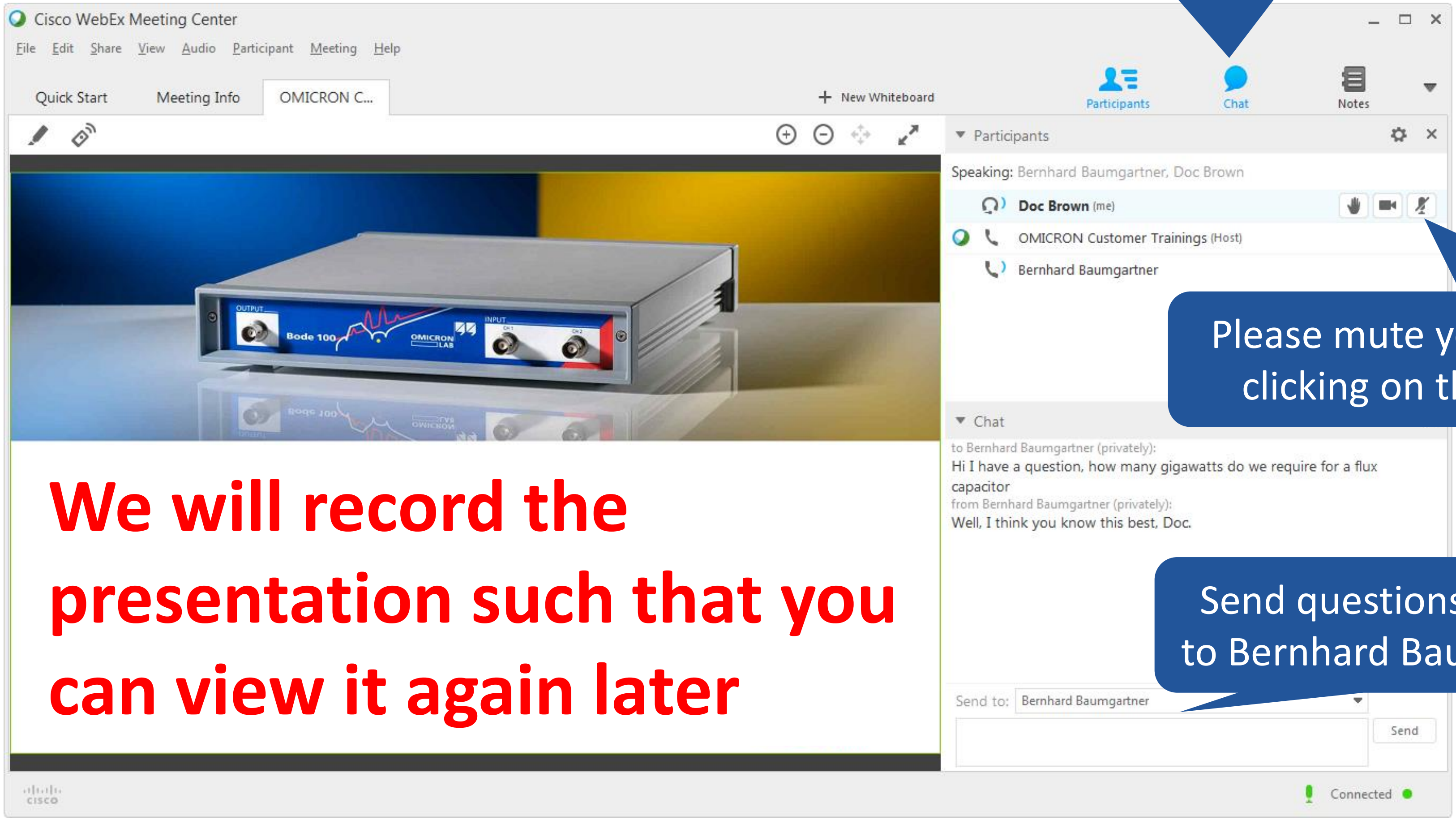
Passive Component Analysis

OMICRON Lab Webinar Nov. 2015

Webinar Hints



to Bernhard Baumgartner (privately):
Hi I have a question, how many gigawatts do we require for a flux capacitor

from Bernhard Baumgartner (privately):
Well, I think you know this best, Doc.

Activate the chat function

Please mute yourself by clicking on this icon!

Send questions via chat to Bernhard Baumgartner

We will record the presentation such that you can view it again later

Agenda

- Why do we analyze passive components
- How to measure component impedance
- A detailed look at a capacitor
- Inductor and transformer
- Filter simulation vs. real world
- Summary

Passive Components

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

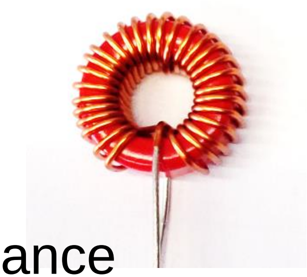
Inductor: $v(t) = L\frac{di(t)}{dt}$ $X_L = \omega L$ $\frac{V}{I} = Z_L = j\omega L$

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

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:

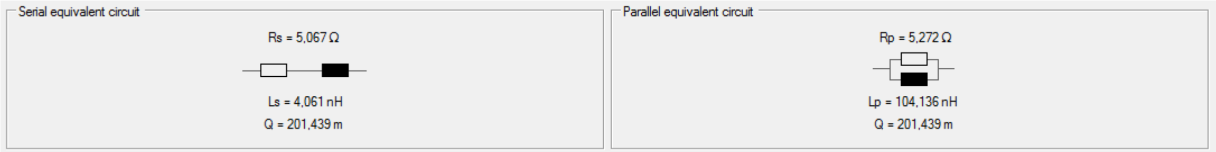
- Wire has resistance
- Windings form electric field
- Core is not lossless

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
  - 1^{st} order models are valid for one frequency
    - Single Frequency Mode in BAS calculates R, L and C



Serial equivalent circuit

Rs = 5,067 Ω

Ls = 4,061 nH

Q = 201,439 m

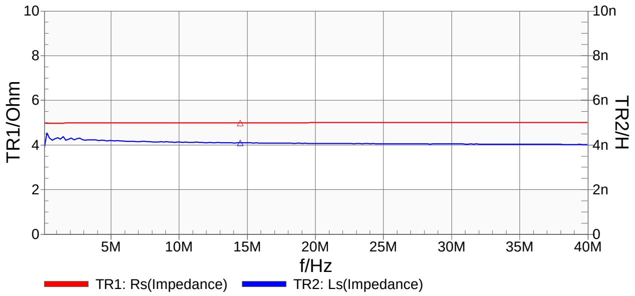
Parallel equivalent circuit

Rp = 5,272 Ω

Lp = 104,136 nH

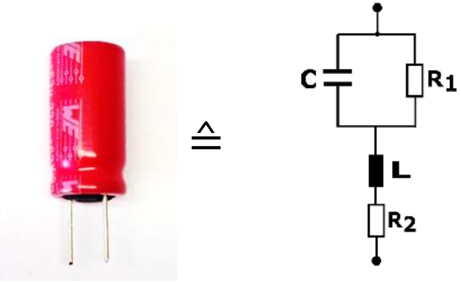
Q = 201,439 m

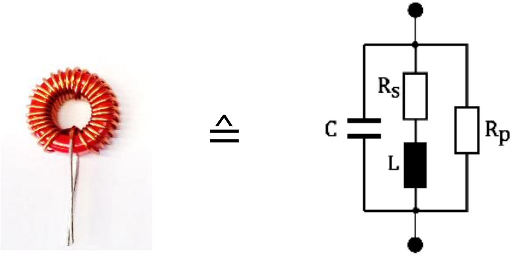
    - Frequency Sweep Mode calculates R, L and C over frequency



