

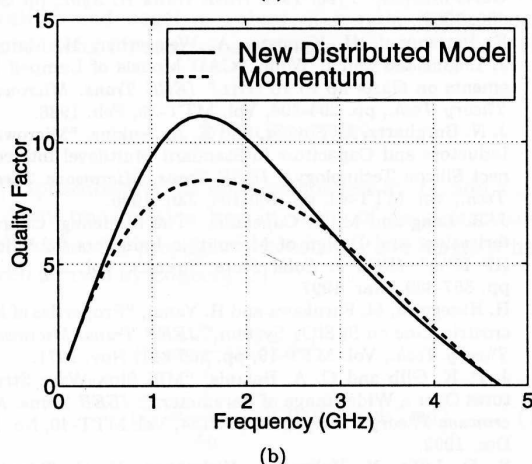
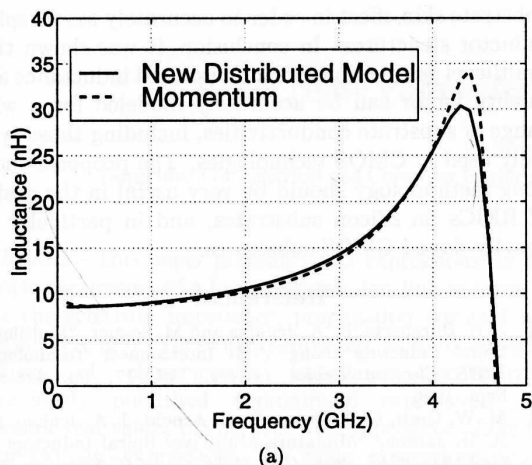


Fig. 3. (a) inductance and (b) quality factor obtained with the proposed distributed model and HP Momentum for a multilevel spiral inductor in a typical BiCMOS environment ($\rho = 12 \Omega\text{-cm}$).

nologies, the multilevel structures can often achieve a higher quality factor in the low frequency range than their single level counterparts, as previously noted in [1].

B. Parallel-Connected Spirals

Figure 5 shows the simulated inductance and quality factor for two eight turn spiral inductors on a typical CMOS substrate ($\rho = 0.01 \Omega\text{-cm}$). One of the spirals exists only on the upper metallization layer (SLS), and the other structure uses two metallization layers in parallel and shunted together by vias (MLS). The total area of both structures is $226 \times 226 \mu\text{m}^2$. The width and spacing for both spiral inductor structures are $6 \mu\text{m}$, and the heights above the silicon substrate for

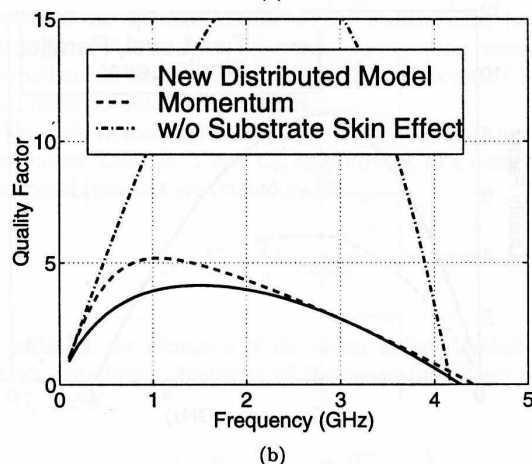
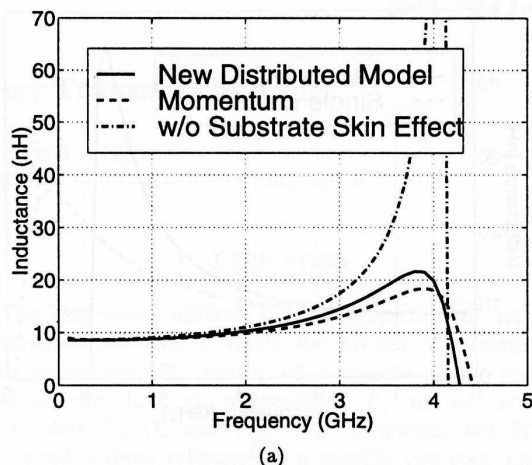


