Electrical Characterisation of Thin Film CZTB Solenoid Inductors for PwrSiP

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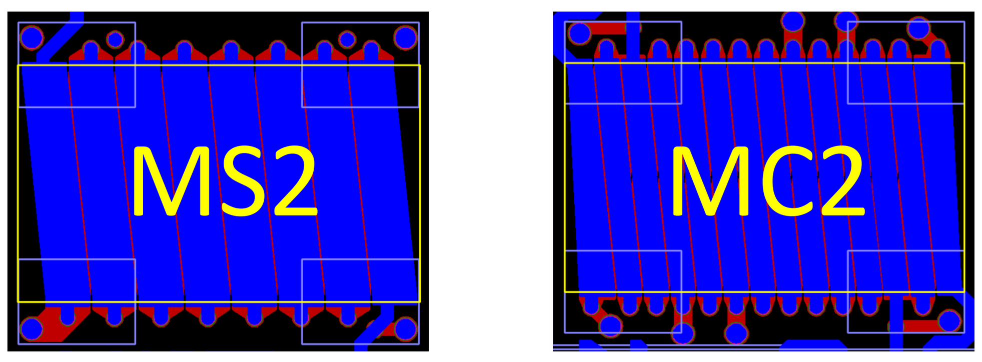
INTRODUCTION and MOTIVATION

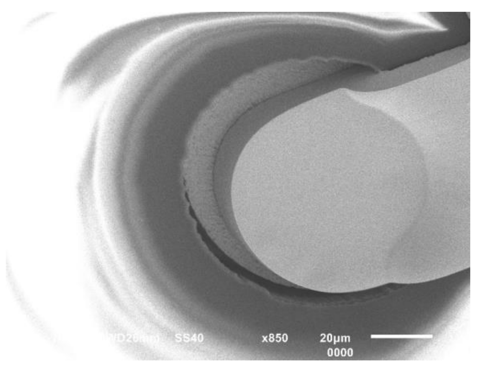
Point-of-Load (POL) converters between the lithium Ion battery and the application System-on-Chip (SOC) in mobile devices are typically single phase Buck, have a switching frequency of approximately ~3MHz and an inductor value of ~1µH. Topology and integration developments might allow order of magnitude increase in effective switching frequency with commensurate decrease in inductor value. It is in this context that we are exploring 50nH single and coupled inductor designs optimised for ~30MHz application. CMOS compatible and wafer scale "back-end-of-line" (BEOL) thin film inductors in planar solenoidal format have recently been fabricated by Tyndall. It is believed that this represents the first use of laminated Co-Zr-Ta-B films in planar solenoidal inductor format. This work presents the electrical performance results for these components and techniques used to abstract the necessary parameters for design of PwrSoC incorporating thin film magnetics-on-silicon (MoS).

Single and Coupled designs are equal in size allowing easy assessment of the value of inverse coupling in application.

SINGLE (MS2) and COUPLED (MC2) INDUCTOR DESIGNS



MS2 and MC2 Devices (each is 1.8 X 2.4 mm)

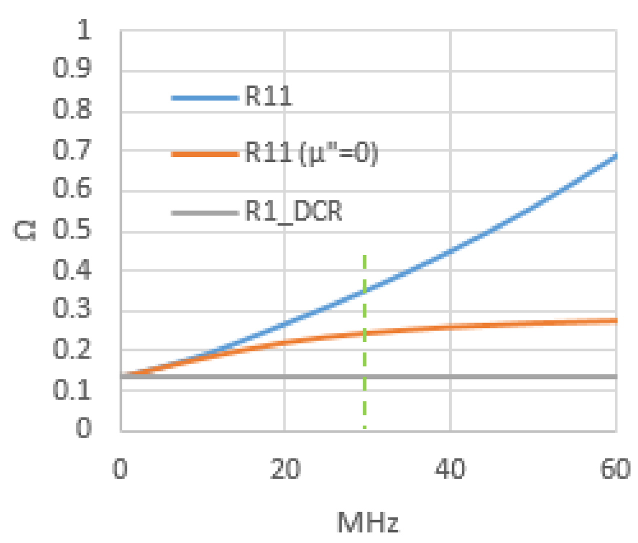


Copper Via in Passivation Well

Planar solenoidal devices have higher DCR than closed-core *Racetrack* format and hence we have selected a larger area device with a more modest inductance density ~10nH/mm^2. This achieves low DCR , very high Q and very good DC bias capability. The design is optimised for 20-50 MHz.

