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DesignCon® 2023

WHERE THE CHIP MEETS THE BOARD

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Expo
February 1 – 2, 2023

Santa Clara Convention Center

ChipHead
Hands-On PDN Impedance & Calibration Basics

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Heidi Barnes, Keysight Technologies

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SPEAKERS

Steve Sandler

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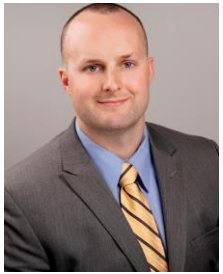
Steve Sandler has been involved with power system engineering for more than 40 years. The founder and CEO of Picotest.com, a company specializing in instruments and accessories for high-performance power system and distributed system testing



Benjamin Dannan

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Benjamin Dannan is a Technical Fellow and an experienced signal and power integrity (SI/PI) design engineer, advancing high-performance ASICs and high-speed digital designs. He is a Keysight ADS Certified Expert with numerous publications on SI/PI-related topics and received the prestigious DesignCon best paper award in 2020.

Heidi Barnes

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Senior Application Engineer in the PSS EDA Group of Keysight Technologies. Her recent activities include the application of electromagnetic, transient, and channel simulators to solve signal and power integrity challenges. Author of over 20 papers on SI and PI and recipient of the DesignCon 2017 Engineer of the Year.

Hands-On PDN Impedance & Calibration Basics

You have probably heard of calibration, de-embedding, and fixture removal for network analyzer measurements, but do you know how to do it for a 2-port shunt low-impedance measurement? Impedance measurements are a must-have skill for Power Integrity engineers. The measurements provide models for Capacitors, Resistors, and Inductors that work in both time and frequency domain simulations. Impedance measurements are also critical for verifying the performance stability of a power delivery network (PDN).

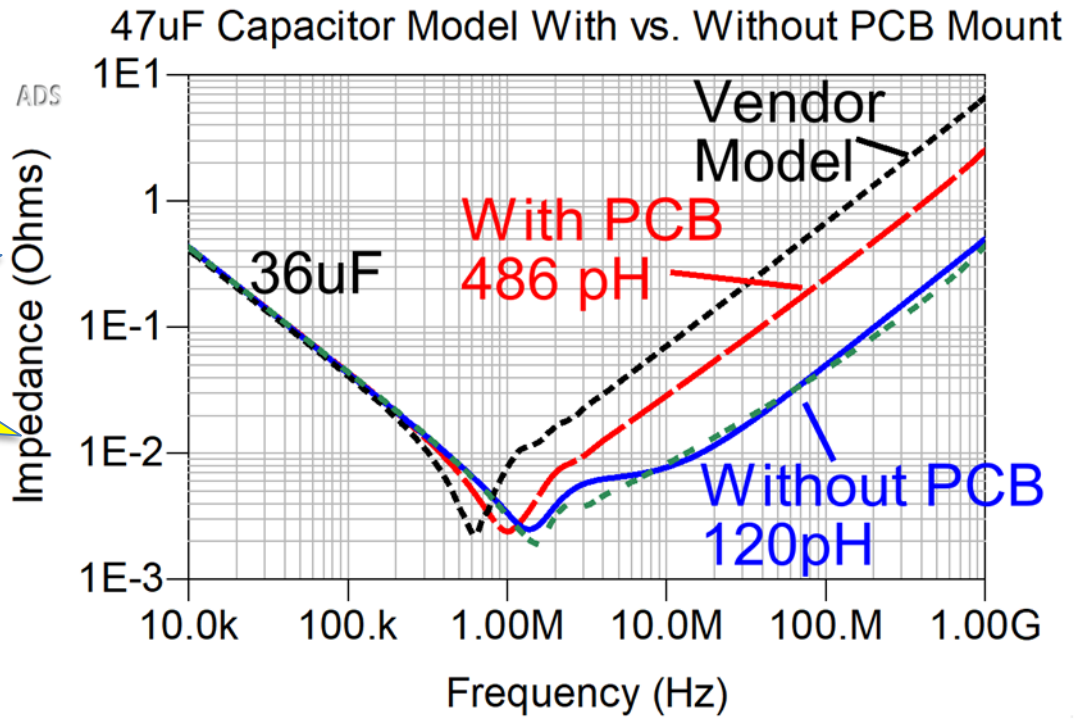
In this session, you'll learn the difference between these terms. You'll learn, with demonstrations, how to remove the impact of fixturing using calibration and de-embedding steps. The process works for both connectorized devices or with PCB browser probes to provide accurate measurements that are compatible with your PCB EM simulator.

Outline

- What is Wrong with Vendor Models
- How to Measure Low Impedance milli-ohms and micro-ohms
- Understanding Inductance
- Calibration and De-embedding to Remove Fixture Effects
- Demo: 2-Port Shunt Measurement with an E5061B
- Demo: 2-Port Shunt Measurement with a Bode 100
- Summary

Vendors get the inductance (ESL) in their models Wrong!

Accurately measuring *ESR* and *ESL* are most challenging and depends on calibration, de-embedding, and fixture removal

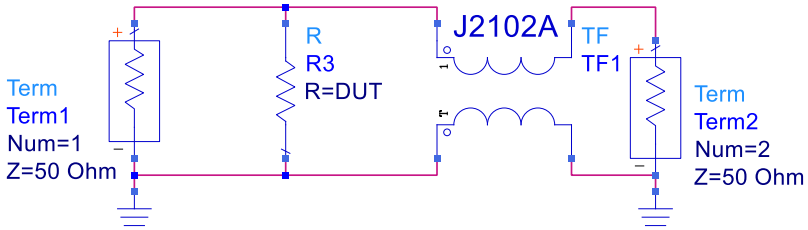


In this example, the measured capacitor has the same impedance as the vendor model at nearly 10x the frequency.

