PARASITIC COMPONENTS IN POWER CONVERTERS – FUNDAMENTALS AND MEASUREMENTS

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ROHDE&SCHWARZ

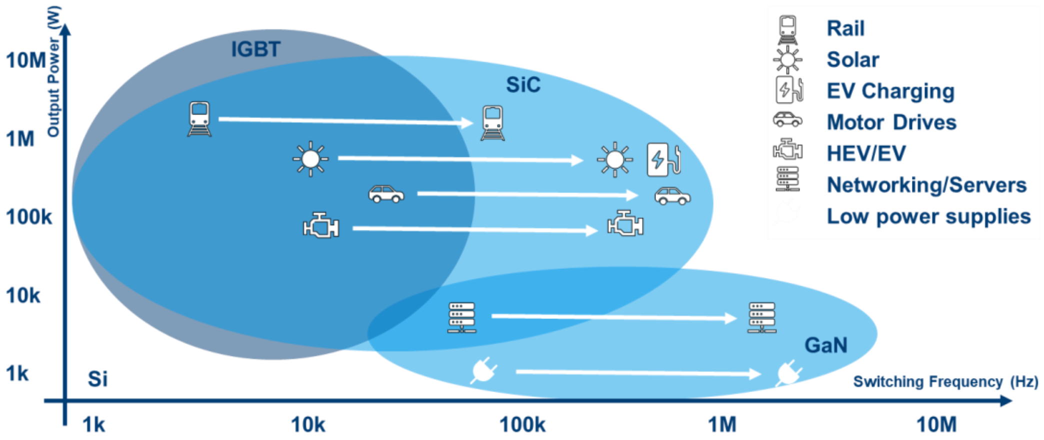
Make ideas real

AGENDA

- Motivation
- Introduction to parasitics
- How to measure parasitics?
- LCR meters as a solution
- Demo

MOTIVATION

IMPORTANCE IN THE DESIGN OF DC-DC CONVERTERS



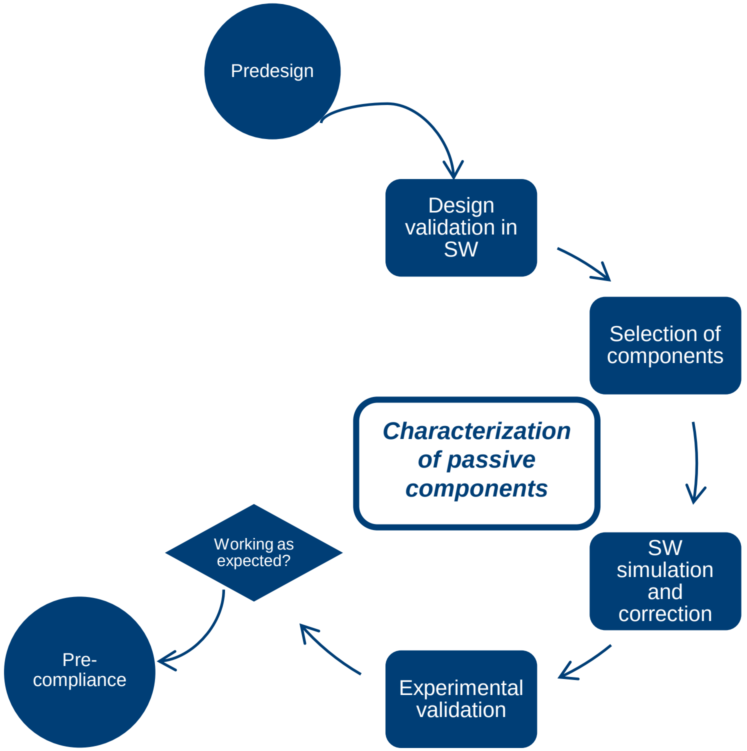
- New technologies with higher power density lead to a faster commutation of the transistors.
- SiC and GaN that operate with switching frequency > 1MHz is growing

- Parasitics appear at higher frequencies and must be considered
- Influence in conducted emissions
- Is important to quantify the stray components in the early stages of the design

IMPORTANCE IN THE DESIGN OF DC-DC CONVERTERS

Typical design procedure

- In the early stages of the design, the parasitic components are roughly estimated or not considered.
- After the design is validated in software, the components are chosen and the DC-DC converter is tested.
- A re-design might be necessary depending on the effect of the parasitic components.
- A proper characterization of the passive components helps to avoid the re-design.



LACK OF INFORMATION

- Sometimes the information provided by the manufacturers is limited

- Even if the information is given, there are major issues to be aware of:

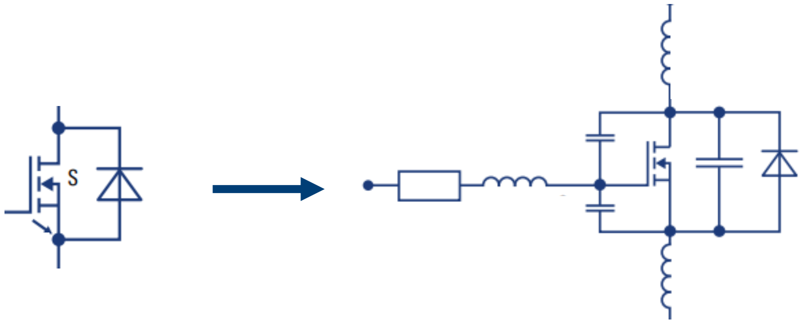
Tolerances	→	Up to 25%
Test conditions	→	Voltage, frequency
Temperature	→	Operating and ambient

PARASITICS

WHAT IS MEANT BY PARASITICS?

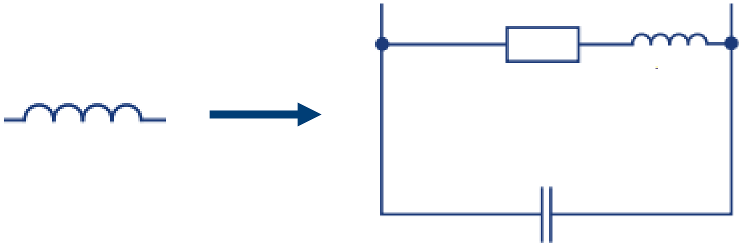
► This term refers to undesirable components or effects that accompany the intended electrical behavior of a circuit.

