DC Biased Impedance Measurements

using Bode 100 / Bode 500 or *"How non-linear can passive components be?"*

15th Power Analysis & Design Symposium

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OMICRON LAB

About Me

- HTL Bregenz (EE & Power Electronics)
- MSc Mechatronics at Vorarlberg University of Applied Sciences

- Working at OMICRON Lab since 2010 in:
  - Technical Support & Applications
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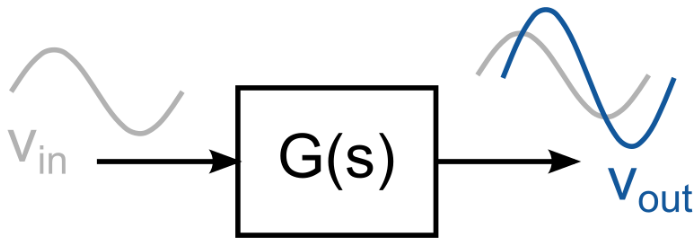
Agenda

- Why DC Biased Measurements
- Impedance Measurement Methods
- Analyzer Port Considerations
- Fixtures Picotest CTF and OMICRON Lab B-TCA
- DC Voltage Biasing
- DC Current Biasing

Some Words on "Linearity"

- Linear means "Sinewave in → Sinewave out"

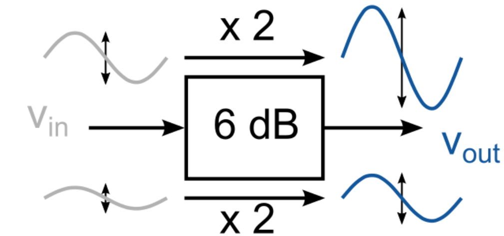


$$v_{out}(s) = v_{in}(s) \cdot G(s)$$

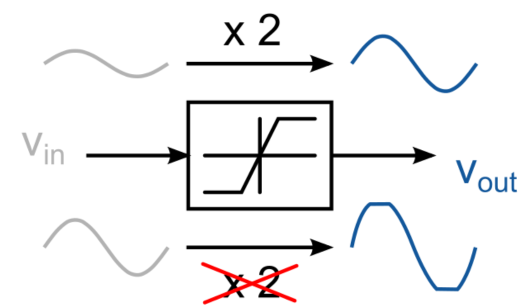
- Linear systems can easily be described via transfer function G(s).
- Impedance is a transfer function: $v(s) = i(s) \cdot Z(s)$
- Non-linear systems can NOT be described with a simple transfer function G(s).

Identify Non-Linearities in Measurements

- In a linear DUT, the result does **not depend** on the signal amplitude



- In a non-linear DUT, the **result changes** when the signal **amplitude changes**

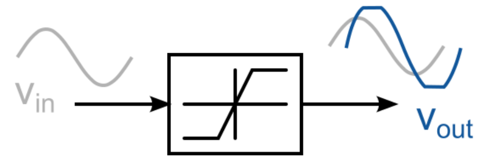


Simple Check: **Change signal amplitude**

a) Result similar? → Linear DUT
b) Result changes? → Non-Linear DUT

Transfer Functions in Non-Linear Systems

- Most real-life systems experience some non-linearities.
  - Hysteresis and saturation
  - Clipping or railing
  - Slew-rate limitations etc...



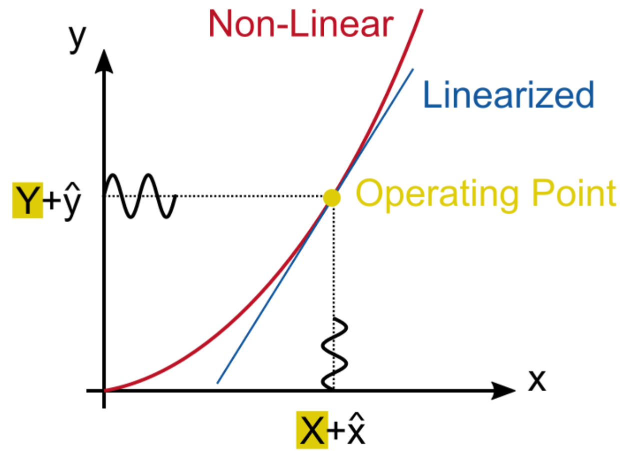
- Linearization or “small-signal analysis” is used.

$$x(t) = X + \hat{x}(t)$$

$$\hat{y}(s) = \hat{x}(s) \cdot G(s)$$

Small-Signal

Transfer Function

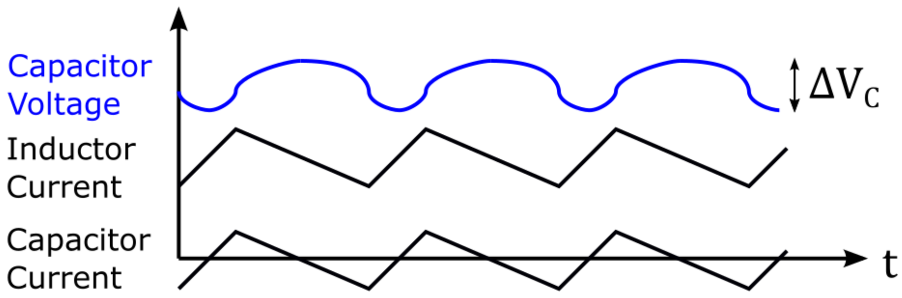


Why Measuring Impedance with DC Bias?

- To investigate nonlinearities of “real” systems.
  - Results can change when the operating point changes.
  - Filters can change their behavior.
- To analyze typical saturation effects.
  - Capacitors like Class 2 dielectrics (X5R, X7R) will lose capacitance when they are being charged.
  - Inductors will lose inductance when the current rises.
- To create models of components including non-linearities.
  - Also refer to the presentation of Sam Ben-Yaakov.

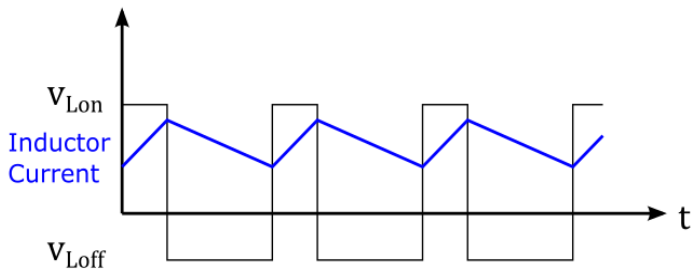
Capacitors with DC Voltage

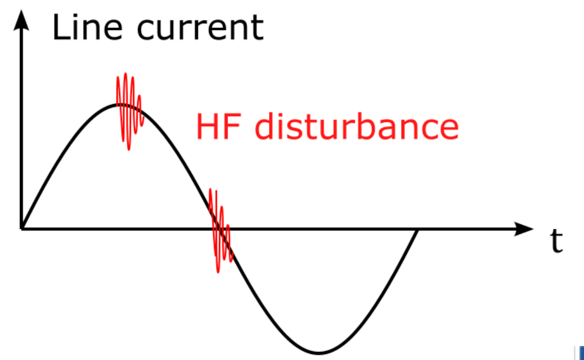
- Capacitors in power electronics applications are often charged with a DC voltage.
- Only “small” AC ripple “flows thru” the capacitor.
- Capacitance at 0 V DC can be significantly different than the effective small-signal capacitance at full charge.



Inductor with DC Current

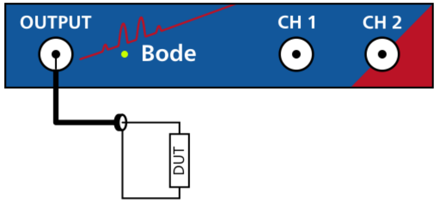
- In power electronic applications, DC current can flow thru the inductor.
- In line filter applications, HF content can occur at various operating points depending on the line current.





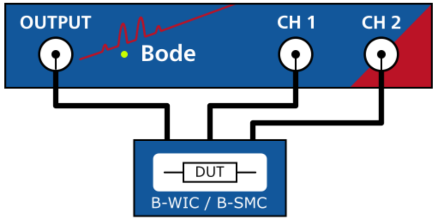
Bode - Measurement Methods (1)

One-Port



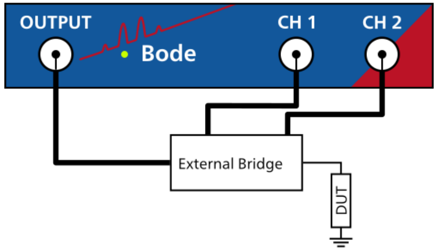
- Optimal range ≈ 0.5 Ω - 10 kΩ
- One DUT point is GND
- Can be calibrated using O/S/L

Impedance Adapter



- Optimal range ≈ 20 mΩ - 600 kΩ
- DUT **must not** be connected to GND
- **Must** be calibrated with O/S/L

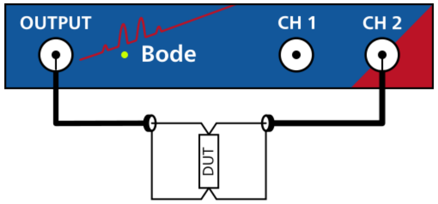
Bridge / Coupler



- Range is variable
- **Must** be calibrated using O/S/L

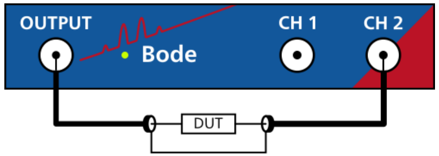
Bode - Measurement Methods (2)

Shunt-Thru



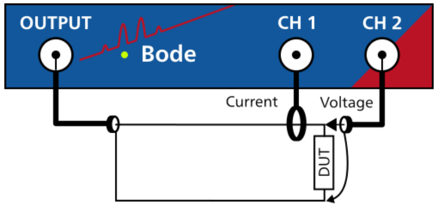
- Optimal range:
  ≈ 1 mΩ - 10 Ω
- One DUT point is GND
- Can be calibrated with Thru or O/S/L
- Note: Ground-loop!

