3.3 Frequency independent antennas - spiral and log periodic antenna

Module:3 HF, UHF and Microwave Antennas

Course: BECE305L – Antenna and Microwave Engineering

-Dr Richards Joe Stanislaus

Assistant Professor - SENSE

Email: richards.stanislaus@vit.ac.in

VIT®
Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)
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: Balanais Antenna Theory and Antennas from theory to practice (Yi Huang)

1. Frequency independent antennas - Introduction

- The use of **simple, small, lightweight, and economical antennas**, designed to operate over **the entire frequency band** of a given system, would be **most desirable**.
- antennas with **broadband pattern** and impedance characteristics having **bandwidths** to as great as **40:1** or more were referred to as ***frequency independent***.
- **geometries were specified by angles**.
- are primarily used in the **10–10,000 MHz region** in a variety of practical applications such as **TV, point-to-point communication, feeds for reflectors and lenses**, and so forth

1. Frequency independent antennas - Introduction

- **Scale model measurements** :
  if ***all* the physical dimensions** are ***reduced* by a factor of two**, the performance of the antenna will remain unchanged if **the operating frequency is *increased* by a factor of two**.
- Also: if the **shape of the antenna were completely specified by angles**, its performance would have to be **independent of frequency**
- **infinite biconical dipole**
  To make infinite
- **structures more practical**, the designs usually require that the **current on the structure decrease with distance away from the input terminals**.
  After a certain point the current is negligible, and the structure **beyond that point to infinity can be truncated and removed**.

1. Frequency independent antennas - Introduction

- Practical bandwidths are on the order of about 40:1. Even higher ratios (i.e., 1,000:1) can be achieved in antenna design but they are not necessary, since they would far exceed the bandwidths of receivers and transmitters
- a general solution for the surface $r = F(\theta, \phi)$

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

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

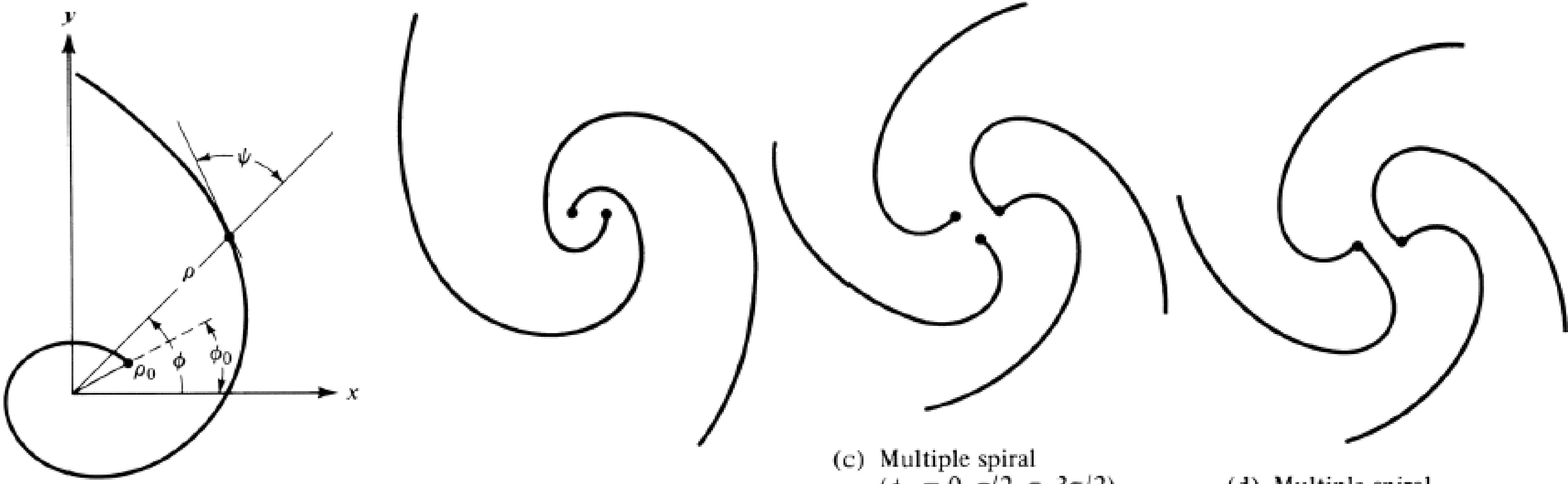
If the antenna is to be scaled to a frequency that is ***K* times lower than the original frequency**, the antenna's physical surface must be made *K* times greater to maintain the **same electrical dimensions**. second antenna to achieve congruence with the first, it must be rotated by an angle *C* so that

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

angle of rotation *C* depends on *K*, *radiation* pattern will be rotated azimuthally through an angle *C*.

2. Planar Spiral Antenna

- Spiral Wire antennas



(a) Single spiral

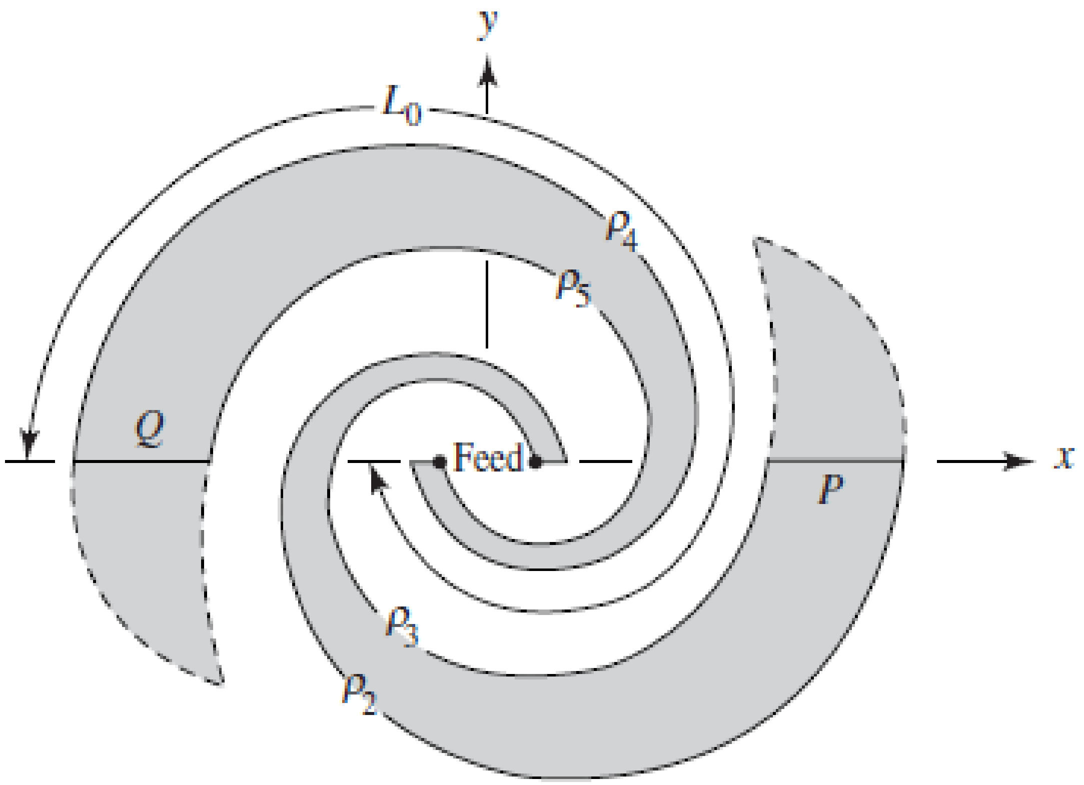
(b) Two spiral ($\phi_0 = 0, \pi$)

(c) Multiple spiral ($\phi_0 = 0, \pi/2, \pi, 3\pi/2$)

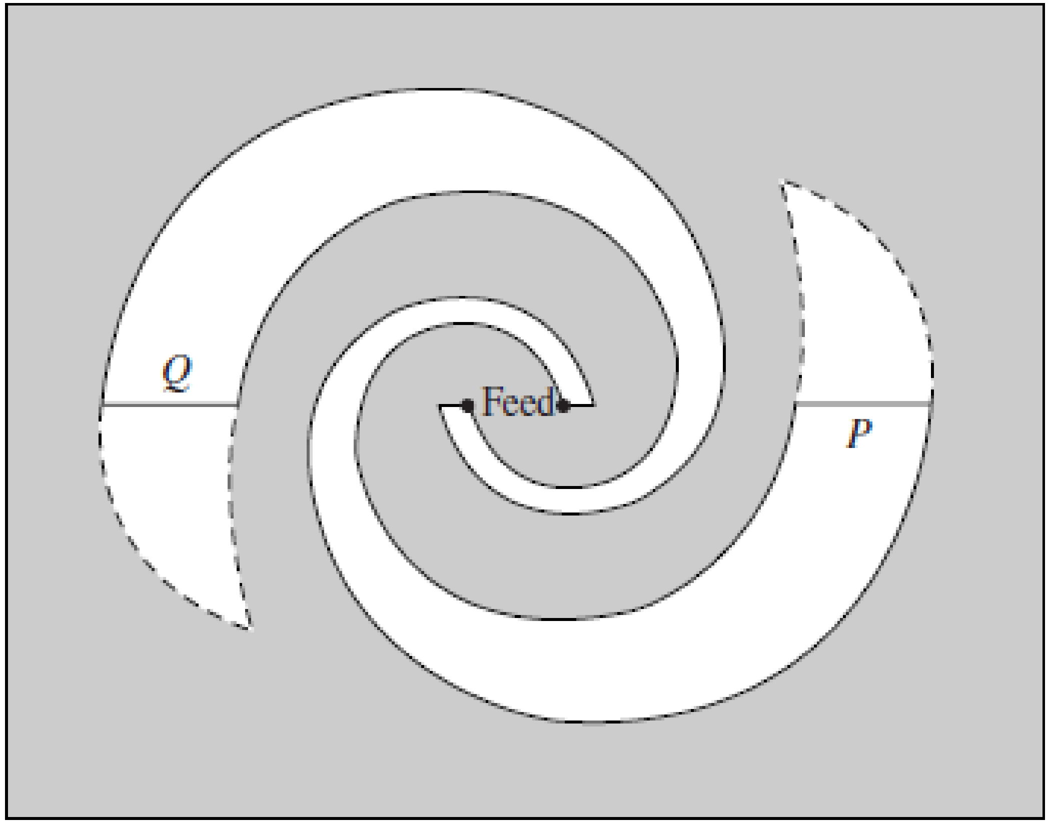
(d) Multiple spiral ($\phi_0 = 0, \pi/2, \pi, 3\pi/2$)

