Chapter 14

Microstrip Antennas

Microstrip (Patch) Antenna

A metallic strip or patch mounted on a dielectric layer (substrate) which is supported by a ground plane

Rectangular Microstrip Antenna

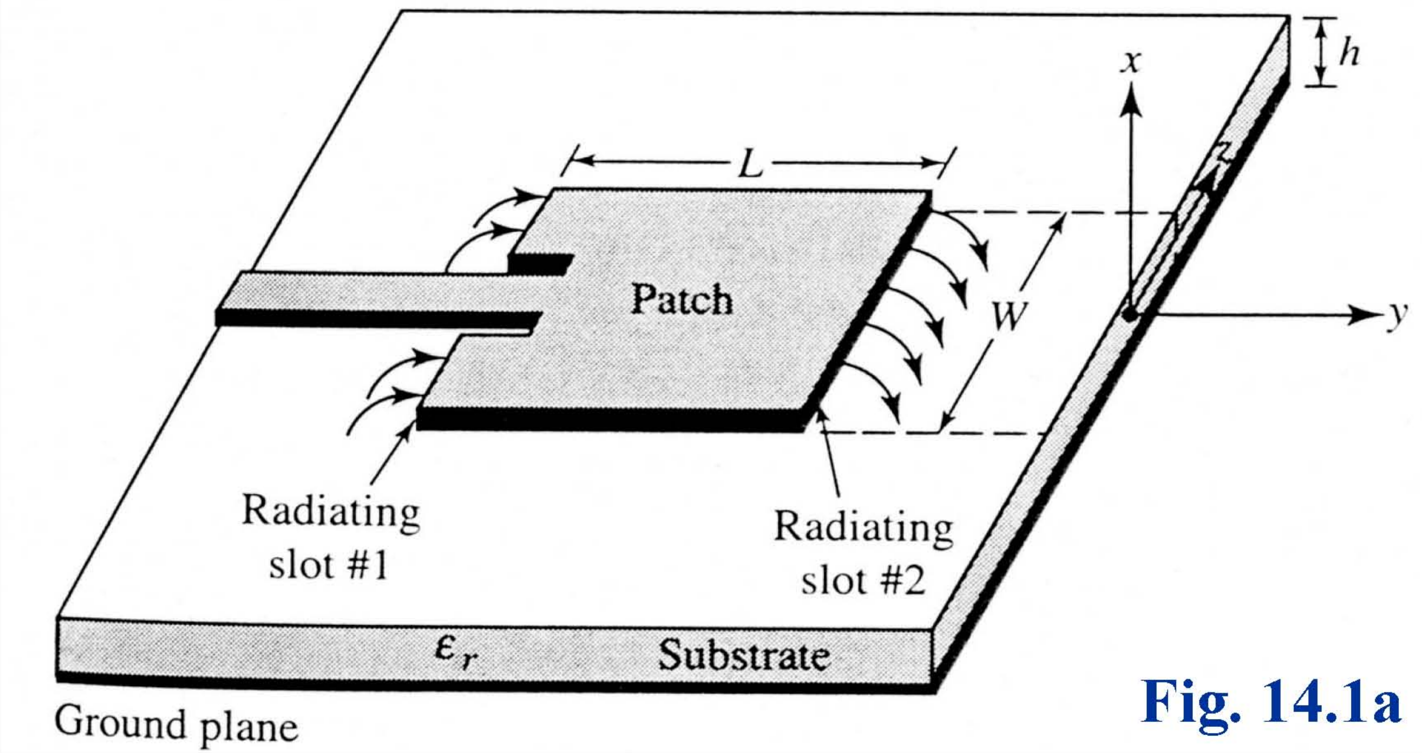


Fig. 14.1a

Side View

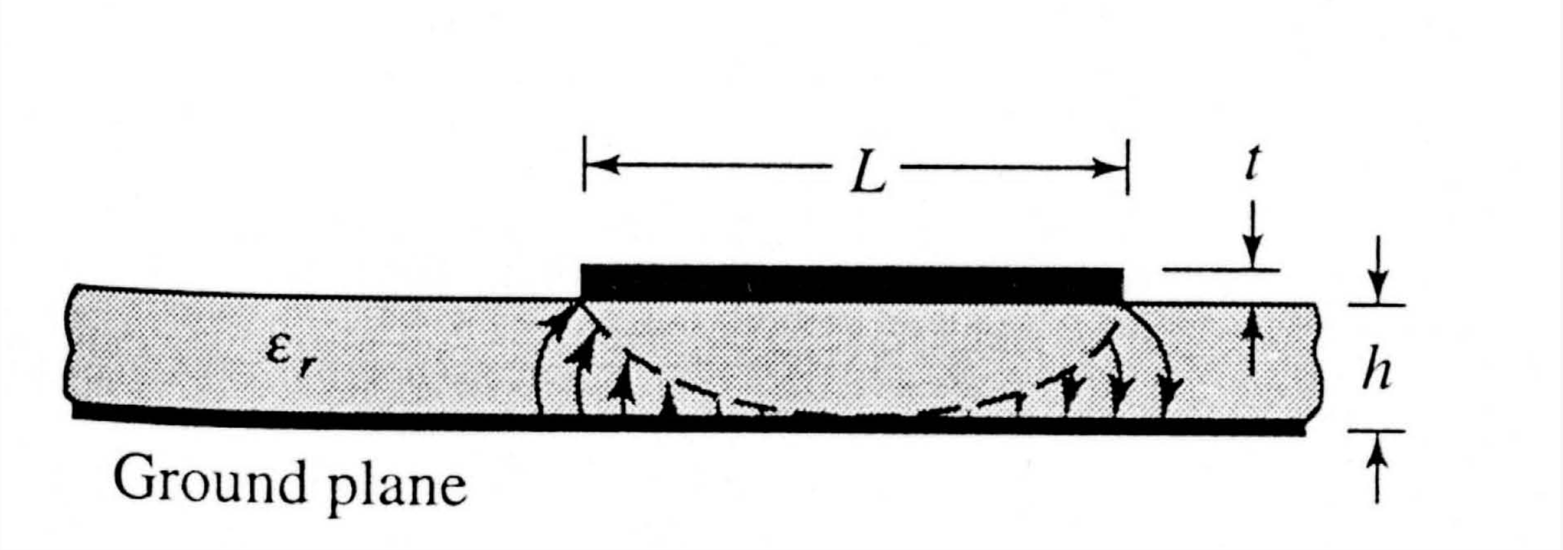


Fig. 14.1b

Patches of Various Shapes

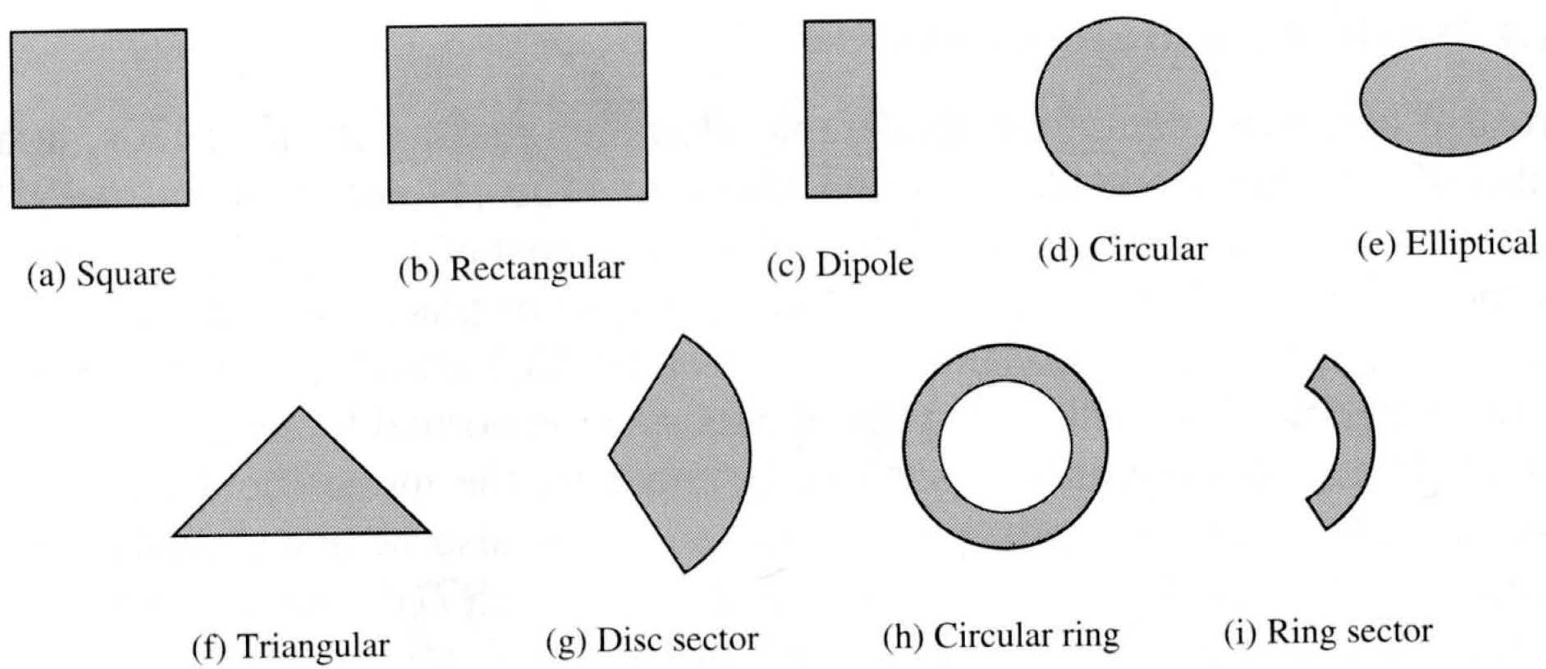


Fig. 14.2

Microstrip (Patch) Antennas
Advantages:

1. Low profile
2. Conformable to nonplanar surfaces
3. Simple and inexpensive
4. Mechanically robust
5. Compatible with mmic designs
6. Very versatile
   a. Resonant frequency
   b. Polarization
   c. Patterns
   d. Impedance

Disadvantages

1. Low power
2. Narrow bandwidth
