AC Loss Behavior of Wireless Power Transfer Coils

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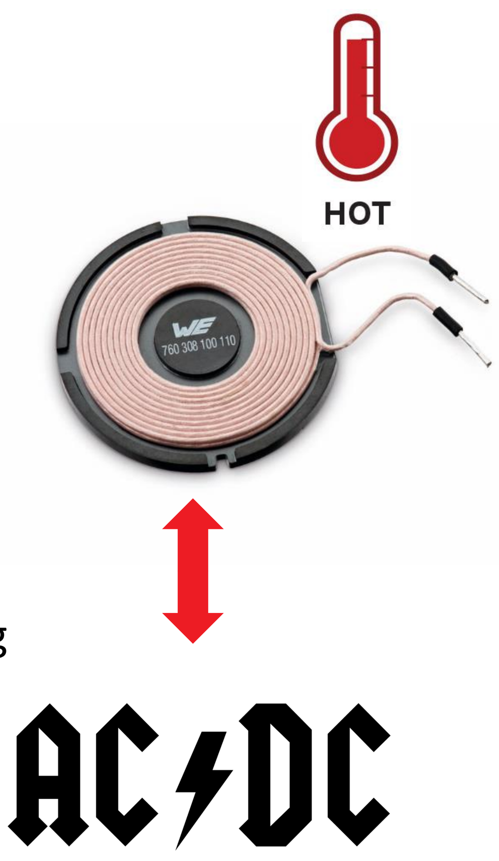
Motivation

- Wireless Power Transfer (WPT) coils are operated at high frequency AC currents
- Although most WPT coils are made of litz wire, the power losses under AC conditions are significantly bigger than under DC conditions
- Power losses lead to self heating of the coil
- Knowledge of power losses and self heating under working conditions is essential for the design of WPT systems



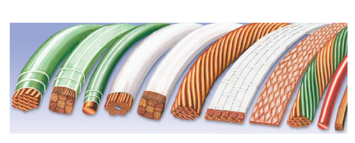
Basic Loss Mechanisms

- Magnetic core loss per Volume: $P_{\mathrm{core}}/V = C_{\mathrm{m}} f^{\alpha} B^{\beta}$ — see Reinert et al., IEEE Trans. Ind. Appl. **37**, 4 (2001)
- Ohmic losses in the winding depend on:

amount of transport current flowing through the winding	amount of magnetic field penetrating the winding
$P_{\mathrm{trans}} = I_{\mathrm{rms}}^2 R_{\mathrm{DC}} F$	$P_{\mathrm{prox}}/l = \frac{1}{\sigma} H_{\mathrm{ext}}^2 D$
rms loss + skin effect independent of winding geometry	proximity loss per length dependent on winding geometry

see Albach, „Induktivitäten der Leistungselektronik“ (2017)

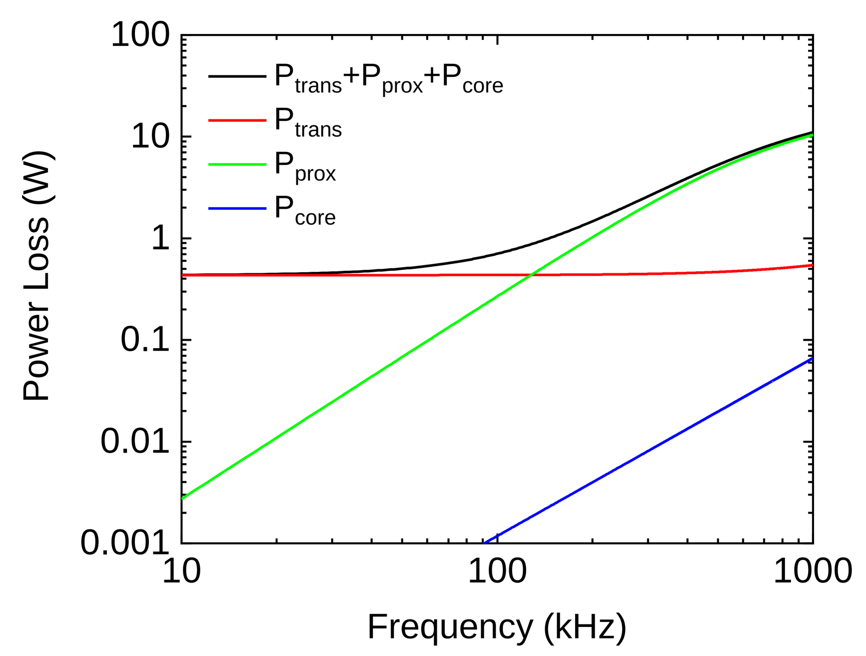
The frequency dependent skin and proximity factors, F and D, can be calculated for different litz wire configurations



