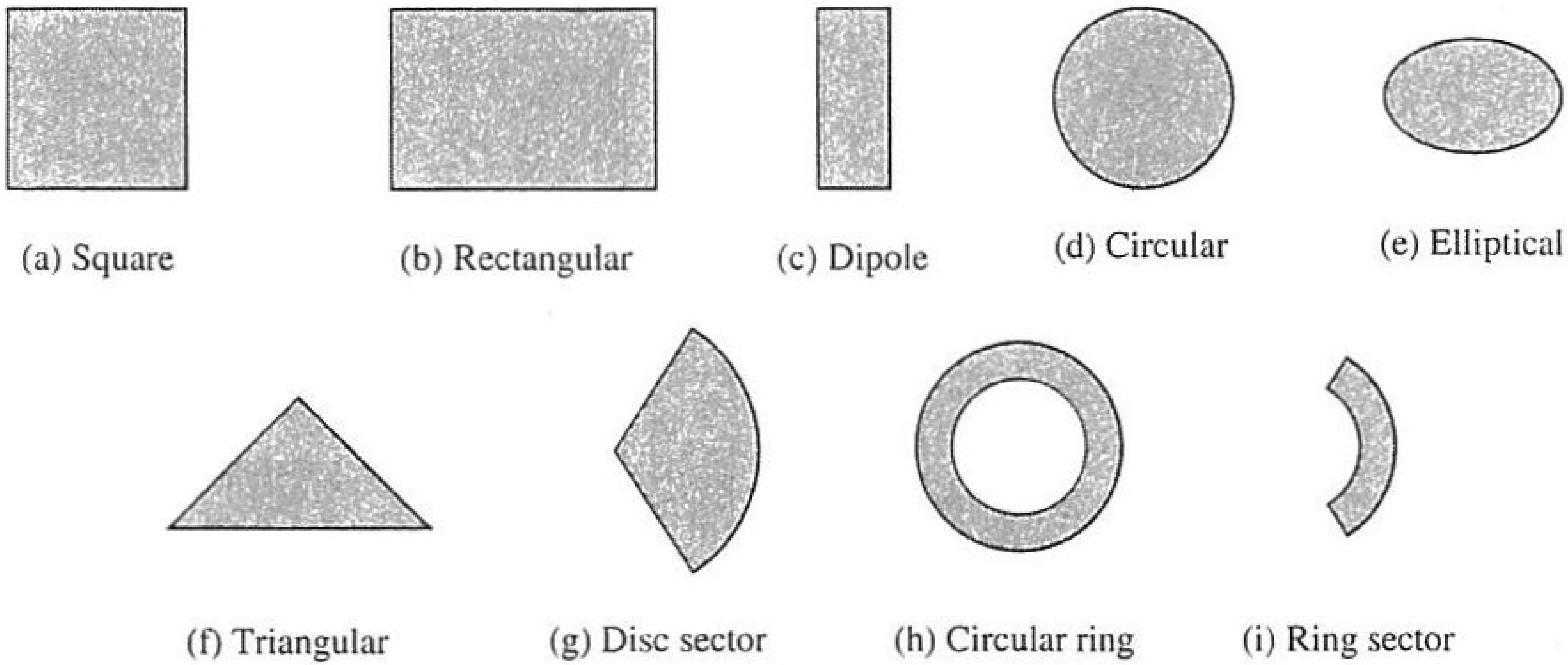
Chapter 14 : Microstrip Antenna

- **Introduction**
  - Advantages & Disadvantages
  - Feeding Methods
  - Analysis Methods
- **Rectangular patch**
  - Transmission line model

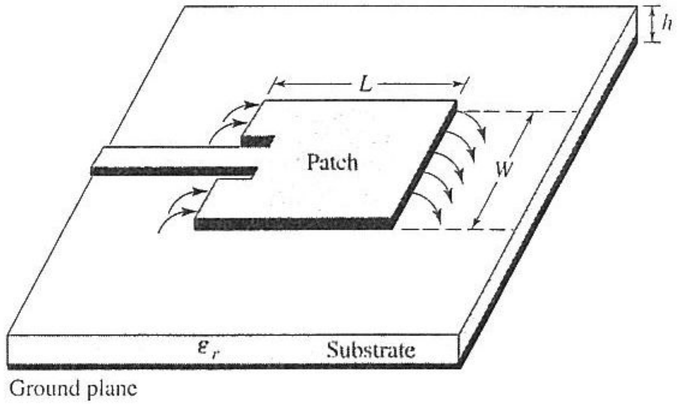
Shapes of microstrip patch elements



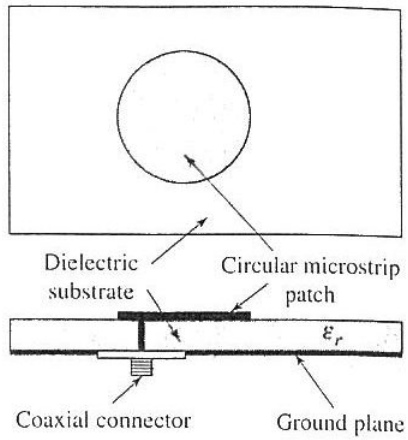
Advantages & Disadvantages

- **Advantages:**
  - Low profile
  - Conformable to planar & non-planar surfaces
  - Manufactured using printed circuit technology
  - Compatible with MMIC designs
- **Disadvantages:**
  - Low power (also power due to surface waves)
  - High Q
  - Narrow bandwidth