3. Large EM signature at certain frequencies outside operating band
4. In large arrays, tradeoff between bandwidth and scan volume
5. Large size (physical) at VHF and possibly UHF bands

Popular Feed Techniques

1. Microstrip line
2. Probe (coaxial)
3. Aperture coupling
4. Proximity coupling

Microstrip Feed Line

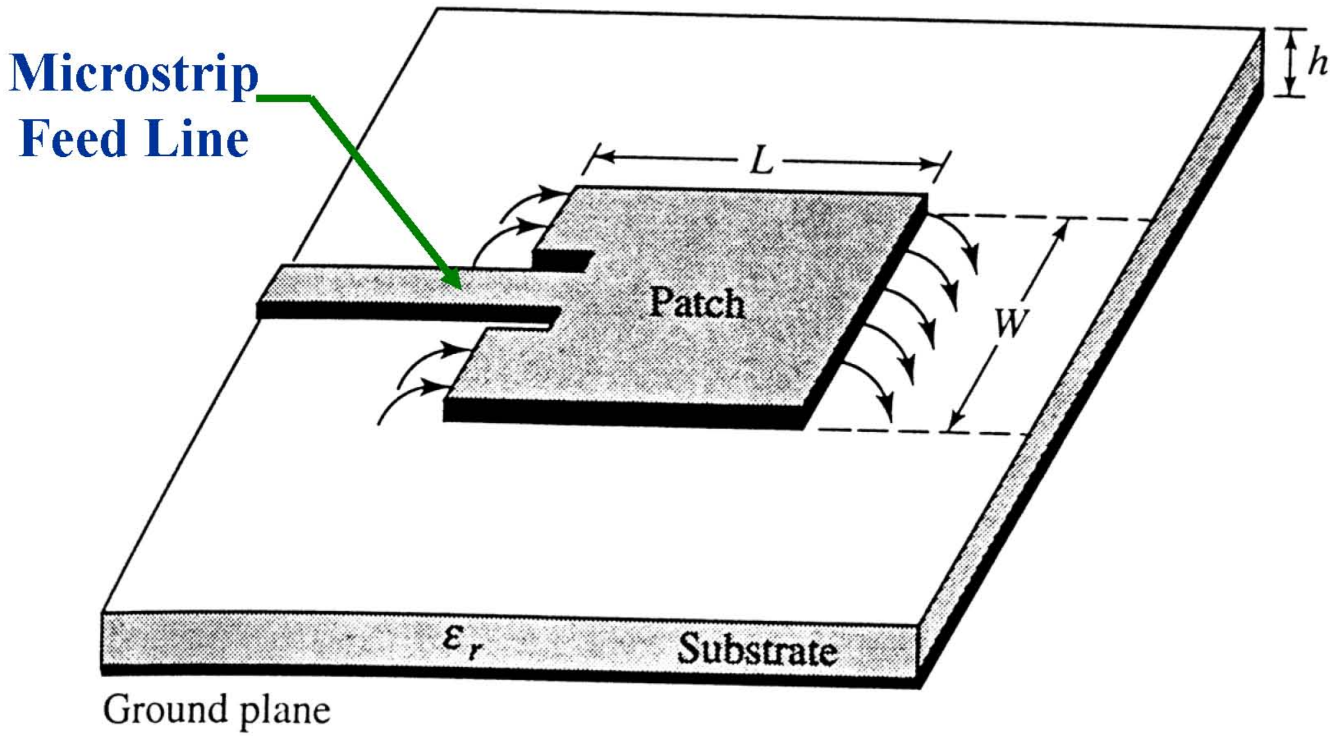


Fig. 14.3a

Coaxial Feed Line

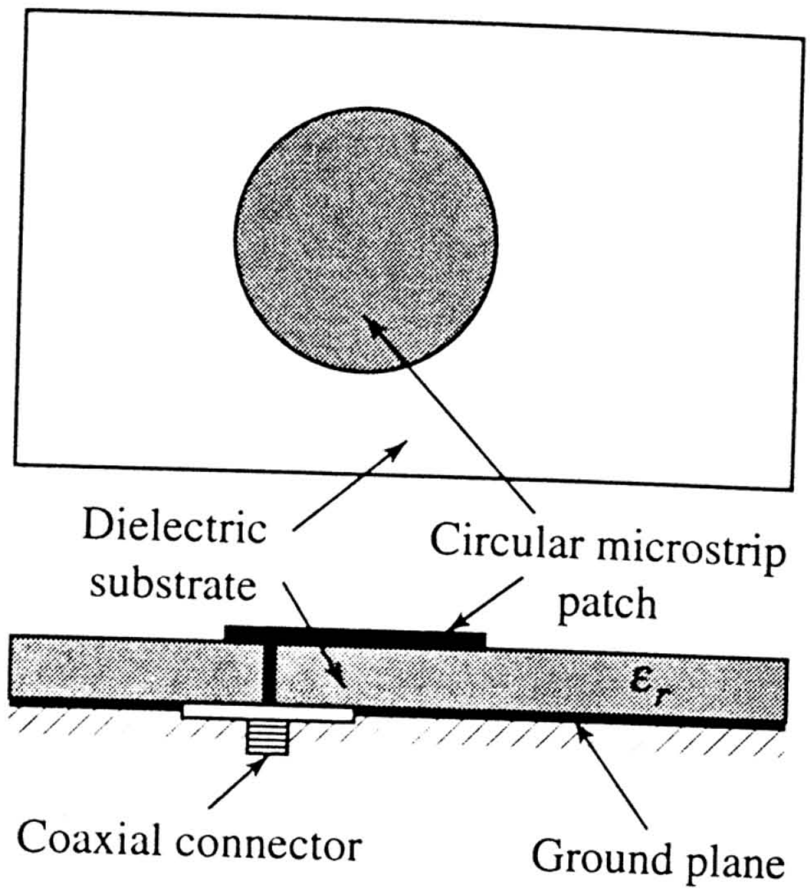


Fig. 14.3b

Microstrip Feed

1. Easy to fabricate
2. Simple to match by controlling the inset feed position
3. Low spurious radiation (≈ -20 dB)
4. Narrow bandwidth (2-5%)
5. As the substrate height increases, the surface waves and spurious feed radiation increases