Series-Thru



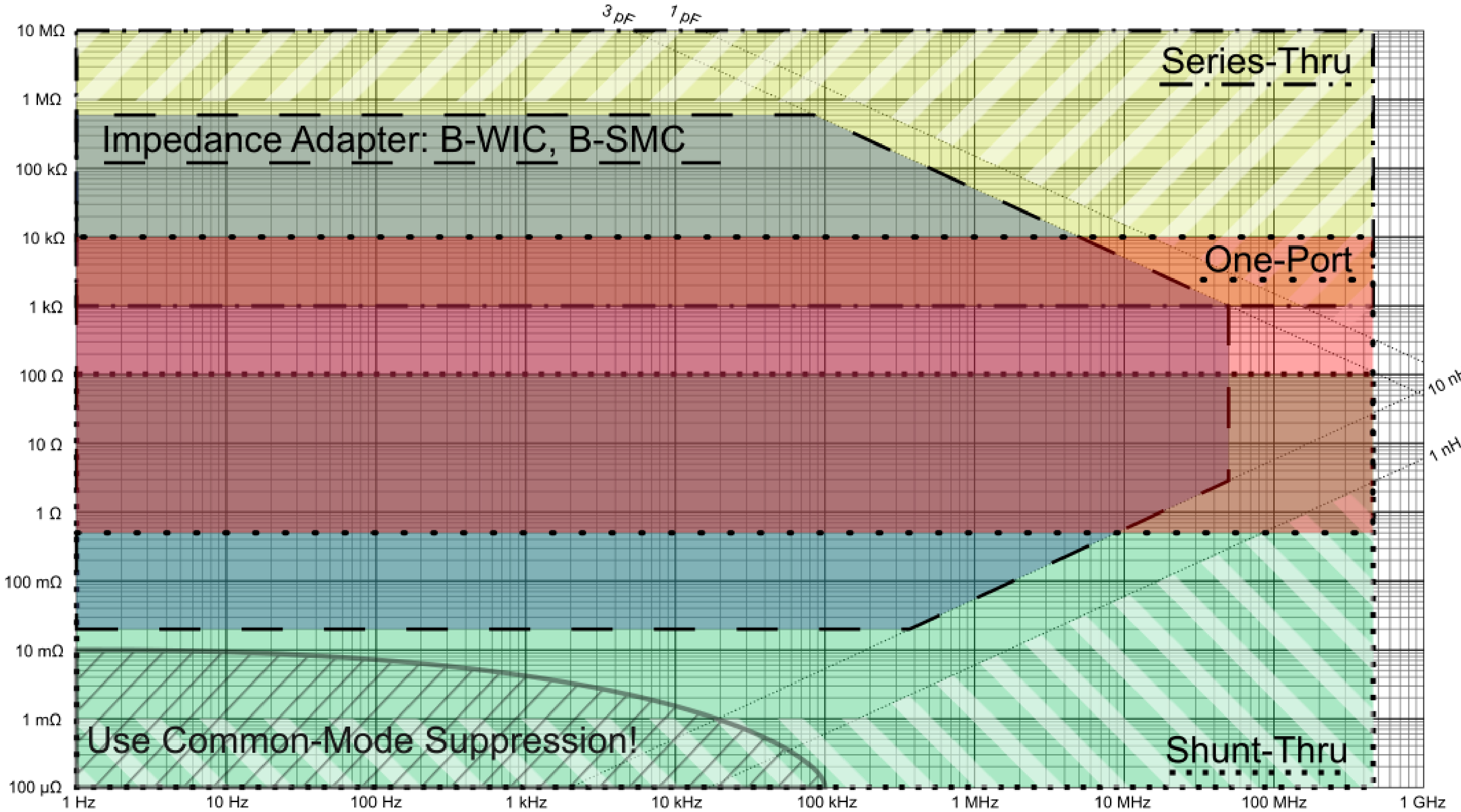
- Optimal range:
  ≈ 1 kΩ - 10 MΩ
- DUT must **not** be connected to GND
- Can be calibrated with Thru or O/S/L

Voltage/Current Gain

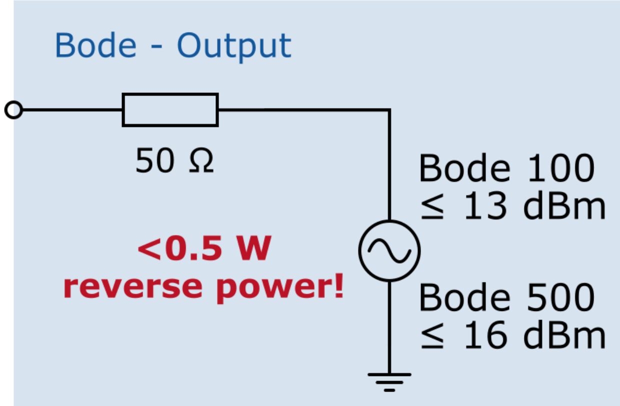


- Range depends on probes and modulator
- Can be calibrated with Thru or O/S/L

Method Range Overview



Bode - Output Port - Limits

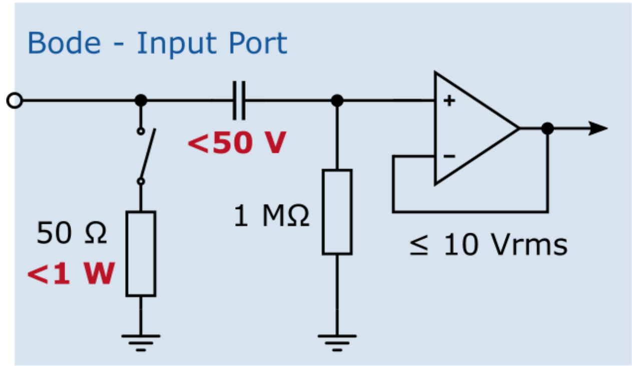


- < 0.5 W reverse power
- < 5 V reverse voltage
- ≤ 3.3 V recommended
- Beware of transients!
- Use external transient protection if necessary
  e.g. antiparallel diodes or Picotest Port Savers

Picotest	**P2131A**	**P2132A**
Maximum DC Voltage	± 75 V	± 6 V
3 dB Frequency Range	200 Hz – 1 GHz	1.3 Hz – 450 MHz
Insertion Loss	0.8 dB	12.1 dB

Bode - Input Ports - Limits

- Max. 1 W when set to 50 Ω
  → max. 7 V_{RMS}
- Max. 50 V DC when set to 1 MΩ
- Maximum AC voltage at 1 MΩ depends on frequency!
  - < 50 V_{RMS} (DC – 1 MHz)
  - < 30 V_{RMS} (1 MHz – 2 MHz)
  - < 15 V_{RMS} (2 MHz – 5 MHz)
  - < 10 V_{RMS} (5 MHz – 10 MHz)
  - < 7 V_{RMS} (10 MHz – 450 MHz)



Note:
Bode can't resolve more than 10 V_{RMS}

Some Words on Safety

Follow all rules and laws applicable to your workplace!

... Read The Manual!

WARNING

Death or serve injury can occur if the appropriate safety instructions are not observed.

CAUTION

Minor or moderate injury may occur if the appropriate safety instructions are not observed.

NOTICE

Equipment damage or loss of data possible.

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Some More Words on Safety

Bode 100 and Bode 500 are SELV devices (Safety Extra Low Voltage).

WARNING

Death or severe injury can occur if hazardous voltages are connected to the *Bode 100*.

Bode 100 is a SELV device (SELV = Safety Extra Low Voltage according to IEC 60950-1), also known as protection class III or ES1 equipment according to IEC 62368-1).

- Do not apply voltage levels > 50 V DC or > 25 V AC to the inputs of *Bode 100*.
- When working with external voltage or current sources in the test setup, ensure that they can not exceed the SELV levels and provide appropriate isolation to other hazardous circuits, such as the AC line voltage supply.
- Be aware that the *Bode 100* has no indicator to show if the output is active. This could be especially critical if amplifiers are connected to the *Bode 100*

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Some More Words on Safety

Back-EMF from energy stored in inductors can cause high voltages! Make sure not to store more than 350 mJ.

WARNING

Death due to electric shock.

Hazardous touchable voltages from external sources when biasing components

- ▶ Only use DC voltage sources below 60 V.
- ▶ Only use DC sources isolated from mains.
- ▶ Ensure that energy stored in inductive components stays below 350 mJ.

You Want to Bias above SELV?

1. Identify all safety relevant rules applicable
2. Take appropriate measures such as
   - Physical barrier (separate danger zone and safe area)
   - **Connect ground terminal of Bode to laboratory ground** using a solid connection of 3.6mm² no longer than 10m
   - Don't forget: USB of Bode is connected to the housing / shield
3. Use appropriate isolation **between DUT and Bode**
4. Use only Bias sources **galvanically isolated** from Earth Ground.

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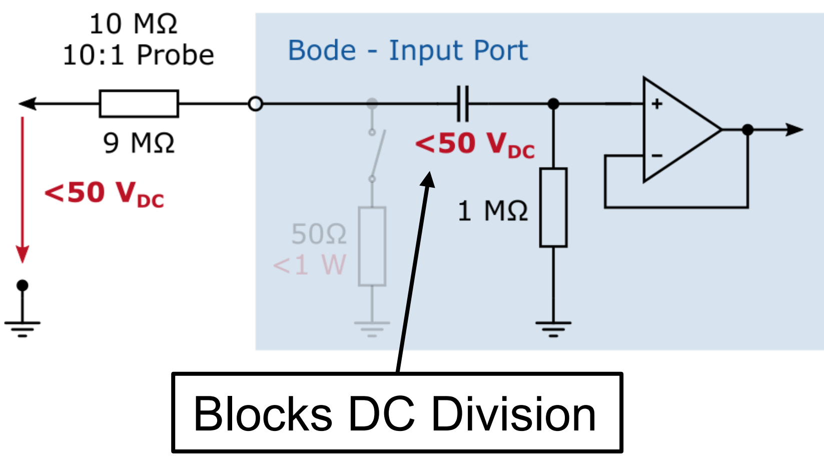
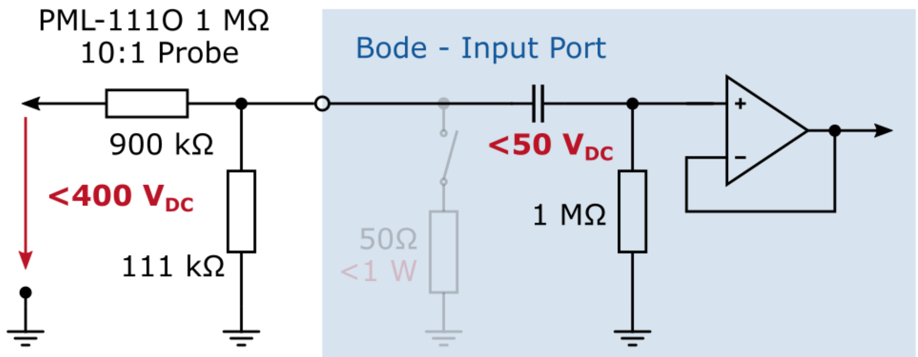
Using External Passive Probes

- Note that Bode inputs are AC coupled when set to 1 MΩ!
- Standard passive 10:1 oscilloscope probes don't help!
- Use suitable probes like PML-111O or PHV 1000-O

