A Compact Model for Temperature and Frequency Dependence of Spiral Inductor

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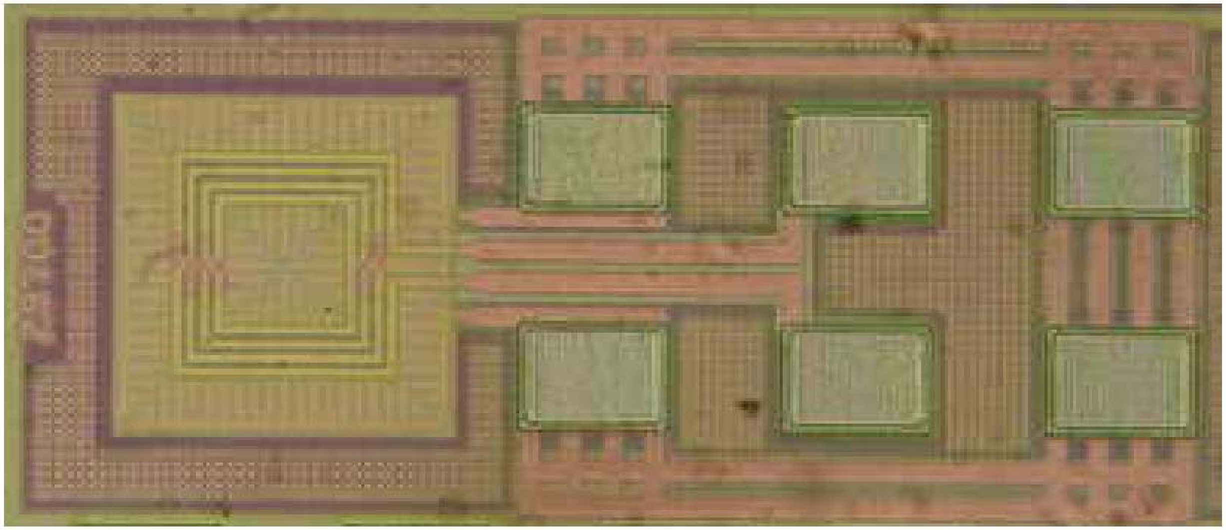
Outline

- Introduction
  - Feature of spiral inductor
- On-chip Spiral inductor layout
- Compact model
  - Equivalent circuit
  - Model and silicon fitting results
- Summary

