3.5 Microstrip antenna

Module:3 HF, UHF and Microwave Antennas

Course: BECE305L – Antenna and Microwave Engineering

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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

1. Introduction to Microstrip

- In **high-performance aircraft, spacecraft, satellite, and missile applications**, many **other government and commercial applications**, such as mobile radio and wireless communications, where **size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints**, low-profile antennas may be required.
- **Microstrip antennas are low profile**, **conformable to planar** and **nonplanar surfaces**, **simple and inexpensive to manufacture using modern printed-circuit technology**, **mechanically robust** when mounted on rigid surfaces, **compatible with MMIC designs**, and when the particular patch shape and mode are selected, they are very **versatile in terms of resonant frequency, polarization, pattern, and impedance**.

1. Introduction to Microstrip

- In addition, by **adding loads between the patch and the ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency, impedance, polarization, and pattern** can be designed.
- **Major operational disadvantages** of the basic Microstrip antennas are **their low efficiency**, **low power**, **high *Q*** (sometimes in excess of 100), **poor polarization purity**, **poor scan performance**, **spurious feed radiation** and very narrow frequency bandwidth, which is typically only a fraction of a percent or at most a few percent.
- These can be overcome with multiple design strategies as required for applications

1. Introduction to Microstrip

TABLE 14.1 Typical Substrates and Their Parameters

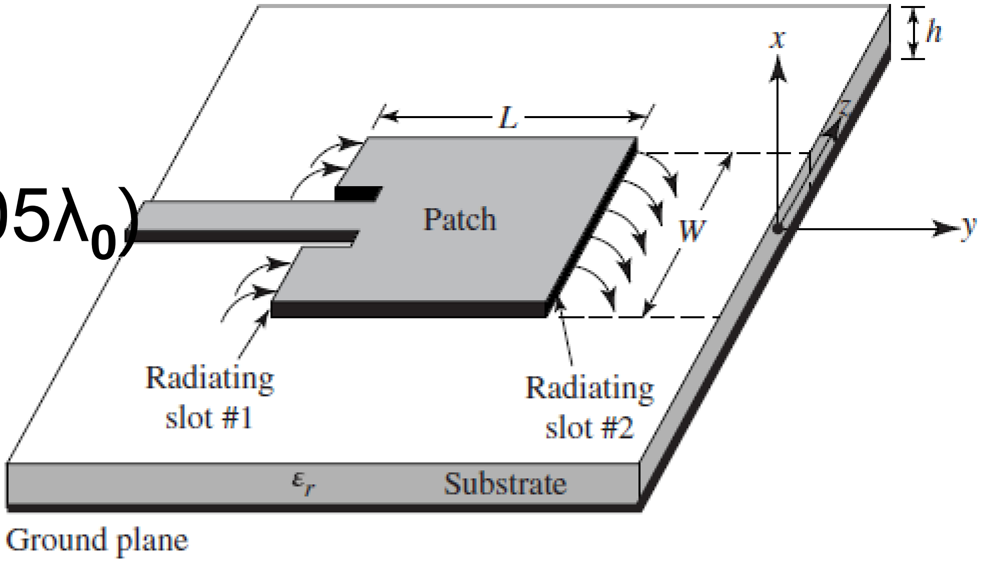
Company	Substrate	Thickness (mm)	Frequency (GHz)	ϵ_r	$\tan\delta$
Rogers Corporation	Duroid® 5880	0.127	0 – 40	2.20	0.0009
	RO 3003	1.575	0 – 40	3.00	0.0010
	RO 3010	3.175	0 – 10	10.2	0.0022
	RO 4350	0.168	0 – 10	3.48	0.0037
		0.508			
		1.524			
—	FR4	0.05 – 100	0.001	4.70	—
DuPont	HK 04J	0.025	0.001	3.50	0.005
Isola	IS 410	0.05 – 3.2	0.1	5.40	0.035
Arlon	DiClad 870	0.091	0 – 10	2.33	0.0013
Polyflon	Polyguide	0.102	0 – 10	2.32	0.0005
Neltec	NH 9320	3.175	0 – 10	3.20	0.0024
Taconic	RF-60A	0.102	0 – 10	6.15	0.0038

1. Introduction to Microstrip

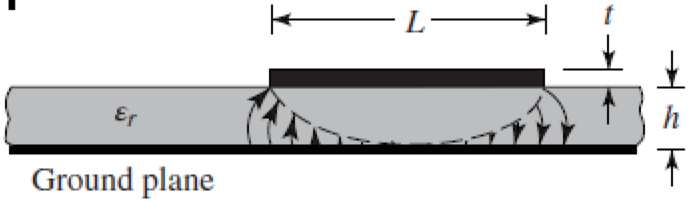
- Rogers substrates are usually referred to as PTFE (polytetrafluorethylene), which are woven glass laminates, and are very popular for microstrip designs.
- FR4 is another very popular substrate.

1. Introduction to Microstrip

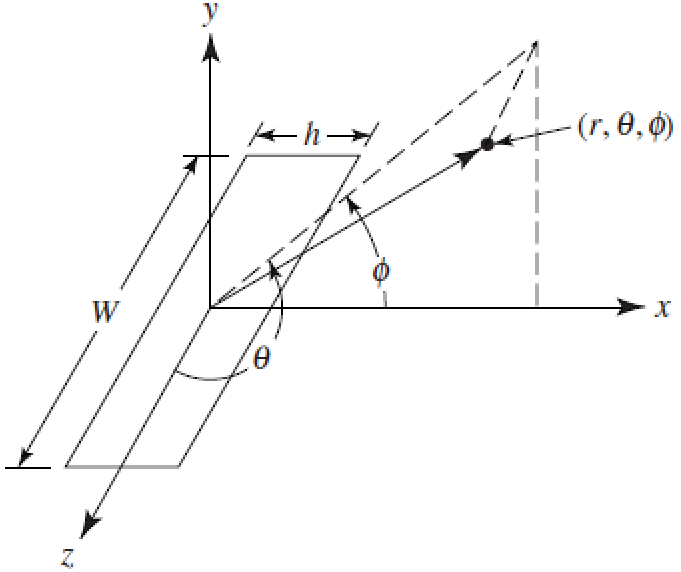
- consist of a **very thin** (***t*** $\ll$ $\boldsymbol{\lambda_0}$, where λ0 is the free-space wavelength) **metallic strip (patch**) placed a small fraction of a wavelength (***h*** $\ll$ $\boldsymbol{\lambda_0}$, usually 0.003λ0 ≤ *h* ≤ 0.05λ_0) above a ground plane.
- **Ususally broadside radiation**
- Endfire can be achieved by proper mode selection