Coaxial Feed

1. Easy to fabricate and match
2. Low spurious radiation (-30 dB)
3. Simple to match by controlling the position
4. Narrow bandwidth (1-3%)
5. More difficult to model, especially for thick substrates ($h > \lambda_o/50$)

Equivalent Circuits

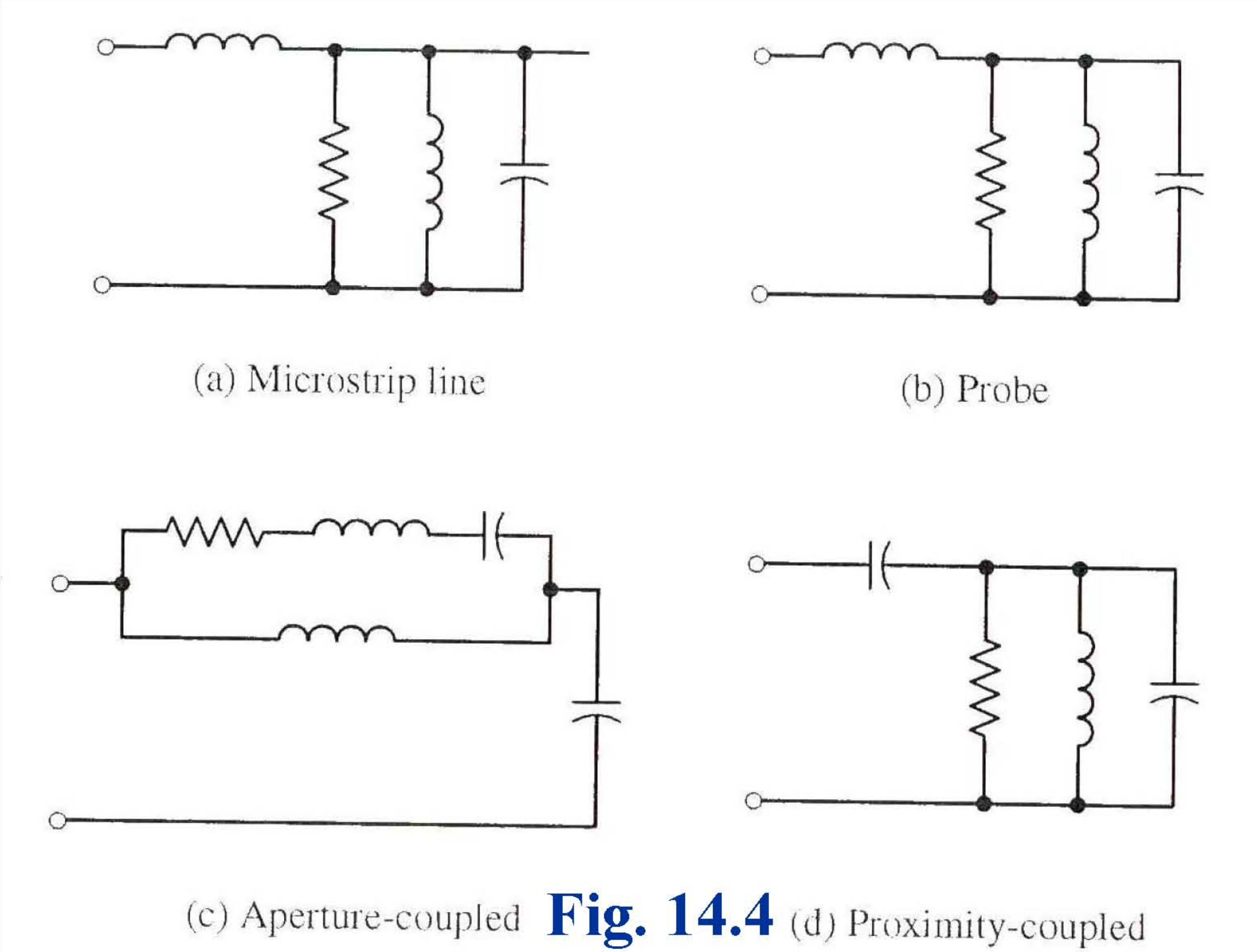


Fig. 14.4

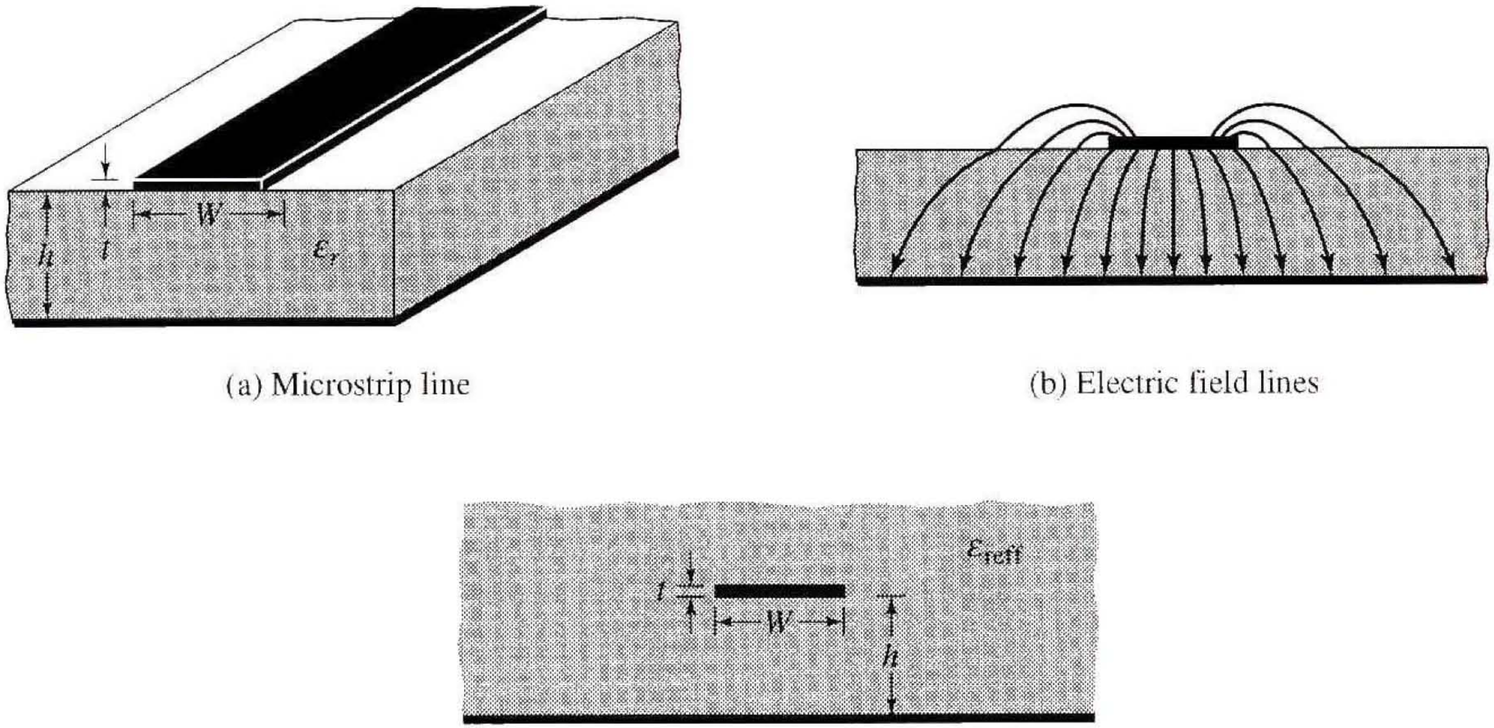
Methods Of Analysis

(Models)