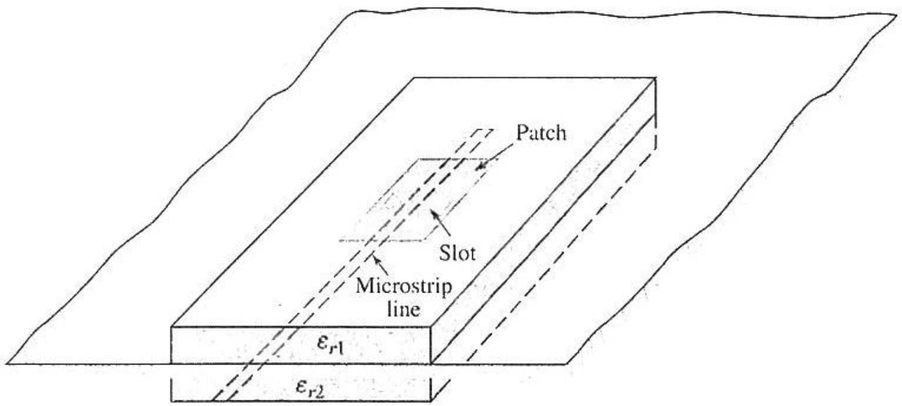
Feeding Methods



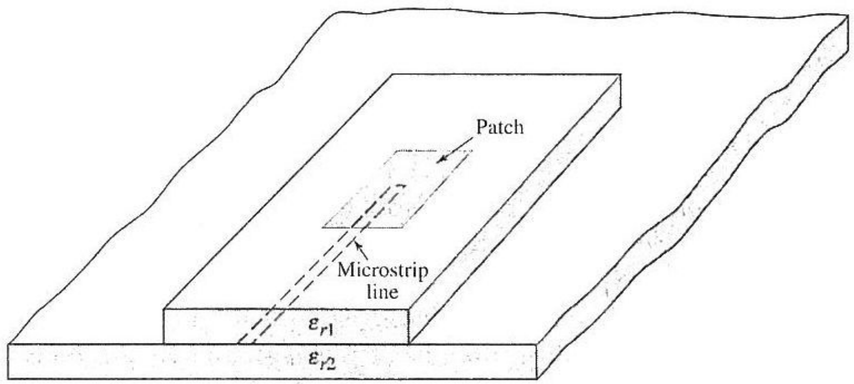
(a) Microstrip line feed



(b) Probe feed



(c) Aperture-coupled feed

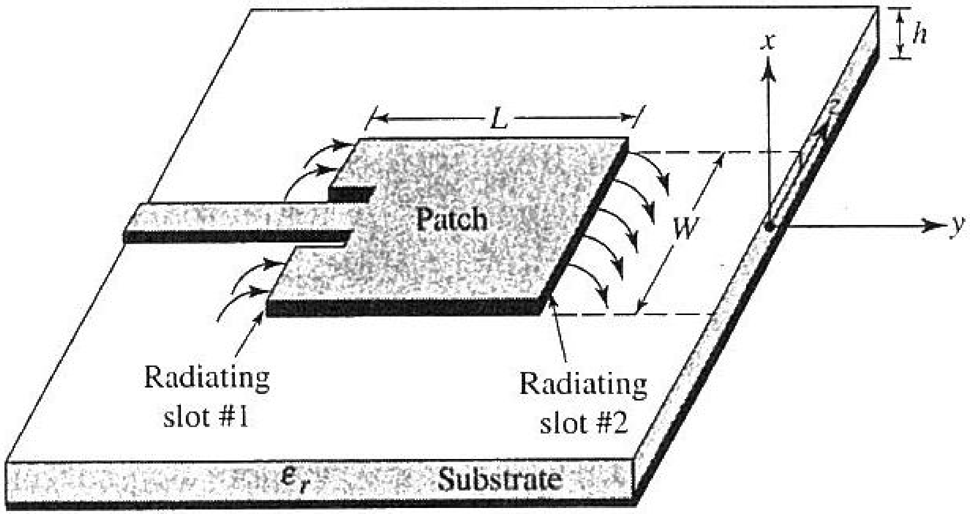


(d) Proximity-coupled feed

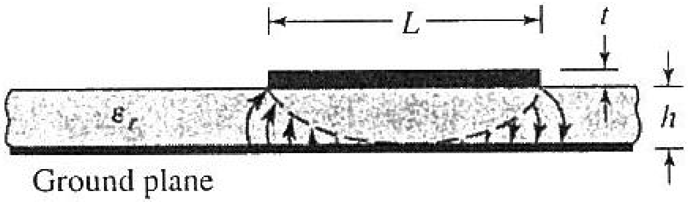
Analysis Methods

- **Transmission-line model**
- **Cavity model**
- **Numerical techniques:**
  - Method of moments (integral equation)
  - Finite element (FEM)
  - Finite difference time domain (FDTD)

