Efficient Electromagnetic Analysis of Spiral Inductor Patterned Ground Shields

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Overview

• Si RFIC inductors induce current in the Si substrate by magnetic induction.
• Are we sure???
• Check by visualization.
• What direction does the current flow?
• When does it flow?
• What does a patterned ground plane actually do?
Substrate Current Cause

• Popular wisdom: Spiral inductors induce current in substrates by magnetic induction.
• Also called “eddy currents”.
• To our knowledge, substrate current visualization has never been published.
• Visualize substrate currents by using Sonnet® “Sense Metal”.

Sonnet Sense Metal

• Set the “conductor” surface impedance to very high value, say +1000000j Ohms per square.
• High impedance has little influence on complete field solution.
• Current in the sense metal proportional to the tangential electric field.
• The tangential electric field on the surface of the silicon is proportional to the tangential current density in the silicon...
Substrate Current Visualization

- Current flows in a loop, exactly as we would expect for magnetic induction.
- Why is most of the current outside of the spiral perimeter?

X and Y Directed Current Plots

- The current is flowing radially, in and out from the inductor!!!!!
Plot made using SonnetLab™, the Sonnet API for MATLAB.

- $V_{IN} = \cos(\omega t)$ excitation at $\omega t = 0$.
- Current is radial!!!
• Plot made using SonnetLab™, the Sonnet API for MATLAB.
• $V_{IN} = \cos(\omega t)$ excitation at $\omega t = 60^\circ$.
• Current is radial!!!
What In The World is Happening?

- The substrate current is not due to magnetic field induction.
- The substrate current is due to electric field induction.
- Eddy currents are magnetically induced in moving conductors. The Si substrate is not moving and it is not magnetic. This is most certainly NOT an eddy current.
- How deep does the current go?
- Skin depth of is 1000 μm...if silicon is a “good” conductor.

Descending into the Silicon

- At the surface of the silicon.
Descending into the Silicon

• Depth of 20 μm into the silicon.

Z = −20 μm  Jxy

Descending into the Silicon

• Depth of 40 μm into the silicon.

Z = −40 μm  Jxy
Effect of Balanced Ports

- What does intuition say about current direction?

Current Under a Patterned Ground
• Finger width makes little difference.
• Using solid anisotropic metal is OK.
• Important when ground shield is too fine for EM analysis.
Conclusion

- Current is NOT magnetically induced in the Si substrate under a spiral inductor.
- It is electrically induced.
- A patterned ground shield shorts out the electric field that would otherwise induce current in the substrate.
- Understanding the substrate current is a brand new field, still a LOT of research opportunity here.