Equivalent Circuits

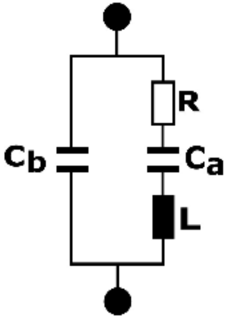
- Higher complexity models are valid for a frequency range
  - 2nd Order equivalent circuits for inductor and capacitor





  - 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

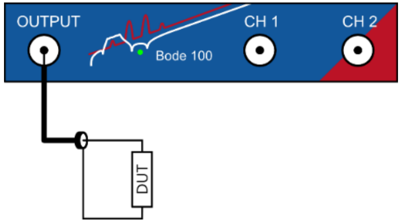
Bode 100 Impedance Measurement Methods

- Direct Measurements
  - One-Port Reflection
  - Impedance Adapter (3-port technique)
  - External bridge (e.g. high impedance bridge)

- Indirect Measurements (via Gain)
  - Shunt-Thru (2-port technique)
  - Series-Thru (2-port technique)
  - Voltage-Current Gain (3-port technique)

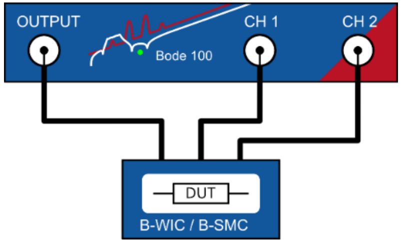
Direct Measurement Methods

One-Port



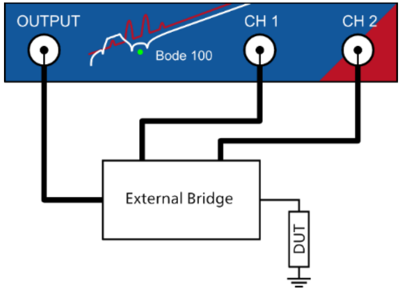
Recommended for 0.5 Ω - 10 kΩ

Impedance Adapter



Recommended for 20 mΩ - 600 kΩ

External Bridge / Coupler

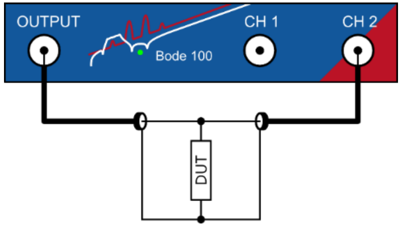


Range depends on bridge

Indirect Measurement Methods

Shunt-Thru

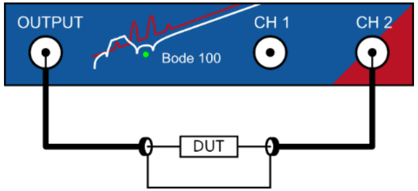
$$Z_{DUT} = 25\Omega \cdot \frac{S_{21}}{1 - S_{21}}$$



Recommended for 1 mΩ - 10 Ω

Series-Thru

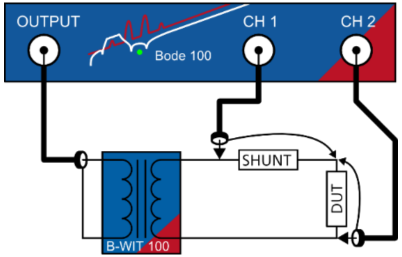
$$Z_{DUT} = 100\,\Omega \cdot \frac{1 - S_{21}}{S_{21}}$$



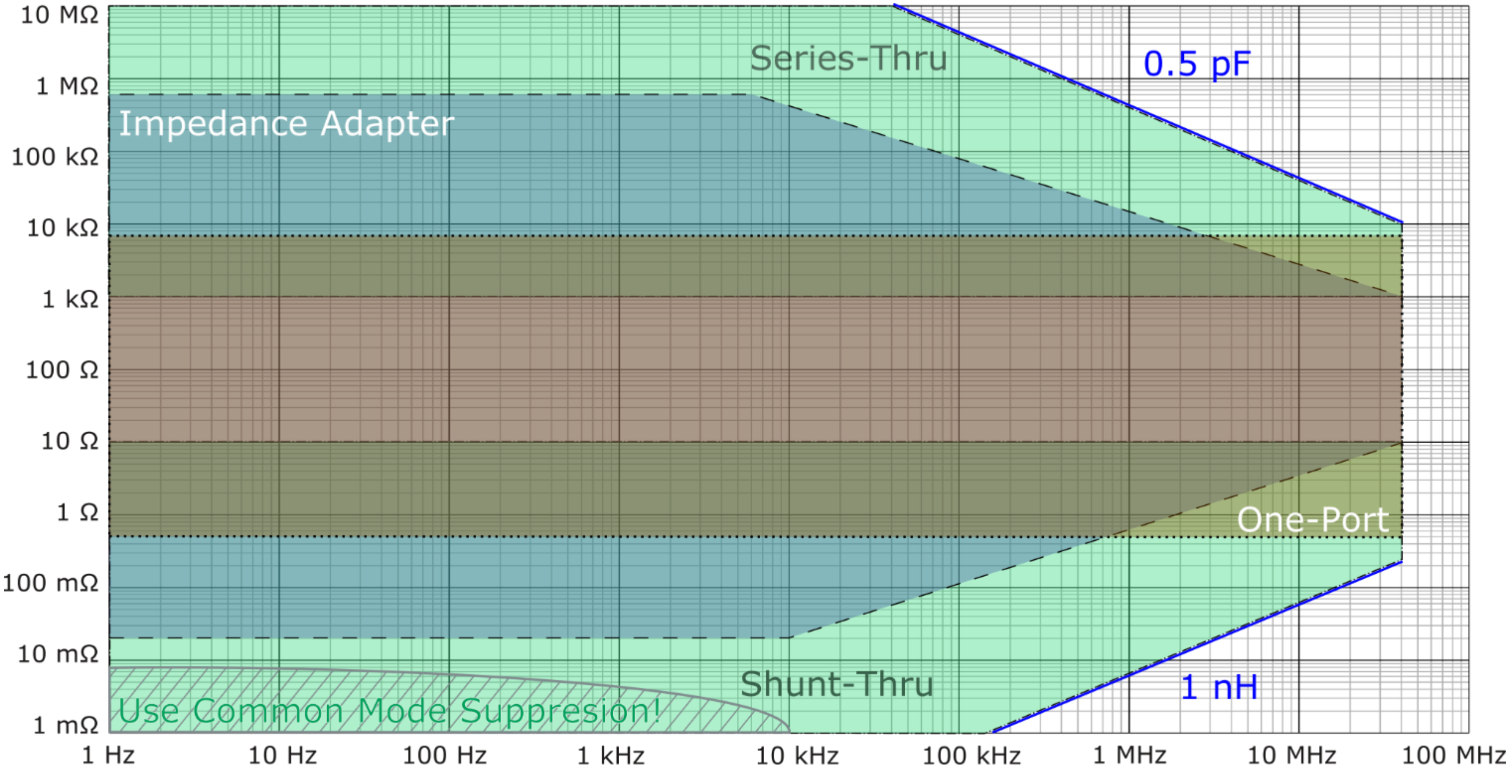
Recommended for 1 kΩ < 10 MΩ

Voltage Current Gain

$$Gain = \frac{V_{CH2}}{V_{CH1}} = \frac{V}{I} = Z_{DUT}$$



Impedance Range Overview

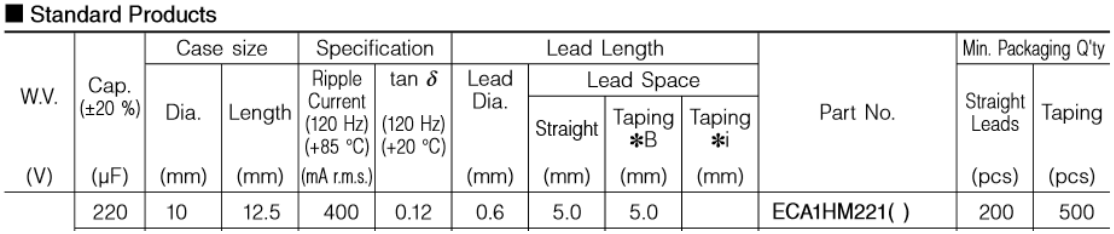


Why is it important to measure capacitors?