2. Planar Spiral Antenna

- Planar spiral: One antenna would consist of two metallic arms suspended in free-space

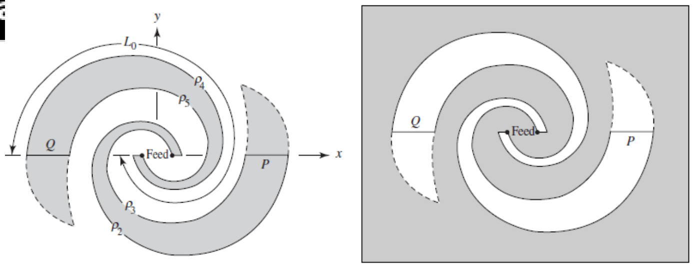


(a) Spiral plate



(b) Spiral slot

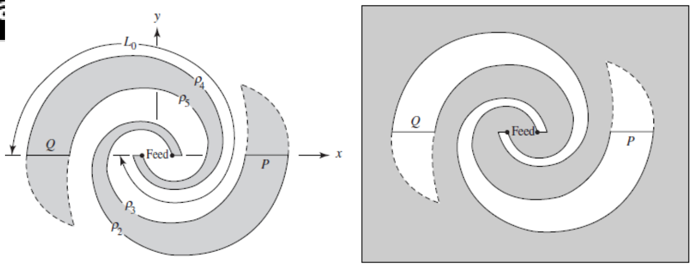
2. Planar Spiral Antenna



(a) Spiral plate (b) Spiral slot

- The **slot antenna is the most practical**, because it can be conveniently **fed by a balanced coaxial arrangement** to maintain its overall balancing
- **input impedance for an infinite structure** should be $Zs = Zc = 188.5 \simeq 60\pi$ ohms
- **Spiral slot antennas**, with good radiation characteristics, can be built **with one-half to three turns**. The most optimum design seems to be that with **1.25 to 1.5 turns with an overall length equal to or greater than one wavelength**. The **rate of expansion should not exceed about 10 per turn**.

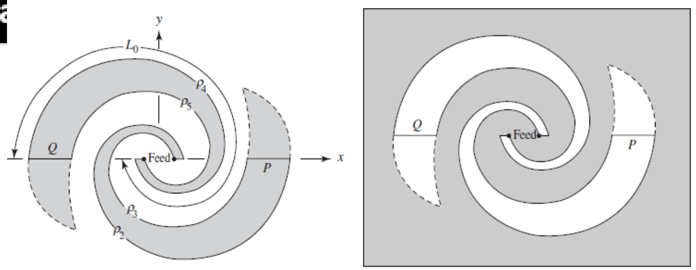
2. Planar Spiral Antenna



(a) Spiral plate (b) Spiral slot

- The **patterns are bidirectional**, **single lobed**, **broadside** (**maximum normal to the plan**e), and must vanish along the directions occupied by the infinite structure.
- The **wave is circularly polarized near the axis of the main lobe** over the usable part of the bandwidth.
  For a fixed cut, **the beamwidth will vary with frequency since the pattern rotates**. Typical variations are on the **order of 10°.**
- however, **slot antennas** with **more broad arms** and/or **more tightly wound spirals** exhibit **smoother and more uniform patterns with smaller variations** in beamwidth with frequency.
- For symmetrical structures, the pattern is also symmetrical with no tilt to the lobe structure.

