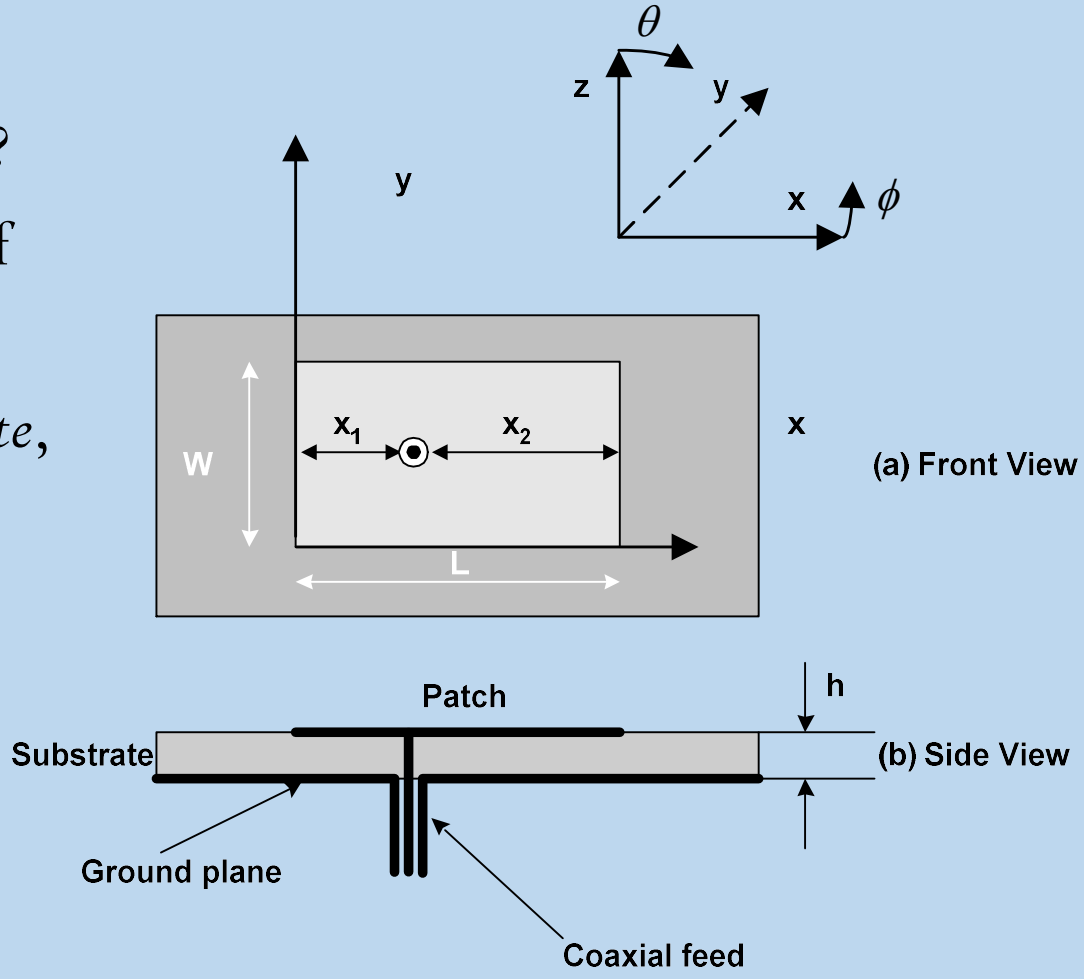
EE540 Advance Electromagnetic Theory & Antennas

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Microstrip antennas

- ***Aperture model:***
- How does a MSA looks like?
- MSA is a conducting strip of metal (*patch*)
- printed on a *dielectric substrate*,
- which is situated above a *ground plane*
- Fig. (a) Front view and (b) Side view of rectangular microstrip antenna (RMSA)



Microstrip antennas

- Possible patch shapes are
  - Rectangular (RMSA)
  - Circular
  - square,
  - triangular,
  - semicircular,
  - sectoral and
  - annular ring, etc.

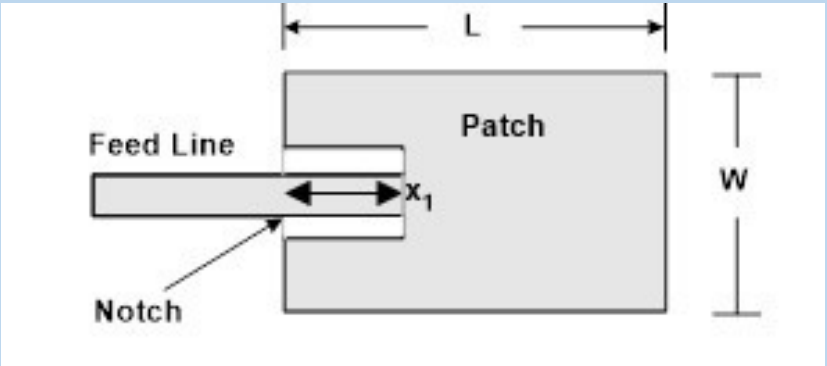


Fig. Microstrip line (MSL) fed MSA

- For signal incoming from MSL
  - it sees the patch (assume $x_1 = 0$ for simplicity) as a low impedance parallel plate transmission line (TL)
- with characteristic impedance $Z_{0p} \cong \frac{\eta_0}{\sqrt{\epsilon_r}} \frac{h}{w}$

