Bode 100 as Impedance Analyzer

OMICRON Lab Webinar Series 2020

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Webinar Hints

Open the Q&A function

Send questions to the presenters

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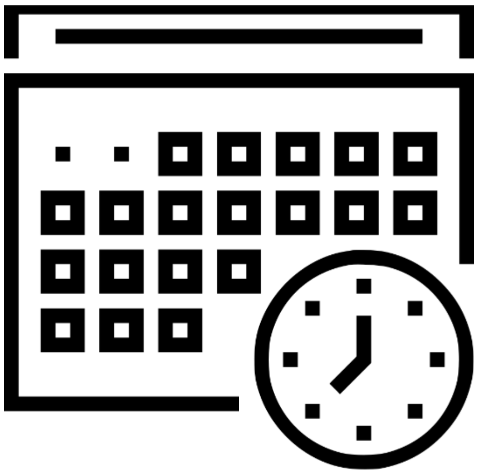
Agenda

- Passive components & equivalent circuits
- Bode 100 impedance measurement methods
- Calibration (user- & full-range)
- Why is it important to measure Cs
  - Live comparison measurement
- Why should we measure Ls
  - Live comparison measurement
  - Leakage inductance
- Additional hands-on live measurements



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Passive Components

- Essential parts in analog circuits
- Inductor and capacitor used e.g. to store energy or to create filter circuits

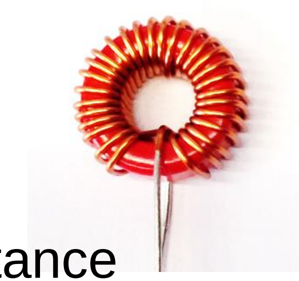
Inductor: $v(t) = L\frac{di(t)}{dt}$ $\quad X_L = \omega L \quad \frac{V}{I} = Z_L = j\omega L$

Capacitor: $i(t) = C\frac{dv(t)}{dt}$ $\quad X_C = \frac{-1}{\omega C} \quad \frac{V}{I} = Z_C = \frac{1}{j\omega C}$

Theory and Reality

- Theoretically inductor and capacitor are purely **reactive** elements → No resistive behavior and therefore **lossless**
- In reality **parasitics** can strongly influence the real behavior especially at higher frequencies

Examples:

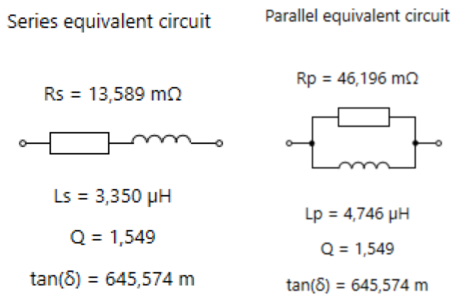


Inductor:
- Wire has resistance
- Windings form electric field
- Core is not lossless

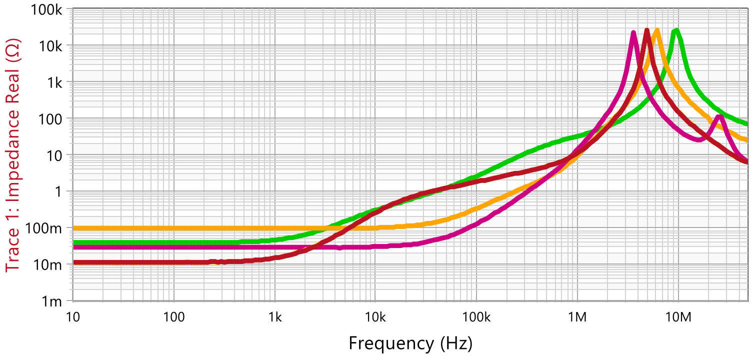
Capacitor:
- Plates are resistive
- Rolling of foils creates inductance
- Insulator not lossless

Equivalent Circuits

- Are used to model the real behavior of the components
- Different complexity of models
  - 1st order models are valid at one particular frequency
    - Fixed Frequency measurement shows R, L and C at one frequency



    - Frequency Sweep calculates R, L and C over frequency



Equivalent Circuits

- Higher complexity models are valid for a frequency range
  - 2nd Order equivalent circuits for inductor and capacitor

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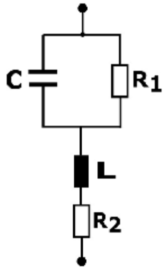

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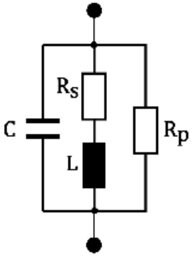
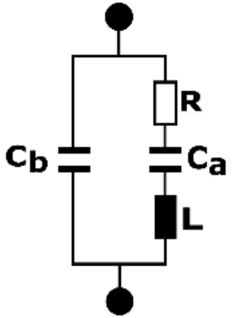


  - 3rd Order models (e.g. quartz crystal or piezo element)



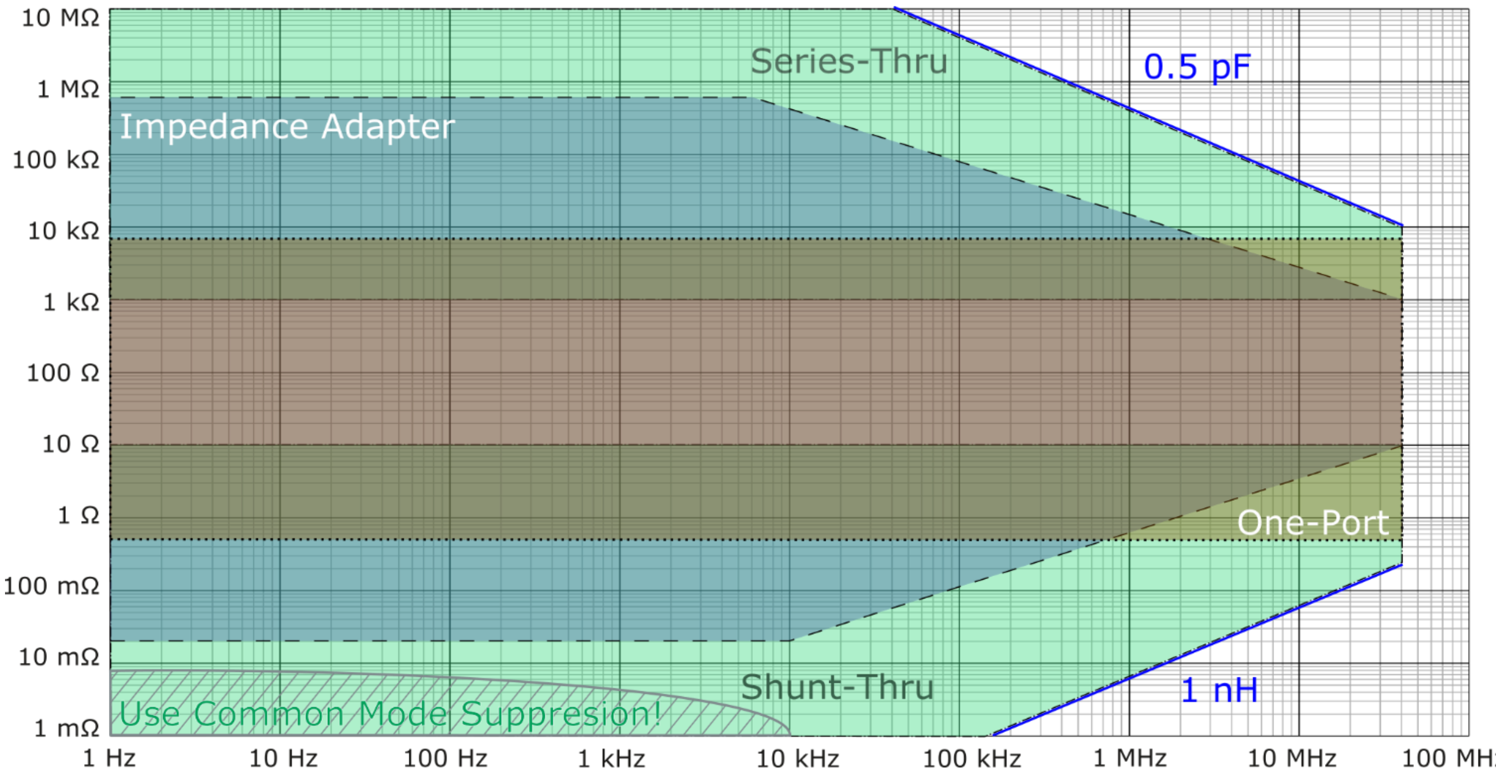
see Application Note:
Equivalent Circuit Analysis of Quartz Crystals
https://www.omicron-lab.com/application-notes/

