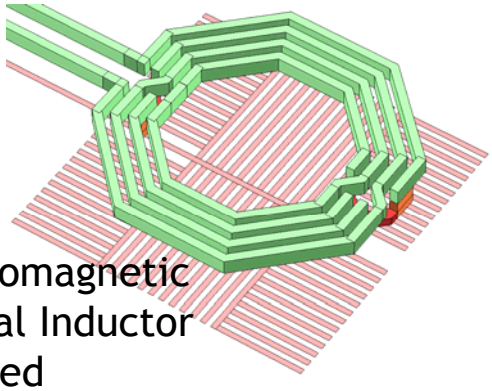

Efficient Electromagnetic Analysis of Spiral Inductor Patterned Ground Shields

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CEO, Founder Sonnet Software

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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?

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Substrate Current Cause

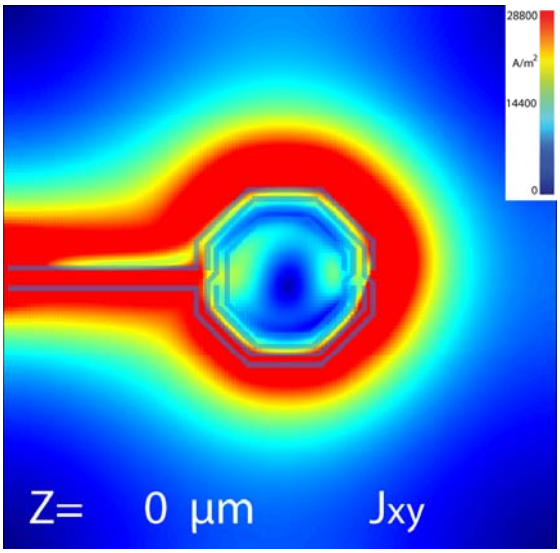
- Popular wisdom: Spiral inductors induce current in substrates by magnetic induction.
- Also called “eddy currents”.
- To our knowledge, substrate current visualization has never been published.
- Visualize substrate currents by using Sonnet® “Sense Metal”.

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?



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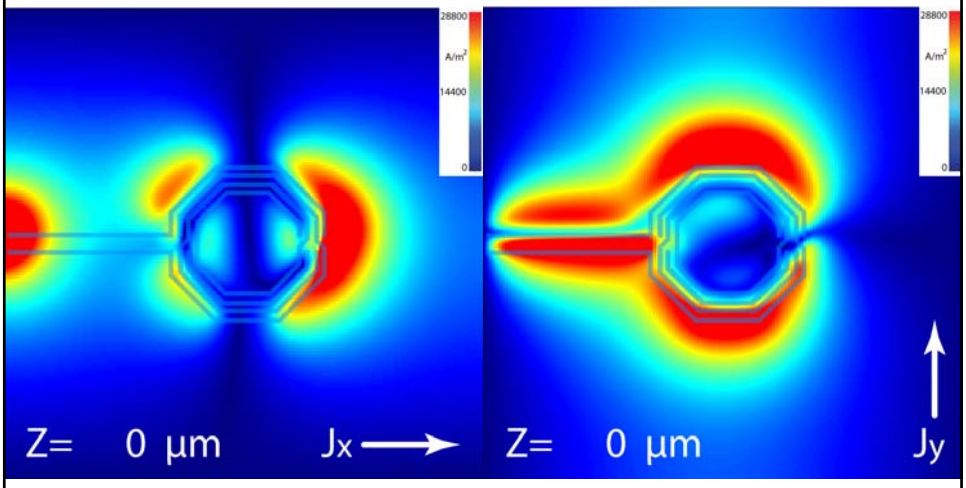
X and Y Directed Current Plots



- The current is flowing radially, in and out from the inductor!!!!!

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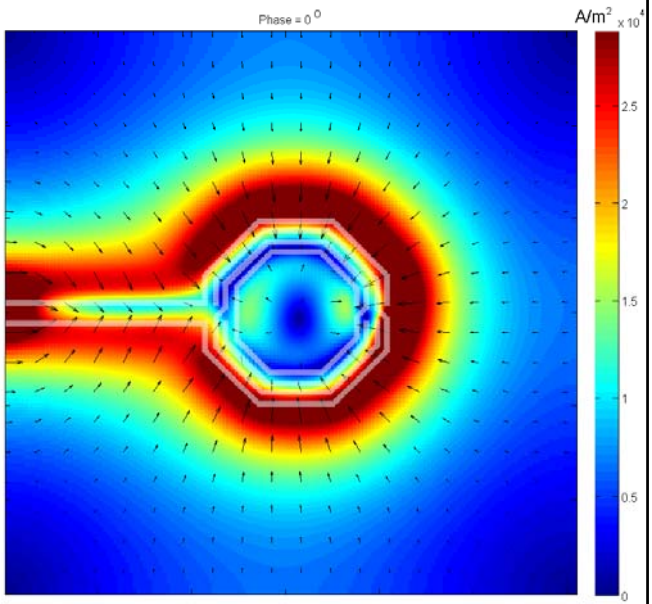
Arrow Plot of Current

- Plot made using SonnetLab™, the Sonnet API for MATLAB.
- V_{IN} = Cos(ωt) excitation at ωt = 0.
- Current is radial!!!