Microstrip antennas

- After some reflection, the signal continues to move and
  - encounters an open circuit at a distance L,
  - which is the length of the microstrip antennas
- At the two ends of the patch there are *two radiating slots* formed as shown in Fig.
- *Why does radiation occurs at the slots?*
- Two radiating slots are separated by a
  - distance of L
- It is a 2 element slot antenna array
- Since the heights are quite small,
  - the field may be assumed to be uniform
- and approximated as

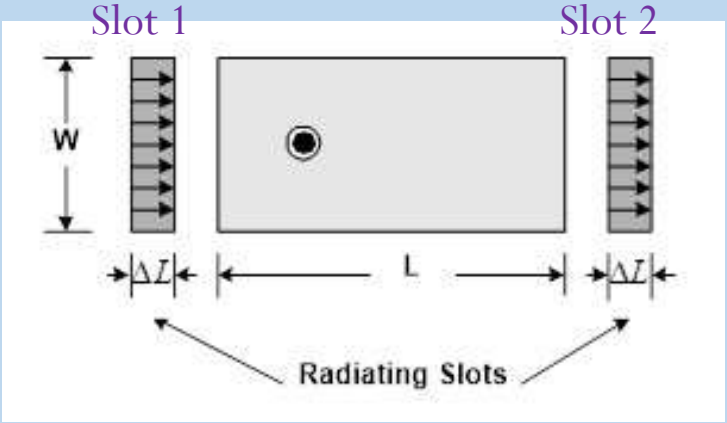


Fig. Slots at the two ends of the patch

Microstrip antennas

- *Step 1:*
- *Establish the fields in aperture (slot)*
- $\vec{E}_a = \begin{cases} \hat{x}E_0, & 0 \le x \le h; -w/2 \le y \le w/2 \\ 0, & elsewhere \end{cases}$
- Consider the first slot at z=-L/2
- In practice,
  - we have a slot from x=0 to x=h
  - Electric field is directed from the ground plane to the microstrip plane like VED over an infinite PEC surface