- Parameter identification requires manual work or e.g. curve-fitting procedure

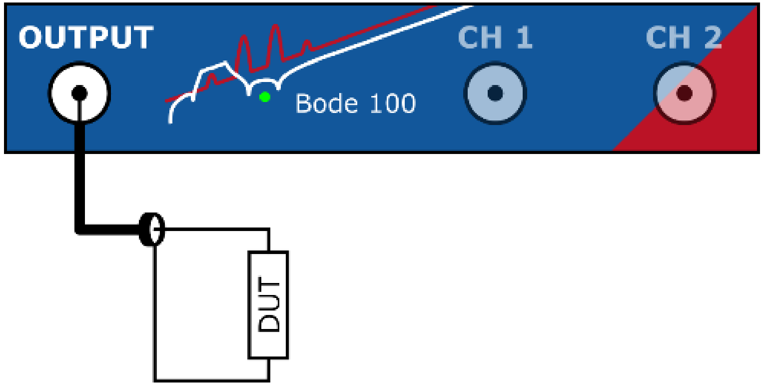
Bode 100 Impedance Measurement Methods

- One-Port Reflection
- Impedance Adapter (3-port technique)
- Shunt-Thru (2-port technique)
- Shunt-Thru with series resistance (similar to Shunt-Thru)
- Series-Thru (2-port technique)
- Voltage-Current Gain (3-port technique)
- External bridge (e.g. high impedance bridge)

Impedance Range Overview



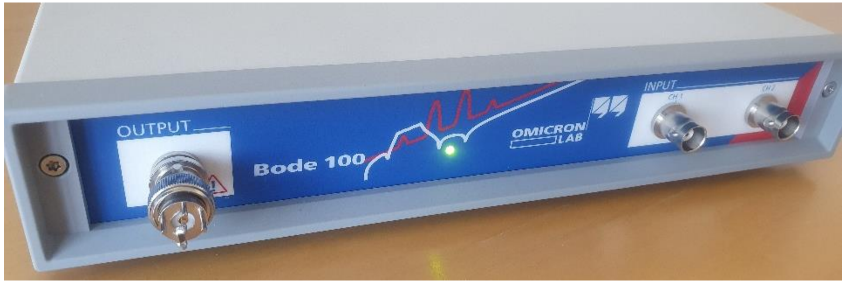
One-Port



- Optimum range ≈ 0.5 Ω - 10 kΩ
- Impedance/Reflection measurement at the output port
- One point is GND
- Can be calibrated with Open/Short/Load (O/S/L)

One-Port (Measurement Setup)

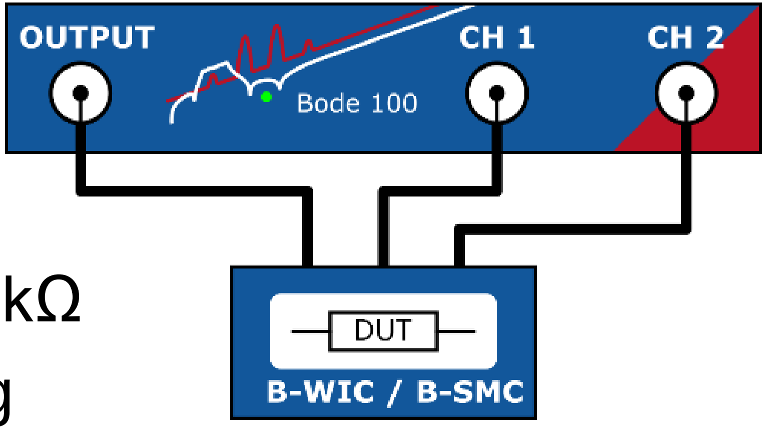
- Solder to BNC connector



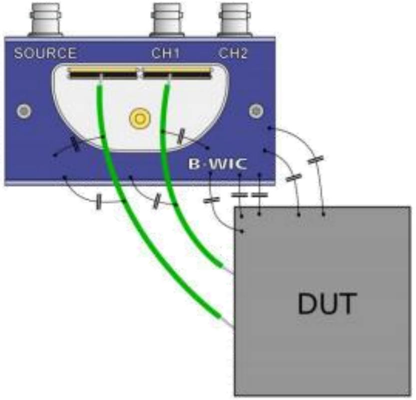
One-Port (Measurement Setup)

- Use BNC to 4 mm adapter

Impedance Adapter

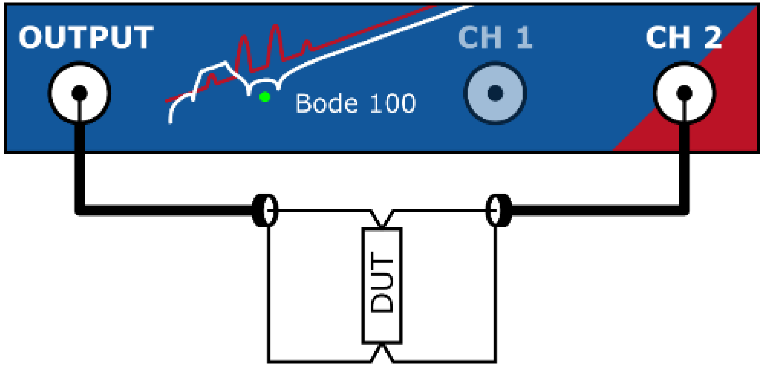


- Optimum range ≈ 20 mΩ - 600 kΩ
- Impedance measurement using the impedance adapters B-WIC or B-SMC
- DUT must not be connected to GND
- Must be calibrated with O/S/L
- Not for physically big components or long leads



Impedance Adapter (Measurement Setup)