(a) Microstrip antenna



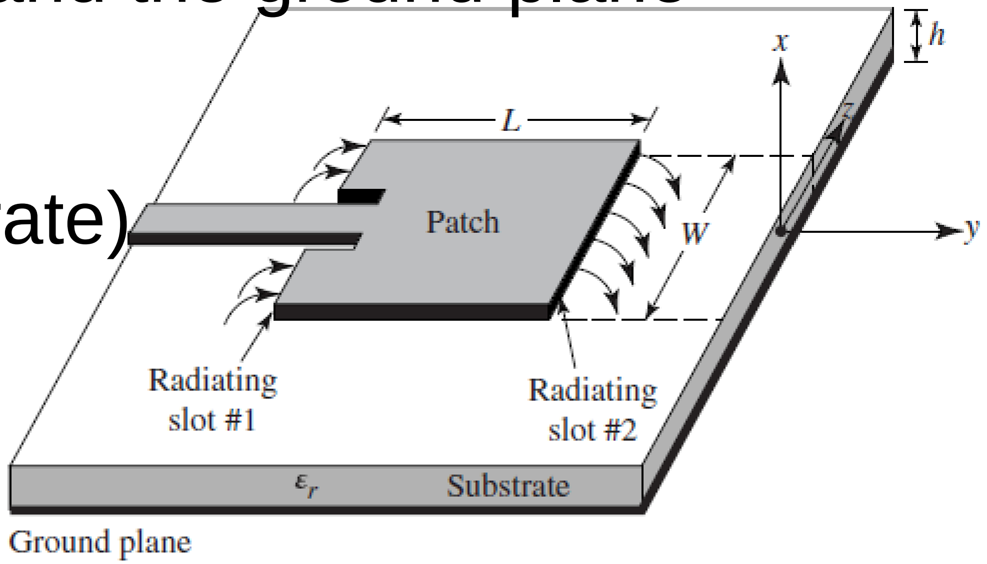
(b) Side view



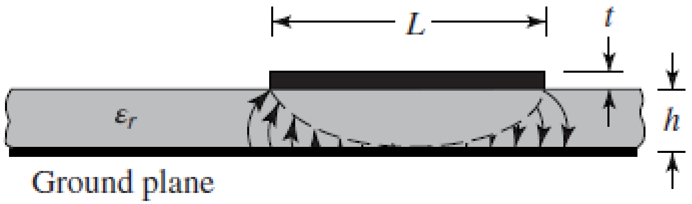
(c) Coordinate system for each radiating slot

1. Introduction to Microstrip

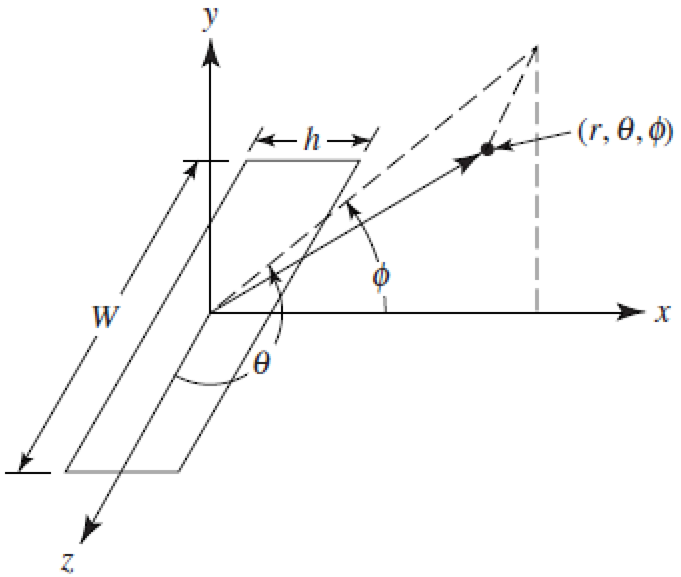
- a rectangular patch, the length L of the element is usually $\boldsymbol{\lambda_0 / 3 < L < \lambda_0 / 2}$. The strip (patch) and the ground plane are separated by a dielectric sheet (referred to as the substrate)



(a) Microstrip antenna



(b) Side view



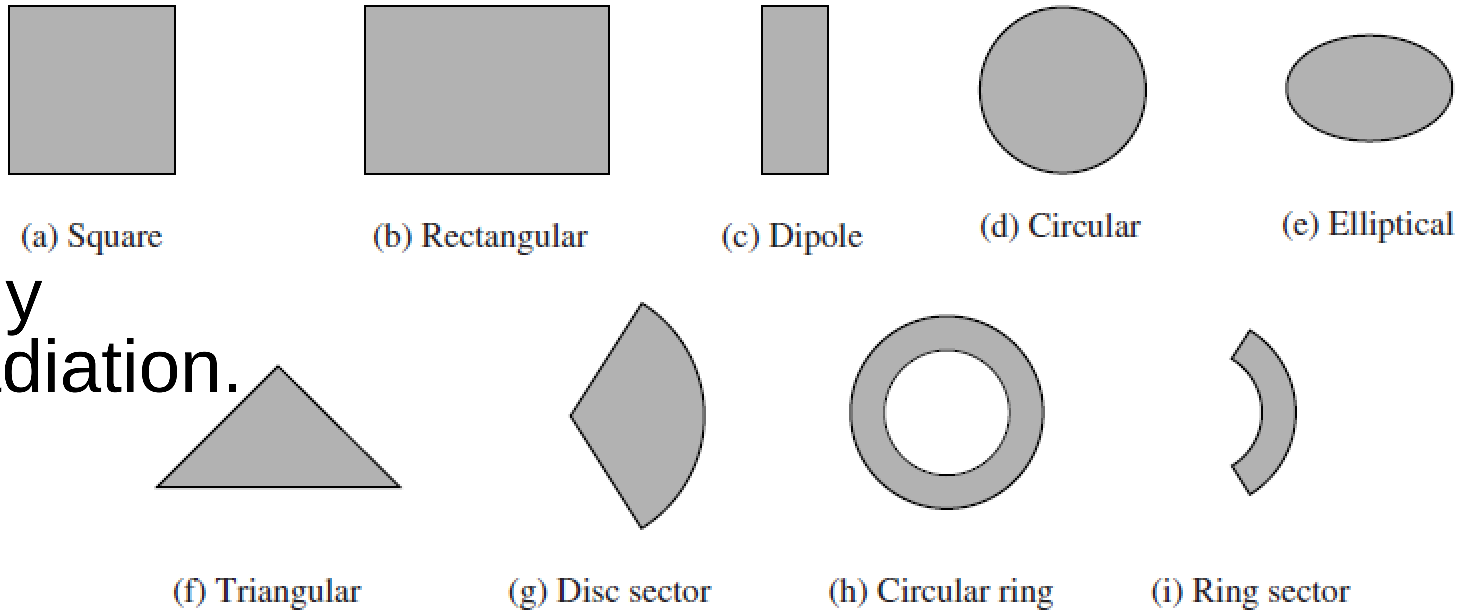
(c) Coordinate system for each radiating slot

1. Introduction to Microstrip

- most desirable for good antenna performance are **thick substrates** whose **dielectric constant is in the lower end** of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size.
- Thin substrates with **higher dielectric constants** are desirable for **microwave circuitry because** they **require tightly bound fields** to **minimize undesired radiation and coupling**, and lead to **smaller element sizes**; however, because of their greater losses, **they are less efficient** and have **relatively smaller bandwidths**
- Often microstrip antennas are also referred to as ***patch* antennas**

1. Introduction to Microstrip

- The radiating elements and the feed lines are **usually photoetched on the dielectric substrate**.
  The radiating patch may be **square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration**.
- Square, rectangular, dipole (strip), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation.

