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How the Braid Impedance of Instrumentation Cables Impact PI and SI Measurements

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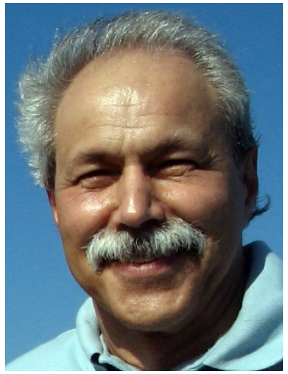
SPEAKER



Istvan Novak

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Istvan Novak is a Principle Signal and Power Integrity Engineer at Samtec, working on advanced signal and power integrity designs. Prior to 2018 he was a Distinguished Engineer at SUN Microsystems, later Oracle. He worked on new technology development, advanced power distribution and signal integrity design and validation methodologies for SUN's successful workgroup server families. He introduced the industry's first 25um power-ground laminates for large rigid computer boards, and worked with component vendors to create a series of low-inductance and controlled-ESR bypass capacitors. He also served as SUN's representative on the Copper Cable and Connector Workgroup of InfiniBand, and was engaged in the methodologies, designs and characterization of power-distribution networks from silicon to DC-DC converters. He is a Life Fellow of the IEEE with twenty-five patents to his name, author of two books on power integrity, teaches signal and power integrity courses, and maintains a popular SI/PI website.

OUTLINE

- Introduction, motivation
- The coupling mechanism
  - The cable shield
  - Transfer impedance
- Measurements
  - Rdc measurements
  - Current measurements
  - Cable braid impedance test setup and results
  - High-frequency transfer impedance setup and results
- Simulations and correlations
- Summary and conclusions

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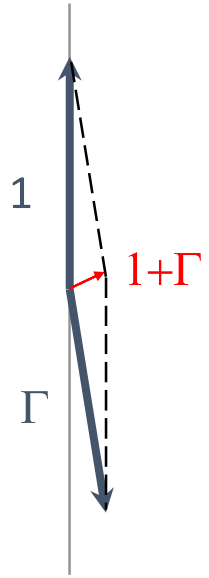
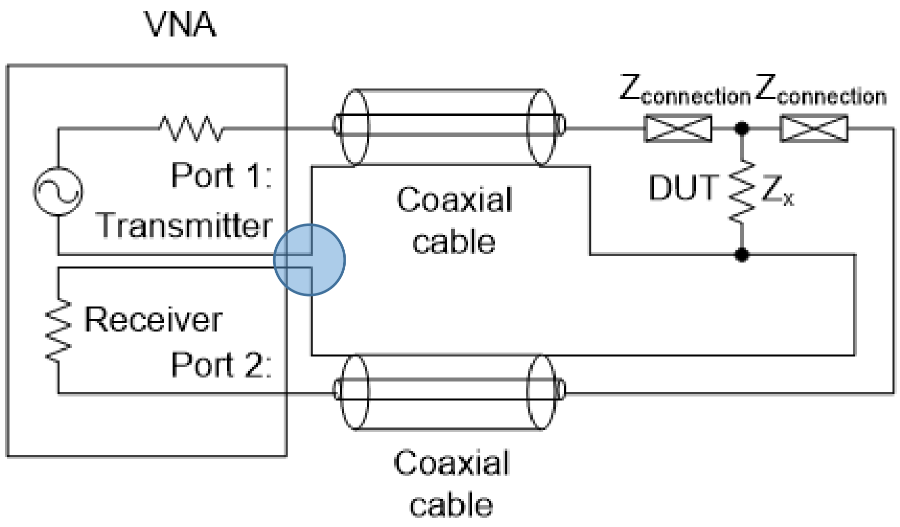
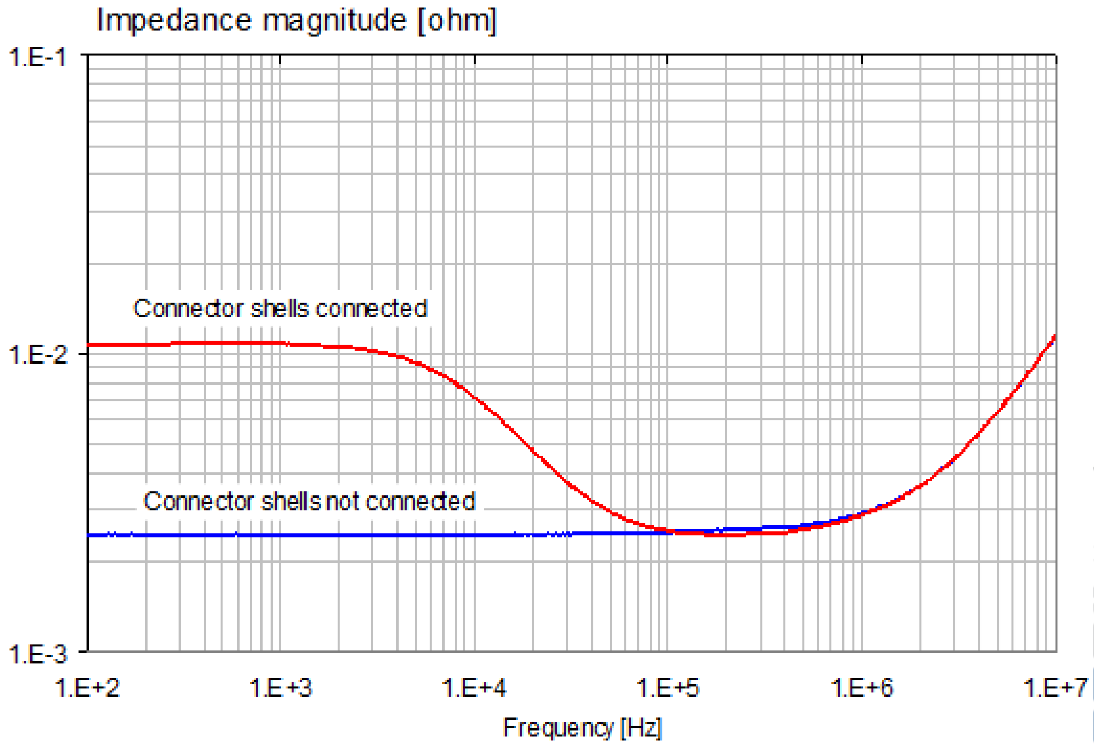
Introduction

$$Z_{DUT} = Z_{VNA} \frac{1+\Gamma}{1-\Gamma}$$



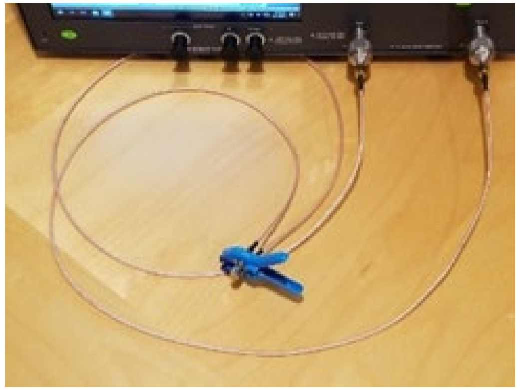
- Measuring low impedances based on reflection does not work
- Measuring low PDN impedances requires two-port shunt-through scheme
- Two-port SI and PI measurements may create cable-braid error



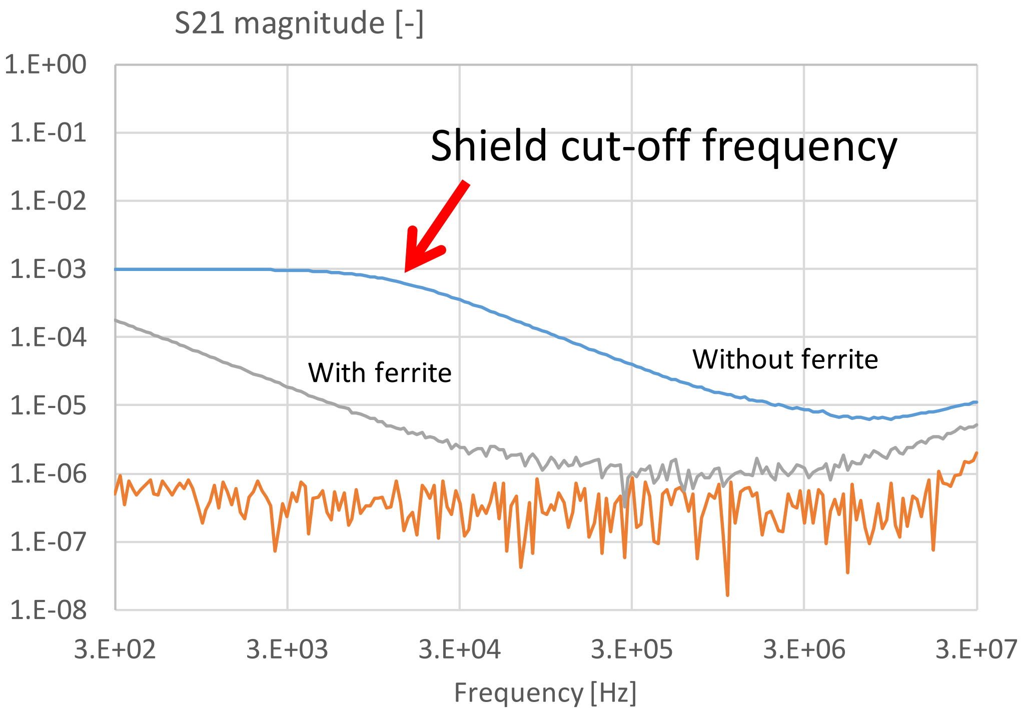


Introduction

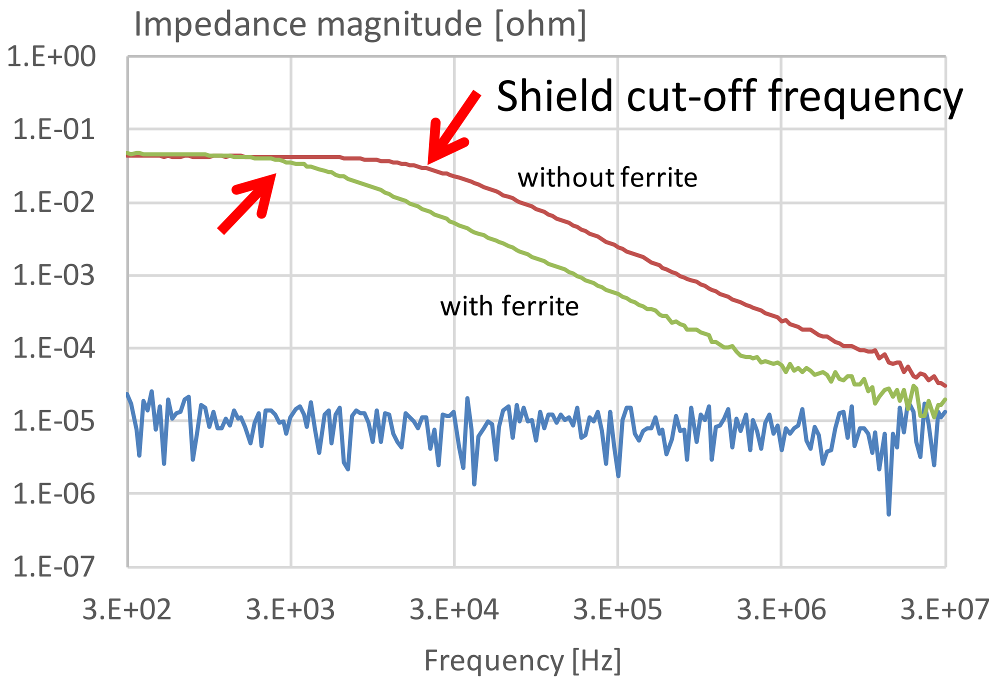
- Cable-braid error drops above shield cutoff frequency
- Error drops monotonically for cables with good shield
- Error saturates and folds back above noise floor for cables with poor shield