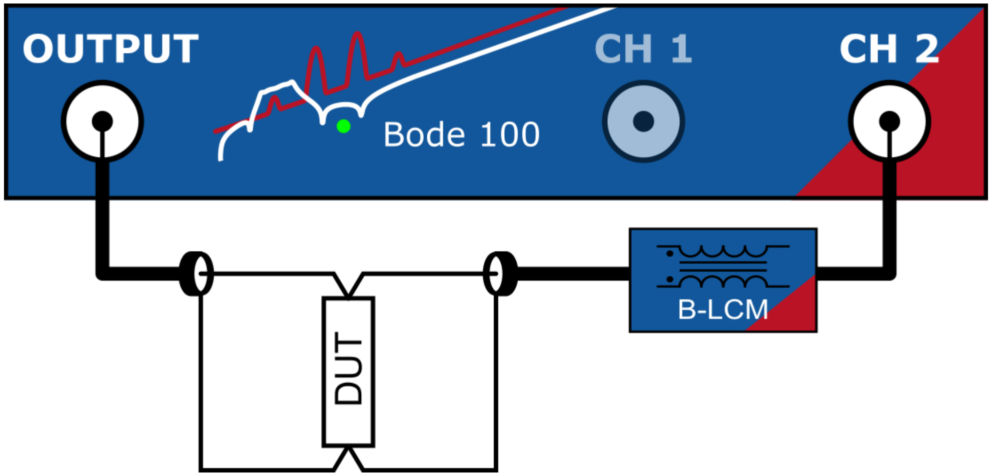
Shunt-Thru



- Optimum range ≈ 1 mΩ - 100 Ω
- Measure impedance using a 2 port shunt-thru setup in the 50 Ω system
- One point is GND
- Can be calibrated with Thru or O/S/L
- Attention: Ground-loop!

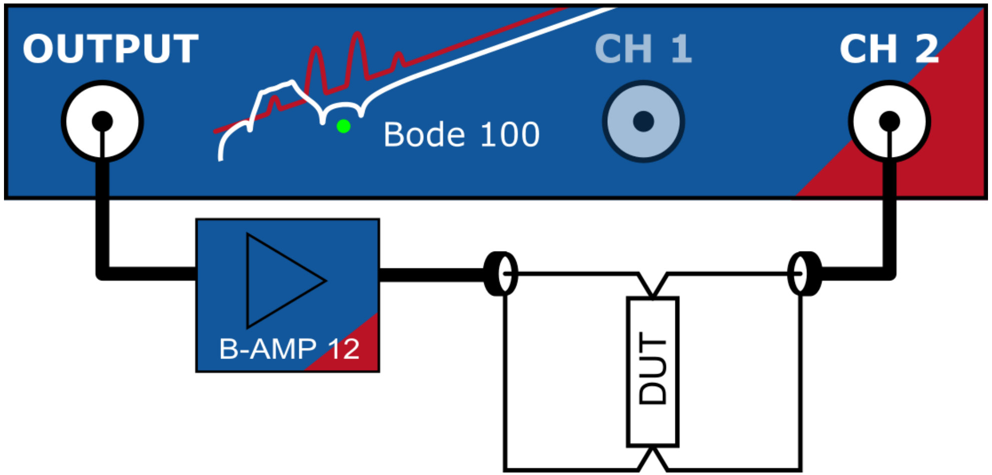
Shunt-Thru (Measurement Setup)

- with the B-LCM to suppress ground-loop error at low frequencies (< 10 kHz to 100 kHz)



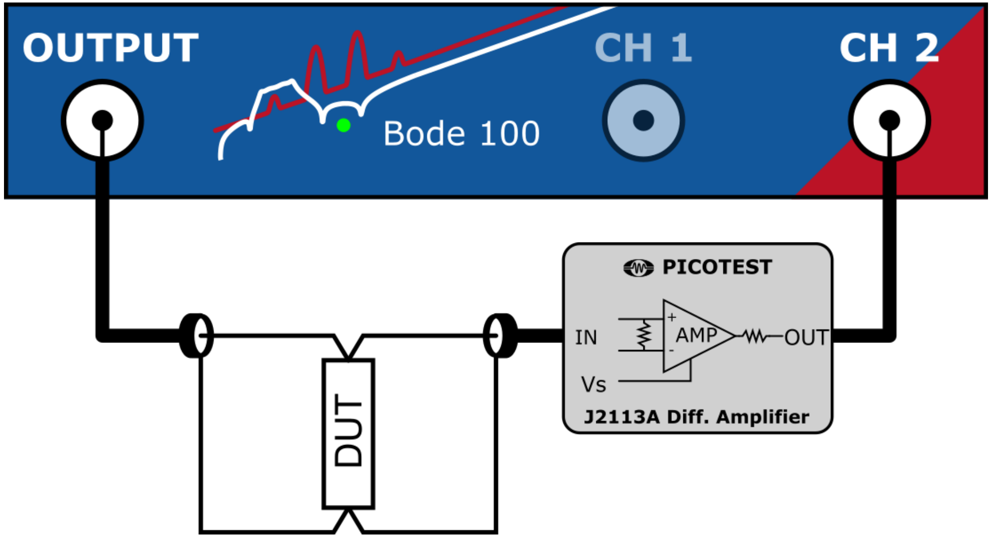
Shunt-Thru (Measurement Setup)

- with the B-AMP 12 to amplify the output signal of the Bode 100 up to 25 dBm



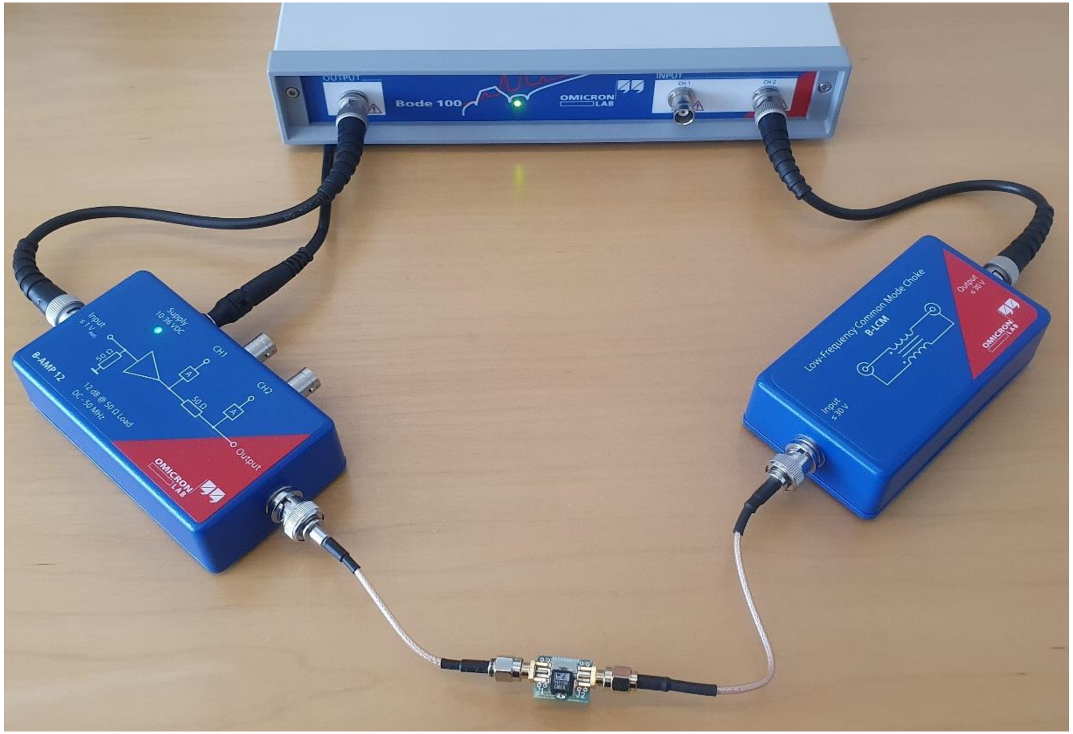
Shunt-Thru (Measurement Setup)