1. Transmission line model
2. Cavity model
3. Full-wave model
   a. Integral equation (MoM)
   B. Modal
   C. Finite-difference time-domain
   D. Finite element
   E. Others

Transmission-Line Model

Effective Dielectric Constant
For Microstrip Line



(a) Microstrip line

(b) Electric field lines

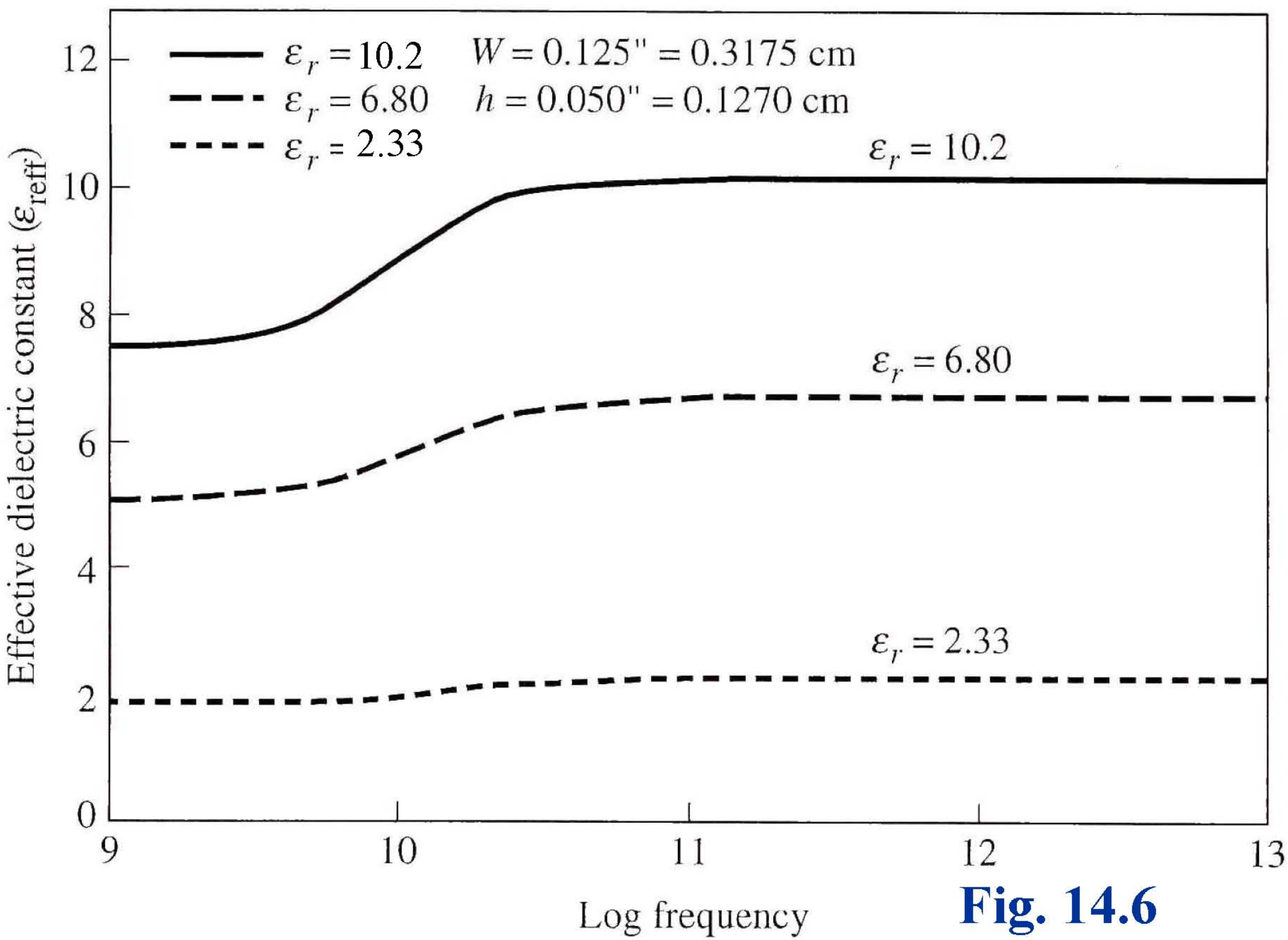
(c) Effective dielectric constant

Fig. 14.5

Effective Dielectric Constant

W/h>1

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (14\text{-}1)$$



$\varepsilon_r = 10.2$
$\varepsilon_r = 6.80$
$\varepsilon_r = 2.33$
$W = 0.125'' = 0.3175$ cm
$h = 0.050'' = 0.1270$ cm
$\varepsilon_r = 10.2$
$\varepsilon_r = 6.80$
$\varepsilon_r = 2.33$
Effective dielectric constant ($\varepsilon_{\mathrm{reff}}$)
0
2
4
6
8
10
12
9
10
11
12
13
Log frequency