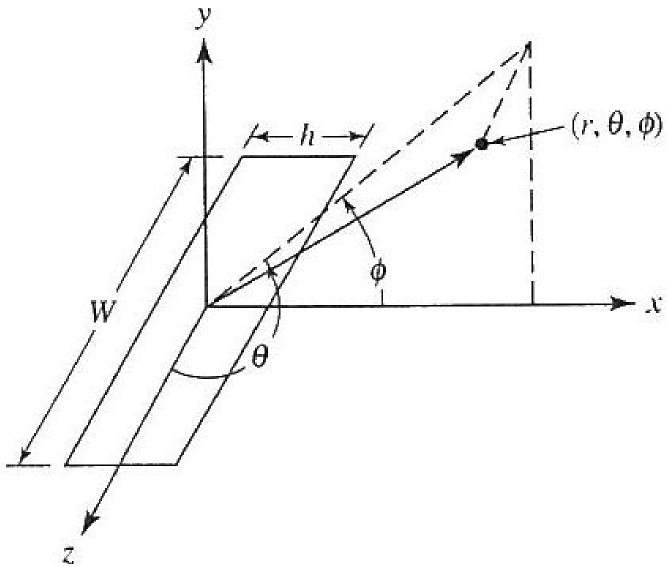
Radiation Mechanism



(a) Microstrip antenna

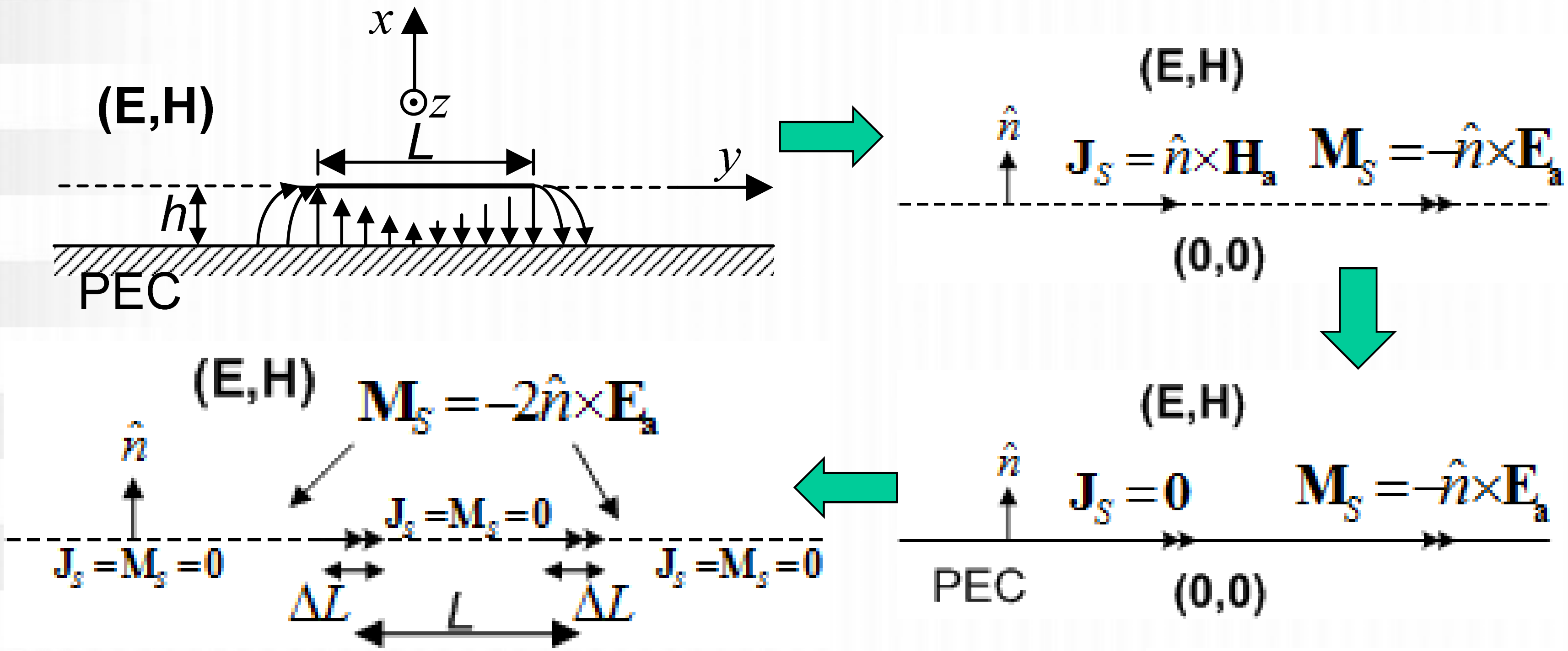


(b) Side view



(c) Coordinate system for each radiating slot

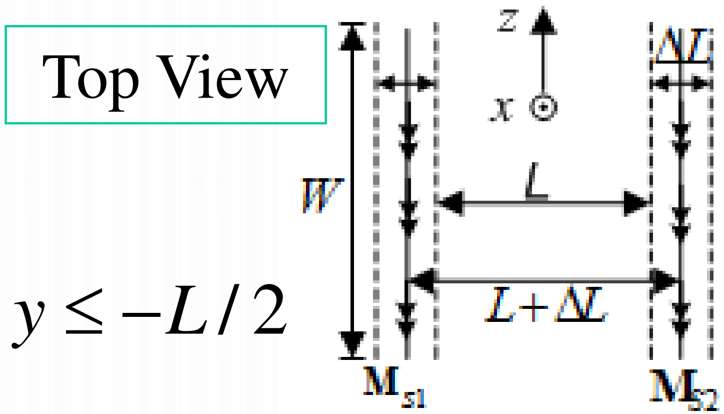
Equivalent currents



$$\mathbf{M}_{S_i} = -2\hat{n} \times \mathbf{E}_a = -2\hat{x} \times \hat{y} E_0$$

$$= -\hat{z} 2E_0$$

$$L/2 \le y \le L/2 + \Delta L; -L/2 - \Delta L \le y \le -L/2$$



Radiated Field

Two-element array separated by a distance of $L+\Delta L$

$$\mathbf{E}=\mathbf{E}_1+\mathbf{E}_2;\mathbf{E}_i=-jk\frac{e^{-jkr}}{4\pi r}\iint_{S_i}\mathbf{M}_{S_i}\times\hat{r}e^{jk\hat{r}\cdot\bar{r}'}dy'dz'$$

$$\mathbf{M}_{S_i}\times\hat{r}=-\hat{z}2E_0\times\hat{r}=-2E_0(\hat{r}\cos\theta-\hat{\theta}\sin\theta)\times\hat{r}$$

$$=-\hat{\phi}2E_0\sin\theta$$

$$\hat{r}\cdot\bar{r}'=y'\sin\theta\sin\phi+z'\cos\theta$$

$$\mathbf{E}_i=jk\frac{e^{-jkr}}{4\pi r}\hat{\phi}2E_0\sin\theta\iint_{S_i}e^{jk(y'\sin\theta\sin\phi+z'\cos\theta)}dy'dz'$$

For i=1