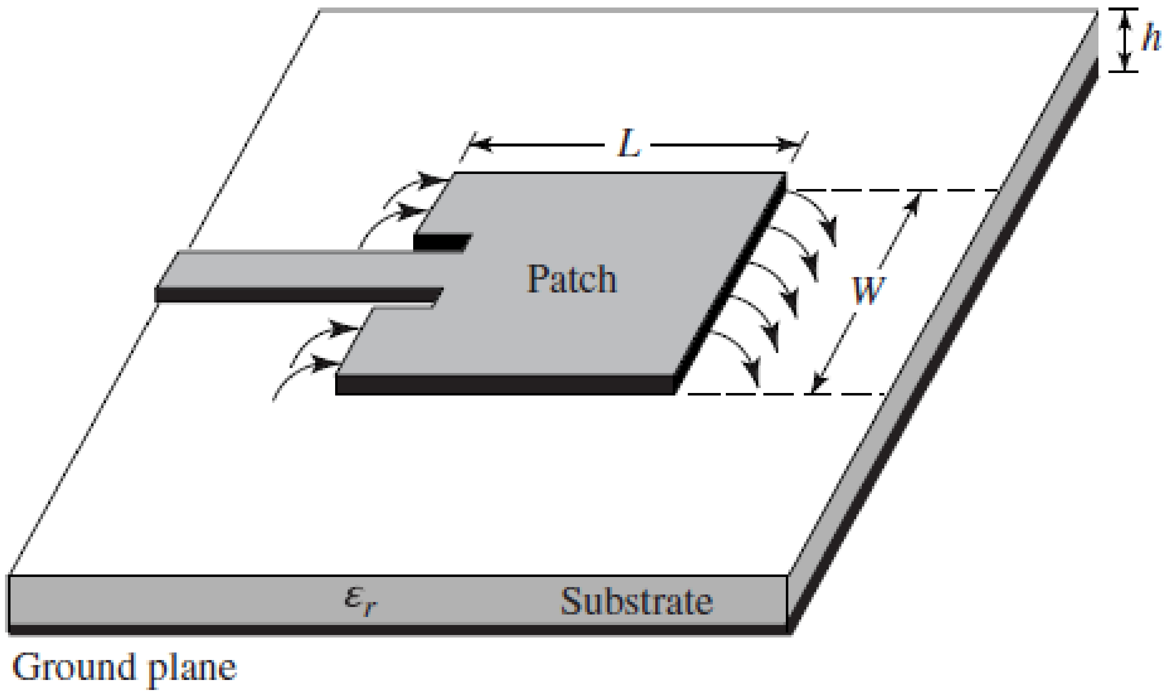


1. Introduction to Microstrip

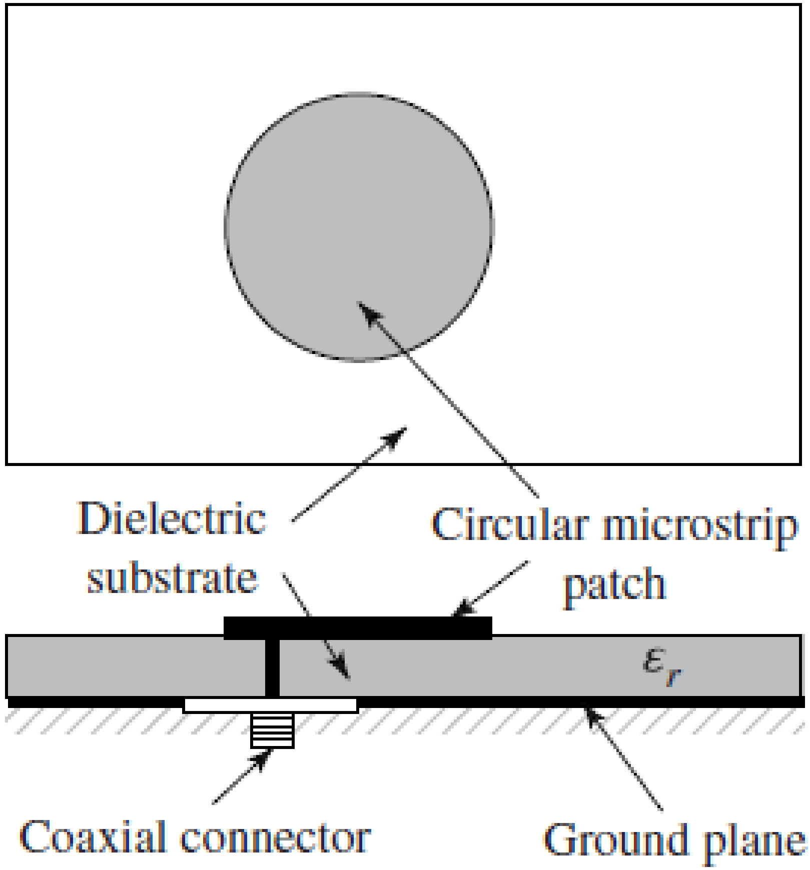
- **Linear and circular polarizations** can be achieved with either **single elements** or **arrays** of microstrip antennas.

- **Arrays** of microstrip elements, with **single or multiple feeds**, may also be used to introduce **scanning capabilities** and achieve **greater directivities**