Fig. 14.6

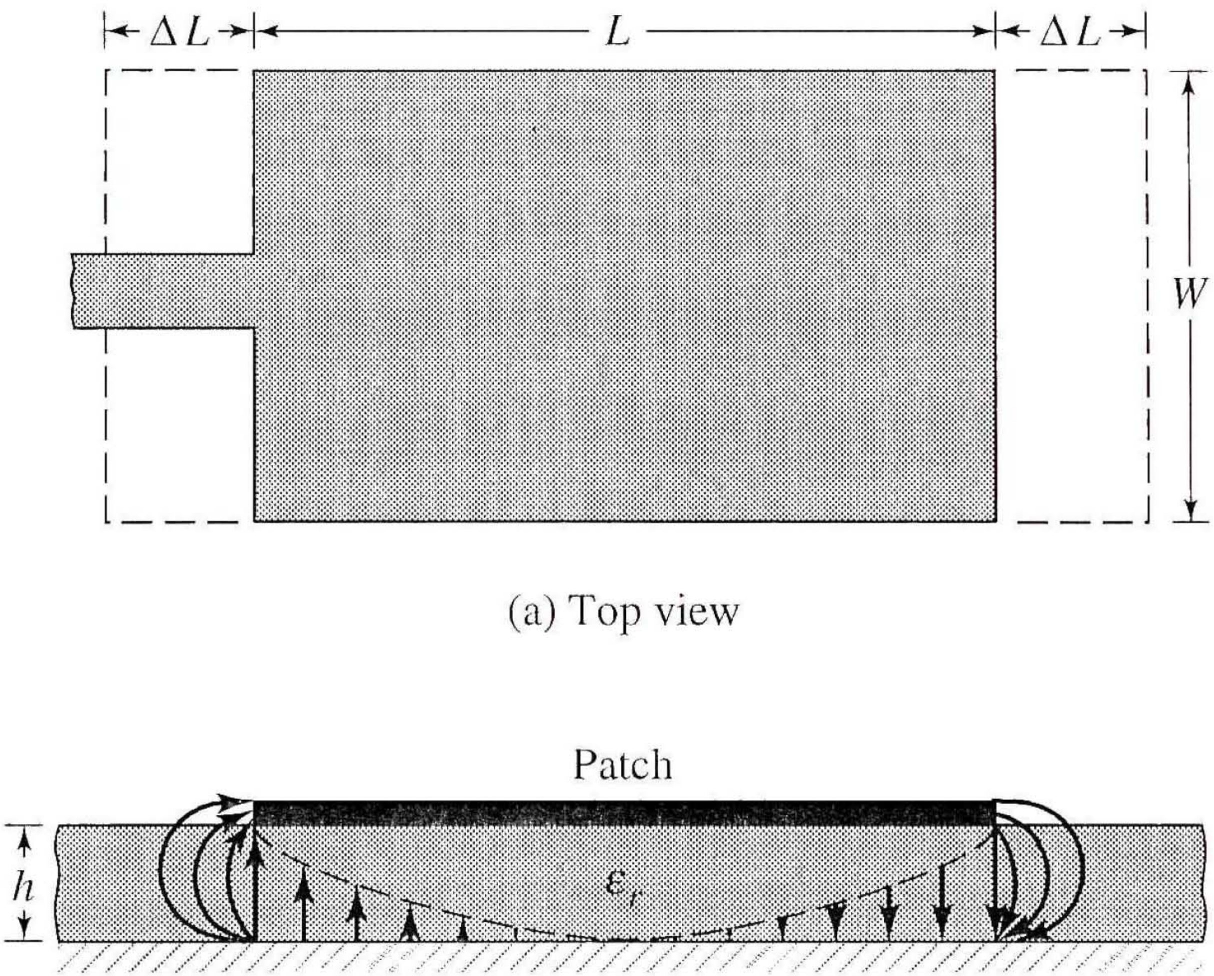


Fig. 14.7

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (14\text{-}2)$$

$$(f_{rc})_{010} = \frac{v_0 / \sqrt{\varepsilon_{reff}}}{2\left[L + 2\Delta L\right]} = g \frac{v_0 / \sqrt{\varepsilon_r}}{2L}$$

g = fringe factor (length reduction factor)

$$L_{eff} = L + 2\Delta L \qquad (14\text{-}3)$$

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \qquad (14\text{-}4)$$

$$(f_{rc})_{010} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} = \frac{v_0}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}}$$

(14-5)

The resonant frequency with no fringing is given by

$$\left(f_r\right)_{010} = \frac{v_o}{2L\sqrt{\varepsilon_r}} \qquad (14\text{-}4)$$

Because of fringing, the effective distance between the radiating edges seems longer than *L* by an amount of Δl at each edge. This causes the actual resonant frequency to be slightly less than f_{ro} by a factor *q*. Thus

$$\left(f_{rc}\right) = \frac{v_o}{2(L + 2\Delta\ L)\sqrt{\varepsilon_{reff}}} = q\frac{v_o}{2L\sqrt{\varepsilon_r}} \qquad (14\text{-}5)$$

Design Procedure

1. Specify: ε_r , f_r, h/λ_o
2. Determine: W, L

Design Procedure

1. Specify: ε_r , f_r, h/λ_o
2. Determine: W, L

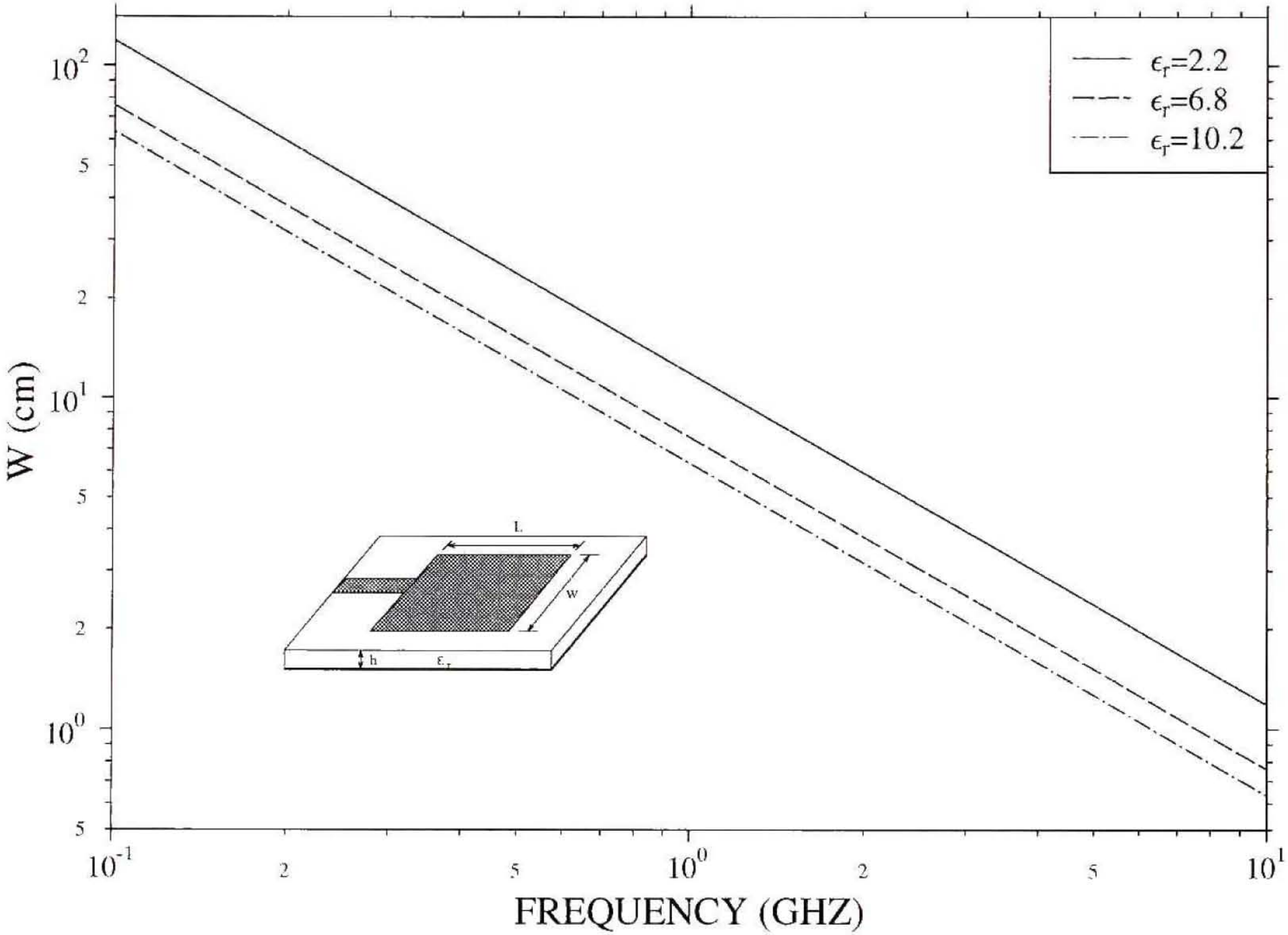
   A. Determine W:

   For an efficient radiator, a practical width which leads to good radiation efficiencies is

$$W = \frac{\upsilon_o}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (14\text{-}6)$$

Plots of W (in cm) as a function of frequency are shown in the attached figure.