$$\int_{-W/2}^{W/2}\int_{-L/2-\Delta L}^{-L/2}e^{jk(y'\sin\theta\sin\phi+z'\cos\theta)}dy'dz'=\int_{-W/2}^{W/2}e^{jkz'\cos\theta}dz'\int_{-L/2-\Delta L}^{-L/2}e^{jky'\sin\theta\sin\phi}dy'=I_1I_2$$

$$I_1=W\mathrm{sinc}\left(\frac{kW}{2}\cos\theta\right);I_2=\left.\frac{e^{jky'\sin\theta\sin\phi}}{jk\sin\theta\sin\phi}\right|_{-L/2-\Delta L}^{-L/2}$$

Radiated Field (2)

For i=2

$$\int_{-W/2}^{W/2}\int_{L/2}^{L/2+\Delta L} e^{jk(y'\sin\theta\sin\phi+z'\cos\theta)}dy'\,dz' = \int_{-W/2}^{W/2} e^{jkz'\cos\theta}dz'\int_{L/2}^{L/2+\Delta L} e^{jky'\sin\theta\sin\phi}dy' = I_1 I_2$$

$$I_1 = W\text{sinc}\left(\frac{kW}{2}\cos\theta\right); I_2 = \left.\frac{e^{jky'\sin\theta\sin\phi}}{jk\sin\theta\sin\phi}\right|_{L/2}^{L/2+\Delta L}$$

The total field becomes

$$\mathbf{E} = \hat{\phi} jkE_0 \frac{e^{-jkr}}{2\pi r}\sin\theta\left[W\text{sinc}\left(\frac{kW}{2}\cos\theta\right)\right]\times$$

$$\left[2\cos\left(k\frac{L+\Delta L}{2}\sin\theta\sin\phi\right)\Delta L\text{sinc}\left(k\frac{\Delta L}{2}\sin\theta\sin\phi\right)\right]$$

