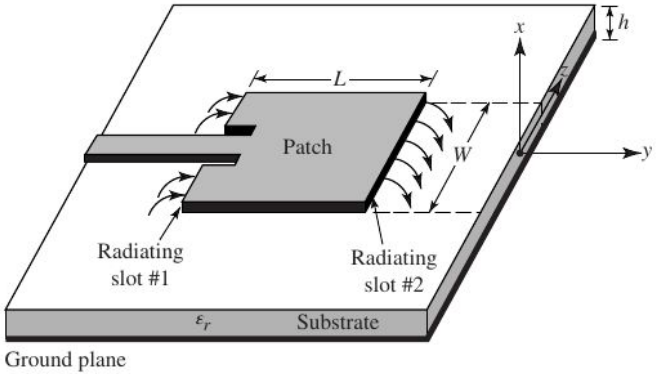
Microstrip Antennas

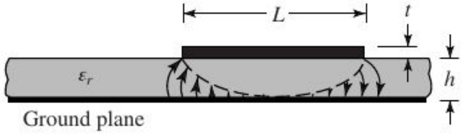
Luke Chapman

What is a Microstrip Antenna?

- Patch antennas consist of a thin metallic strip above a ground plane separated by a dielectric substrate
- Microstrip (patch) antennas are used extensively in applications where physical dimensions are limited
- Radiation is caused by an electric field induced between the patch and the ground plane
- The primary direction of radiation is normal to the plane of the patch



(a) Microstrip antenna



(b) Side view

What is a Microstrip Antenna?

Pros:

- High Gain
- Easy Fabrication
- Low Cost

Cons:

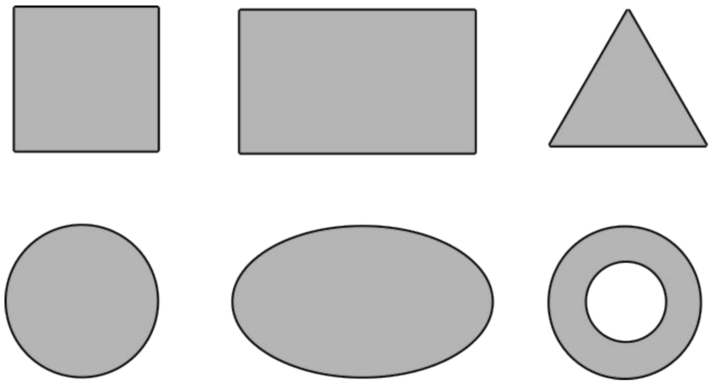
- Narrow Bandwidth
- Restricted to Low Power Applications
- Typically lower efficiency than other antennas
- Only practical at higher frequencies (>1 GHz)

Applications:

- GPS Antennas
- Satellite Communication
- High-Frequency Communication
- Mobile Communication

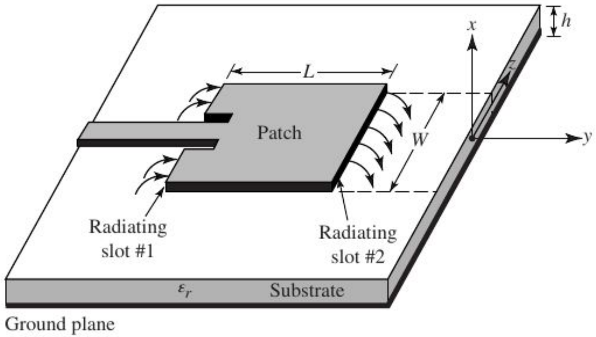
Types of Patch Antennas

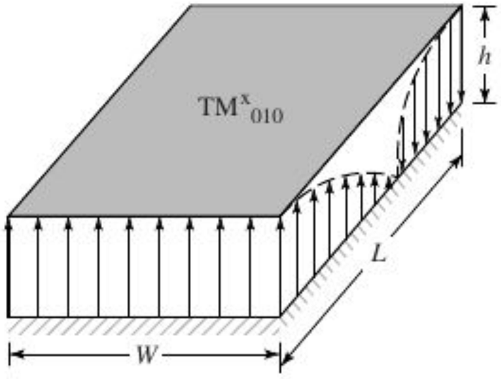
- Common patch antenna shapes include rectangle, square, equilateral triangle, circle, ellipse, and ring
- Rectangle and square are the most common shapes