Requires 1 MΩ from Input:	Complete Divider in Probe:





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Voltage Biasing using the **Picotest CTF**

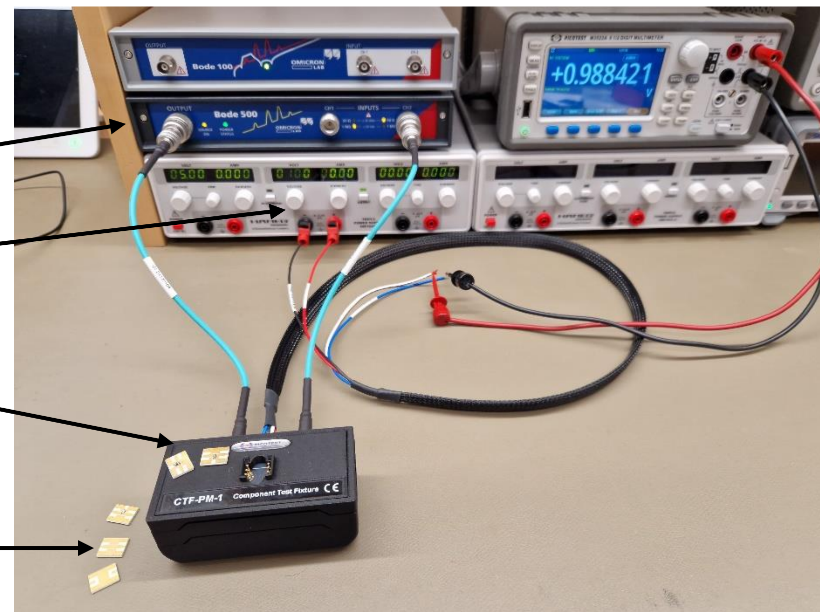
- 2-Port Shunt-Thru measurement setup
- DC Bias module for capacitor measurements to 75 V
- Convenient to use

Bode 500 VNA

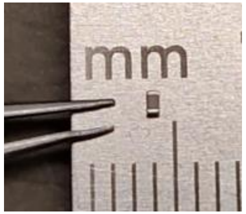
DC Voltage Source

Picotest CTF with DC Bias Module

DUT mounts and Calibrators

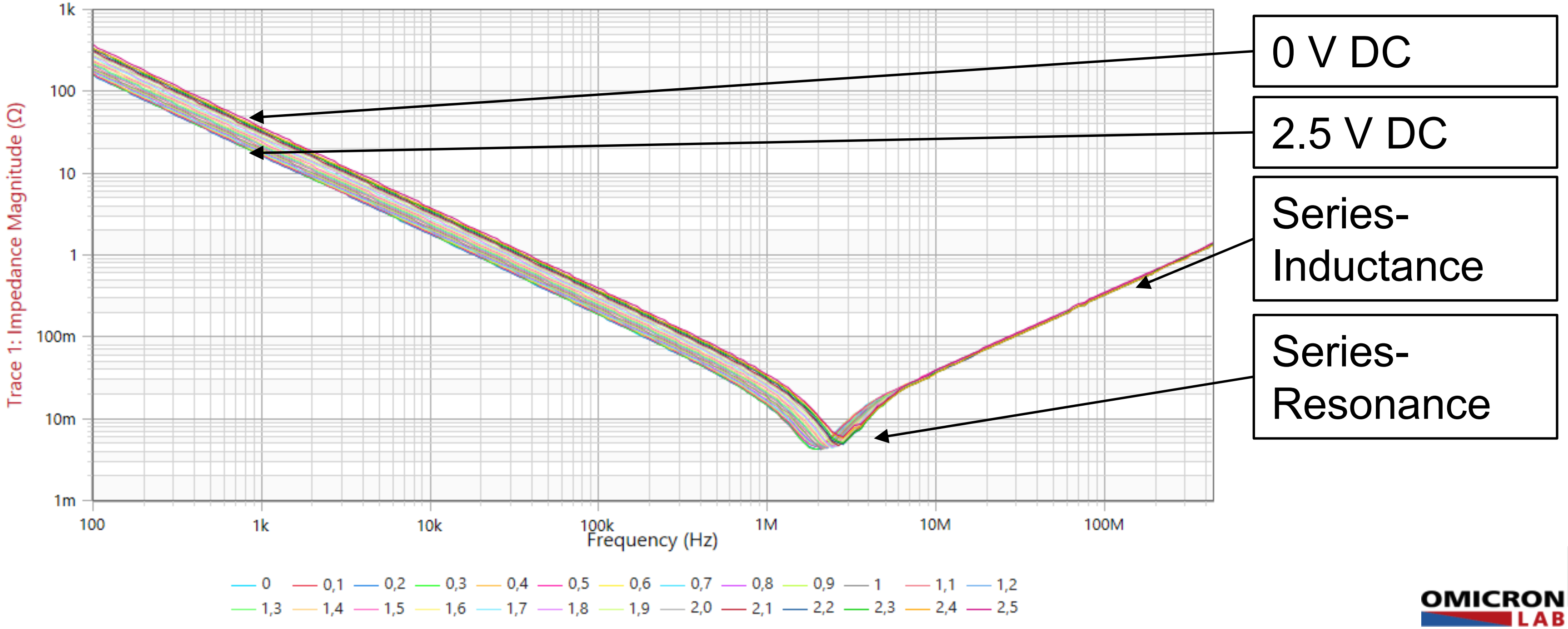


Example: GRM155R60E106ME16



0402 Chip Capacitor, X5R, 10 µF, 20 %, DC 2.5 V

Measured using Bode 500 with Picotest CTF (0 dBm Signal)



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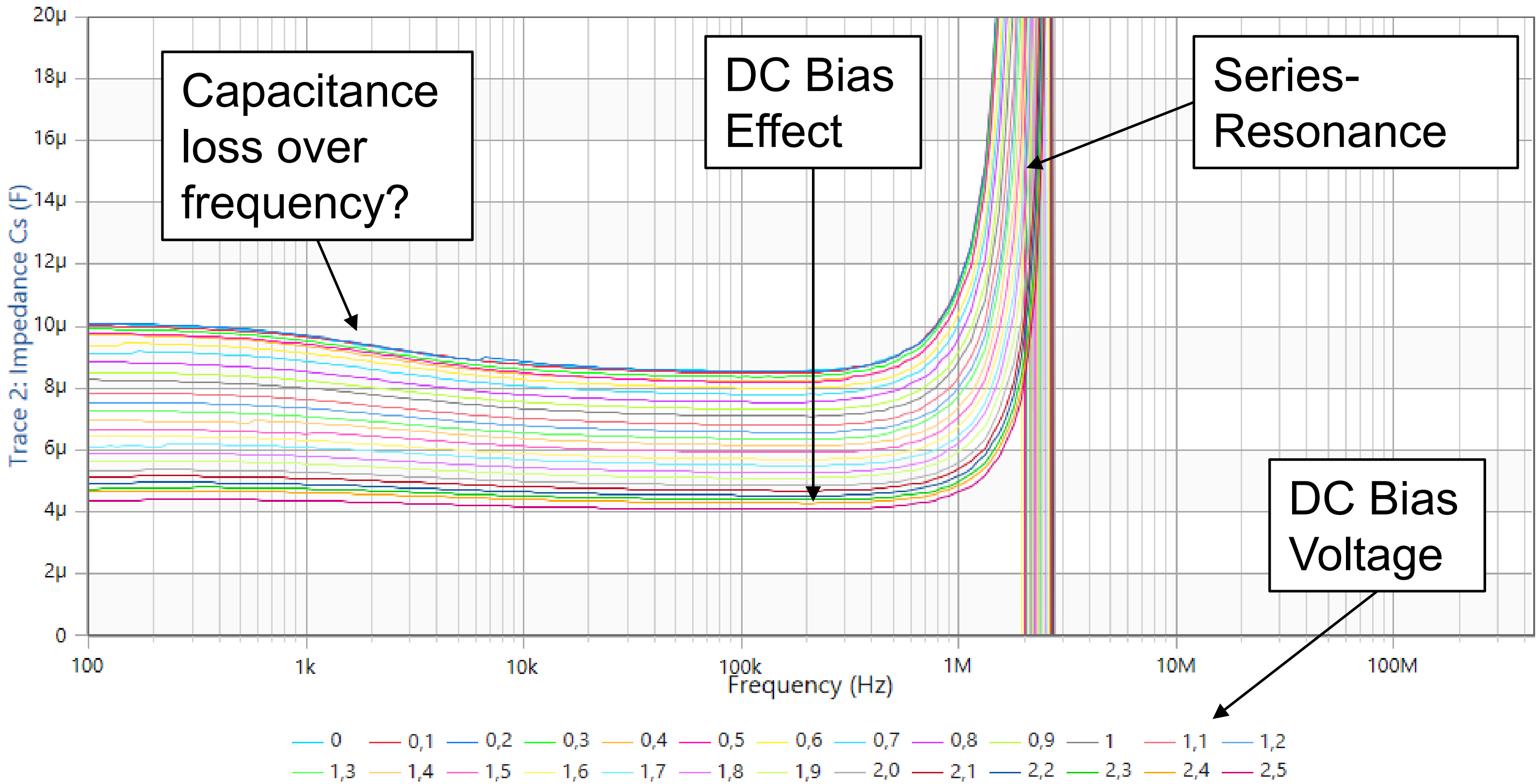
GRM155R60E106ME16 – Cs Format



