3 Tips to Reduce Cable-Braid Loop Error in Low-Impedance PDN Measurements

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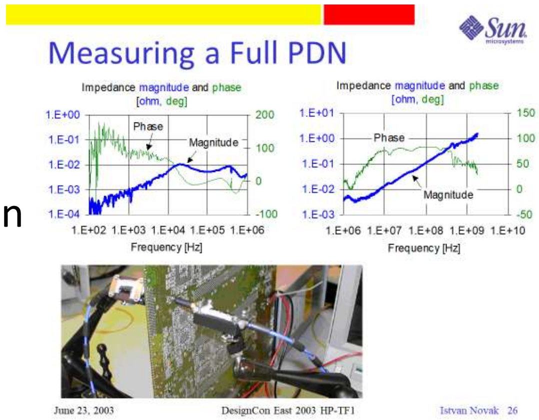
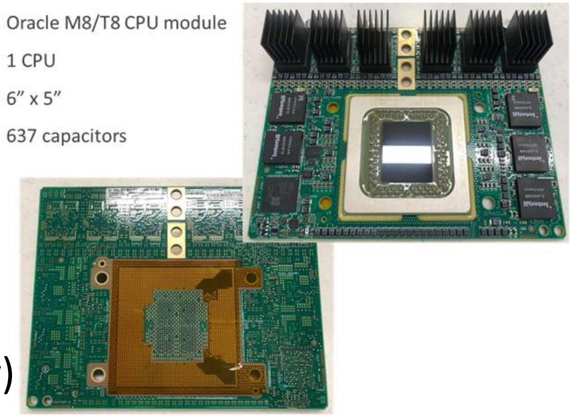
Power Integrity, the Big Picture

- Paradigm Shift #1: late 1990s
  - Frequency domain design and verification became common
  - Increased power >> requirements to measure milliohms
  - Horizontal incremental impedance was relatively small
  - 3D interactions in PI measurements were small
  - **Solution: VNA with Two-port Shunt-through connection**
  - Frequency and time-domain verifications lined up
- Paradigm Shift #2: early 2020s
  - Requirements to measure microohms
  - 3D interactions in PI measurements become dominant
  - Horizontal incremental impedance becomes relatively high
  - Increasing gap between frequency and time-domain verification results (and mostly NOT because of nonlinearity)
  - **Solution: ???**



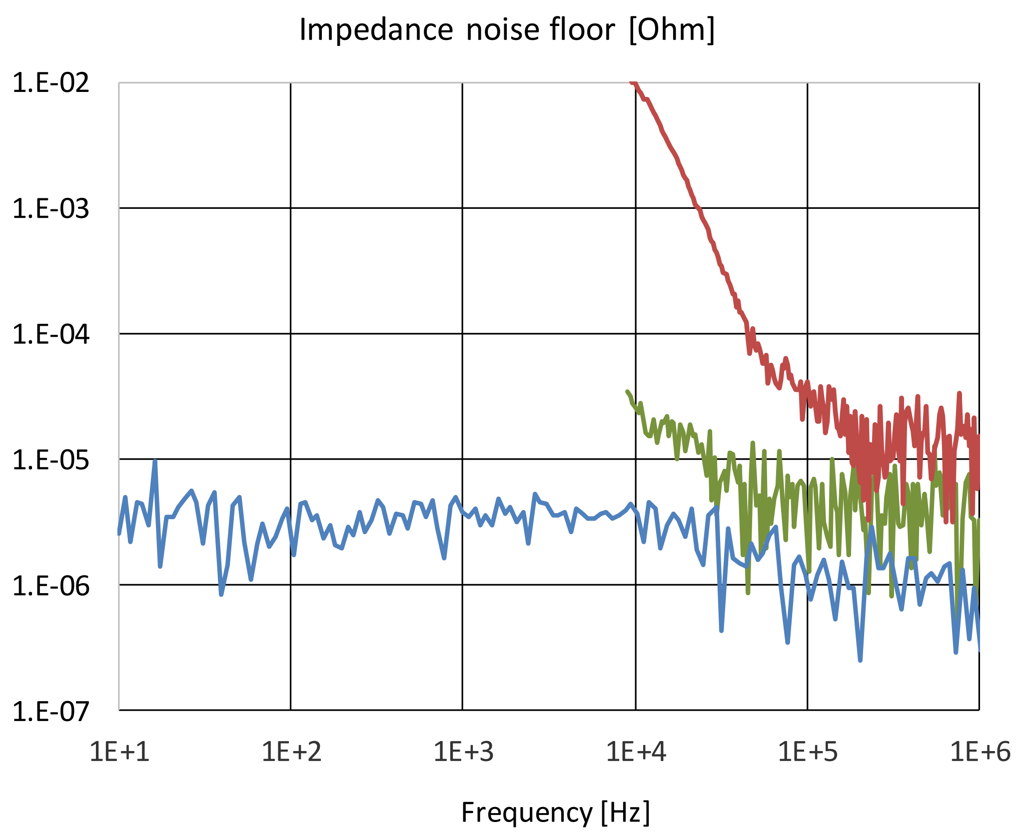
- Oracle M8/T8 CPU module
- 1 CPU
- 6" x 5"
- 637 capacitors