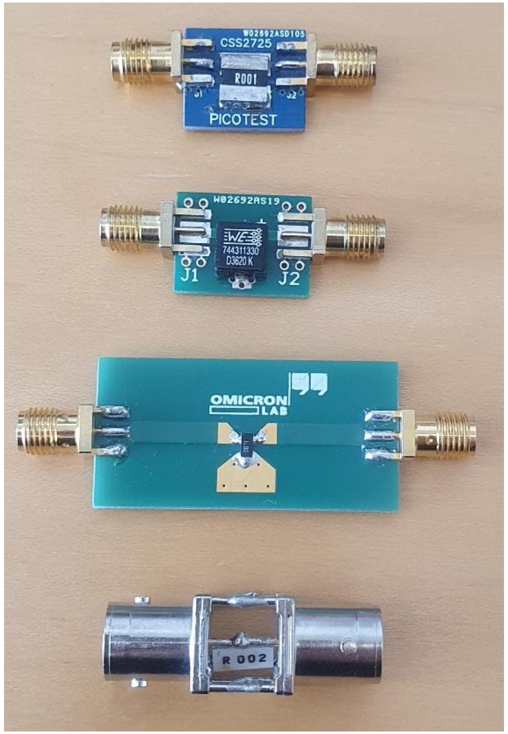
- with the Picotest J2113A differential amplifier to suppress ground-loop error at low frequencies



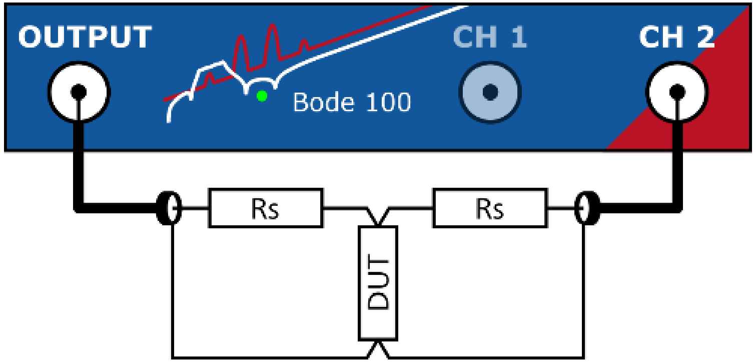
Shunt-Thru (Measurement Setup)

- with B-AMP12 and B-LCM





Shunt-Thru with series resistance



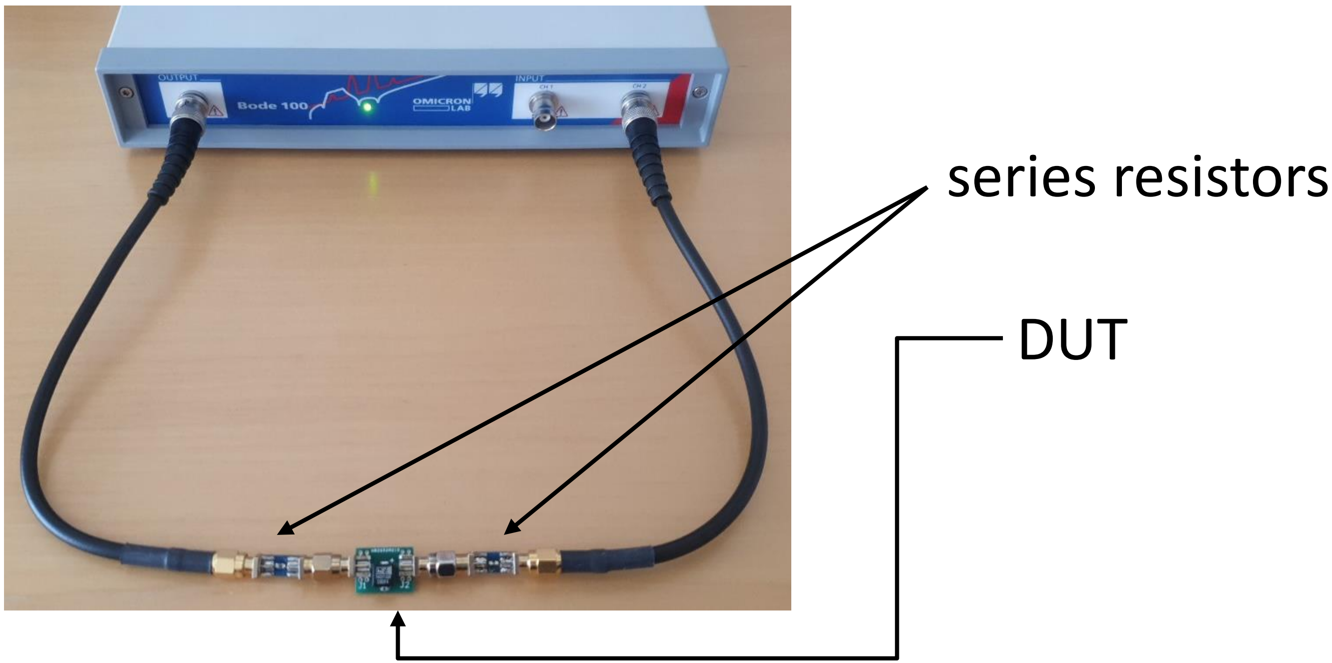
- Optimum range depends on series resistors

  Rs = 200 Ω -> 5 mΩ – 1125 Ω

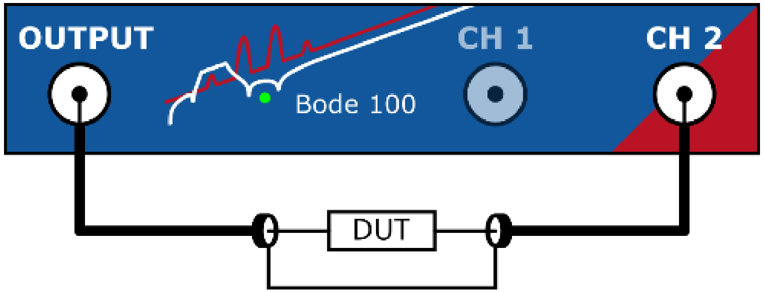
  Rs = 499 Ω -> 11 mΩ – 2480 Ω
- One point is GND
- Must be calibrated
- Higher DC voltages possible
- Attention: Ground-loop!

