STUDENT PROJECT

PRINTED INVERTED F ANTENNAS (PIFA)

Antennas

1. INTRODUCTION

This antenna is typically used for wireless communication in the 2.4 GHz ISM band. It is advantageous because of its small size and the fact that it can be integrated onto to the same printed circuit board as other electronics. The antenna is similar to the conventional inverted-F antenna except that the ground plane and antenna are flattened in the plane of the F.

The antenna consists of etched metal lines above a dielectric, forming an inverted F shape. The outside prong of the F is shorted to the edge of the ground plane which is located below the dielectric. The ground plane covers one section of the dielectric, namely that which does not fall directly beneath the inverted F. The antenna is fed with respect to the edge of the ground plane at the second prong. The antenna can be fed with respect to the ground plane using a via through the dielectric or a microstrip feed line.

This antenna is essentially a planar monopole which has been bent parallel to the edge of the ground plane to reduce its height. The capacitance introduced in doing so is compensated for by a short circuit stub [Soras, C. et al.].

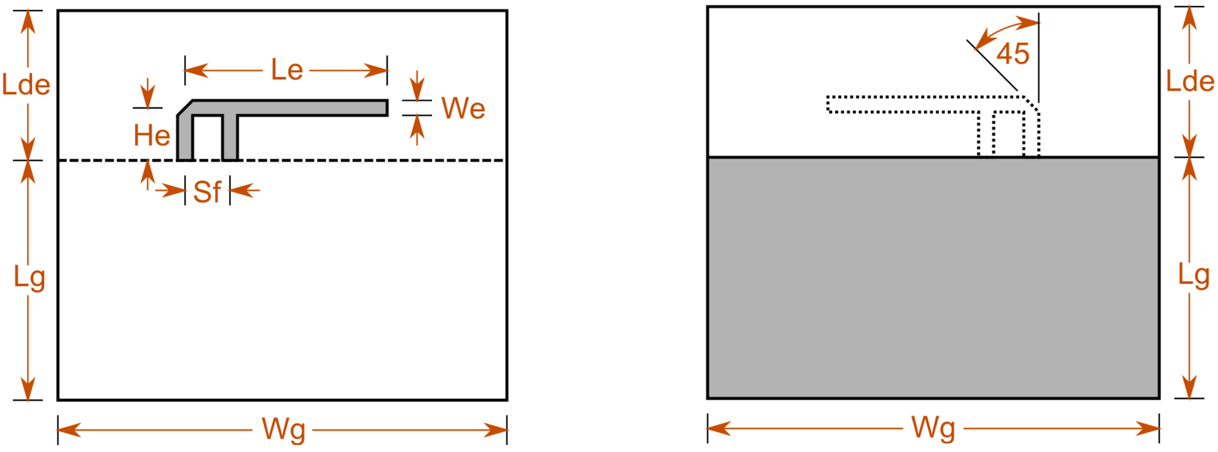

Figure 1. PIFA, (left) top view, and (right) bottom view.

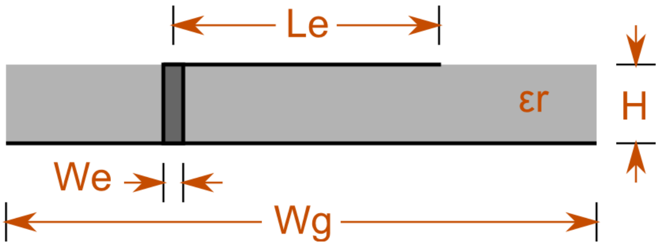

Figure 2. PIFA, side view.

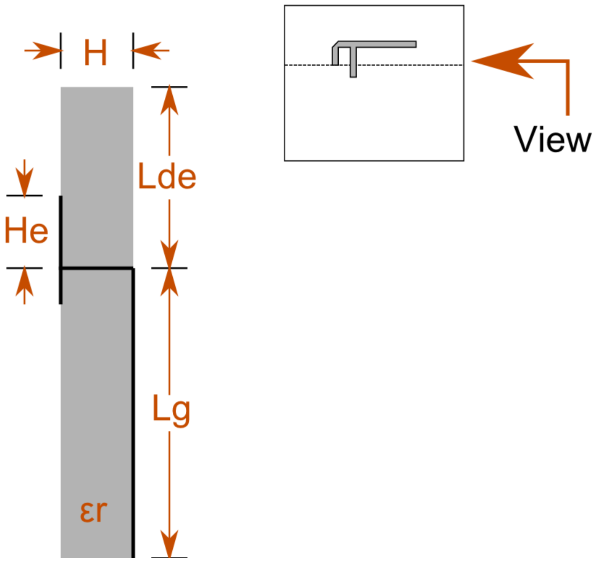

Figure 3. PIFA, end view.

2. DESIGN GUIDELINES

Because the fields of this antenna are not constrained to the dielectric as in the case of a microstrip patch, the relative permittivity of the substrate has less of an effect on the resonant frequency than expected.

- To increase the resonant frequency, decrease the antenna element dimensions and feed spacing.
- To increase the input impedance, increase the element height and/or spacing between the short and feed.

Note: Antennas on thick and higher permittivity substrates may lead to performance degradation due to surface waves.