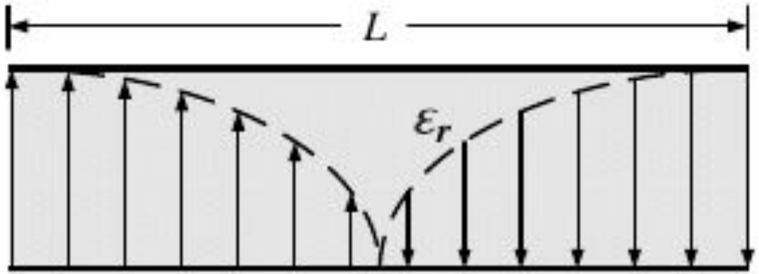
How Patch Antennas Work

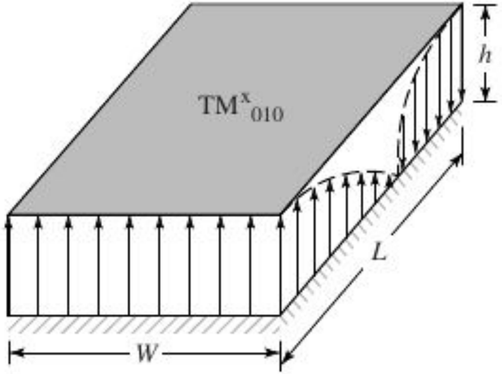
- The simplest model of a patch antenna is as a transmission line
- By feeding the antenna at some frequency, there will be current distributions on the patch and ground plane and a voltage distribution between
- Given an input wave, some energy will be reflected back, causing standing waves
  - This causes the current and voltage distributions





Patch Antenna Radiation Mechanism





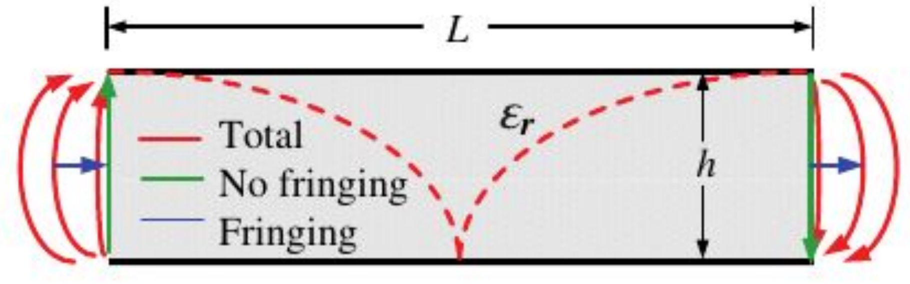
- If the dimensions are suitable at a given frequency, the patch antenna will resonate as an open-circuited transmission line
    - The voltage and current are out of phase
    - The voltage is maximum at the edges, the current is maximum in the center
- The TM_{010} distribution is the most commonly used
    - Will result in linear polarization along the L-axis
- In this ideal model, the antenna does not radiate

$$E_x = E_0 \cos\left(\frac{\pi}{L} y'\right)$$

$$H_z = H_0 \sin\left(\frac{\pi}{L} y'\right)$$

$$E_y = E_z = H_x = H_y = 0$$

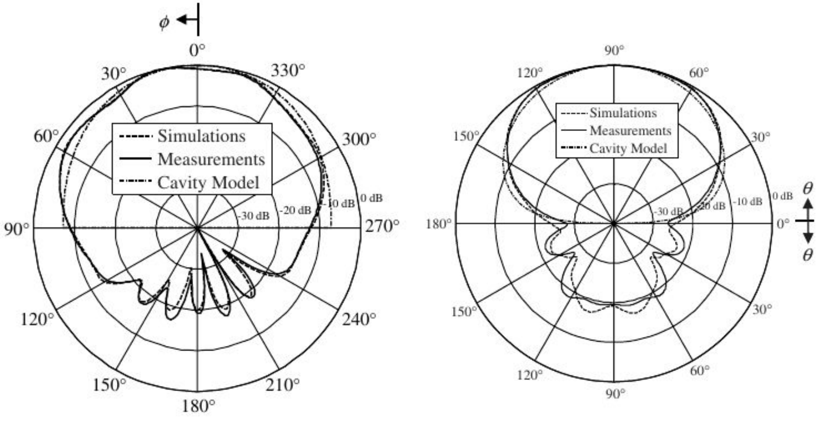
Patch Antenna Radiation Mechanism



- For radiation to occur, the voltage must be at a maximum at the edges
- Fringe fields will be induced at the edges of the patch antenna
- The horizontal components of the fringes (blue) are in phase and in the same direction and add up
- These electric fields superimpose and provide the primary method of radiation of the antenna