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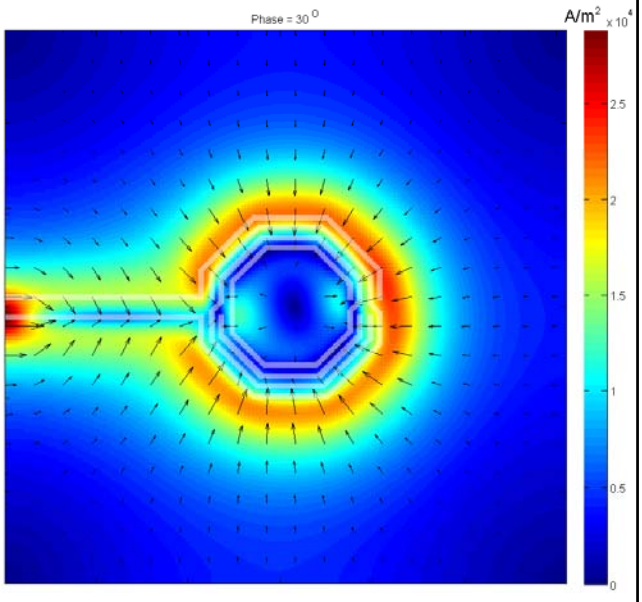
Arrow Plot of Current

- Plot made using SonnetLab™, the Sonnet API for MATLAB.
- V_{IN} = Cos(ωt) excitation at ωt = 30°.
- Current is radial!!!



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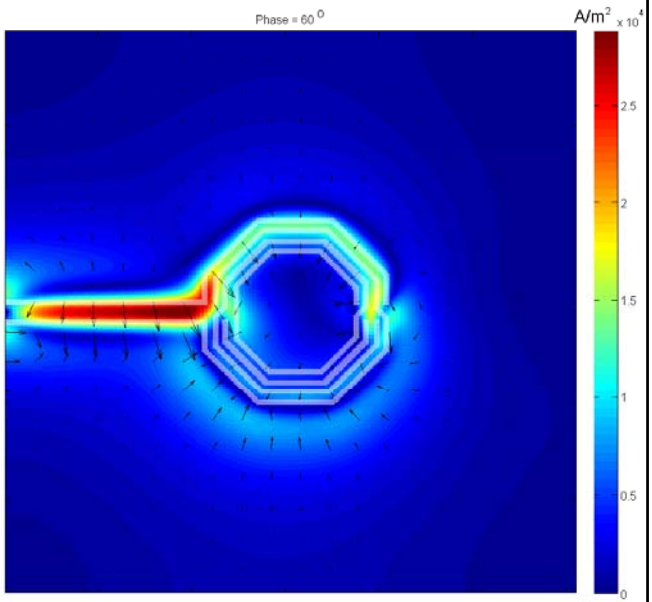
Arrow Plot of Current

- Plot made using SonnetLab™, the Sonnet API for MATLAB.
- V_{IN} = Cos(ωt) excitation at ωt = 60°.
- Current is radial!!!



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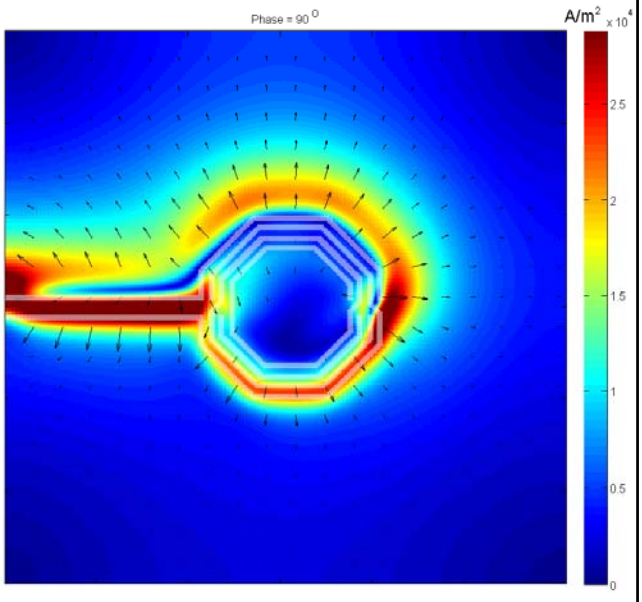
Arrow Plot of Current

- Plot made using SonnetLab™, the Sonnet API for MATLAB.
- V_{IN} = Cos(ωt) excitation at ωt = 90°.
- Current is radial!!!