"3 Design Tips for Power Distribution Networks," EDICON Online, October 4, 2023 and "Is Power Integrity the New Black Magic?," Cadence Design Forum, April 2021
Cadence Live Boston, September 12, 2023, and "3D Connection Artifacts in PDN Measurements," DesignCon 2023

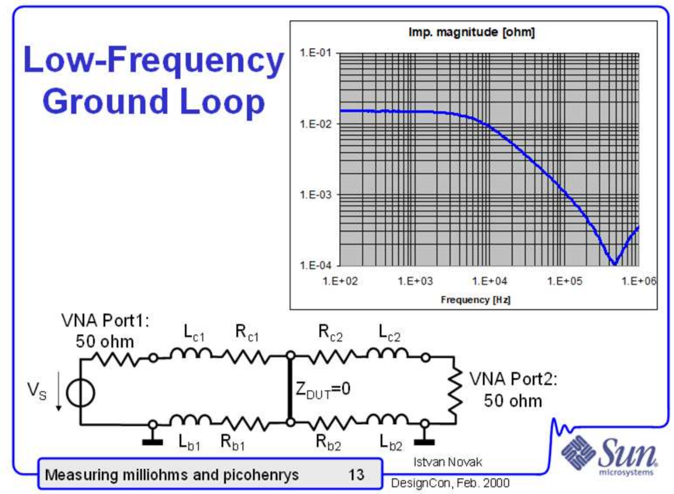
Very Low Impedances; Be Aware

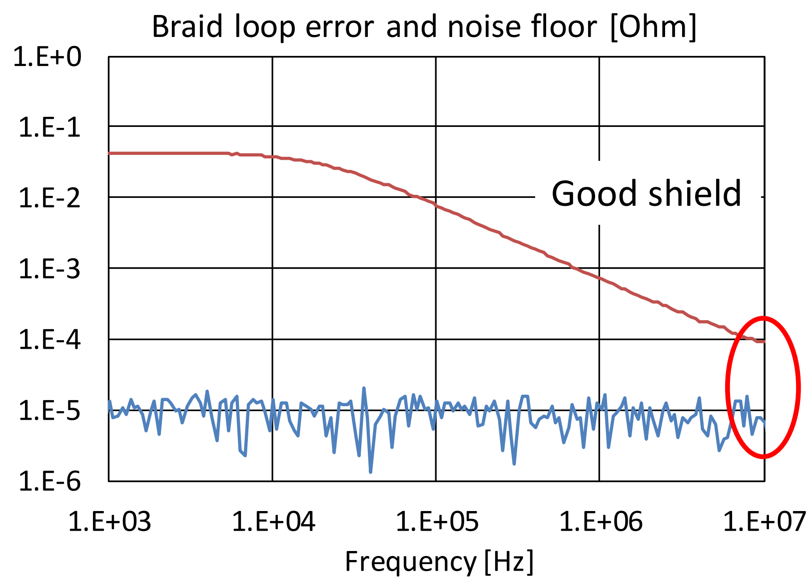
- Instrument trace noise may be the limit
- Always check before start measuring