Transistor



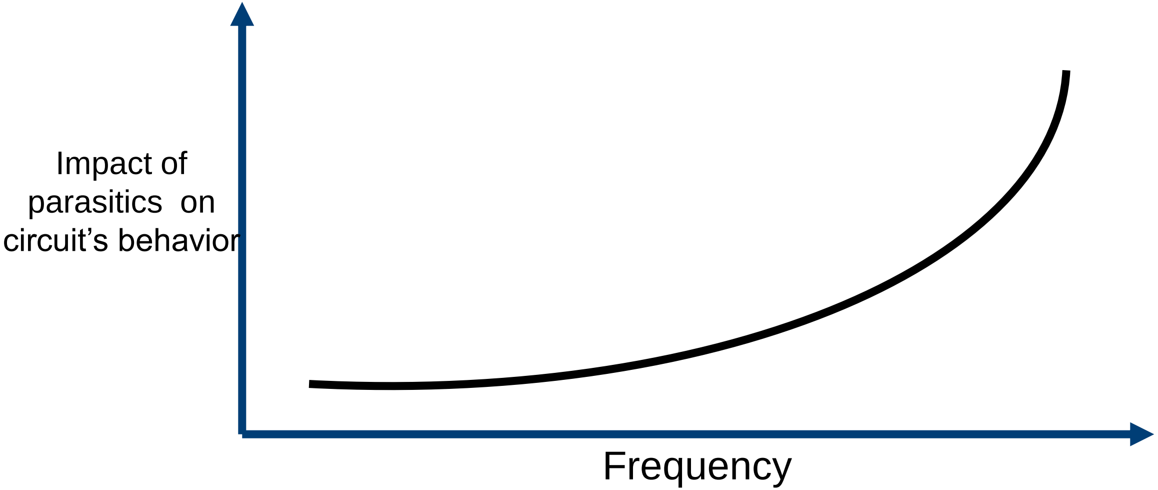
Capacitor

Inductor



IS IT ALWAYS AT HIGH FREQUENCIES?

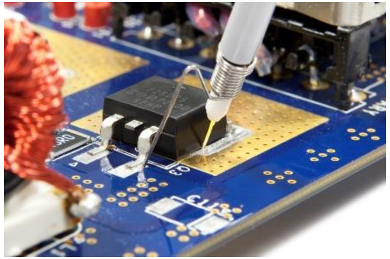
- Parasitic elements can exist at low frequencies.
- However, their impact may be less noticeable at lower frequencies compared to higher frequencies, as the parasitic elements may not have a significant effect on the behavior of the circuit.

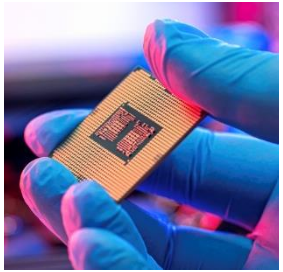


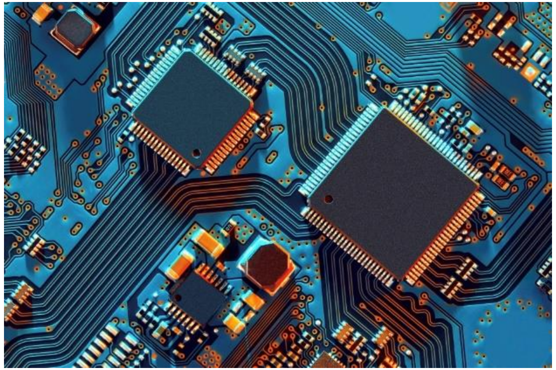
WHERE CAN I FIND THE PARASITICS?

Parasitics can be found in various parts of a circuit:

- ► Interconnections
- ► Passive components
- ► Integrated circuits (ICs)
- ► Packages
- ► Printed circuit boards (PCBs)



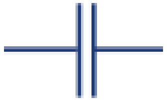




WHERE CAN I FIND THE PARASITICS?
PARASITICS APPEAR AS…

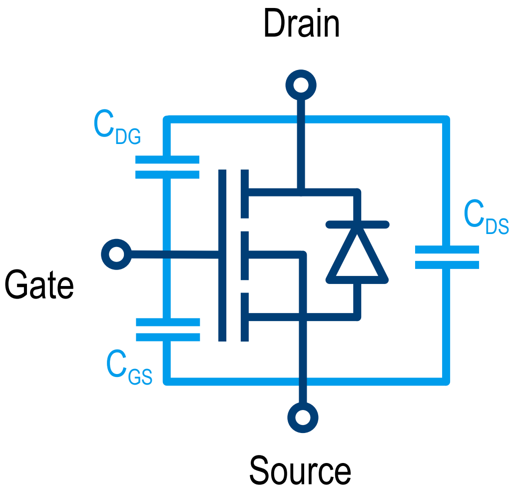
- **Parasitic inductance:** arise from the magnetic field created by the flow of current in a circuit, such as the loop created by a trace on a printed circuit board.

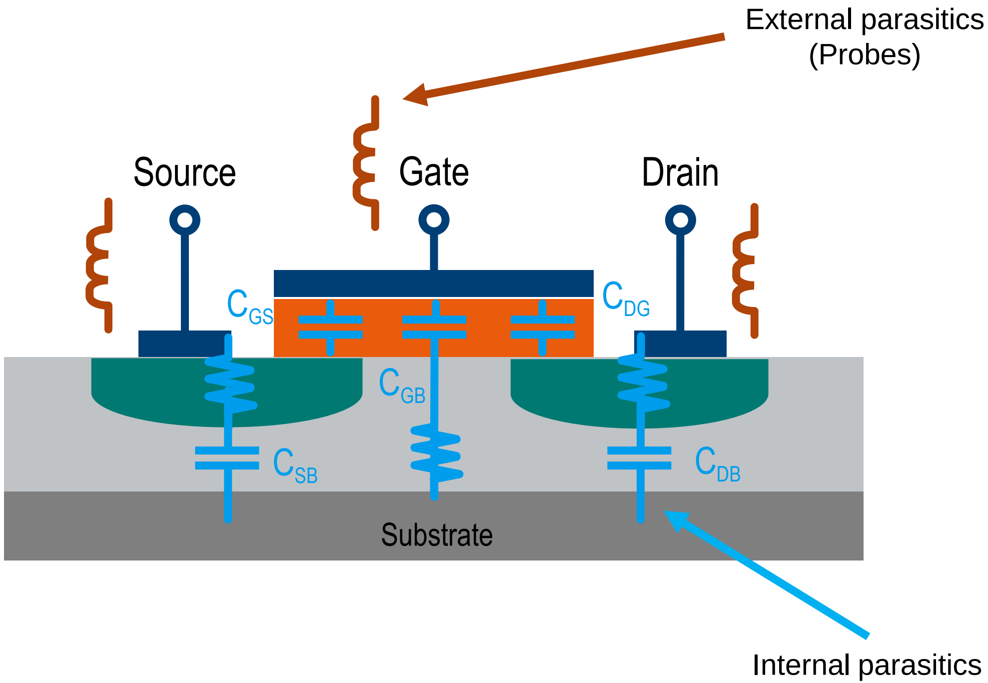
- **Parasitic capacitance:** arise from the close proximity of conductive elements in a circuit, such as the metal interconnects on an integrated circuit or the leads of a passive component.



- **Parasitic resistance:** arise from the resistance of the conductive elements in a circuit, such as the resistance of the metal interconnects or the resistance of the leads of a passive component.