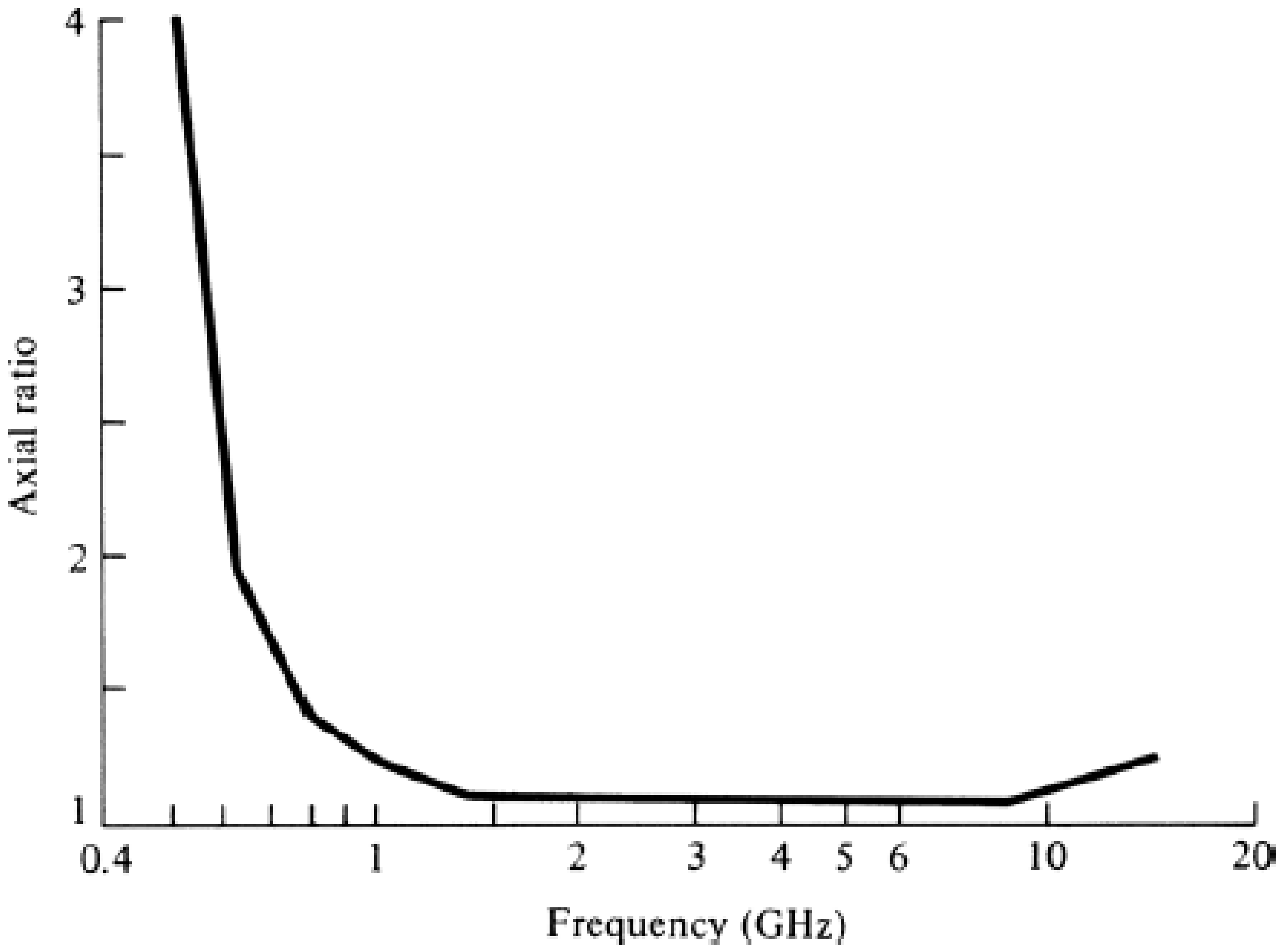
2. Planar Spiral Antenna

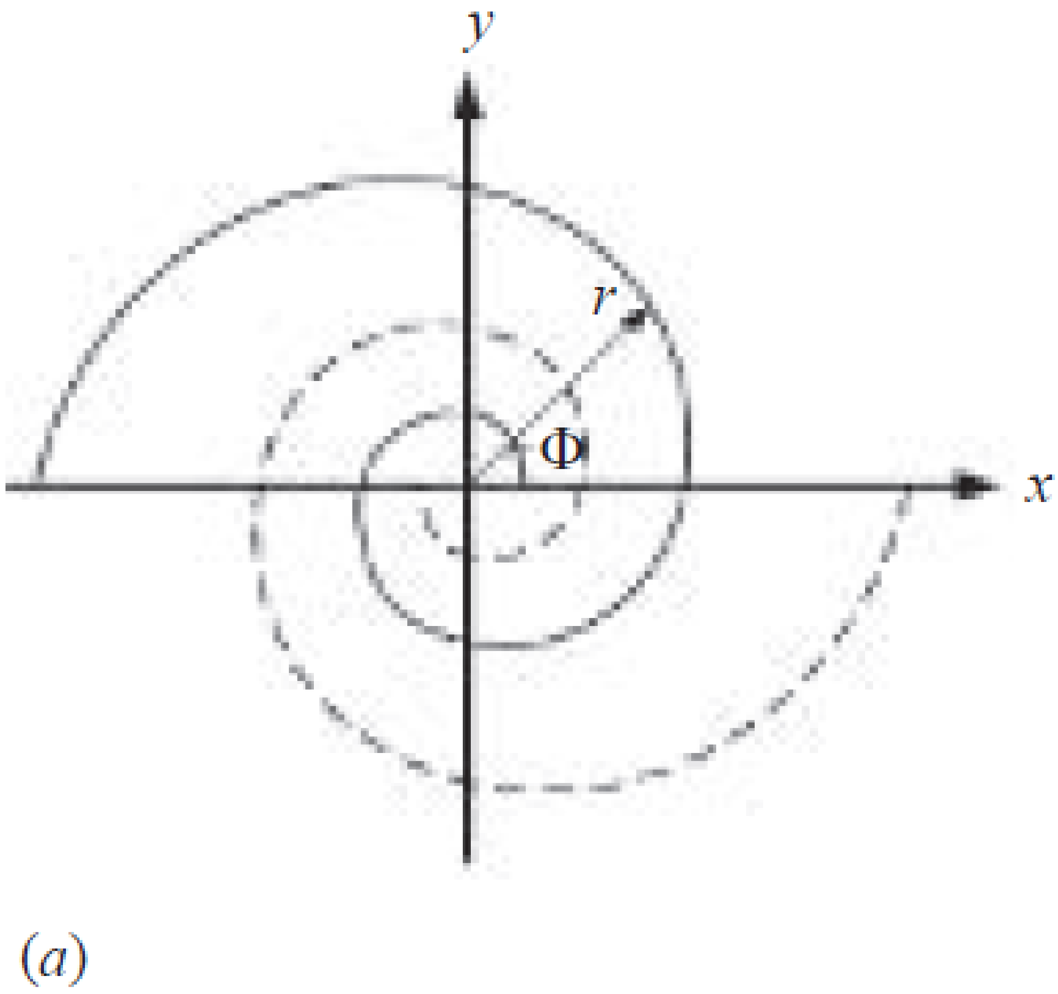


(a) Spiral plate (b) Spiral slot

- The **polarization of the radiated wave is controlled by the length of the arms**.
  For **very low frequencies**, such that the total arm length is small compared to the wavelength, the **radiated field is linearly polarized**.
  As the **frequency increases**, the wave becomes elliptically polarized and eventually **achieves circular polarization**.
- Pattern is essentially unaltered through this frequency
- the **polarization change with frequency can be used as a convenient criterion** to select
  the lower cutoff frequency of the usable bandwidth chosen to be the point where **the axial ratio is equal or less than 2 to 1,** when the overall arm length is about one wavelength.

On-axis polarization as a function of frequency for one-turn spiral slot.





