Assignment-1

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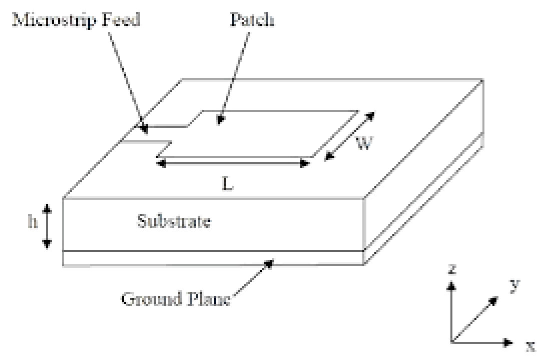
1st Question

a) Micro-strip Patch Antenna Structure



A **Micro-strip Patch Antenna (MPA)** is a low-profile, lightweight antenna commonly used in wireless communication, satellites, GPS, and radar systems. It consists of several key parts, each with a distinct role in radiation and impedance matching.

1) Micro-strip Feed Line

- Function: Delivers RF power to the patch with minimal loss.
- Structure: A narrow conducting strip placed on the same side as the patch or beneath it, depending on the feed technique (e.g., direct feed, inset feed, coaxial feed).
- Purpose:
  - Matches the input impedance of the patch to the source (usually 50 ohms).
  - Controls how efficiently power is transferred.
- Common Types:
  - Inset Feed: A notch in the patch to match impedance.
  - Coaxial Feed: A probe connected through the substrate.

2) Patch

- Function: Radiates electromagnetic energy.
- Structure: A flat metal (usually copper or gold) rectangle or circle on top of the substrate.
- Resonance: The patch acts like a resonant cavity; dimensions (typically ~$\lambda/2$) determine the resonant frequency.
- Polarisation & Bandwidth: Shape and size influence the radiation pattern, polarisation (linear or circular), and bandwidth.
- Common Shapes:
    - Rectangular (most common)
    - Circular, triangular, elliptical

3) Substrate

- Function: Supports the patch and feed, affects bandwidth and efficiency.
- Material: Dielectric like FR4, Rogers, or Duroid with specific permittivity (εr).
- Thickness: Thicker substrates improve bandwidth but can cause surface waves (unwanted energy losses).
- Dielectric Constant (εr):
    - Low εr (~2-4): Better radiation, lower losses.
    - High εr (>6): More compact design, but reduced efficiency.

4) Ground Plane

- Function: Reflects energy and helps define field distribution.
- Structure: A conductive layer (copper or similar) on the bottom of the substrate.
- Purpose:
    - Prevents back radiation.
    - Provides a return path for the current.
    - Controls the radiation pattern and gain.
    - Size: Should be larger than the patch for good performance.

How It Works Together:

1. RF signal enters via the feed line.

2. Signal excites the patch, setting up standing waves due to resonance.

3. The patch emits electromagnetic radiation into space.

4. The substrate controls impedance, confinement of fields, and size.

5. The ground plane reflects fields, minimising back radiation and shaping the radiation pattern.

b) Feeding MPA

1. Microstrip Line Feed (Edge Feed)

- A thin conducting strip (transmission line) is connected directly to the edge of the patch.
- The feed line is printed on the same substrate as the patch.

  Advantages:

  - Easy to fabricate.
  - Integrates well with printed circuits.

  Drawbacks:

  - Can cause spurious radiation from the feed line.
  - Impedance matching can be tricky, sometimes requiring tapering or inset feed.

2. Inset Feed

- A variant of microstrip line feed where the feed line enters into the patch inside its edge.
- The patch edge is “cut-in” (inset) to a certain depth where the feed line is connected.
- Allows better impedance matching by controlling the feed point location along the patch width.

- Effectively adjusts the input impedance.

3. Coaxial (Probe) Feed

- A coaxial cable's inner conductor is connected directly to the patch at a specific point.
- The outer conductor is connected to the ground plane on the other side of the substrate.
- Feed point location is chosen to match the antenna input impedance.

  Advantages:

  - Good control of impedance.
  - Minimal feed radiation.

  Drawbacks:

  - More complex fabrication.
  - Difficult for very thin substrates.