Cable with poor shield:

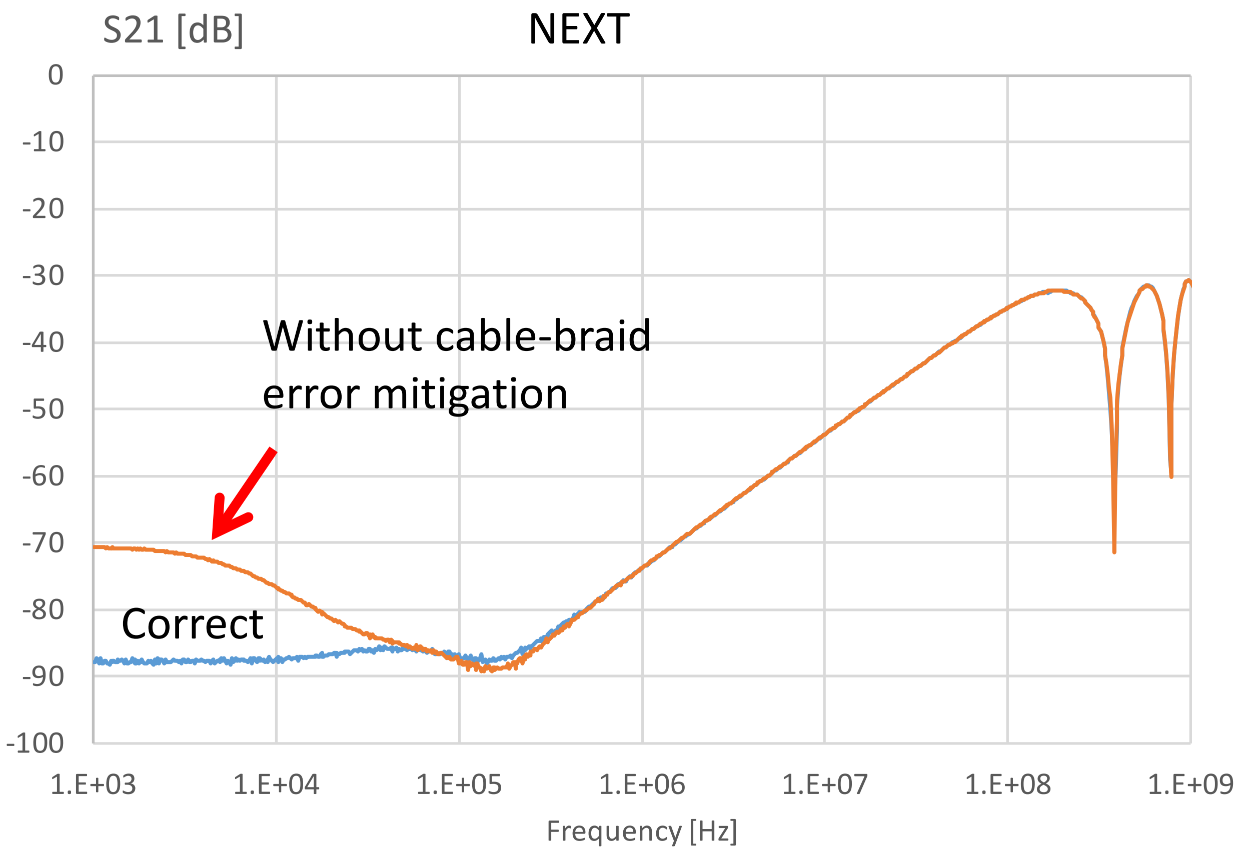


Cable with good shield:



Introduction

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



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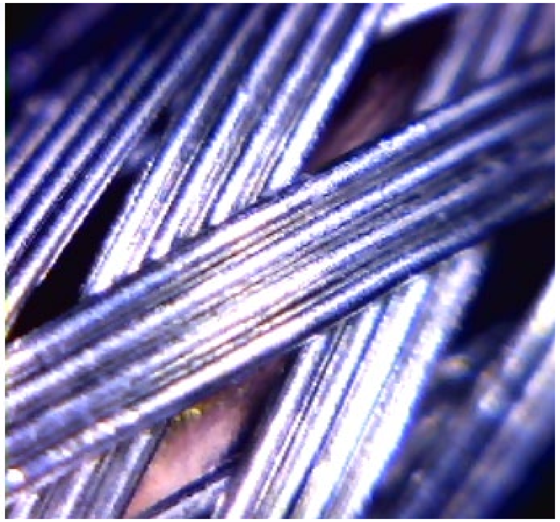
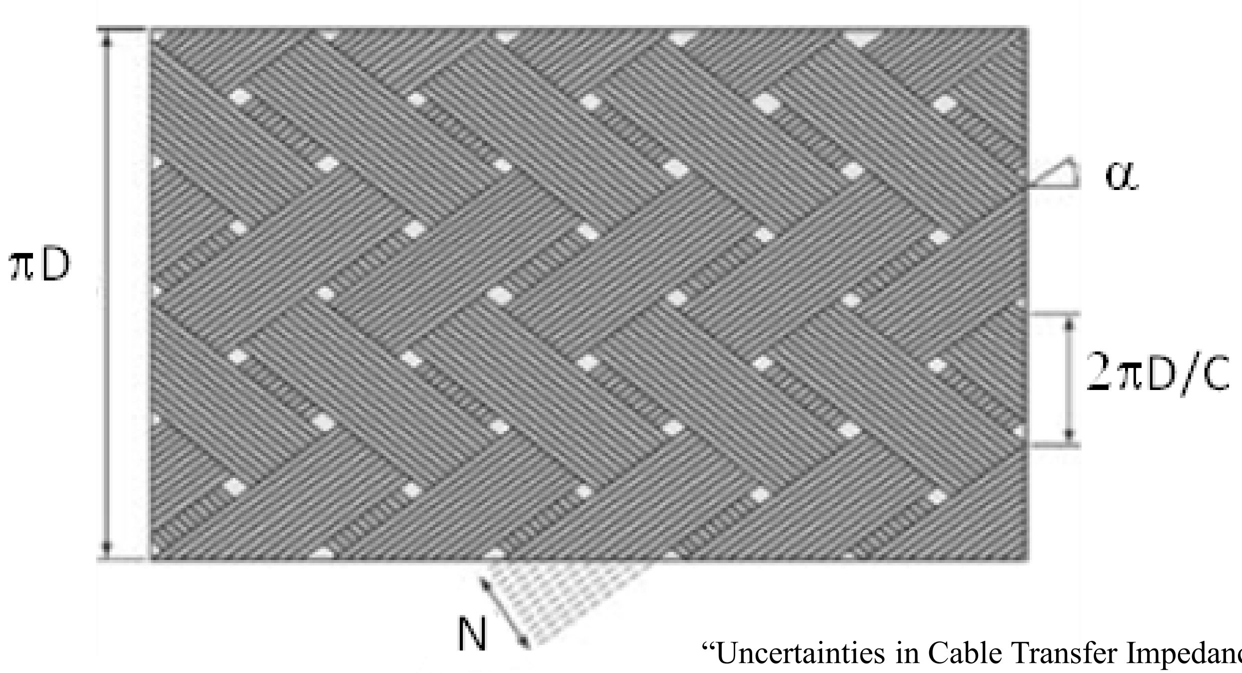
The Coupling Mechanism
The cable shield

- Cable braids have small openings
- Photo of RG174 cable braid





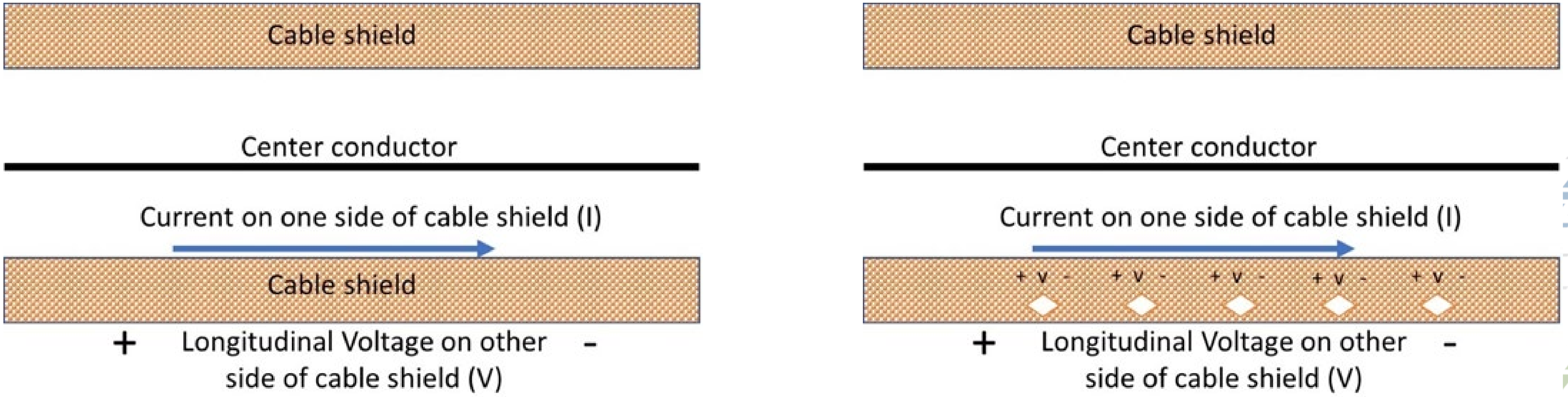
- Diameter D of the braid
- Number of carriers C in the braid
- Number of wires N in a carrier
- Diameter d of a single wire
- Conductivity σ of the wires (S/m)
- Pitch angle (or weave angle) α of the braid

"Uncertainties in Cable Transfer Impedance", JL Rotgerink, et.al, 2018 IEEE EMC Magazine, Volume 7, Quarter 3

The Coupling Mechanism

Transfer impedance

- Sketches for the definition of cable shield transfer impedance
- Solid shield on the left, braided shield on the right