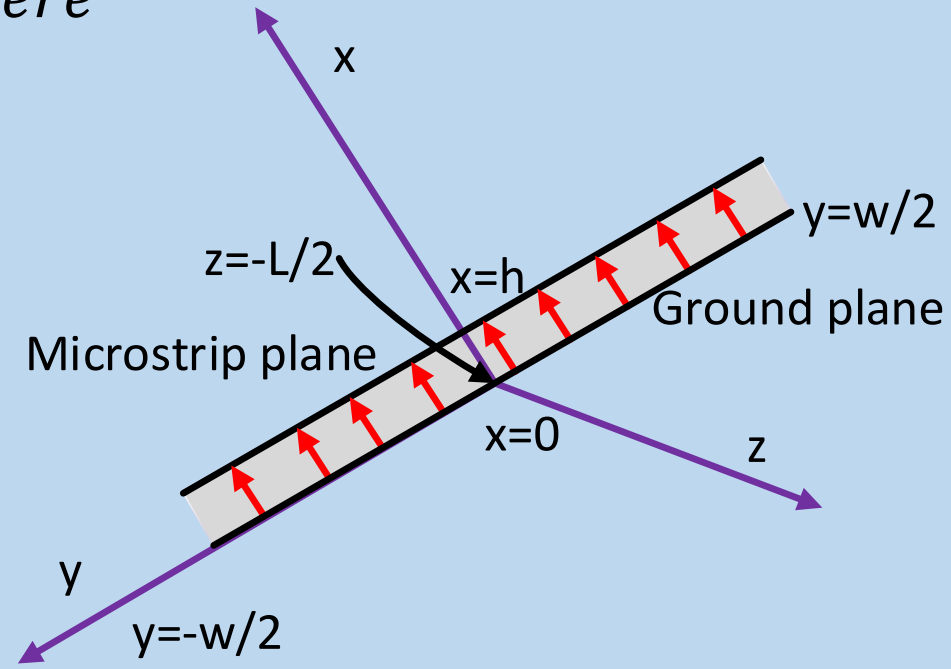


Fig. Model of slot aperture fields

Microstrip antennas

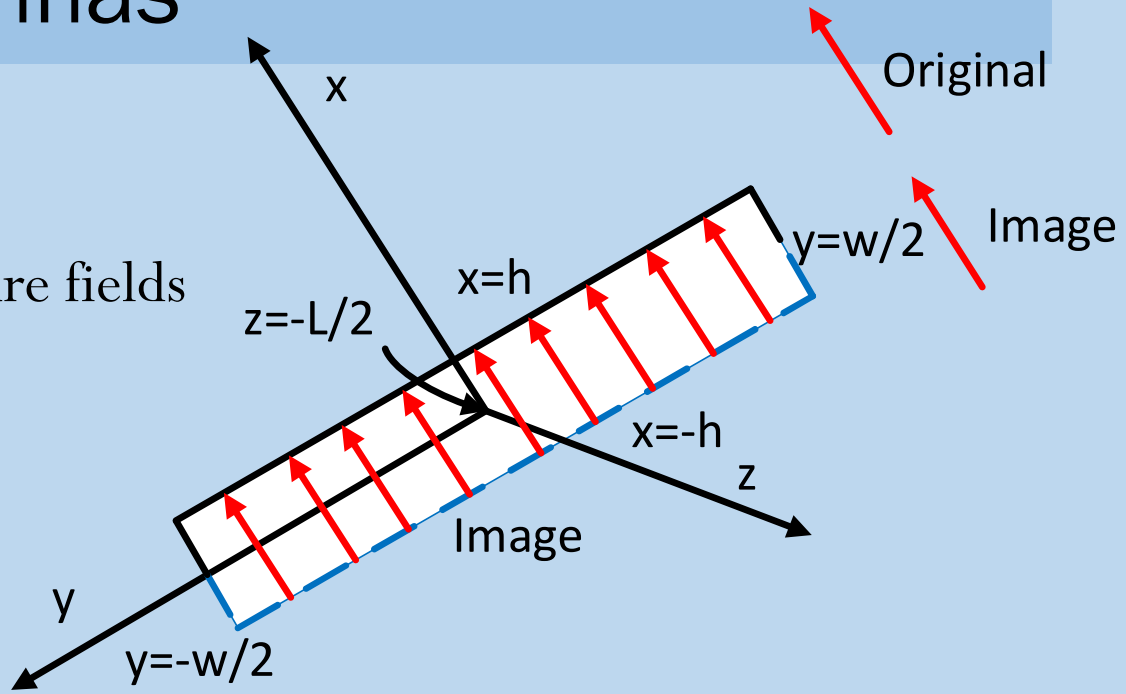


Fig. Model of slot aperture fields using method of images

Using method of images,

- remove the ground plane
- Image (like the case of VED over PEC)
  - from x=-h to x=0
  - will follow the same direction of original field
- $\vec{E}_a = \begin{cases} \hat{x}E_0, & -h \le x \le h; -w/2 \le y \le w/2 \\ 0, & elsewhere \end{cases}$

Microstrip antennas

- Since the electric field is
- assumed to zero
- everywhere
  - except over the slot,
  - it looks like a
  - uniformly excited aperture
- in an infinite ground plane
- A small field exists in the region $z<0$
- Hence, PEC can be introduced
  - behind the aperture or slot