4. Aperture Coupled Feed

- The feed line is on the opposite side of the substrate (bottom layer).
- A slot (aperture) in the ground plane couples energy from the feed line to the patch.

  Advantages:

  - Better isolation between feed and radiating patch.
  - Improved bandwidth.

  Drawbacks:

  - Complex to fabricate.

5. Proximity Coupled Feed

- Feed line and patch are on two different substrate layers.
- Energy is coupled capacitively from feed to patch without direct connection.
- Allows wide bandwidth and low spurious feed radiation.
- Complex multilayer fabrication needed.

What physically happens during feeding?

- The feed line applies an alternating voltage/current at the feed point.
- This creates oscillating electric and magnetic fields on the patch surface.
- Standing waves form on the patch edges (which act like radiating slots).
- The patch radiates energy as electromagnetic waves into free space.

c) Inset Feeding

Inset feeding means connecting the microstrip feed line not at the very edge of the patch, but slightly inside the patch edge, by making a notch (an inset) into the patch.

- The feed line runs into this notch and connects directly to the patch conductor.
- The inset length controls how far inside the patch the feed is connected.

The main reason is to match the input impedance of the antenna to the feed line impedance (usually 50 Ω) for maximum power transfer.

The Problem With Edge Feeding:

- At the edge of the patch, the input impedance is usually very high (several hundred ohms) because the edge acts like an open circuit in the transmission line model of the patch.
- Connecting the 50 Ω feed line directly at the edge causes a mismatch, leading to reflections, poor power transfer, and lower antenna efficiency.

How Inset Feeding Helps:

- By moving the feed point inside the patch (inset), you tap the patch where the impedance is lower.

- The patch behaves like a resonant transmission line, so impedance varies along its length:
  - At the edge: impedance is maximum.
  - Moving inward: impedance gradually decreases.
- By selecting the right inset depth, you can find a point where the patch input impedance matches the feed line impedance (e.g., 50 Ω).

Benefits of Inset Feeding:

- Better impedance matching: Minimises reflections and maximises power transfer.
- Simple structure: No additional matching networks needed.
- Easy to fabricate: Just cut the inset notch into the patch metal.

2nd Question

Design Equations (for micro-strip patch):

1. **Patch Width (W):**

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

2. **Effective Dielectric Constant (ε_{eff}):**

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2}$$

3. **Length Extension (ΔL):**

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

4. **Patch Length (L):**

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L$$

Considerations:

- The ground plane must extend beyond the patch to reduce back radiation.
- Impedance matching is critical to minimise S11.

Calculating Patch Antenna Dimensions for 6 GHz Using FR4 Substrate

1> Patch Width (W)

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{3\times10^8}{2\times6\times10^9}\sqrt{\frac{2}{4.4+1}} = \frac{1}{40}\times\sqrt{\frac{2}{5.4}}$$

$$= 0.025\times\sqrt{0.3704} = 0.025\times0.6086$$

$$= 0.0152\ \text{m} = \boxed{15.2\,\text{mm}}$$

2> Effective dielectric constant (ε_{eff})

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\cdot\frac{h}{w}\right)^{-1/2}$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2}\left(1+12\cdot\frac{1.6}{15.2}\right)^{-1/2}$$

$$= 2.7 + 1.7\,(1+1.263)^{-1/2} = 2.7+1.7\times(2.263)^{-0.5}$$

$$= 2.7 + 1.7\,(0.665) = \boxed{3.833}$$

3> Length Extension (ΔL)

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

$$= 0.412\,(1.6)\,\frac{(3.833+0.3)(9.5+0.264)}{(3.833-0.258)(9.5+0.8)}$$

$$= 0.6592\left(\frac{4.133\times9.764}{3.575\times10.3}\right) = 0.6592\times1.096$$

$$= \boxed{0.723\,\text{mm}}$$

4> Patch Length (L)

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L$$

$$= \frac{3\times10^8}{2\times6\times10^9\times\sqrt{3.833}} - 2\times0.723\times10^{-3}$$

$$= \frac{0.025}{1.957} - 0.001446 = 0.01132\ \text{m}$$

$$= \boxed{11.32\,\text{mm}}$$