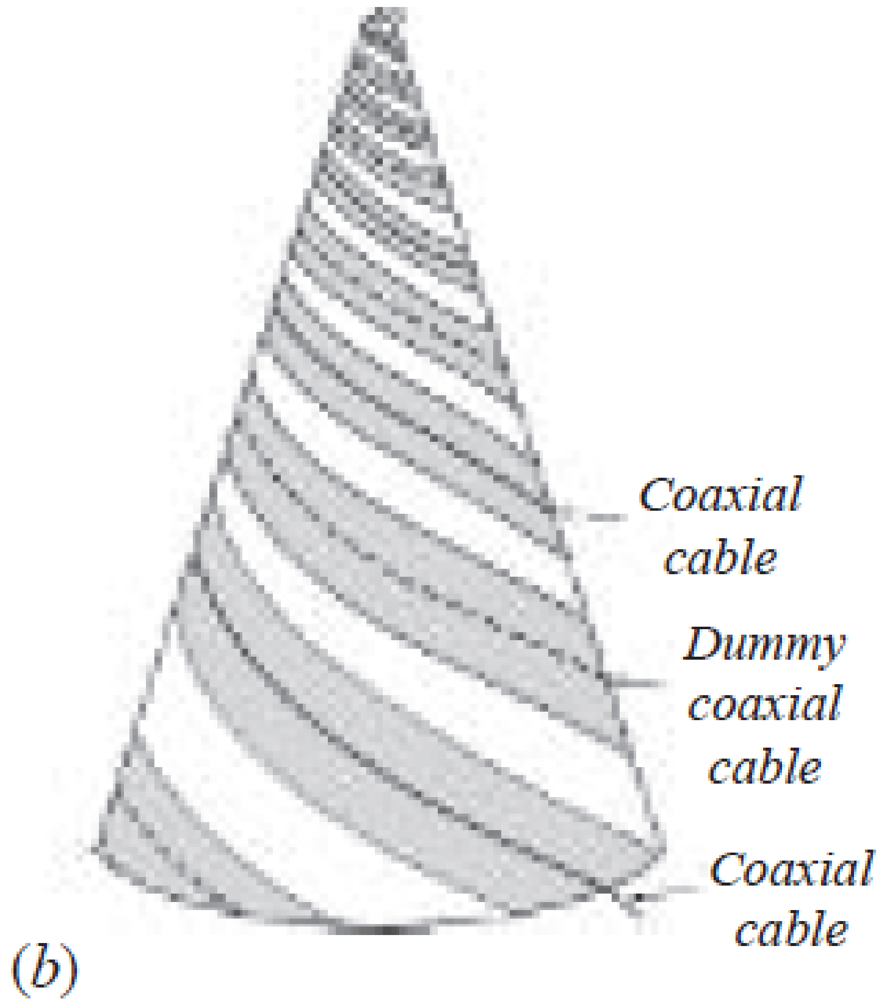


Figure 5.21 Spiral antennas (a) the wire type; (b) the conical type

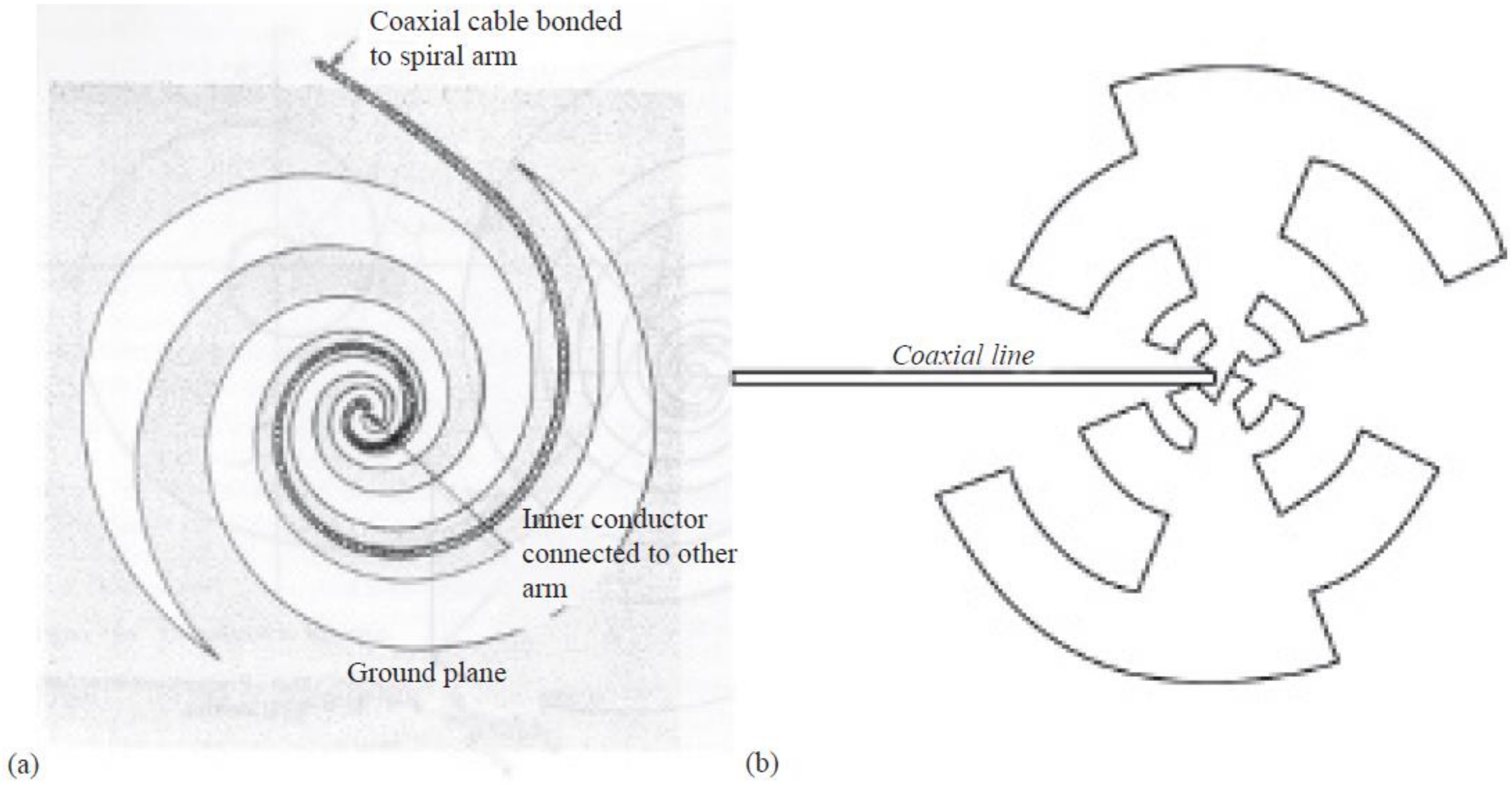
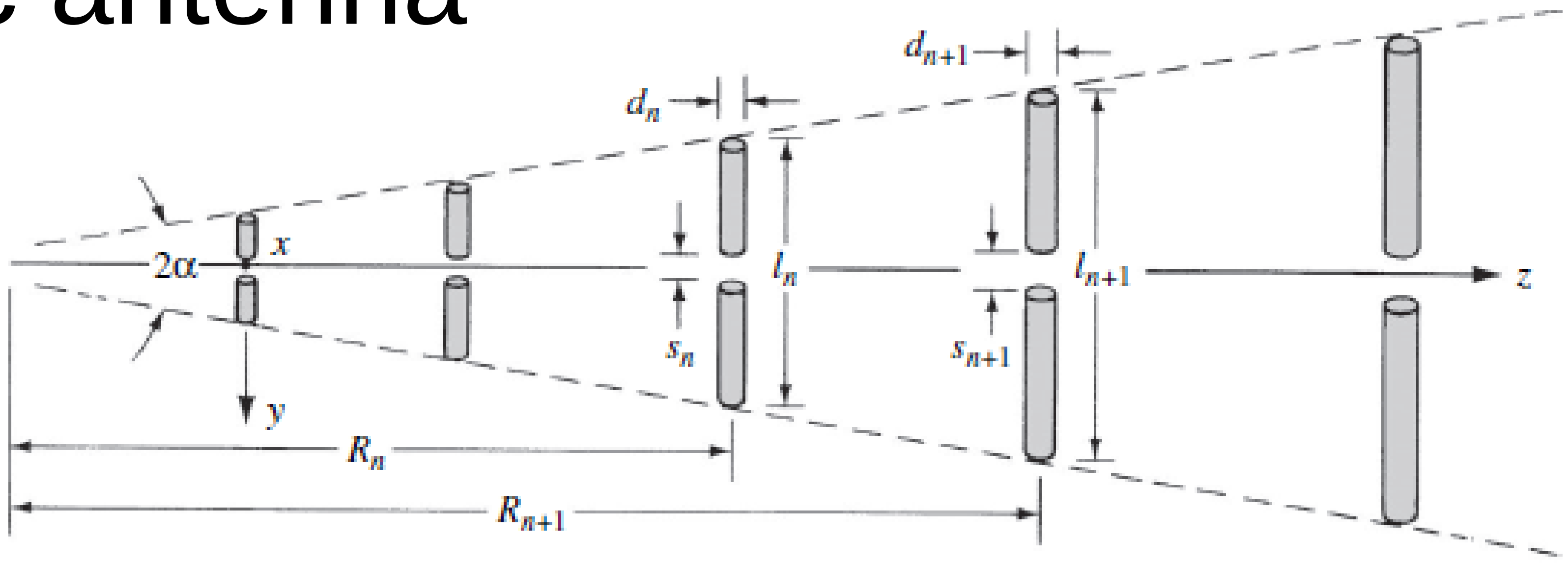
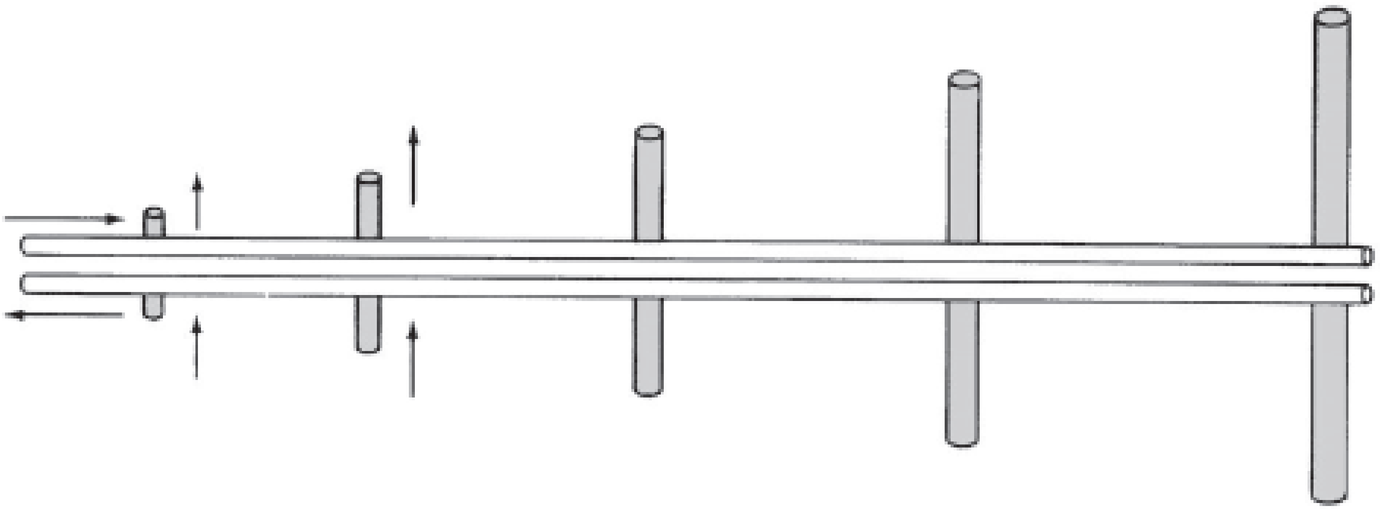


Figure 5.22 Two examples of self-complementary antennas (a) planar spiral; (b) log-periodic toothed planar antenna. (Reproduced by permission of John Wiley & Sons, Inc.)