Feature of Spiral Inductor

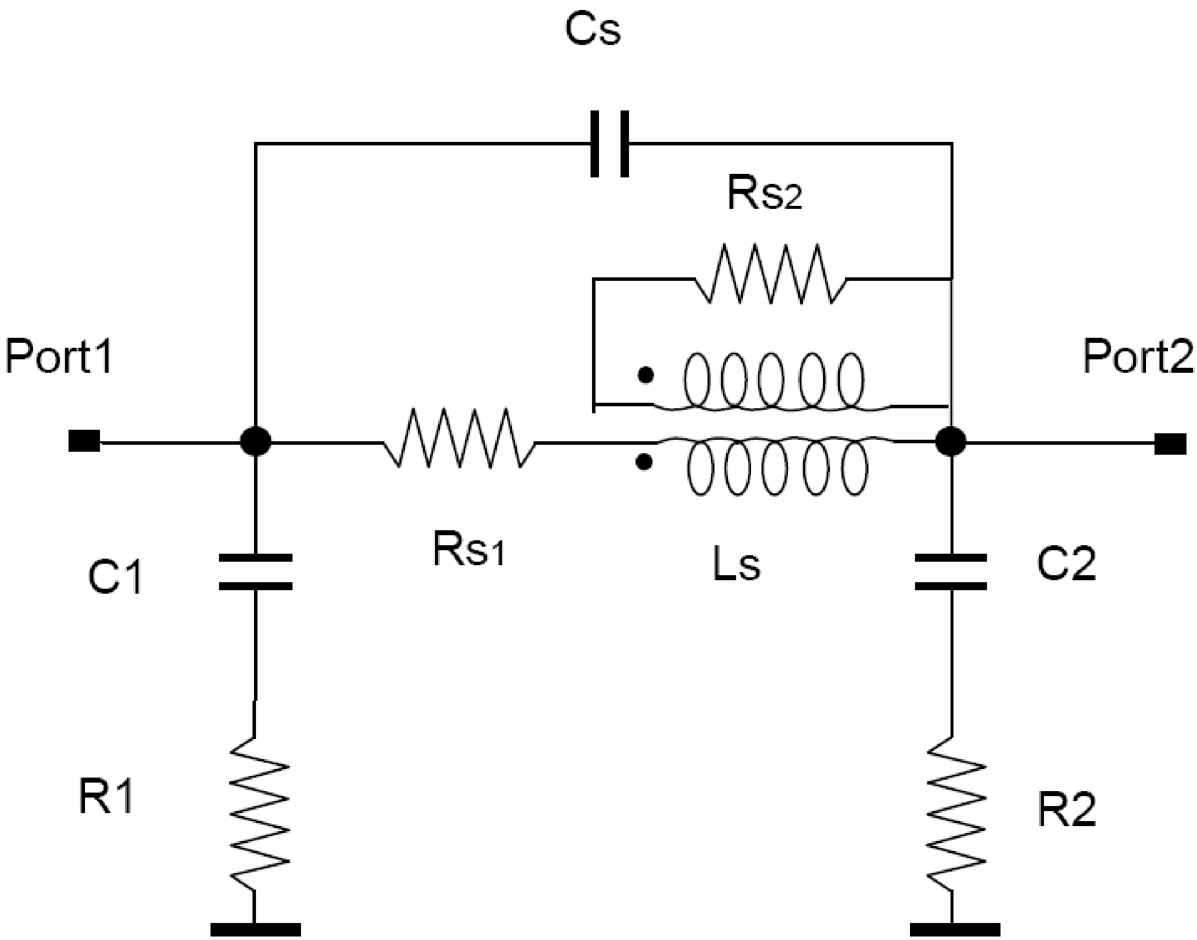
- Critical component for CMOS RF applications
  - VCO, Filter and PLL
- Compatible with CMOS process flow
  - Low cost
  - high reliability
- Drawbacks
  - Low Quality factor limiting phase noise
  - Substrate loss increases with frequency
- Need accurate model to take full advantage of on-chip spiral inductor

Spiral Inductor Layout



- 4-turn spiral inductor
- Pattern ground shield and special dummy for better performance and process control
- Standard G-S-G for high frequency measurement
  - Similar layout features for de-embedding structures

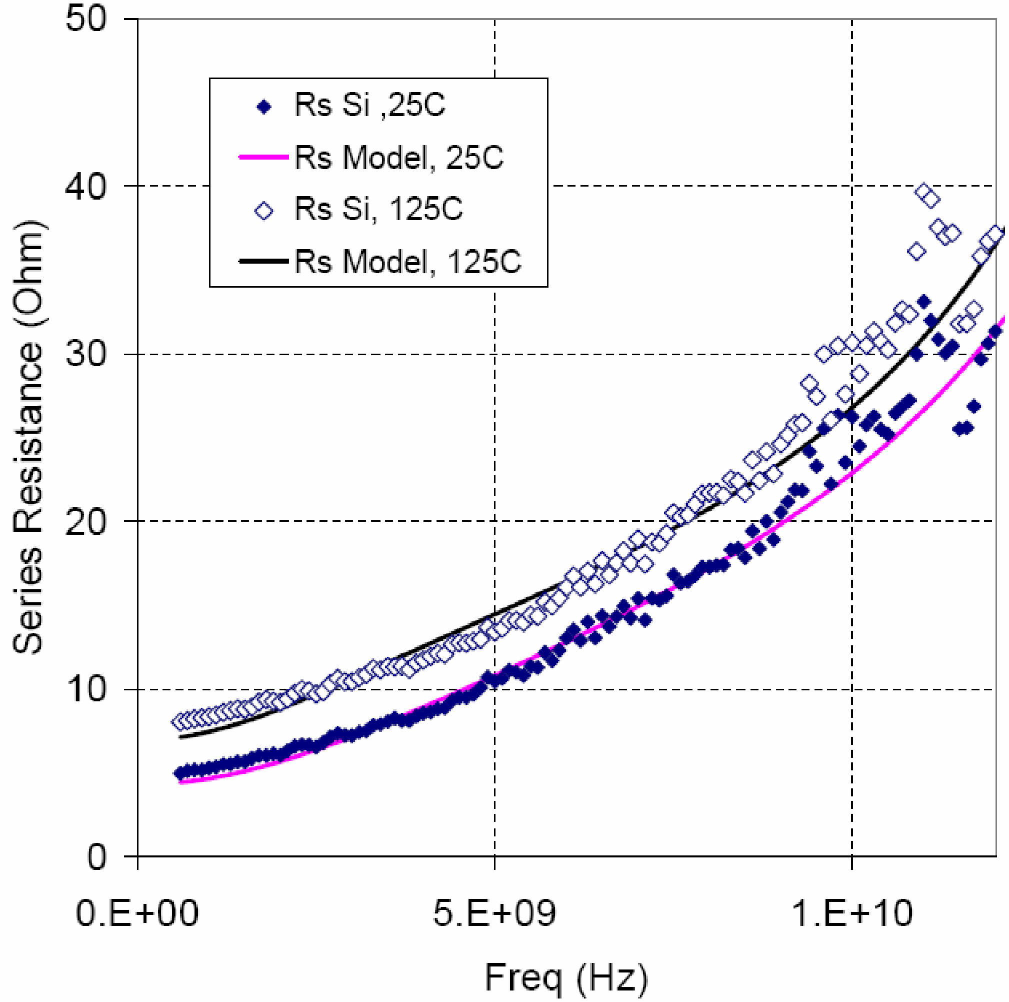
Equivalent Circuit for Inductor (1)



