High Frequency Large Signal Characterization for Two Phase on-silicon Coupled Inductors

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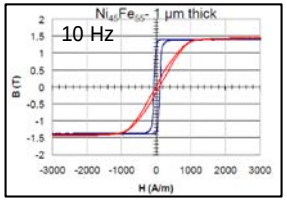
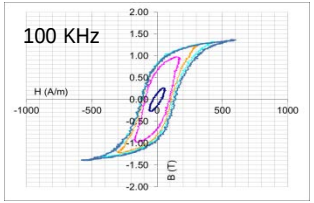
Motivation

- Large signal characterization of integrated coupled inductors up to 120MHz
- Characterization of a coupled inductor under more realistic operating conditions in comparison to standard small signal impedance meter or S-parameter characterization
- Includes non-linear core effects
- Self inductance, mutual inductance and resistance at various frequencies, dc currents and ac currents are calculated to estimate the inductor performance at current levels similar to those in the actual voltage regulator
- The key issue of the test is a proper compensation of voltage and current probes. This calibration is done by measuring voltage and current waveforms on a device with known impedance (220 pF chip capacitor with very high Q-factor). Calculated attenuation and time skew are applied in the post processing of the inductor voltage and current waveforms to extract its impedance at the test frequency.

Small vs large signal characterization

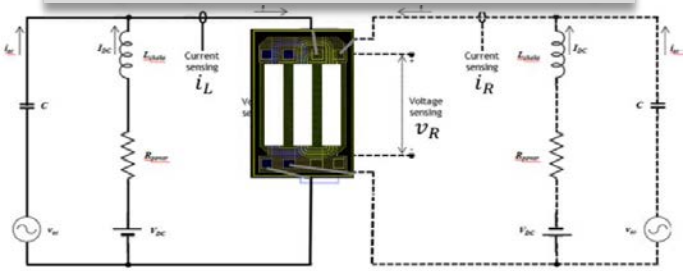
- Core saturation effect
  - Influence on V & I waveforms at close to real circuit condition
- Core losses
  - Small signal measurement
    - Only eddy current loss included

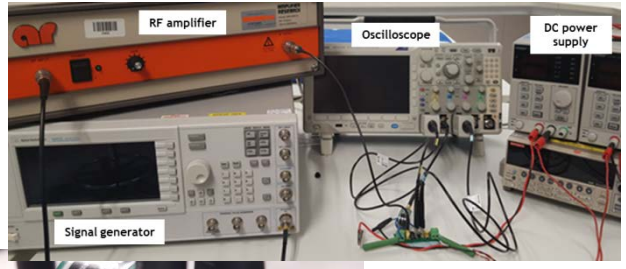


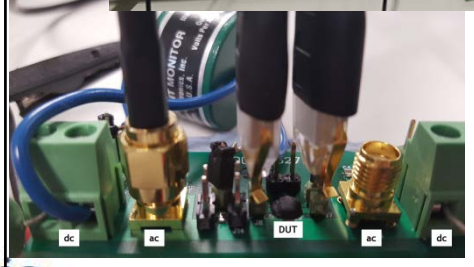


  - Large signal measurement
    - Eddy current loss
    - Hysteresis loss
    - Anomalous loss
- Area of the BH loop is the measure of power loss in the core
- Coercivity measure of losses
- Increase in coercivity with increasing I_{ac}
- Hysteresis + Anomalous > 50% of the overall core loss (NiFe)
- **Not captured by small signal test**

Large Signal Characterization Set-up







- Signal generator - Agilent E8257D
- Power amplifier - Applied Research 25A250A
- Current probe – Pearson 2877
- Voltage probe – Tap500

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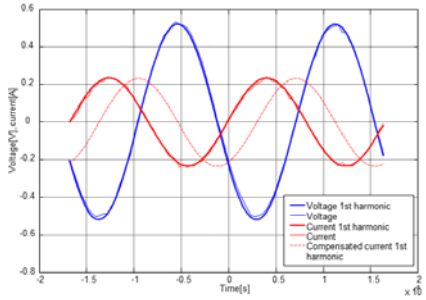
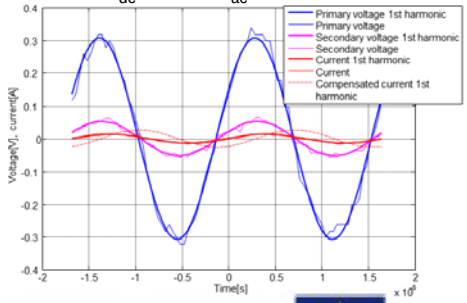
Validation of the large signal test setup at single phase dc and ac currents for PowerSwipe coupled inductor device