Element Width vs. Frequency for Different Dieletric Substrates



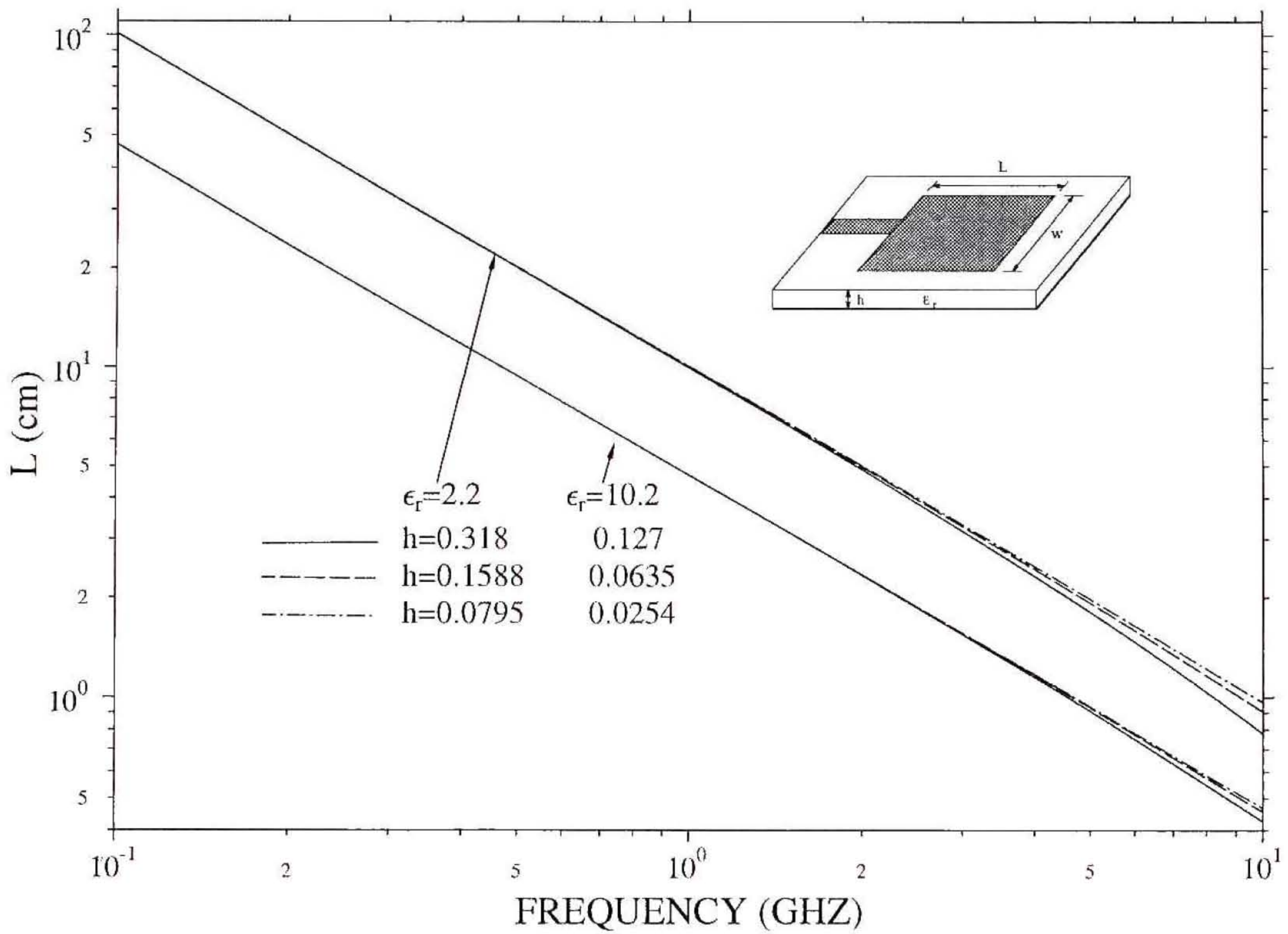
B. Determine L:

once W is known, and the effective dielectric constant and length extension have been computer, the

$$L = \frac{\upsilon_o}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (14\text{-}7)$$

Plots of L (in cm) VS. frequency are shown in the attached figure.

Element Length vs. Frequency for Different Dielectric Substrates



Rectangular Microstrip

($L = 0.906$ cm, $W = 1.186$ cm, $h = 0.1588$ cm,
$y_o = 0.3126$ cm, $\varepsilon_r = 2.2$, $f = 10$ GHz)

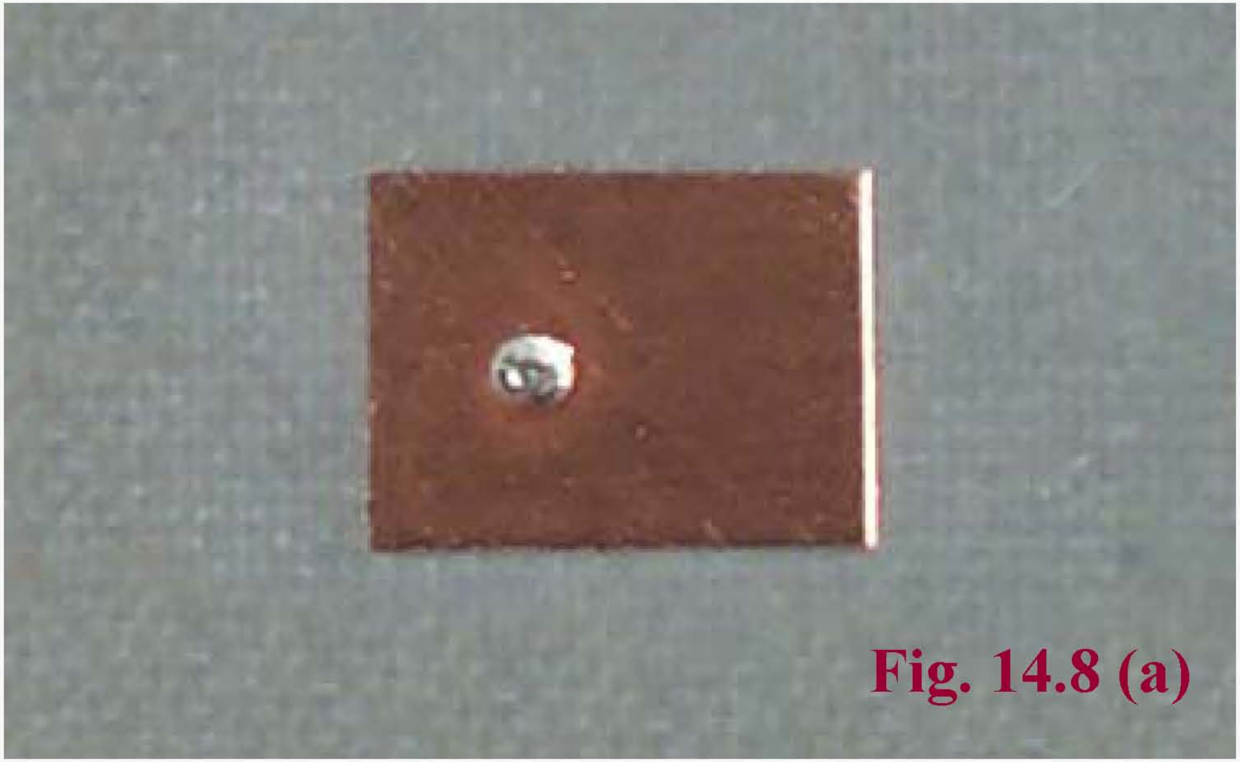
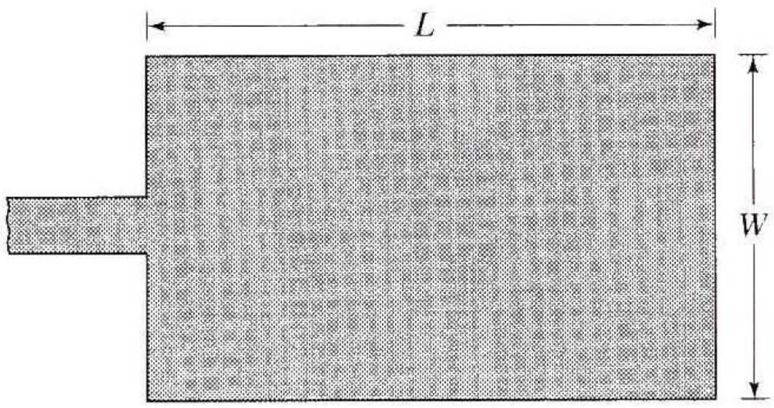