- Total power loss in WPT coils: $P_{\mathrm{tot}} = P_{\mathrm{trans}} + P_{\mathrm{prox}} + P_{\mathrm{core}}$

Calculation of AC power losses requires knowledge of:
1. skin and proximity factors
2. magnetic field distribution

- ➢ Proximity loss is integrated along the wire
- ➢ Core loss is integrated over the core volume

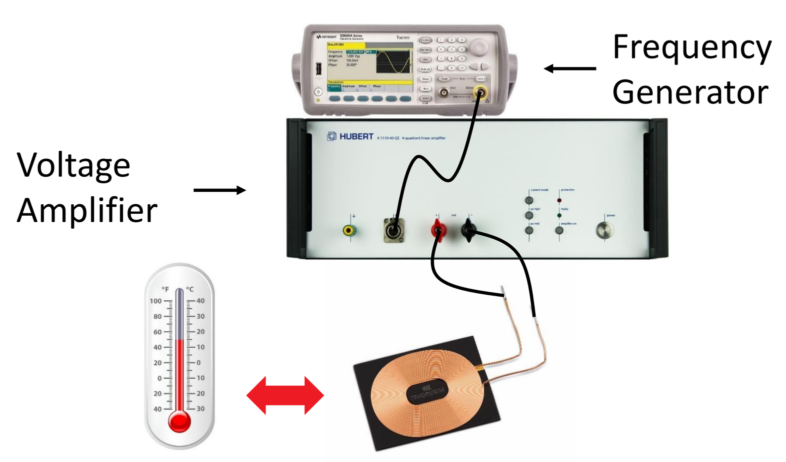


Experimental Measurement Techniques

Small Signal Measurement

High precision LCR-Meter:
- small voltage signal is applied to the coil
- phase shift between current and voltage is analysed
- frequency dependent AC resistance is measured

Large Signal Measurement



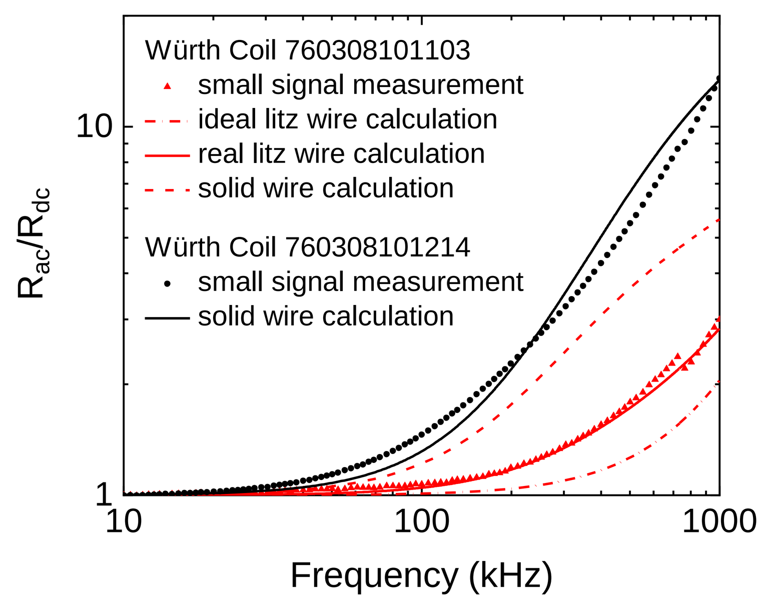
AC rated current setup
- frequency controlled linear voltage amplifier drives AC current through the coil
- temperature rise of the coil is measured