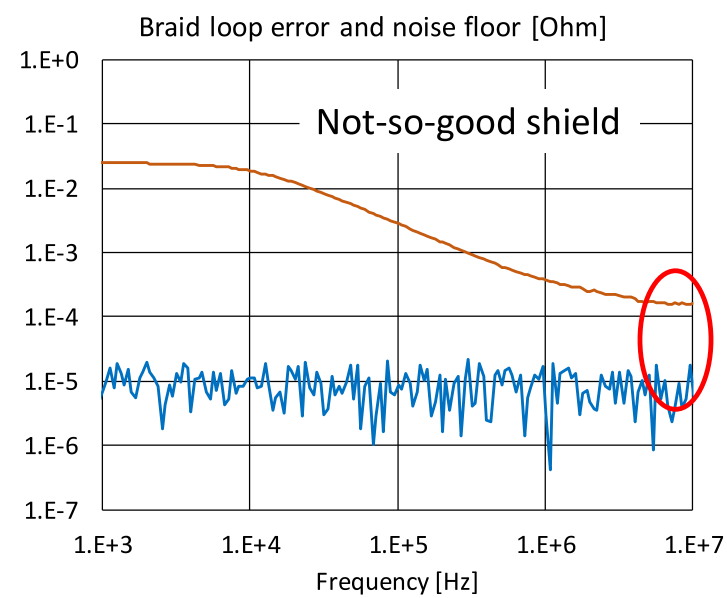


The Cable Braid Error

- Braid loop error
- Shield leakage error







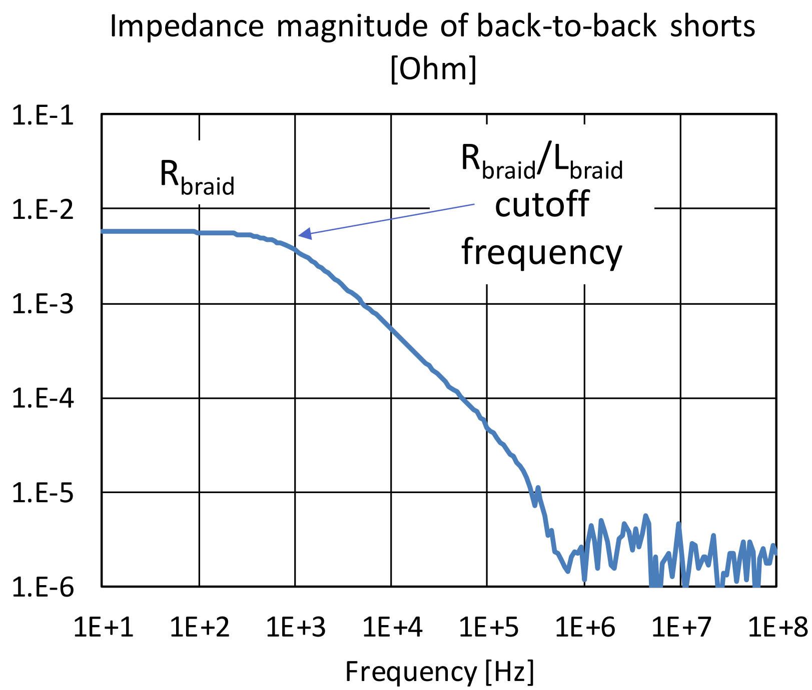
“Measuring Milliohms and Picohenrys,” DesignCon 2000
“How the Braid Impedance of Instrumentation Cables Impact PI and SI Measurements,” DesignCon 2019

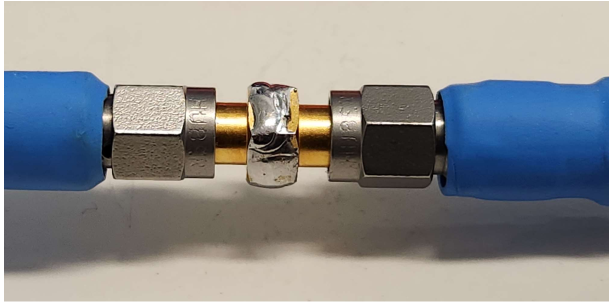
The Cable Braid Loop Error

Can we calibrate it out? ***NO***

- The cable braid error is caused by the return-path resistance
- Flexible coax braid resistance may change with flexing
- Connector shell contact resistance may change with re-torquing
- In general, it is not a good idea to try to calibrate out an error that is 40…60dB higher than the measured value