Source: EDICon 2021 Partial Inductance – The secret to correlating simulation and measurement – S. Sandler, B. Dannan, & H. Barnes

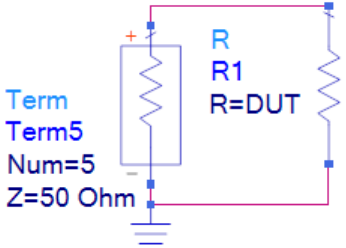
Gold Standard for Low Impedance Measurement = 2-port Shunt Thru

2-Port Shunt



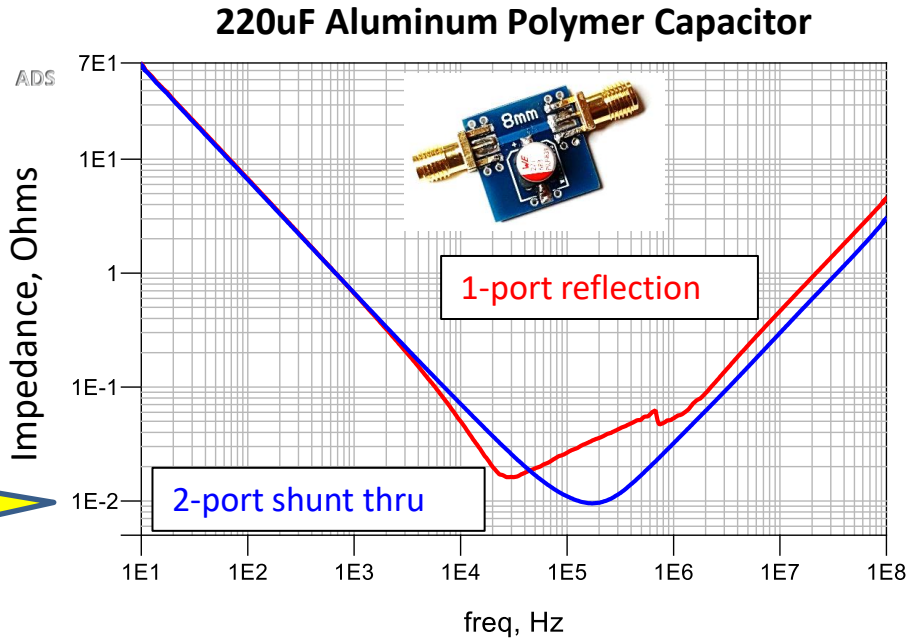
1 mΩ - 225 Ω ≥ 105 dB

1-Port



1 Ω - 2 kΩ ≥ 66 dB

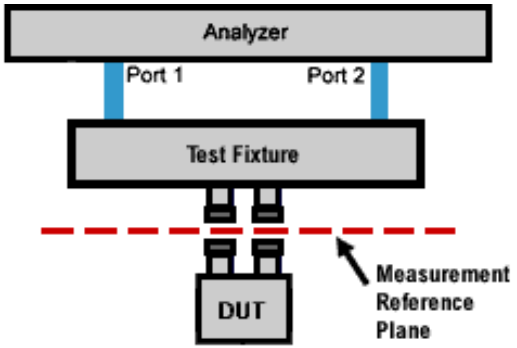
Its all about the *dynamic range*!



Source: Power Integrity Target impedance Says it All, Power Delivery is AC not DC by H. Barnes

Measurement Calibration vs. Equipment Calibration

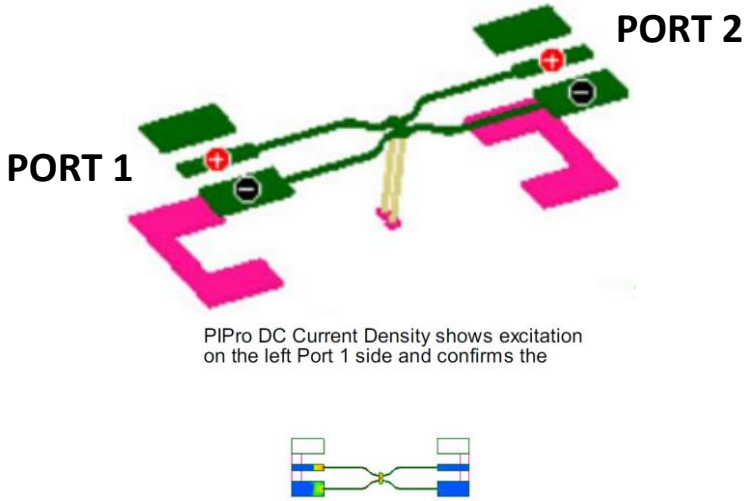
- The effects of cables, connectors, and probes tips must be zeroed-out before measurements can be taken.
- Measurement calibration moves the measurement reference plane.
- Equipment (Instrument) calibration is used to maintain instrument accuracy.

