

# Development of Specialized Basis Functions and Efficient Substrate Integration Techniques for Electromagnetic Analysis of Interconnect and RF Inductors

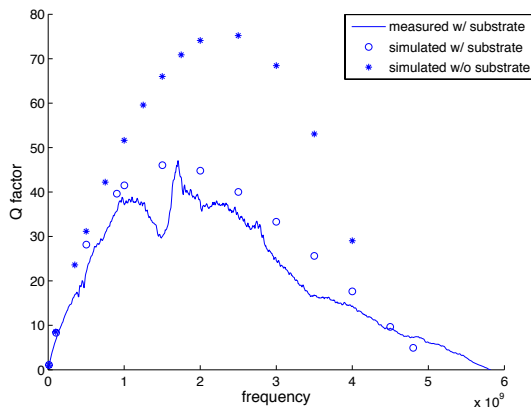
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The performance of several mixed-signal and RF-analog platforms depends on substrate effects that need to be represented in the library model with critical field solver accuracy. For instance, substrate-induced currents in RF inductors can severely affect quality and hence RF filter selectivity. We have developed an efficient approach to full-wave impedance extraction that accounts for substrate effects through the use of two-layer media Green's functions in a mixed-potential-integral-equation (MPIE) solver. In particular, we have developed accelerated techniques for both volume and surface integrations in the solver.

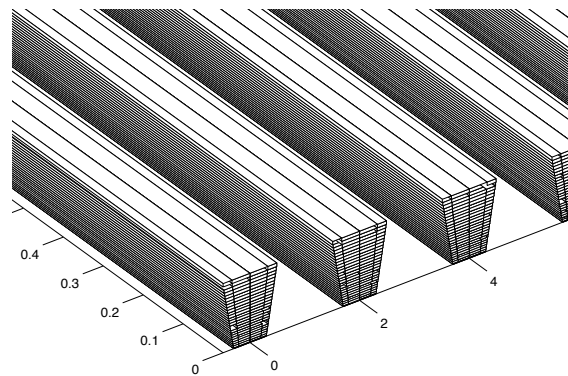
In this work, we have also introduced a technique for the numerical generation of basis functions that are capable of parameterizing the frequency-variant nature of cross-sectional conductor current distributions. Hence skin and proximity effects can be captured utilizing many fewer basis functions in comparison to the prevalently-used piecewise-

constant basis functions. One important characteristic of these basis functions is that they only need to be pre-computed once for a frequency range of interest per unique conductor cross-sectional geometry, and they can be stored off-line with a minimal associated cost. In addition, the robustness of these frequency-independent basis functions is enforced using an optimization routine.

We have shown in [2] that the cost of solving a complex interconnect system using our new basis functions can be reduced by a factor of 170 when compared to the use of piecewise-constant basis functions over a wide range of operating frequencies. Furthermore our volume and surface integration routines result in additional efficient improvement by a factor of 9.8 as shown in [1]. Our solver accuracy is validated against measurements taken on fabricated devices.



▲ Figure 1: Measured and simulated Q-factors for a square RF inductor with an area of 15 mm x 15 mm and surrounded by a ground ring.



▲ Figure 2: Our basis functions avoid the expensive cross-sectional discretization shown in figure necessary to account for trapezoidal cross-sections or skin and proximity effects.

## REFERENCES

- [1] X. Hu, J.H. Lee, J. White, and L. Daniel, "Analysis of full-wave conductor-system-impedance over substrate using novel integration techniques," in *Proc. of the IEEE/ACM Design Automation Conference*, June 2005.
- [2] X. Hu, T.A.E. Moselhy, J. White, and L. Daniel, "Novel development of optimization-based, frequency-parameterizing basis functions for the efficient extraction of interconnect system impedance," submitted to *the IEEE/ACM Design Automation Conference*, July 2006.