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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.

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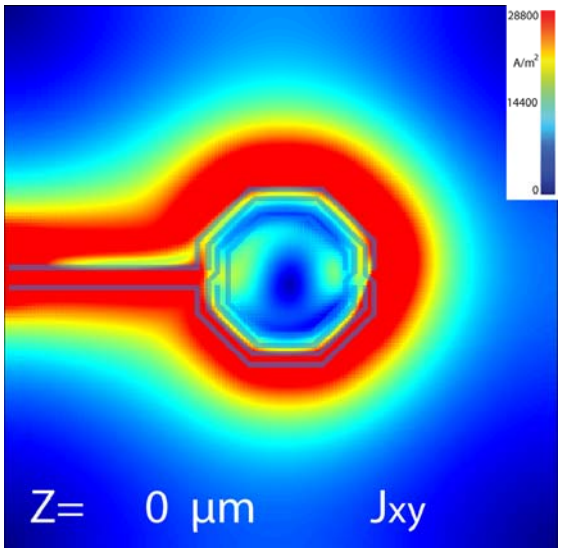
Descending into the Silicon

- At the surface of the silicon.



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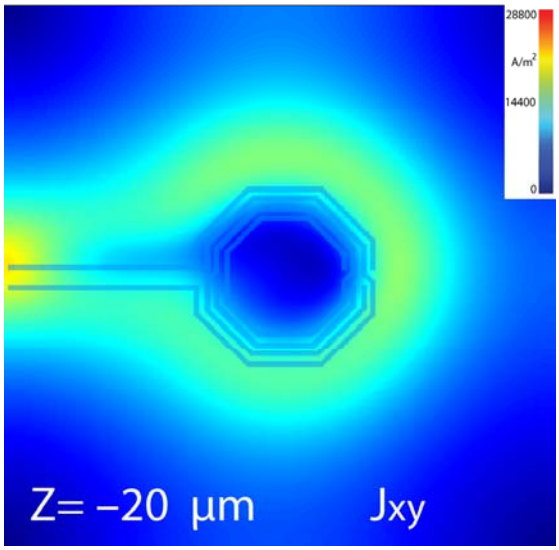
Descending into the Silicon

- Depth of 20 μm into the silicon.



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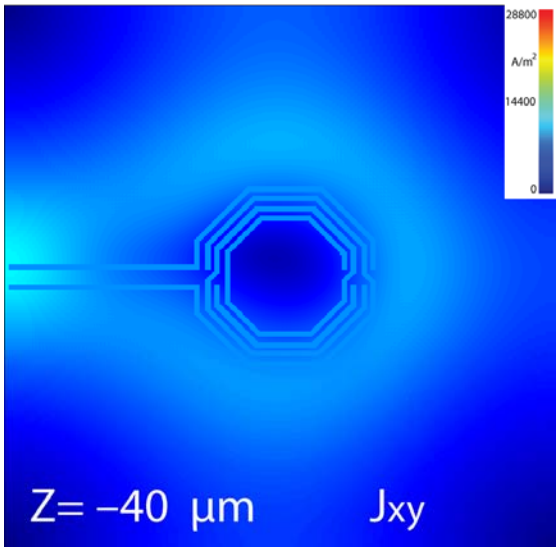
Descending into the Silicon

- Depth of 40 μm into the silicon.



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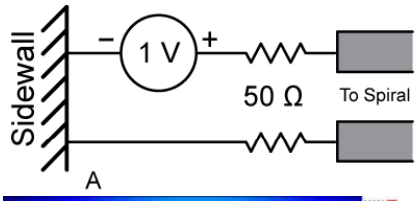
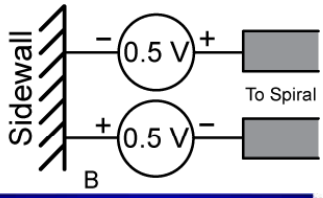
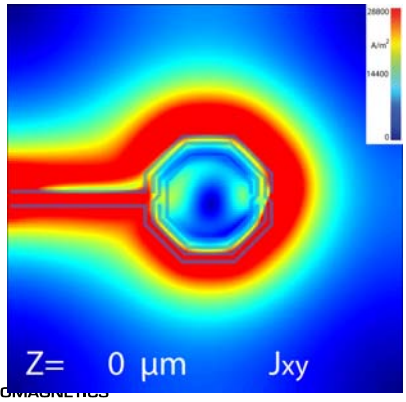
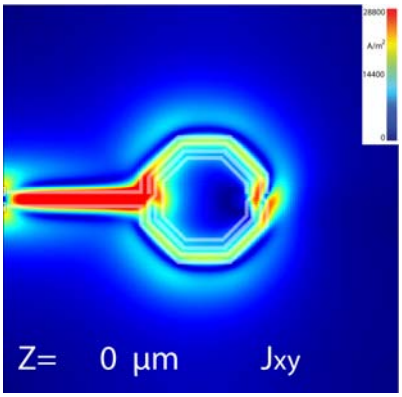
Effect of Balanced Ports