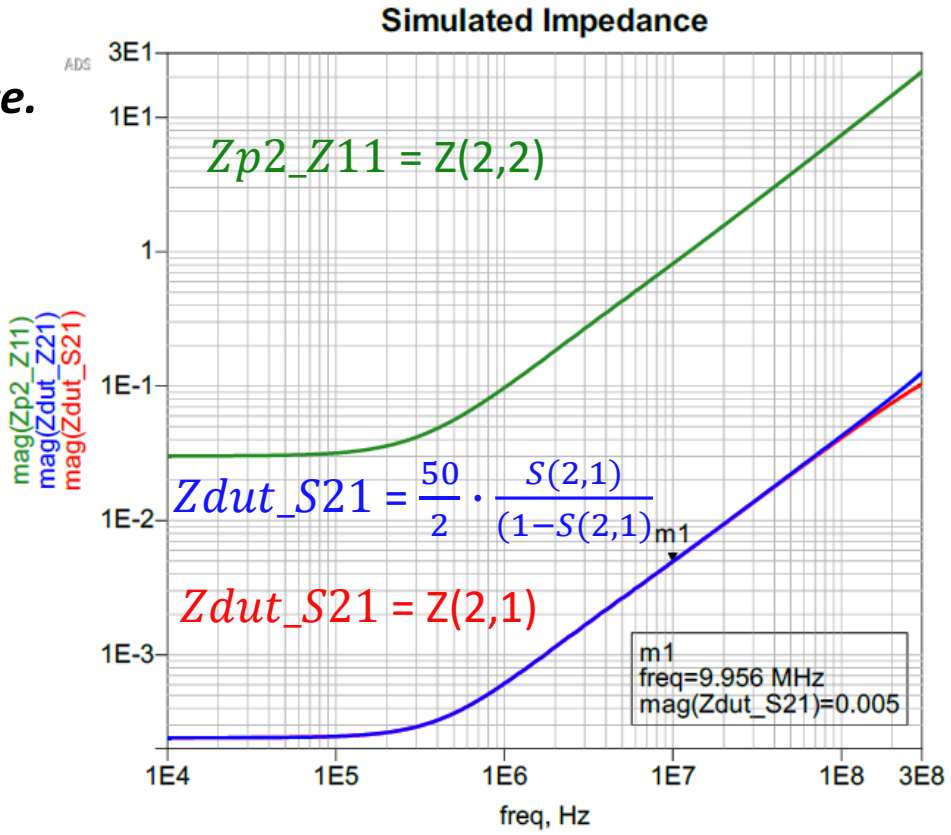


Source: https://rfmw.em.keysight.com

What do we want know?

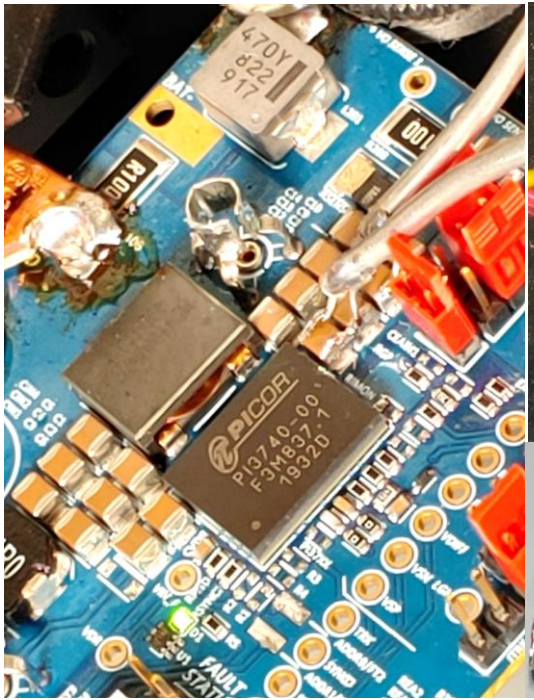
- ***How to calculate the mounting inductance.***
- ***But how do we get the mounting inductance per pitch?***

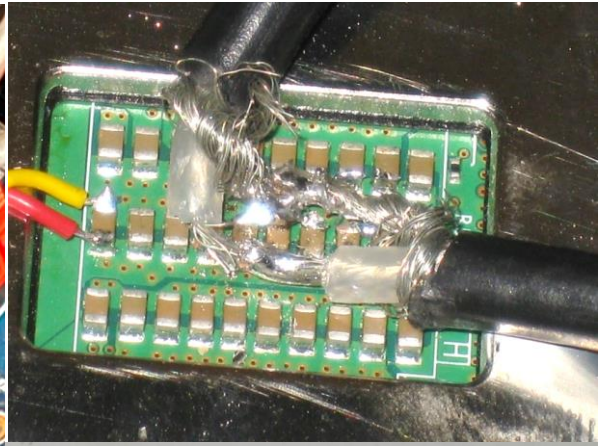




Why you cannot use clip leads or soldered wires?

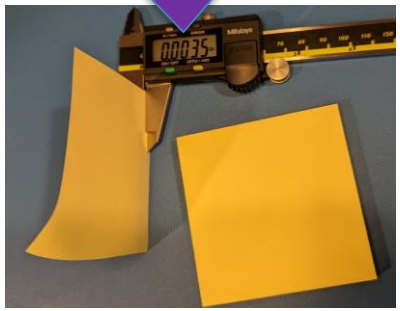
- We want repeatability. This comes with a connector or a probe.
- Most boards are not designed with proper probe points to make measurements.
- The inductance of this measurement limits your measurement setup noise floor.