TRANSISTORS





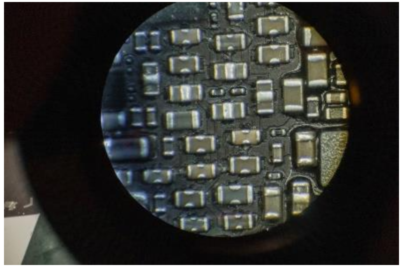
… internal parasitics are silicon based, normally capacitances of the substrate

… external parasitics are formed due to bonding interconnections and probing

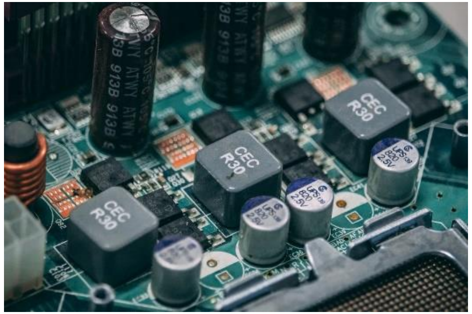
PASSIVE COMPONENTS

Focus are passive components:

- ► Inductors (L)
- ► Capacitors (C)
- ► Resistors (R)
- ► Transformers



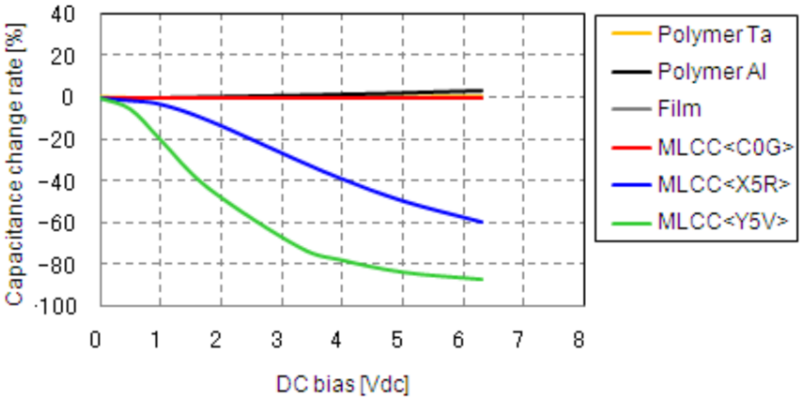
wired or SMD type



CAPACITORS

- The characteristics of a capacitor depend on:
  - the dielectric material
  - the capacitance value
  - construction details, like the contacts and packaging

- Test conditions:
  - frequency
  - amplitude
  - bias voltage



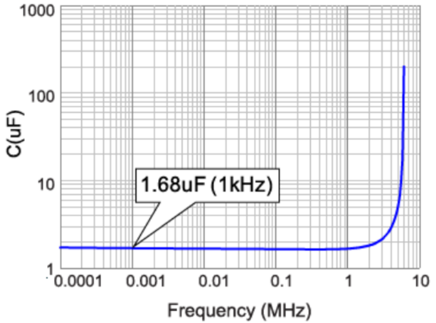


Figure 1: Capacitance-frequency characteristics (GRM15

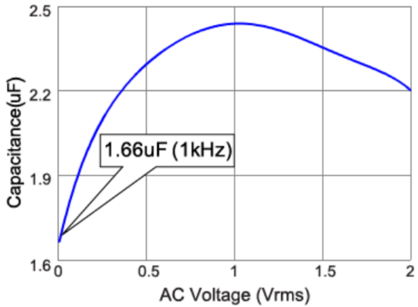
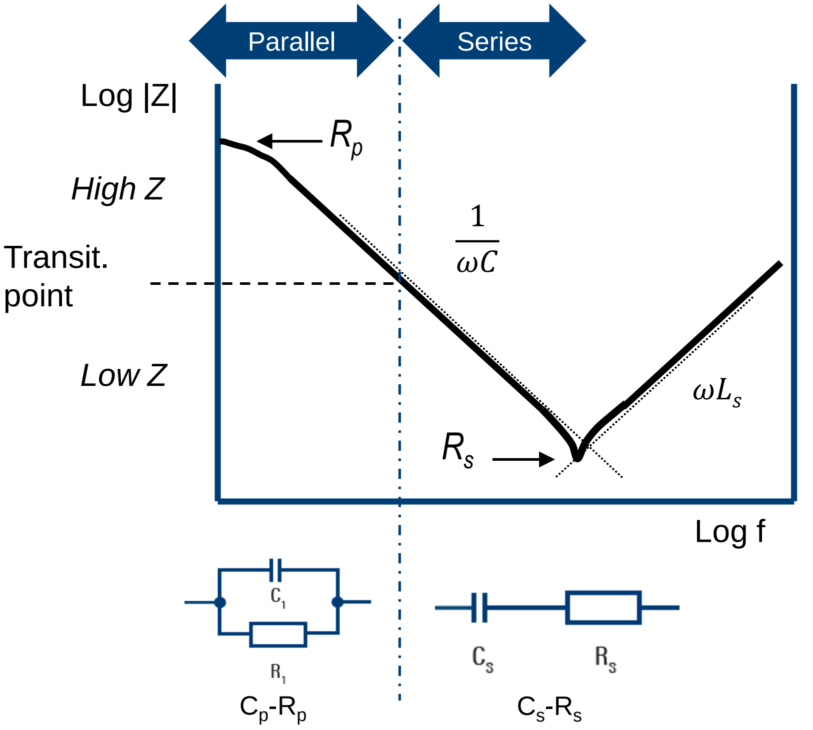


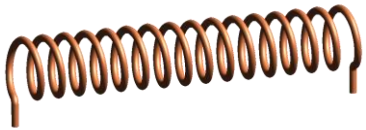
Figure 3: AC voltage characteristics (GRM155B30J225KE95)

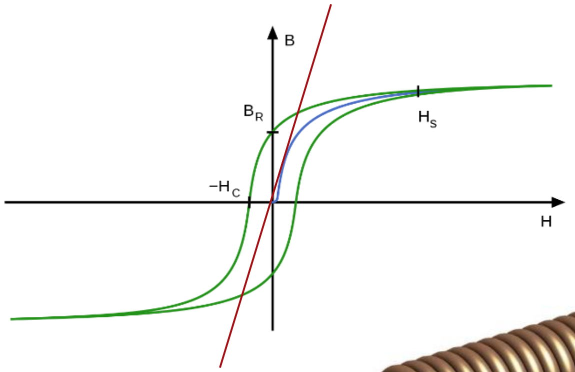
CAPACITOR MODEL

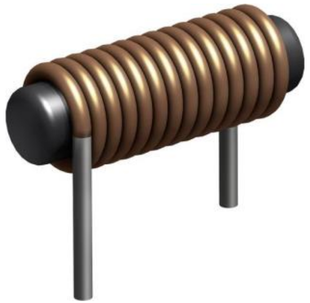


INDUCTORS

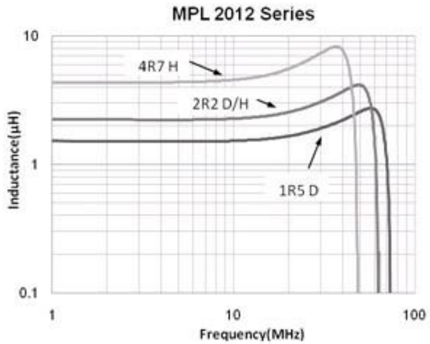
- The observed characteristics of an inductor depend on the measurement settings as well
- The measurement of inductance has some potential errors, depending on the construction
  - air core is not critical
  - coil with magnetic core
    - the core can saturate
    - the core shows residual magnetism/ hysteresis, the AC current flow is no longer linear