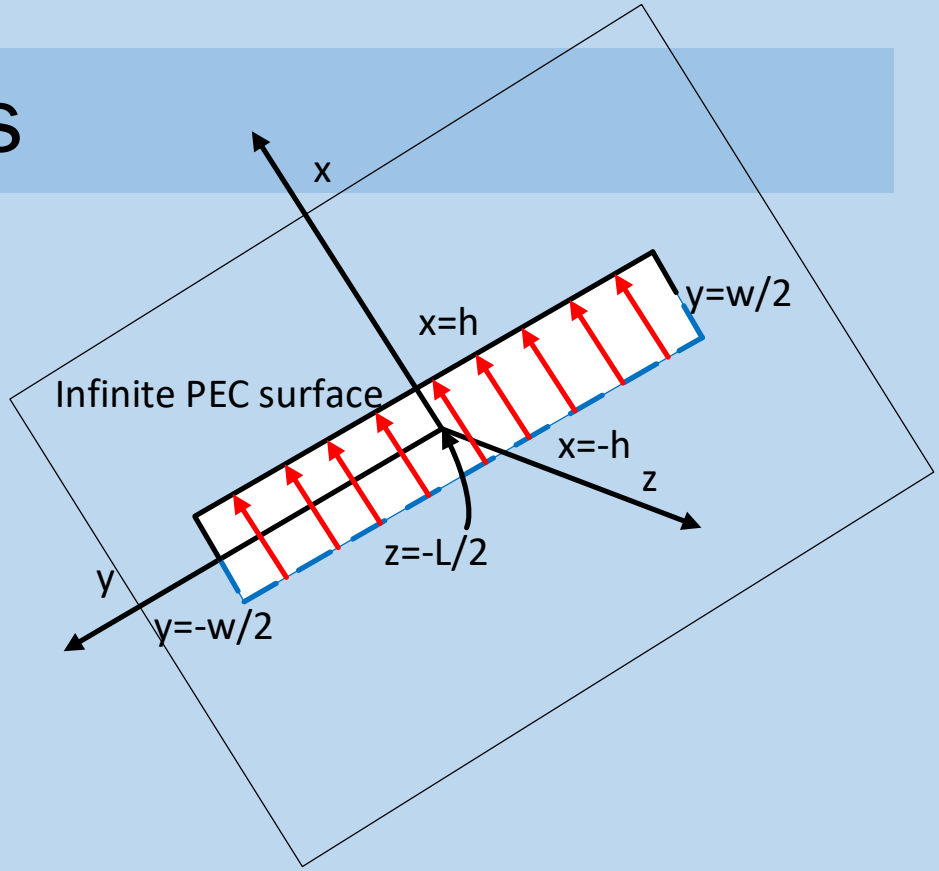


Fig. Equivalent vertical electric current density over an infinite PEC surface

Microstrip antennas

- Equivalent source over the slot or aperture
- $\vec{M} = -\hat{z} \times \vec{E}_a = -\hat{z} \times \hat{x}E_0 = -\hat{y}E_0$
- Looks like a HMD
- Apply method of images
- Image HMD
  - same direction at the same location
  - adds up
- $\vec{M} = -\hat{y}2E_0$
- A factor of 2 comes up
- Equivalently multiply a factor of 2
  - in aperture field

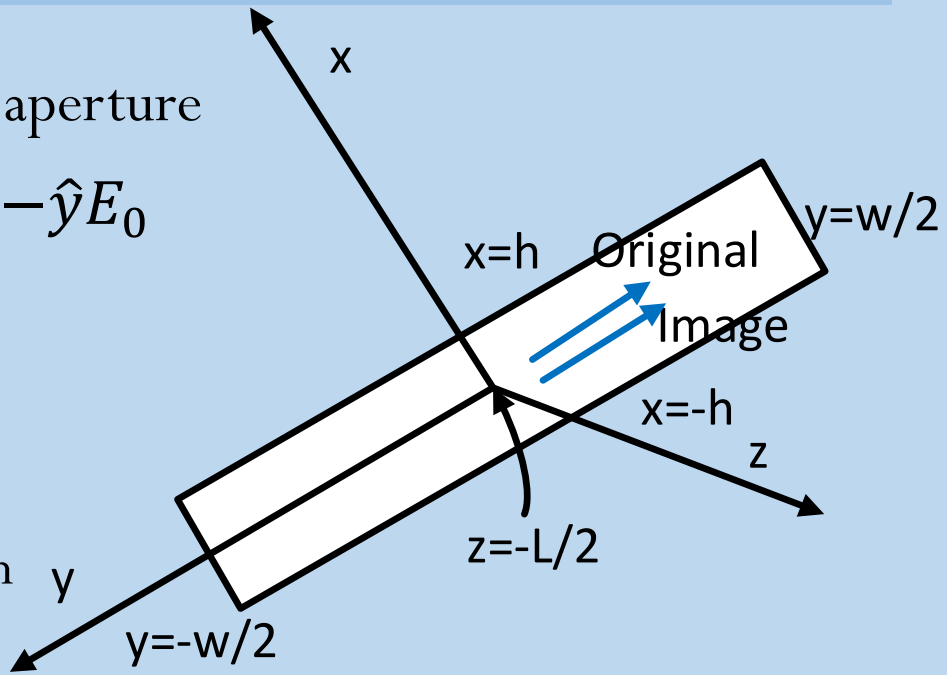


Fig. Equivalent magnetic current density and application of method of images

Microstrip antennas

- *Step 2:*
- *2-D FT of the aperture fields*
- $\tilde{E}_{ay} = \int_{-\frac{w}{2}}^{\frac{w}{2}} \int_{-h}^{h} 2E_0 \, e^{(j\beta_x x' + j\beta_y y')} dx' dy'$

$$= 2E_0 \left\{ \frac{e^{(j\beta_x h)} - e^{(-j\beta_x h)}}{j\beta_x} \right\} \left\{ \frac{e^{\left(j\beta_y \frac{w}{2}\right)} - e^{\left(-j\beta_y \frac{w}{2}\right)}}{j\beta_y} \right\}$$

$$= 8E_0 \left\{ \frac{e^{(j\beta_x h)} - e^{(-j\beta_x h)}}{2j\beta_x} \right\} \left\{ \frac{e^{\left(j\beta_y \frac{w}{2}\right)} - e^{\left(-j\beta_y \frac{w}{2}\right)}}{2j\beta_y} \right\}$$