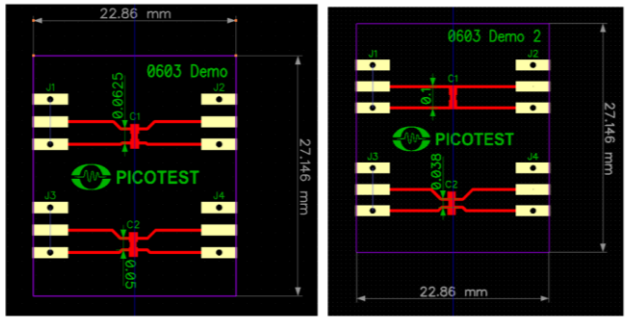


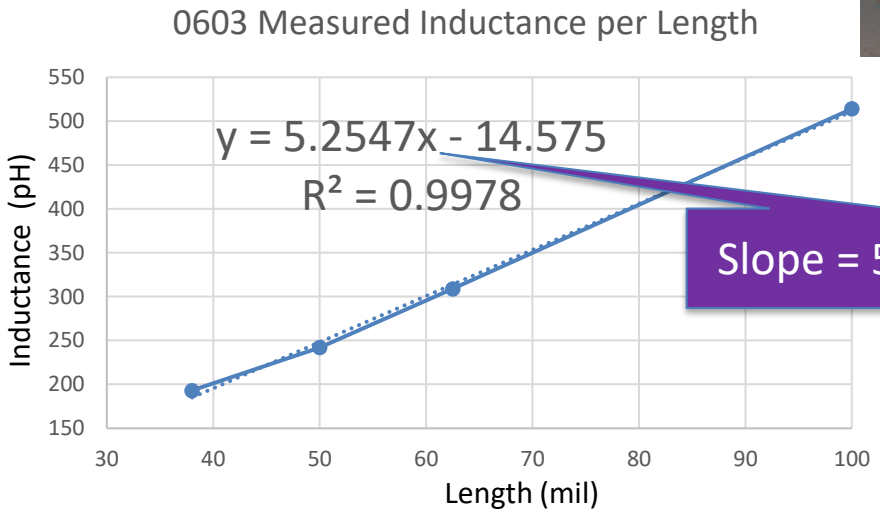
What does 3pH look like?

Post-it Note = 3.5 mil thick (~18.4 pH)



- **Four 0603 boards with different pitches (38, 50, 62.5, 110 mil)**
- **Everything is constant except for the pitch (i.e. the distance between the two contact points)**



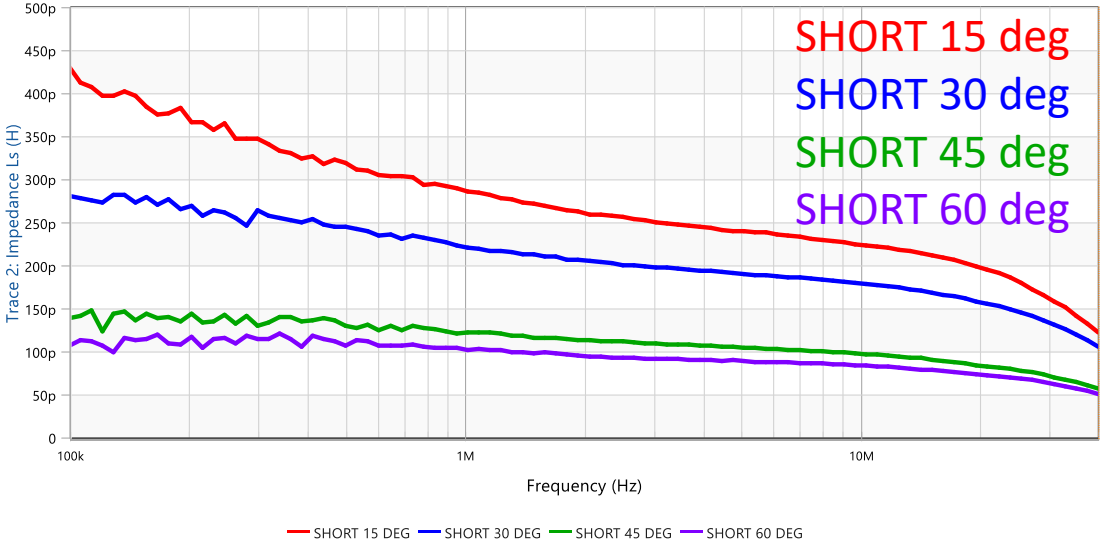


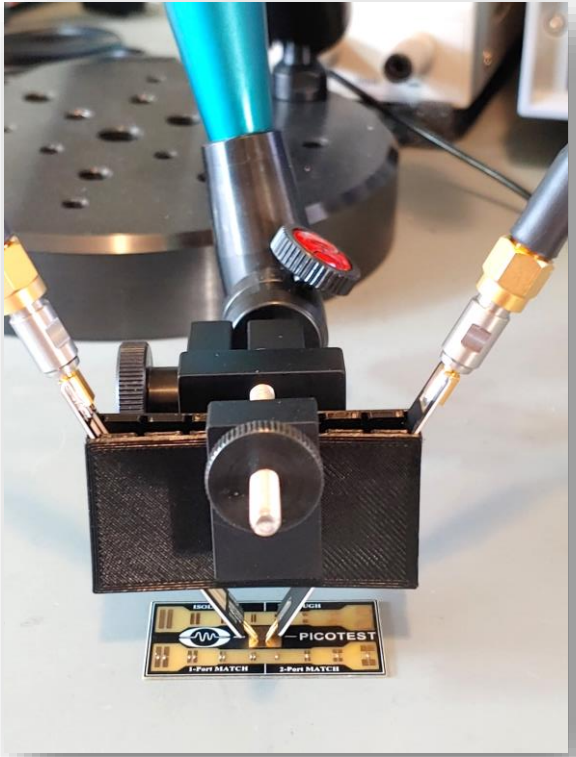
Slope = 5.2547 pH/mil

*This inductance per length is dependent on the aspect ratio

Inductance is a function of (Probe) Angles

- Probes have a lot of coupling, but the angles are fixed.
- With the 2-port probe….
  - Downside 2-port probe has a lot of coupling
  - Upside is coupling is fixed with 2-port probe

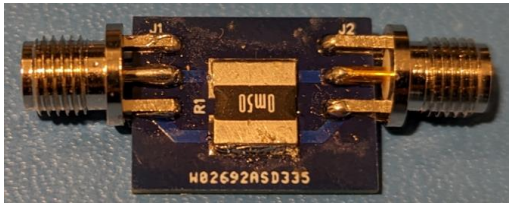




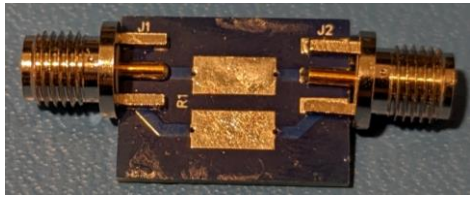
What is De-embedding?