3. Log periodic antenna

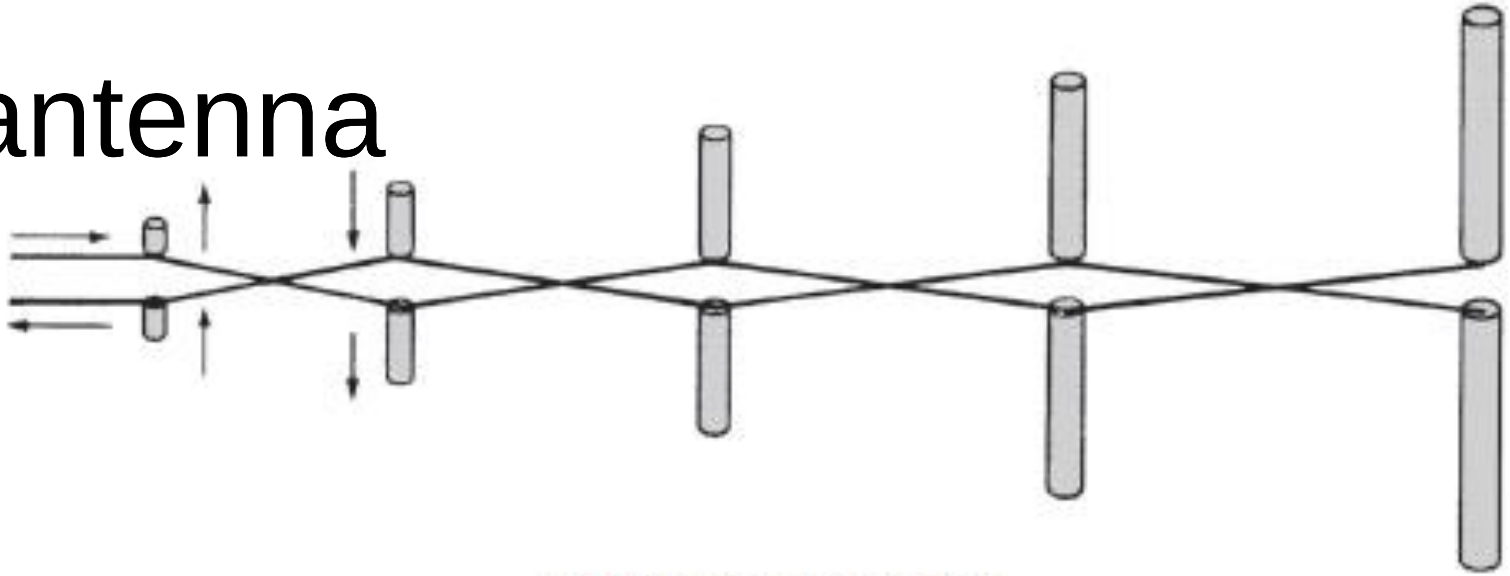


(a) Dipole array

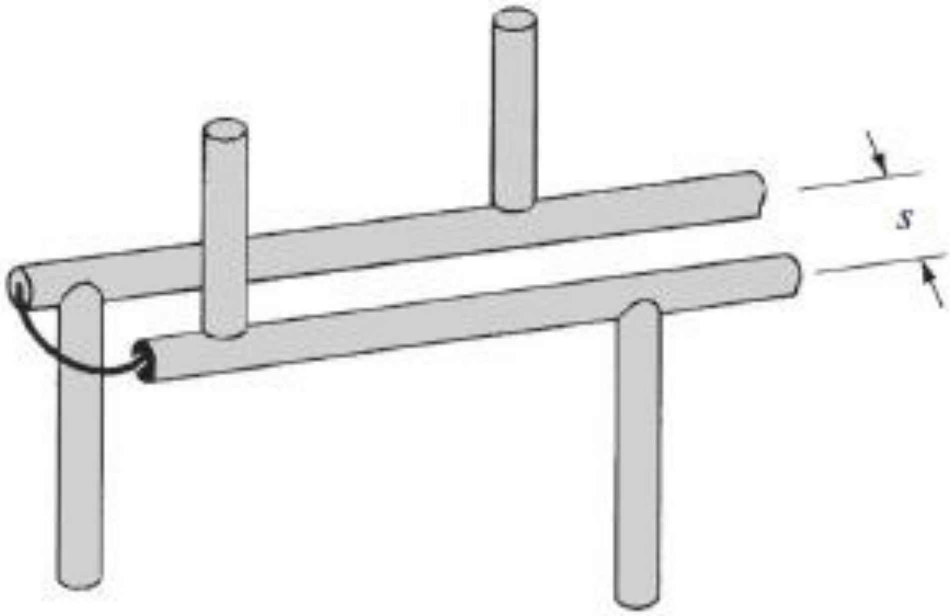


(b) Straight connection

3. Log periodic antenna



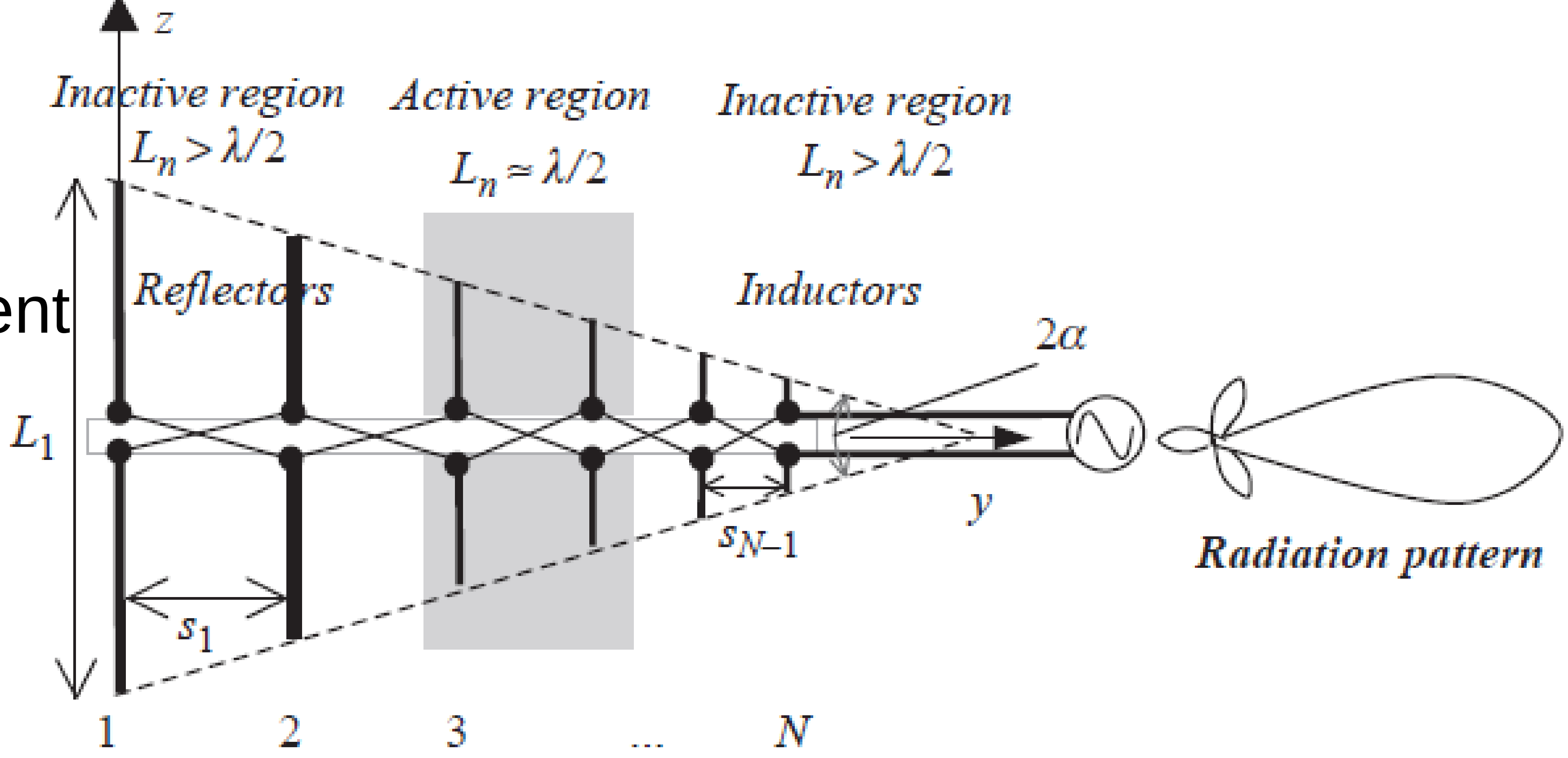
(c) Crisscross connection



(d) Coaxial connection

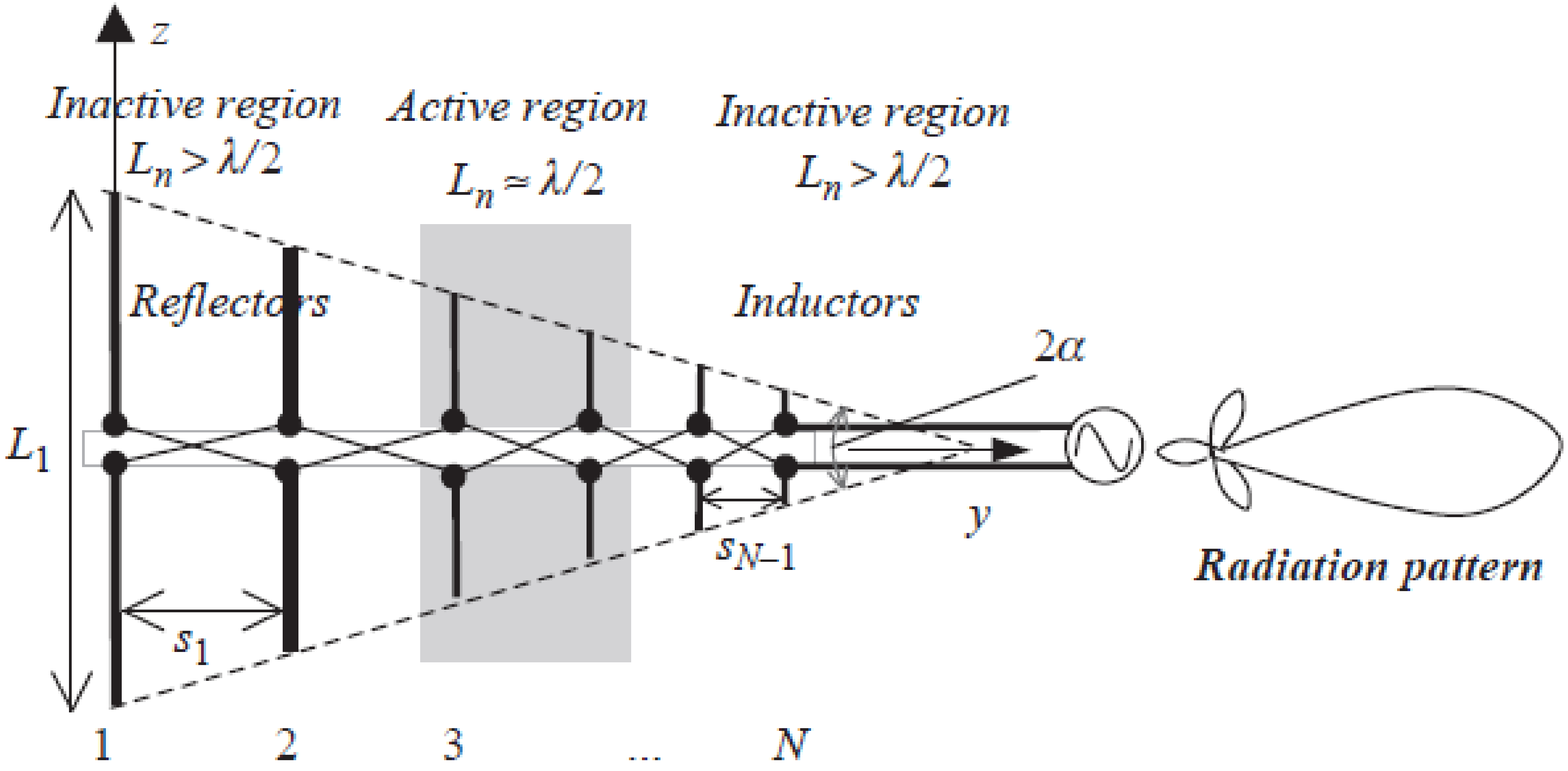
3. Log periodic antenna

- end-fire radiation pattern and directivity (typically between 7 and 15 dBi)
- widely used in the VHF andUHF bands.
- Much wider bandwidth than Yagi-Uda
- Feeder: Each element is connected to source
  Each element is active