Design Equation

Approximate relation for ΔL

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

where

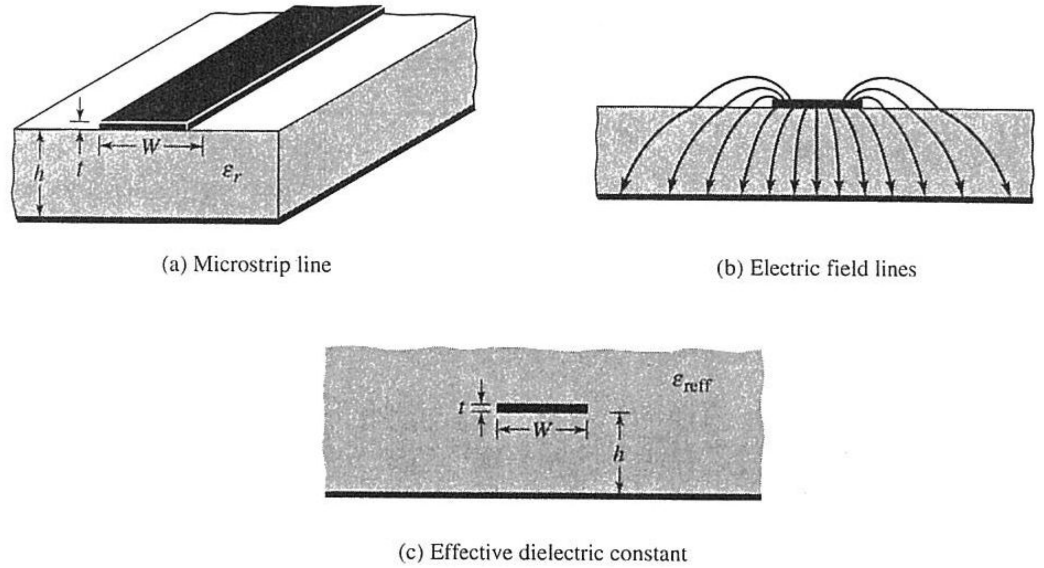
$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad \text{for } W/h > 1$$

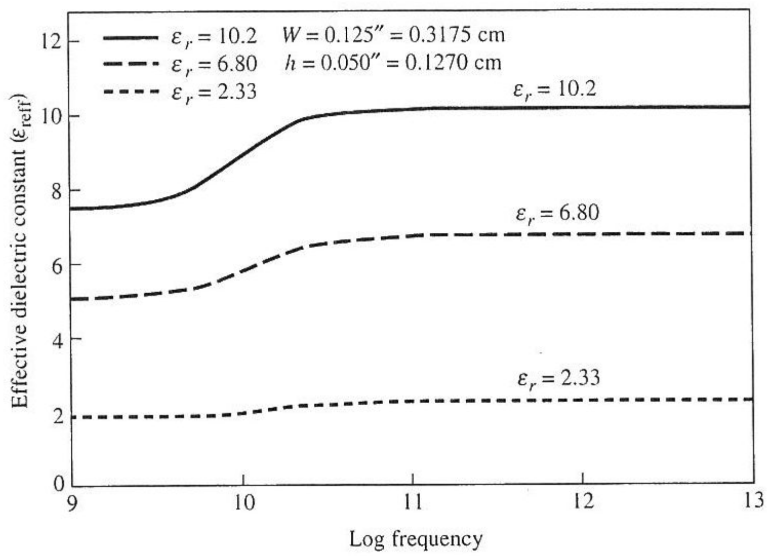
Effective Length: $L_{eff} = L + 2\Delta L$

At resonance: $L_{eff} = \dfrac{\lambda_{eff}}{2}$

Effective Dielectric Constant

- **Effective dielectric constant = the dielectric constant of an equivalent homogeneous medium**





Design Procedure

- **Given ε_r, f_r and h where f_r is the operation frequency**
- **Design procedure**
  1. Calculate W $$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$
  2. Determine the effective dielectric constant
  3. Determine the effective length

$$L_{eff} = \frac{\lambda_{eff}}{2} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$$

  4. Calculate ΔL
  5. Determine L

Design Example

- **Given a substrate (RT/duroid 5880) with ε_r=2.2, h=0.1588 cm and f_r=10 GHz.**

$$W=\frac{3\times 10^8}{2(10\times 10^9)}\sqrt{\frac{2}{2.2+1}}=1.186\,\text{cm}$$