The mount is part of our measurement, but we don't want it in our model

Fixture + DUT

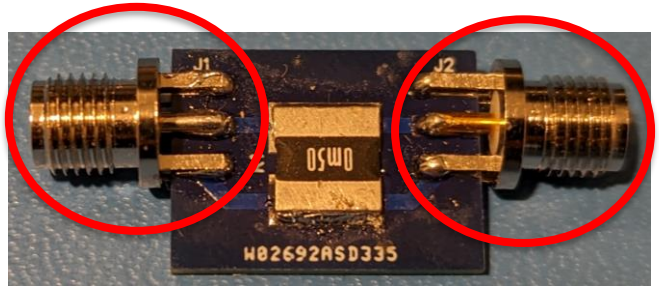


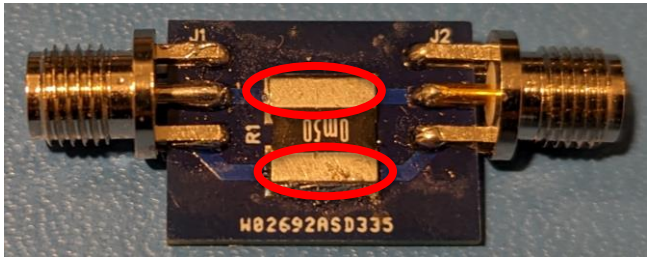
Fixture



DUT

De-embedding can be thought of as moving our reference point from the end of the SMA connectors to the mount pads



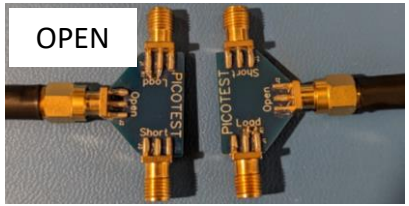


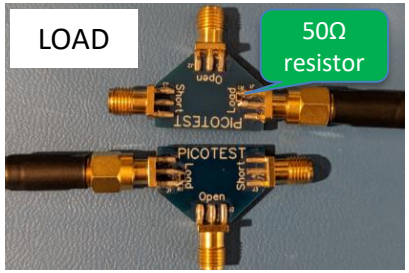
De-embedding vs. Calibration vs. Fixture Removal

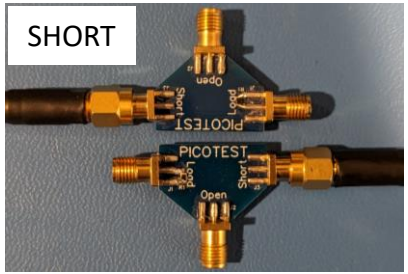
- De-embedding vs. Calibration vs. Fixture Removal – What's the difference?
- Calibration is removing the error terms from the measurement.
- De-embedding uses a behavioral model to remove fixture from a measurement altogether.
- Fixture removal can be done with calibration or with de-embedding.

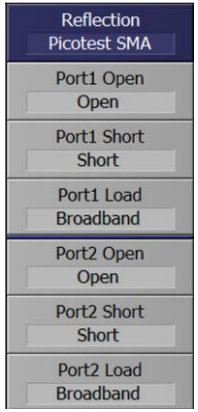
E5061B Calibration for 2-port shunt-thru

Calibration with SMAs

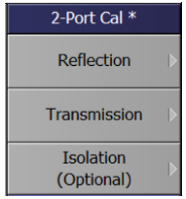


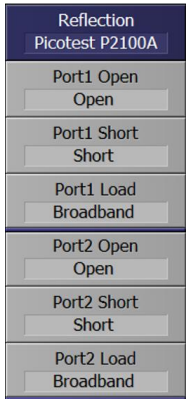






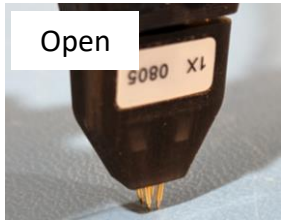
Calibrate 1-port at a time



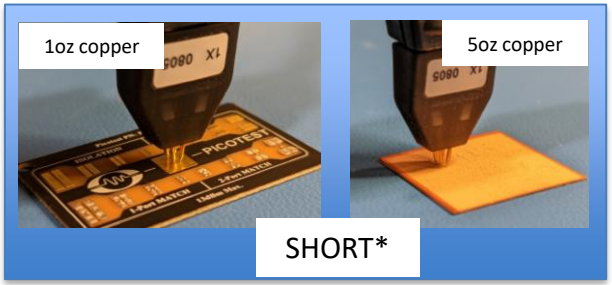


*Short calibration quality contributes to overall noise floor

Calibration with 2-port Probe



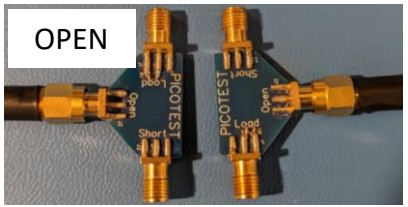
1 port Match

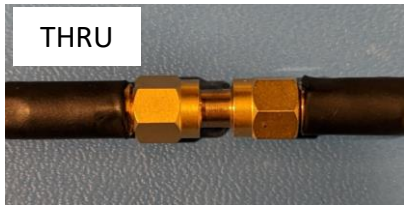


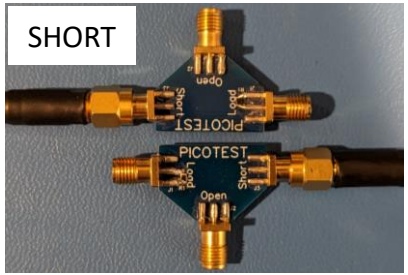
E5061B Calibration for 2-port shunt-thru