- 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

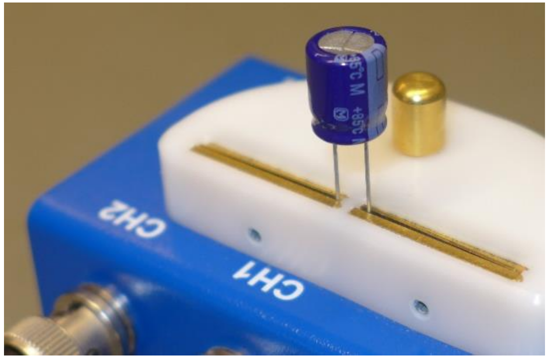
What does the data sheet tell us?

220 µF aluminum capacitor



■ **Standard Products**

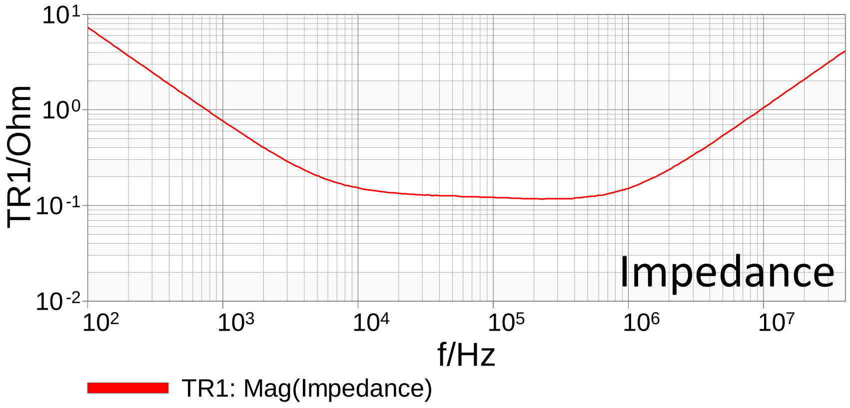
W.V. (V)	Cap. (±20 %) (µF)	Case size		Specification		Lead Length				Part No.	Min. Packaging Q'ty	
		Dia. (mm)	Length (mm)	Ripple Current (120 Hz) (+85 °C) (mA r.m.s.)	tan δ (120 Hz) (+20 °C)	Lead Dia. (mm)	Lead Space				Straight Leads (pcs)	Taping (pcs)
							Straight (mm)	Taping ✻B (mm)	Taping ✻i (mm)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

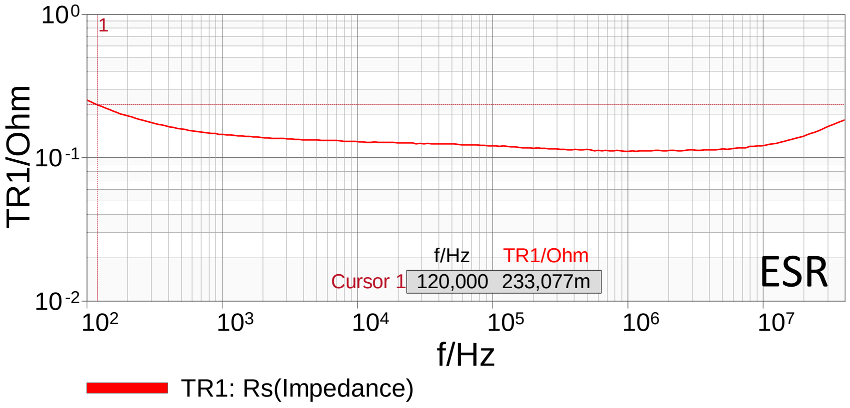


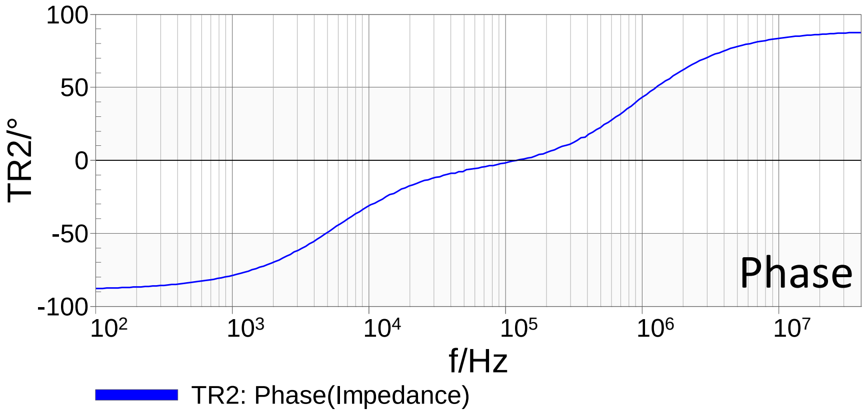
$$\mathrm{C} = 220\mu\mathrm{F}\ (\pm\ 20\%)$$

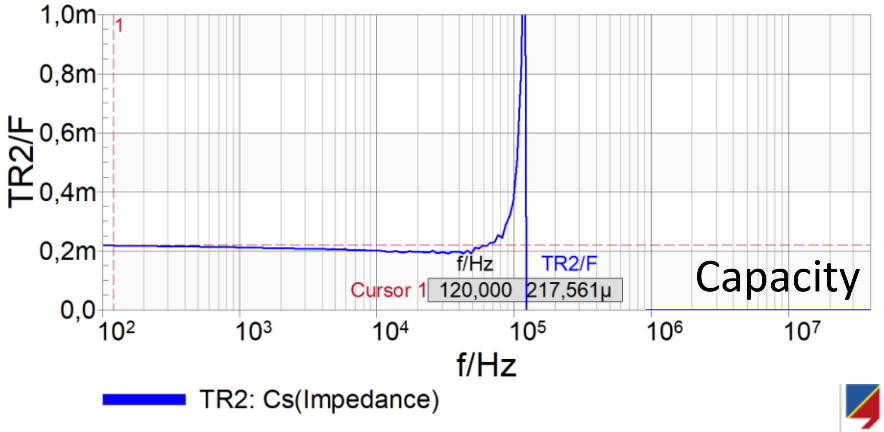
$$ESR = \frac{\tan(\delta)}{\omega C} = \frac{0.12}{2\pi \cdot 120Hz \cdot 220\mu\mathrm{F}} = 0.72\ \Omega\ @\ 120\ Hz$$