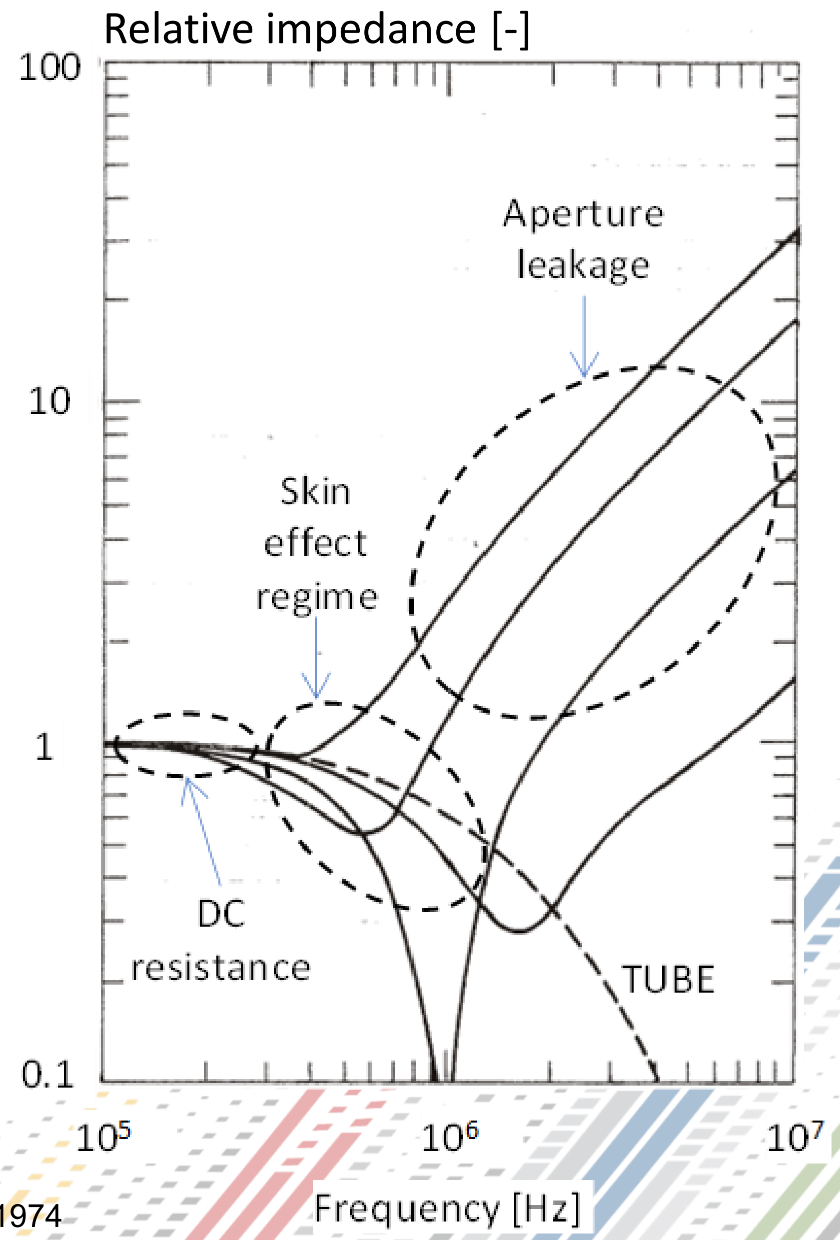


The Coupling Mechanism

Transfer impedance

Cable shield transfer impedance has several distinct regions

- DC resistance region
- Skin-loss and inductive region
- Aperture leakage region



Source: “Shielding Effectiveness of Braided Wire Shields”, Instruction Note 172, E. F. Vance, 1974

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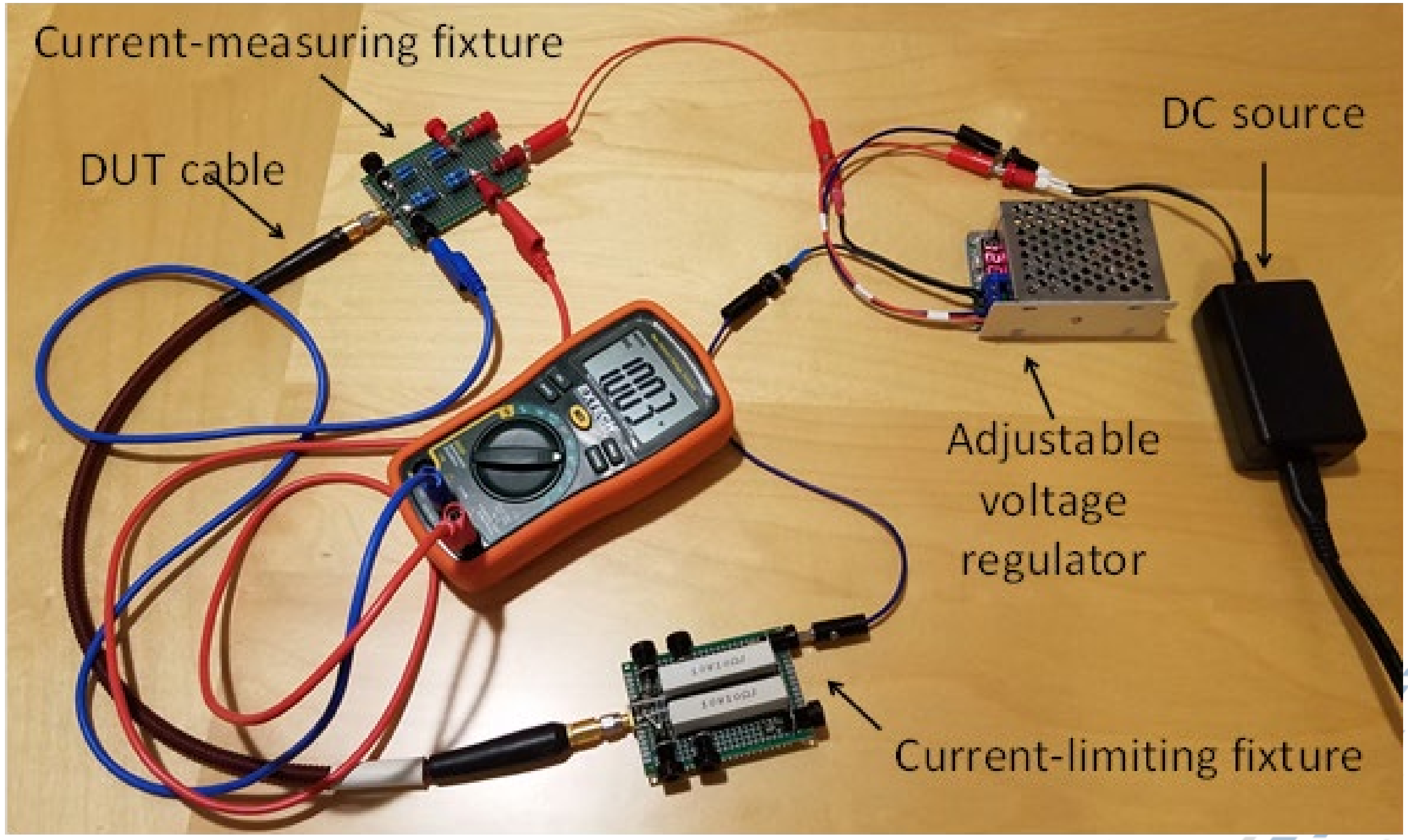
Measurements

Rdc measurements

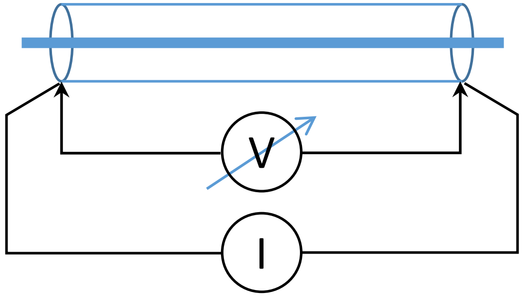
Home-made setup for cable braid DC resistance measurements

- Adjustable voltage source
- Current-limiting resistors
- Current-measuring resistors
- Voltmeter

Note: probe contact resistance, termination and/or connector(s) add to DC resistance



Cable	Length [m] w, w/o connector	Rdc [mOhm] w/o connector
Red Gore	0.51/0.43	5.7
HP Grey	0.61/0.51	6.3
Storm	0.91/0.85	10.6
Sucoflex	1/0.92	12.7

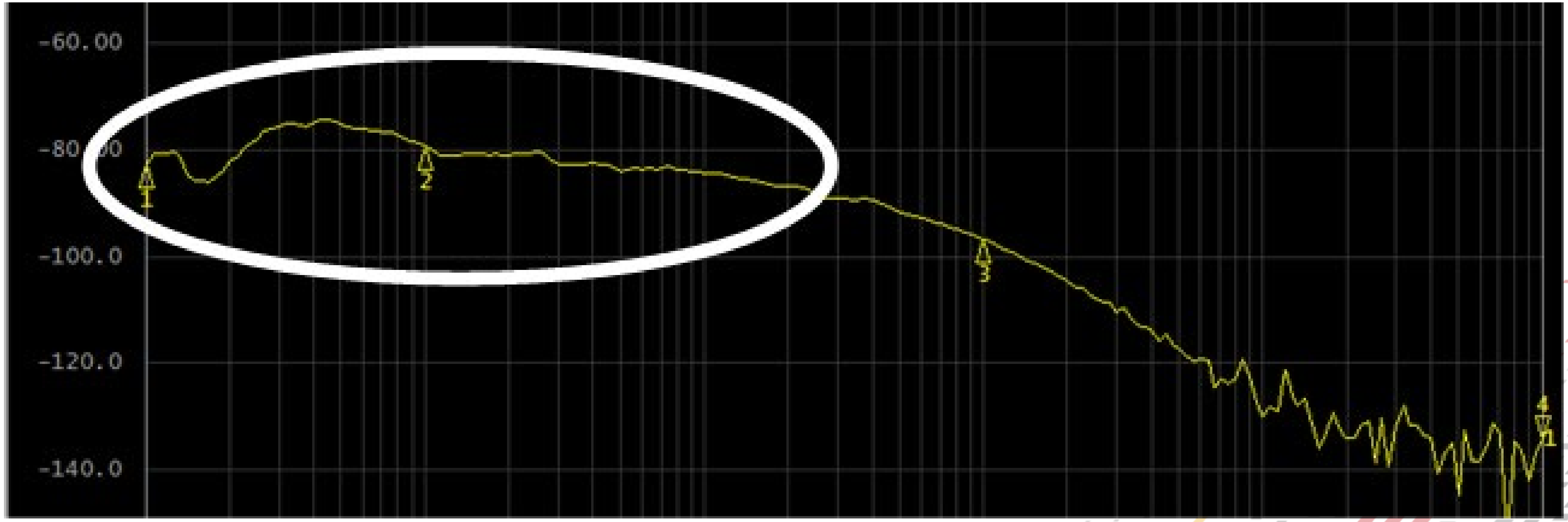


Measurements

Rdc measurements

Some cables exhibit time-varying DC resistance during and after flexing

- Some double-braided shields
- Some shields with braid and foil

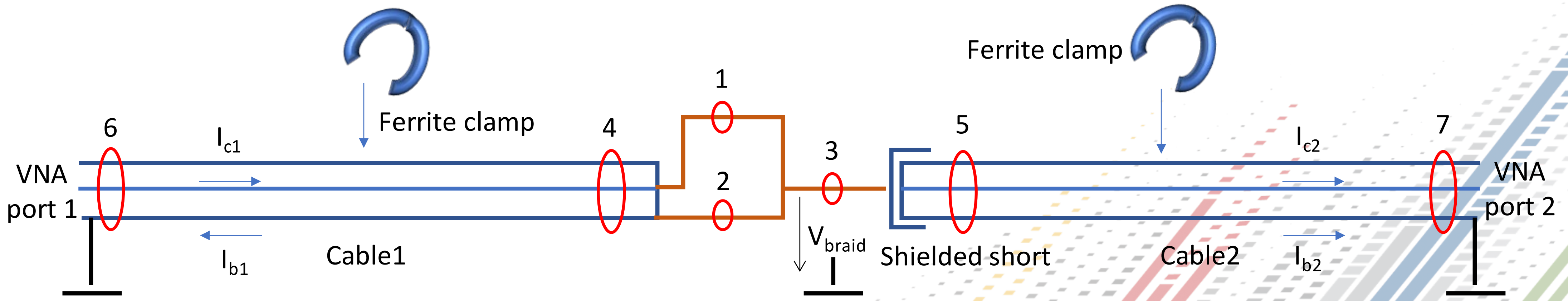


Measurements

Current measurements

Current sensors and probe locations on two-port shunt-through impedance measurement cabling

- (1): measures source current
- (2): return current on cable 1 braid
- (3): current into cable 2 braid
- (4): through (7): net cable current