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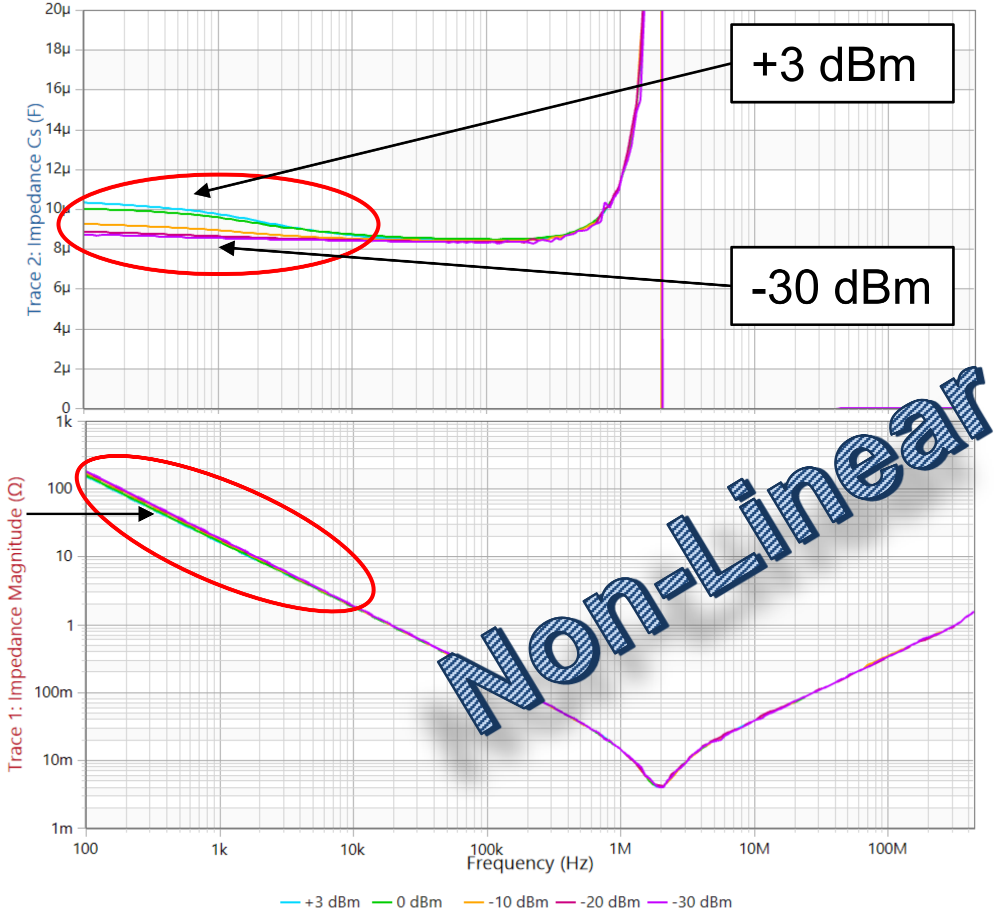
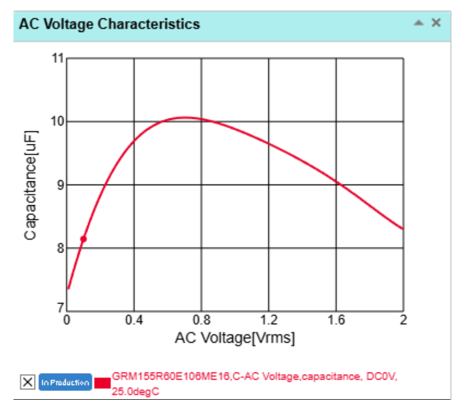
Linearity Check with Signal Level



Note: Bode has 50 Ω source impedance → voltage at DUT changes when DUT impedance changes.

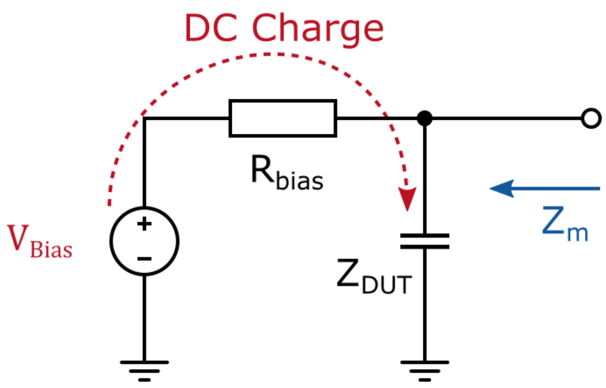
But: DUT capacitance changes when voltage changes... ☺

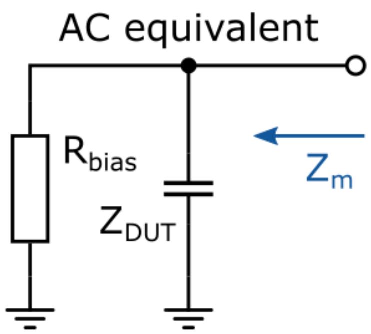


Source: https://ds.murata.co.jp/simsurfing

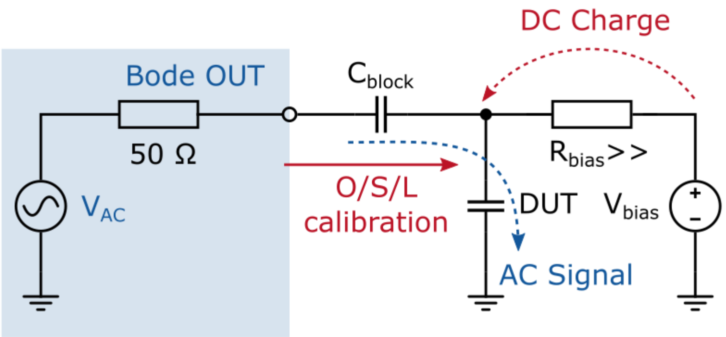
Voltage Biasing Principles

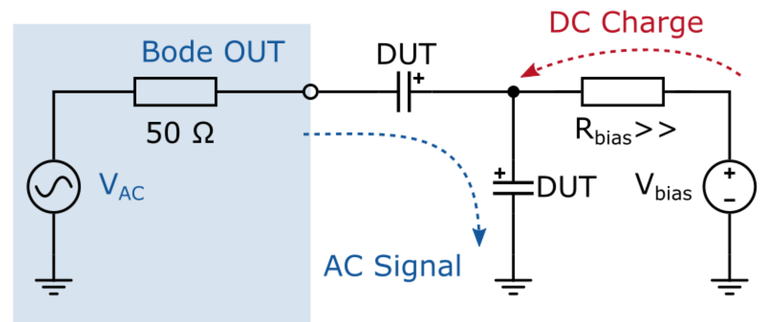
- Bode ports need to be protected from harmful DC voltage
- Voltage sources have low impedance ($Z \approx 0$)
- Capacitors can be charged via a resistor R_{bias}
  - R_{bias} reduces measurement error when $|R_{bias}| \gg |Z_{DUT}|$
  - R_{bias} slows charging and discharging, avoiding transients





Two Possibilities to Bias Capacitors





A: Using a DC block capacitor

- ☺ Only one DUT needed
- ☺ $Z_{DUT} = Z_m$
- ☺ Simple for low voltages
- ☹ $C_{block} \gg C_{dut}$ (> factor 10)
- ☹ DC block can introduce errors

B: Using two similar DUTs

- ☺ No extra DC block needed
- ☺ Suitable for higher voltages
- ☹ $Z_m = Z_{DUT} \cdot 2,\ C_{DUT} = C_m \cdot 2$
- ☹ Two similar DUTs required

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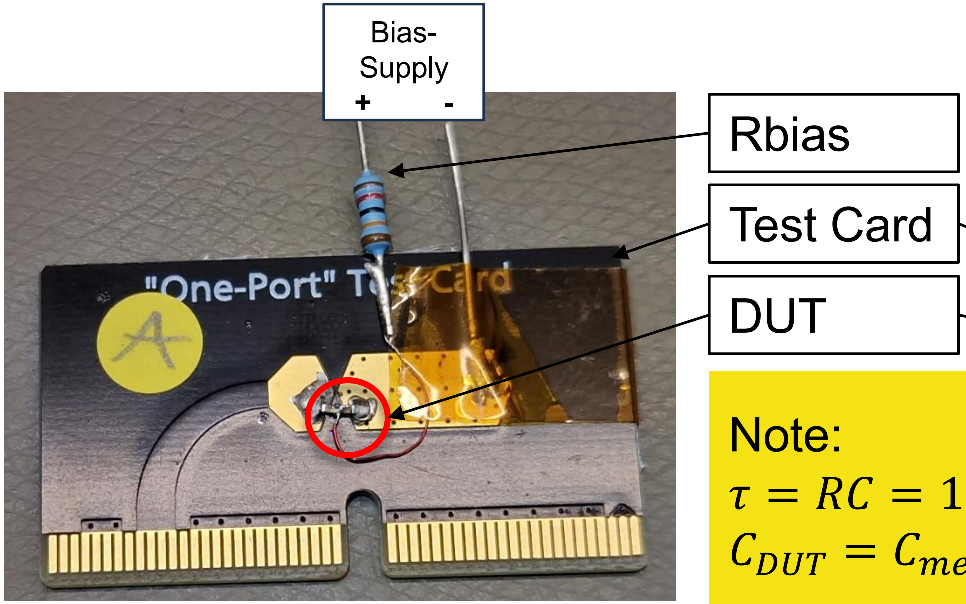
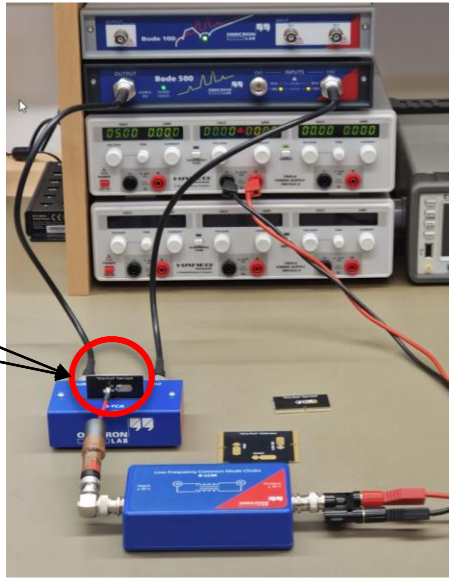
GRM155R60E106ME16 on **B-TCA**

- Using two capacitors (DUT) in series, charging the center-tap via 120 kΩ series resistor (Setup B)
- Focus on **1 kHz** → ≈ 16 Ω → One-Port measurement