Shunt-Thru with series resistance (Measurement Setup)

- using Picotest PITK01 boards



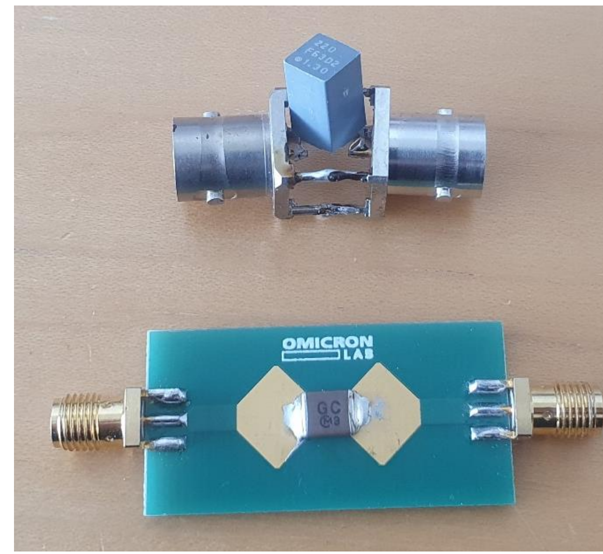
Series-Thru



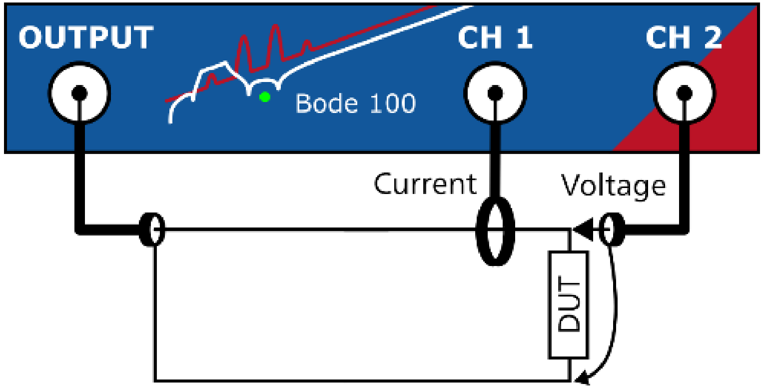
- Optimum range ≈ 1 kΩ - 1 MΩ
- Measure impedance using a 2 port series-thru setup in the 50 Ω system
- DUT must not be connected to GND
- Can be calibrated with Thru or O/S/L

Series-Thru (Measurement Setup)

- with the B-AMP 12 to amplify the output signal of the Bode 100 up to 25 dBm



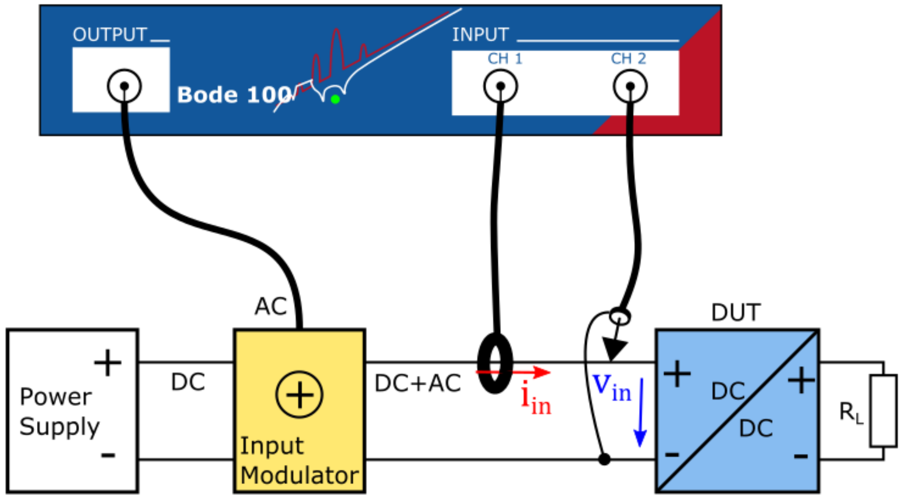
Voltage / Current



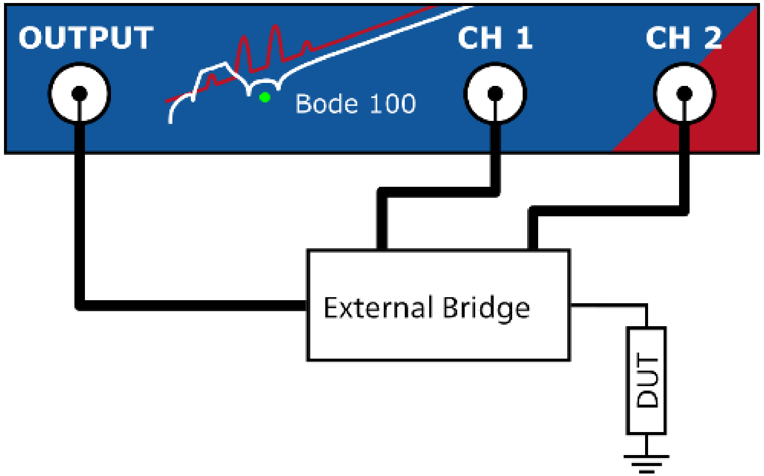
- Range depends on probes
- Measure impedance by using a voltage probe at CH2 and a current probe at CH1
- Can be calibrated with Thru or O/S/L

Voltage / Current (Measurement Setup)

- e.g. for input or output impedance measurement



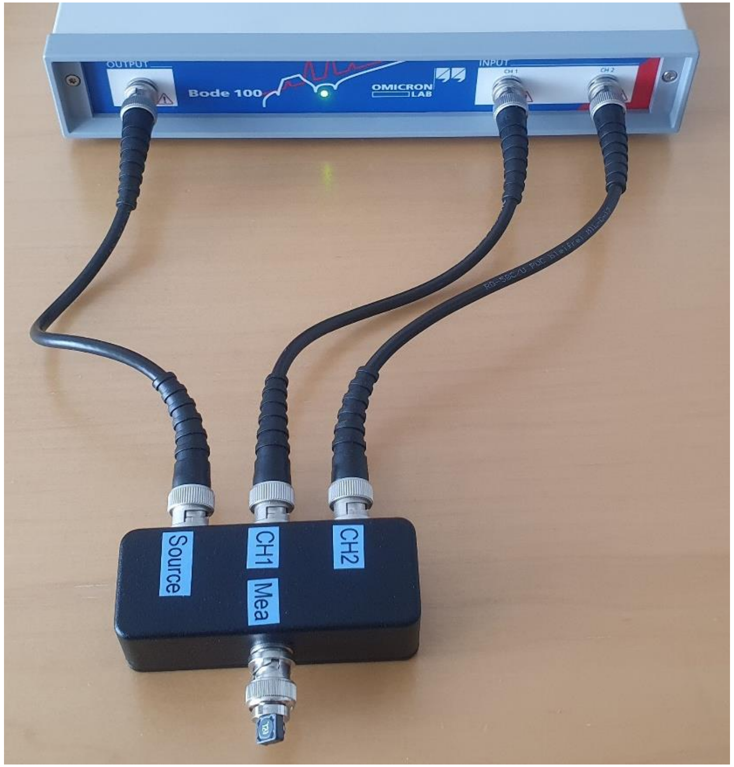
External Bridge



- Range is variable
- Measure impedance using a custom measurement bridge
- Must be calibrated with O/S/L