This is what the measurement tells us



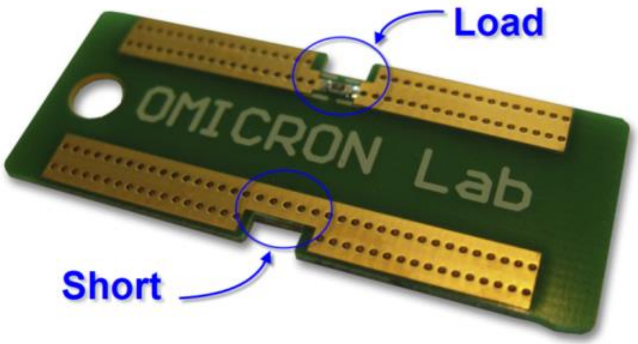


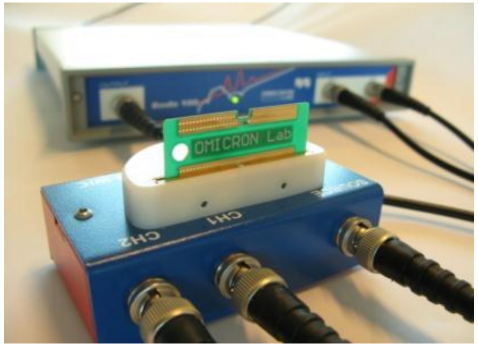




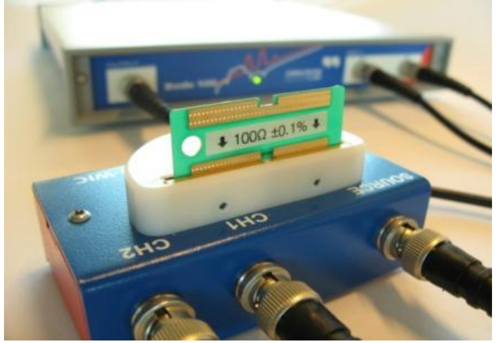
Calibration

Open





Short



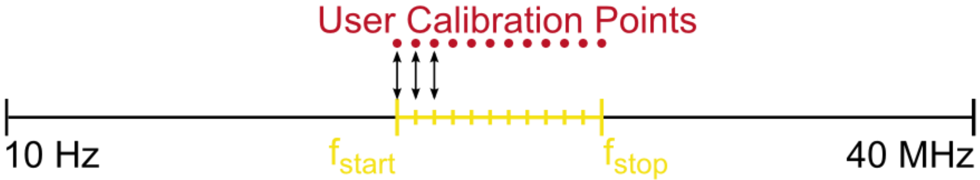
Load

User Calibration / Probe Calibration

- User Calibration (User Range Calibration)

  Calibrates at exactly the frequencies that are currently measured

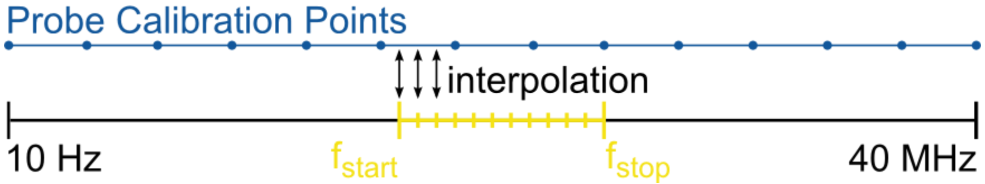
  \+ No interpolation, suitable for narrowband probes



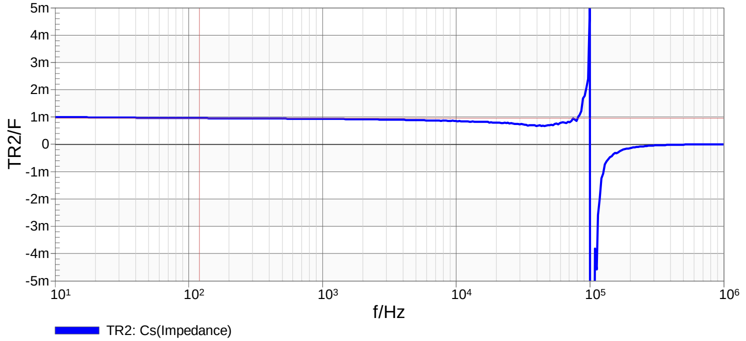
- Probe Calibration (Full Range Calibration)

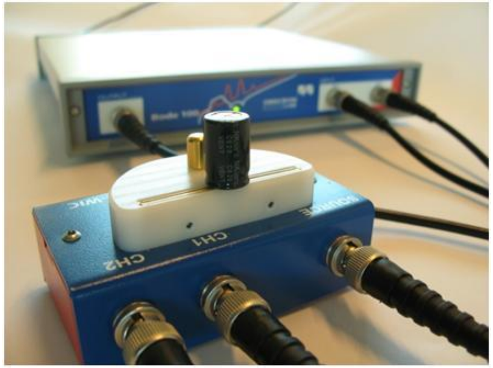
  calibrates at pre-defined frequencies and interpolates in-between

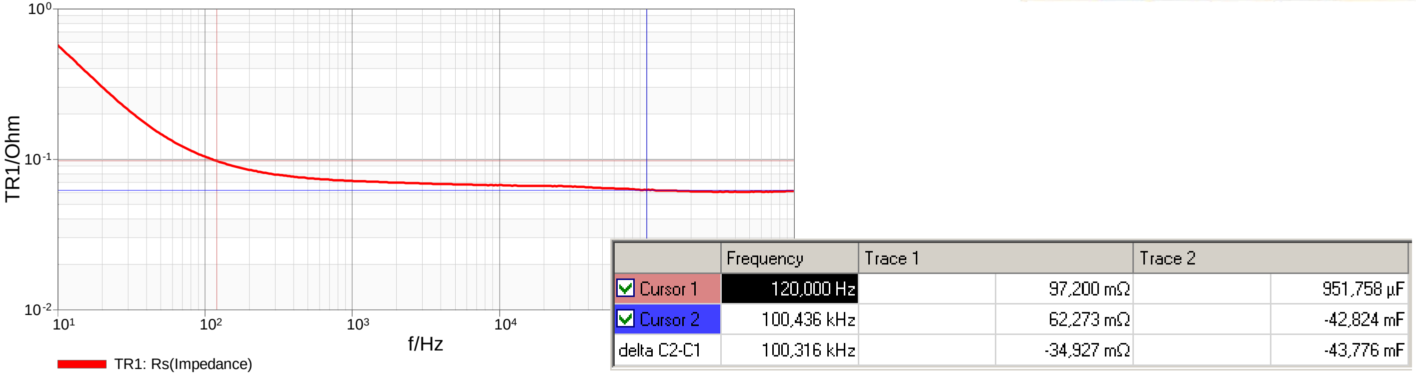
  \+ Calibration does not get lost when frequency range is changed



Detailed Example available







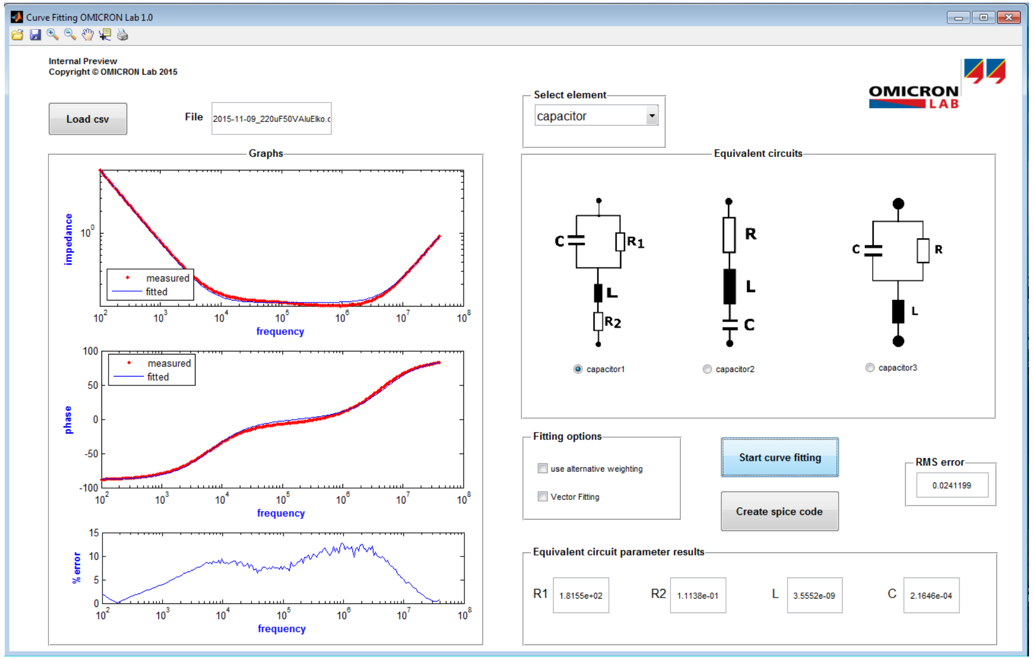
	Frequency	Trace 1	Trace 2
☑ Cursor 1	120,000 Hz	97,200 mΩ	951,758 µF
☑ Cursor 2	100,436 kHz	62,273 mΩ	-42,824 mF
delta C2-C1	100,316 kHz	-34,927 mΩ	-43,776 mF

see Application Note:

Capacitor ESR Measurement with Bode 100 and B-WIC

https://www.omicron-lab.com/application-notes/

Fitting Model to Measured Impedance



File: 2015-11-09_220uF50VAluElko.c

Select element: capacitor

● capacitor1

☐ use alternative weighting

☐ Vector Fitting

RMS error: 0.0241199

Equivalent circuit parameter results

R1 1.8155e+02

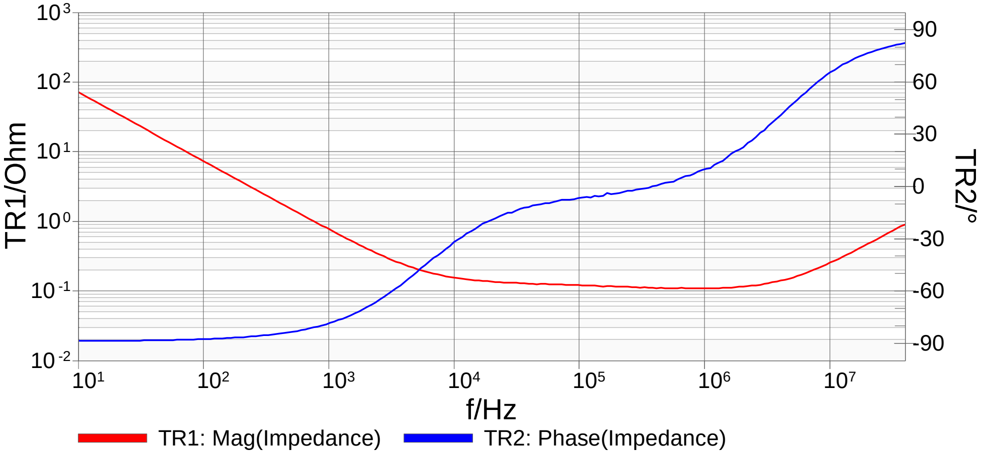
R2 1.1138e-01

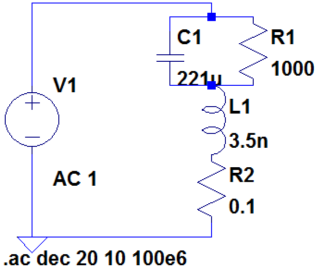
L 3.5552e-09

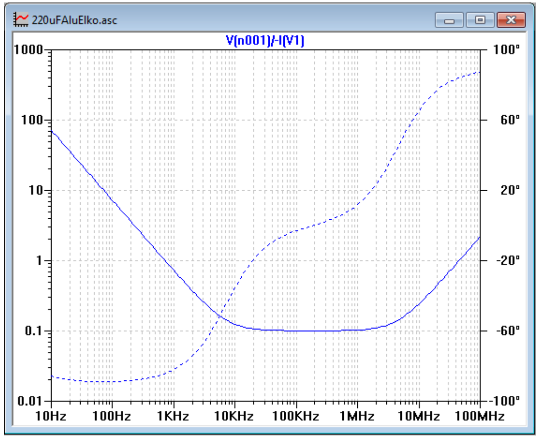
C 2.1646e-04

- Various methods available
- We use curve-fitting
- A Preview tool is available on request

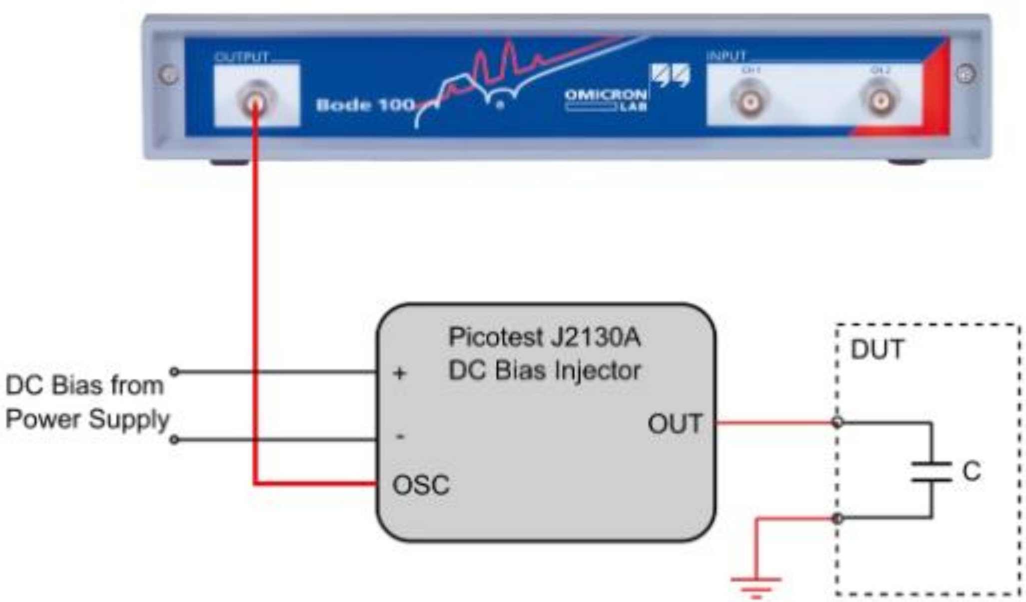
Simulation vs. Measurement

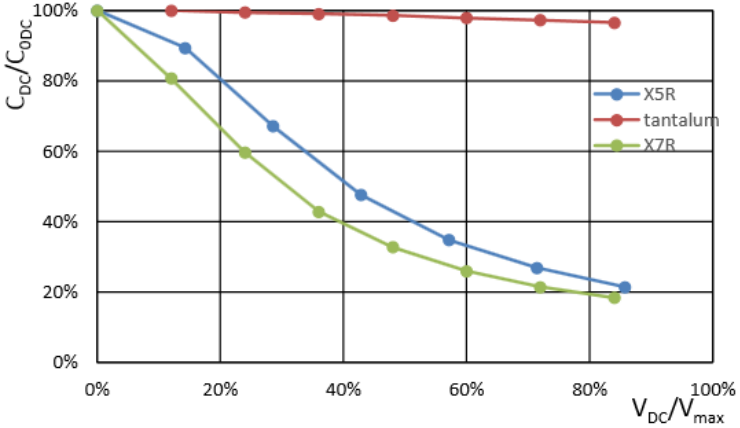






Voltage sensitivity of capacitors





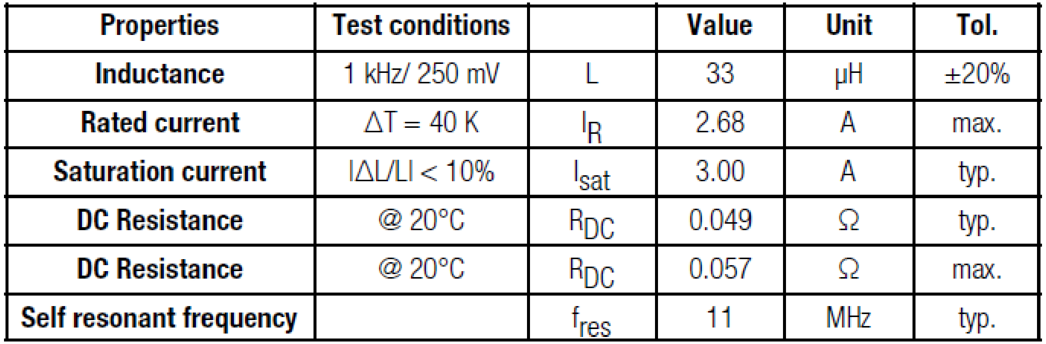
see Application Note:
DC Biased Impedance Measurements
https://www.omicron-lab.com/application-notes/

Why should we measure inductors?