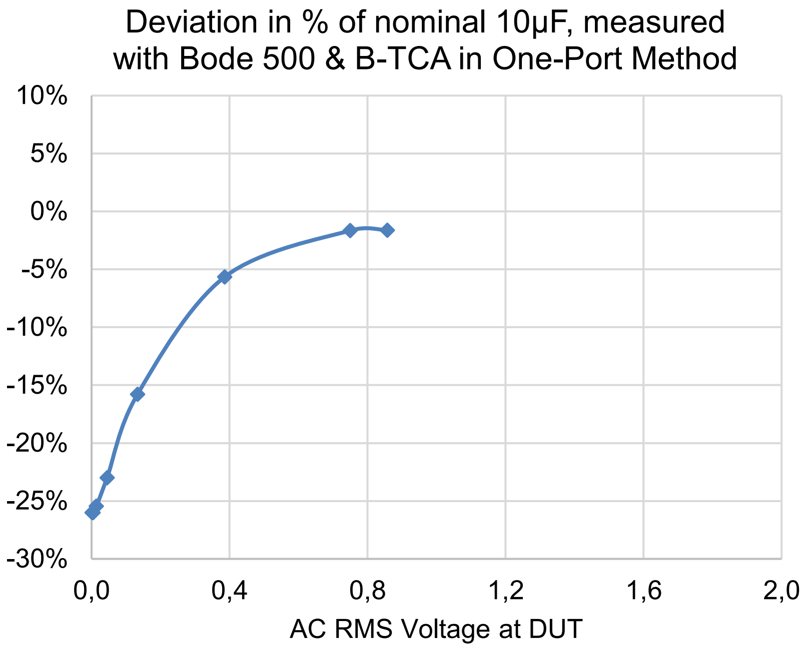


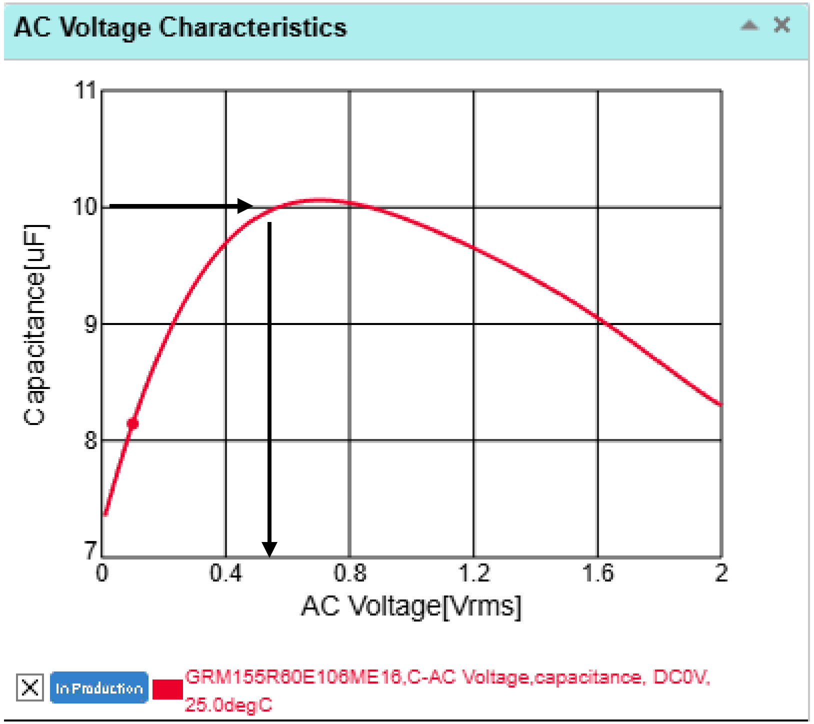
Note:
$\tau = RC = 1.2\ s$
$C_{DUT} = C_{measure} \cdot 2$



GRM155R60E106ME16 – AC Dependency

Source: https://ds.murata.co.jp/simsurfing

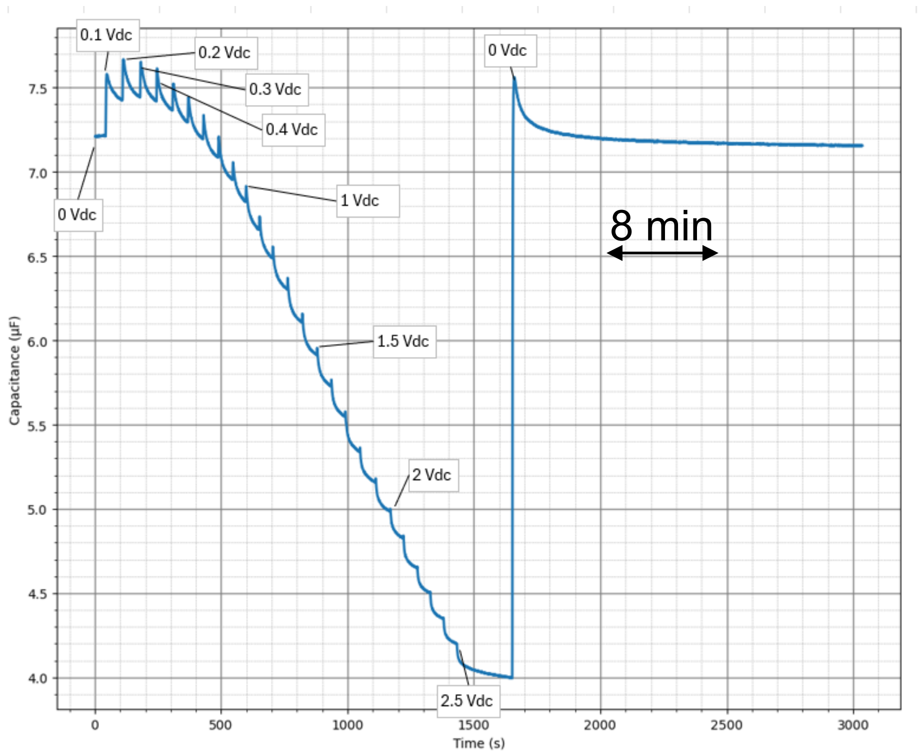




Difference maybe from different source impedance?

VNA 50 Ω, LCR-Meter 100 Ω, Is level control used?

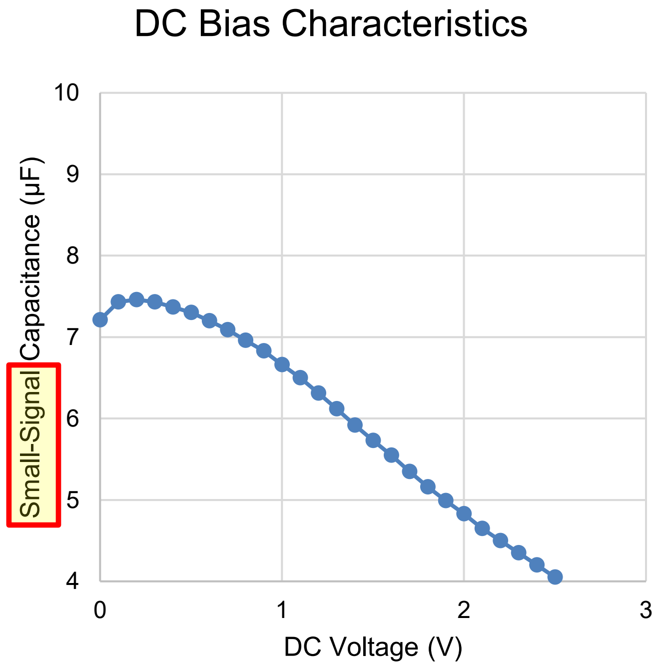
GRM155R60E106ME16 – DC Bias Effect



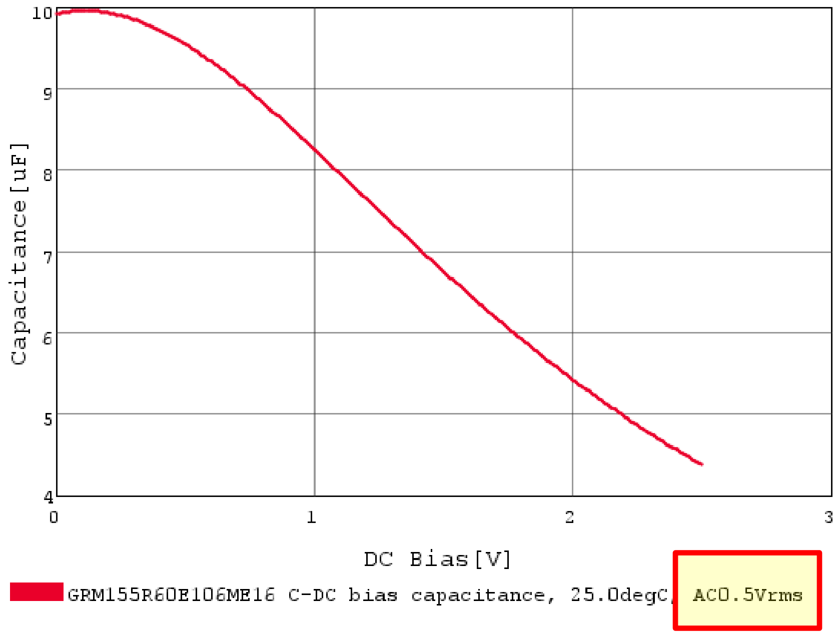

```python
import pyvisa
import time
import matplotlib.pyplot as plt
import matplotlib.animation as animation

SCPI_server_IP = '10.77.192.5'
SCPI_Port = '5025'

SCPI_timeout = 20000 # milliseconds
VISA_resource_name = 'TCPIP::' + SCPI_server_IP + '::' + SCPI_Port + '::SOCKET'

Start_frequency = '1kHz'
Receiver_bandwidth = '10Hz'
Number_of_points = '1'
Source_level = '-30'


# Storage for data
x_data = []
y_data = []

print('Trying to connect to VISA resource: ' + VISA_resource_name + '. Be sure
that IP address and port number are correct!')
    visaSession = pyvisa.ResourceManager().open_resource(VISA_resource_name)
    visaSession.timeout = SCPI_timeout
    visaSession.read_termination = '\n'

    print('SCPI client connected to SCPI server: ' + visaSession.query("*IDN?"))

    lockOk = visaSession.query(":SYST:LOCK:REQ?")
    if lockOk != "1":
        print("Locking was not successful, exiting!")
        return
    else:
        print("Locking was successful!")
    try:
        # Here comes the measurement configuration data for measurement sweep
        # Start_frequency is already string and doesn´t require any conversion
        visaSession.write(':SENS:FREQ:STAR ' + Start_frequency)
```

Small-Signal capacitance (-30 dBm) changes over minutes...

