Accurately Measure Inductance with DC BIAS to 125Amps

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Why Measure Inductors at All?

- As efficiencies increase, the inductor losses have more impact
- Major influence on voltage ripple
- Counterfeit materials abound
- To Obtain, L, R, C model for simulation
Why With DC Bias

Saturated inductors result in higher ripple current, degrading efficiency.

Ripple Current

Saturated inductors results in higher ripple voltage.

Ripple Voltage

DC-DC Converters are shrinking, we need smaller components.

Optimizing is important.
Saturated inductors result in increased high frequency content causing increased core loss, increased skin effect loss, and increased EMI.
Three Port FRA Measurement

- Set bias current using constant current mode on bench power supply
- Modulate inductor voltage using a modulator (J2121A used here)
- Measure inductor voltage
- Measure inductor current using monitor or external current probe
- Perform THROUGH calibration with 1Ω resistor
Frequency Domain

Frequency domain offers much higher resolution data, in a variety of formats that are easier to assess and compare.
Example
Advantages and Disadvantages

Advantages
• Can usually measure at operating switching frequency
• Same Setup Can Measure Negative DC-DC input Impedance

Disadvantages
• Requires external modulation of the voltage source
• Limited Frequency range
• Requires high current power supply and interconnects
• Ground Loop, Requires Differential Probe or Isolation transformer
2-Port Shunt-Through Measurement

Using a 2-Port VNA, the device is measured in shunt with the 2-ports.

An inherent DC ground loop is broken using either a coaxial transformer (J2102B) or a solid-state isolator (J2113A).

S21 scatter parameter is transformed to impedance within the VNA.

The 2-Port Shunt-Through measurement can be used for impedance from 10’s of uOhms to 100’s of Ohms.

https://www.picotest.com/measurements/2-port.html

https://www.picotest.com/measurements/2-portUltralowImpedance.html
Example 400nH/70A

Standex PQ2007-0R4-70-G

The raw 400nH Measurement is 20% below nominal value
De-embedding

\[
\text{Measured} = \text{Mount} // \text{DUT} = \frac{\text{Measured} \cdot \text{Mount}}{\text{Mount} + \text{Measured}}
\]

\[
\text{De-Embedded DUT} = \frac{\text{Measured} \cdot \text{Mount}}{\text{Mount} - \text{Measured}}
\]

MOUNT including the J2131A

\[
\text{Uncorrected Error} = \frac{\text{mount}}{\text{DUT} + \text{mount}} - 1
\]

DC BIAS (J2131A)

Raw % Error vs Inductance in uH

-8% at 100 nH
-24% at 414 nH
-79% at 5 uH

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Post De-Embedded Measurement

A simple math expression can be applied to separate the DUT from the measurement that includes the mount (J2131A and PCB).

De-Embed expression for the 48A measurement

\[
\frac{[48A][mount]}{[mount] - [48A]}
\]
De-embedding Comparison

Ideal vs De-embedded Measurement

- 150 nH
- 150 nH de-embedded — 1.5 µH
- 1.5 µH de-embedded — 5 µH
- 5 µH de-embedded

2.2% average difference
3.3% average difference
2.5% average difference
Advantages and Disadvantages

**Advantages**

- Can measure at operating switching frequency
- Wider frequency range
- No external modulator is required
- Measured using VNA which is better calibration for improved accuracy
- A source amplifier allows measurement with larger AC sources for core loss and Q dependencies
- Much lower current power supply

**Disadvantages**

- Requires a ground isolator
- Requires de-embedding

*Design, Fabrication, and Characterization of Package Embedded Solenoidal Magnetic Core Inductors for High-Efficiency System-In-Package Integrated Voltage Regulators*
Measuring at Higher Signal Levels
Summary

• Two simple methods for measuring frequency dependent inductance with bias were shown
• Up to 20 Amps, the 3-port FRA measurement works well
• Up to 125 Amps, the 2-port shunt-through using a Bias Source works well
• Above 125 Amps, it is possible to parallel Bias Sources

Be careful about self heating which can impact the results. Fewer datapoints, higher receiver bandwidth and limited frequency range all result in faster sweeps. Automation could enable bias, sweep, disable bias

It is possible to damage the VNA if the inductor breaks or becomes desoldered during testing. The energy stored in the bias source is substantial
Thank You and Links

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