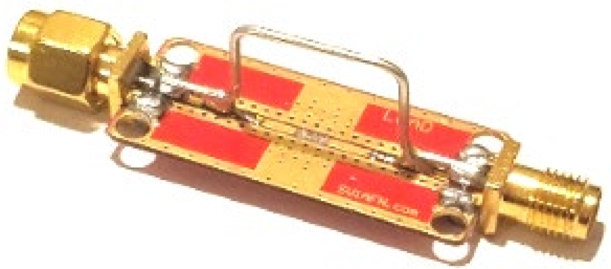


Measurements

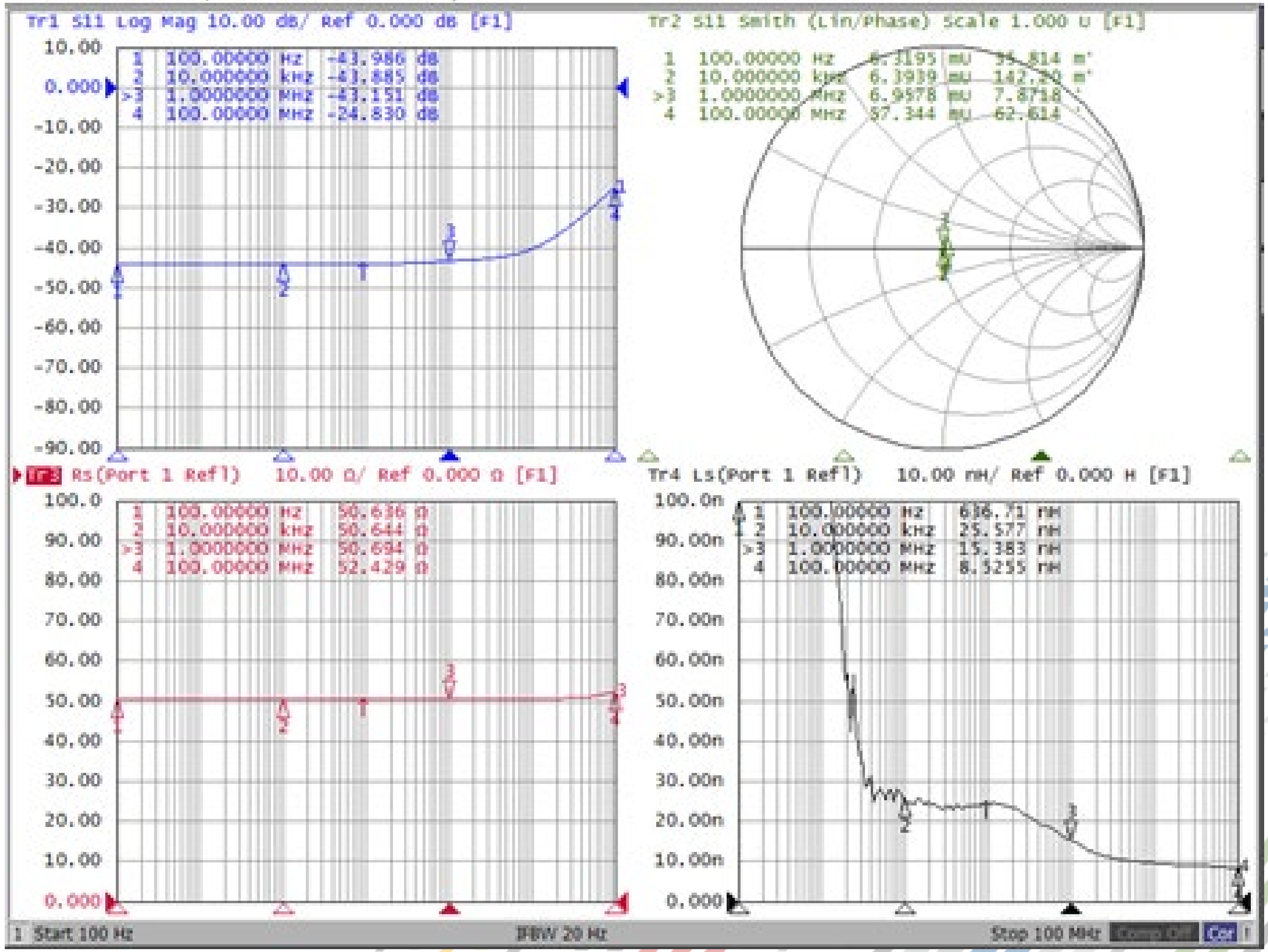
Current measurements

Current can be measured with clamp-on probe and sensor loop

- One-inch long sensor loop with insertable SMA connectors
- Adds approx. 25 nH inductance
- Minimal impact below 10 MHz
- Used for calibration



https://www.sv1afn.com/rf-experimenter-s-pcb-panel.html

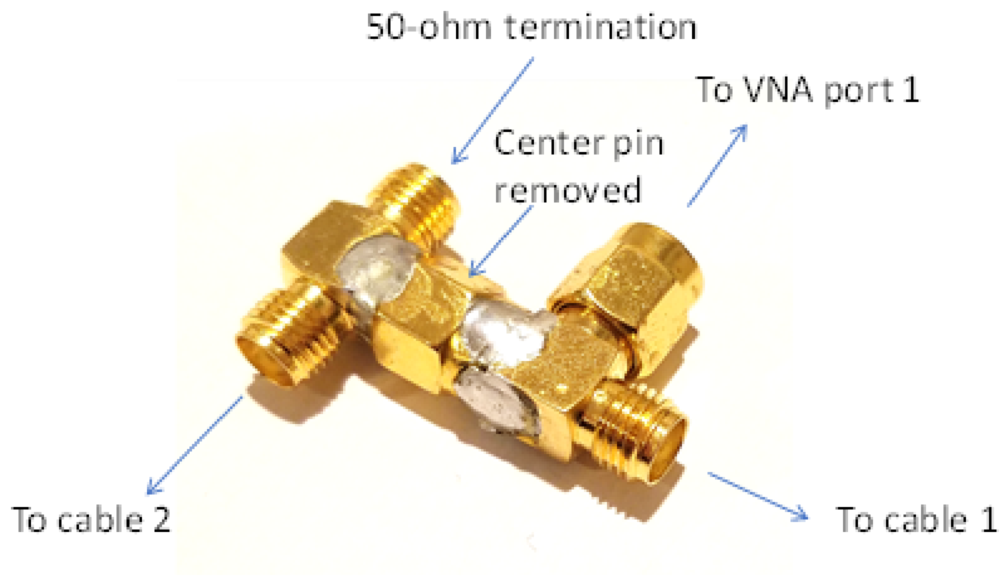


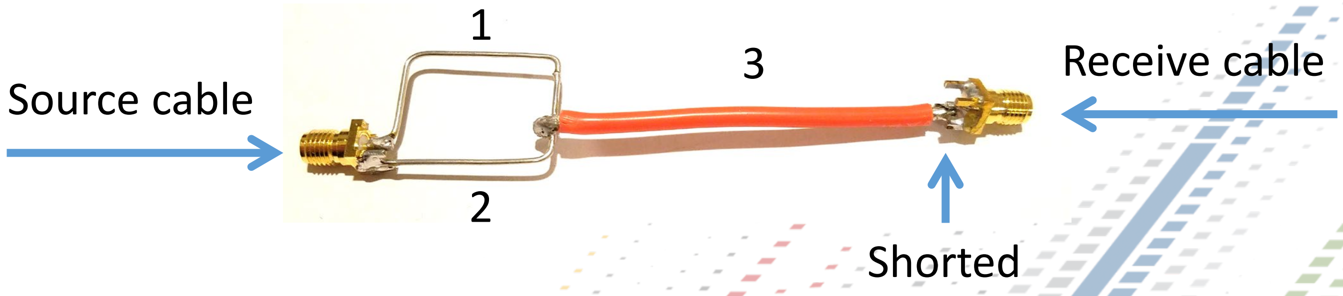
Measurements

Current measurements

Termination and current sensor elements for two-port shunt-through current measurements

- Left: terminates cable 2 and solidly connects cable braids
- Right: three-point current sensor





Measurements

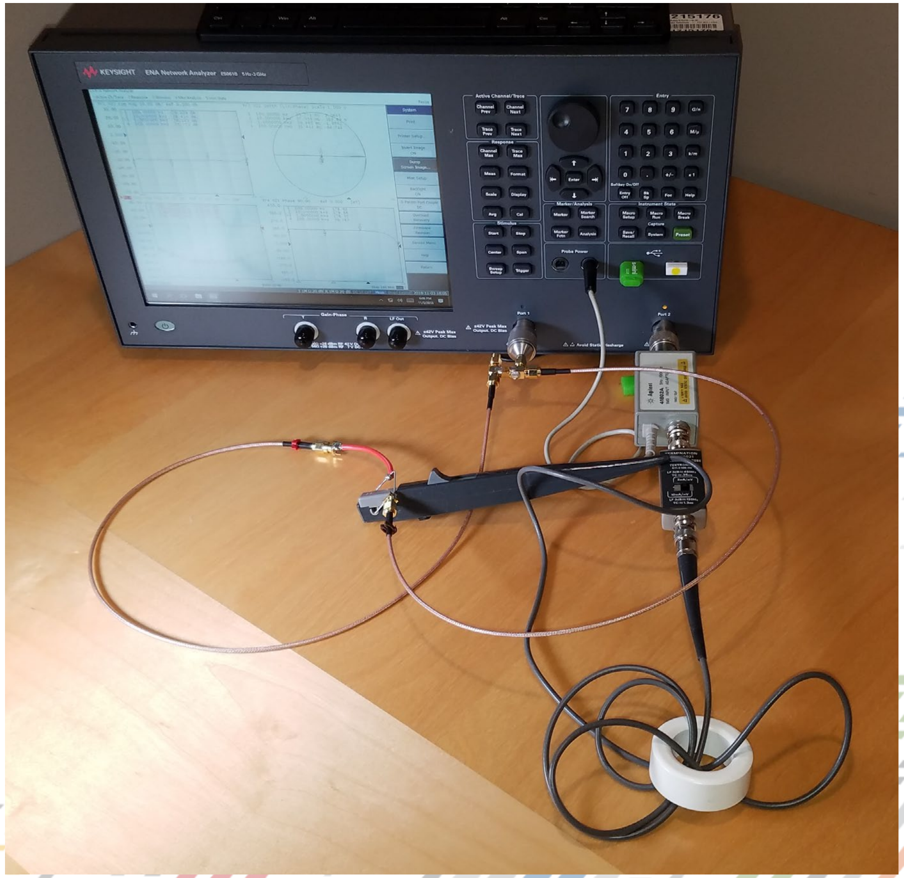
Current measurements

Current measuring setup

- Keysight E5061B VNA
- Tektronix P6021 current probe with termination block
- Agilent 41802A preamplifier
- Toroid on current-probe cable to suppress resonances