Fig. 14.8 (a)

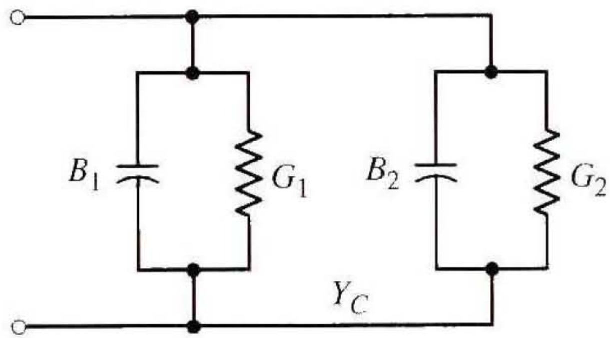
Slot Admittance

Each radiating aperture is modeled as a narrow slot of width W and height h radiating into half space.

Rectangular Patch and Equivalent Circuit



(a) Rectangular patch



(b) Transmission model equivalent

Fig. 14.9

Slot #1:

$$Y_1 = G_1 + jB_1 \qquad (14\text{-}8)$$

$$G_1 = \frac{W}{120\lambda_0}\left[1 - \frac{1}{24}(k_0 h)^2\right] \qquad \frac{h}{\lambda_0} < \frac{1}{10} \qquad (14\text{-}8a)$$

$$B_1 = \frac{W}{120\lambda_0}\left[1 - 0.636\ln(k_0 h)\right] \qquad \frac{h}{\lambda_0} < \frac{1}{10} \qquad (14\text{-}8b)$$

Similarly For Slot #2

$$G=\frac{2P_{rad}}{|V_0|^2}=\frac{1}{\pi\eta_0}\int_0^{\pi}\frac{\sin^2\left(\frac{k_0W}{2}\cos\theta\right)}{\cos^2\theta}\sin^3\theta d\theta$$

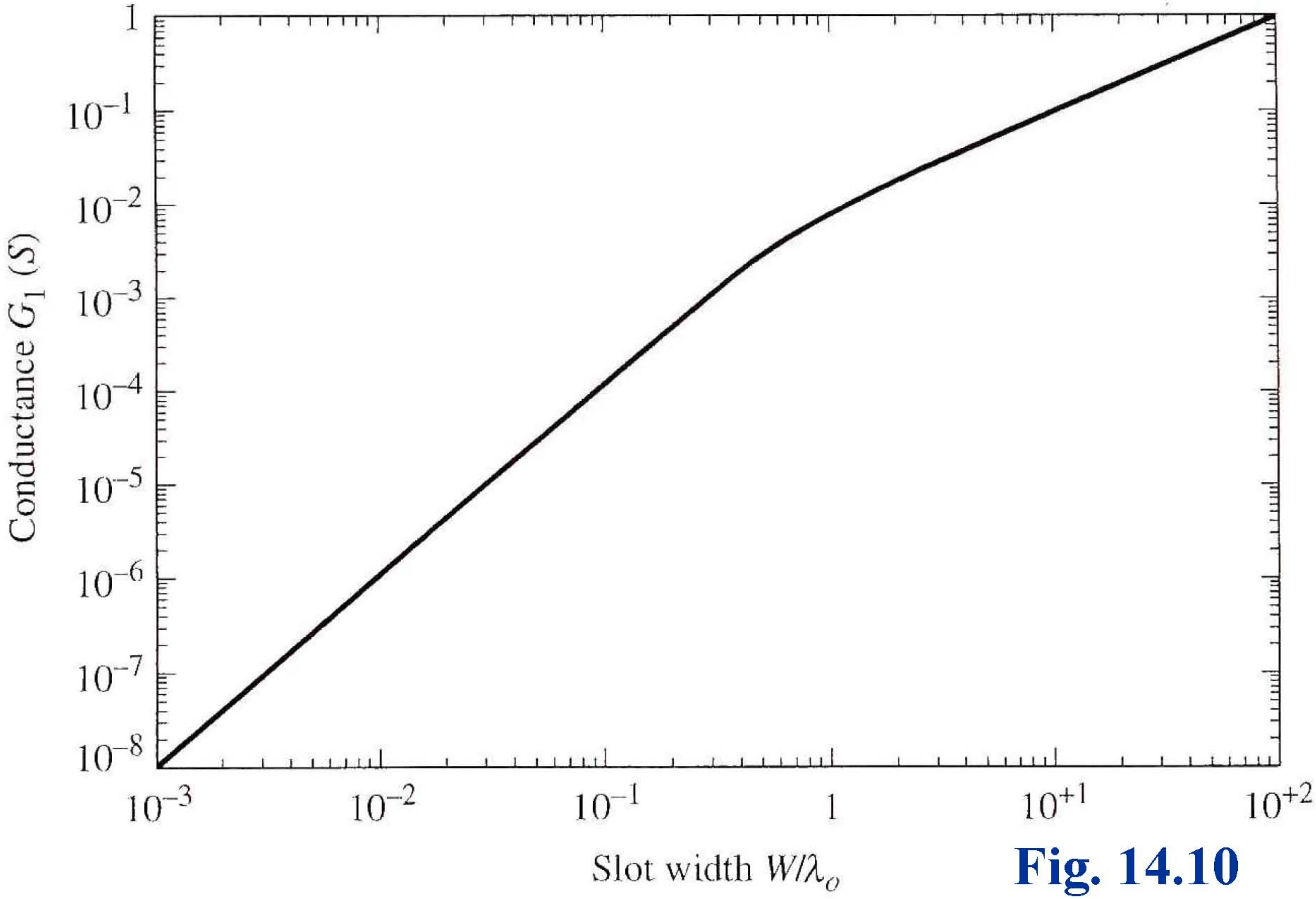
$$=\frac{1}{120\pi^2}\int_0^{\pi}\frac{\sin^2\left(\frac{k_0W}{2}\cos\theta\right)}{\cos^2\theta}\sin^3\theta d\theta \qquad (14\text{-}11)$$

$$G=\frac{I_1}{120\pi^2},\ I_1=\int_0^{\pi}\frac{\sin^2\left(\frac{k_0W}{2}\cos\theta\right)}{\cos^2\theta}\sin^3\theta d\theta \qquad (14\text{-}12)$$

$$W<<\lambda_0:\quad G\simeq\frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2$$

$$(14\text{-}13)$$

$$W<<\lambda_0:\quad G\simeq\frac{1}{120}\left(\frac{W}{\lambda_0}\right)$$



1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Conductance G_1 (S)
10^{-3}
10^{-2}
10^{-1}
1
10^{+1}
10^{+2}
Slot width W/λ_o

Fig. 14.10

Input Admittance

The slight reduction from $\lambda_d/2$ is necessary to account for the fringing at the radiating edges.