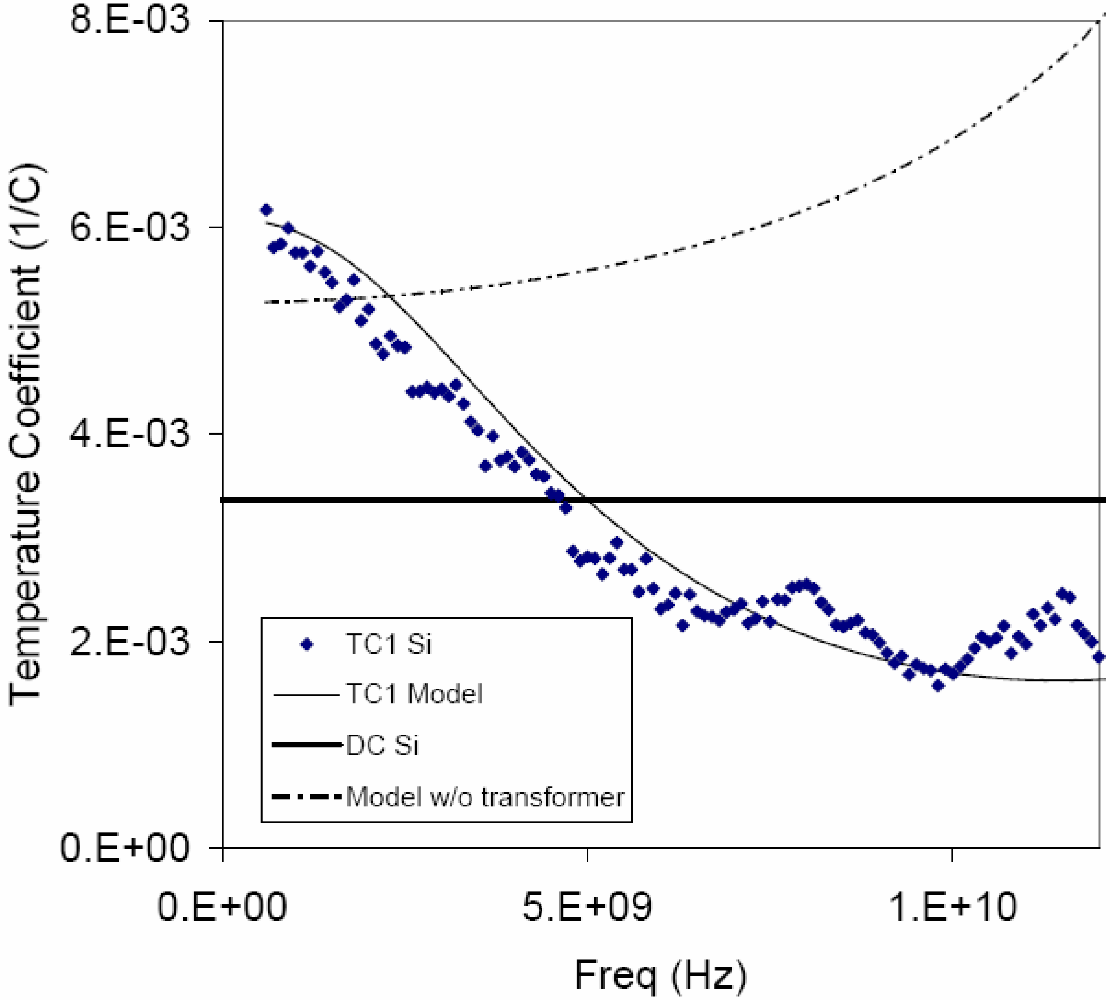
Equivalent Circuit for Inductor (2)