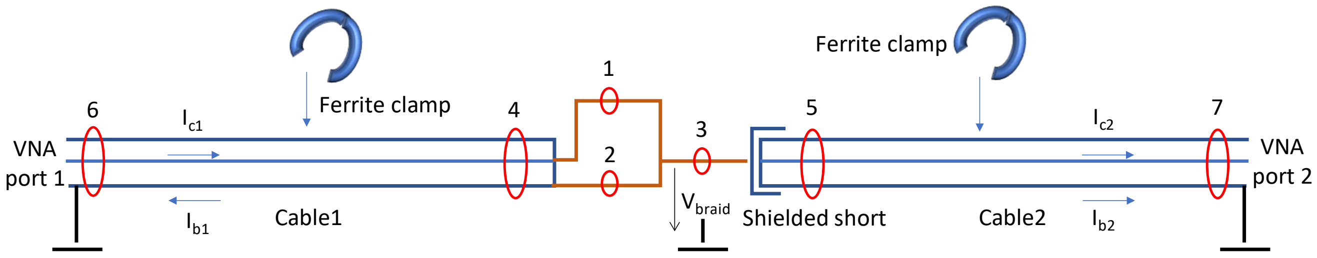
Calibration setup

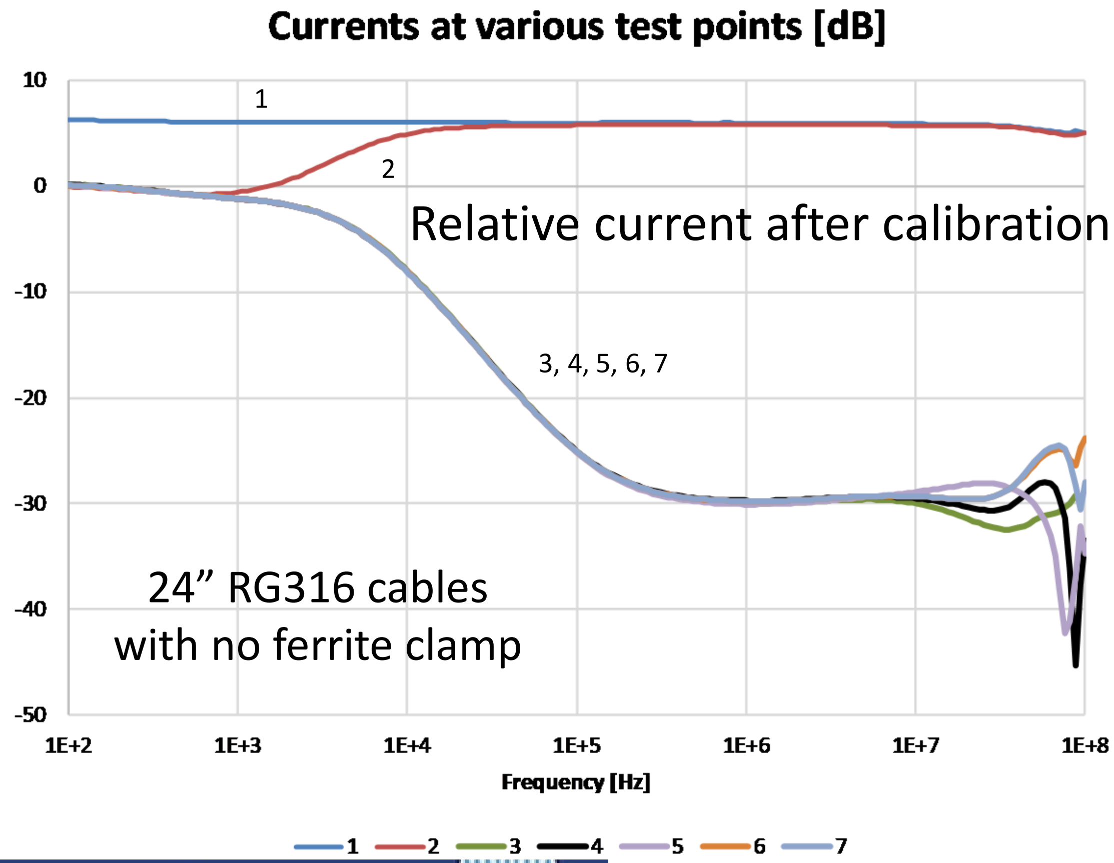
Measurement setup

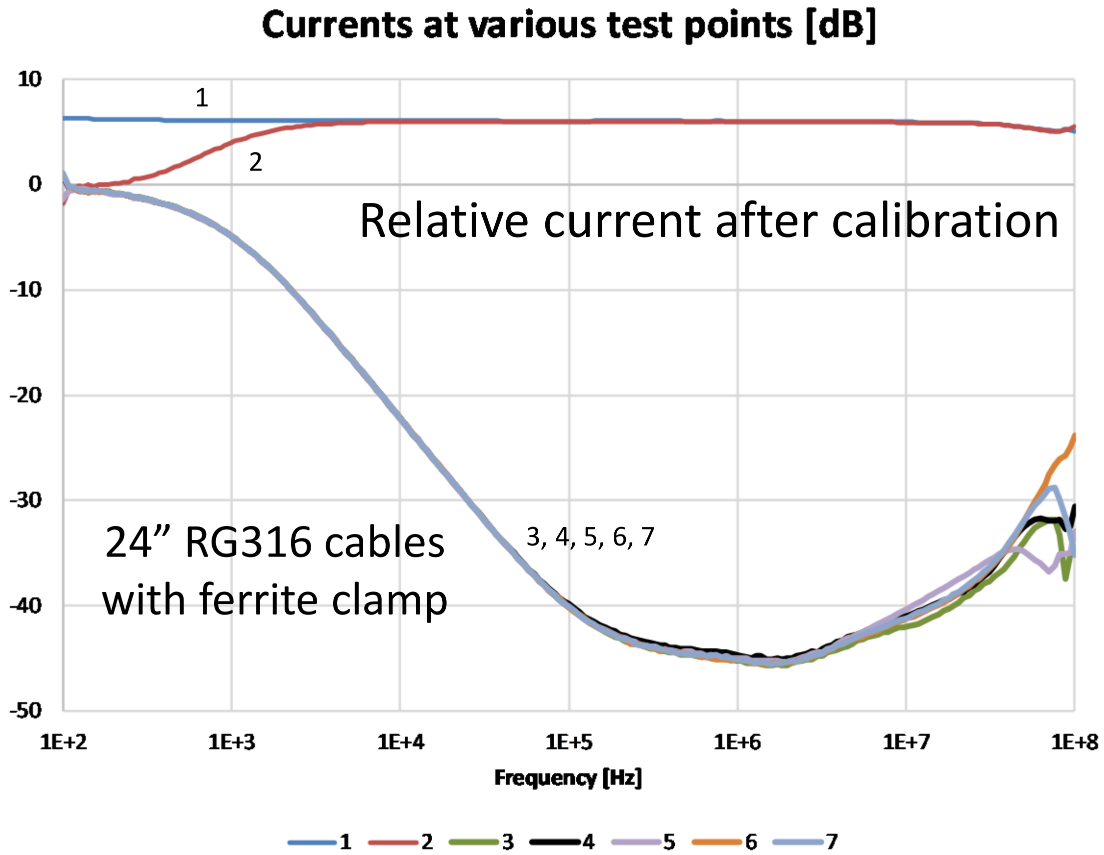


Measurements

Current measurements



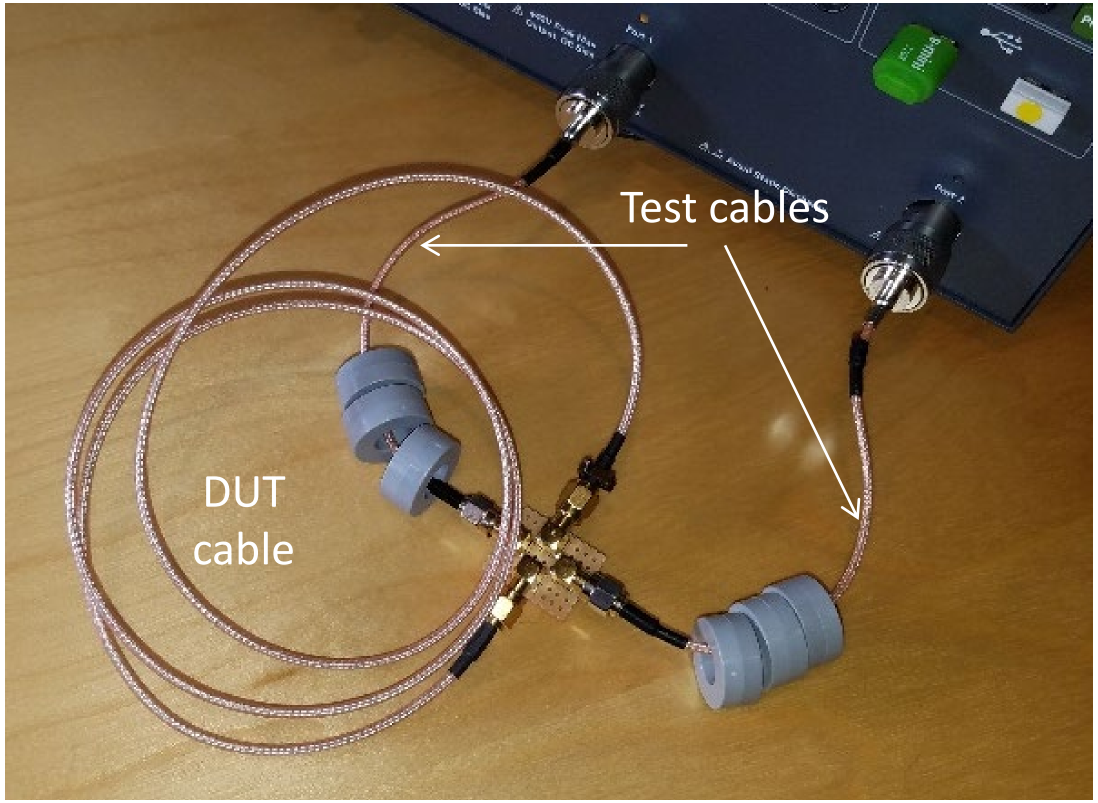




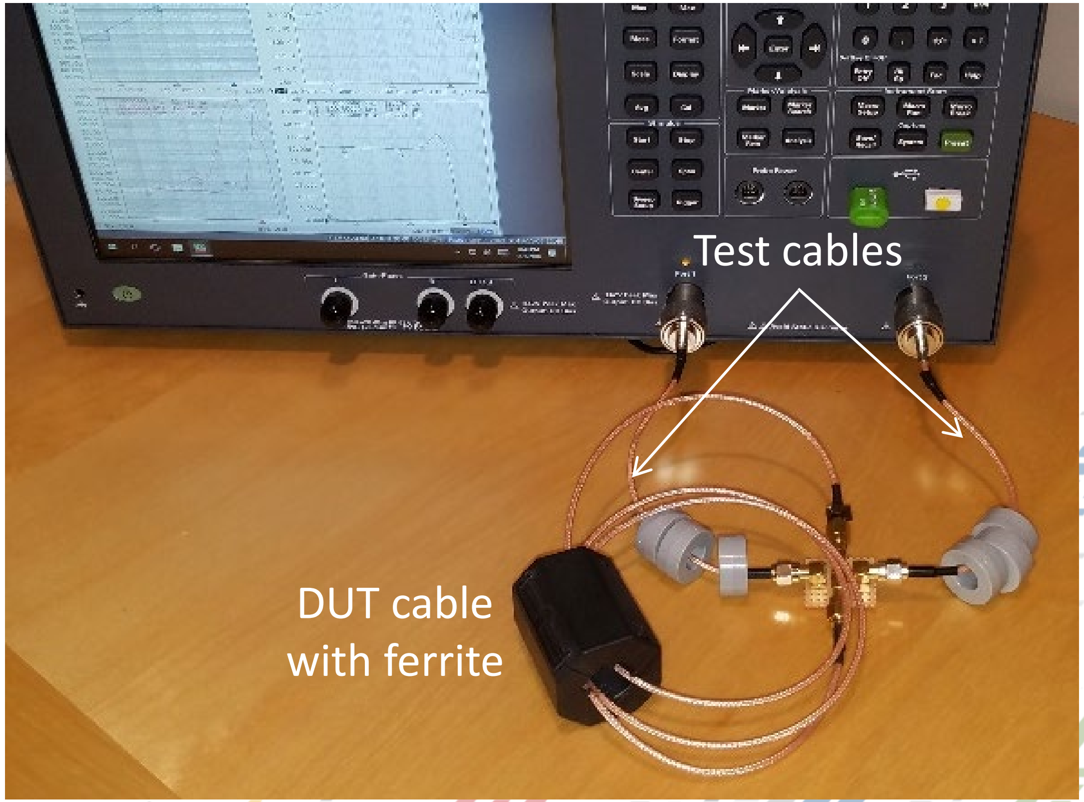
Measurements

Cable braid impedance measurement

24” RG316 cables with no ferrite clamp:



24” RG316 cables with ferrite clamp:

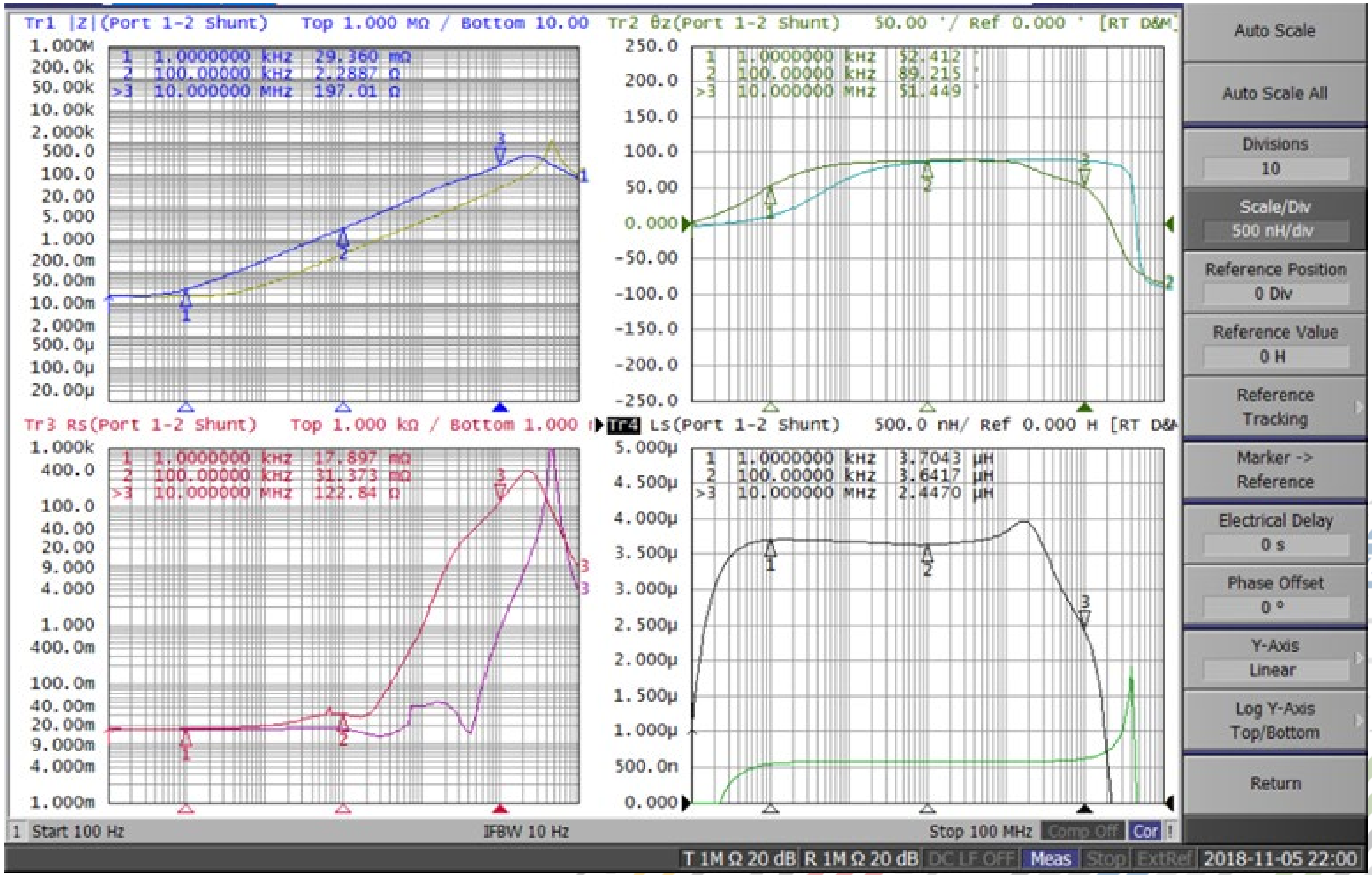


Measurements

Cable braid impedance measurement

Impedance of the braid of a 24” RG316 cable

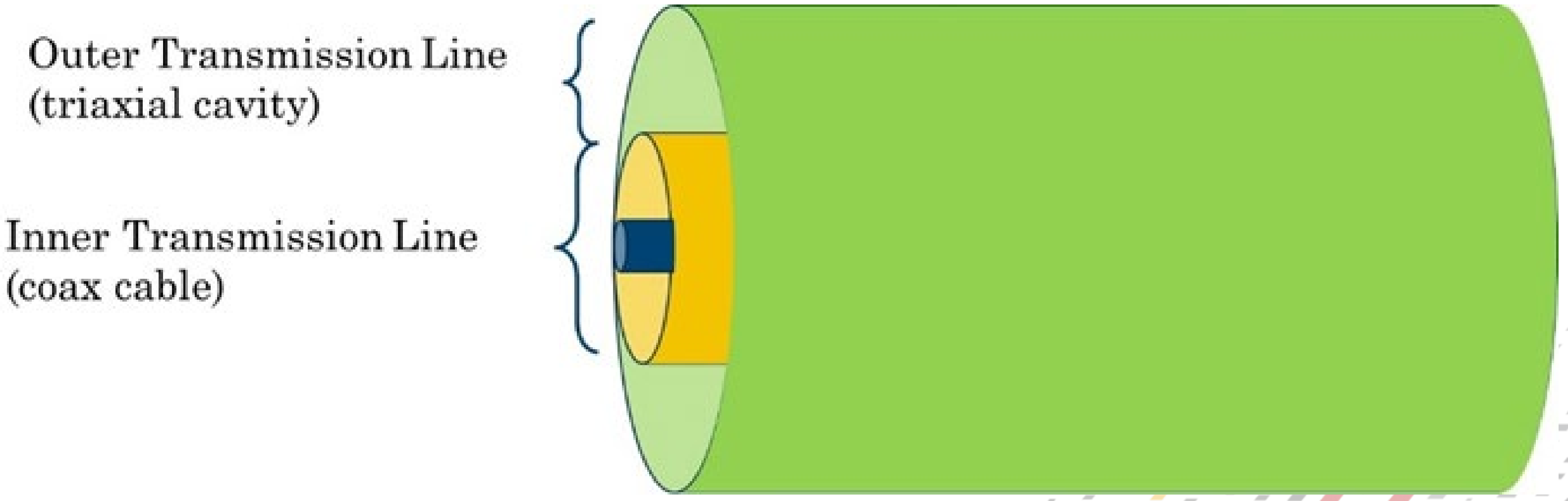
- Light trace: no ferrite clamp
- Heavy trace: with ferrite clamp



Measurements

High-frequency transfer impedance measurement

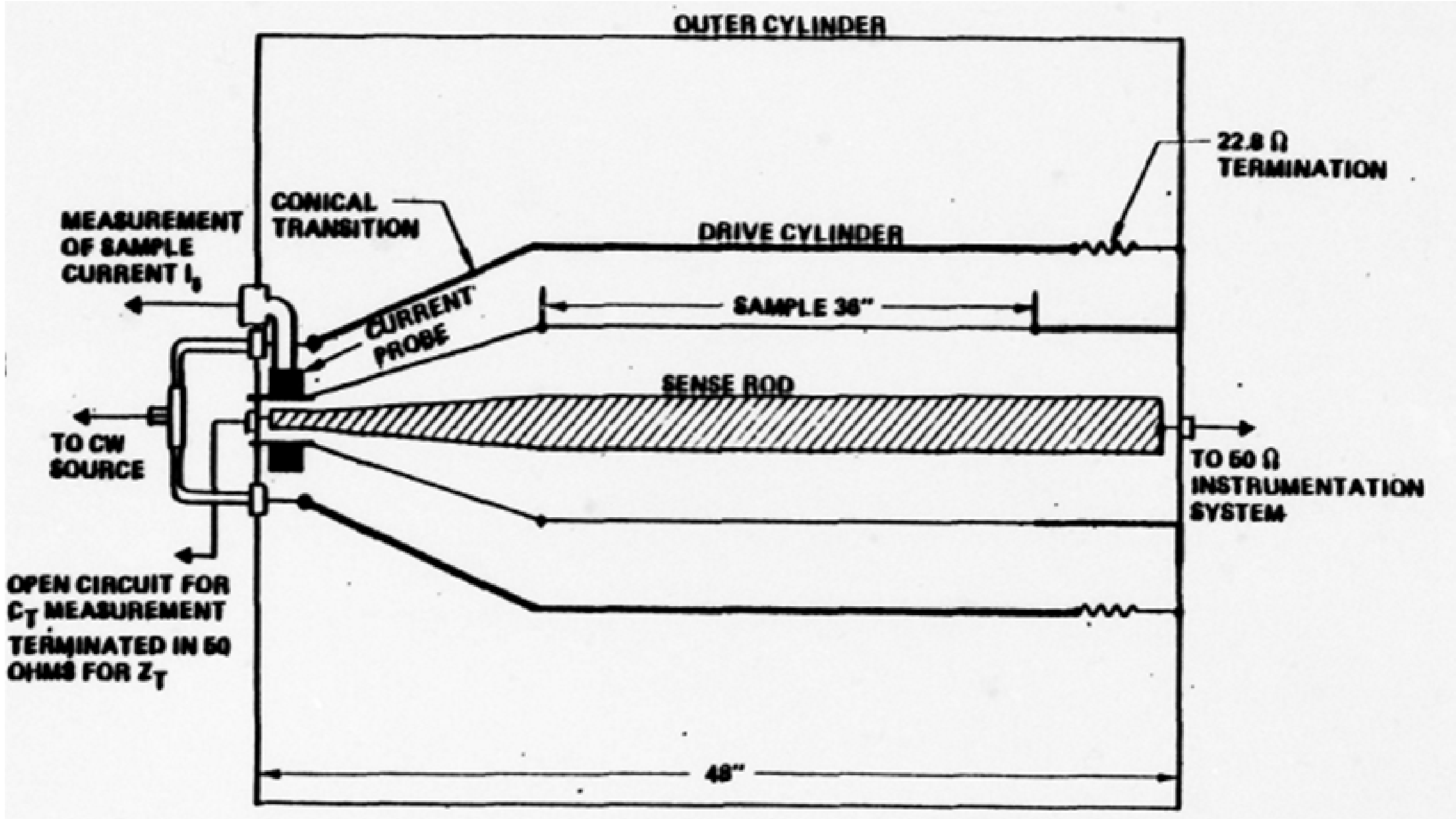
By exciting the inner transmission line with a constant voltage, the cable shield current can be extracted if we know the impedance of the inner transmission line. Voltage measured on the outer transmission line is due to the AC impedance of the cable shield.