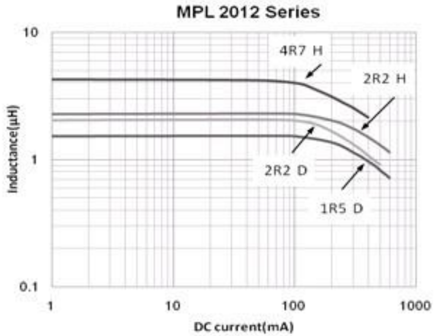


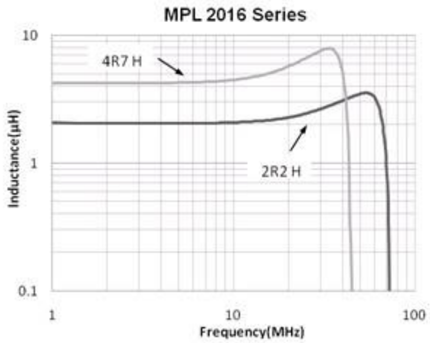


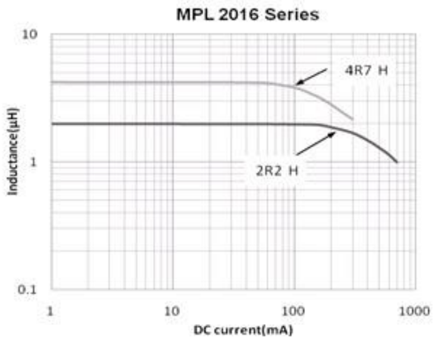


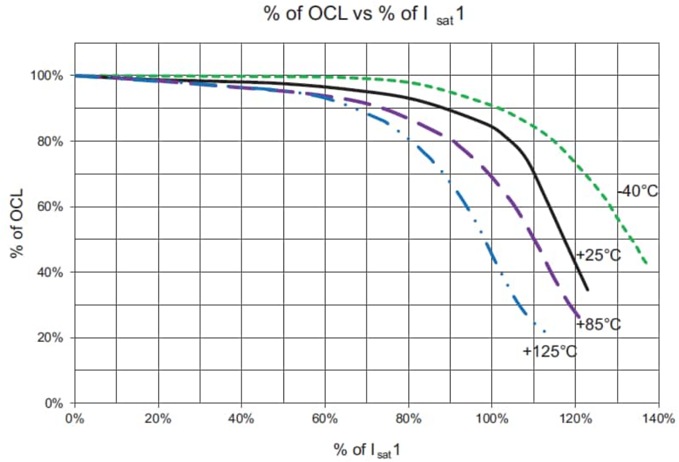
INDUCTORS







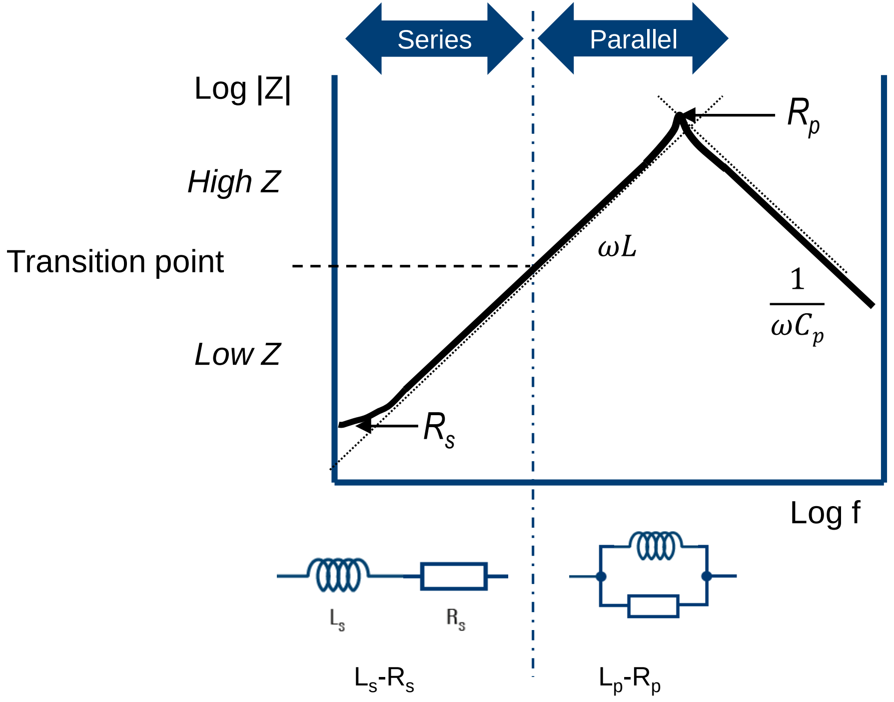




Dependencies on

- frequency
- DC current
- temperature

INDUCTOR MODEL



RESISTORS

- Nominally, resistors do not have a frequency dependency
- Considering data sheets, there are
  - resistance tolerance
  - parasitic capacitance
  - temperature coefficient of resistance
  - voltage coefficient of resistance

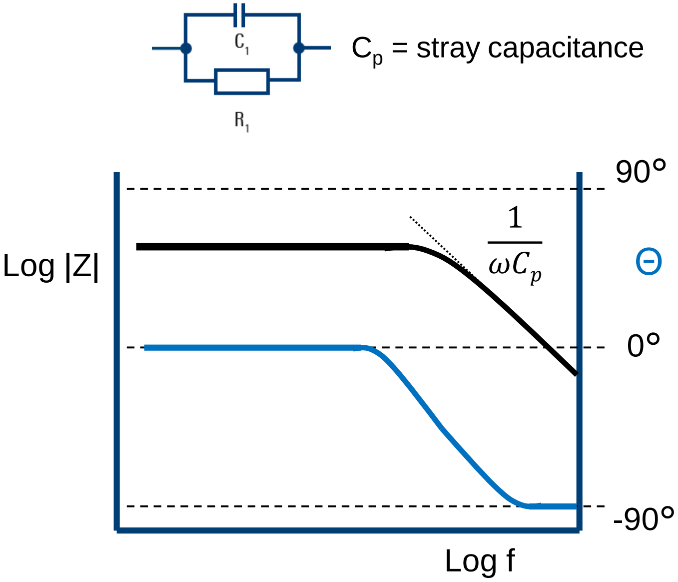
Resistance Range (Ohms)	Power	Voltage Rating	Available Tolerances*	Capacitance (pf)
re (silicone coated)	@70°C			
500Ω to 300,000M	0.35W	2,500V	1% to 20%	1.00
750Ω to 600,000M	0.70W	5,000V	1% to 20%	0.75