- Typical π-model
- Ls and transformer form main inductance
- Rs1 series resistance of metal lines
  - With metal DC temperature coefficients
- Rs2 resistance non-series
  - Different temperature coefficients used
- C1/R1 C2/R2 represent coupling to pattern ground shield

Fitted Resistance vs Frequency



Temp coefficient vs Frequency (1)

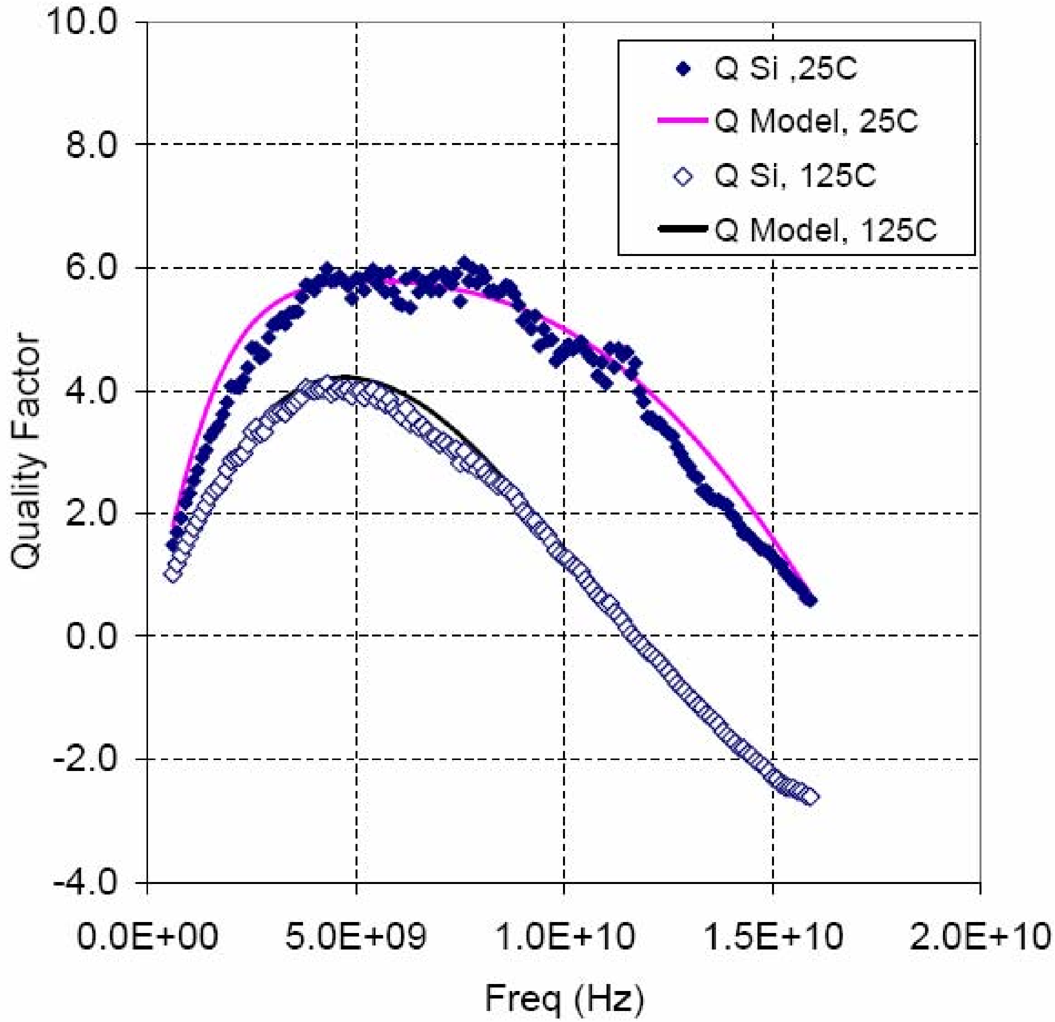


$$\frac{R_s(125^oC) - R_s(25^oC)}{100 \cdot R_s(25^oC)}$$

Temp coefficient vs Frequency (2)