2. Feeding methods

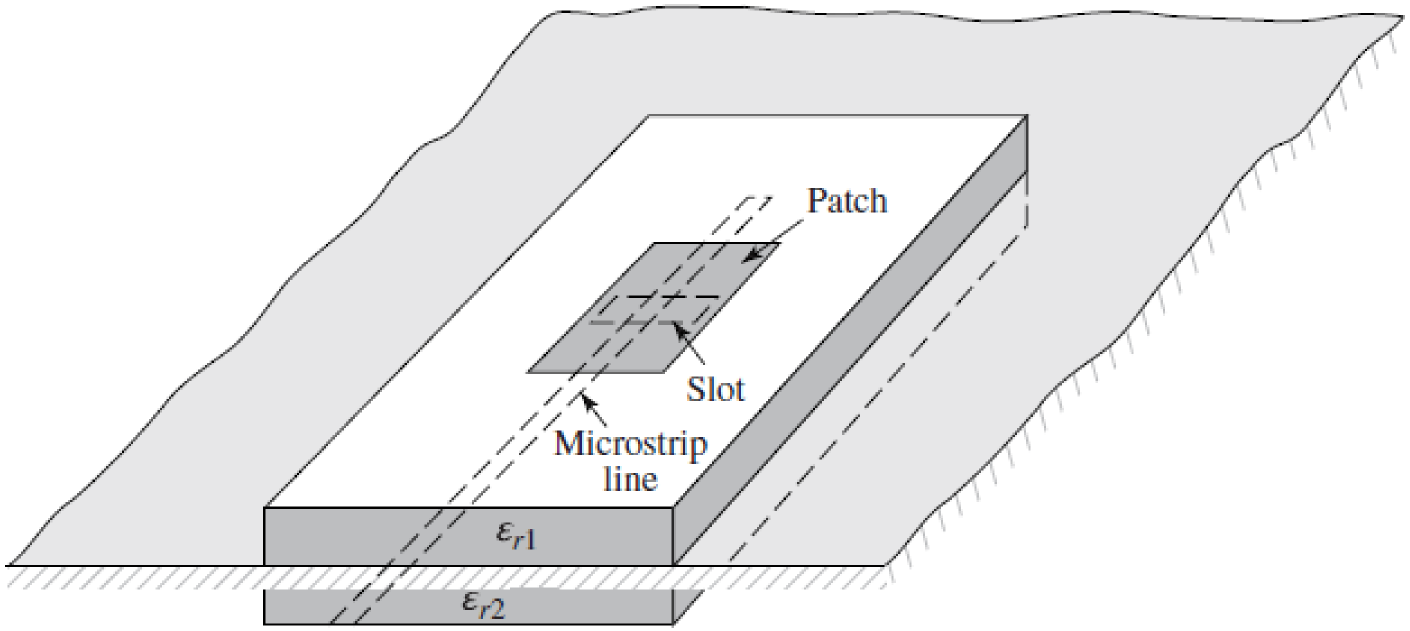


(a) Microstrip line feed

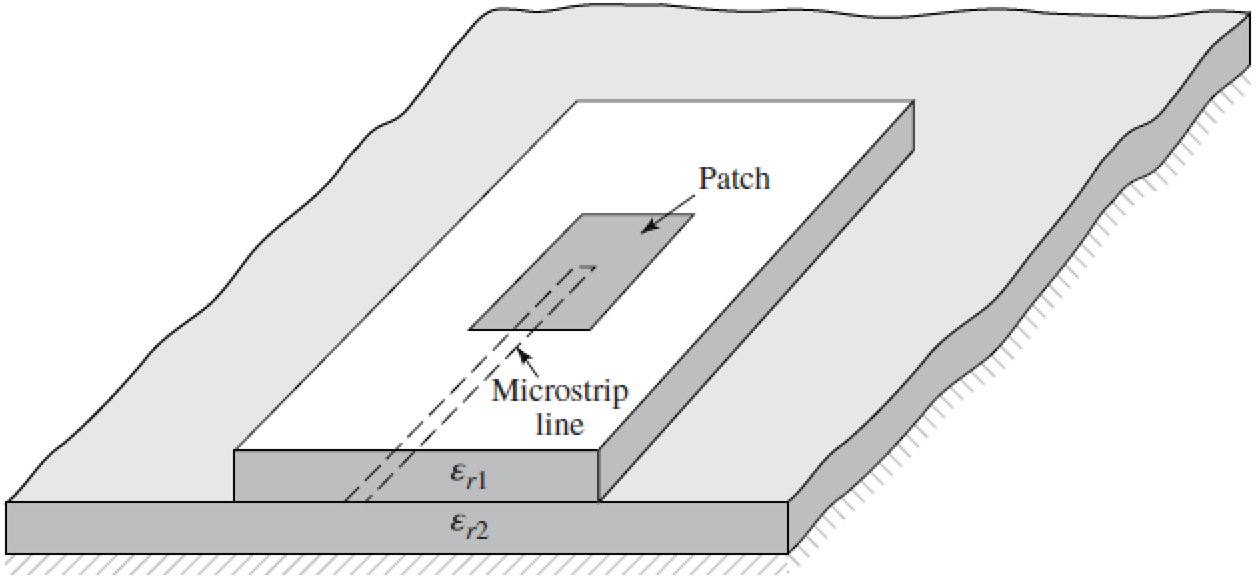


(b) Probe feed

2. Feeding methods



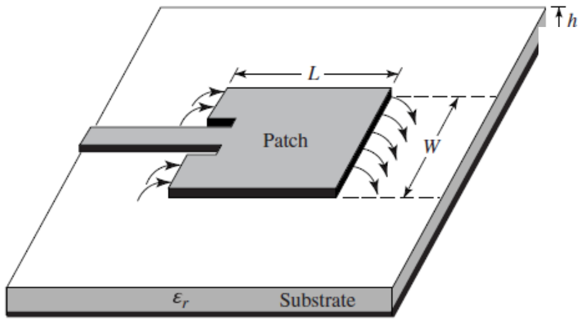
(c) Aperture-coupled feed



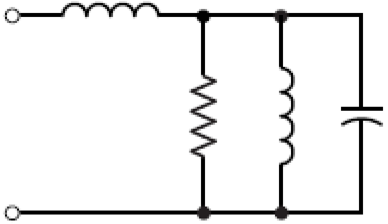
(d) Proximity-coupled feed

2. Feeding methods

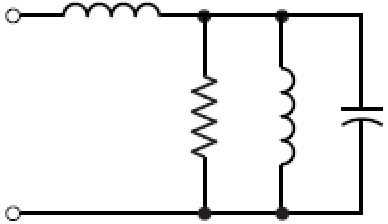
- The four most popular are the microstrip line, coaxial probe, aperture coupling, and proximity coupling