Radiation Patterns

- Patch antennas display high gain in the broadside direction of the patch
- Side and rear lobes are present, but can be improved by using different feeding techniques
- Patch antennas are also easy to make into arrays, improving the main lobe gain substantially

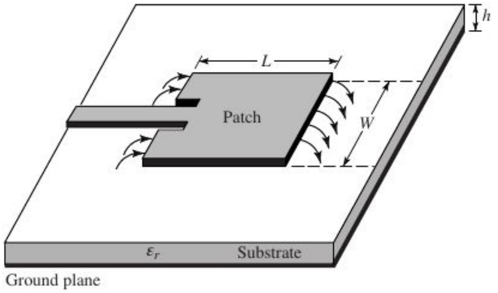


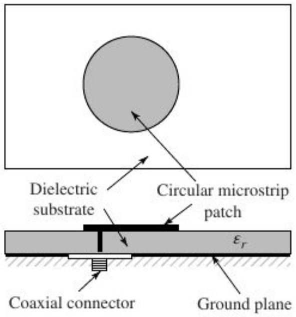
(c) E-plane ($\theta = 90°$)

(d) H-plane ($\phi = 0°$)

Methods of Feeding Patch Antennas

- Feeding method of the patch antenna is extremely important
- Various feed methods provide better bandwidth, spurious radiation, etc.

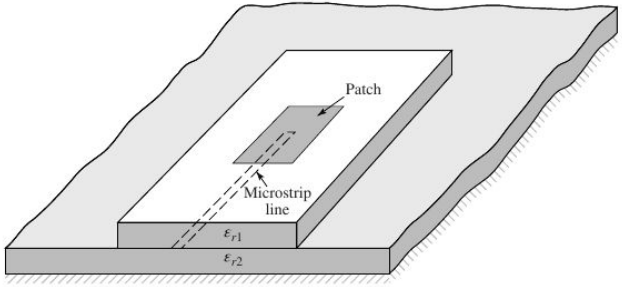


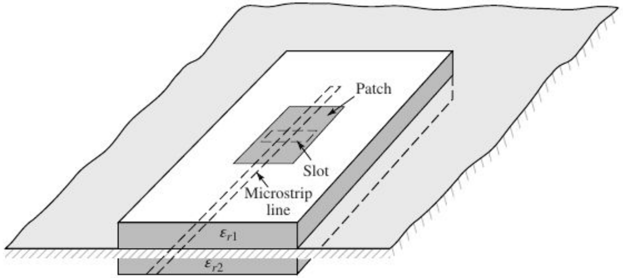


- Coplanar Microstrip Feed (left)
  - Antenna fed by microstrip line
  - Most common
  - Requires impedance matching
- Coaxial Feed (right)
  - Inner conductor of coaxial connector passed up through the substrate to the patch
  - Simple to implement, but with thicker substrates causes large amounts of spurious radiation

Methods of Feeding Patch Antennas

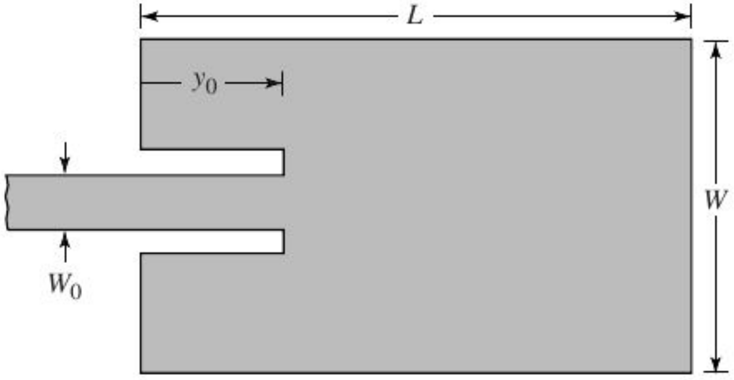
- Proximity Coupling Fed (Top)
  - A feedline is fed between the ground plane and patch inside of the substrate, which couples to the patch
  - This method provides low spurious radiation and higher bandwidth
- Aperture Fed (Bottom)
  - The feedline is placed on the bottom of the substrate
  - A ground plane with a slot aperture is placed between the patch and the feed line
  - This shields the patch from the radiation from the end of the feedline
  - Provides high bandwidth and polarization purity