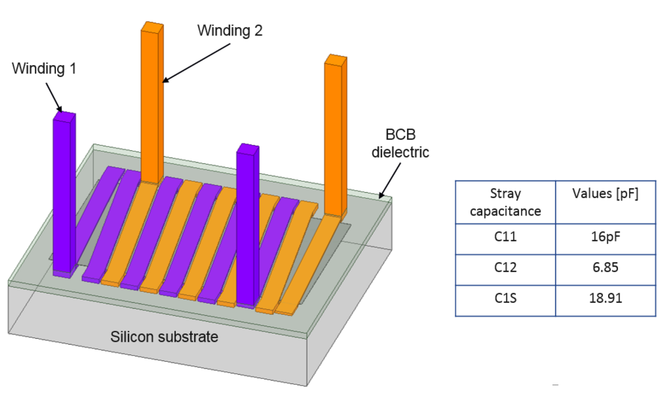
Cu thickness (top & bottom)	15 µm
Core thickness	4 µm
B_{SAT}	1.1 T
L (per phase)	45 nH
DCR (MS2, MC2)	80, 180 mΩ
I_{SAT}	0.9A
Coupling Factor (tap 1) MC2	74%

3-D FEM SIMULATION MS2 R11 vs R11(µ''=0)

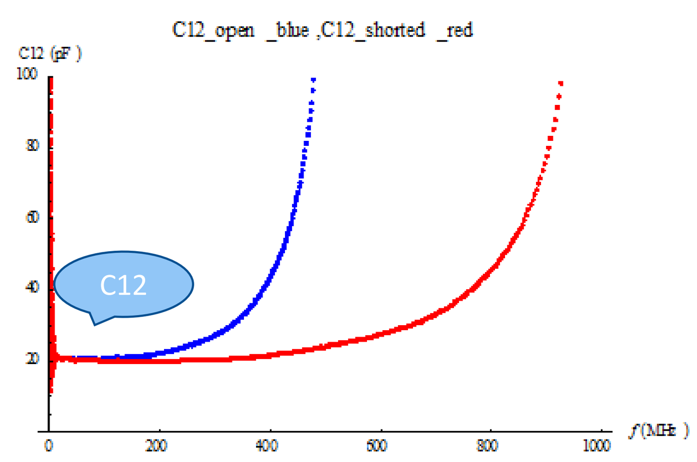


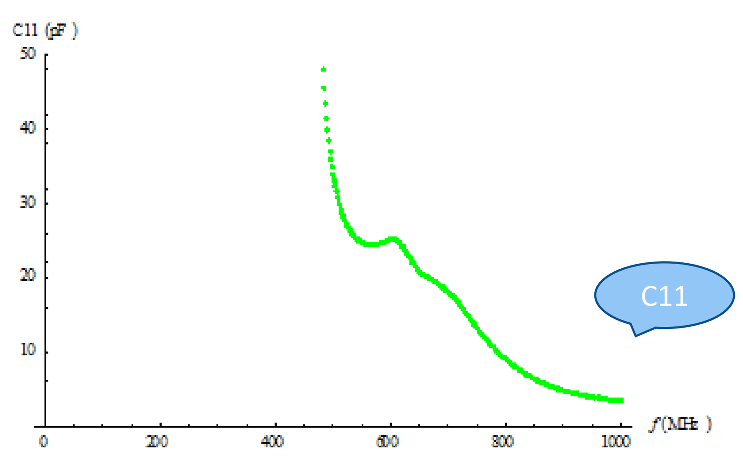
DC, AC Copper Losses and Core Loss are all equal at 30MHz

DEVICE CAPACITANCES



Electrostatic Capacitances:
3-D FEM Electrostatic Solver. C11, left, refers to self capacitance of W1 to core, ∞, substrate and to W2 (not the same as high frequency winding self capacitance).