GRM155R60E106ME16 – DC Bias Effect

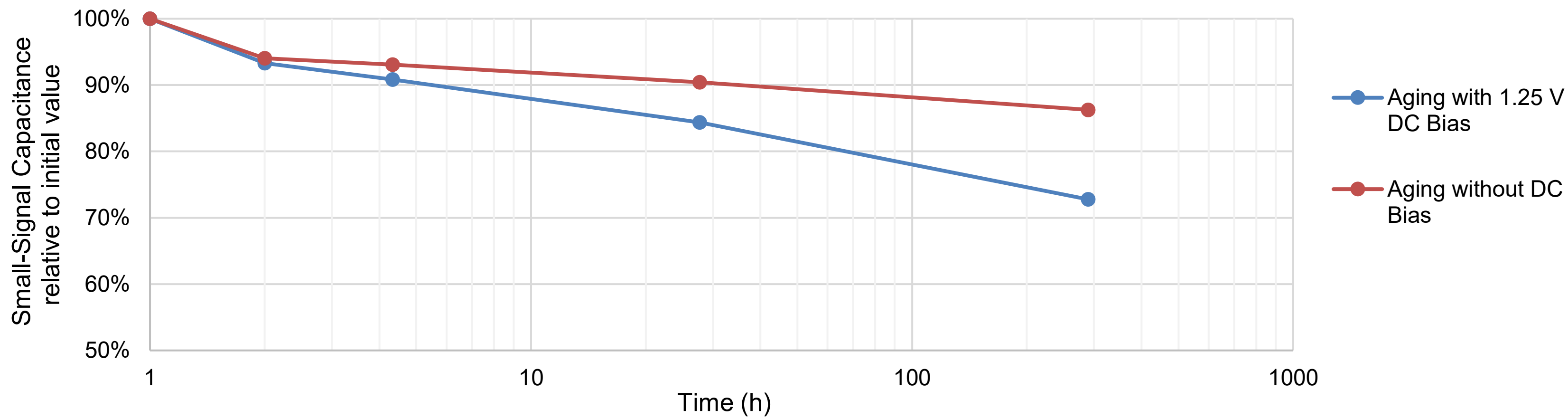


Source: https://ds.murata.co.jp/simsurfing



Small-Signal capacitance (5mVrms) different to 500 mVrms

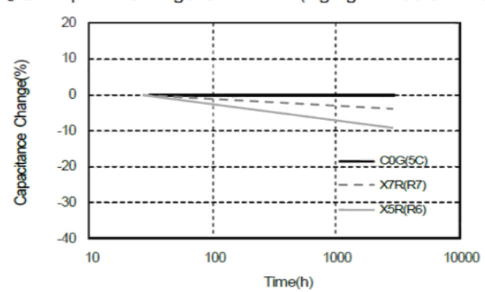
GRM155R60E106ME16 – "Aging"



6. Capacitance Aging

1. The high dielectric constant type capacitors have an Aging characteristic in which the capacitance value decreases with the passage of time. When you use a high dielectric constant type capacitors in a circuit that needs a tight (narrow) capacitance tolerance (e.g., a time-constant circuit), please carefully consider the characteristics of these capacitors, such as their aging, voltage, and temperature characteristics. In addition, check capacitors using your actual appliances at the intended environment and operating conditions.

[Example of Change Over Time (Aging characteristics)]

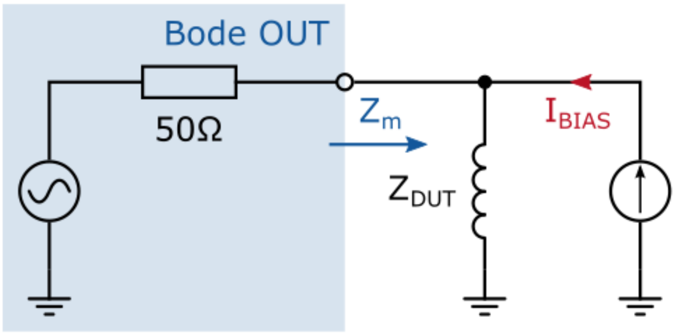


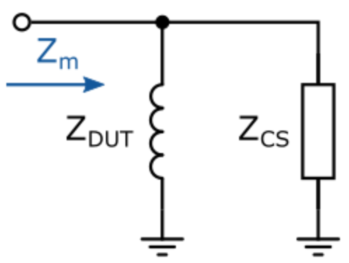
DC Bias seems to accelerate capacitance drop over time.

Source: GRM155R60E106ME16 Reference Sheet

The Challenges of Current Biasing

- Ideal current source has infinite impedance ($Z_{CS} \approx \infty$), real current source has output capacitance → $f \uparrow \cdots Z_{CS} \downarrow$
- DUT is often inductive → $f \uparrow \cdots Z_{DUT} \uparrow$
- Source impedance cannot be "decoupled via > Rbias".





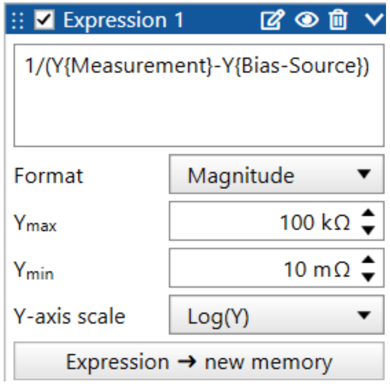
$$Z_m = Z_{DUT} || Z_{CS}$$

Error gets large at high frequencies.

Correcting the Source Impedance Error

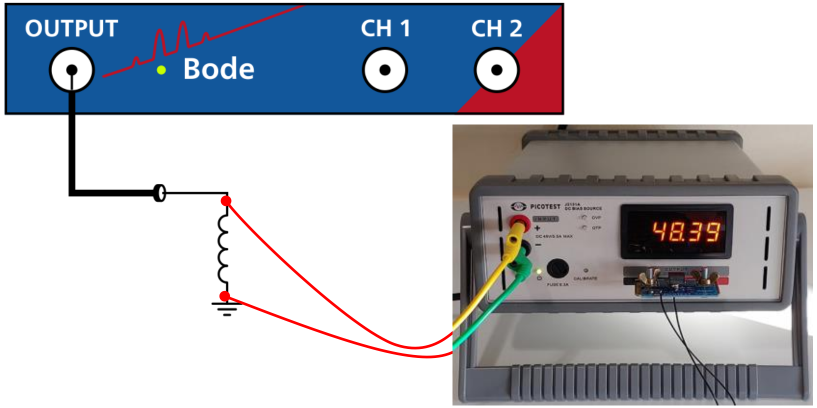
If the source impedance Z_{CS} stays constant and is known or measurable it can be corrected using the expression trace in Bode Analyzer Suite:

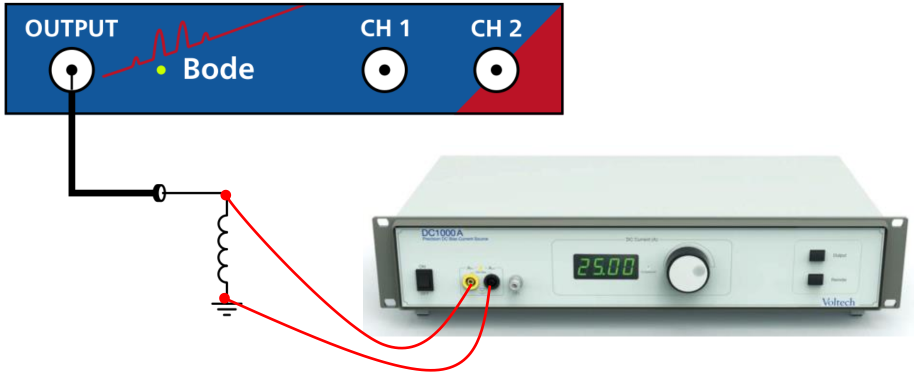
1. Measure or determine Z_{CS}.
2. Store Z_{CS} to a memory trace, name it “Bias-Source”.
3. Add the following Expression:



Assuming a parallel circuit, the admittance makes the correction a simple subtraction.

Inductor Biasing Possibilities (1)





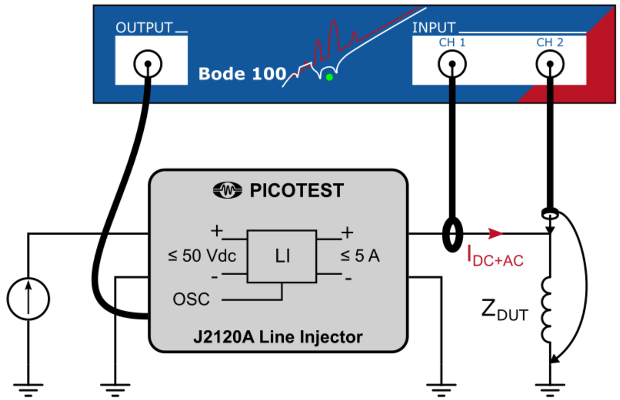
Bias Source Picotest J2131A

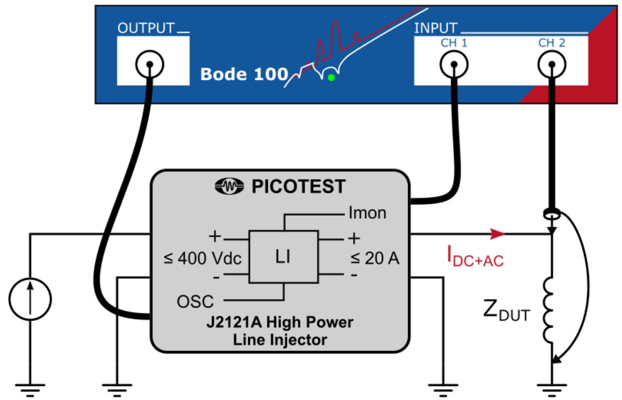
- ☺ Up to 125 A in one device
- ☺ Includes DUT mount
- ☹ Error should be corrected
- ☹ Requires extra power supply

Bias Source Voltech DC 1000

- ☺ Scalable up to 500 A
- ☺ Usable to some MHz
- ☹ Expensive
- ☹ 25 A with one unit

Inductor Biasing Possibilities (2)





Picotest J2120A
Line Injector

- ☺ Price-effective
- ☺ Usable to ≈ 10 MHz
- ☹ Limited to 5 A
- ☹ Current Probe needed

Picotest J2121A
High Power Line Injector

- ☺ Up to 20 A_{DC}
- ☺ Current monitor output
- ☹ More expensive
- ☹ Limited to 1 MHz

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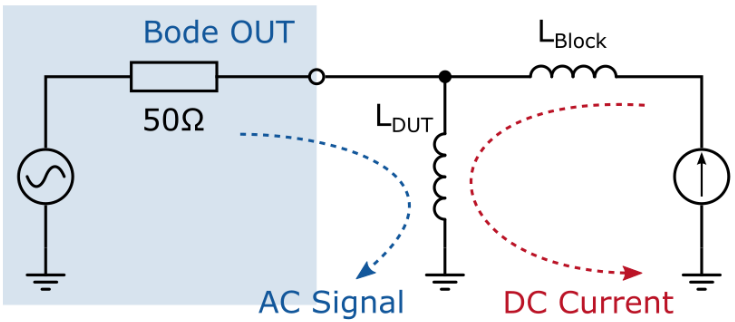
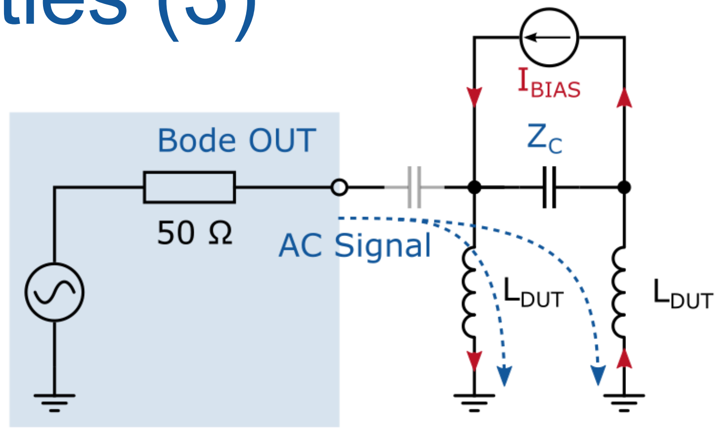
Inductor Biasing Possibilities (3)