- Voltage and current probe compensation waveforms

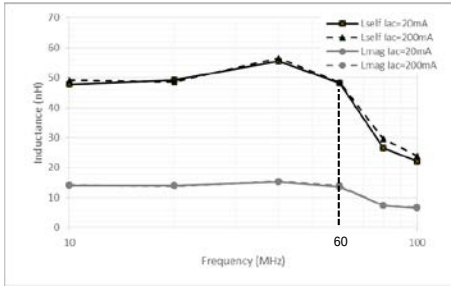


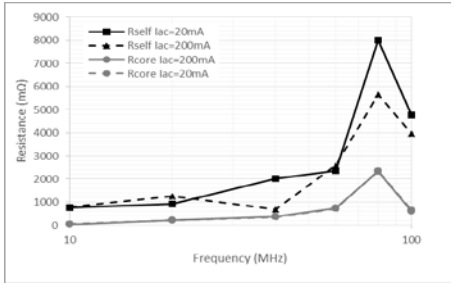
- Time lag @ 60MHz- 2.77 ns
- Current attenuation- 1.05

- Inductor V & I waveforms at 60MHz and I_{dc} = 1.2A, I_{ac} = 20mA

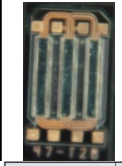


- L, R vs frequency @ different ac currents



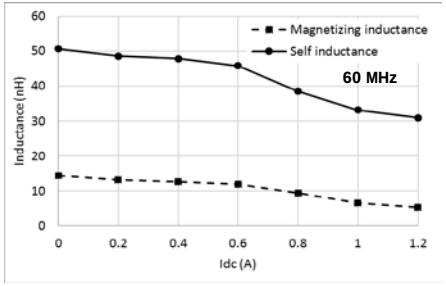


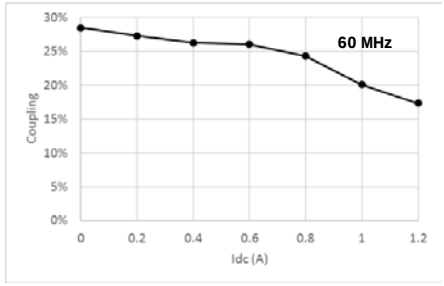
- Power Swipe coupled inductor



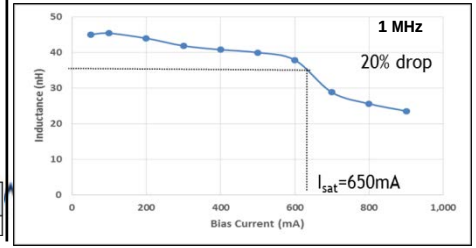
L (nH)	Core Thickness	Core Length	Copper width	Copper Thickness	DCR (Ohm)	Device Footprint
47 Coupled (k=0.4)	1.6 µm	1.78 mm	50.62 µm	15 µm	0.3425	2 mm²

- L_{self}, L_{mag} & k vs I_{dc} @ I_{ac_peak}=20mA

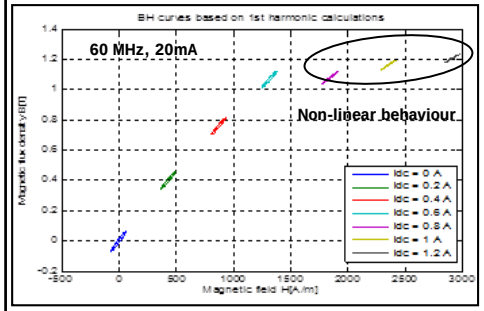




- Small signal + DC current source



- BH loops at different bias currents



- B calculated from $V=-d(B \cdot A_e)/dt$
- H calculated from $H \cdot l_{mag}=I_{ac}$

- **Key takeaways**

- Large signal characterization essential for loss and saturation measurements under conditions similar to real operation
- Verified large signal power measurement setup and methodology for very high frequency (up to 100MHz)
- Accurate compensation of current probe essential for precise extraction of L & R

- Acknowledgements

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