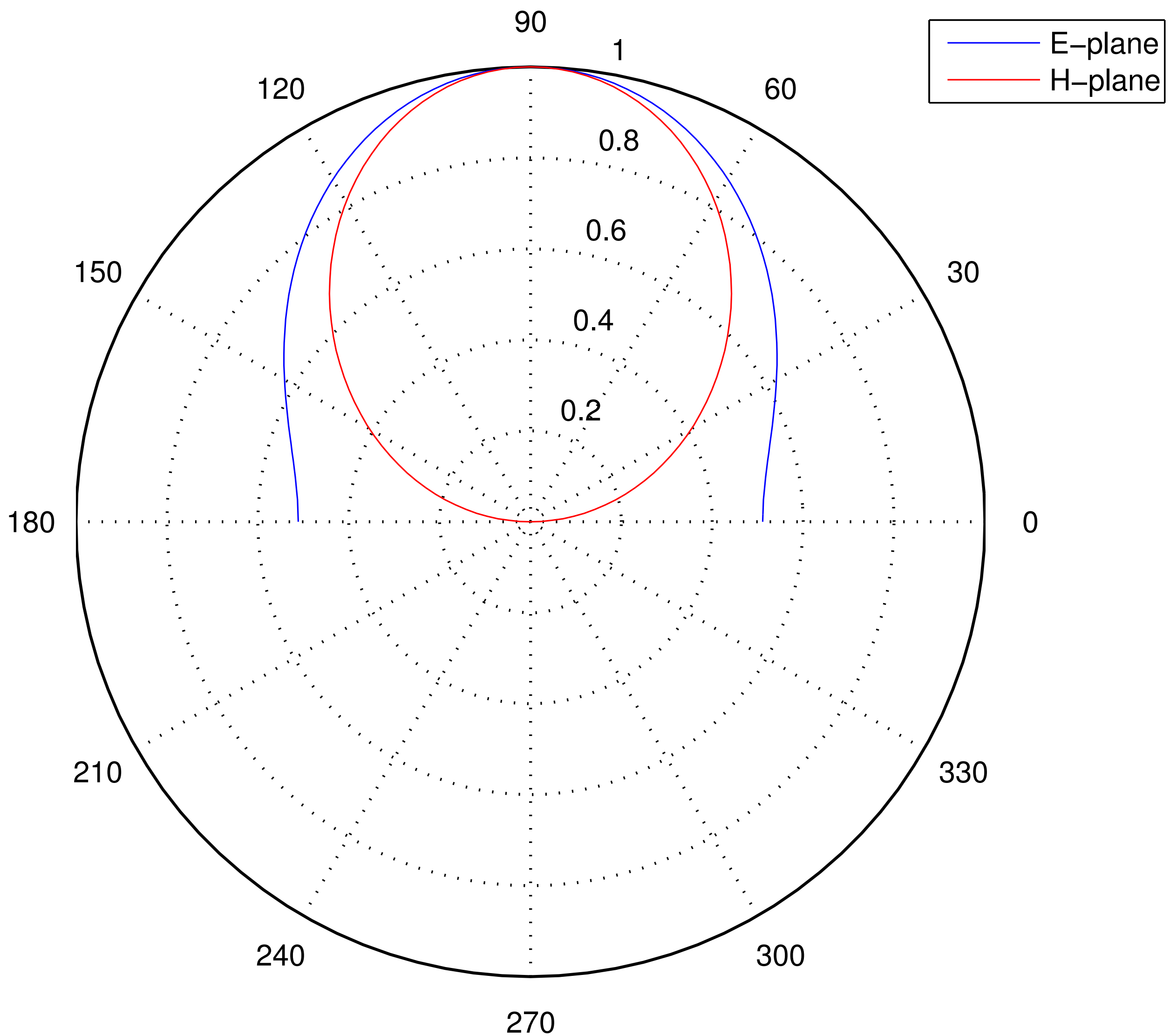
$$\varepsilon_{reff}=\frac{2.2+1}{2}+\frac{2.2-1}{2}\left[1+12\frac{0.1588}{1.186}\right]^{-1/2}=1.972$$

$$\Delta L=0.1588\times 0.412\frac{1.972+0.3}{1.972-0.258}\frac{\frac{1.186}{0.1588}+0.264}{\frac{1.186}{0.1588}+0.8}=0.081\,\text{cm}$$