A: Blocking Inductor

- ☺ Only 1 DUT needed
- ☹ $Z_{L_{Block}} \gg Z_{L_{DUT}}$
- ☹ L_{Block} must not saturate
- ☹ L_{Block} must not resonate

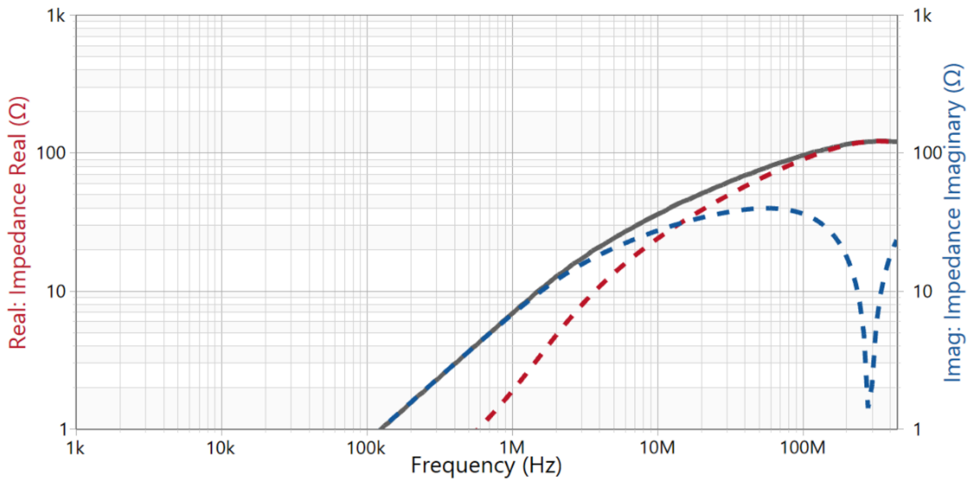
B: Two identical DUTs

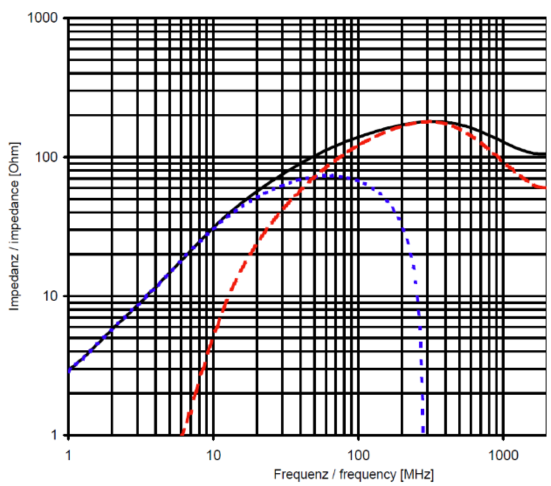
- ☺ No block-inductor needed
- ☺ Source impedance can be <<
- ☹ Two identical DUTs needed
- ☹ $Z_C \ll Z_{L_{DUT}}$ (problem at low f)

Example: 742792023 Chip Ferrite

0805 Multilayer-SMD-Ferrite, 120 Ω @ 100 MHz, 180 Ω @ 250 MHz. R_{DC} < 30 mA, I_{DC} < 3 A.

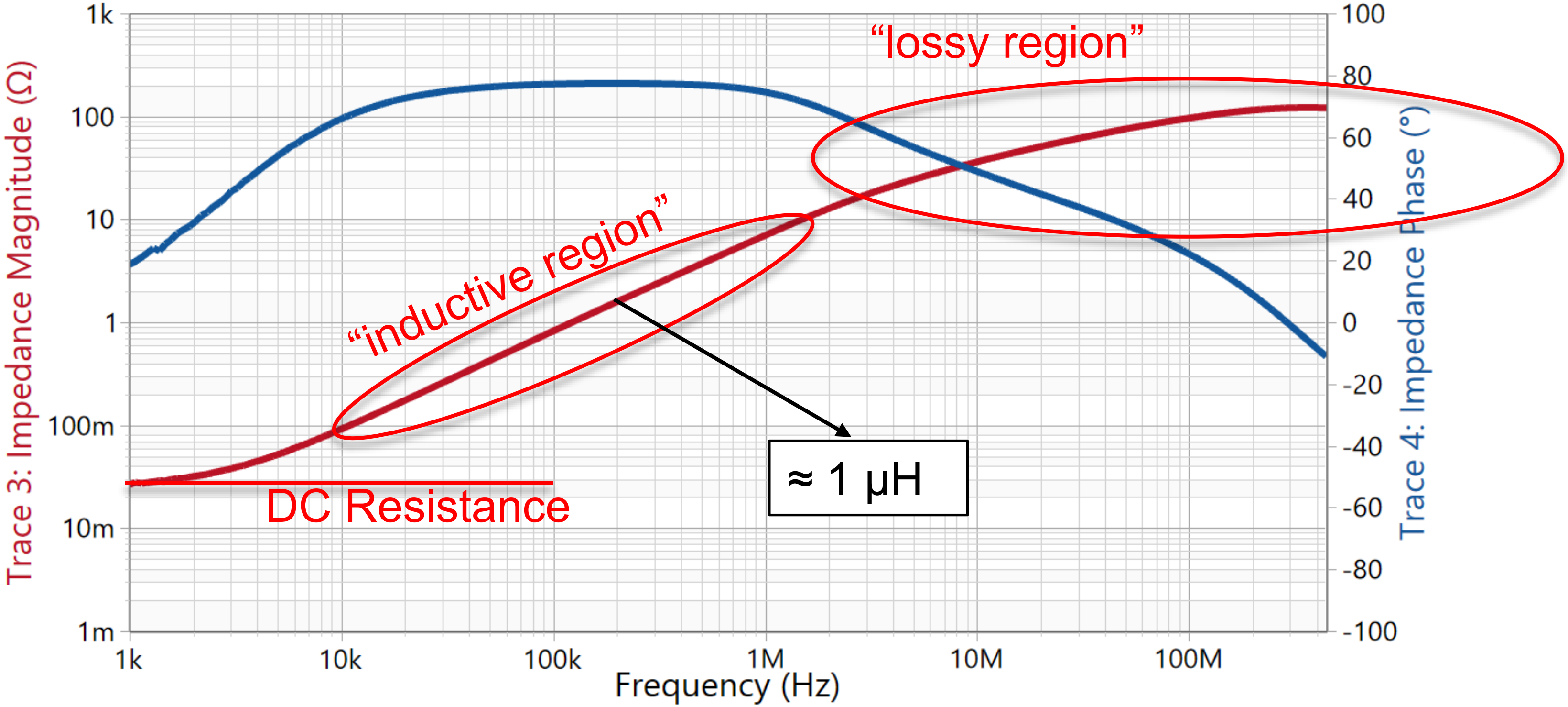
Measured using Bode 500 with B-TCA in One-Port method.





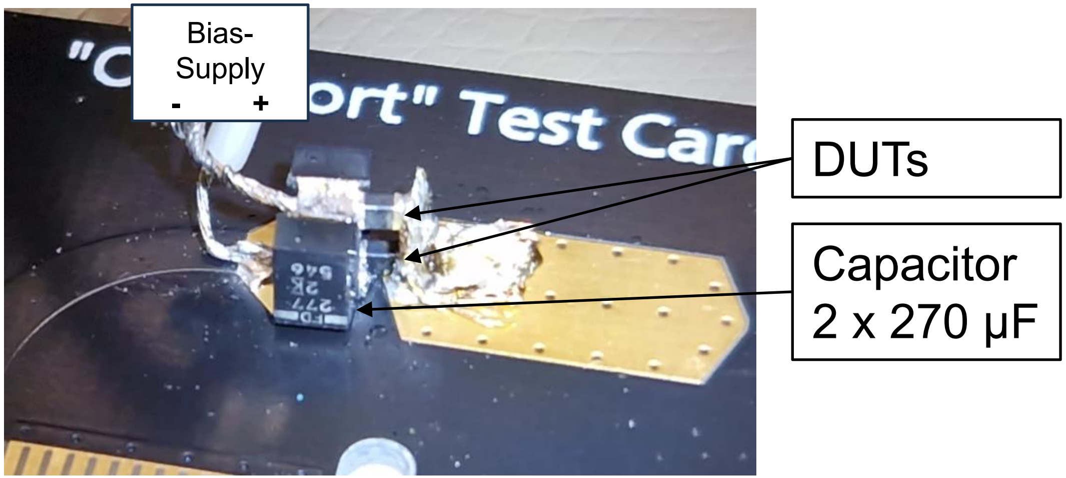
Source: WE742792023 Spec. Sheet

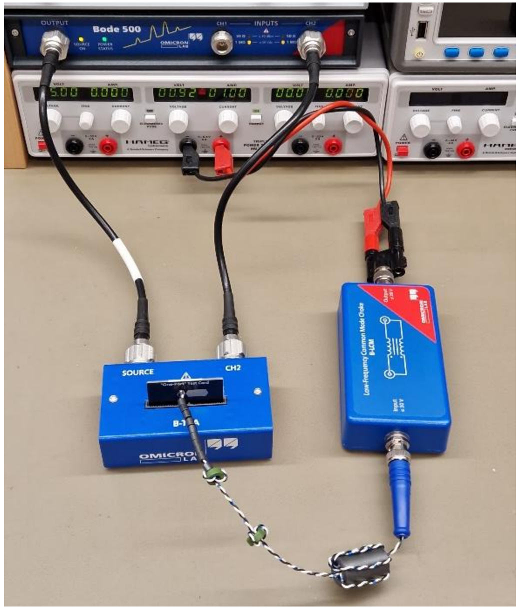
742792023 Chip Ferrite – Full Picture



742792023 Chip Ferrite – DC Biasing

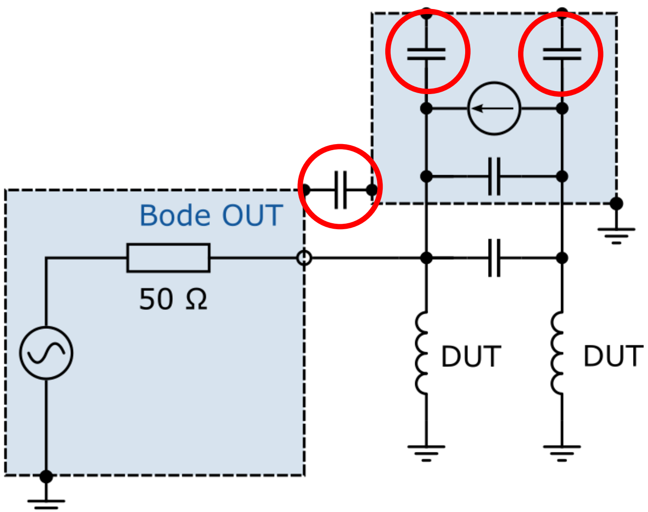
- Using two ferrites in parallel (Setup B)
- Focus on high frequencies (B-TCA in One-Port)
- Bias current delivered via common mode chokes
- Capacitor $Z_C = 520\ \mu F$ tantalum for 2 V