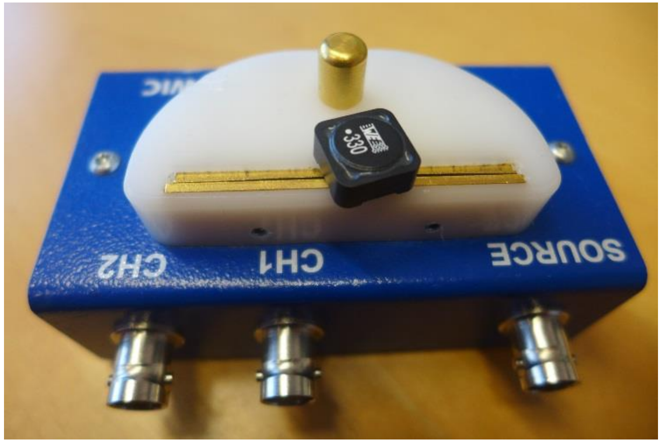
- An inductor is **NEVER** just an inductor
- AC resistance <> DC resistance
  - skin effects
  - “Eddie Currents”
- Inductors have resonance frequencies
- Inductors with magnetic cores can have core losses

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	$\Delta T = 40$ K	I_R	2.68	A	max.
Saturation current	$\|\Delta L/L\| < 10\%$	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.



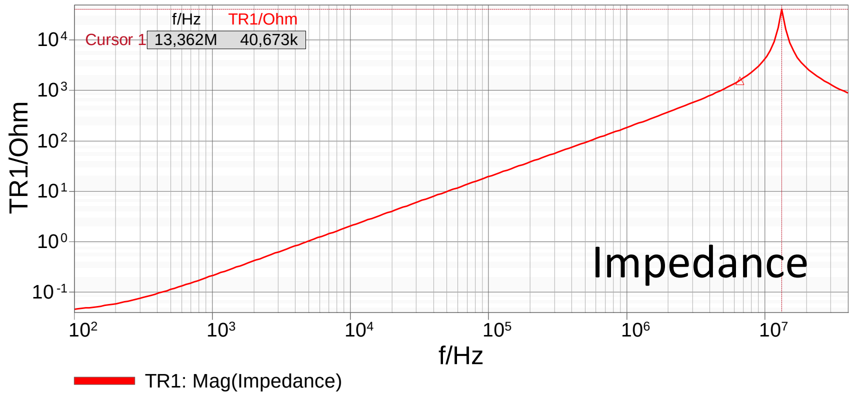
$$\mathrm{H} = 33\mu\mathrm{H}\ (\pm\ 20\%)\ @\ 1\ \mathrm{kHz}$$

