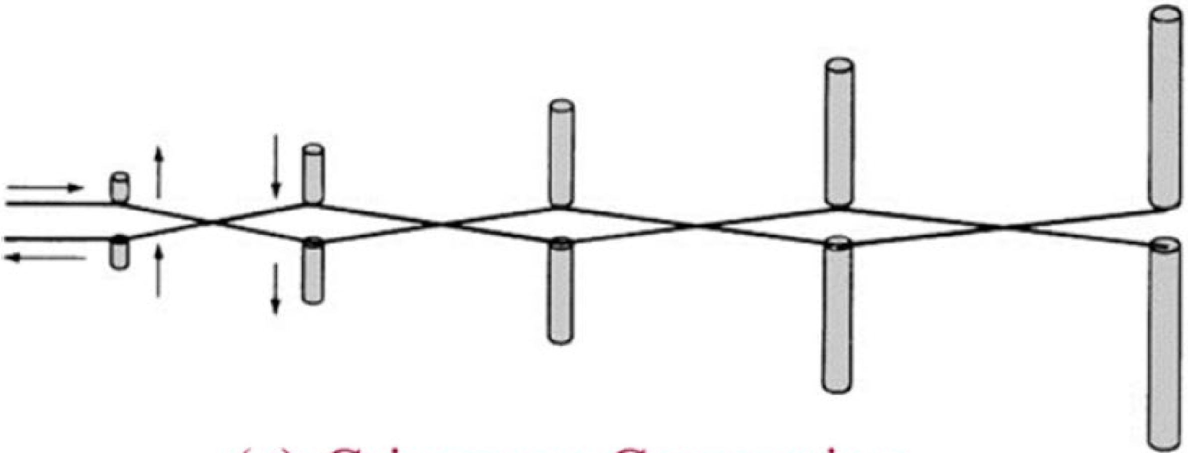
$$=\frac{d_2}{d_1}=\frac{d_{n+1}}{d_n}=\frac{s_2}{s_1}=\frac{s_{n+1}}{s_n} \quad (11\text{-}26)$$

Spacing Factor σ:

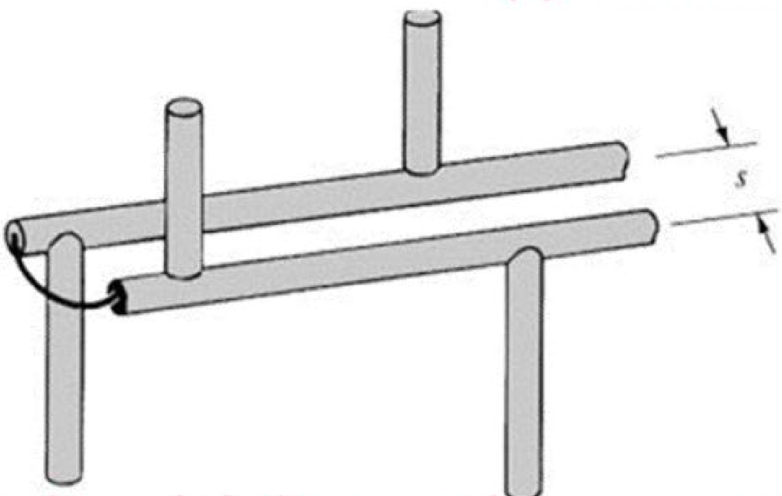
$$\sigma=\frac{R_{n+1}-R_n}{2\ell_{n+1}} \quad (11\text{-}26a)$$

lengths (l_n's), spacings (R_n's), diameters (d_n's), and even gap spacings at dipole centers (s_n's)