$$= 4E_0 hw \left\{ \frac{sin(\beta_x h)}{\beta_x h} \right\} \left\{ \frac{sin\left(\beta_y \frac{w}{2}\right)}{\beta_y \frac{w}{2}} \right\}$$

$$= 4E_0 hw sinc(\beta_x h) sinc\left(\beta_y \frac{w}{2}\right)$$

Microstrip antennas

- *Step 3:*
- *Use equation (24.1) and (24.2) to find the aperture fields*
- $E_{ff\theta} \cong \frac{j\beta e^{(-j\beta r)}}{4\pi r}\left[\eta\left(\tilde{H}_{ay}cos\theta cos\phi - \tilde{H}_{ax}cos\theta sin\phi\right) + \left(\tilde{E}_{ay}sin\phi + \tilde{E}_{ax}cos\phi\right)\right]$ ---(24.1)
- Similarly, $E_{ff\phi} \cong \frac{j\beta e^{(-j\beta r)}}{4\pi r}\left[-\eta\left(\tilde{H}_{ay}sin\phi + \tilde{H}_{ax}cos\phi\right) + \left(\tilde{E}_{ay}cos\theta cos\phi - \tilde{E}_{ax}cos\theta sin\phi\right)\right]$ ---(24.2)

Since we have only x component of aperture electric field, simplify further

- $E_{ff\theta} \cong \frac{j\beta e^{(-j\beta r)}}{4\pi r}\left[\tilde{E}_{ax}cos\phi\right]$
- Similarly, $E_{ff\phi} \cong \frac{j\beta e^{(-j\beta r)}}{4\pi r}\left[-\tilde{E}_{ax}cos\theta sin\phi\right]$

Microstrip antennas

- Hence
- $E_{ff\theta} \cong \frac{j\beta e^{(-j\beta r)}}{\pi r}\left[E_0 hw sinc(\beta_x h) sinc\left(\beta_y \frac{w}{2}\right) cos\phi\right]$
- Similarly, $E_{ff\phi} \cong$
  $\frac{j\beta e^{(-j\beta r)}}{\pi r}\left[-E_0 hw sinc(\beta_x h) sinc\left(\beta_y \frac{w}{2}\right) cos\theta sin\phi\right]$
- For very thin substrate ($h \ll \lambda$) and usually it is true for MSA, then
- $\beta_x h = \beta h sin\theta cos\phi = \frac{2\pi h}{\lambda} sin\theta cos\phi \to 0$
- Hence, $sinc(\beta_x h) \approx 0$
- $E_{ff\theta} \cong \frac{j\beta e^{(-j\beta r)}}{\pi r}\left[E_0 hw sinc\left(\beta_y \frac{w}{2}\right) cos\phi\right]$
- $E_{ff\phi} \cong \frac{j\beta e^{(-j\beta r)}}{\pi r}\left[-E_0 hw sinc\left(\beta_y \frac{w}{2}\right) cos\theta sin\phi\right]$

Microstrip antennas

- This is for single slot 1
- But, we have a two element slot array
- We need to find the AF
- $AF = e^{j\vec{\beta}\cdot\vec{r}_1'} + e^{j\vec{\beta}\cdot\vec{r}_2'}$
- where $\vec{r}_1' = -\frac{L}{2}\hat{z}$ and $\vec{r}_2' = \frac{L}{2}\hat{z}$