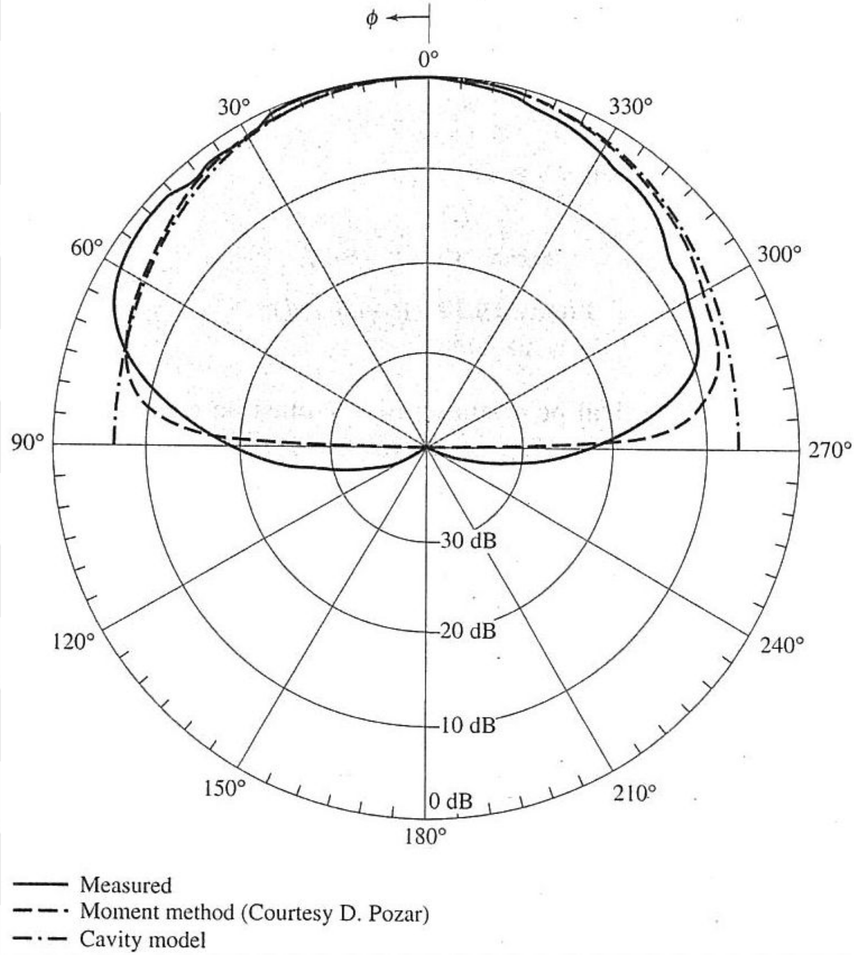
$$L_{eff}=\frac{3\times 10^8}{2\times 10\times 10^9\sqrt{1.972}}=1.068\,\text{cm}$$