External Bridge (Measurement Setup)

- high impedance bridge

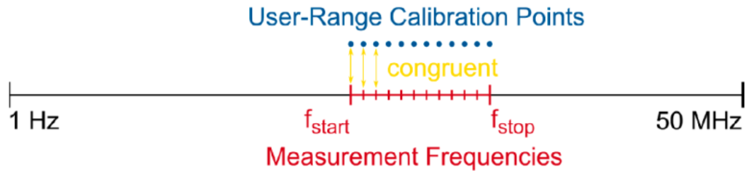


User-Range / Full-Range Calibration

- User Range Calibration

  Calibrates at exactly the frequencies that are currently measured

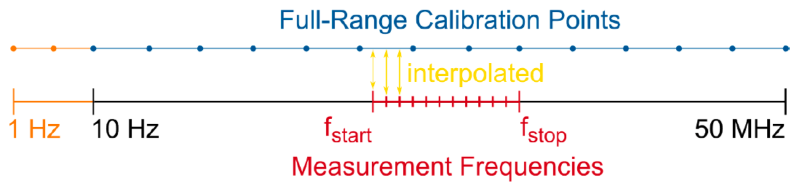
  \+ No interpolation → suitable for narrowband probes



- Full-Range Calibration

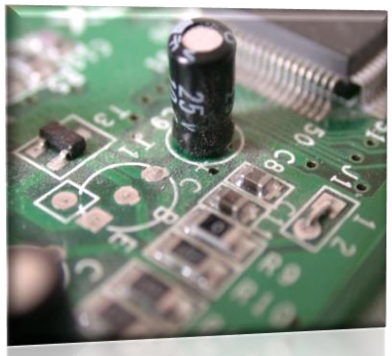
  calibrates at pre-defined frequencies and interpolates in-between

  \+ Calibration does not get lost when frequency range is changed



Why is it important to measure capacitors?

- A capacitor is **NEVER** just a capacitor
- Capacitor ESR influences the phase margin of power supplies
- Capacitor ESR influences the output ripple at the switching frequency of a SMPS
- ESR can change over Frequency
- Capacitors are inductors above their resonance frequency



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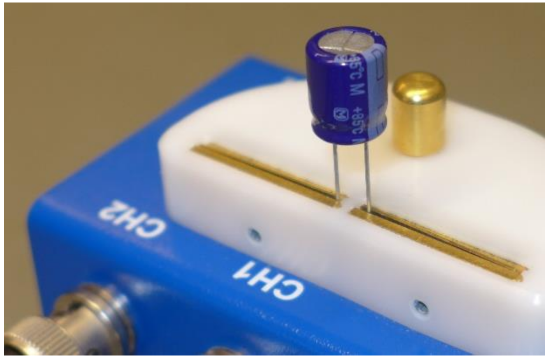
What does the data sheet tell us?

220 µF aluminum capacitor

■ **Standard Products**

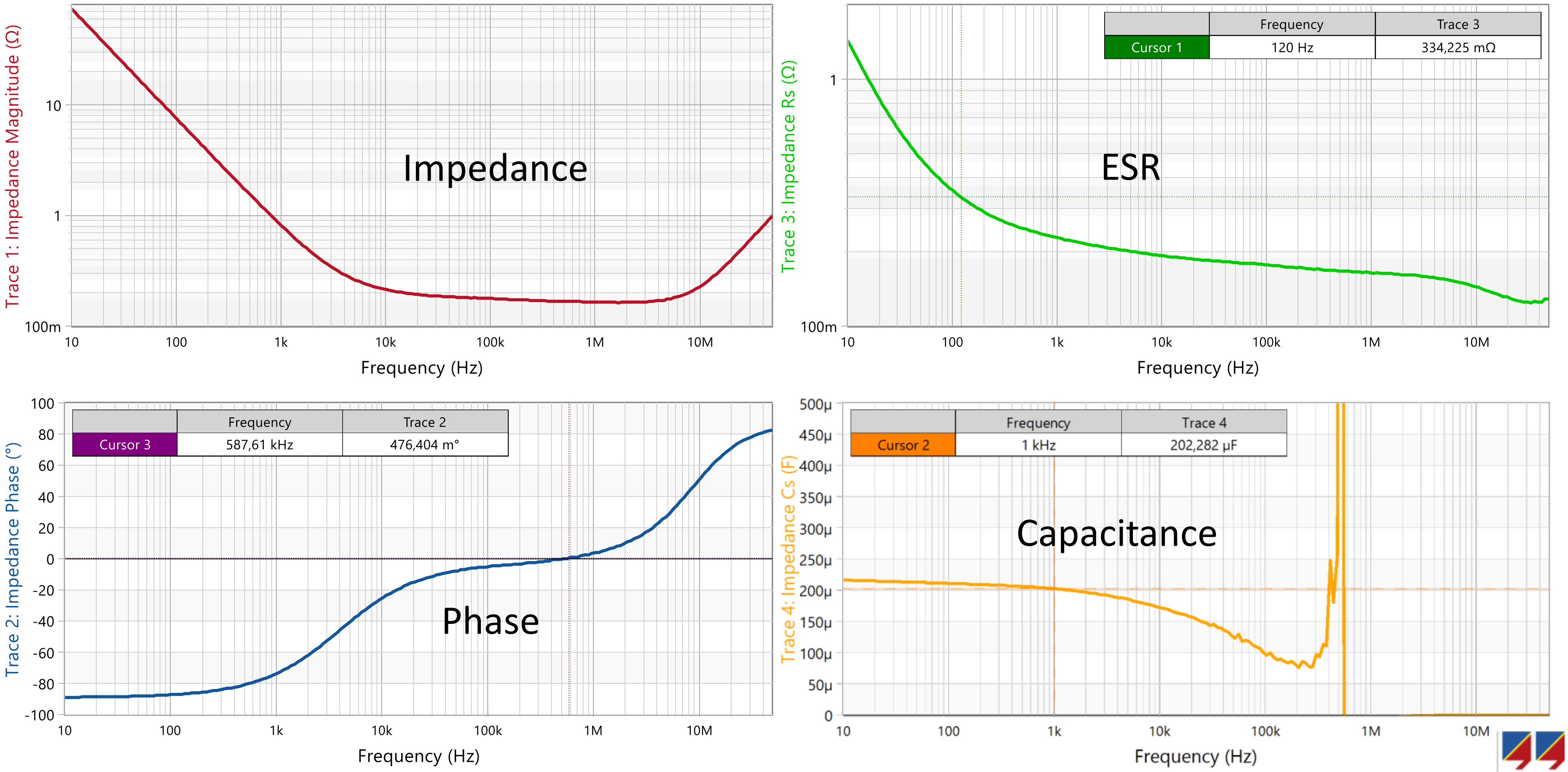
W.V. (V)	Cap. (±20 %) (µF)	Case size		Specification		Lead Length				Part No.	Min. Packaging Q'ty	
		Dia. (mm)	Length (mm)	Ripple Current (120 Hz) (+85 °C) (mA r.m.s.)	tan δ (120 Hz) (+20 °C)	Lead Dia. (mm)	Lead Space: Straight (mm)	Lead Space: Taping ✻B (mm)	Lead Space: Taping ✻i (mm)		Straight Leads (pcs)	Taping (pcs)
	220	10	12.5	400	0.12	0.6	5.0	5.0		ECA1HM221( )	200	500



$$\mathrm{C} = 220\mu\mathrm{F}\ (\pm\ 20\%)$$

$$ESR = \frac{\tan(\delta)}{\omega C} = \frac{0.12}{2\pi \cdot 120Hz \cdot 220\mu\mathrm{F}} = 720\ \mathrm{m}\Omega\ @\ 120\ Hz$$