Experimental Results

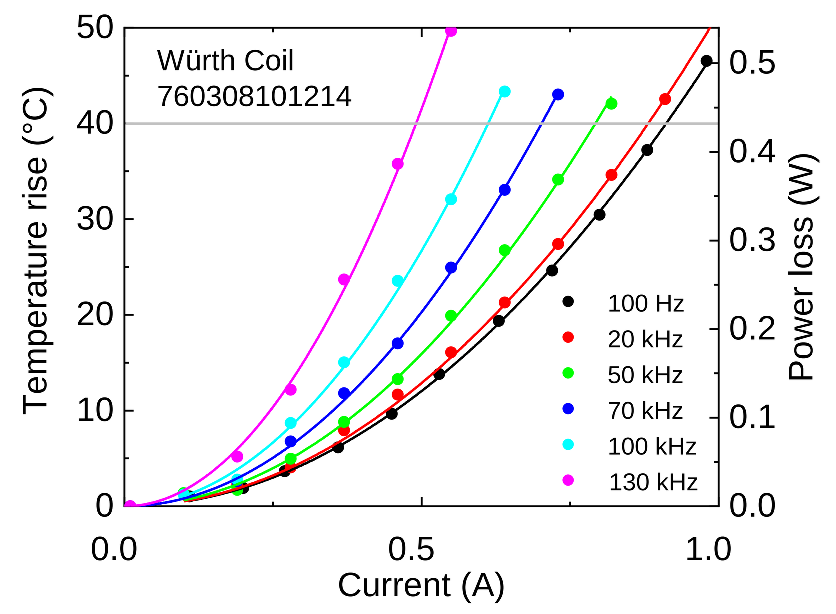
Frequency dependent AC resistance

analytic loss calculation ⟷ small signal measurement

- very good agreement between analytic loss calculations and small signal measurements
- prediction of power losses during the coil design is possible