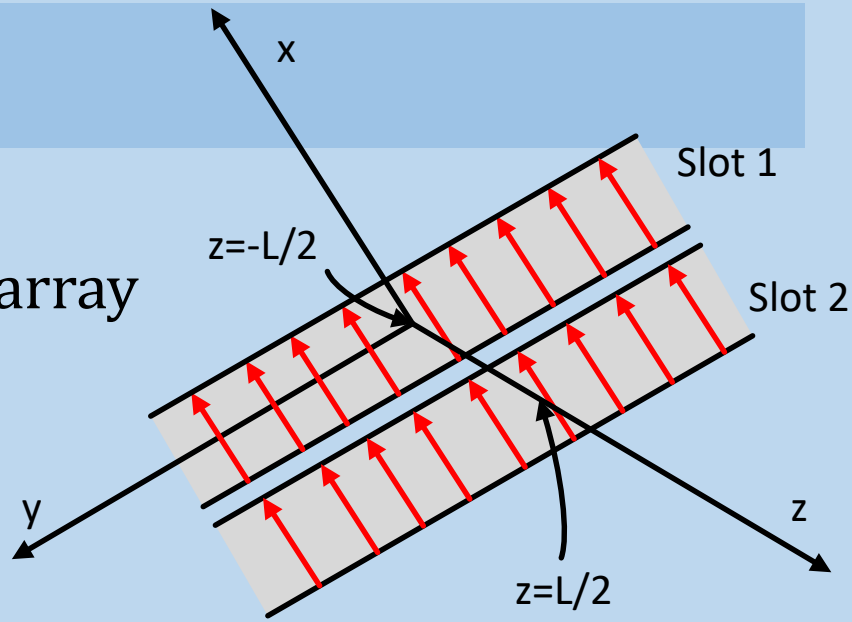


Fig. Two slot array

- Hence, $AF = e^{-j\beta_z\frac{L}{2}} + e^{j\beta_z\frac{L}{2}} = 2cos\left(\beta_z\frac{L}{2}\right) = 2cos\left(\beta cos\theta\frac{L}{2}\right)$
- Therefore using pattern multiplication principle,
- $E_{f\theta} \cong \frac{2j\beta e^{(-j\beta r)}}{\pi r}\left[E_0 hw sinc\left(\beta_y\frac{w}{2}\right)cos\left(\beta cos\theta\frac{L}{2}\right)cos\phi\right]$
- $E_{f\phi} \cong \frac{2j\beta e^{(-j\beta r)}}{\pi r}\left[-E_0 hw sinc\left(\beta_y\frac{w}{2}\right)cos\left(\beta cos\theta\frac{L}{2}\right)cos\theta sin\phi\right]$
- where $\beta_y = \beta sin\theta sin\phi$

Microstrip antennas

- E-plane ($\phi = 0$)
- $E_{ff\theta} \cong \frac{2j\beta e^{(-j\beta r)}}{\pi r}\left[E_0 hw cos\left(\beta \frac{L}{2} cos\theta\right)\right]$
- $E_{ff\phi} \cong 0$
- H-plane ($\theta = \pm\frac{\pi}{2}$)
- $E_{ff\theta} \cong \frac{2j\beta e^{(-j\beta r)}}{\pi r}\left[E_0 hw sinc\left(\beta sin\phi \frac{w}{2}\right) cos\phi\right]$
- $E_{ff\phi} \cong 0$
- Typical values of dimensions:
- $L = \frac{\lambda_g}{2} \cong \frac{\lambda}{2\sqrt{\epsilon_r}}, w = \frac{\lambda}{4}, h = 0.1\lambda$ and $\epsilon_r = 4.4$
- You can plot radiation patterns in E- and H-planes

Microstrip antennas

- Gain:
- $G(\theta,\phi) = \frac{4\pi r^2 S(\theta,\phi)}{P_i} = \frac{2\pi r^2 \left|\vec{E}(\theta,\phi)\right|^2}{\eta_0 P_i}$
- Let us find the input power P_i
- Consider the input power is coming from a uniform TEM field line of width w_m, then
- $P_i \cong \frac{\sqrt{\varepsilon_r} w_m h \left|\vec{E}_i\right|^2}{2\eta_0}$
- Note that the incident electric field and aperture electric field are related as $(E_0)^2 = \left|\vec{E}_i\right|^2 (1 - |\Gamma_i|^2)$
- where Γ_i is the input reflection coefficient of the MSA

Microstrip antennas

- Γ_i is the input reflection coefficient of the MSA can be calculated as
- $\Gamma_i = \frac{Z_{0p} - Z_{0m}}{Z_{0p} + Z_{0m}}$
- where $Z_{0p} \cong \frac{\eta_0}{\sqrt{\epsilon_r}} \frac{h}{w}$
- and $Z_{0m} \cong \frac{\eta_0}{\sqrt{\varepsilon_r}\left(\tau + 1.393 + 0.667 ln(\tau + 1.444)\right)}, \tau = \frac{w_m}{h} + 0.398 \frac{t}{h}\left(1 + ln\left(\frac{2h}{t}\right)\right)$, t is the thickness of the microstrip
- The above formula gives accuracy upto 1% for $\frac{w_m}{h} > 1$
- Hence the maximum gain is for $\theta = \frac{\pi}{2}$,
- $E_{f\theta} \cong \frac{2j\beta e^{(-j\beta r)}}{\pi r}[E_0 hw]$