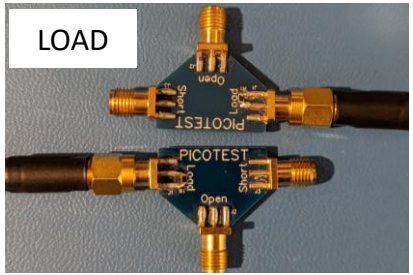
Calibration with SMAs

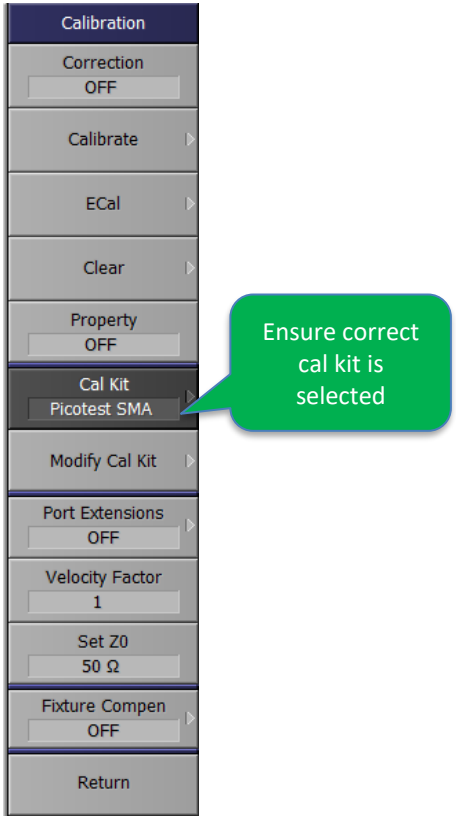
Calibrate 1-port at a time





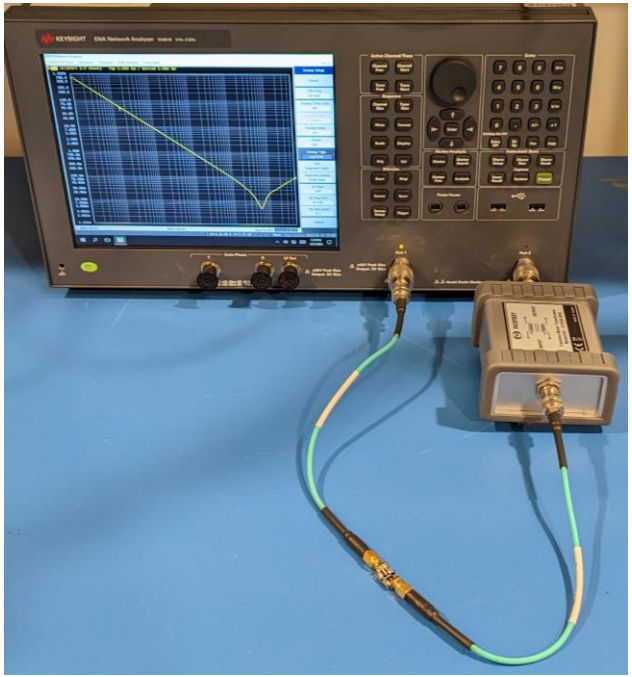




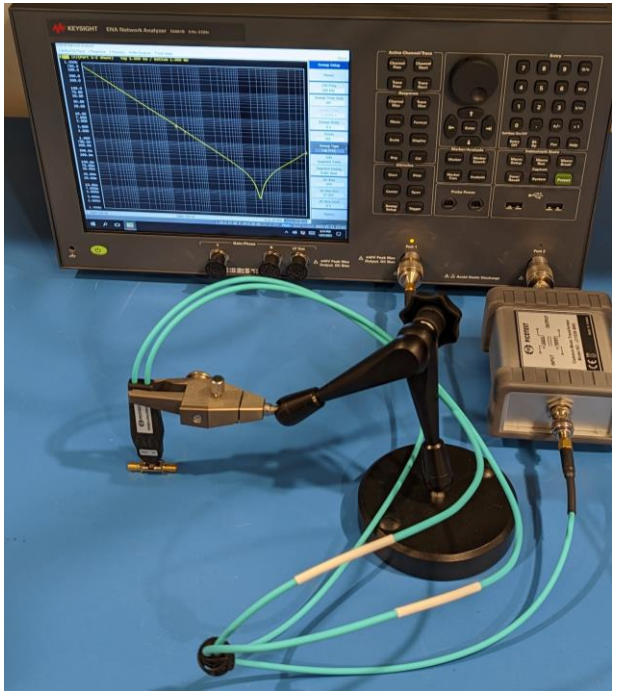


E5061B Measurement Setup for Passives

Setup for Mounted Passives with SMAs



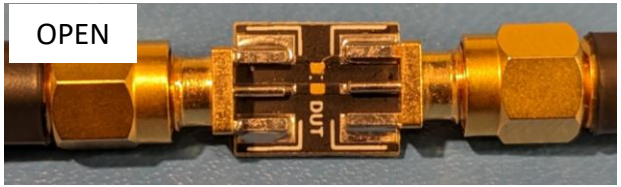
Setup for 2-port Probe

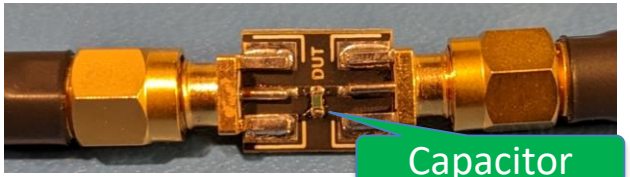


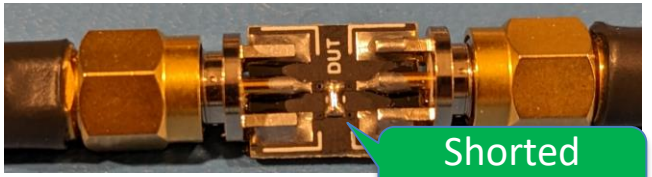
E5061B Measurement Demo

Bode 100 Impedance Calibration

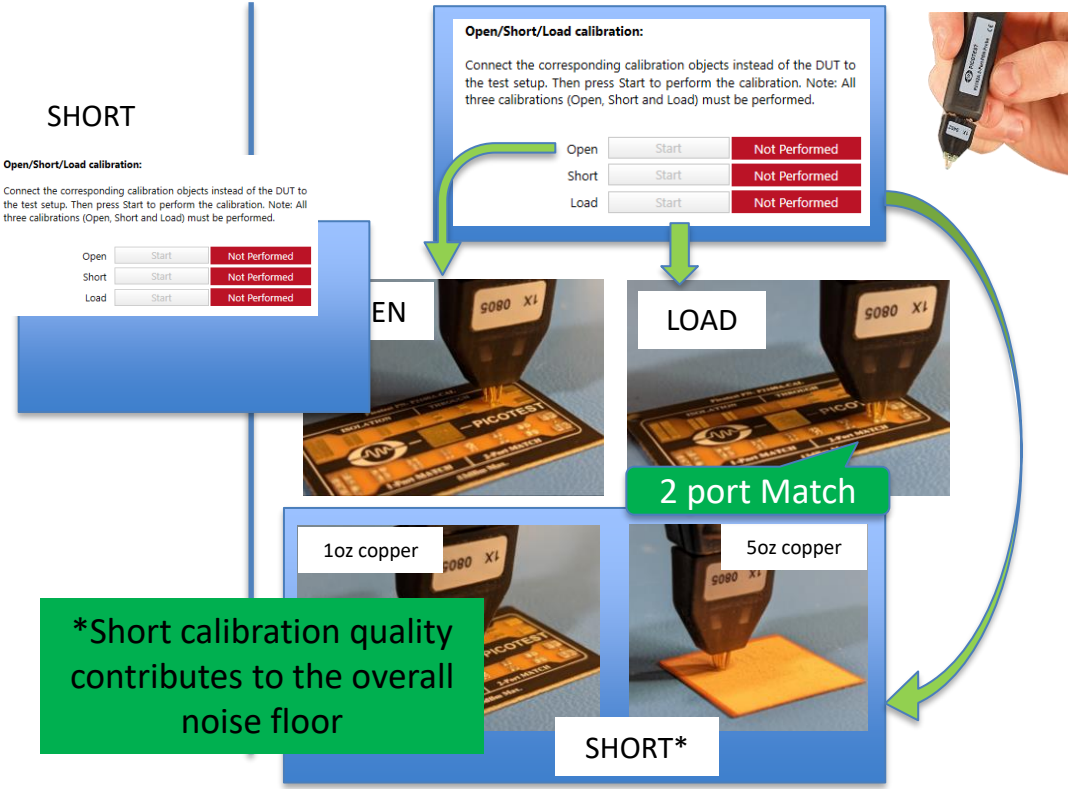
Calibration with SMAs





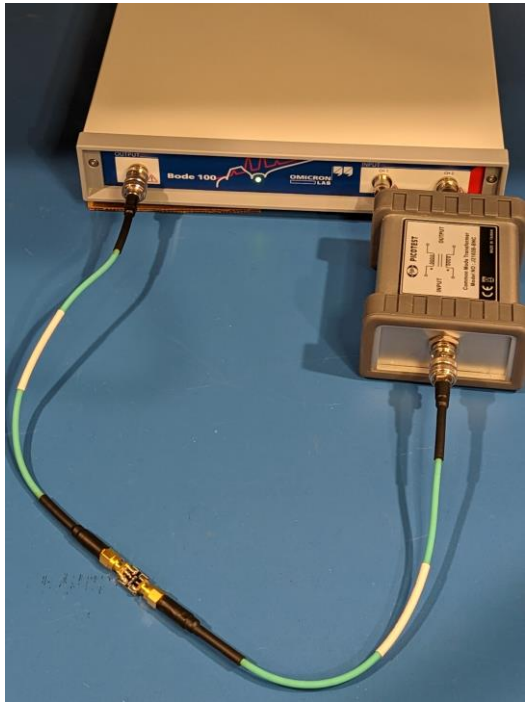


