STUDENT PROJECT

APERTURE COUPLED MICROSTRIP PATCH ANTENNAS

Antennas

1. INTRODUCTION

Microstrip antennas, also called patch antennas, are very popular antennas in the microwave frequency range because of their simplicity and compatibility with circuit board technology. The rectangular patch antenna is the one of the most commonly used microstrip antennas. The aperture fed variation employs two stacked substrates with a ground-plane sandwiched between them. The patch element on the top substrate is coupled through a slot in the ground-plane to the feed-network on the bottom substrate.

The common pin-fed and edge-fed rectangular patch variations suffer from limitations in bandwidth due the feed-pin inductance for the pin-fed patch and the conflicting substrate requirements for transmission lines and antenna elements for the edge-fed patch. Since the aperture coupled patch allows different choices for the top and bottom substrates a thicker, low relative permittivity substrate can be used for the patch element and a thinner higher relative permittivity substrate for the feed network. The ground-plane also shields off the feed network radiation, resulting in better forward radiation pattern performance.

While the aperture coupled patch is harder to design than patches with simpler feeds, it has several advantages. The aperture coupled patch provides better operational bandwidth than patches with simpler feeds. It is well suited to direct integration with microstrip circuits (like the edge-fed and inset-fed patch variations) since these can be etched on the bottom substrate. It can also be designed for a range of input impedances (like pin-fed and inset-fed patches).

The aperture coupled feed arrangement make this antenna popular as an array element, since the feed network on the bottom substrate is separated from the radiating element on the top substrate. Active components (like phase shifters and amplifiers) have also been integrated on the bottom substrate in some applications [Sanzgiri et al.]

The rectangular aperture coupled patch consists of two stacked planar dielectric substrates with a metallised ground-plane sandwiched in between. A rectangular patch element is typically etched in the top of the top substrate. Larger antenna elements are sometimes constructed by bonding metal cut-outs to a bare substrate. A rectangular aperture (slot), usually centred under the patch, is cut in the ground plane. The slot's long dimension is along the width of the patch. The feed network is etched in the bottom of the bottom substrate. The basic feed network consists of a feed-line of the desired characteristic impedance running in the resonant direction of the patch, and a stub that extends beyond the centre of the aperture.

The antenna is fed by a microstrip line of the desired characteristic impedance on the bottom of the bottom substrate. The feed line effectively 'crosses' the aperture, thereby allowing energy from the feed network to couple to the patch through the aperture. The coupled antenna impedance is seen in series with the impedance of the stub, which is therefore usually approximately a quarter wavelength long in order to present a virtual short. By varying the size of the aperture and the length of the feed-line stub that extends beyond the aperture, a good impedance match may be obtained.

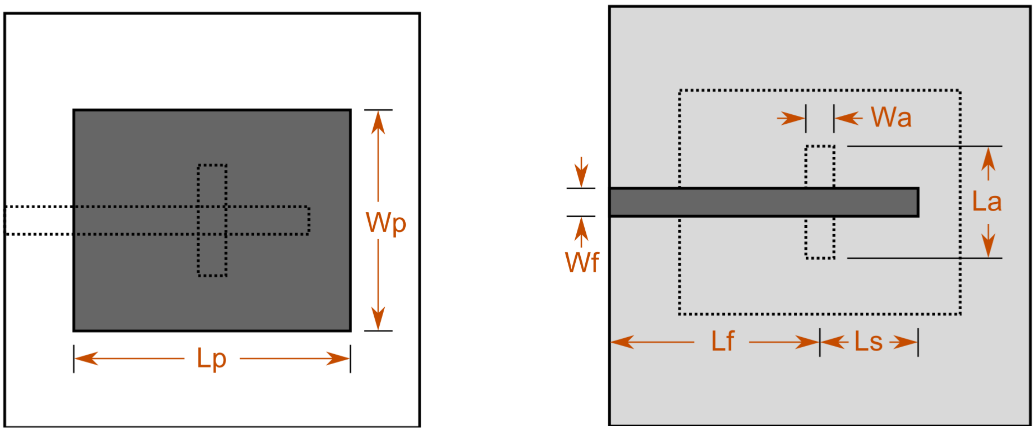

Figure 1. A microstrip aperture coupled patch antenna, (left) top view, and (right) bottom view.

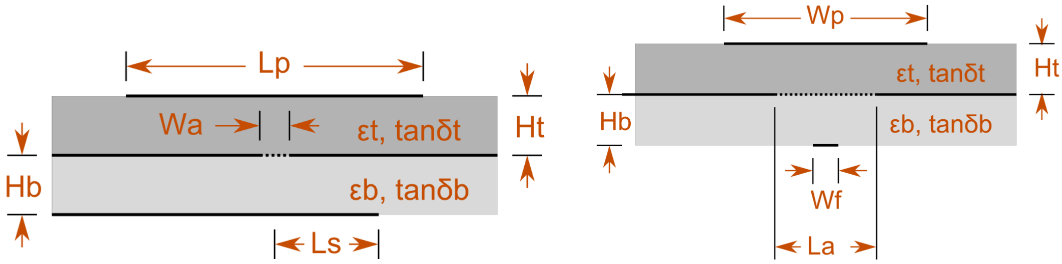

Figure 2. A microstrip aperture coupled patch antenna, (left) side view, and (right) end view.

2. DESIGN GUIDELINES

There are two modes of operation depending on whether thick or thin substrates are used. For both cases:

- To increase (decrease) the reactive impedance, make the stub length longer (shorter).
- To increase (decrease) impedance bandwidth increase (decrease) the top substrate height. Diminishing returns for substrates thicker than about 10% of a wavelength.
- To increase (decrease) impedance bandwidth increase (decrease) the patch width.