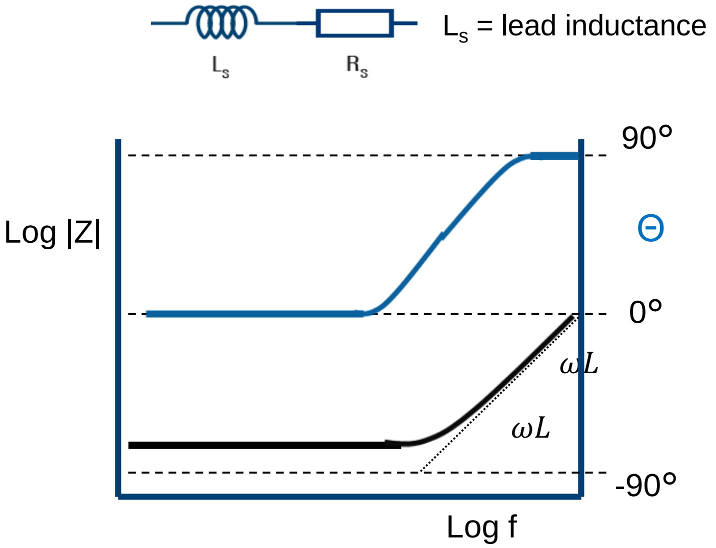
STANDARD TEMP./VOLTAGE COEFFICIENTS OF RESISTANCE

Resistor Series	Temp. Coeff. of Resistance 25 PPM/°C	50 PPM/°C	Voltage Coeff. of Resistance** 100 PPM/°C	< 2PPM/Volt	< 5PPM/Volt
MOX-400	1K-99M	100M-450M	451M-30,000M	1K-1,000M	1,001M-100,000M
MOX-750	1K-199M	200M-900M	901M-70,000M	1K-2,000M	2,001M-100,000M
MOX1125	1K-299M	300M-1,350M	1,351M-100,000M	1K-3,000M	3,001M-100,000M

RESISTORS

- ► High value resistance – the stray capacitance dominates
- ► Low value resistance – the lead inductance dominates



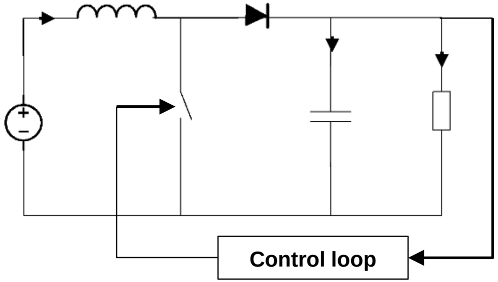


HOW THE PARASITICS AFFECT MY MEASUREMENTS?

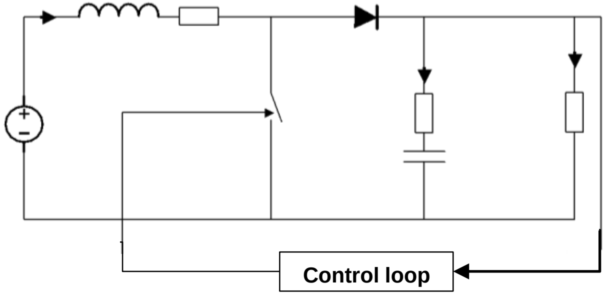
Distortion of voltage and current waveforms	Reduced efficiency and increased power loss
Unwanted resonances	Power loss, increased electromagnetic interference (EMI) and reduced system stability
Mismatches between the passive component and the surrounding circuit	Reduced efficiency and increased power loss
Stability issues	Increased power loss, increased EMI, and reduced system reliability
Increased switching losses	increased power loss and reduced efficiency

EXAMPLE BOOST CONVERTER
EFFECTS OF PARASITICS

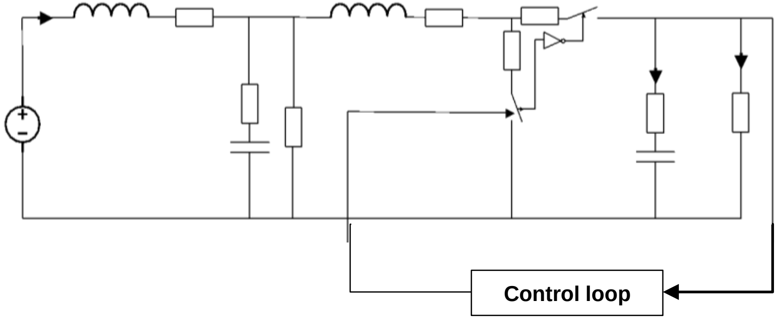
Basic topology: No parasitics



Simplified topology: ESR of capacitor and inductor (Values given by manufacturer)

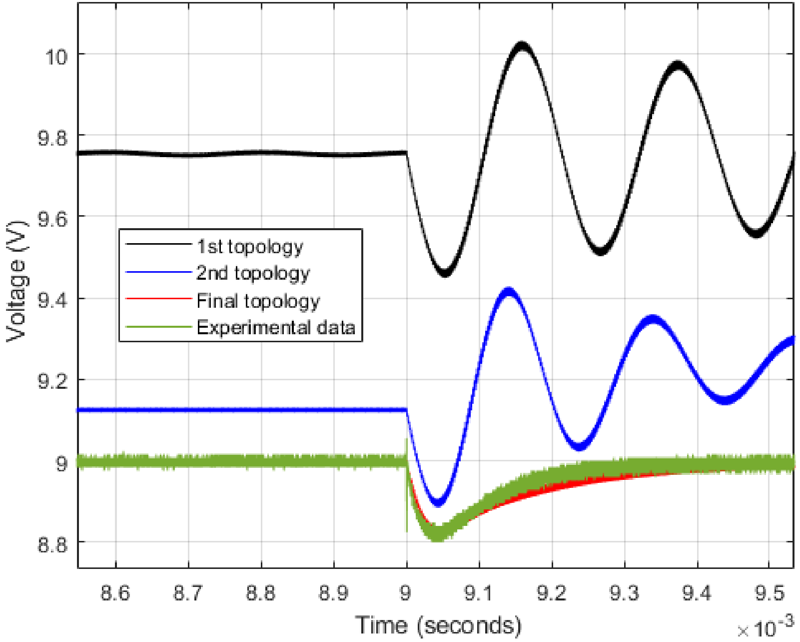


Complex topology: Considering parasitics (Characterization of passive components)