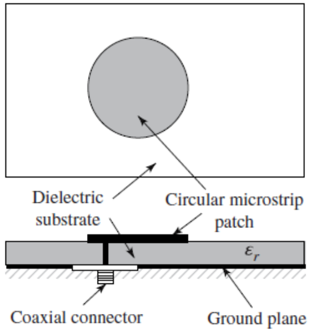
(a) Microstrip line feed



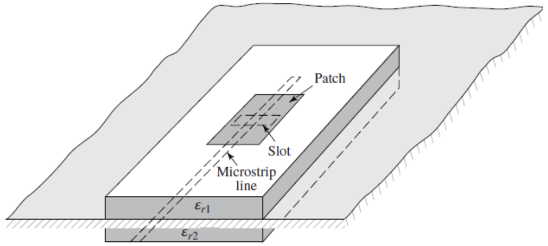
(a) Microstrip line



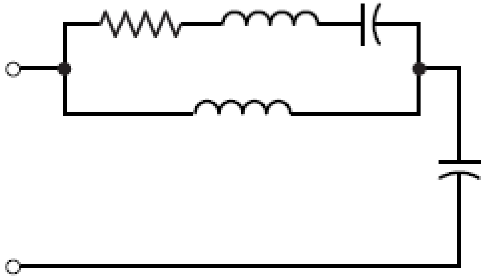
(b) Probe



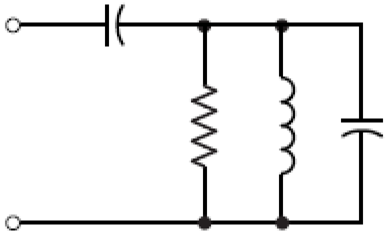
(b) Probe feed



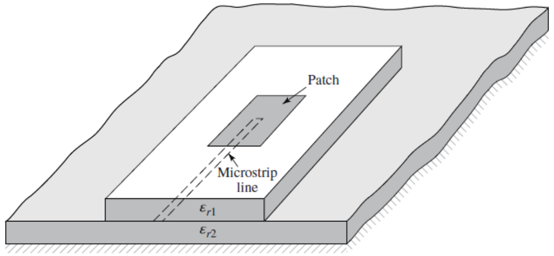
(c) Aperture-coupled feed



(c) Aperture-coupled



(d) Proximity-coupled

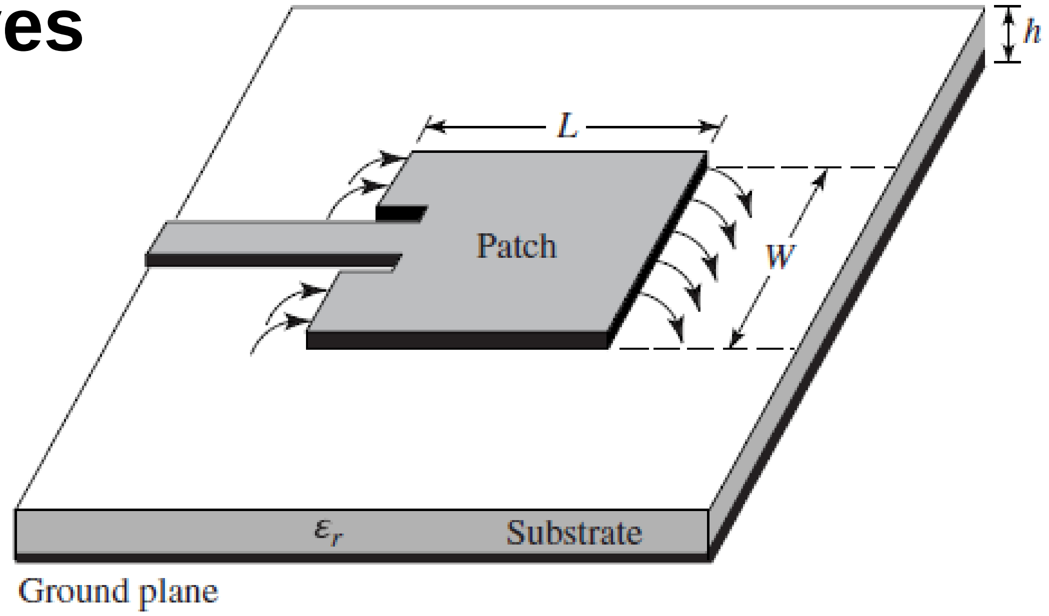


(d) Proximity-coupled feed

Figure 14.4 Equivalent circuits for typical feeds of Figure 14

2. Feeding methods

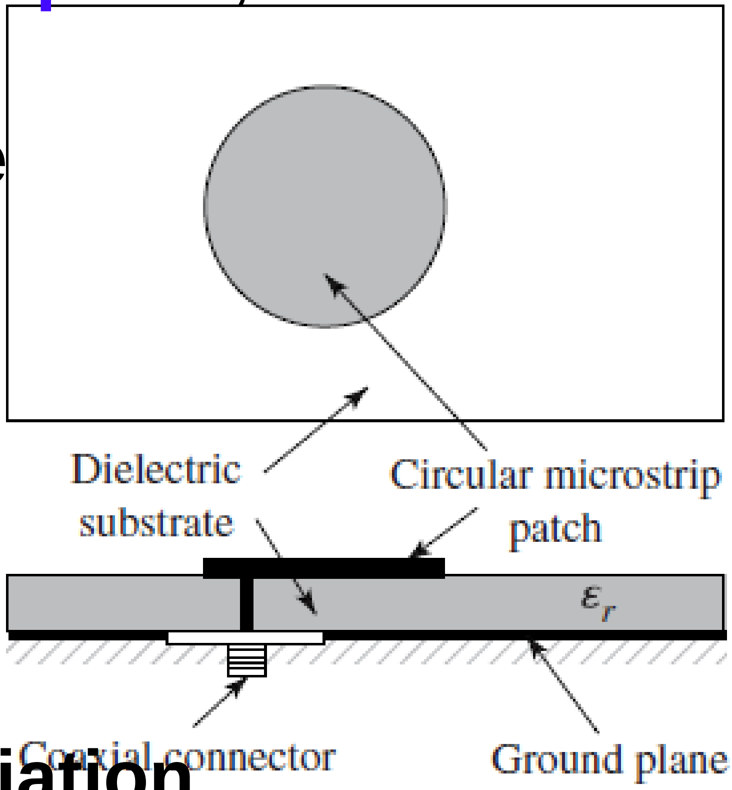
- The **<u>microstrip feed line</u>** is also a conducting strip, usually of much smaller width compared to the patch.
- is easy to fabricate, simple to match by controlling the inset position and rather simple to model
- **Bandwidth limited due to surface waves**



(a) Microstrip line feed

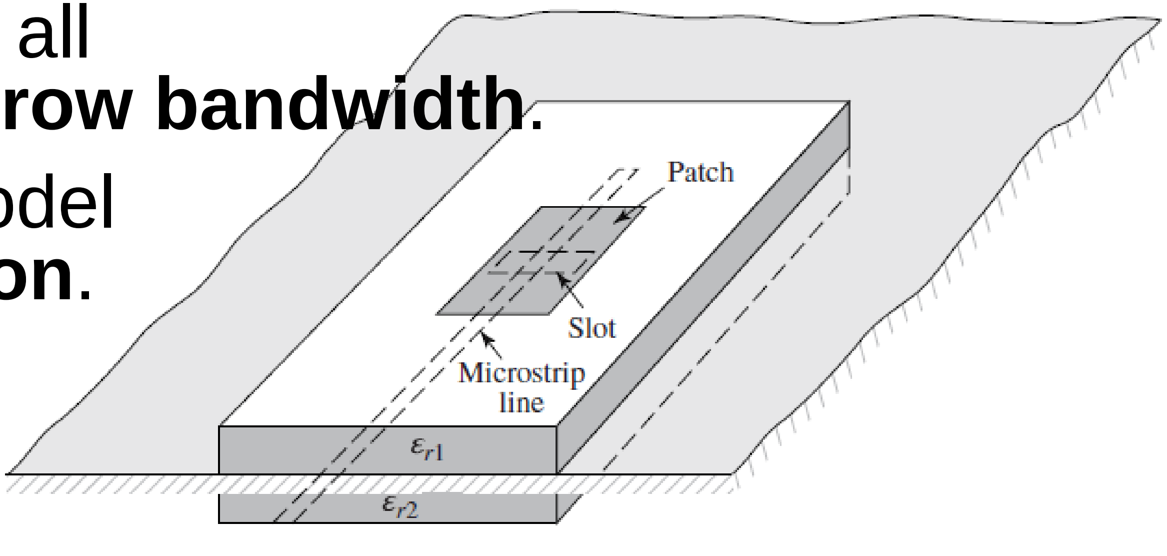
2. Feeding methods

- **Coaxial-line feeds**, where the **inner conductor of the coax is attached to the radiation patch** while the **outer conductor is connected to the ground plane**, are also widely used.
- The **coaxial probe feed is also easy to fabricate** and **match**, and it has low spurious radiation.
- However, **it also has narrow bandwidth** and it is **more difficult to model**, especially **for thick substrates** ($h > 0.02\lambda_0$).
- **microstrip feed line** and the **probe** possess **inherent asymmetries** which generate higher order modes which **produce cross-polarized radiation**



(b) Probe feed

2. Feeding methods

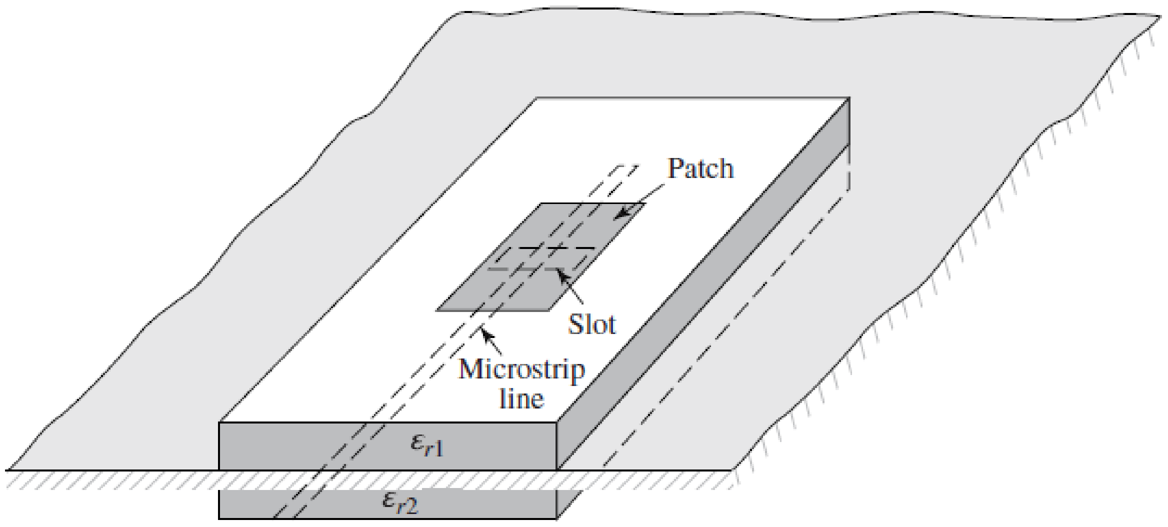


(c) Aperture-coupled feed

- **Aperture coupled** : most **difficult** of all four to **fabricate and it also has narrow bandwidth**.
- However, it is somewhat easier to model and has **moderate spurious radiation**.
- The aperture coupling consists of **two substrates separated by a ground plane**.
- On the **bottom side of the lower substrate there is a microstrip feed line** whose **energy is coupled to the patch through a slot on the ground plane** separating the two substrates.
- This arrangement allows **independent optimization of the feed mechanism and the radiating element**