Fig. 4. (a) inductance and (b) quality factor obtained with the proposed distributed model and HP Momentum for a multilevel spiral inductor in a typical CMOS environment ($\rho = 0.01 \Omega\text{-cm}$). Results obtained with a distributed model which neglects the substrate skin effect are also shown.

the two metallization layers are $4.5 \mu\text{m}$ and $7.5 \mu\text{m}$, respectively. The via connections are taken to be at each corner and are assumed to be perfectly conducting.

As expected, the quality factor achieved with the shunted two-level structure is greater than that of the single level counterpart. However, the self-resonant frequency of the parallel-connected spiral is slightly lower, mainly due to the increased shunt oxide capacitance which results from the lower level being closer to the substrate. The low frequency inductance values for both structures are virtually identical, indicating that inductance is lowered only slightly by the parallel connection.

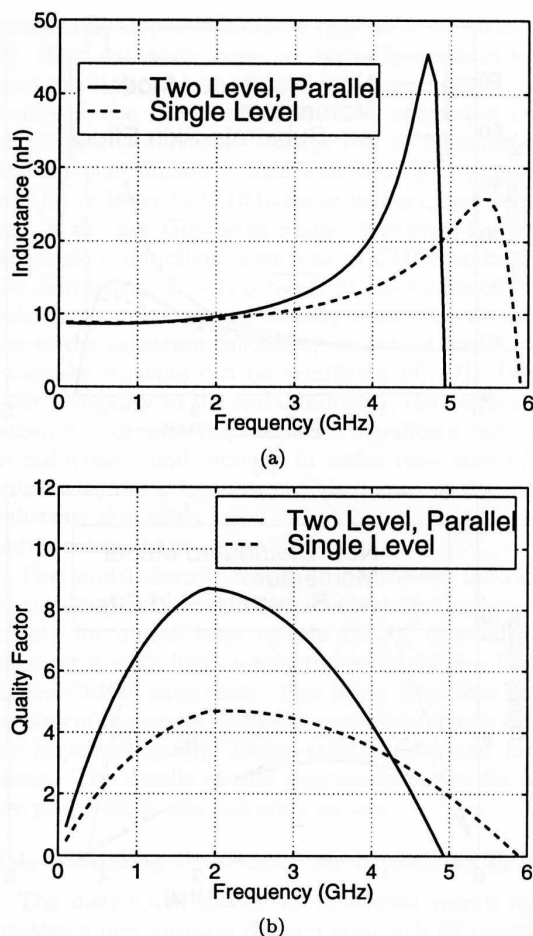


Fig. 5. Comparison of (a) inductance and (b) quality factor for a two level parallel-connected spiral inductor and a single level spiral in a typical CMOS environment ($\rho = 0.01\Omega\text{-cm}$). All results are computed using distributed equivalent circuit models including the substrate skin effect.

V. Conclusion

A new modeling methodology for multilevel spiral inductors on lossy substrates has been presented. It has been shown that the multilevel series configuration yields a higher inductance/area ratio as well as higher quality factors for low frequencies, although the usable frequency range is reduced as compared to a single level spiral with the same inductance value. Parallel-connected multilevel spiral inductors yield a lower series resistance and can often achieve a higher quality factor than the identical single level structure. This, however, comes at the expense of a slightly reduced self resonant frequency. It was shown that in a high conductivity environment, it is necessary to account for the

substrate skin effect in order to accurately model spiral inductor structures. In conclusion, it was shown that multilevel spiral inductors for enhanced inductance and quality factor can be accurately modeled for a wide range of substrate conductivities, including those typically used in CMOS technologies. The proposed modeling methodology should be very useful in the design of RFICs on silicon substrates, and in particular on heavily-doped CMOS substrates.

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