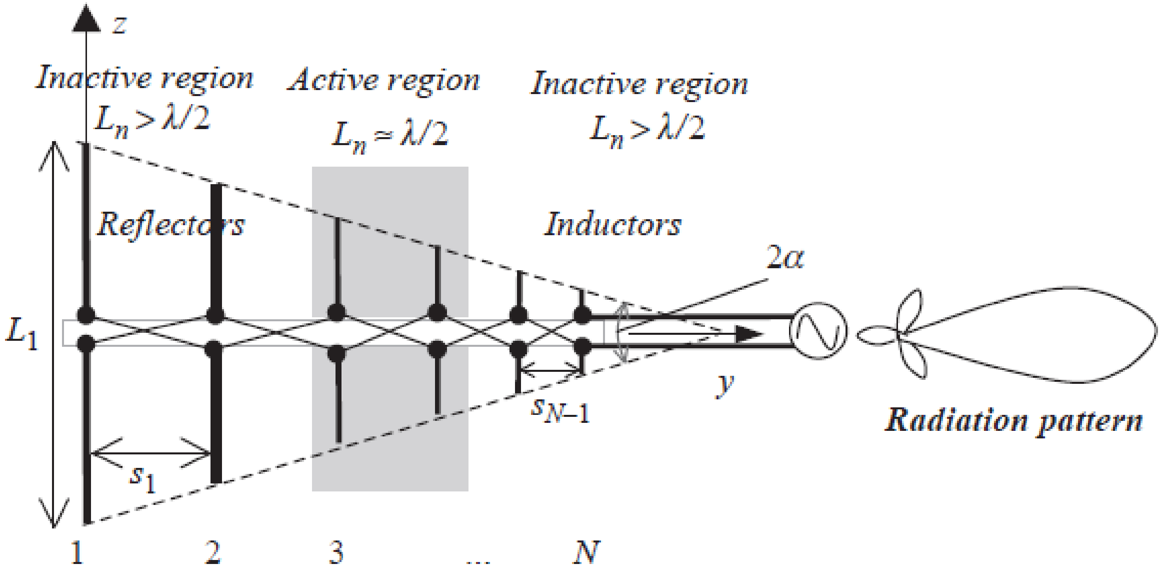
3. Log periodic antenna (log-periodic dipole antenna (LPDA))

- consists of many dipoles of different lengths.
- antenna is divided into the so-called ***active region*** and ***inactive regions***



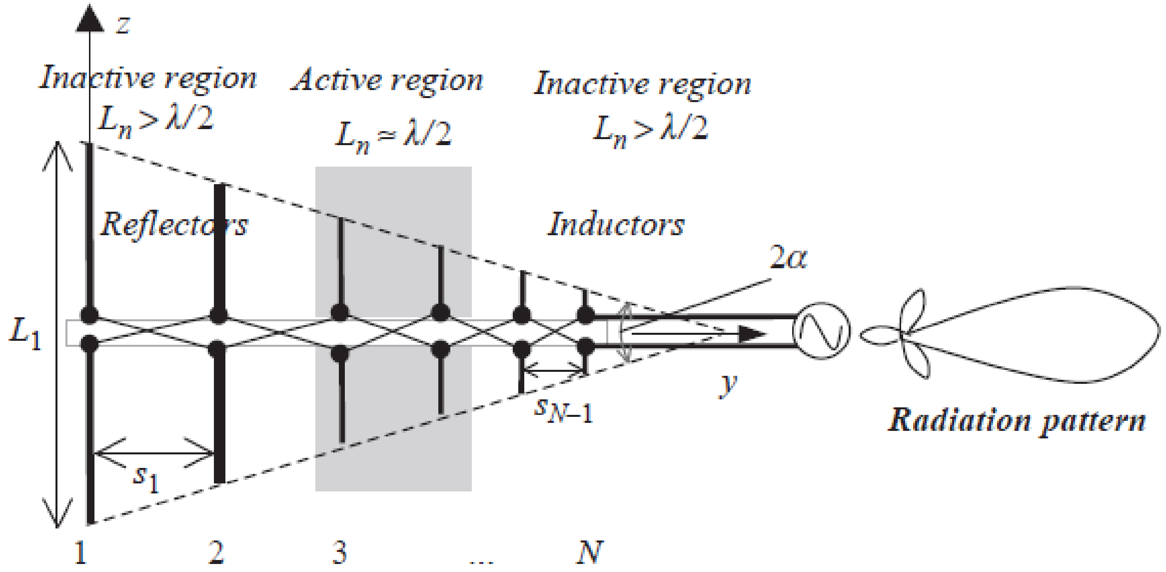
3. Log periodic antenna (log-periodic dipole antenna (LPDA))

- **role of a specific dipole element is linked to the operating frequency**:
- if its length, ***L*, is around half of the wavelength**, **it is an active dipole** and within the active region;
- if its **length is greater than half the wavelength**, it is in an inactive region and acts as a **reflector**;
- if its **length is smaller than half the wavelength**, it is also in an inactive region but acts as a **director**, which is very similar to the Yagi–Uda antenna.



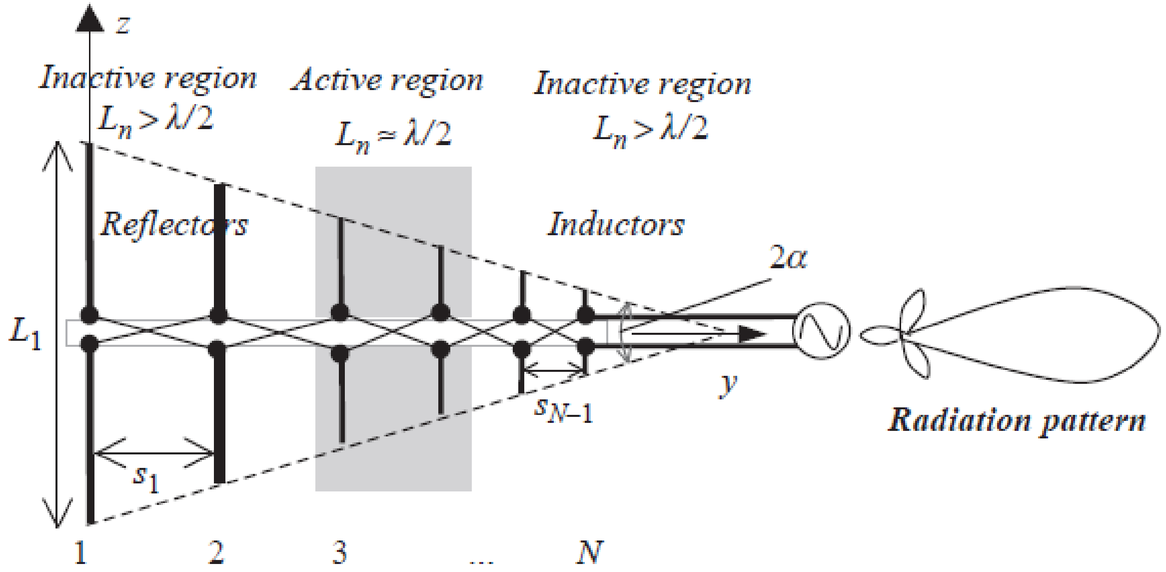
3. Log periodic antenna (log-periodic dipole antenna (LPDA))

- The difference is that the **driven element shifts with the frequency** – this is why this antenna can offer a **much wider bandwidth** than the Yagi– Uda.
- A traveling wave can also be formed in the antenna.
- The **highest frequency** is basically determined by the **shortest dipole length (L_N)** while the **lowest frequency is determin** by the **longest dipole length (L_1).**



3. Log periodic antenna (log-periodic dipole antenna (LPDA))

- The reason for this antenna being called a *log-periodic antenna* is that
  its **input impedance is a periodic function of the logarithm of the frequency**.
  Other parameters that undergo similar variations include the radiation pattern, directivity and beamwidth.



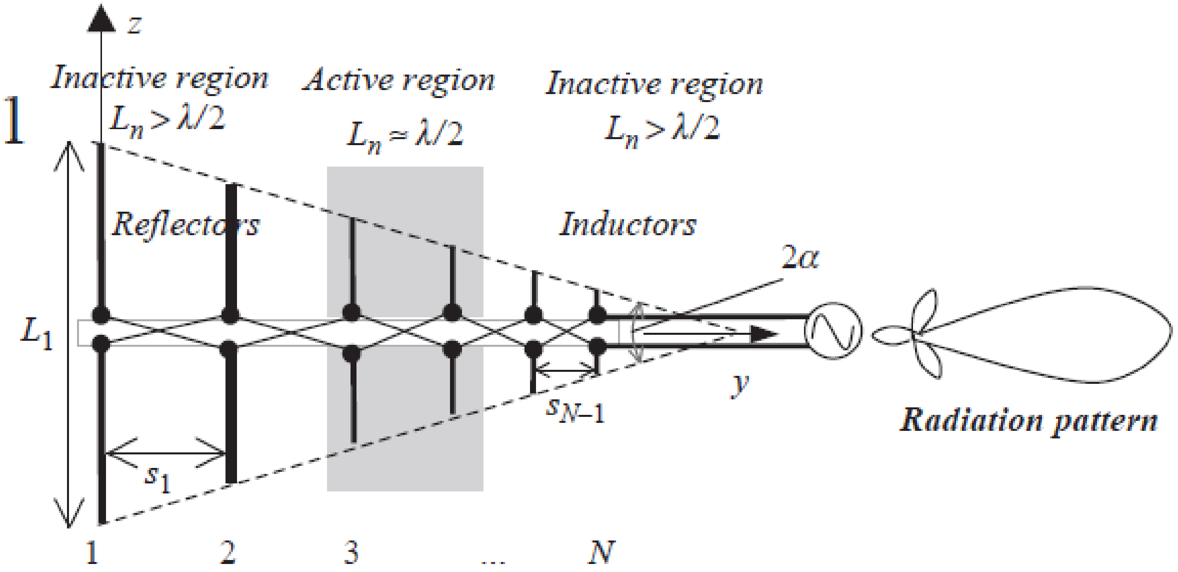
3.1 Log periodic antenna: Design

- L_n = the length of element *n*, and *n* = 1, 2, . . . , *N*;
- s_n = the spacing between elements *n* and (*n* + 1);
- d_n = the diameter of element *n*;
- g_n = the gap between the poles of element *n*.
- ***scaling factor***:

$$\tau = \frac{L_2}{L_1} = \frac{L_{n+1}}{L_n} = \frac{s_{n+1}}{s_n} = \frac{d_{n+1}}{d_n} = \frac{g_{n+1}}{g_n} < 1$$