Tip 1: Reducing Cable Braid Error with Common-Mode Transformer





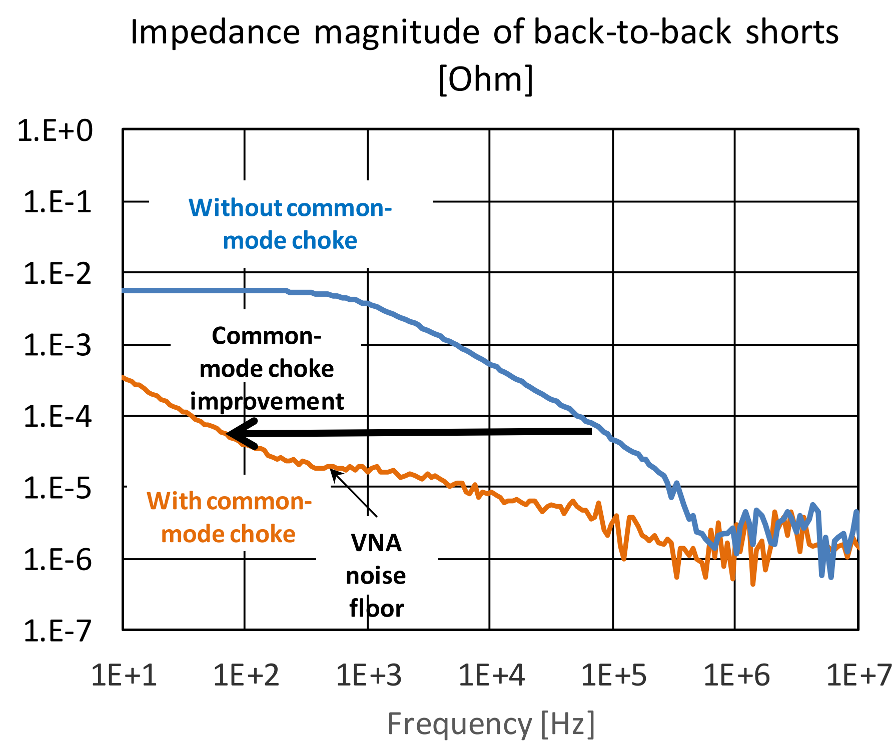
Goal: lower the braid cutoff frequency by increasing inductance more than resistance.

Use common-mode transformer.

Tip 1: Reducing Cable Braid Error with Common-Mode Transformer

Picotest J102B common-mode transformer

Home-made common-mode transformer



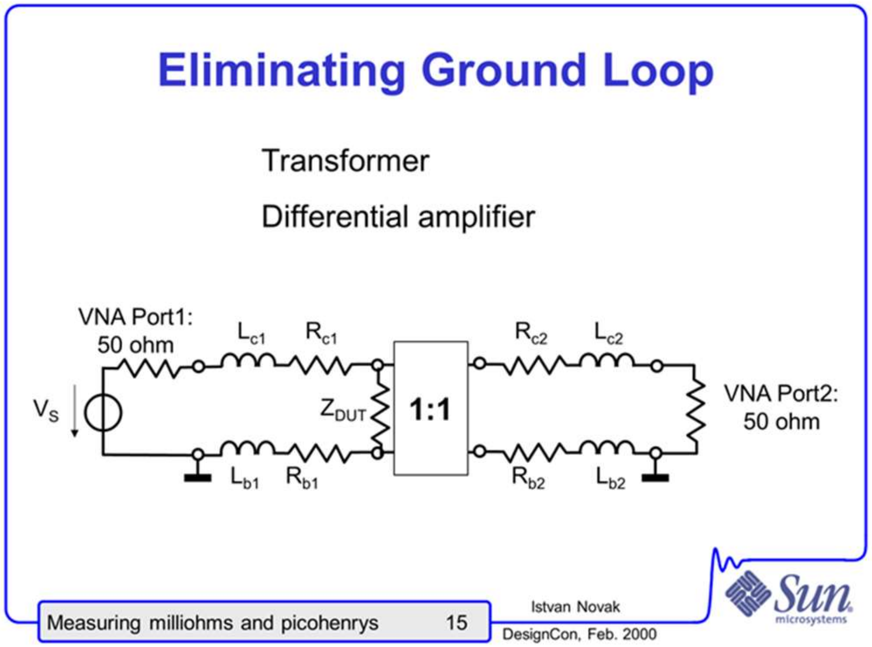
Tip 1: Reducing Cable Braid Error with Common-Mode Transformer

The good news: full two-port calibration still can be used

Be aware:

- DC (current) bias may alter the inductance of the common-mode transformer
  - Measuring passive components (capacitors) with DC bias
  - Measuring active DUT
- AC (current) bias may alter the inductance of the common-mode transformer
  - Measuring DUTs with high source power