2. Feeding methods

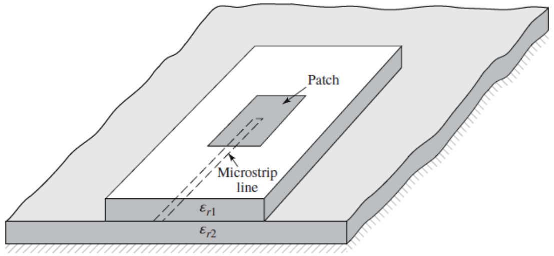
- **Aperture coupled** Typically a **high dielectric material** is used for the **bottom substrate**, and **thick low dielectric constant** | material for the **top substrate**.
- Typically **matching** is performed by controlling **the width of the feed line** and **the length of the slot**.



(c) Aperture-coupled feed

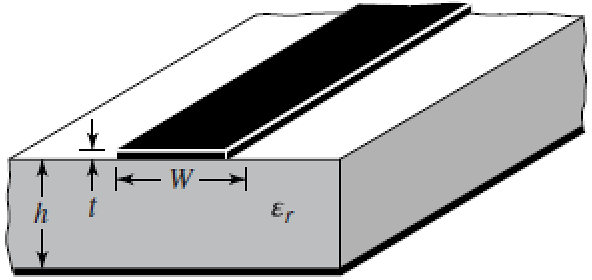
2. Feeding methods

- the **proximity coupling** has the **largest bandwidth** (as high as 13 percent), is somewhat easy to model and has **low spurious radiation**.
- However its fabrication is somewhat more difficult.
- The **length of the feeding stub** and the **width-to-line ratio of the patch** can be used to **control the match**

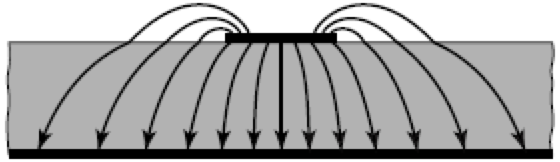


(d) Proximity-coupled feed

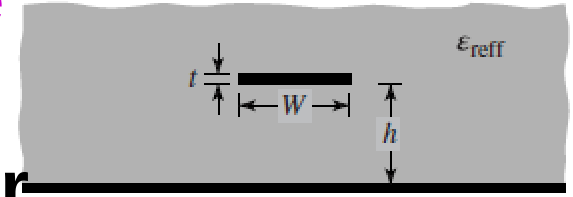
Analysis of Rectangular Patch:
A. Fringing fields



(a) Microstrip line



(b) Electric field lines



(c) Effective dielectric constant

Figure 14.5 Microstrip line and its electric field lines, and effective dielectric constant geometry.

- This is a **nonhomogeneous line** of **two dielectrics**; typically the **substrate and air**. **most of the electric field lines reside in the substrate** and parts of some lines exist in air.
- **Fringing** makes the microstrip line **look wider electrically** compared to its physical dimensions.
- Since **some of the waves travel in the substrate** and **some in air**, an ***effective dielectric constant*** ε_{reff} is introduced to account for fringing and the wave propagation in the line.
- Only when $W/h \gg 1$ and $\varepsilon_r \gg 1$, the electric field lines concentrate mostly in the substrate.

Analysis of Rectangular Patch:
A. Fringing fields

- **effective dielectric constant** is defined as the | **dielectric constant of the uniform dielectric material** so that the line of Figure 14.5(c) has **identical electrical characteristics**, particularly propagation constant, as the actual line of Figure 14.5(a).

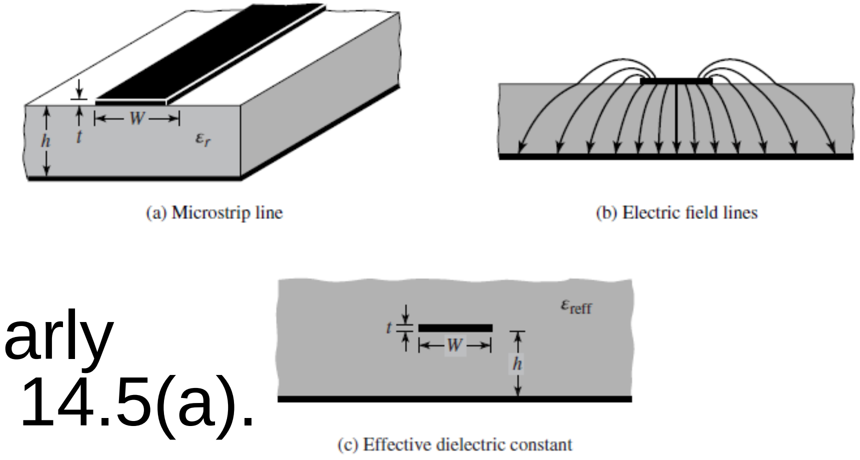
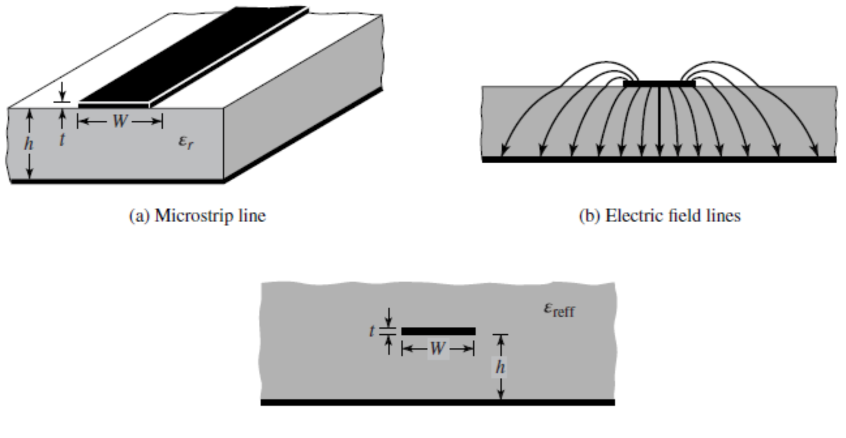


Figure 14.5 Microstrip line and its electric field lines, and effective dielectric constant geometry.