- ***spacing factor***

$$\sigma = \frac{s_1}{2L_1} = \frac{s_n}{2L_n} < 1$$

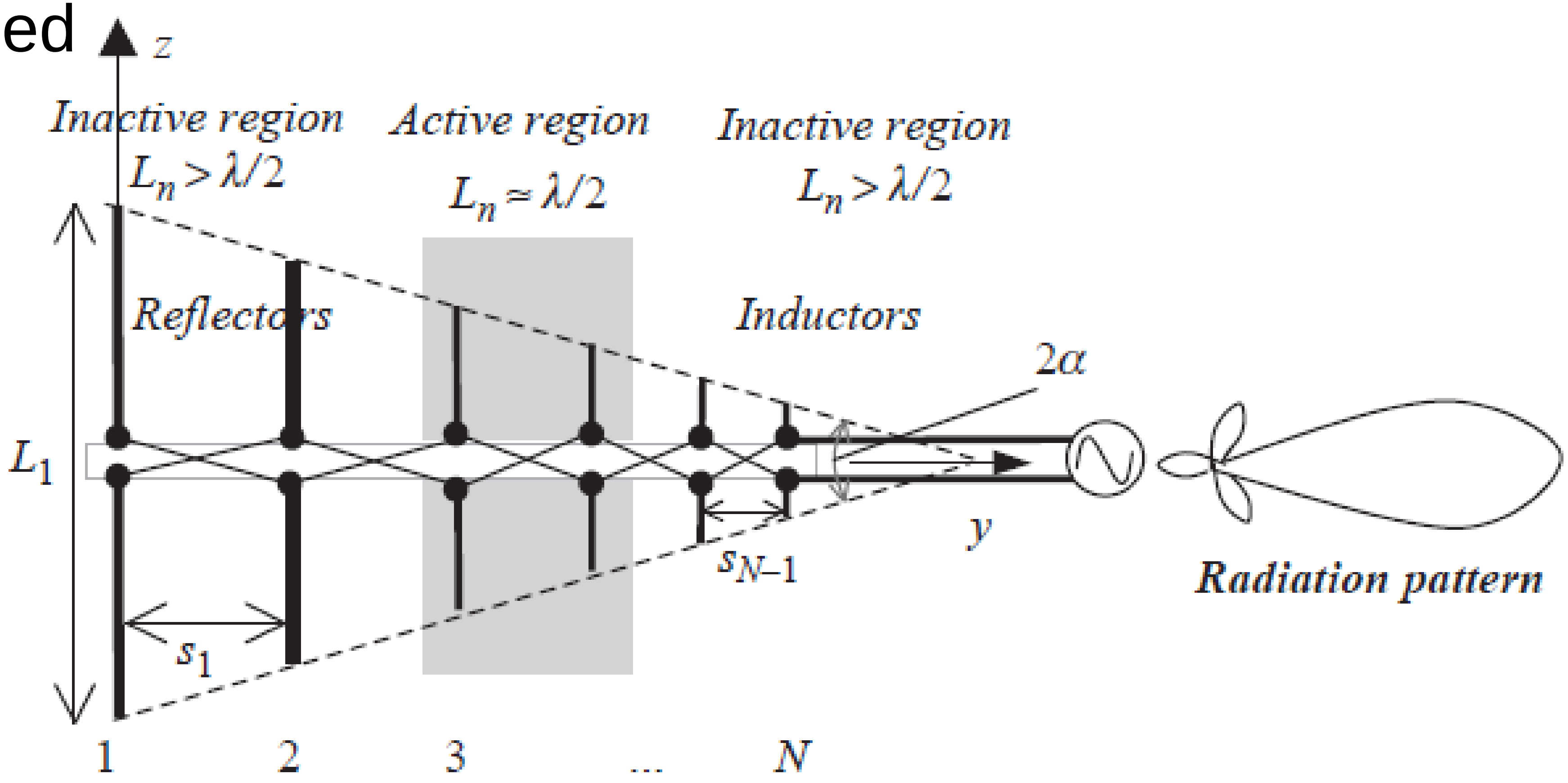


3.1 Log periodic antenna: [

$$\tau = \frac{L_2}{L_1} = \frac{L_{n+1}}{L_n} = \frac{s_{n+1}}{s_n} = \frac{d_{n+1}}{d_n} = \frac{g_{n+1}}{g_n} < 1$$

$$\sigma = \frac{s_1}{2L_1} = \frac{s_n}{2L_n} < 1$$

- **two straight lines through the dipole ends form an angle 2*α***, is a characteristic of the frequency-independent structure
- The angle *α* is called the ***apex angle*** of the log-periodic antenna



$$\alpha = \tan^{-1}\left(\frac{(L_n - L_{n+1})}{2s_n}\right) = \tan^{-1}\left(\frac{L_n(1-\tau)}{2s_n}\right) = \tan^{-1}\left(\frac{(1-\tau)}{4\sigma}\right)$$

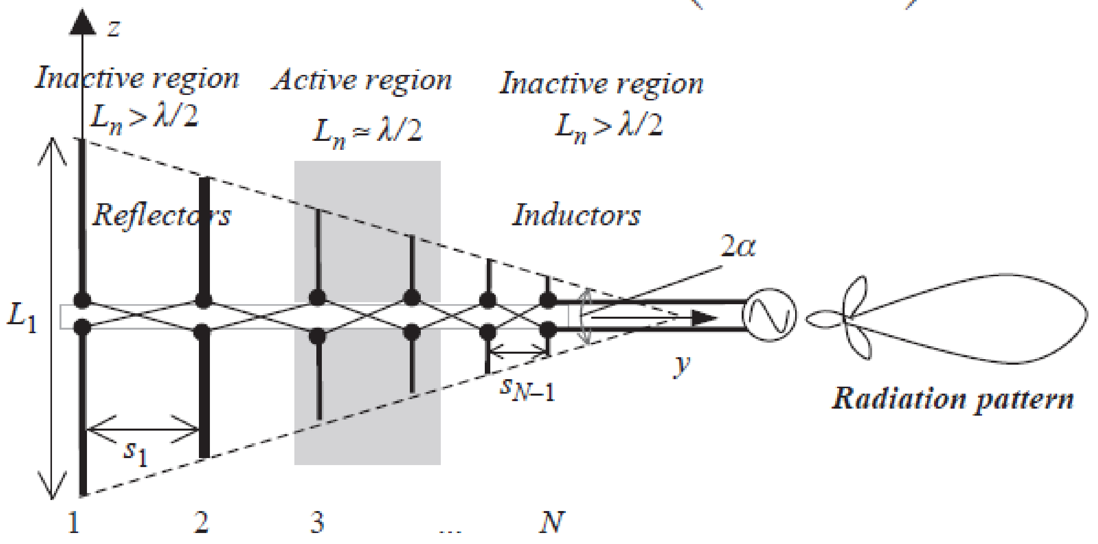
3.1 Log periodic antenna: D

$$\tau = \frac{L_2}{L_1} = \frac{L_{n+1}}{L_n} = \frac{s_{n+1}}{s_n} = \frac{d_{n+1}}{d_n} = \frac{g_{n+1}}{g_n} < 1$$

$$\sigma = \frac{s_1}{2L_1} = \frac{s_n}{2L_n} < 1$$

- From **frequency aspect** $\tau = \frac{L_{n+1}}{L_n} = \frac{f_n}{f_{n+1}}$
- logarithm of both sides $\log f_{n+1} = \log f_n - \log \tau$
- **resonant frequency in log scale is increased** by **every |log τ |.**
- performance of the antenna is periodic in a logarithmic fashion, Hence, **log-periodic antenna**

$$\alpha = \tan^{-1}\left(\frac{(L_n - L_{n+1})}{2s_n}\right) = \tan^{-1}\left(\frac{L_n(1-\tau)}{2s_n}\right) = \tan^{-1}\left(\frac{(1-\tau)}{4\sigma}\right)$$