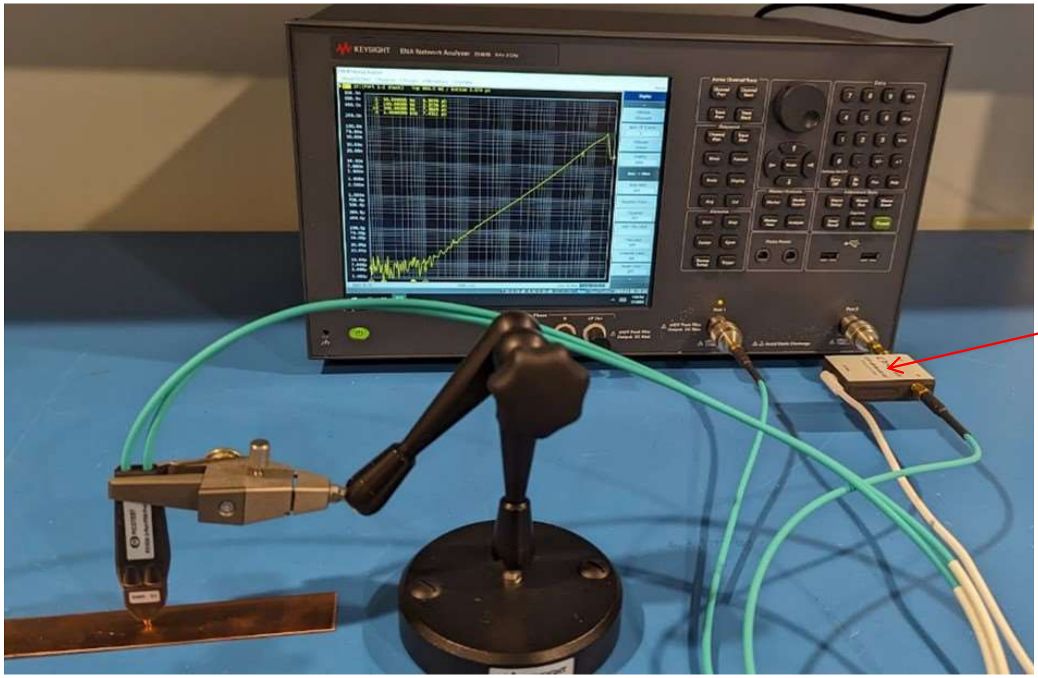
Tip 2: Reducing Cable Braid Error with Amplifier



The ground loop can be opened up by

- Differentially sensing or transmitting the DUT voltage, or
- Boosting the test current at the DUT

Tip 2: Reducing Cable Braid Error with Amplifier



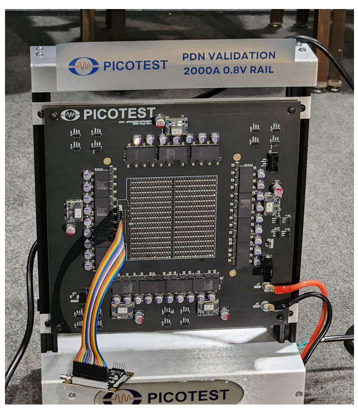
The large common-mode rejection ratio of the Picotest J2114A Prototype Isolator eliminates the DC potential lift

Figure 5 from “Extreme Measurements, Part 3,” SignalIntegrity Journal, April 2024 gEEk® spEEk

Tip 2: Reducing Cable Braid Error with Amplifier

By boosting the test current locally at the DUT, we can minimize the drive current

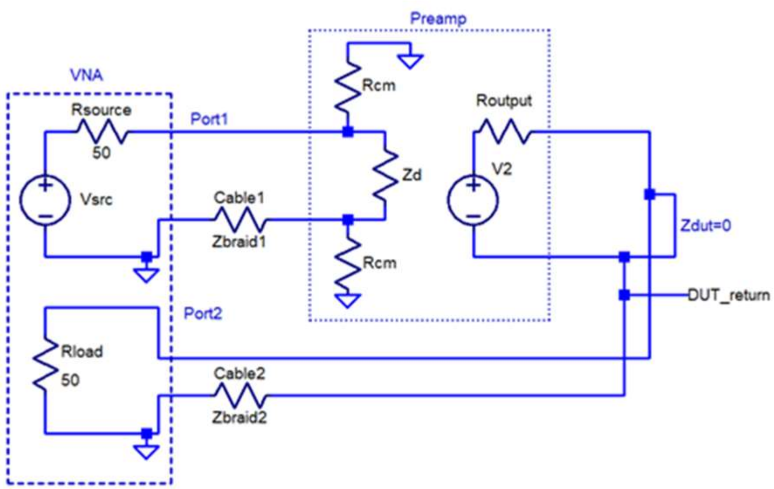
Load stepper visual from https://www.picotest.com/products_transient-load-steppers.html