Log-Periodic Dipole Array

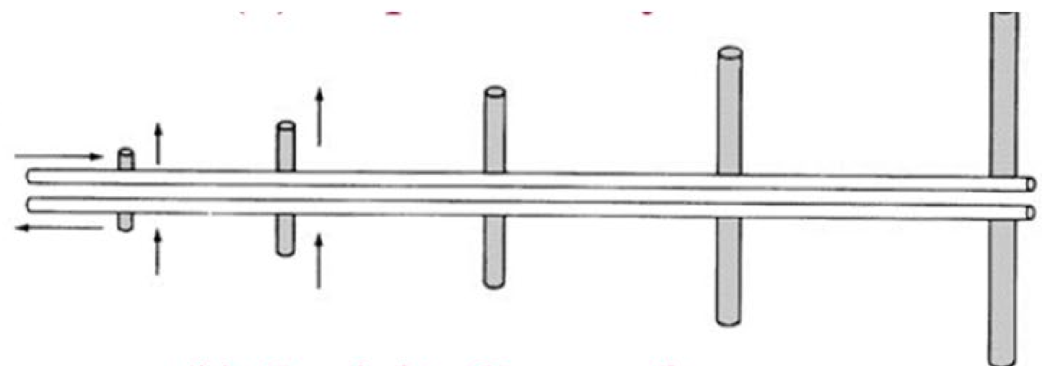


(c) Crisscross Connection



(d) Coaxial Connection

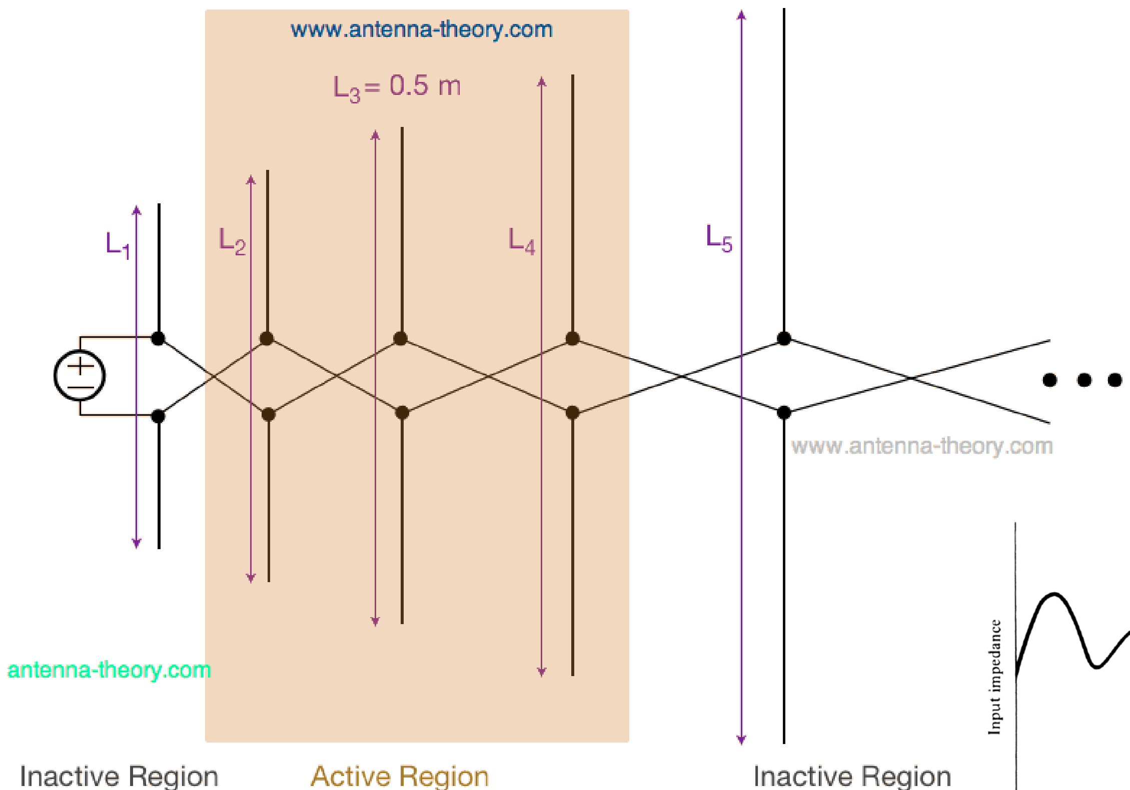
Fig

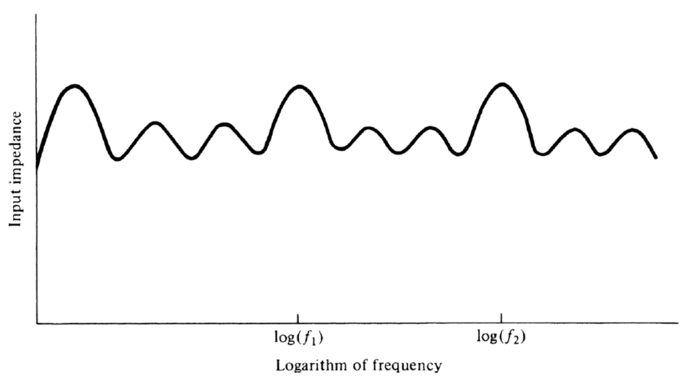


(b) Straight Connection

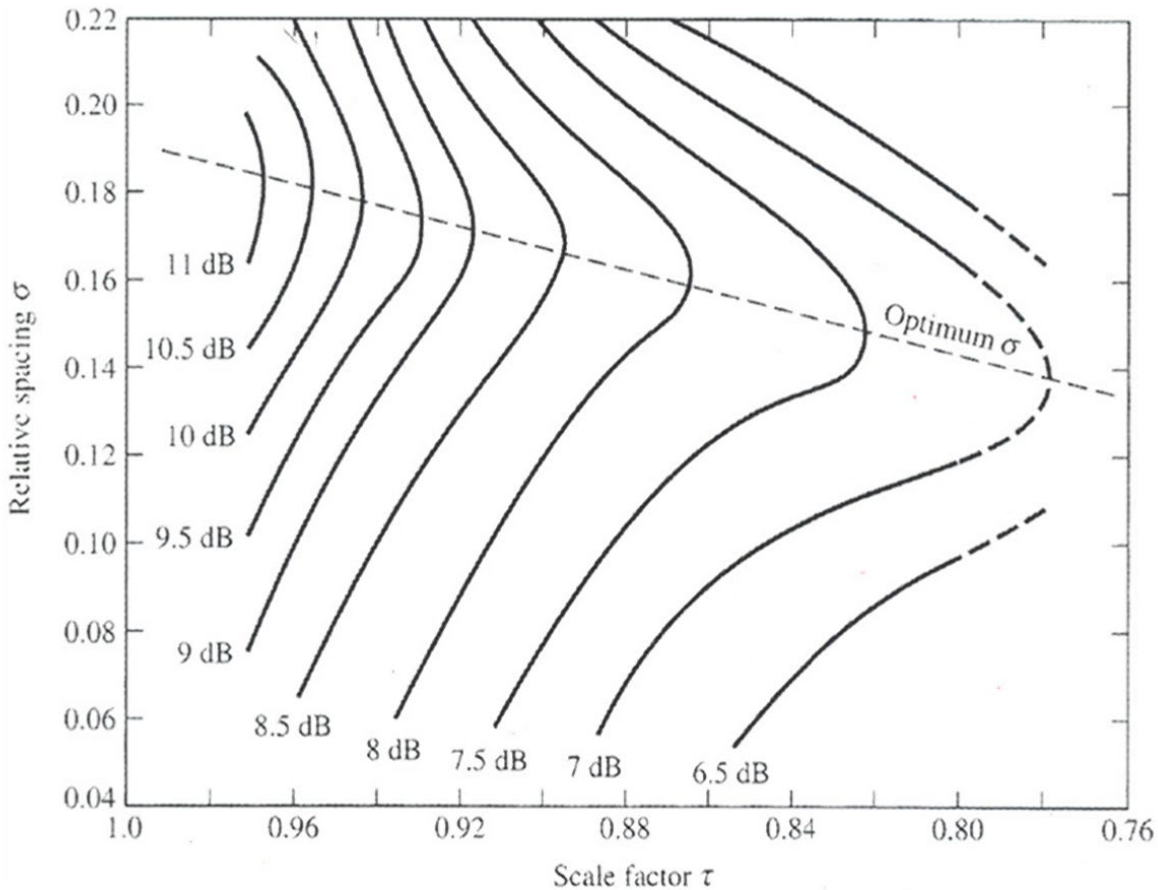
Log-Periodic Dipole Array – Active Region

- The log periodic antenna working the way intuitively
- "active region" -- the portion actually radiating or receiving radiation efficiently shifts with frequency
- The longest element is active at the antenna's lowest usable frequency where it acts as a half wave dipole





Log-Periodic Dipole Array – Design Procedure



Computed contours of constant directivity versus σ and τ for log-periodic dipole arrays.