Adjust the feed line width for the correct characteristic impedance if designing for a different impedance level.

For thinner substrates (when the input impedance shows a single resonance):

- To increase (decrease) the impedance level, increase (decrease) the slot length or width. Increasing the slot dimensions will lower the resonant frequency slightly.
- Increasing patch width will decrease the impedance level.
- To increase (decrease) resonant frequency, decrease (increase) patch length.

For thicker substrates (when the input impedance shows a double resonance) the resonances of the patch and aperture need to be tuned to provide a good input match. The slot resonance should be at a frequency somewhat higher than the centre frequency, and the patch resonance at a frequency somewhat lower. When spaced too far apart, the patch resonance will be seen as low impedance peak in the real impedance and the aperture resonance as a typical high impedance resonance. Moving the resonances optimally close together will result in a frequency band between the two resonances with fairly flat impedance behaviour.

- To increase (decrease) frequency of the patch resonance, decrease (increase) the patch length.

- To increase (decrease) frequency of the aperture resonance, decrease (increase) the aperture length.
- Adjust the stub length to tune out reactive impedances.
- The impedance level can be reduced by offsetting the feed line relative to the aperture centre.

When designing a patch at very high frequencies it is advisable to use a wider and shorter aperture to reduce the sensitivity of the design to manufacturing tolerances.

The level of coupling between the feed line and the patch is determined by the size and shape of the aperture, as well as by the height and relative permittivity of the substrates. Larger apertures result in tighter coupling (and higher input impedance), while thicker substrates result in lower coupling (and lower input impedance). The maximum height (and hence operational bandwidth) of the antenna substrate is usually limited by the maximum coupling achievable before the aperture becomes too big and back radiation unacceptable. Tighter coupling and potentially improved performance may be achieved by using modified aperture shapes.

3. PROJECT PREPARATION

Given: Target frequency f_0 (e.g. 900 MHz or 2400 MHz).

Fixed parameters: Substrate parameters ε_r, $tan\delta$, H. The substrate should be FR4. Thickness ≈ 0.8 mm.

Output: $|S_{11}|$, input impedance Z_{in}, radiation efficiency/gain, resonance frequency f_r, radiation pattern.

STEP 1 — MATERIAL AND EFFECTIVE PARAMETERS

Task:

- Choose target frequency f_0 (e.g., 2.4 GHz).
- Estimate ε_{eff} for patch and feed line.

Questions:

- Why does the two-layer structure help isolate the feed and improve bandwidth?
- What happens if H_b is too thin?

STEP 2 — PATCH DESIGN (TOP LAYER)

Task:

- For TM_{10} mode use:
  - $L_p \approx c / (2 f_0 \sqrt{\varepsilon_{eff},p}) - 2\Delta L$
  - $W_p \approx (c / 2 f_0) \sqrt{(2 / (\varepsilon_t + 1))}$
  - where ΔL accounts for fringing.
- Simulate a standalone patch with an ideal slot feed to estimate $|S_{11}|$.

Questions:

- Why does larger W_p tend to increase bandwidth?
- What happens to L_p and W_p when εt increases?

STEP 3 — FEED LINE (BOTTOM LAYER)

Task:

- Determine W_f for 50 Ω on lower substrate (H_b).
- Set L_f roughly λg,f / 4 initially to observe impedance transformation behavior.

Questions:

- How does changing L_f behave like adding series reactance?
- If ε_b is small (foam-type), what is its effect on losses and bandwidth?

STEP 4 — GROUND SLOT DESIGN

Task:

- Choose slot length L_s ≈ λg,slot / 2 (for resonance).
- Slot width W_a controls coupling strength (larger W_a → stronger coupling, wider BW).
- Offset L_a adjusts input impedance (small L_a usually helps matching).

Questions:

- If W_a doubles, how do $|S_{11}|$, Q, and back radiation change?
- Why is L_s often slightly shorter than λ/2 for wide slots?

STEP 5 — FULL STRUCTURE ASSEMBLY

Task:

- Simulate all three layers: patch, slotted ground, and feed.
- Sweep W_a, L_s, L_a, and L_f to achieve $|S_{11}| < -10$ dB.
- Check current distributions to ensure minimal feed radiation.

Questions:

- Which parameter mostly affects resonance? Which affects matching depth?
- Identify the real radiating aperture — patch or slot?

STEP 6 — BANDWIDTH OPTIMIZATION

Task:

- To increase BW, try:
  - a. Increasing H_t moderately.
  - b. Enlarging W_a (and adjusting Ls).
  - c. Using a low-ε_b substrate for feed isolation.
  - d. Adding a stacked patch on top.
- Re-tune L_p for center frequency.

Questions:

- Why is bandwidth sensitive to dielectric losses ($tan\delta$)?
- Compare advantages and disadvantages of stacked vs. single patch designs.

STEP 7 — CROSS-POLARIZATION AND FEED LEAKAGE

Task:

- Plot radiation patterns at multiple frequencies.
- Measure cross-polarization and minimize by adjusting L_a and W_a.
- Optionally, modify slot shape (e.g., H-slot or I-slot).

Questions:

- Why does large La increase cross-polarization?
- How does an H-slot differ from a simple slot in terms of matching and polarization?

4. FINAL EVALUATION

Acceptance criteria:

$|S_{11}| < -10$ dB across the band, efficiency > 60 %, gain ≥ 6 dBi, dimensions within design limits.

Deliverables: Final geometry table (L_p, W_p, L_f, W_f, L_s, H_t, H_b, W_a, L_a). Plots: $|S_{11}|$, gain, and radiation pattern. Comparison of simulated and theoretical results. Written answers to all step questions in a report format

5. REFERENCES

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