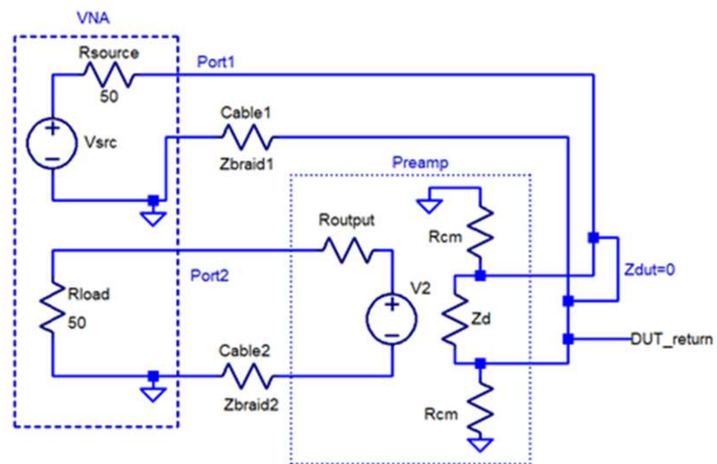


“Transient Load Tester for Time Domain PDN Analysis,” EDICON 2017

Tip 2: Reducing Cable Braid Error with Amplifier

Connection options for small-signal amplifiers



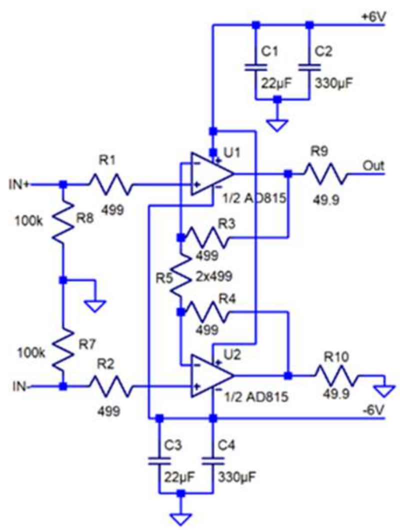


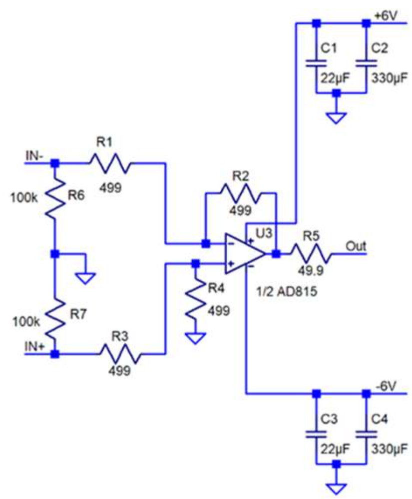
“Preamplifier Options for Reducing Cable-Braid Loop Error,” http://www.electrical-integrity.com/Quietpower_files/QuietPower-48.pdf

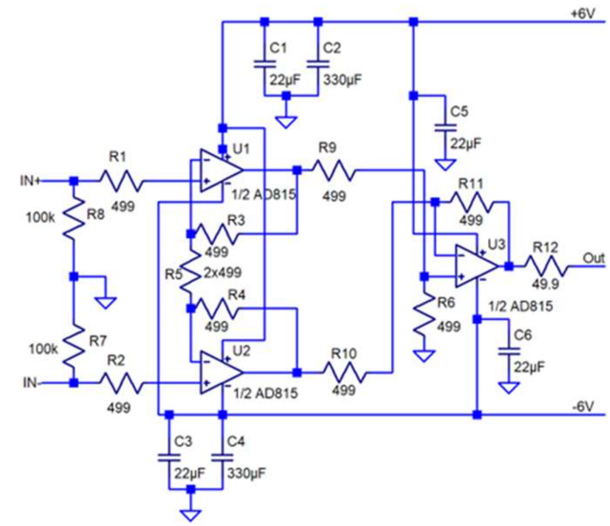
Tip 2: Reducing Cable Braid Error with Amplifier

Amplifier options for small-signal amplifiers

- High input impedance, no CMRRR (left)
- High CMRR, low input impedance (middle)
- High CMRR, high input impedance (right)







“Preamplifier Options for Reducing Cable-Braid Loop Error,” http://www.electrical-integrity.com/Quietpower_files/QuietPower-48.pdf

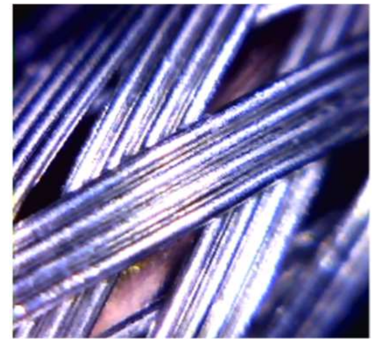
Tip 2: Reducing Cable Braid Error with Amplifier