High Frequency Winding Capacitances: S-Parameter measurement allows inter and intra winding capacitances to be deduced by analytical solution.

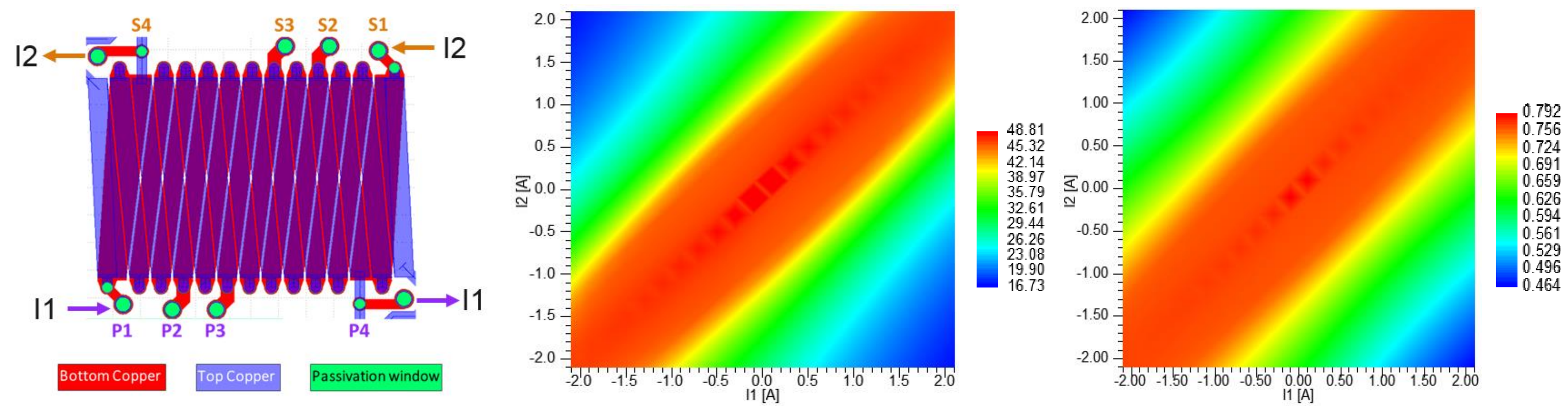
KEY CONTRIBUTIONS

- First thin film laminated CZTB planar solenoidal core with electrical properties suitable for inductor application over 10-100 MHz.
- BEOL compatible planar solenoid inductor with thickness < 40 µm.
- Measured device Q ~24 at ~30MHz.
- Equal area 1-Φ and 2-Φ designs with a variety of coupling factors.

INVERSE COUPLED INDUCTOR OPERATION

(3D FEM – Magnetostatic Solver)

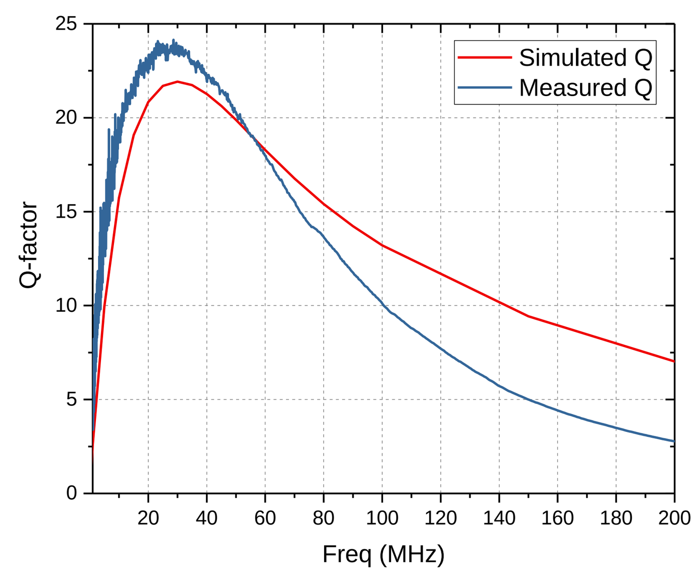
Inverse coupling increases DC current capability and may reduce per phase current ripple (increase effective steady state equivalent inductance).