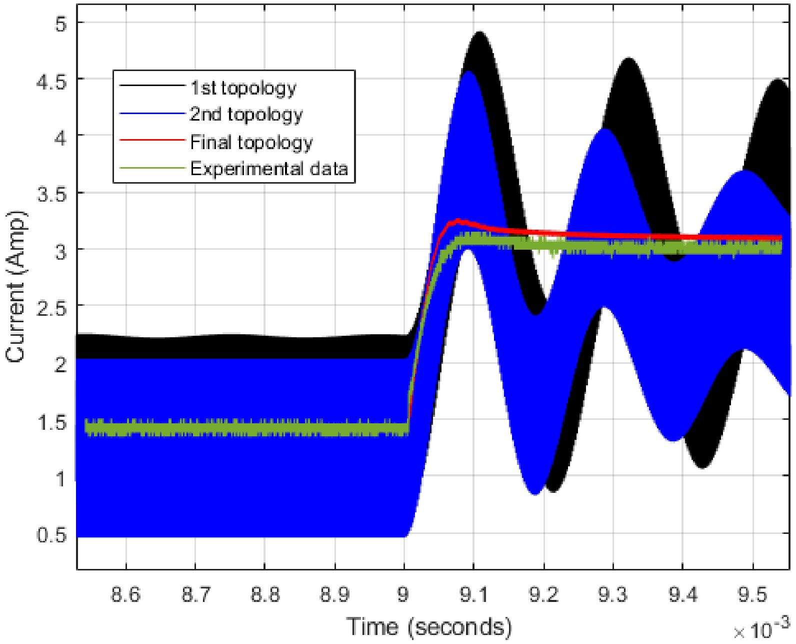


EXAMPLE BOOST CONVERTER
EFFECTS OF PARASITICS

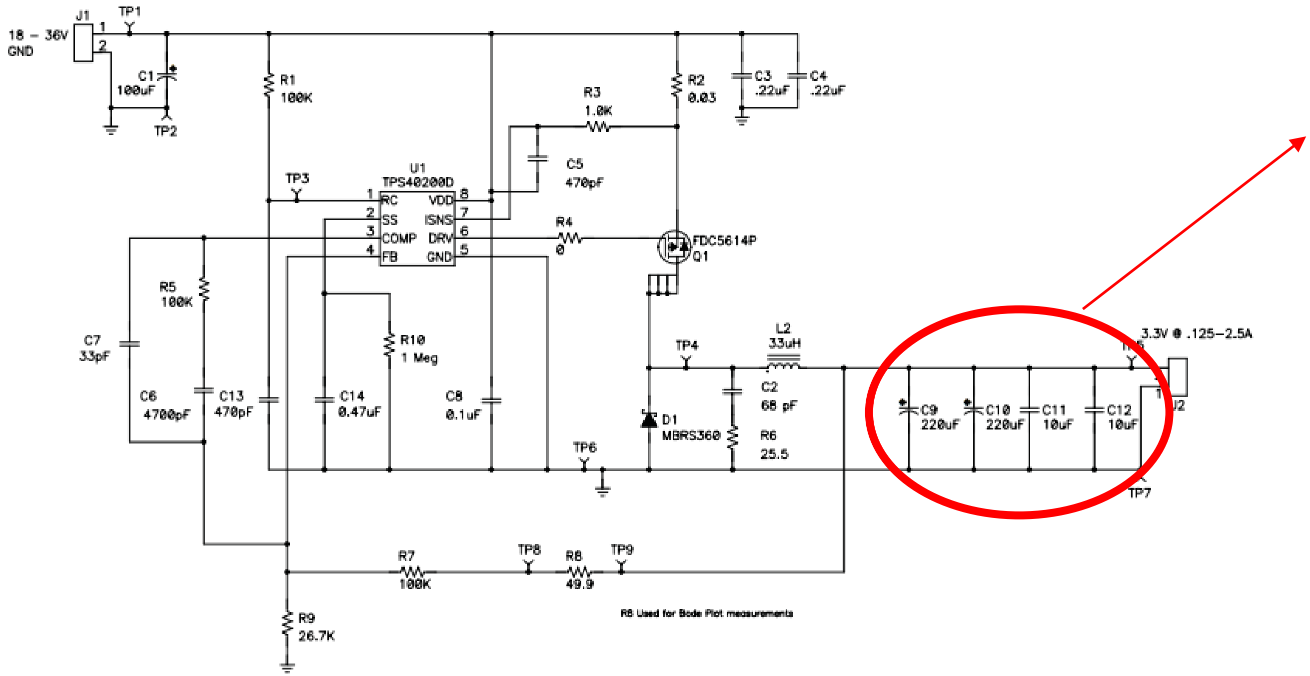
Output voltage



Output current



EXAMPLE BUCK CONVERTER
OUTPUT CAPACITOR

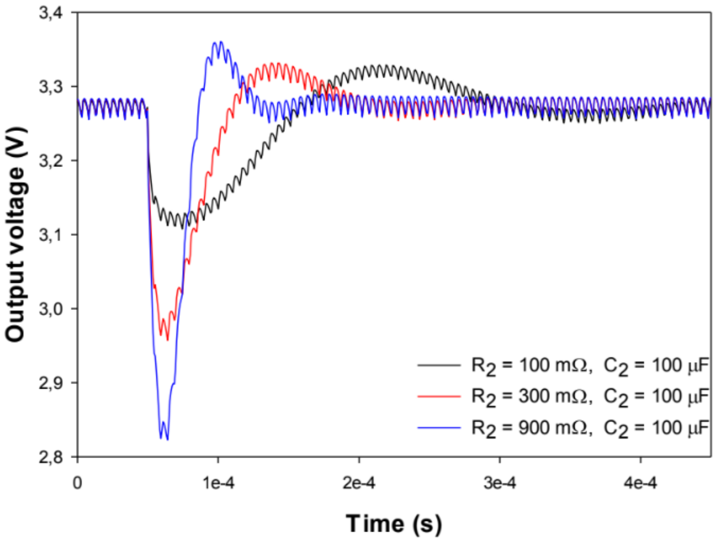


TPS40200EVM-002 converter schematic

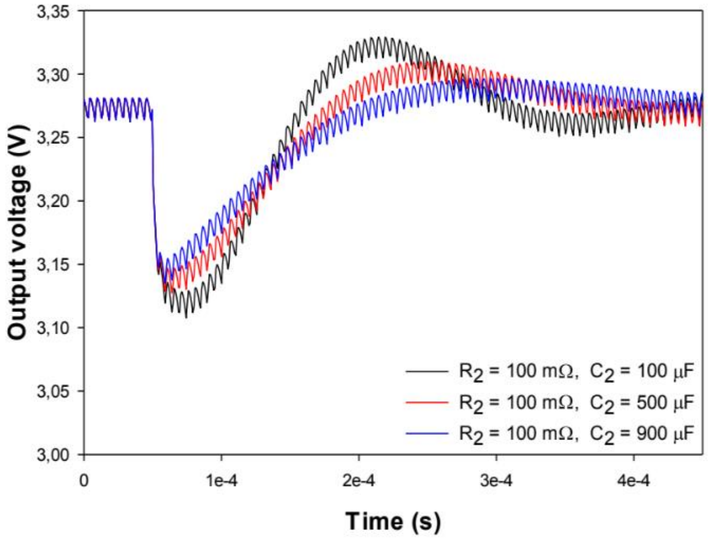
- Multiple output capacitors at the output of the DC-DC converter
- Ceramic and aluminum electrolytic
- Ceramic: Small capacitor which affects the output ripple
- Electrolytic: Large capacitor that affects the transient response of the converter