Calibration with 2-port Probe

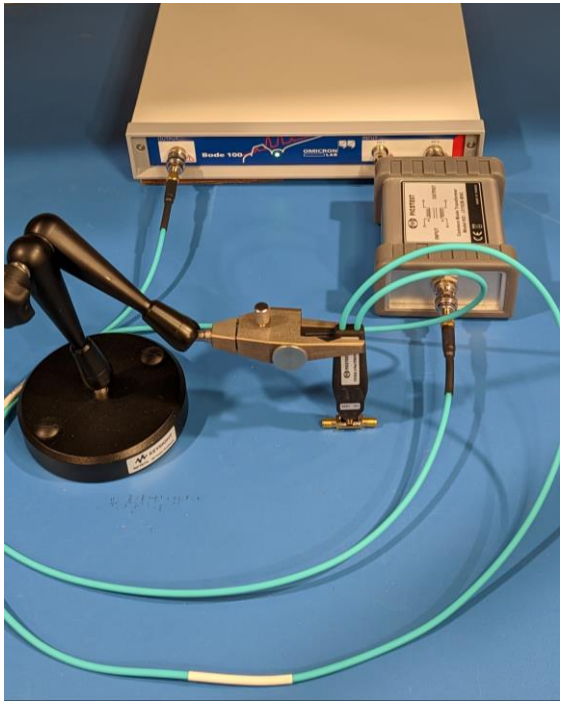


Bode 100 Measurement Setup for Passives

Setup for Mounted Passives with SMAs



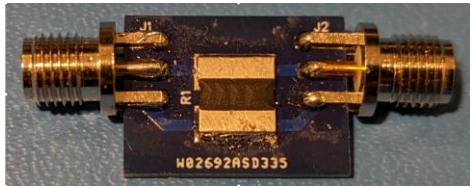
Setup for with 2-port Probe



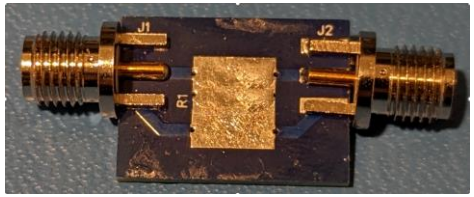
Bode 100 Measurement Demo

Calculating the Mounting Inductance: Shorted Pads

Fixture + DUT



Shorted Fixture



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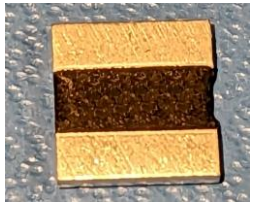
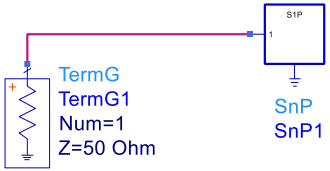
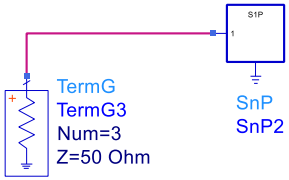


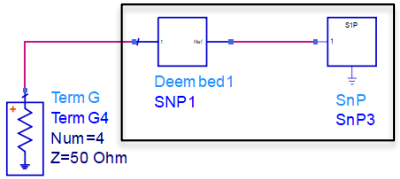
Fixture + DUT