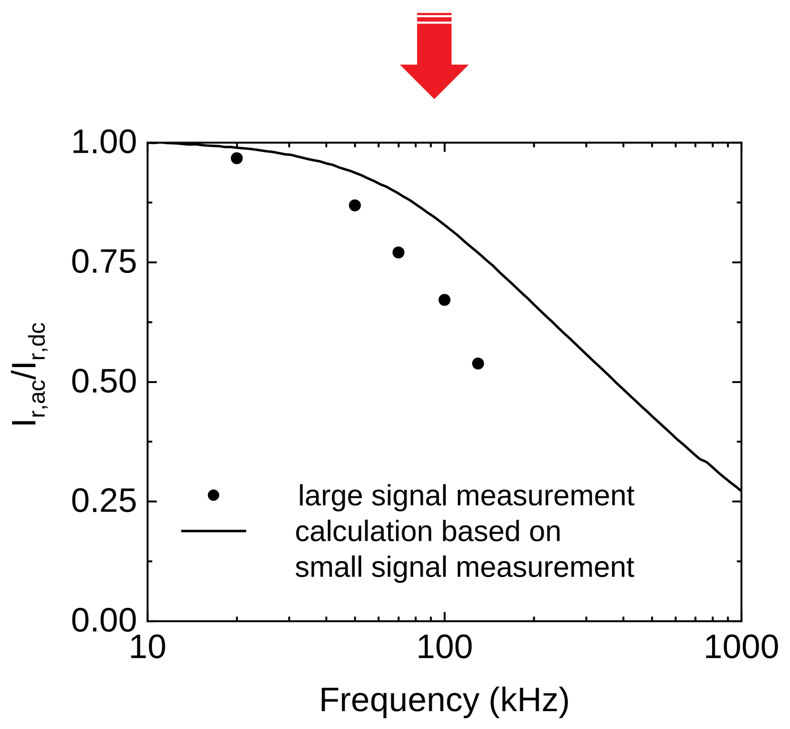


Frequency dependent self heating



- strongly increased self heating at high frequencies
- temperature rise is related to power loss by: $P_{\mathrm{loss}} = \frac{\Delta T}{\alpha}$
- conversion factor α is calibrated by DC measurement

Frequency dependent derating of the rated current

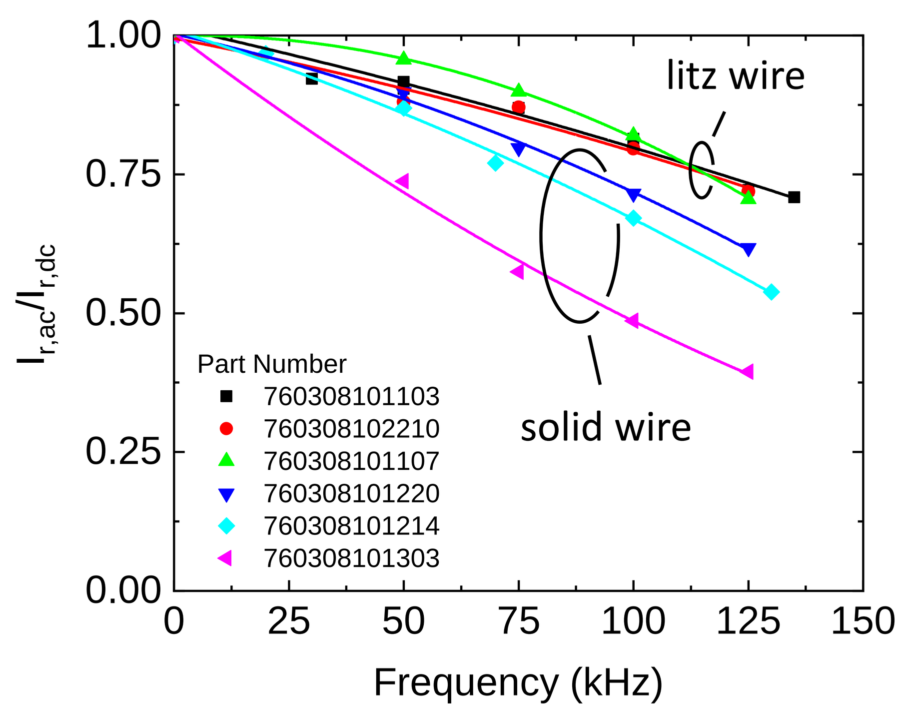


small signal measurement ⟷ large signal measurement

- Significant deviation between small and large signal measurement
- the derating is stronger than expected from the AC resistance measurement

Performance comparison of different Würth Elektronik eiSos WPT coils

- AC behavior of each coil is determined by interplay of wire type, winding geometry, number of layers and density of turns
- Litz wire coils outperform their solid wire counterparts
- Solid wire coils with high density of turns show strongest derating



Conclusion and Outlook

- Analytic calculation of power losses and small signal measurements show good agreement. Estimation of the self heating for any WPT coil during the design process is possible.
- Large signal measurements show, that power losses under real working conditions are slightly higher than expected from small signal measurements
- The rated current of WPT coils shows a derating with frequency
- At the working frequency of $f = 125\ \mathrm{kHz}$, the derating, compared to DC operation, can reach 25 % for litz wire coils and up to 50 % for solid wire coils
- We plan to further investigate the AC losses of WPT coils and we plan to provide complete and comprehensive measurement data for the broad portfolio of Würth Elektronik eiSos coils.