- DC model independent on frequency
- Model without transformer show opposite trend on frequency dependency
- New model with transformer accurately model resistance temperature coefficient vs frequency
- Other parameters also fit very well

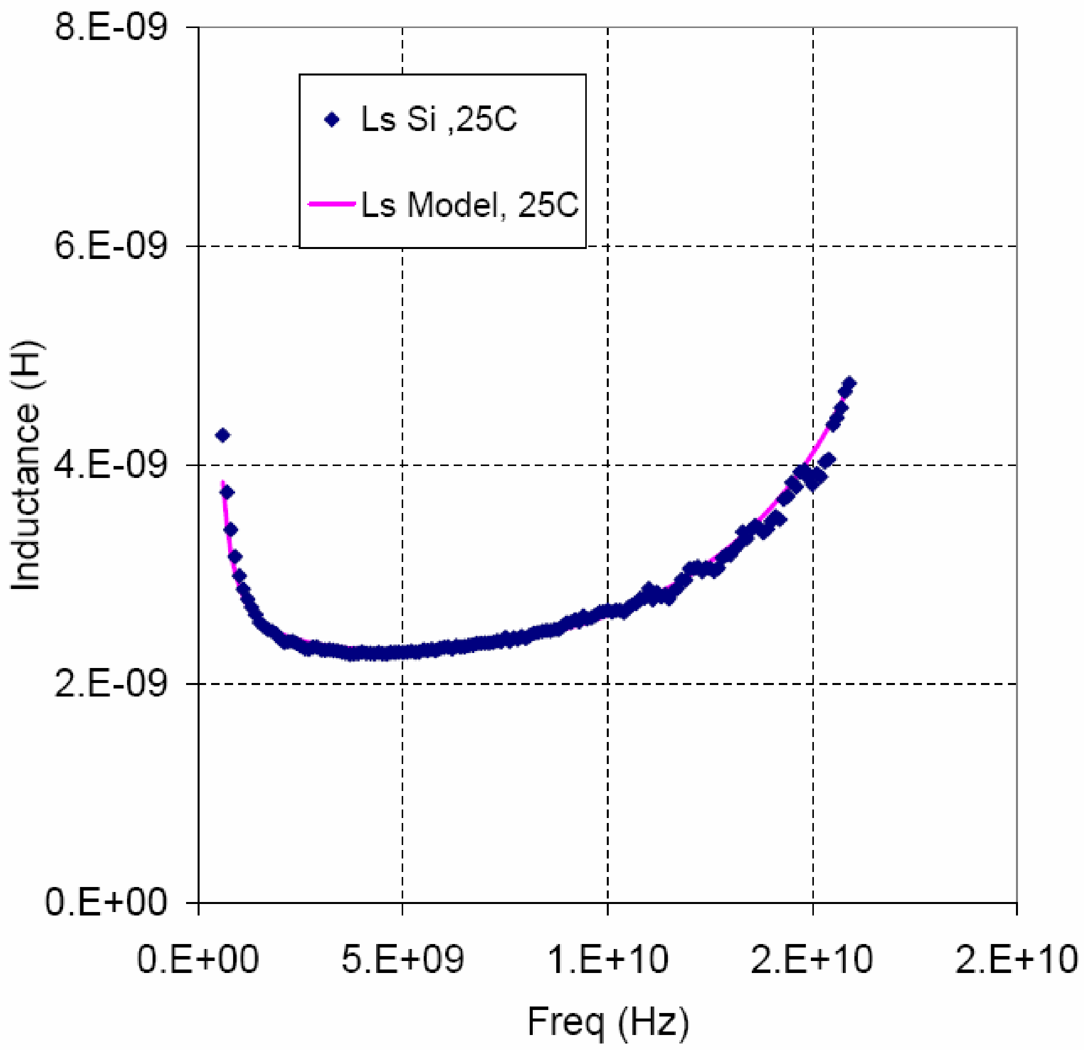
Quality Factor vs Frequency



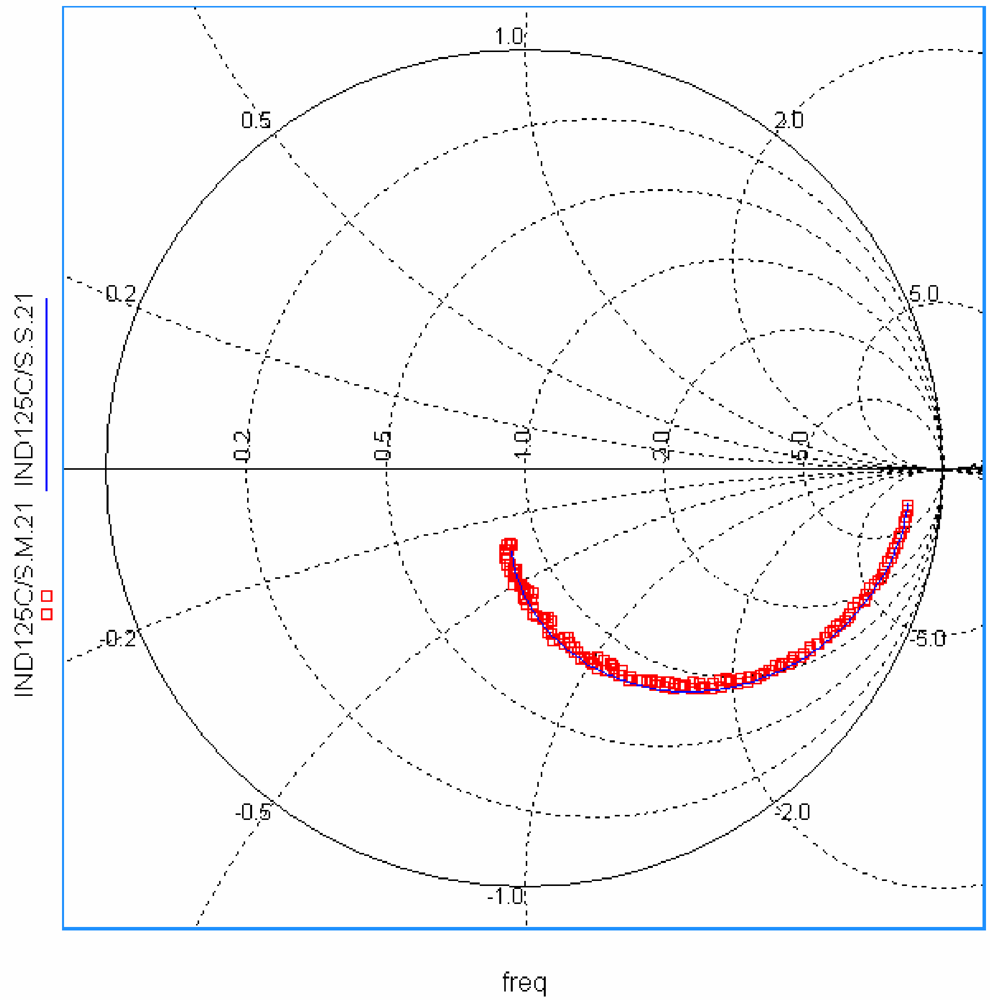
$$\frac{1}{Q} = \frac{1}{Q_{Rp}} + \frac{1}{Q_L} + \frac{1}{Q_c}$$

- System quality factor determined by inductor
- Fitting qualtiy of Q at different temperature important for whole system optimization

Model Inductance vs Si



Measured and Model S-parameter



Summary (1)

- On-chip spiral inductor designed
  - With pattern ground shield
  - Standard G-S-G pads for both DUT and de-embedding structures
- Need accurate model at different temperatures
  - System Q (or phase noise) determined by spiral inductor
  - Conventional π-model not able to accurately model inductor at different temperatures

Summary (2)

- New π-model with a transformer for on-chip inductor proposed
- Accurately model resistance temperature coefficients
  - A prerequisite to accurately model Q factor
- Good fitting qualities for all parameters
  - Q vs frequency
  - Ls vs frequency
  - S parameters