3.1 Log periodic antenna: Design

Table 5.5 Optimum design data for log-periodic antenna

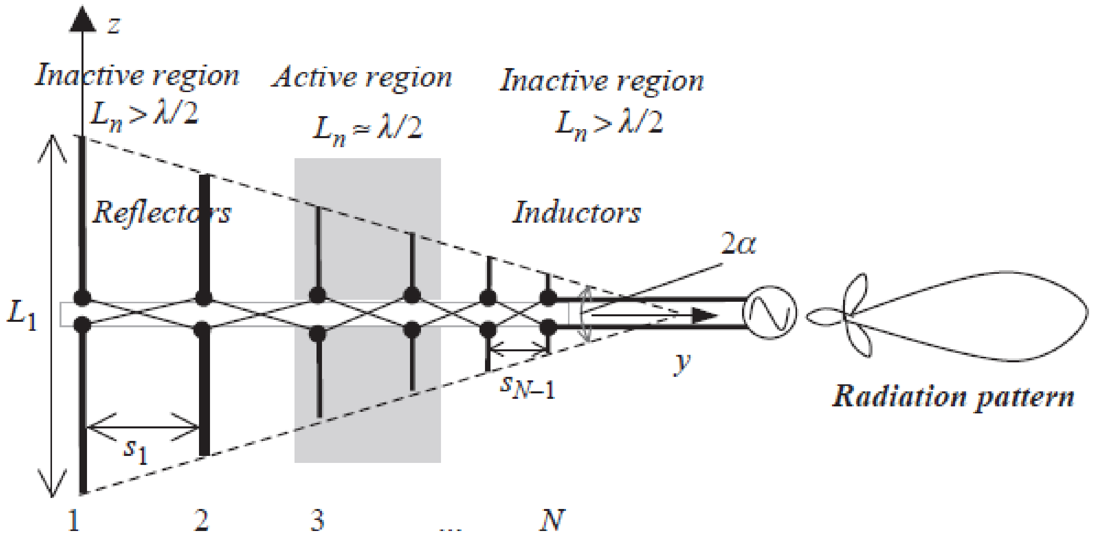
Directivity/dBi	Scaling factor τ	Spacing factor σ	Apex angle α
7	0.782	0.138	21.55°
7.5	0.824	0.146	16.77°
8	0.865	0.157	12.13°
8.5	0.892	0.165	9.29°
9	0.918	0.169	6.91°
9.5	0.935	0.174	5.33°
10	0.943	0.179	4.55°
10.5	0.957	0.182	3.38°
11	0.964	0.185	2.79°

3.1 Log periodic antenna: Design

- directivity, length of the antenna, apex angle, the upper frequency and the lower frequency, should come with the design specifications.
- Another important aspect of the design is the **antenna input impedance**, which can be **tuned by changing the diameter *d* of the element** and **the feeding gap *g* between the two poles**

$$g = d \cosh(Z_0/120)$$

- ***Z0* is the characteristic impedance of the feed line to be connected (the desired impedance).**



3.1 Log periodic antenna: Design

- **Practical design**: most likely scenario is that the frequency range is given from

$$L_1 \geq \frac{\lambda_{\max}}{2} = \frac{c}{f_{\min}};\ L_N \leq \frac{\lambda_{\min}}{2} = \frac{c}{f_{\max}}$$

$$\frac{f_{\min}}{f_{\max}} = \frac{L_N}{L_1} = \tau \frac{L_{N-1}}{L_1} = \tau^{N-1}$$

- geometrical dimensions are obtained, it is desirable to find the radiation pattern

Log-periodic antenna design. Design a log-periodic dipole antenna to cover al UHF TV channels, which is from 470 MHz for channel 14 to 890 MHz for channel 83. Each channel has a bandwidth of 6 MHz. The desired directivity is 8 dBi

- desired directivity is 8 dBi,

$$f_{\min} = 470\,\text{MHz},\ f_{\max} = 890\,\text{MHz},\ \text{and } D = 8\,\text{dBi}$$

- Optimum design from table:
  Scaling factor $\tau = 0.865$
  Spacing factor $\sigma = 0.157$
  Apex angle $\alpha = 12.13°$

Table 5.5 Optimum design data for log-periodic antenna

Directivity/dBi	Scaling factor τ	Spacing factor σ	Apex angle α
7	0.782	0.138	21.55°
7.5	0.824	0.146	16.77°
8	0.865	0.157	12.13°
8.5	0.892	0.165	9.29°
9	0.918	0.169	6.91°
9.5	0.935	0.174	5.33°
10	0.943	0.179	4.55°
10.5	0.957	0.182	3.38°
11	0.964	0.185	2.79°

Log-periodic antenna design. Design a log-periodic dipole antenna to cover al UHF TV channels, which is from 470 MHz for channel 14 to 890 MHz for channel 83. Each channel has a bandwidth of 6 MHz. The desired directivity is 8 dBi

Table 5.5 Optimum design data for log-periodic antenna

Directivity/dBi	Scaling factor τ	Spacing factor σ	Apex angle α
7	0.782	0.138	21.55°
7.5	0.824	0.146	16.77°
8	0.865	0.157	12.13°
8.5	0.892	0.165	9.29°
9	0.918	0.169	6.91°
9.5	0.935	0.174	5.33°
10	0.943	0.179	4.55°
10.5	0.957	0.182	3.38°
11	0.964	0.185	2.79°

- desired directivity is 8 dBi,

$$f_{\min} = 470\,\text{MHz},\ f_{\max} = 890\,\text{MHz},\ \text{and } D = 8\,\text{dBi}$$

- Optimum design from table:
  Scaling factor $\tau = 0.865$
  Spacing factor $\sigma = 0.157$
  Apex angle $\alpha = 12.13°$

$$N = \log\left(\frac{f_{\min}}{f_{\max}}\right) \Big/ \log(\tau) + 1 = \log\left(\frac{470}{890}\right) \Big/ \log(0.865) + 1 = 4.40 + 1 = 5.40 \approx 6$$

- at least six elements are required. Lets take 8 elements for safe side

Log-periodic antenna design. Design a log-periodic dipole antenna to cover al UHF TV channels, which is from 470 MHz for channel 14 to 890 MHz for channel 83. Each channel has a bandwidth of 6 MHz. The desired directivity is 8 dBi

- desired directivity is 8 dBi,

$$f_{\min} = 470\,\text{MHz},\ f_{\max} = 890\,\text{MHz},\ \text{and } D = 8\,\text{dBi}$$

- N = 8, we can afford to start from a lower frequency, say 400 MHz

Table 5.5 Optimum design data for log-periodic antenna

Directivity/dBi	Scaling factor τ	Spacing factor σ	Apex angle α
7	0.782	0.138	21.55°
7.5	0.824	0.146	16.77°
8	0.865	0.157	12.13°
8.5	0.892	0.165	9.29°
9	0.918	0.169	6.91°
9.5	0.935	0.174	5.33°
10	0.943	0.179	4.55°
10.5	0.957	0.182	3.38°
11	0.964	0.185	2.79°

$$L_1 = \frac{c}{f_{\min}} = \frac{300}{400} = 0.75\,(\text{m})$$

Log-periodic antenna design. Design a log-periodic dipole antenna to cover al UHF TV channels, which is from 470 MHz for channel 14 to 890 MHz for channel 83. Each channel has a bandwidth of 6 MHz. The desired directivity is 8 dBi

Table 5.5 Optimum design data for log-periodic antenna

Directivity/dBi	Scaling factor τ	Spacing factor σ	Apex angle α
7	0.782	0.138	21.55°
7.5	0.824	0.146	16.77°
8	0.865	0.157	12.13°
8.5	0.892	0.165	9.29°
9	0.918	0.169	6.91°
9.5	0.935	0.174	5.33°
10	0.943	0.179	4.55°
10.5	0.957	0.182	3.38°
11	0.964	0.185	2.79°

- desired directivity is 8 dBi,

$$f_{\min} = 470\,\text{MHz},\ f_{\max} = 890\,\text{MHz},\ \text{and } D = 8\,\text{dBi}$$

- N = 8, we can afford to start from a lower frequency, say 400 MHz

$$L_1 = \frac{c}{f_{\min}} = \frac{300}{400} = 0.75\,(\text{m})$$

$$L_2 = \tau L_1 = 0.865 * 0.75 = 0.6487\,(\text{m}), \ldots, L_8 = 0.2718 < \frac{c}{f_{\max}} = \frac{300}{890} = 0.3371\,(\text{m})$$

$$s_n = 2L_n\sigma = 0.314L_n$$

Log-periodic antenna design. Design a log-periodic dipole antenna to cover al UHF TV channels, which is from 470 MHz for channel 14 to 890 MHz for channel 83. Each channel has a bandwidth of 6 MHz. The desired directivity is 8 dBi

Table 5.5 Optimum design data for log-periodic antenna

Directivity/dBi	Scaling factor τ	Spacing factor σ	Apex angle α
7	0.782	0.138	21.55°
7.5	0.824	0.146	16.77°
8	0.865	0.157	12.13°
8.5	0.892	0.165	9.29°
9	0.918	0.169	6.91°
9.5	0.935	0.174	5.33°
10	0.943	0.179	4.55°
10.5	0.957	0.182	3.38°
11	0.964	0.185	2.79°

- desired directivity is 8 dBi,

$$f_{\min} = 470\,\text{MHz},\ f_{\max} = 890\,\text{MHz},\ \text{and } D = 8\,\text{dBi}$$

- N = 8, we can afford to start from a lower frequency, say 400 MHz

$$L_1 = \frac{c}{f_{\min}} = \frac{300}{400} = 0.75\,(\text{m})$$

$$L_2 = \tau L_1 = 0.865 * 0.75 = 0.6487\,(\text{m}), \ldots, L_8 = 0.2718 < \frac{c}{f_{\max}} = \frac{300}{890} = 0.3371\,(\text{m})$$

$$s_n = 2L_n\sigma = 0.314L_n$$

n = 1 to 7. ($s1$ = 0.2355; . . . , $s7$ = 0.0986) Total length:

$$L = \sum_{n}^{7} s_n = 1.1142\,(\text{m})$$