- $1 < \varepsilon_{reff} < \varepsilon_r$
- where the dielectric constant of the substrate is much greater than unity ($\varepsilon_r \gg 1$), the value of ε_{reff} will be closer to the value of the actual dielectric constant εr of the substrate.
- As the **frequency of operation increases**, most of the **electric field** lines **concentrate in the substrate**. Therefore the microstrip line **behaves homogeneous line of one dielectric** (only the substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate.

Analysis of Rectangular Patch: A. Fringing fields

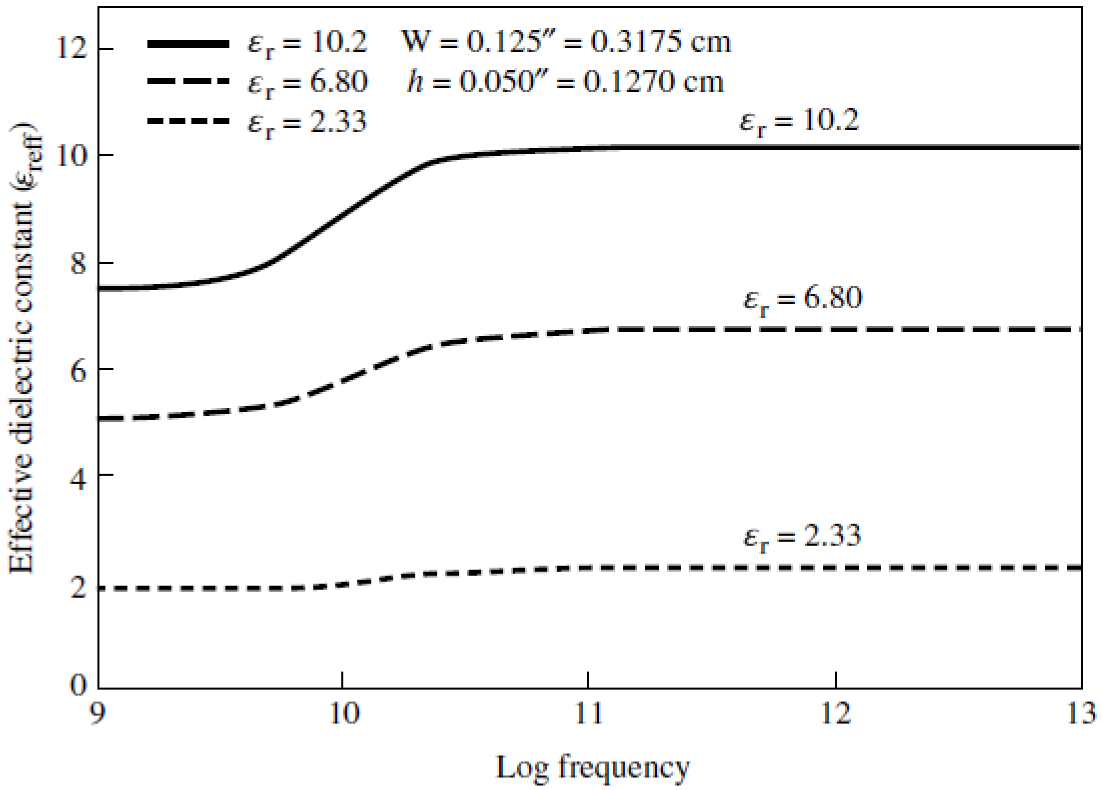


(a) Microstrip line
(b) Electric field lines
(c) Effective dielectric constant

Figure 14.5 Microstrip line and its electric field lines, and effective dielectric constant geometry.

<u>$W/h > 1$</u>

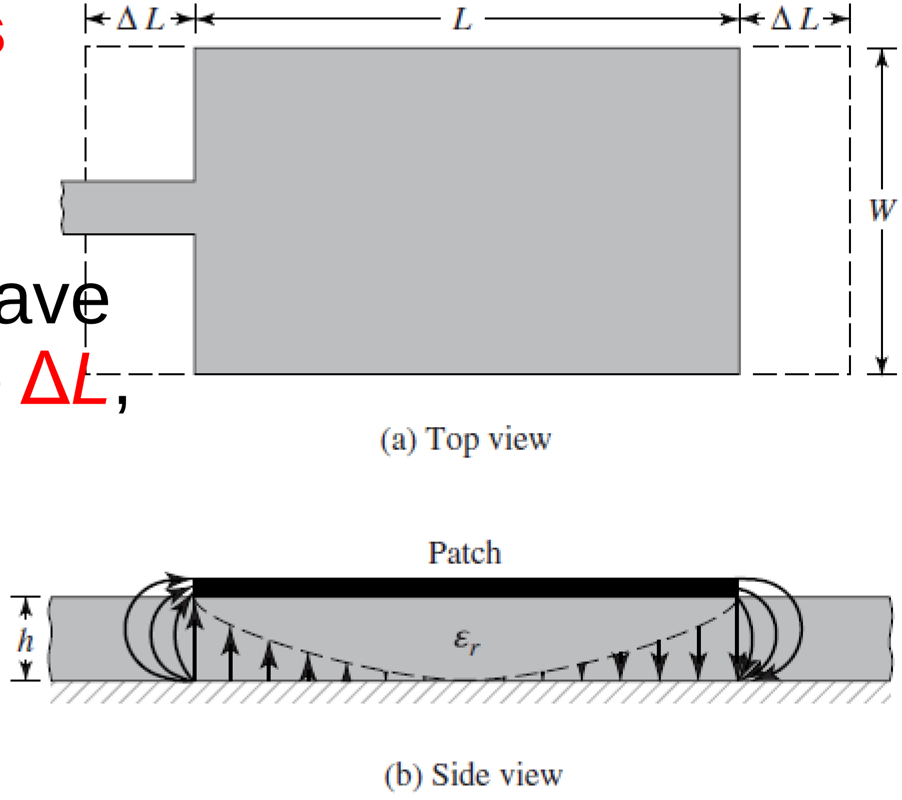
$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$



gure 14.6 Effective dielectric constant versus frequency for typical substrates.

B. Effective Length, Resonant Frequency, and Effective Width

- **dimensions of the patch are finite along the length and width**, the **fields at the edges of the patch undergo fringing**
- Because of the fringing effects, **electrically the patch** of the microstrip antenna **looks greater than its physical dimensions**.
- For the principal *E*-plane (*xy*-plane), dimensions of the patch along its length have been extended on each end by a distance ΔL,



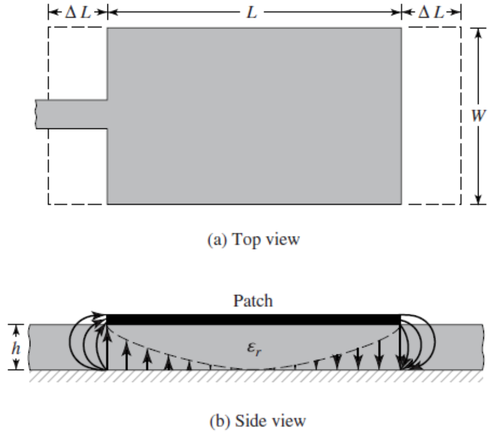
14.7 Physical and effective lengths of rectangular microstrip patch.