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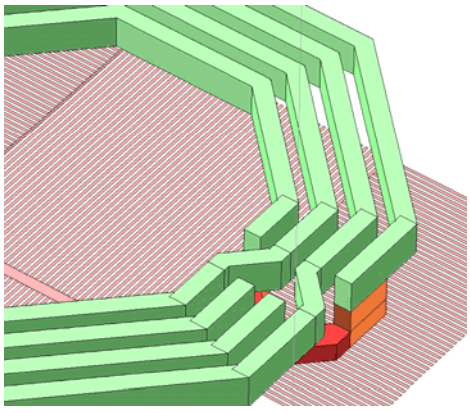
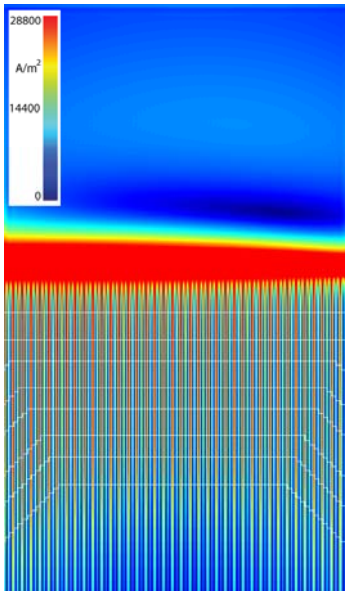
Current Under a Patterned Ground





- What does intuition say about current direction?

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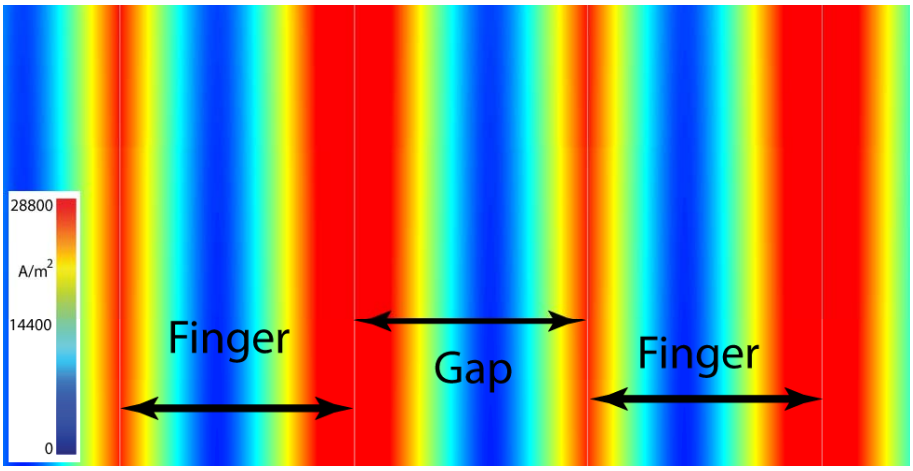
Very Fine Detail of Current Under Fingers



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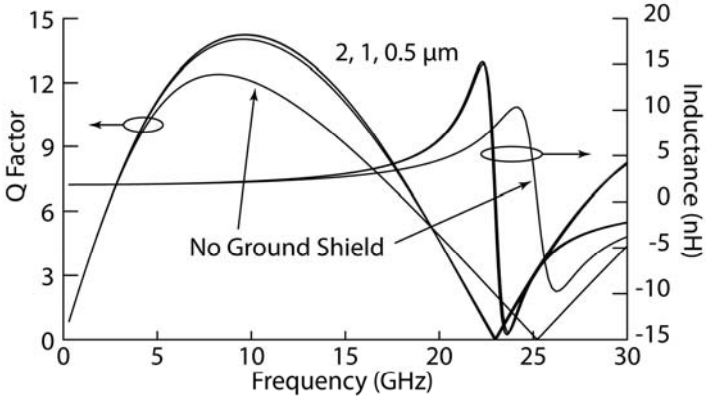
Effect of Finger Width



- Finger width makes little difference.
- Using solid anisotropic metal is OK.
- Important when ground shield is too fine for EM analysis.

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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.

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