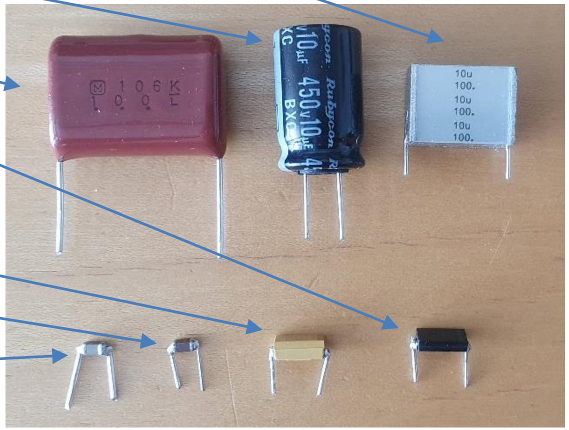
This is what the measurement tells us



Live Comparison Measurement

Measurement of different types of 10 µF capacitors

- film (MKT / PET)
- aluminum
- film (PET)
- aluminum polymer
- tantalum
- ceramic (X5R)
- ceramic (X7R)



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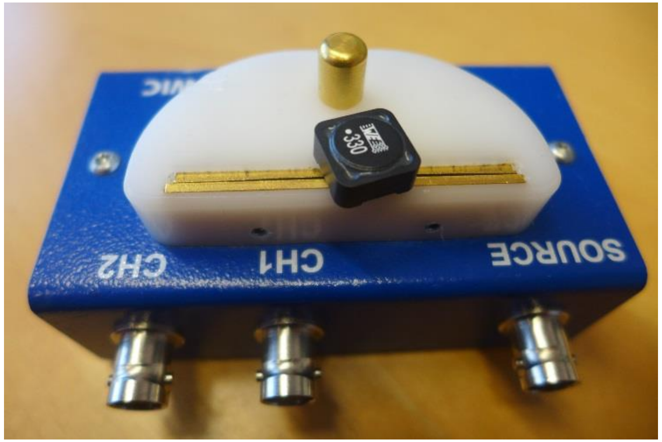
Why should we measure inductors?

- An inductor is **NEVER** just an inductor
- AC resistance <> DC resistance
  - skin effects
  - “Eddie Currents”
- Inductors have resonance frequencies
- Inductors with magnetic cores can have core losses

What does the data sheet tell us?

33 µH shielded power inductor

Properties	Test conditions		Value	Unit	Tol.
Inductance	1 kHz/ 250 mV	L	33	µH	±20%
Rated current	ΔT = 40 K	I_R	2.68	A	max.
Saturation current	|ΔL/L| < 10%	I_{sat}	3.00	A	typ.
DC Resistance	@ 20°C	R_{DC}	0.049	Ω	typ.
DC Resistance	@ 20°C	R_{DC}	0.057	Ω	max.
Self resonant frequency		f_{res}	11	MHz	typ.



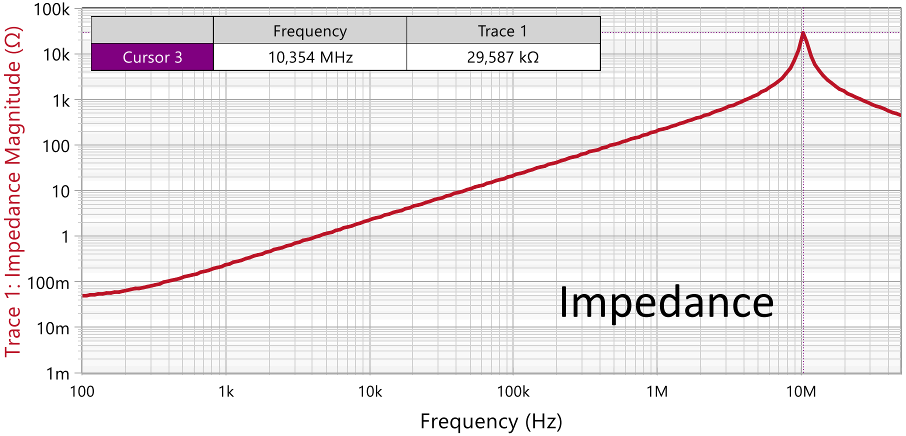
$\mathrm{H} = 33\mu\mathrm{H}\ (\pm\ 20\%)\ @\ 1\ \mathrm{kHz}$