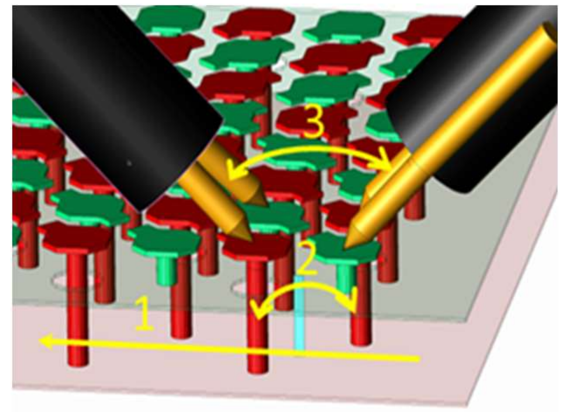
When using amplifiers, be aware

- High CMRR will suppress built-in bias (use on undriven port)
- Active DUT and built-in bias may drive the amplifier to saturation
- Opening up the cable braid loop may introduce mid- and high-frequency resonances

When using transient loads, be aware

- Large-area drive raises questions about where and how the response is obtained





“Impact of Finite Interconnect Impedance Including Spatial and Domain Comparison of PDN Characterization,” DesignCon 2024

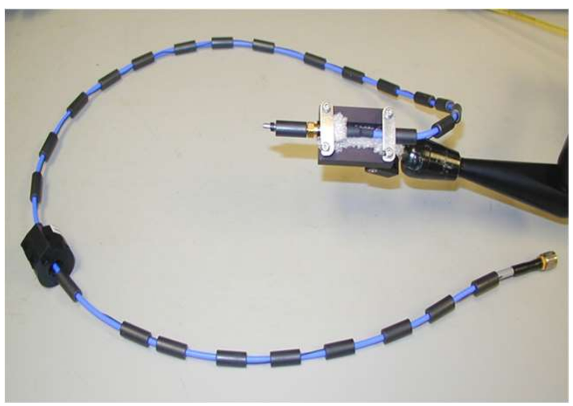
Tip 3: Reducing Cable Braid Error with Absorbers

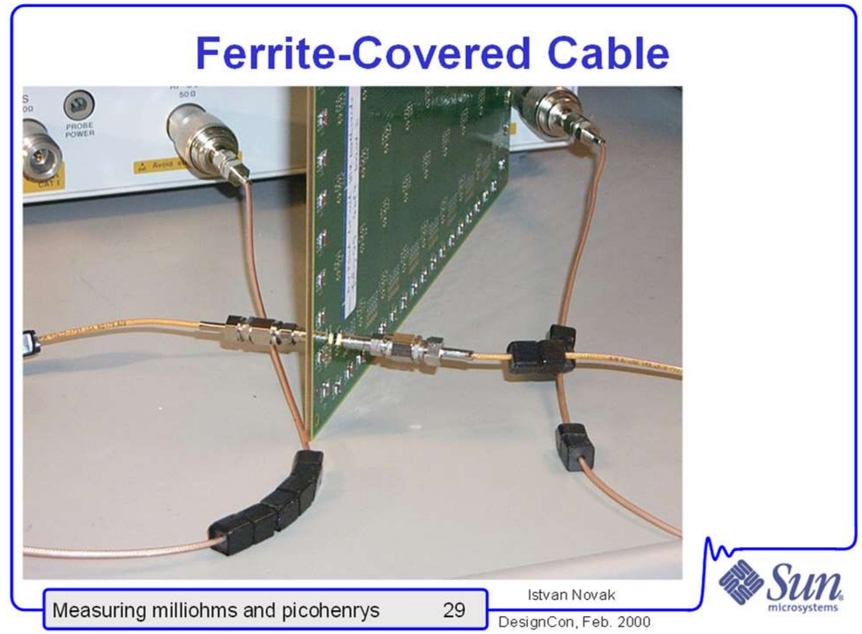
At medium and high frequencies

- finite surface transfer impedance and direct shield leakage
- shield resonances