Measurements

High-frequency transfer impedance measurement

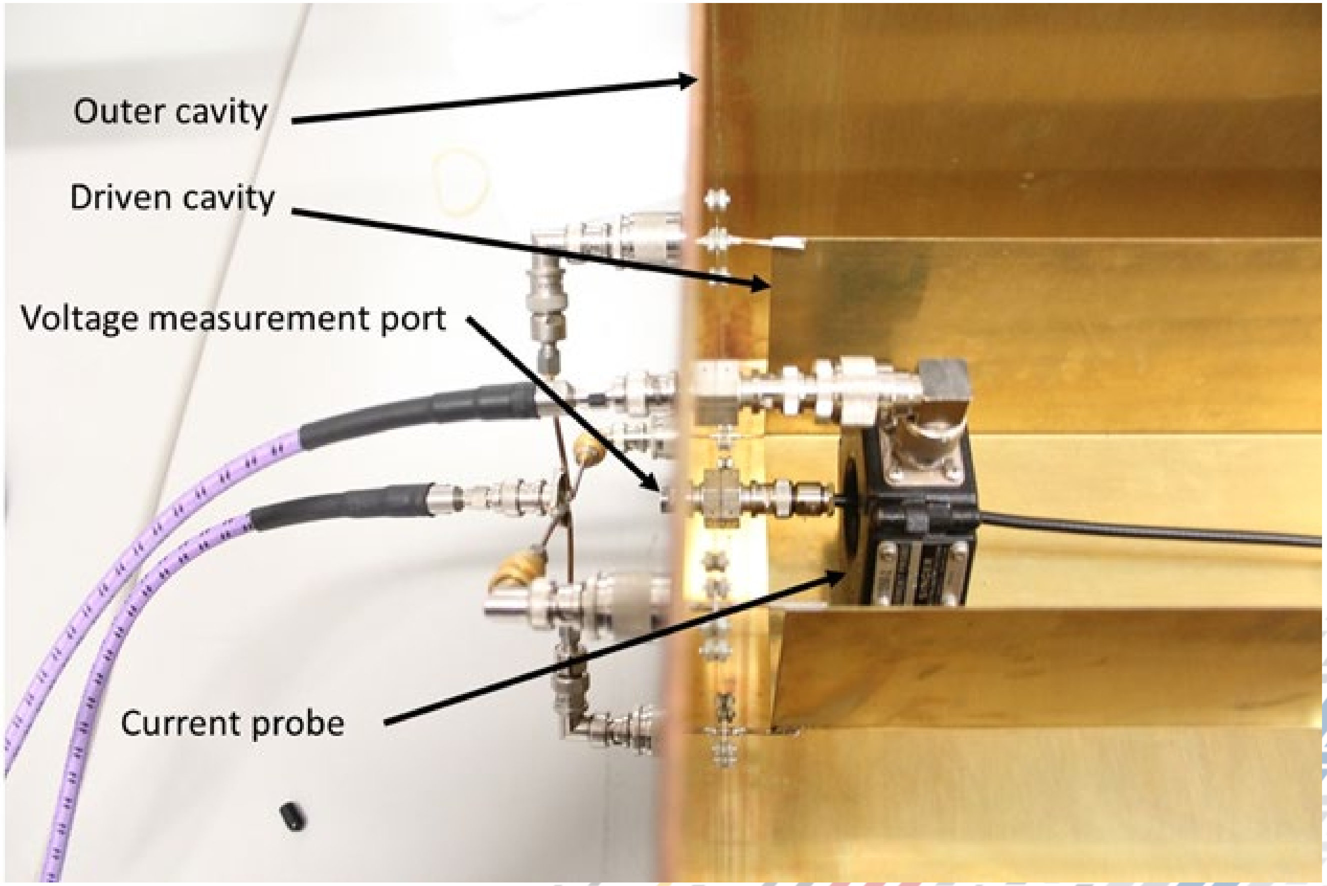
Standard procedures are the line injection method (IEC 6253-4-6) and the triaxial method (IEC 62353-4-15)]. The quadriaxial test method was developed by Boeing.



Measurements

High-frequency transfer impedance measurement

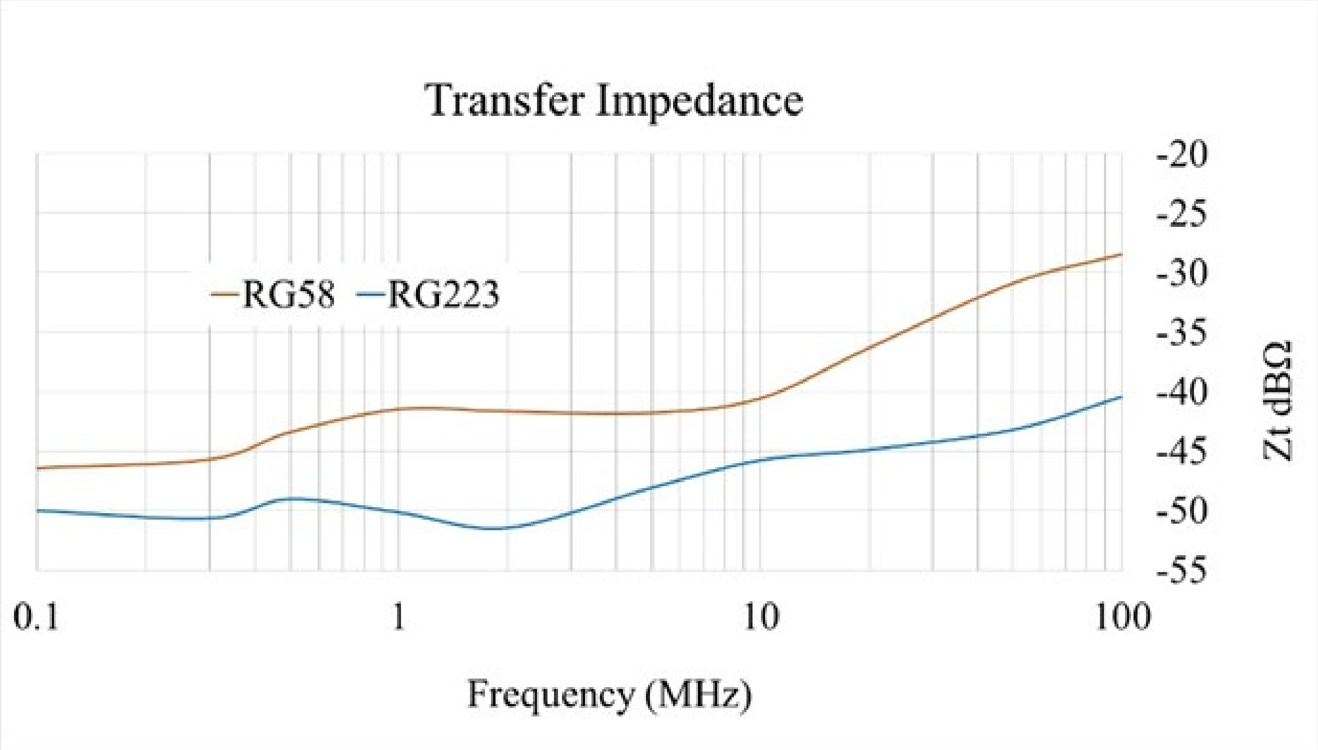
Photo of quadraxial test fixture by Electronics Consulting Laboratory.



Measurements

High-frequency transfer impedance measurement

Transfer impedance of two coaxial cable samples, measured with the quadraxial test fixture.



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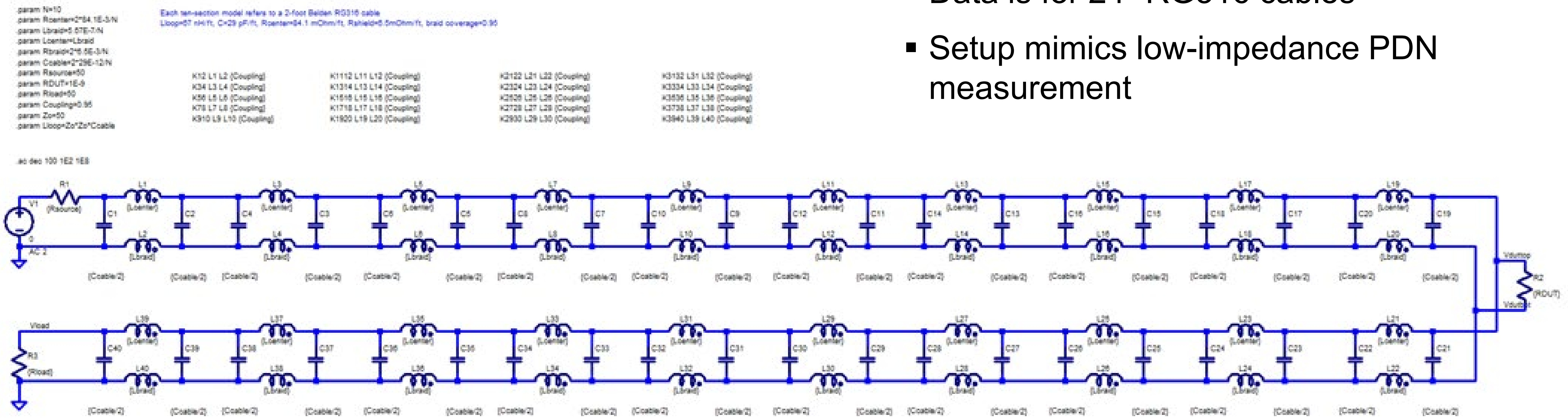
Simulations and Correlations

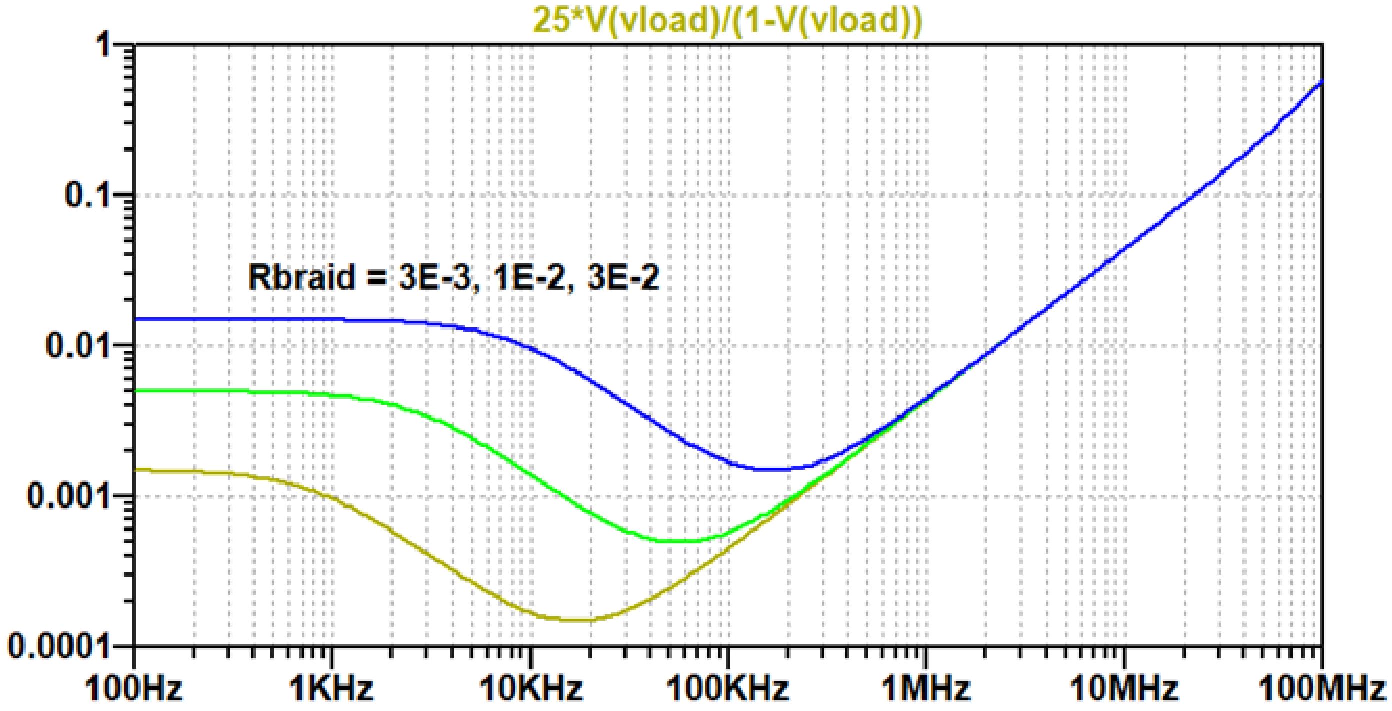
LTSPICE simulation model

- RLGC cascaded model
- Ten segments per cable
- Data is for 24” RG316 cables
- Setup mimics low-impedance PDN measurement