EXAMPLE BUCK CONVERTER
OUTPUT CAPACITOR

- Effect of ESR in the transient response of the converter



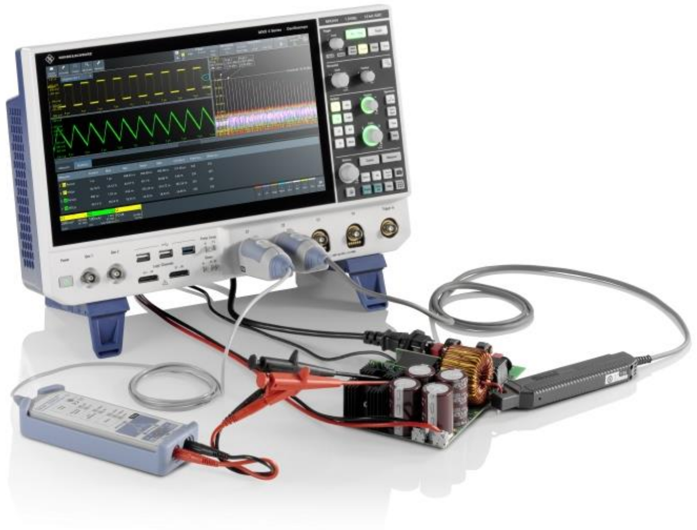
- Effect of capacitance in the transient response of the converter



HOW TO MEASURE PARASITICS?

ON-LINE MEASUREMENTS

- In some cases, the passive components of a converter can be characterized while the circuit is 'live'.
- An example of this is the in-circuit characterization of an electrolytic capacitor in a SMPS.
  - Current and voltage drop across the capacitor are measured
  - Capacitance and equivalent series resistance of the capacitor are estimated
  - AppNote and Webinar on-demand available in our webpage



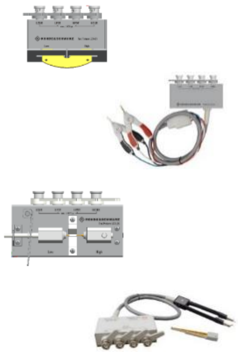
- In general, on-line measurements are done using oscilloscopes and probes.

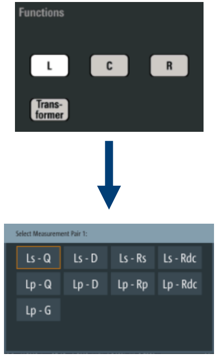
OFF-LINE MEASUREMENTS

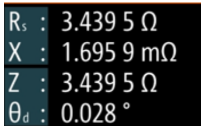
- ► The passive component is characterized when the circuit is off
- ► The test conditions must resemble to the actual operating point of the component:
  - Voltage/current ripple
  - Voltage/current offset
  - Temperature
  - Frequency
- ► An LCR meter is the perfect tool to perform this characterization

PROCESS

1. Prepare the passive component
2. Select the proper fixture
3. Select the measurement type
4. Set the frequency, voltage/current level and bias
5. Perform the measurement
6. Repeat for different measurement types, if necessary



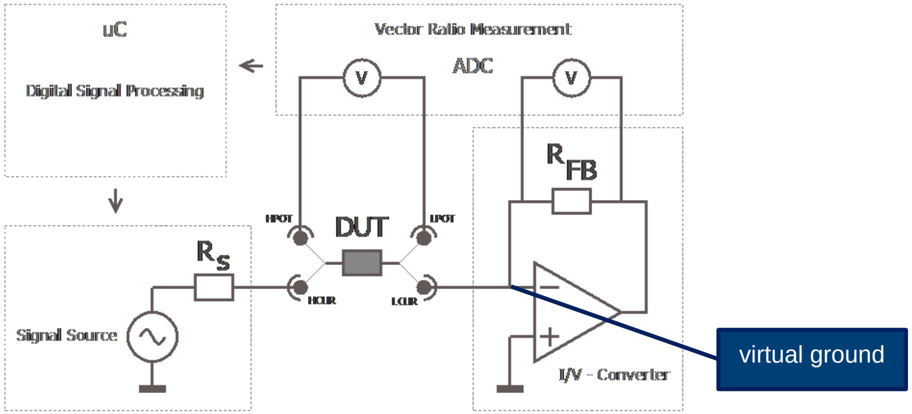





Zurich Instruments
MFIA
Impedance Analyzer
Precision LCR Meter
500 kHz / 5 MHz
Signal Input
Signal Output
Aux Input
Aux Output
ROHDE&SCHWARZ
LCX200 · LCR Meter
Power

LCR METERS

AUTO BALANCING BRIDGE



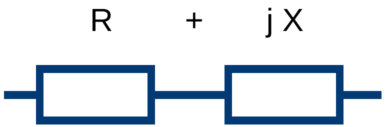
$$\underline{Z} = \frac{\underline{u}}{\underline{i}} = \frac{\hat{u} \cdot e^{j(\omega t + \varphi_u)}}{\hat{\imath} \cdot e^{j(\omega t + \varphi_i)}} = \frac{\hat{u}}{\hat{\imath}} \cdot e^{j(\varphi_u - \varphi_i)}$$

$$\underline{Z} = R + jX$$

- The measurement of the AC voltage across the DUT, and the resulting AC current through the DUT provide amplitudes of and phase shift between these two quantities
- The calculated result is the complex impedance of the DUT at a given operational point

IMPEDANCE MEASUREMENT

- ► the LCR-Meter measures the complex ratio between voltage and current.
- ► Every other parameter (L,C,R, etc.) is calculated from this result:



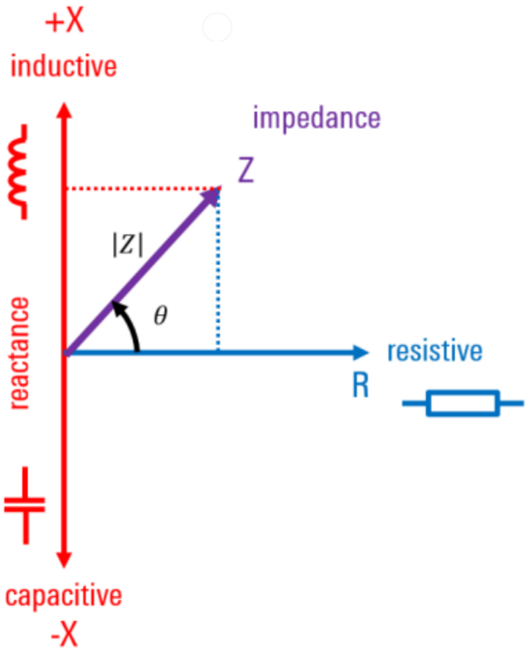
$$|Z| = \sqrt{R_S^2 + XS^2}$$

$$\Theta = \tan^{-1}(X_S / R_S)$$

Rs: series resistance
Xs: series reactance ($X_L = \omega L_s$, $X_C = -1/\omega C_s$)