will become the limit

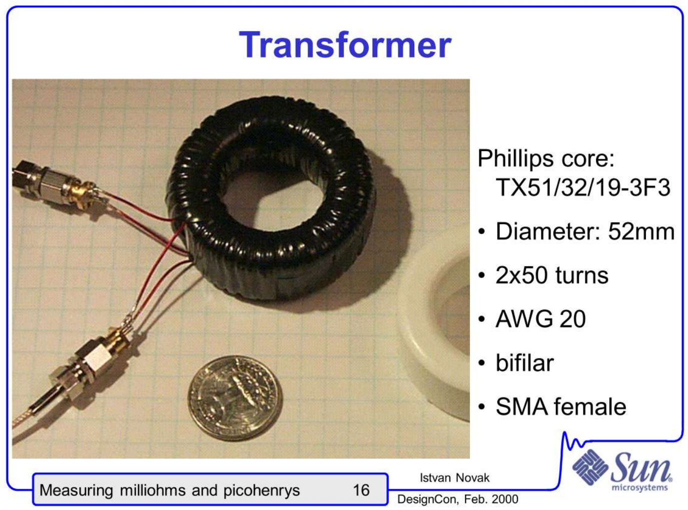
Use ferrite absorbers to address both





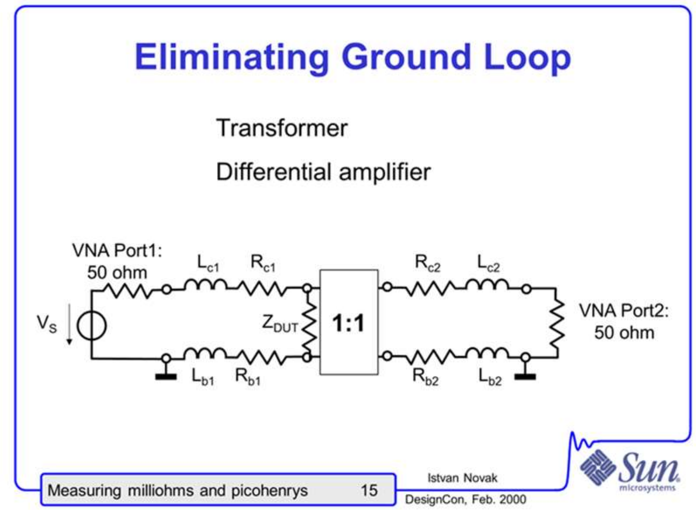
"Measuring Milliohms and PicoHenrys in Power Distribution Networks," DesignCon 2000
"Overview of Frequency-Domain Power-Distribution Measurements," DesignCon East 2003

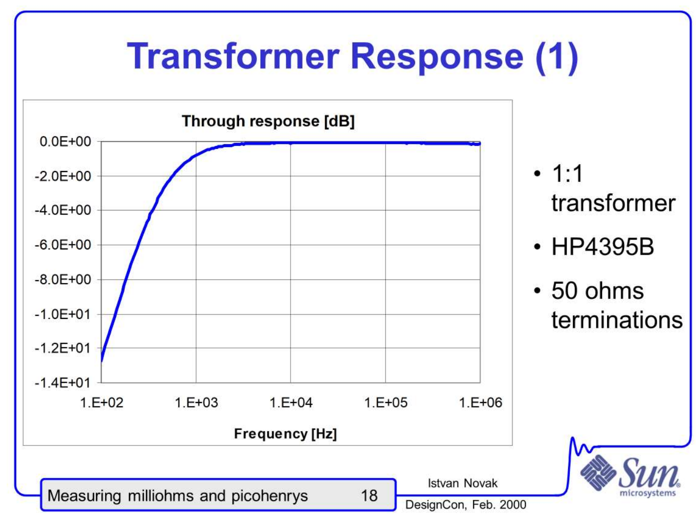
Reducing Cable Braid Error; Further Options



- Works well with passive DUTs
- Be careful with
  - DC bias
  - Active DUTs

"Measuring Milliohms and Picohenrys," DesignCon 2000

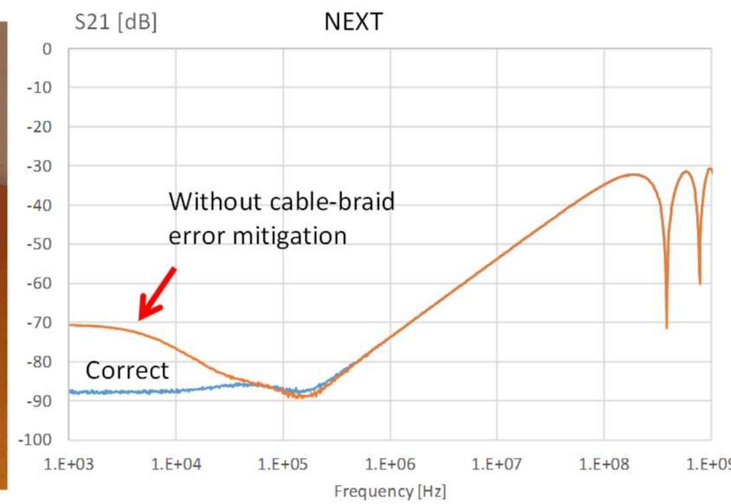




Happens in SI, Too

Introduction

- Illustration of cable braid error in SI measurements
- All crosstalk measurements are prone to this error
- DUT: coupled microstrip traces



"How the Braid Impedance of Instrumentation Cables Impact PI and SI Measurements," DesignCon 2019

Summary

Cable-braid error becomes more important as we need to measure sub-milliohm impedance

Cable-braid error can be mitigated by

- Differential amplifiers
- Locally amplifying the test signal
- Common-mode transformers
- Ferrite absorbers

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