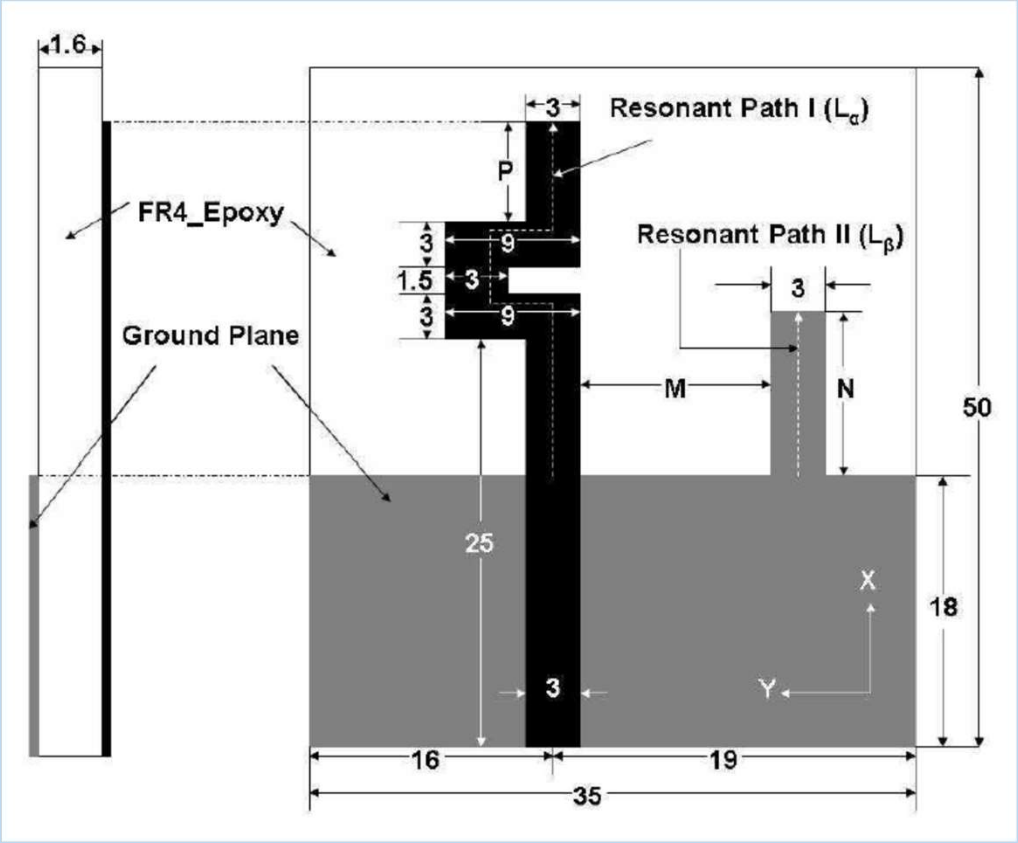
Microstrip antennas

- Hence
- $E_{ff\theta} \cong \frac{2j\beta e^{(-j\beta r)}}{\pi r}[E_0 hw]$
- $G(\theta,\phi) = \frac{2\pi r^2 \left|\frac{2j\beta e^{(-j\beta r)}}{\pi r}[E_0 hw]\right|^2}{\frac{\sqrt{\varepsilon_r} w_m h \left|\vec{E}_i\right|^2}{2\eta_0}\eta_0} = \frac{16(\beta hw)^2 \left|\vec{E}_i\right|^2 \left(1-|\Gamma_i|^2\right)}{\pi\sqrt{\varepsilon_r} w_m h \left|\vec{E}_i\right|^2}$
- $= \frac{64\pi h(w)^2\left(1-|\Gamma_i|^2\right)}{\sqrt{\varepsilon_r}\lambda^2 w_m} = \frac{64\pi}{\sqrt{\varepsilon_r}}\frac{wh}{\lambda^2}\frac{w}{w_m}\left(1-|\Gamma_i|^2\right)$
- Typical values for MSA:
- $\Gamma_i \leq 0.25, w > 2w_m, w = 0.25\lambda, h = 0.1\,\lambda, \varepsilon_r =$ 4.4 for FR4 substrate
- $G_{max} = 4.49, G_{maxdBi} = 6.5dBi$