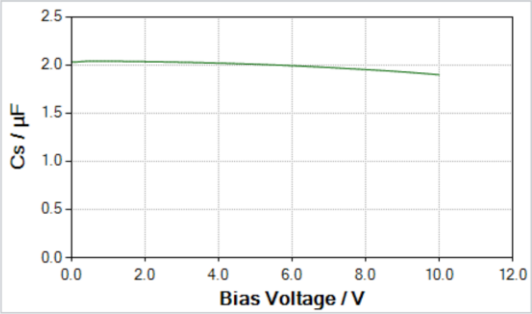
Ls: series inductance (= X_L / ω)
Cs: series capacitance (= $-1/\omega X_C$)

D: dissipation factor (= $R_s/X_s = R_s/(\omega L_s)$ or $\omega C_s R_s$)
Q: quality factor (= $X_s/R_s = (\omega L_s)/R_s$ or $1/(\omega C_s R_s)$)

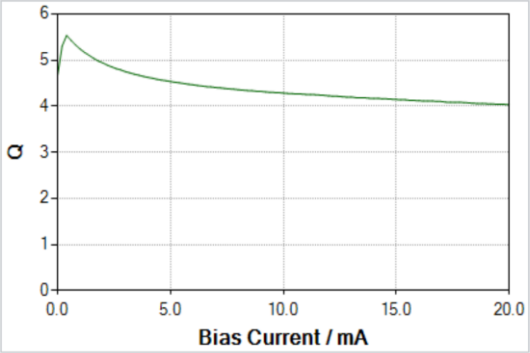


DC BIAS

- The properties of passive components depend on the frequency, amplitude of the applied AC voltage or current and the superimposed **DC bias**.
- It is important to apply a DC voltage bias in order to obtain a more accurate representation of the parasitic element at the operating conditions of the circuit.



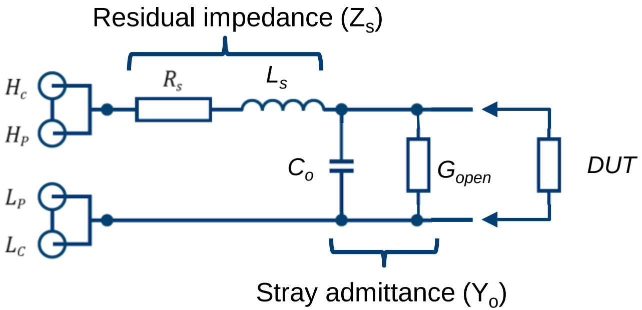
- **Ceramic capacitors:** The dielectric constant of dielectric material with high permittivity can vary significantly with the applied field strength.
- **Core in inductors:** The core always exhibit nonlinear behavior. This may lead to hysteresis losses or saturation.

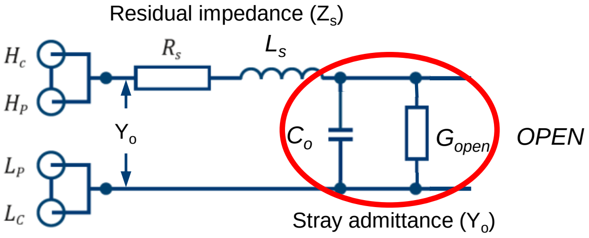


DEMO

OPEN/SHORT COMPENSATION

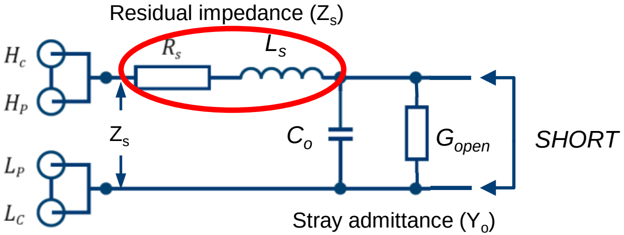
► The Open/Short compensation is used to eliminate the residual parameters of the test setup





$$Y_o = Go + j\omega C_o \text{ , assuming:}$$

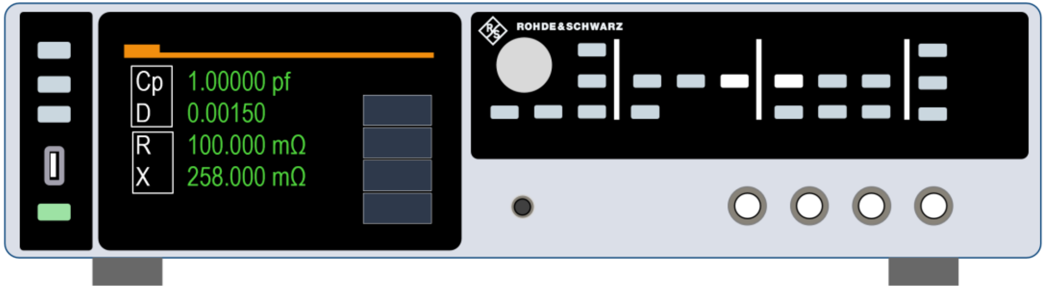
$$R_s + j\omega L_s \ll \frac{1}{G_o + j\omega C_o}$$

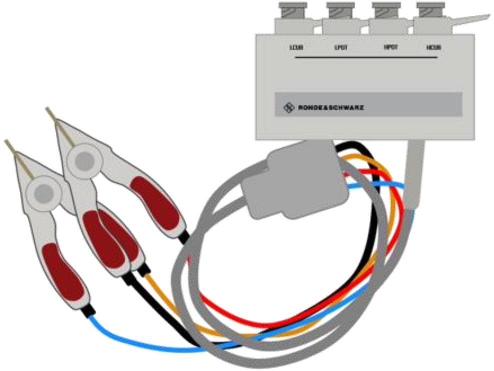


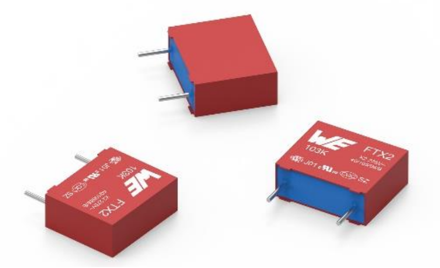
$$Z_s = R_s + j\omega L_s \text{ , assuming:}$$

$$\text{SHORT} \ll R_s + j\omega L_s$$

LCR-METER







CONCLUSION

- The use of wide bandgap semiconductors in power electronics brings many benefits, but it is equally important to characterize the parasitic components in order to fully realize the potential of these technologies.
- An accurate characterization of passive components is essential for ensuring reliable and efficient operation of systems governed by power electronics.
- By using an LCR meter and other appropriate measurement tools, engineers can minimize the effects of parasitic components and optimize the performance of the system.
- By incorporating the measurements into the design process, it can be ensured that the intended behavior of the circuit is achieved.

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