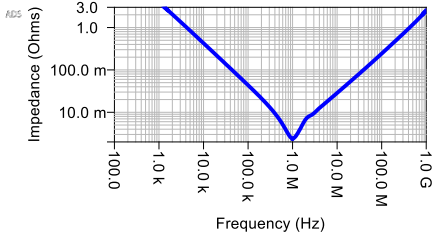


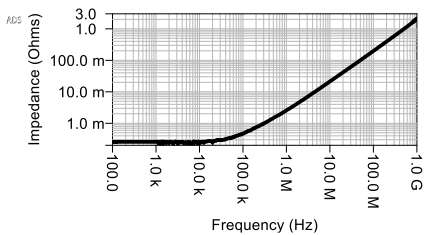
Shorted Fixture

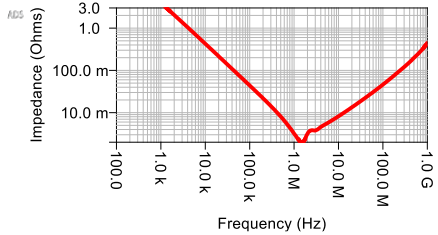


De-Embedded DUT



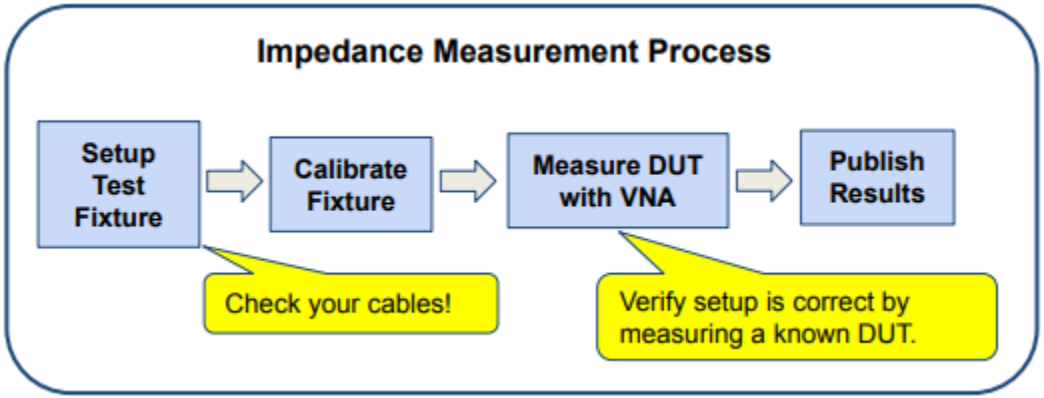






Summary and Final Tips

- Make sure you measure something you know in the same order of magnitude
- Simulate to know what to expect
- Repeat the calibration every time you do the measurement
- Make sure you are using the appropriate cal-kit
- Vendor models are usually not correct. Trust but verify!



Thank you for attending!

QUESTIONS?

References

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