Microstrip antennas

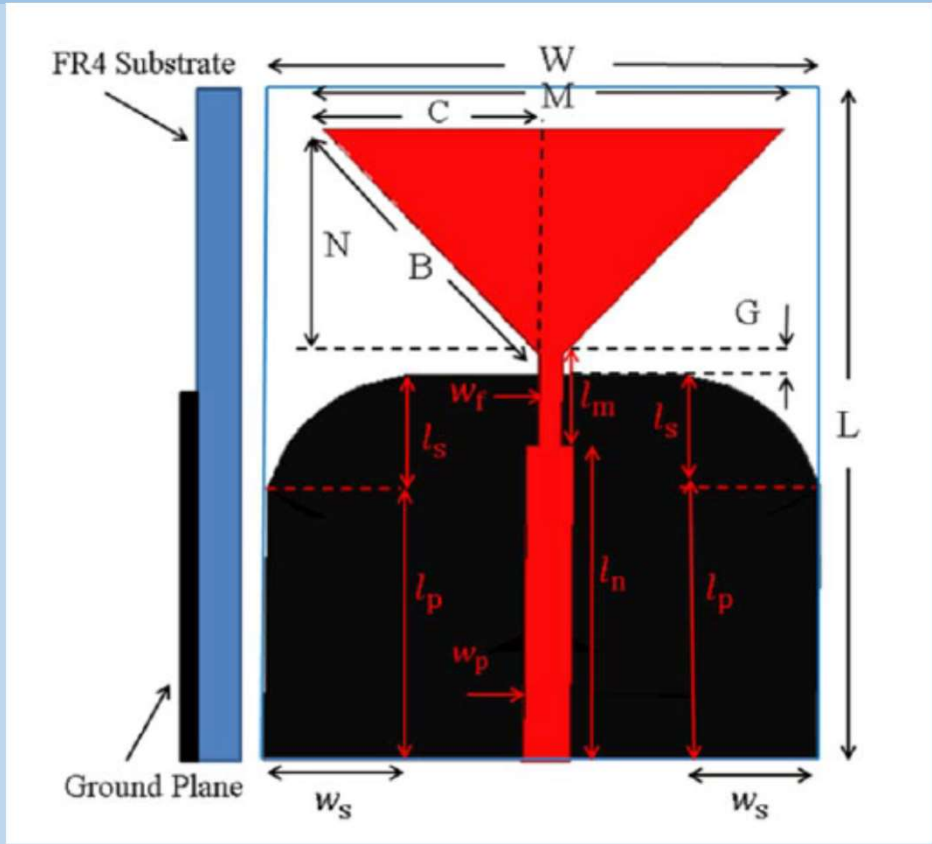
- ***Some microstrip antennas and it variants from our research group:***
- Dual-band folded strip Printed Monopole Antenna (DB-FSPMA) for RFID and WLAN applications
- Printed Triangular Monopole Antennas (PTMA) for UWB applications
- Printed monopole antenna (PMA) with tapered feed line, feed region and patch for super wideband (SWB) applications

Microstrip antennas



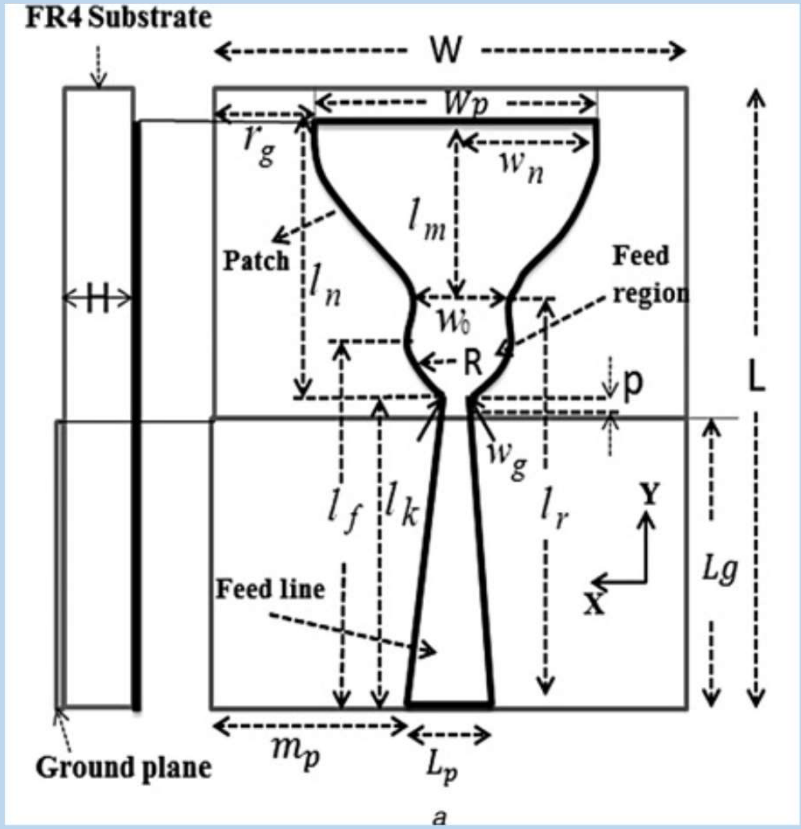
- Fig. DB-FSPMA for RFID & WLAN applications (fc=2.4 GHz (BW=2.05-2.86 GHz) & fc=5.81 GHz (BW=5.55-6.14 GHz)) [Source: http://www.jpier.org/PIER/pier.php?paper=11051301]

Microstrip antennas



- Fig. PTMA for UWB applications (BW=1.8-15 GHz) [Source: https://onlinelibrary.wiley.com/doi/full/10.1002/mop.28290]

Microstrip antennas



- Fig. SWB PMA with tapered feed line, feed region and patch (− 10 dB bandwidth 2.5–80 GHz) [Source: https://ieeexplore.ieee.org/document/6715623]