If the reduction of L from $\lambda_d/2$ is properly chosen (choosing properly the length reduction factor q), the transformed admittance of slot #2 becomes

$$\widetilde{Y}_2 = \widetilde{G}_2 + j\widetilde{B}_2 = G_1 - jB_1$$

$$G_2 + jB_2 = G_1 + jB_1$$

$$\tilde{G}_2 + j\tilde{B}_2 = G_1 - jB_1 \quad (14\text{-}14)$$

$$Y_{in} = G_1 + jB_1 + (\tilde{G}_2 + j\tilde{B}_2) = G_1 + jB_1 + (G_1 - jB_1)$$

$$Y_{in} = 2G_1 \quad (14\text{-}15)$$

$$Z_{in} = R_{in} = \frac{1}{Y_{in}} = \frac{1}{2G_1} \quad (14\text{-}16)$$

Taking into account coupling:

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \qquad (14\text{-}17)$$

where

+ is used with odd (antisymmetric) resonant voltage distribution beneath the patch and between the slot

- is used with even (symmetric)…

$$G_{12} = \frac{1}{|V_0|^2} \operatorname{Re} \iint_S \underline{E}_1 \times \underline{H}_2^* \cdot d\underline{s} \qquad (14\text{-}18)$$

E_1=E-field radiated by slot #1

H_2=H-field radiated by slot #2

V_0= voltage across the slot

$$G_{12} = \frac{1}{120\pi^2} \int_0^\pi \left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta} \right]^2 J_0(k_0 L \sin\theta) \sin^3\theta \, d\theta$$

(14-18a)

The resonant input resistance can be decreased by increasing the width *W* of the patch. This is acceptable as long as the ratio *W/L* does not exceed 2 because the aperture efficiency of a single patch begins to drop, as *W/L* increases beyond 2.

Characteristic Impedance/ Admittance

$$\upsilon = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\mu\varepsilon}}$$

$$L = \frac{\mu\varepsilon}{C}$$

$$Z_c = \sqrt{\frac{L}{C}} = \frac{\sqrt{\mu\varepsilon}}{C}$$

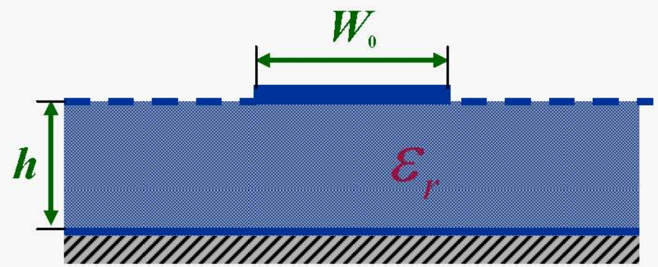
$$Z_c = \sqrt{\frac{L}{C}} = \frac{\sqrt{\mu\varepsilon}}{C}$$

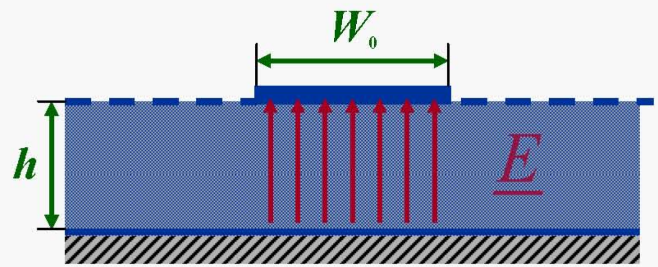
$$C = \varepsilon \frac{W_0}{h} = \varepsilon_0 \varepsilon_r \frac{W_0}{h}$$

$$Z_c = \frac{\sqrt{\mu_0 \varepsilon_0 \varepsilon_r}}{C} = \frac{\sqrt{\mu_0 \varepsilon_0 \varepsilon_r}}{\varepsilon_0 \varepsilon_r} \frac{h}{W_0}$$

$$Z_c = \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{h}{W_0 \sqrt{\varepsilon_r}} = \frac{\eta_0 h}{W_0 \sqrt{\varepsilon_r}}$$

$$Y_c = \frac{1}{Z_C} = \frac{W_0 \sqrt{\varepsilon_r}}{\eta_0 h}$$





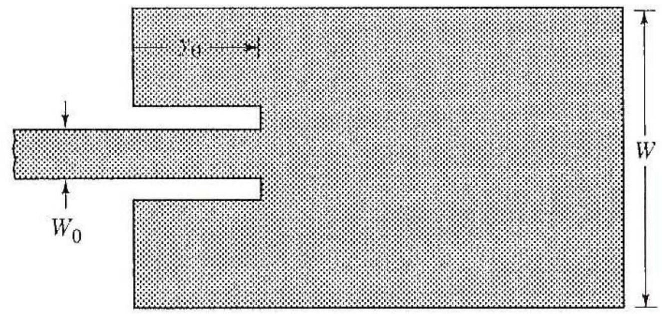
A better approximation for the characteristic impedance is *(for $W_o/h>1$)*

$$Z_c = \frac{120\pi / \sqrt{\varepsilon_{reff}}}{\frac{W_0}{h} + 1.393 + 0.667 \ln\left(\frac{W_0}{h} + 1.444\right)} \tag{14-20}$$

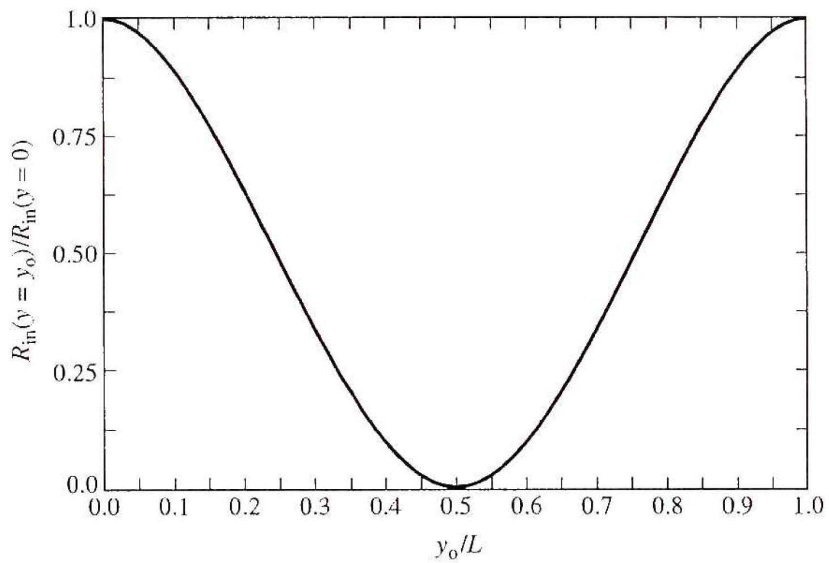
where

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_0}\right]^{-1/2} \tag{14-1}$$

Inset Feed-Point Impedance



(a) Recessed microstrip-line feed



(b) Normalized input resistance

Fig. 14.11

Using the modal-expansion analysis, it has been shown that the inset-feed-point impedance is given by

$$R_{in}(y = y_o) = R_{in}(y = 0)\cos^2\left(\frac{\pi}{L} y_o\right) \quad \text{(14-20a)}$$

As the inset feed-point distance y_o increases, the resonant input resistance decreases. In fact, at $y_o = L/2$, the input resistance vanishes. This feeding mechanism can be very useful for matching patches to lines with small values of characteristic impedance on the order of 50 ohms.

Problem

1) Problem 6-12 (6-10 in 2nd edition)
2) Design a patch antenna for Bluetooth, (frequency 2.402 to 2.480 GHz). Use PP material with Er=2.2 and a thickness of 3 mm.

   Find the input impedance at the edge and calculate the position for 50 Ohm impedance. Find the W for a 50 Ohm microstrip.

   Make the antenna.