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

B. Effective Length, Resonant Frequency, and Effective Width

- Dominant mode TM_{010} : $L = \lambda/2$
- the resonant frequency of the microstrip antenna is a function of its length, and **without account of fringing**:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \frac{v_0}{2L\sqrt{\varepsilon_r}}$$



14.7 Physical and effective lengths of rectangular microstrip patch.

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

- length of the patch has been extended by ΔL on each side **due to fringing**:
  the effective length of the patch : $L_{\text{eff}} = L + 2\Delta L$
- To include edge effects, resonant frequency of the microstrip:
  q fringe factor (length reduction factor).

$$(f_{rc})_{010} = \frac{1}{2L_{\text{eff}}\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_0\varepsilon_0}} = \frac{1}{2(L+2\Delta L)\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_0\varepsilon_0}}$$

$$= q\frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = q\frac{v_0}{2L\sqrt{\varepsilon_r}}$$

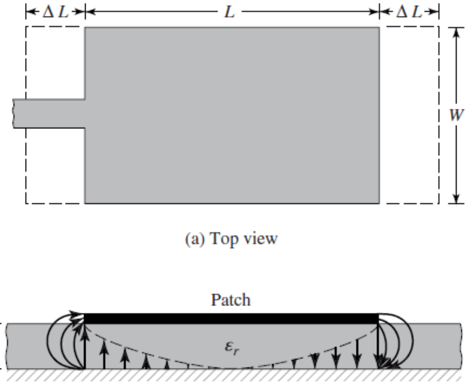
B. Effective Length, Resonant Frequency, and Effective Width

- *q fringe factor* (length reduction factor).

- The **designed resonant frequency**, based on fringing, **is lower as the patch looks longer**

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

$$L_{\text{eff}} = L + 2\Delta L$$



(a) Top view

(b) Side view

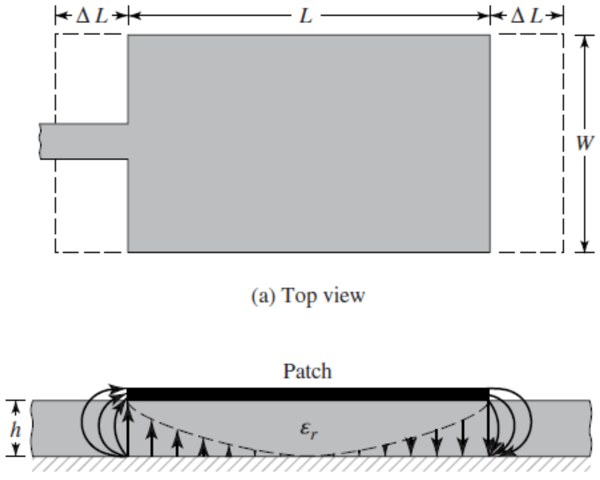
14.7 Physical and effective lengths of rectangular microstrip patch.

$$(f_{rc})_{010} = \frac{1}{2L_{\text{eff}}\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_0\varepsilon_0}} = \frac{1}{2(L + 2\Delta L)\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_0\varepsilon_0}}$$

$$= q\frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = q\frac{v_0}{2L\sqrt{\varepsilon_r}}$$

C. Design

- **<u>Given</u>**: the dielectric constant of the substrate (ε_r), the resonant frequency (f_r), the height of the substrate *h* $(v_0: 3 \times 10^8 m/s)$
- ***<u>To determine</u>***: *W and L*



(a) Top view

(b) Side view

14.7 Physical and effective lengths of rectangular microstrip patch.

C. Design

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

- **Procedure**:

1. a practical width that leads to good radiation efficiencies
2. Effective dielectric constant:

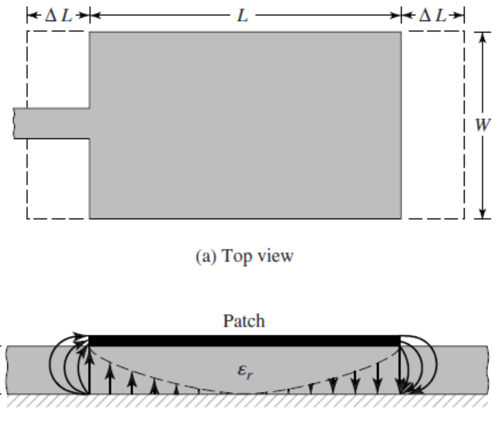
$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$$

3. Find ΔL:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{\text{reff}}-0.258)\left(\frac{W}{h}+0.8\right)}$$

4. Actual length

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$$



14.7 Physical and effective lengths of rectangular microstrip patch.

Typical length:

λ_d is the wavelength in the dielectric

$$L \approx (0.47-0.49)\frac{\lambda_o}{\sqrt{\varepsilon_r}} = (0.47-0.49)\lambda_d$$

Design a rectangular microstrip antenna using a substrate (RT/duroid 5880) with dielectric constant of 2.2, $h = 0.1588$ cm (0.0625 inches) so as to resonate at 10 GHz.

- width W of the patch is

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

$$W = \frac{30}{2(10)}\sqrt{\frac{2}{2.2 + 1}} = 1.186 \text{ cm } (0.467 \text{ in})$$

- effective dielectric constant of the patch

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

$$\varepsilon_{\text{reff}} = \frac{2.2 + 1}{2} + \frac{2.2 - 1}{2}\left(1 + 12\frac{0.1588}{1.186}\right)^{-1/2} = 1.972$$

Design a rectangular microstrip antenna using a substrate (RT/duroid 5880) with dielectric constant of 2.2, $h = 0.1588$ cm (0.0625 inches) so as to resonate at 10 GHz.

- width W of the patch is

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

$$W = \frac{30}{2(10)}\sqrt{\frac{2}{2.2 + 1}} = 1.186 \text{ cm } (0.467 \text{ in})$$

- effective dielectric constant of the patch

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

$$\varepsilon_{\text{reff}} = \frac{2.2 + 1}{2} + \frac{2.2 - 1}{2}\left(1 + 12\frac{0.1588}{1.186}\right)^{-1/2} = 1.972$$

- extended incremental length of the patch ΔL

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

$$\Delta L = 0.1588(0.412)\frac{(1.972 + 0.3)\left(\frac{1.186}{0.1588} + 0.264\right)}{(1.972 - 0.258)\left(\frac{1.186}{0.1588} + 0.8\right)}$$

$$= 0.081 \text{ cm } (0.032 \text{ in})$$

Design a rectangular microstrip antenna using a substrate (RT/duroid 5880) with dielectric constant of 2.2, $h = 0.1588$ cm (0.0625 inches) so as to resonate at 10 GHz.

- width W of the patch is

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

$$W = \frac{30}{2(10)}\sqrt{\frac{2}{2.2+1}} = 1.186 \text{ cm } (0.467 \text{ in})$$

- effective dielectric constant of the patch

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

$$\varepsilon_{\text{reff}} = \frac{2.2+1}{2} + \frac{2.2-1}{2}\left(1 + 12\frac{0.1588}{1.186}\right)^{-1/2} = 1.972$$

- extended incremental length of the patch ΔL

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

$$\Delta L = 0.1588(0.412)\frac{(1.972+0.3)\left(\frac{1.186}{0.1588} + 0.264\right)}{(1.972-0.258)\left(\frac{1.186}{0.1588} + 0.8\right)} = 0.081 \text{ cm } (0.032 \text{ in})$$

- actual length L of the patch

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$$

$$L = \frac{\lambda}{2} - 2\Delta L = \frac{30}{2(10)\sqrt{1.972}} - 2(0.081) = 0.906 \text{ cm } (0.357 \text{ in})$$

- Effective length L_e

$$L_e = L + 2\Delta L = \frac{\lambda}{2} = 1.068 \text{ cm } (0.421 \text{ in})$$