Impedance Matching

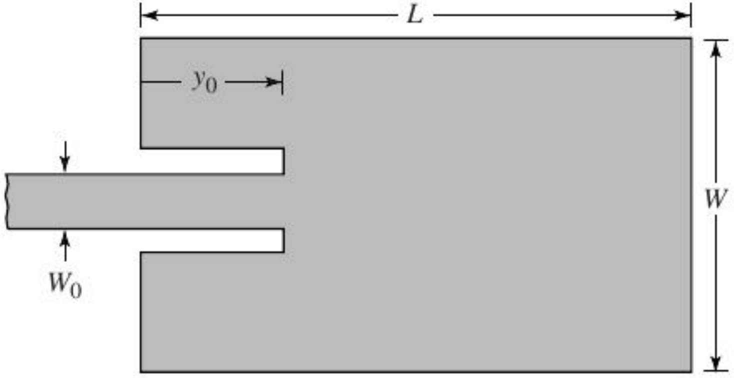
- Typically the input impedance of the patch antenna will be very high and not matched to the feedline (typically 50 Ohms)
- Several methods to impedance match
  - Matching circuit
  - Stub matching
  - Inset Feedline
- The inset feedline is one of the most popular techniques



- Because the effective resistance at a point on the patch antenna is determined by the characteristics of voltage and current

Impedance Matching

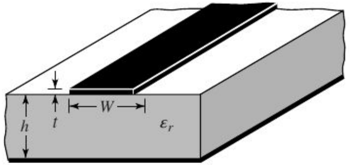
- Because the patch is high-impedance at the edge (high voltage, zero current), it will be poorly matched to a 50 Ohm feedline
- By moving the feedline connection to a different position on the patch antenna, resistance will be different
- By choosing the correct inset distance, the patch input impedance can be matched to the impedance of the feedline



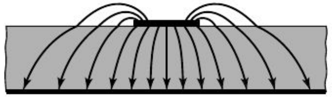
$$R_{in} = 90 \frac{(\varepsilon_r)^2}{\varepsilon_r - 1} \left(\frac{L}{W} \right)$$

Designing Patch Antennas

- The process for designing a patch antenna is fairly straightforward
- The target frequency and dielectric constant should be known
- Because of the difference in dielectric constants, the patch “looks” larger than it actually is and must be corrected
- The formulas to calculate the width and length of the patch antenna are shown on the right



(a) Microstrip line



(b) Electric field lines

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

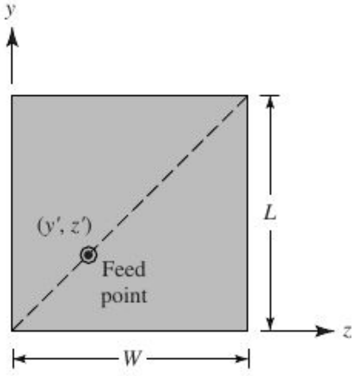
$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

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

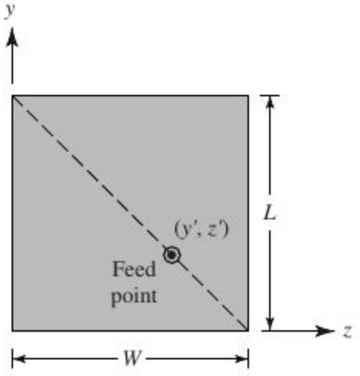
$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Circular Polarization

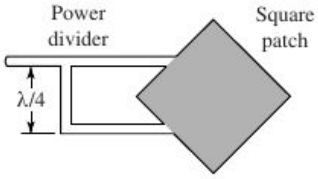
- Circular polarization is often advantageous, especially when a received signal is of an unknown polarization
- Circular polarization can be done in several different ways
    - Array of linear polarized patch antennas with perpendicular polarizations excited in quadrature
    - Single patch antenna that has two perpendicular modes excited with a 90-degree phase difference

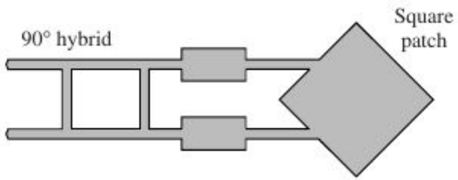


(b) Left-hand circular (LHC)



(c) Right-hand circular (RHC)





References

[1] R. Garg, Microstrip Antenna Design Handbook. Boston, MA: Artech House, 2001.

[2] C. A. Balanis, Antenna Theory Analysis and Design. Hoboken, NJ: Wiley, 2016.

[3] D. R. Jackson, “Introduction to microstrip Antennas,” University of Houston, https://courses.egr.uh.edu/ECE/ECE6345/Short Course/Introduction to Microstrip Antennas.pdf (accessed Mar. 1, 2024).