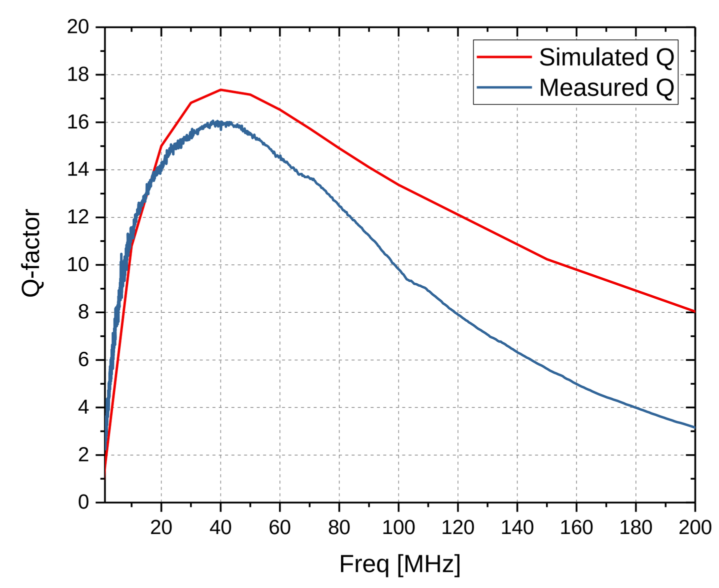
I1 and inverse excitation I2 | L11 (nH) vs (I1,I2) | k12 vs (I1,I2)

INDUCTOR DEVICE LOSS MEASUREMENT

Small Signal Measured Q – Device Probe on Wafer



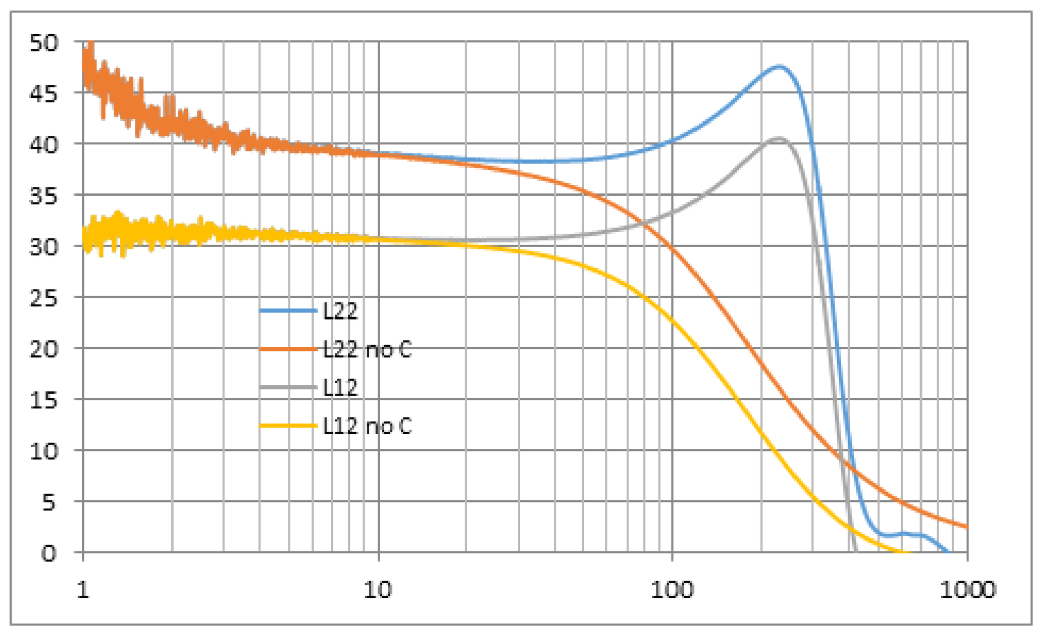
Q MS2 Single Inductor Device (45nH)



Q MC2 Coupled Inductor Device

Measured: Agilent E5071C ENA small signal wafer probe – S-Parameter Matrix.
Simulated: Maxwell 3D FEM Eddy Current Solver.