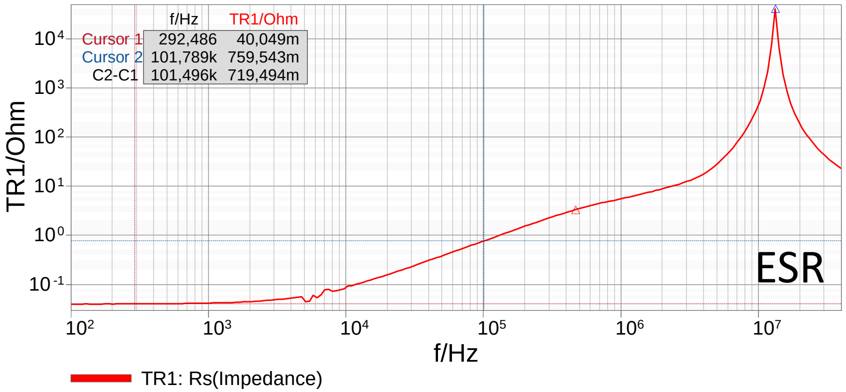
$$R_{DC}{=}0{,}049\ \Omega\ (typ.)$$

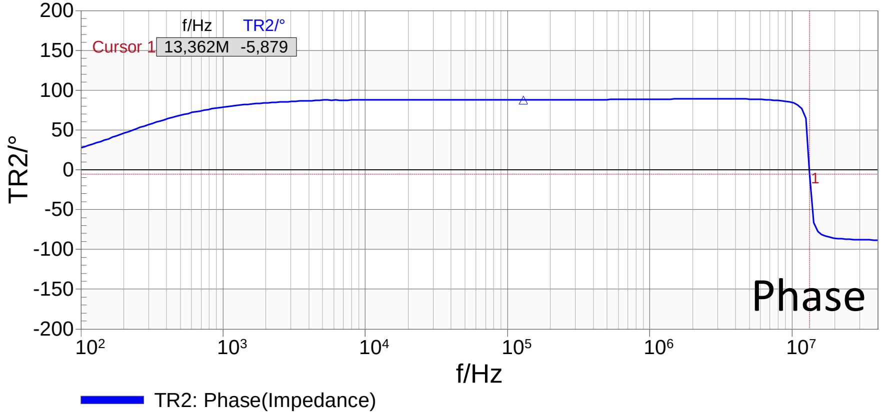
$$R_{DC}{=}0{,}057\ \Omega\ (max.)$$

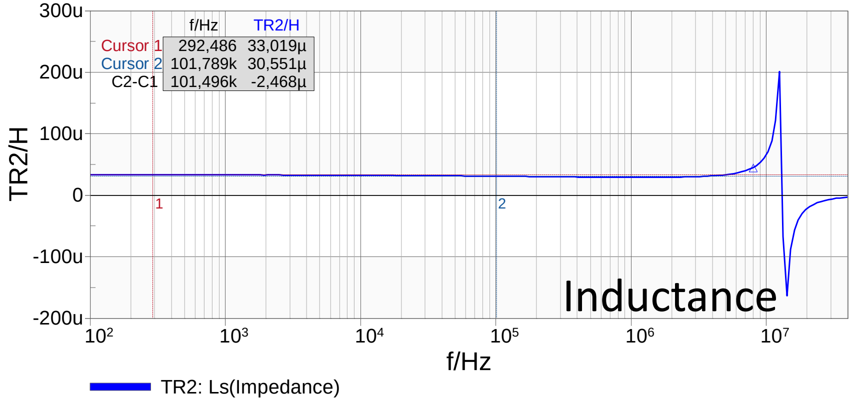
$$\mathrm{f_{res}} = 11\ \mathrm{MHz}$$

This is what the measurement tells us



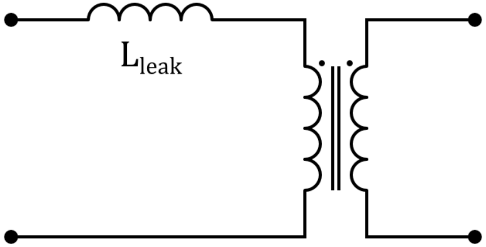






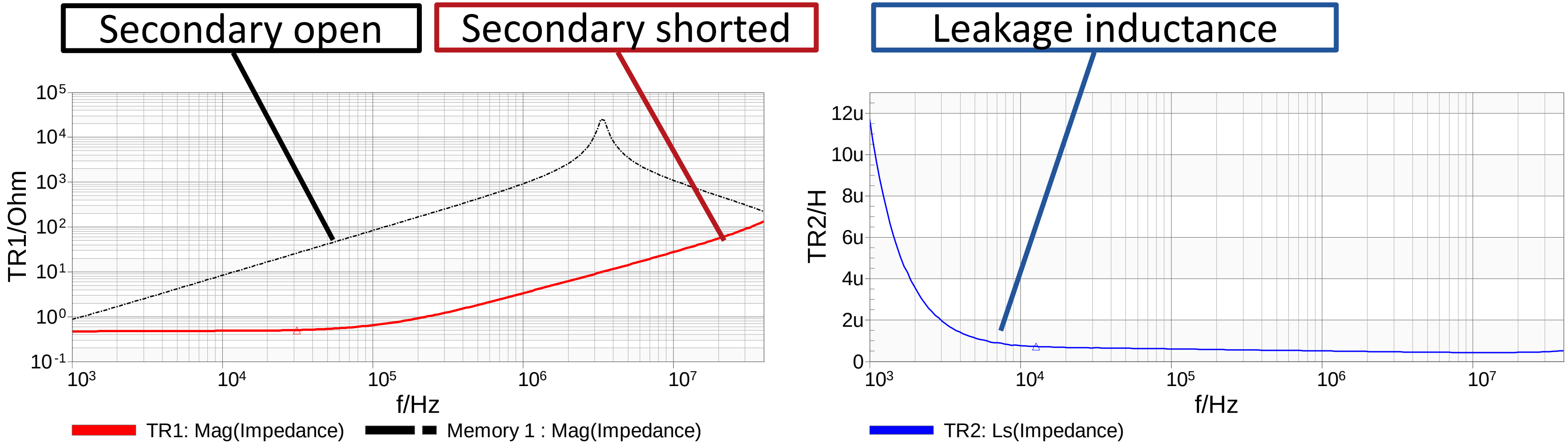
Flyback Transformer Leakage Inductance

- 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



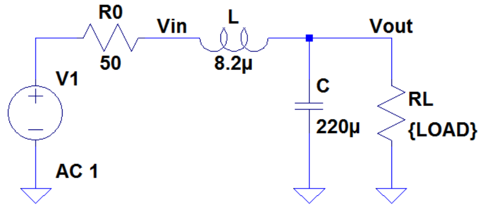
Secondary open

Secondary shorted

Leakage inductance

→ Leakage inductance is not constant over frequency

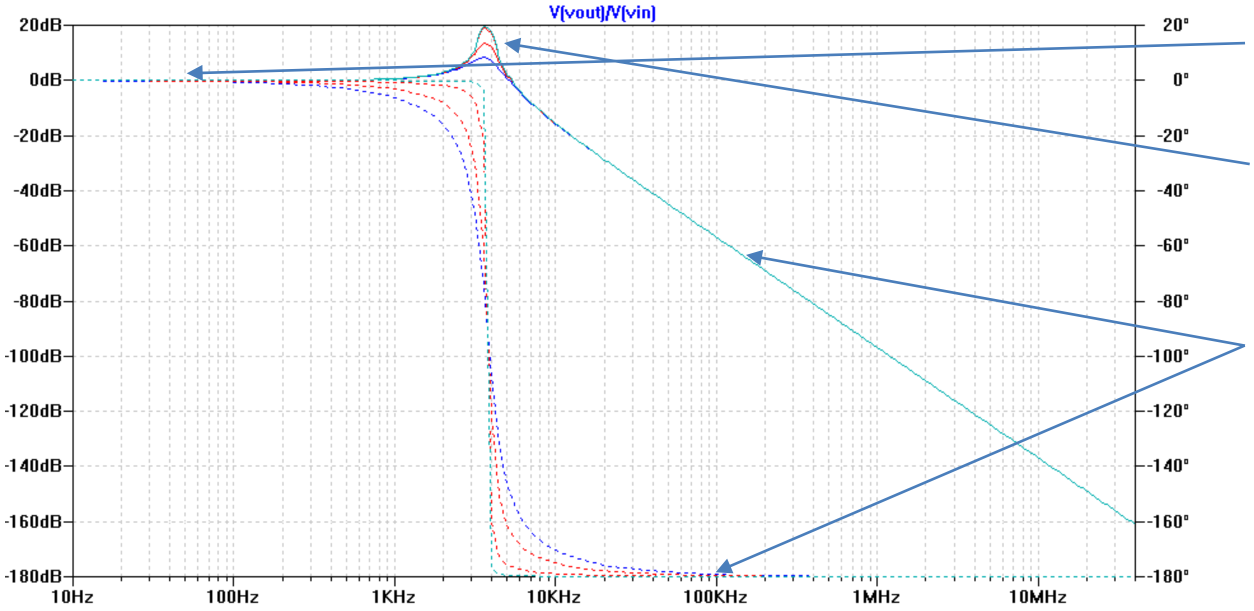
LC Filter Bode Diagram



.ac dec 20 10 40meg

.step param LOAD list .5 1 5 500

Simulation in LTSpice:

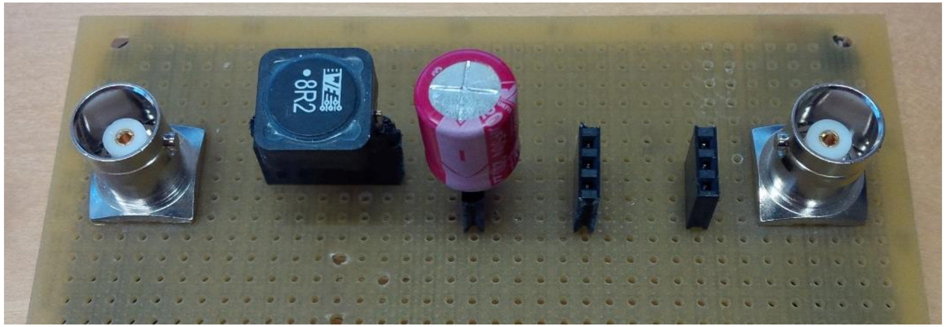


Passband

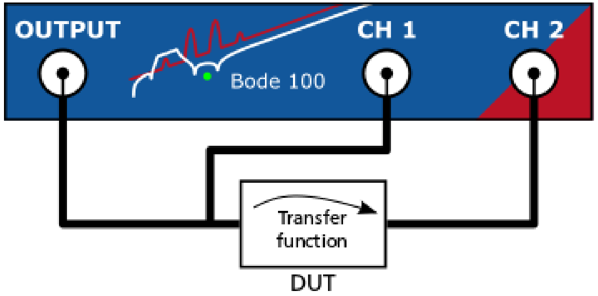
Resonance
(Double-pole)