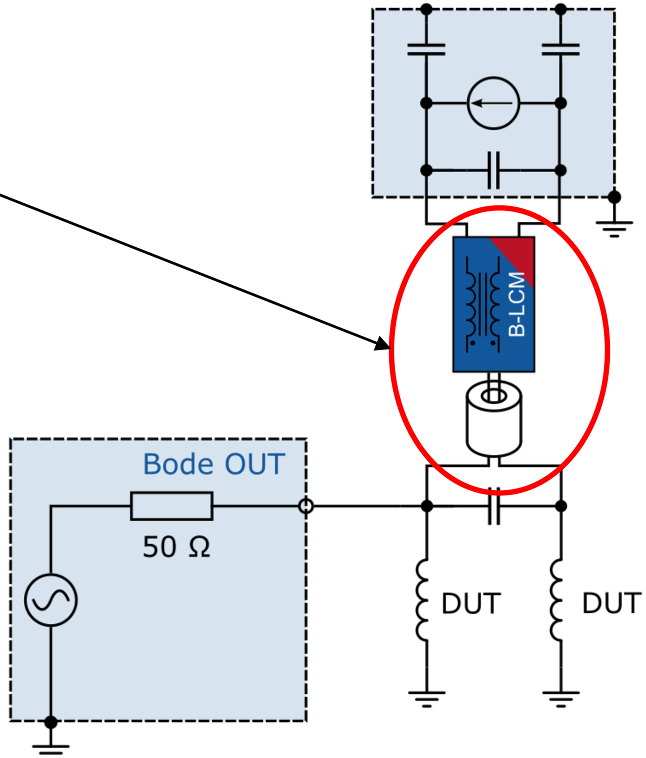




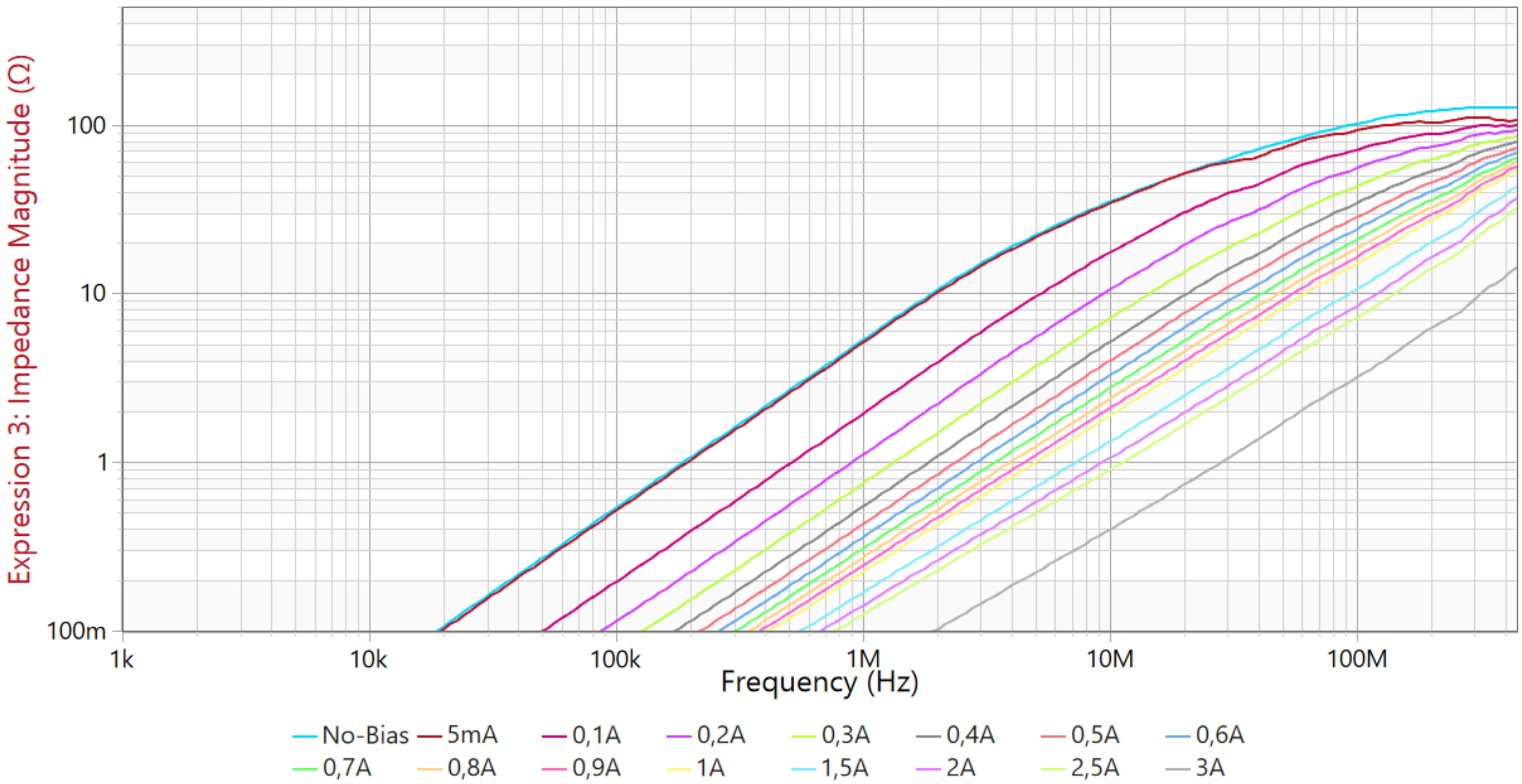
Error at High Frequency

- Parasitic capacitances to ground cause error due to high-frequency coupling
- Common Mode Chokes can reduce the impact

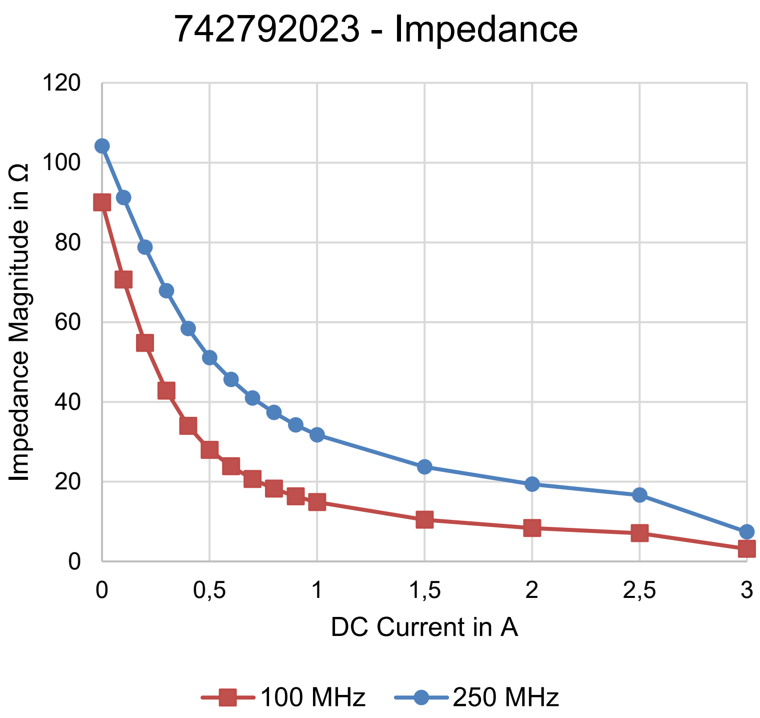


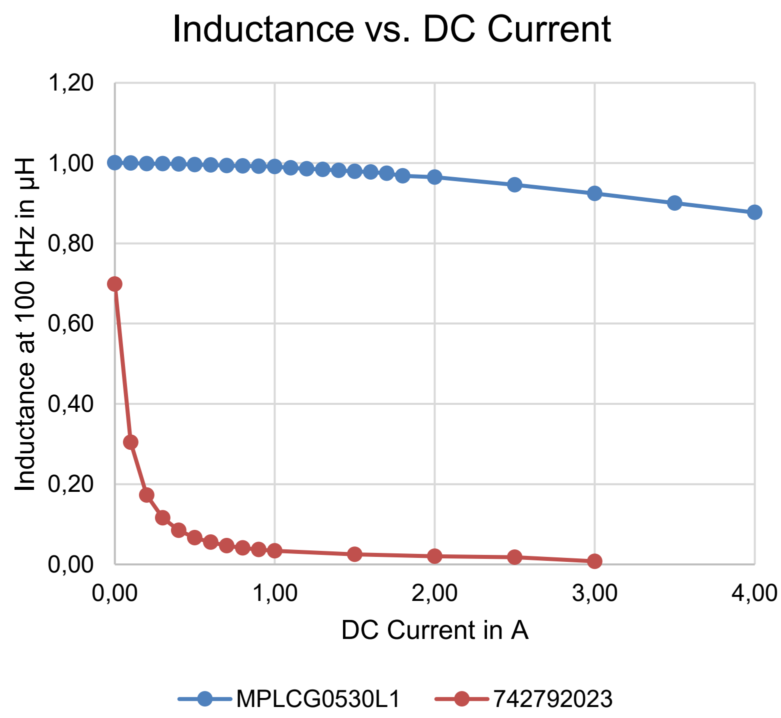


742792023 Chip Ferrite – DC Bias Effect



742792023 Chip Ferrite – DC Bias Effect





Chip ferrite beads have inductance but can show a strong bias loss.

Summary

- Impedance measurements under DC bias are possible
- Not always straight-forward
- Challenges can be high voltages, high currents or high frequencies
- Measurements are subject to systematic errors
- Some errors can be corrected, others can be reduced

Thank you for your attention!

If you have questions or proposals to the OMICRON Lab team, please contact us via info@omicron-lab.com.

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