3. PROJECT PREPARATION

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

Fixed parameters: Ground plane width W_g and length L_g, 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 – ESTIMATING THE RADIATOR LENGTH (QUARTER-WAVE APPROXIMATION)

Task:

- Compute $L_{eff} \approx \lambda_{eff}/4$ and derive the initial top-plate length L_e. Set strip width W_e.
- Simulation: Start with an ideal monopole to verify the quarter-wave resonance.

Questions:

If εr increases from 2.2 to 4.4, how does Le change (qualitatively and percentage-wise)? Why?

STEP 2 – ADDING THE SHORTING PLATE OR PIN

Task:

- Add the shorting plate to convert the monopole into a folded quarter-wave PIFA.
- Simulation: Check $|S_{11}|$ with feed removed (short only) to visualize current distribution.

Questions:

Explain how the shorting plate converts the half-wave monopole mode into a quarter-wave resonance. Sketch the current path.

STEP 3 – FEED LOCATION AND INPUT IMPEDANCE (PARAMETER SF)

Task:

- Place the feed point at horizontal distance S_f from the short to achieve Z_{in} ≈ 50 Ω at f_r.
- Output: Plot $Z_{in}(S_f)$ and $|S_{11}|$.

Questions:

If the measured Zin is higher than 50 Ω, should Sf be increased or decreased? Explain using the E-field/current distribution on the top plate.

STEP 4 – FREQUENCY TUNING BY RADIATOR LENGTH (LE AND TIP SHAPE)

Task:

- Trim or extend Le to align f_r with the target f_0.
- Optional: Add a 45° chamfer at the open end and observe matching improvement.

Questions:

How did you correct the frequency shift? Discuss the role of fringing fields at the radiator edge.

STEP 5 – HEIGHT AND BANDWIDTH (H AND HE)

Task:

- Increase H or effective height H_e gradually.
- Output: Record bandwidth (BW), quality factor (Q), and required re-tuning of L_e.

Questions:

Why does increasing He usually broaden BW (reduce Q)? What trade-off in efficiency or gain did you observe?

STEP 6 – CLEARANCE REGION (LDE)

Task:

- Extend the clearance (no-metal) region L_{de}, keeping other parameters constant.
- Output: Observe changes in f_r, $|S_{11}|_{\text{min}}$, and efficiency.

Questions:

Explain physically why fr shifts with Lde and why an intermediate Lde gives the best matching.

STEP 7 – RADIATOR WIDTH (WE) AND BANDWIDTH/GAIN

Task:

- Sweep W_e. Retune L_e each time to keep $f_r = f_0$.
- Output: BW and gain versus W_e.

Questions:

Describe the qualitative relationship between We and BW. When does further widening no longer help?

STEP 8 – TIP CHAMFER (45° TRANSITION)

Task:

- Add/remove a 45° chamfer at the open end; compare $|S_{11}|$ before and after.
- Interpretation: The chamfer acts as a gradual impedance transformer.

Questions:

Did the chamfer improve or degrade matching? Provide a physical explanation.

STEP 9 – DUAL-BAND ENHANCEMENT (OPTIONAL)

Task:

- Insert a narrow slot of length L_s or an L-shaped branch on the top plate to create a second resonance to achieve $f_2 \approx c\,/\,(4\sqrt{\varepsilon_{eff}}(L_e + L_{seff}))$.
- Output: $|S_{11}|$ with two resonances f_1, f_2.

Questions:

Which modification gave a clearer second band, and why did/ didn't it strongly couple to the main band?

STEP 10 – ENVIRONMENTAL DETUNING AND COMPENSATION

Task:

- Place a dielectric block (e.g. plastic or human hand) near the clearance region L_{de}. Record $|S_{11}|$ and f_r. Re-tune L_e or S_f slightly to restore matching.

Questions:

Suggest two design methods to reduce environmental detuning without enlarging the ground plane.

4. FINAL EVALUATION

Acceptance criteria:

$|S_{11}| < -10$ dB across the band, efficiency > 60 %, gain ≥ 2 dBi, dimensions within design limits.

Deliverables: Parametric simulation file, sweep tables, three key plots ($|S_{11}|$ vs f, Smith chart of Z_{in}, gain at f_0), and answer the questions.

5. REFERENCES

[1] C. A. Balanis, Antenna Theory: Analysis and Design, 3rd Edition. Hoboken, NJ: Wiley-Blackwell, 2005.

[2] A. K. Skrivervik, ‘Rayonnement et antennes: notes du cours’, EPFL.

[3] M. Ali and G. J. Hayes, “Analysis of integrated inverted-F antennas for Bluetooth applications,” in Proc. IEEE Antennas and Propagation Conference on Wireless Communications Digest, Waltham, MA, 6–8 November 2000, pp. 21–24.

[4] M. Ali, R. A. Sadler and G. J. Hayes, “A uniquely packaged internal inverted-F antenna for Bluetooth or wireless LAN application,” IEEE Antenna and Wireless Communication Letters, vol. 1, 2002, pp. 5–7.

[5] C. Soras, M. Karaboikis, G. Tsachtsiris and V. Makios, “Analysis and design of an inverted-F antenna printed on a PCMCIA card for the 2.4 GHz ISM band,” IEEE Antennas and Propagation Magazine, vol. 44, no. 1, Feb 2002, pp. 37–44.