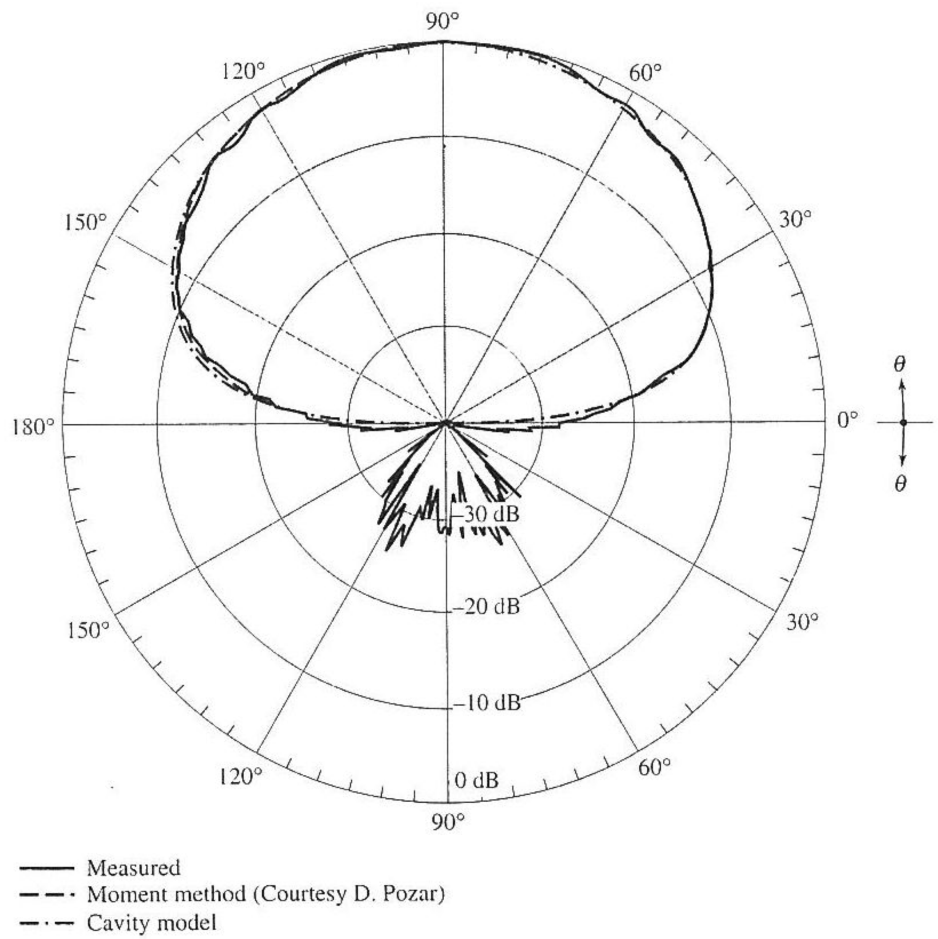
$$L=1.068-2(0.081)=0.906\,\text{cm}$$

Radiation Pattern



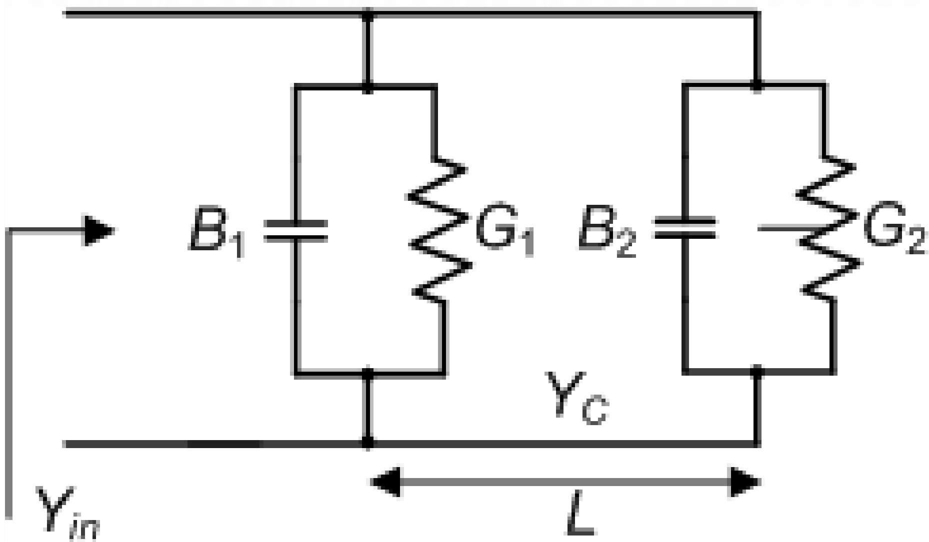
Radiation Pattern (2)





Transmission line model

Each radiating edge can be modeled by an equivalent admittance $Y = G + jB$



$$Y_1 = G_1 + jB_1; Y_2 = G_2 + jB_2;$$

$$G_1 = G_2; B_1 = B_2; W/h > 1$$

$$Y_{in} = Y_1 + Y_c \frac{Y_2 + jY_c \tan(\beta L)}{Y_c + jY_2 \tan(\beta L)}; \beta = \frac{2\pi}{\lambda}\sqrt{\varepsilon_{reff}}$$

where

$$Z_c = \frac{1}{Y_c} = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left\{\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.444\right)\right\}}$$

Transmission line model (2)

$$G_1 = \frac{I_1}{120\pi^2}; I_1 = -2 + \cos(k_0 W) + kWS_i(k_0 W) + \frac{\sin(k_0 W)}{k_0 W}$$

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

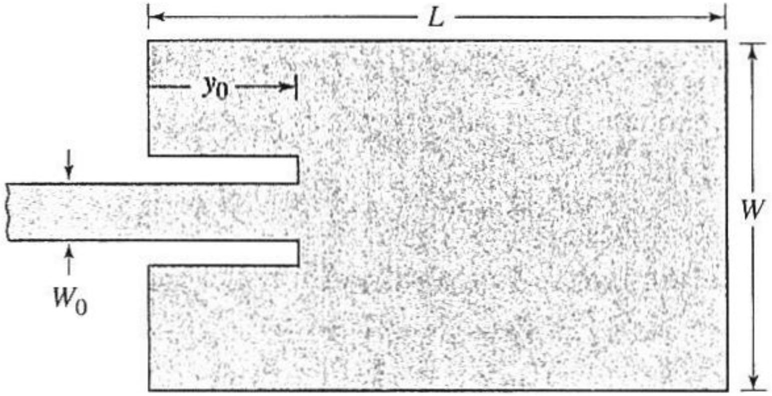
Asymptotic values:

$$G_1 \approx \begin{cases} \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2 & W << \lambda_0 \\ \frac{1}{120}\left(\frac{W}{\lambda_0}\right) & W >> \lambda_0 \end{cases}$$

At resonance ($f=f_r$), $Y_{in}=Y_1+Y^*_1=2G_1$ and $Z_{in} = \frac{1}{2G_1} = R_{in}$

To change the value of G_1, the location of the feed point has to be moved.

Input resistance



$$R_{in}(y = y_0) \approx R_{in}(0)\cos^2\left(\frac{\pi y_0}{L}\right);$$

where $R_{in}(0) = \dfrac{1}{2G_1}$