Log-Periodic Dipole Array – Design Procedure

Aperture angle:

$$\alpha = \tan^{-1}\left[\frac{1-\tau}{4\sigma}\right]$$

Bandwidth of the active region:

$$B_{ar} = 1.1 + 7.7(1-\tau)^2 \cot(\alpha)$$

A more 'practical' bandwidth (B is in fractional form):

$$B_s = B B_{ar}$$

$$B_s = designed\ bandwidth$$

$$B = desired\ bandwidth$$

The total length of the structure is

$$L = \frac{\lambda_{max}}{4}\left(1 - \frac{1}{B_s}\right)\cot(\alpha)$$

Where

$$\lambda_{max} = 2l_{max} = \frac{c_0}{f_{min}}$$

Log-Periodic Dipole Array – Design Procedure

The number of elements is determined by

$$N = 1 + \frac{\ln(B_s)}{\ln\left(\frac{1}{\tau}\right)}$$

The average characteristic impedance of the elements is given by

$$Z_a = 120\left[\ln\left(\frac{l_n}{d_n}\right) - 2.25\right]$$

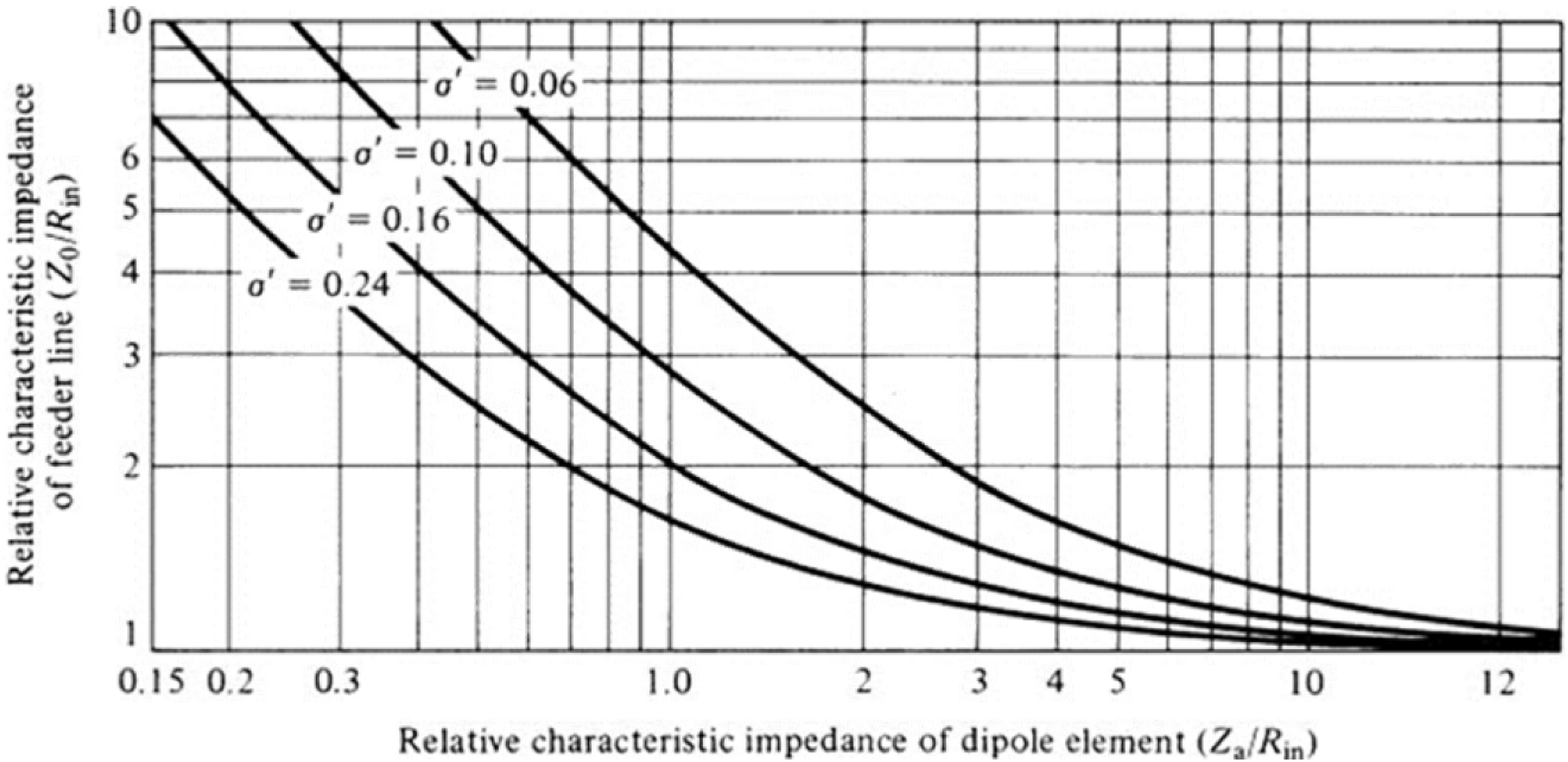
The relative mean spacing between elements is