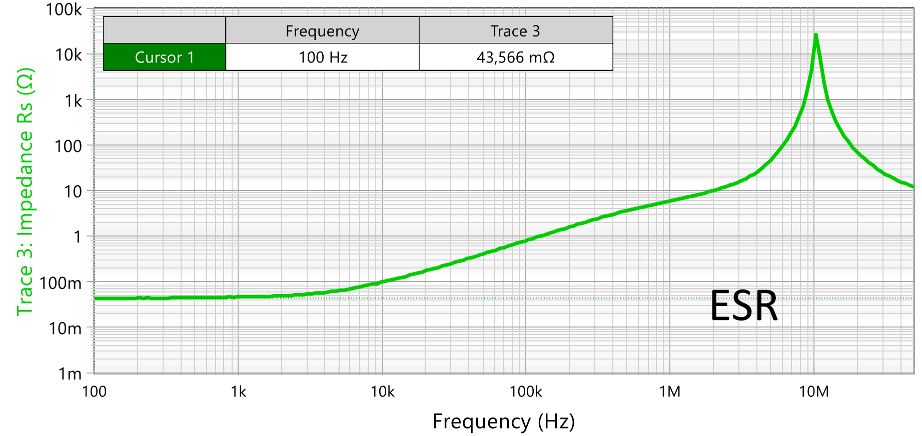
R_{DC}=0,049 Ω $(typ.)$

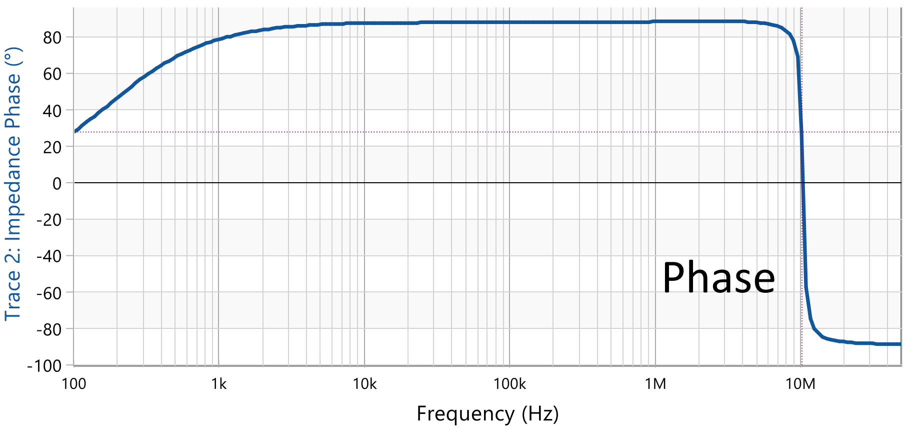
R_{DC}=0,057 Ω $(max.)$

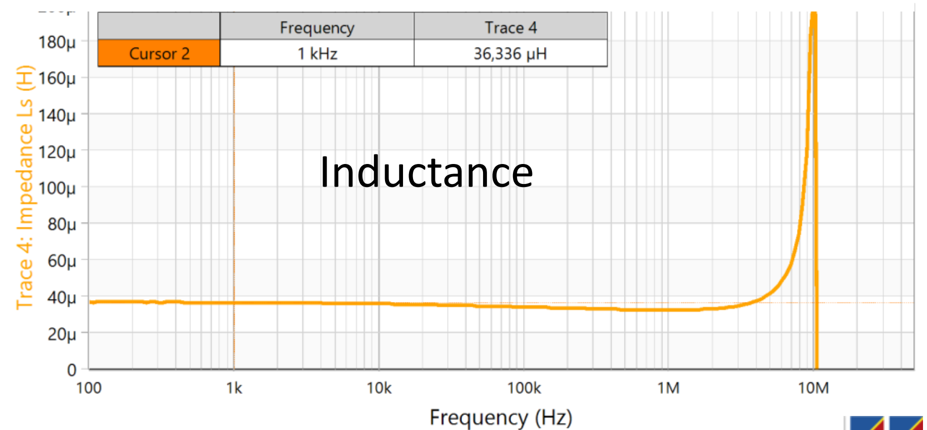
$\mathrm{f_{res}} = 11\ \mathrm{MHz}$

This is what the measurement tells us:





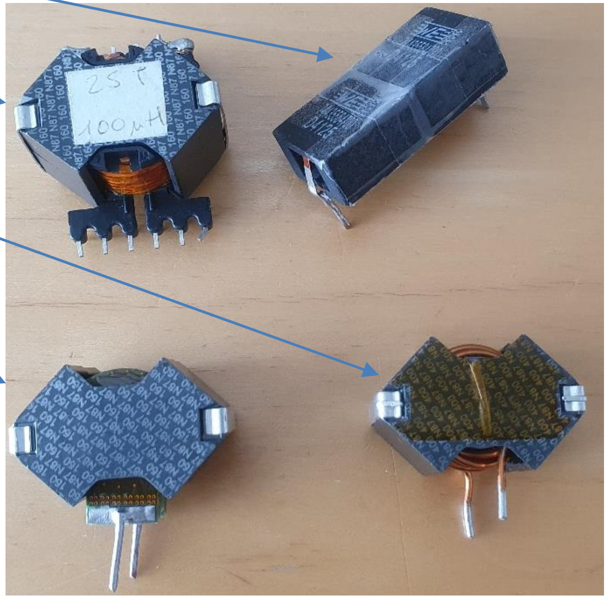




Live Comparison Measurement

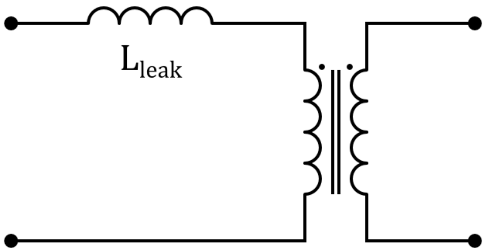
Measurement of different types of 100 µH inductors

- SMD flat band
- litz wire
- copper wire
- planar coils
  (PCB winding structure)



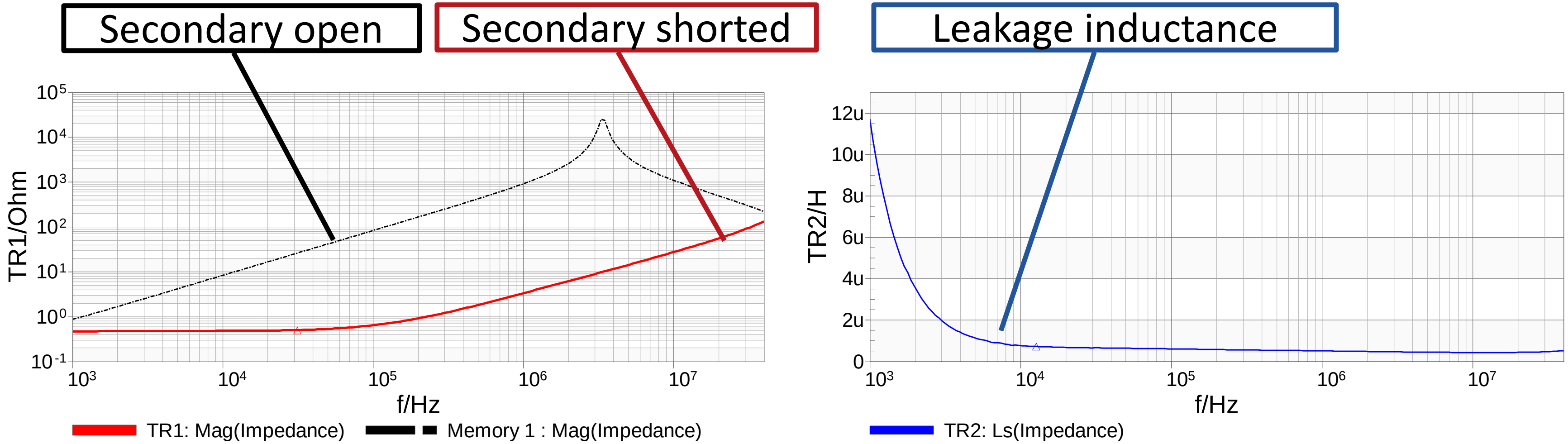
Flyback Transformer Leakage Inductance

- Not all flux generated by the primary winding is coupled to the secondary winding
  - some flux leaks
  - some contributes to core losses
- Represented by a series inductance in the circuit
- Leakage inductance creates a voltage spike when turning off current through primary side (flyback converter)



Measuring Leakage Inductance

Leakage inductance is measured by shorting all other windings except the primary winding



→ Leakage inductance is not constant over frequency

Additional Hands-On Live-Measurements

- Shunt-Thru measurement of
  - mΩ resistor
  - low ESR capacitor

- Series-Thru measurement

Summary

- Component parasitics are important to understand real life circuit behavior
- Models considering parasitics allow better simulation
- Measuring components can tell us more than the data sheet says

References and Further Reading

[1] OMICRON Lab, Bode 100 User Manual, https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/

[2] OMICRON Lab, Impedance Measurement Application Notes, https://www.omicron-lab.com/applications/vector-network-analysis/application-notes/#cuid1:pathGroup=.cuid10

Feel free to ask questions via the Q&A function...

If time runs out, please send us an e-mail and we will follow up.

You can contact us at: info@omicron-lab.com

Thank you for your attention!

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