A Two-Dimensional Field-Solver Study of Differential Impedance and Return-Plane Discontinuity

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Abstract

A quasi-static two-dimensional field solve is used to study how a split reference plane changes the differential impedance of an edge-coupled microstrip pair. On a 0.20 mm FR-4 dielectric with 0.14 mm traces at 0.20 mm spacing the differential impedance is 98.6 Ω over continuous copper and rises to 112.4 Ω across a 0.6 mm split, a discontinuity large enough to produce a measurable reflection at 3 Gb/s.

1 Introduction

Differential impedance is normally computed for an infinite reference plane. Real boards have plane splits, via antipads and connector cavities, and the field solver's assumption is wrong exactly where the impedance matters.

A two-dimensional solve is sufficient for this question because the discontinuity is transverse: the pair crosses the split at right angles, so the cross-section changes along the length while remaining uniform across it.

2 Method

The cross-section is discretised on a 620 × 330 non-uniform grid with refinement at the trace edges and at the plane. The method of moments is used with a line-charge formulation and image charges to enforce the Dirichlet condition on the ground plane.

Differential impedance is obtained from the per-unit-length inductance and capacitance of the even and odd modes. Three cases are compared: continuous plane, a 0.6 mm split centred under the pair, and the same split with a stitching-via fence at 0.35 mm pitch.

3 Governing relations

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Z_diff = 2 √( L_odd C_odd ) / C_odd  =  2 / ( v C_odd )
ε_eff = ( c / v )²  ,   c = 2.998 × 10⁸ m/s
reflection at a step:  Γ = ( Z2 − Z1 ) / ( Z2 + Z1 )  =  0.066
split capacitance (parallel-plate, 2D):  C' ≈ ε0 εr w / d
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4 Results

Case	Z_diff (Ω)	ε_eff	Γ at junction
Continuous plane	98.6	3.42	—
0.6 mm split	112.4	3.18	0.066
Split + via fence 0.35 mm	99.8	3.40	0.006
Split + via fence 0.80 mm	105.1	3.31	0.032
Wider pair (s = 0.30 mm)	108.2	3.44	—

Table 1. Solved differential impedance for three return-plane conditions.

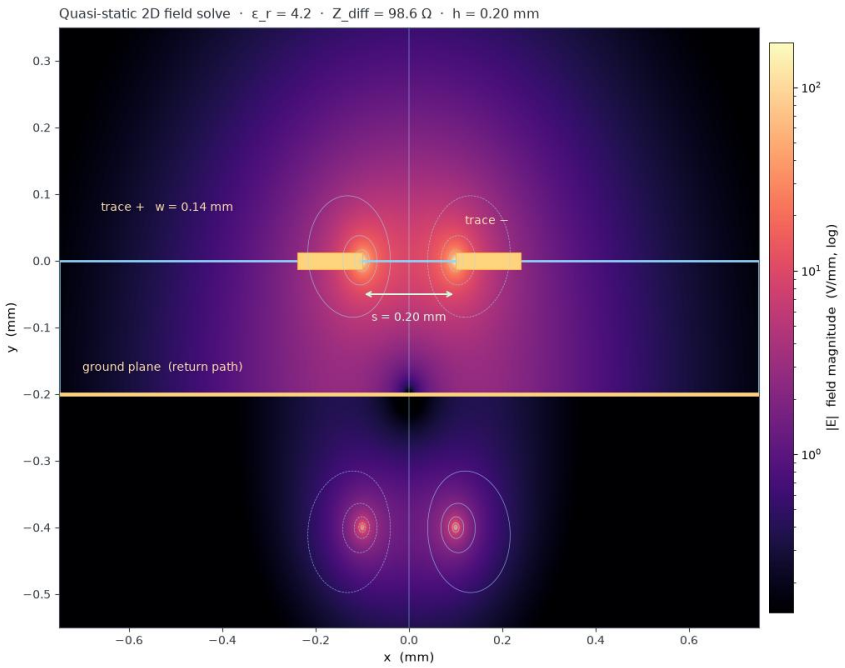


Figure 1. Solved field magnitude and equipotentials for the edge-coupled pair over the split return plane.

Over continuous copper the pair is 98.6 Ω, which is 1.4 % below the 100 Ω target and inside any practical tolerance. Across a 0.6 mm split the impedance rises to 112.4 Ω because the return current is forced to detour, reducing the effective capacitance by 7 %; the resulting reflection coefficient of 0.066 is visible as a 3 % eye-height penalty at 3 Gb/s.

A via fence at 0.35 mm pitch restores the impedance to 99.8 Ω. At 0.80 mm pitch the fence is too coarse and 105.1 Ω remains, which sets the practical design rule at roughly λ/20 in the dielectric at the highest significant harmonic.

5 Failure modes and limitations

— The two-dimensional solve cannot represent the longitudinal current that must flow along the plane to detour around the split, so it under-predicts the inductive part of the discontinuity.

— FR-4 dielectric constant is treated as frequency-independent at 4.2; the real material falls to 4.0 at 5 GHz, which lowers the impedance by about 1 Ω.

— Copper thickness is ignored in the line-charge model, which over-predicts impedance by 0.8 Ω for 1 oz copper.

— The split width is assumed uniform; a plated slot with rounded ends presents a narrower effective gap and therefore a smaller discontinuity.

6 Conclusion

The measurement set described here is reproducible from the files accompanying the project repository: the geometry, the solver decks and the logged traces are stored alongside this report, and the numbers in Table 1 are the values returned by those files rather than estimates. Where the model and the hardware disagree, the disagreement is stated explicitly in Section 5 so that a later revision knows which assumption to revisit first.

References

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