$$\sigma' = \sigma/\sqrt{\tau}$$

The center-to-center spacing between the two rods of the feeder line is

$$s = d\cosh\left(\frac{Z_0}{120}\right)$$

Log-Periodic Dipole Array – Design Procedure



Homework: (UG)

You need to design a yagi antenna with a frequency of 260 MHz. The maximum estimated directivity is 12.93 dBi. Using the table below, calculate the dimensions of all the elements of your antenna and draw it by specifying all these dimensions.

Table 5.4 Optimized elements for Yagi–Uda antennas (the normalized diameter $d/\lambda = 0.0085$, spacing $S_1 = 0.2\lambda$)

Boom length/λ	0.4	0.8	1.2	2.2	4.2	Note
L_1/λ	0.482	0.482	0.482	0.482	0.475	Reflector
L_2/λ		$\lambda/2$ folded dipole ~ 0.47				Driven element
L_3/λ	0.442	0.428	0.428	0.432	0.424	Director
L_4/λ		0.423	0.420	0.415	0.424	
L_5/λ		0.428	0.420	0.407	0.420	
L_6/λ			0.428	0.398	0.407	
L_7/λ				0.390	0.403	
L_8/λ				0.390	0.398	
L_9/λ				0.390	0.394	
L_{10}/λ				0.390	0.390	
L_{11}/λ				0.398	0.390	
L_{12}/λ				0.407	0.390	
L_{13}/λ					0.390	
L_{14}/λ					0.390	
L_{15}/λ					0.390	
Spacing/λ	0.20	0.20	0.25	0.20	0.308	Between directors
D in dBd	7.1	9.2	10.2	12.25	14.2	Measured
D in dBi	9.2	11.3	12.3	14.35	16.3	Measured
Estimated D_{max} *in dBi*	9.93	12.14	12.93	15.95	16.91	Equation (5.35)

Homework: Helical Antenna 1 (UG)

Design a 10-turn helix to operate in the axial mode.
Determine

a) The circumference in wavelengths, the pitch angle in degrees, and
separation between turns (in wavelengths)
b) HPBW of the main lobe in degrees
c) Directivity in dB

Homework: Helical Antenna 2 (PG)

Design a 5-turn helical antenna at $400\ \mathrm{MHz}$ to operate in the normal mode. The spacing between turns is $\lambda_0/50$. It is desired that the antenna possesses circular polarization.

Determine

a) The circumference of the helix in meters
b) Length of a single turn in meters
c) Length of the entire helix in meters
d) Pitch angle in degrees

Homework: (PG) Log-Periodic Dipole Array Design

Design a log-periodic dipole antenna, to cover all VHF channels ($54\ \mathrm{MHz}$ for Channel 2 to $216\ \mathrm{MHz}$ for Channel 13). The desired directivity is 8 dB and the input impedance needs to be matched to a $50\ \Omega$ coaxial cable.

*The antenna elements are made of aluminum tubing $3/4$ in. $(1.9\ \mathrm{cm})$ for the largest element and the feeder line and $3/16$ in. $(0.48\ \mathrm{cm})$ for the smallest element. These diameters yield identical l/d ratios for the smallest and largest elements. However, for ease of fabrication, all the elements can have the same diameter. You can use a diameter of 3/16 in for calculation for instance.