Stopband
-40dB/Decade
-180° Phase

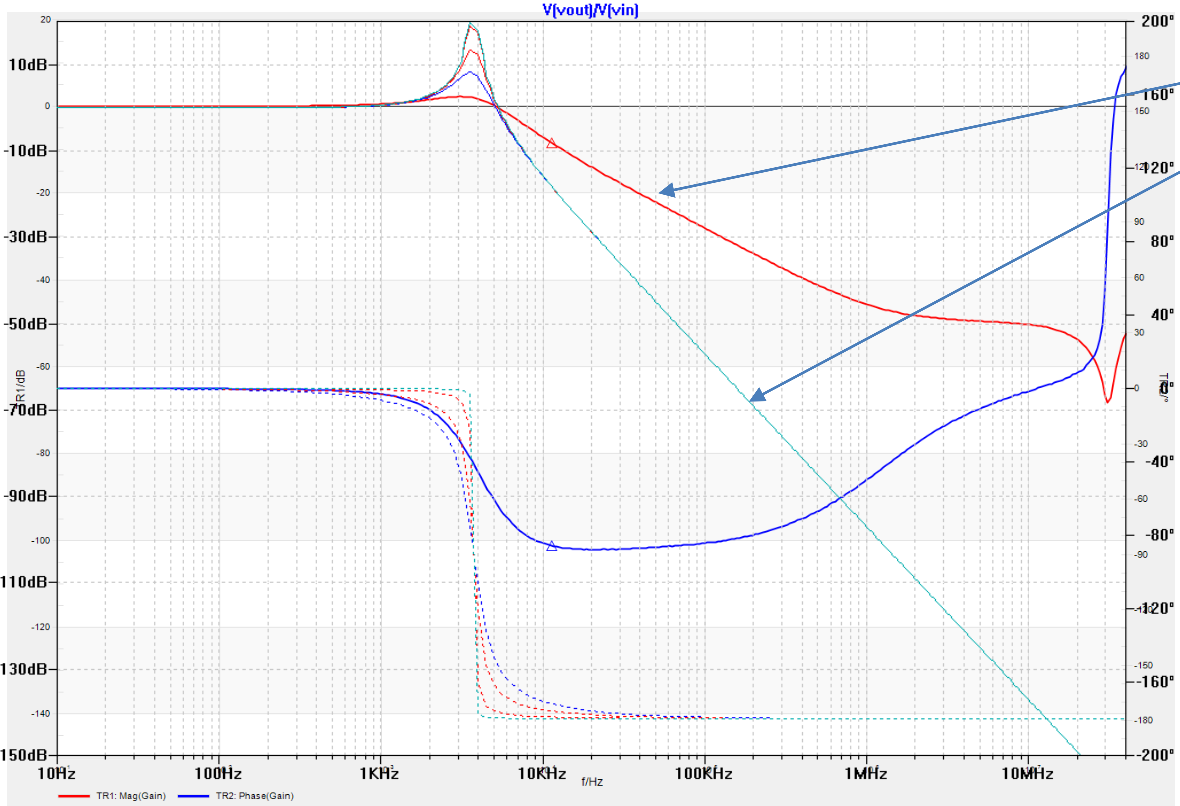
LC Filter Test board



Measuring the voltage transfer function $H(j\omega) = \frac{V_{out}}{V_{in}}$



Measurement vs. Simulation



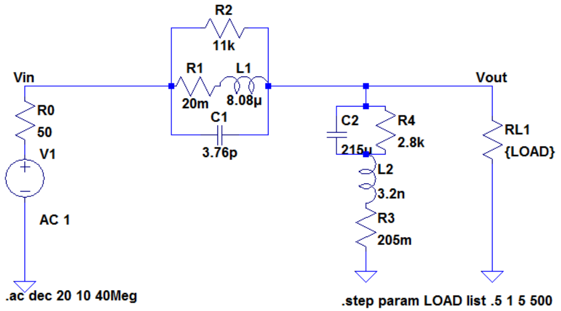
Measurement

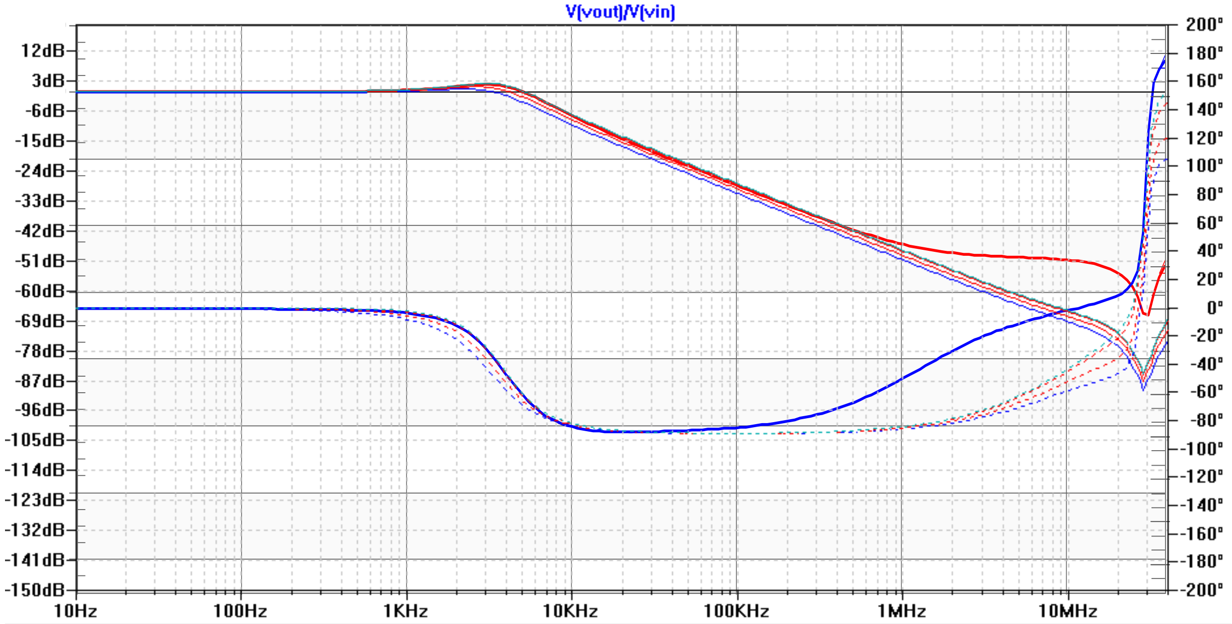
Simulation

- Stopband is different
- Phase does not reach -180°
- Second resonance at 30 MHz

→ parasitic effects

LC Filter Including Parasitics





- much better fit between simulation and measurement
- Could be further improved by better component models

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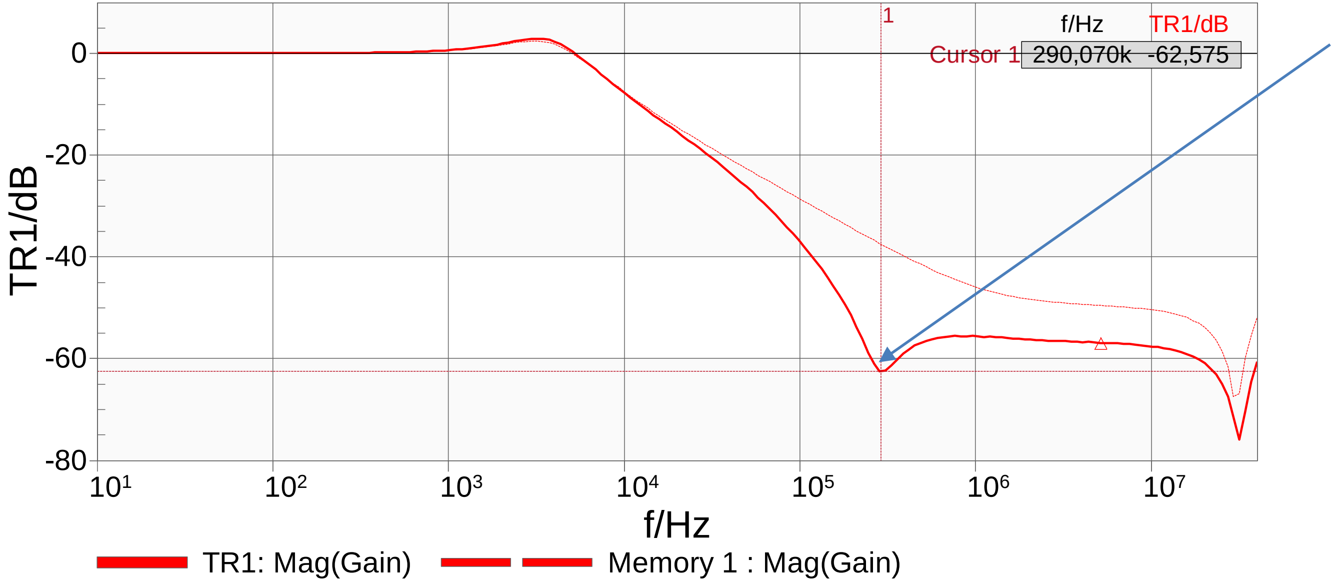
Reducing Output Ripple

→ 2 x 10µF ceramics adds 20dB attenuation at 300 kHz



Imroved stop band performance at 300 kHz (e.g. switching frequency)

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

Feel free to ask questions via the chat 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!