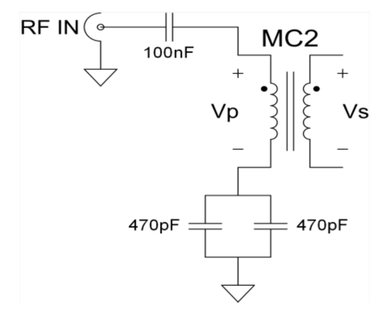
Small Signal Self and Mutual Inductances (MC2)

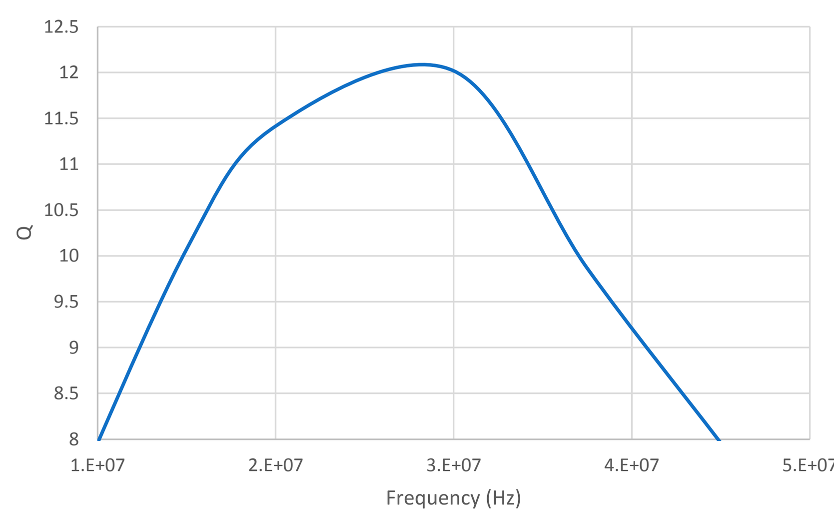


Impedances are generally represented by Ls-Rs in basic analytic extraction and by LCR Analysers. Here inter and intra winding capacitance effects are analytically removed.

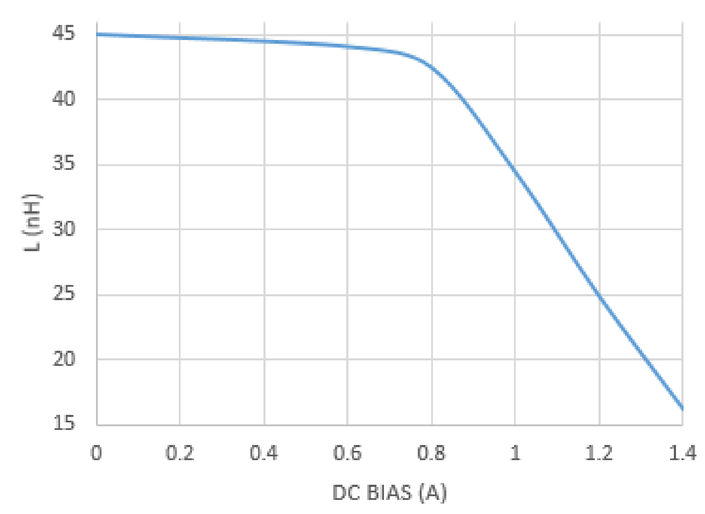
Large Signal Measurements on MC2 Wire Bonded on PCB

A sinusoidal signal source through an RF amplifier was connected to test circuit. Current sense was performed on two low ESL 0402 capacitors in parallel. FFT based 1st harmonic extraction removed some noise effects.





MC2 Large Signal Q11 @ Iac_pk = 200mA



MS1 Saturation Characteristic L (10mA, 29MHz) vs DC Bias (A)

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