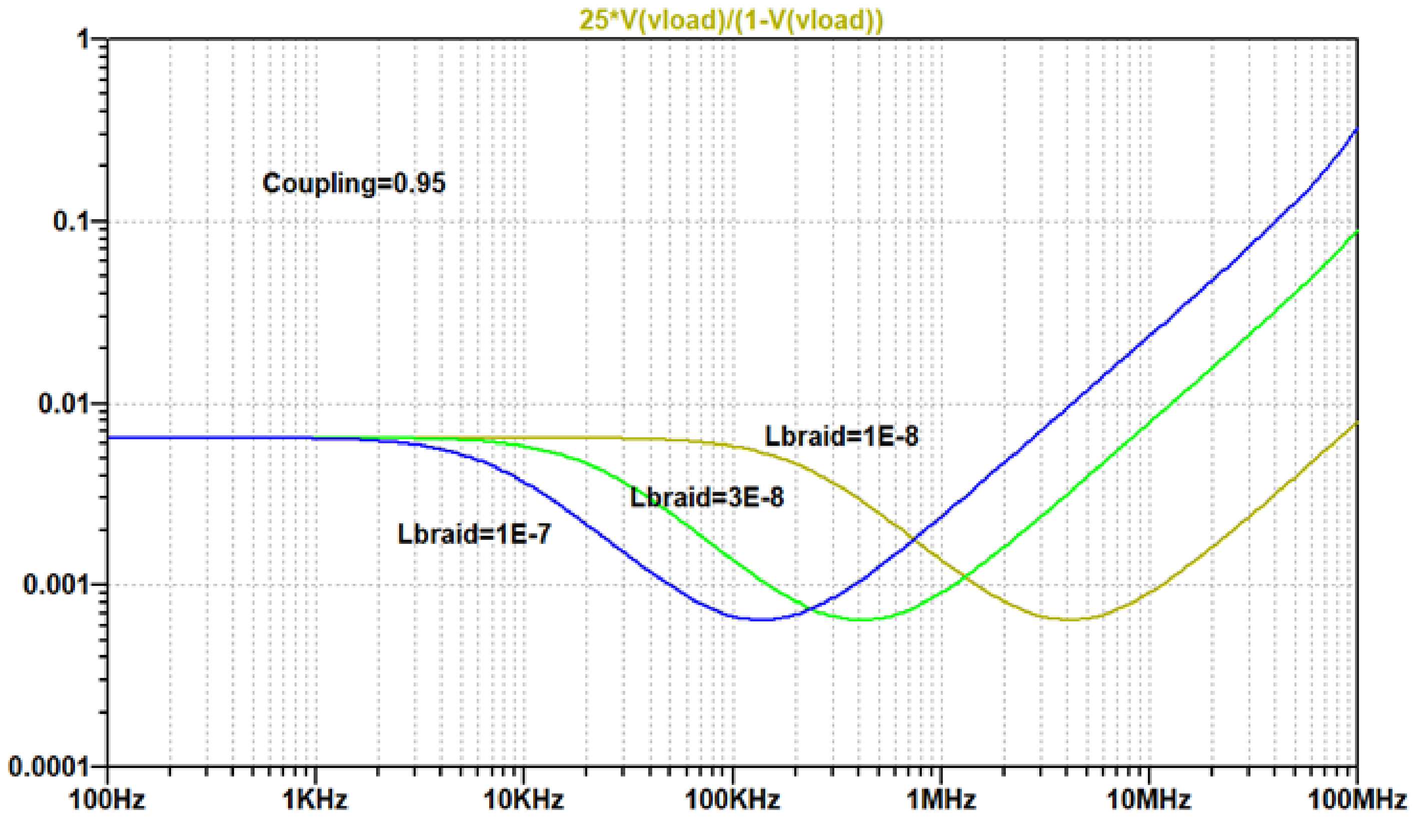
Simulations and Correlations

Simulated impedance reading with different braid resistances.



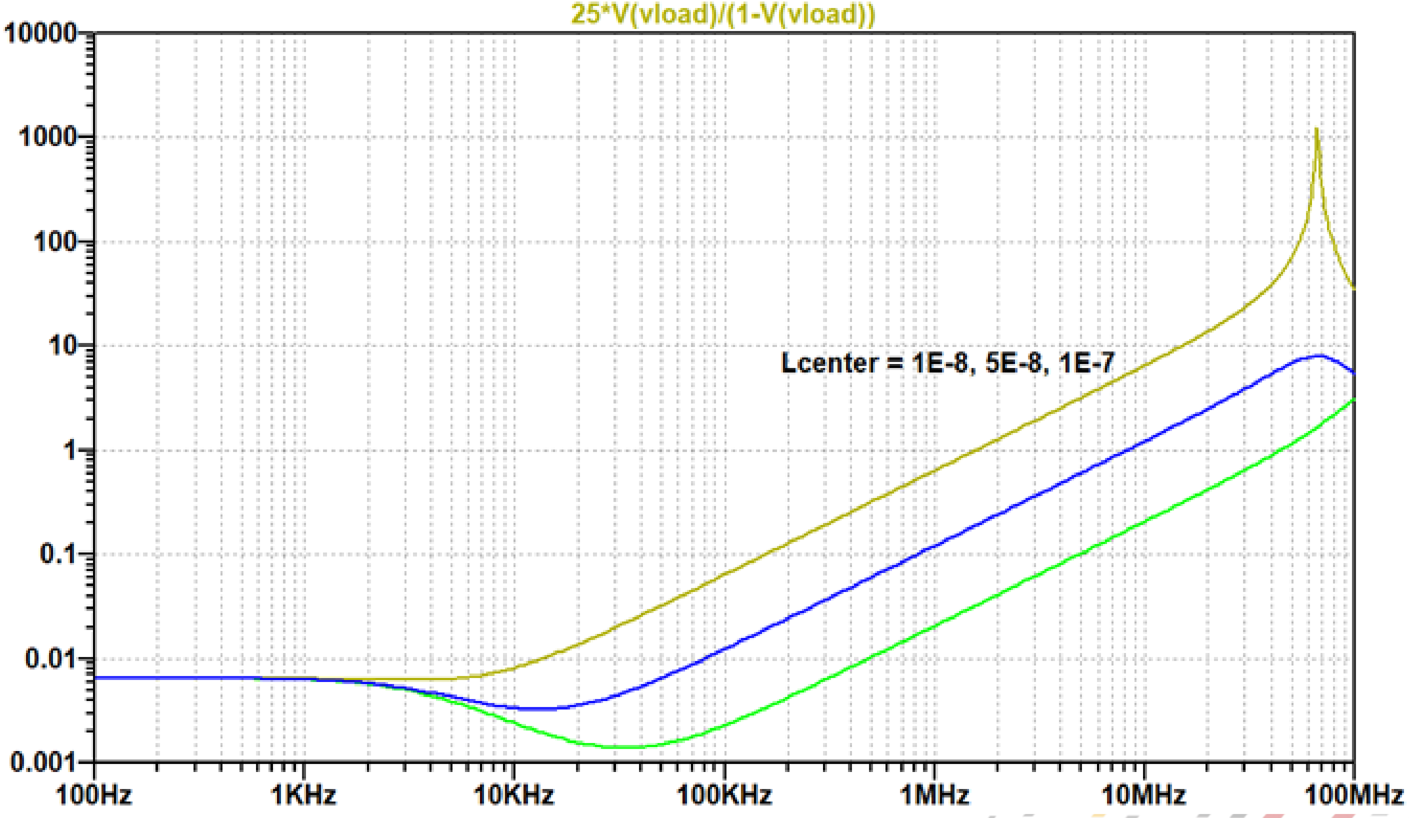
Simulations and Correlations

Simulated impedance reading with different cable-braid inductances.



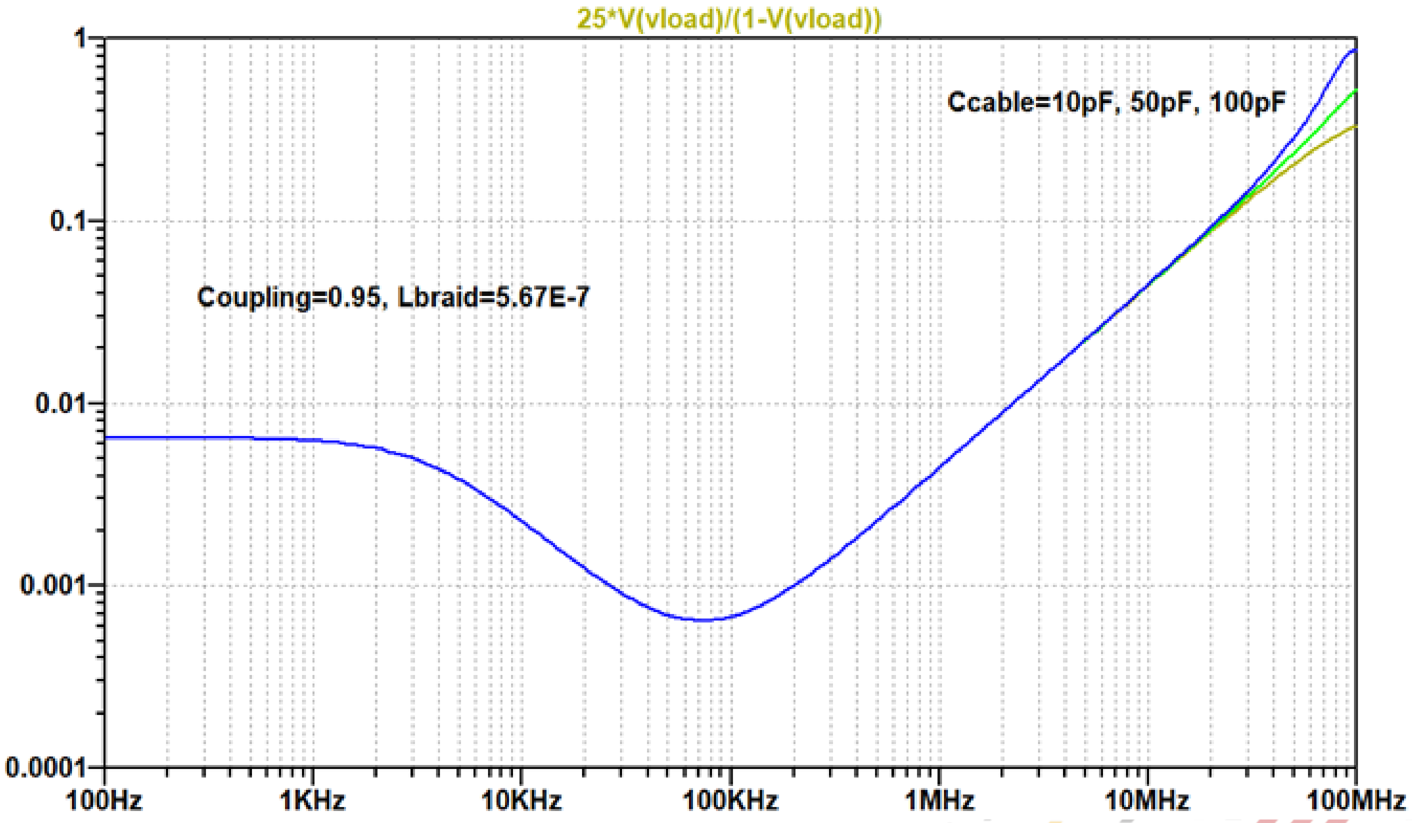
Simulations and Correlations

Simulated impedance reading with different center-wire inductances.



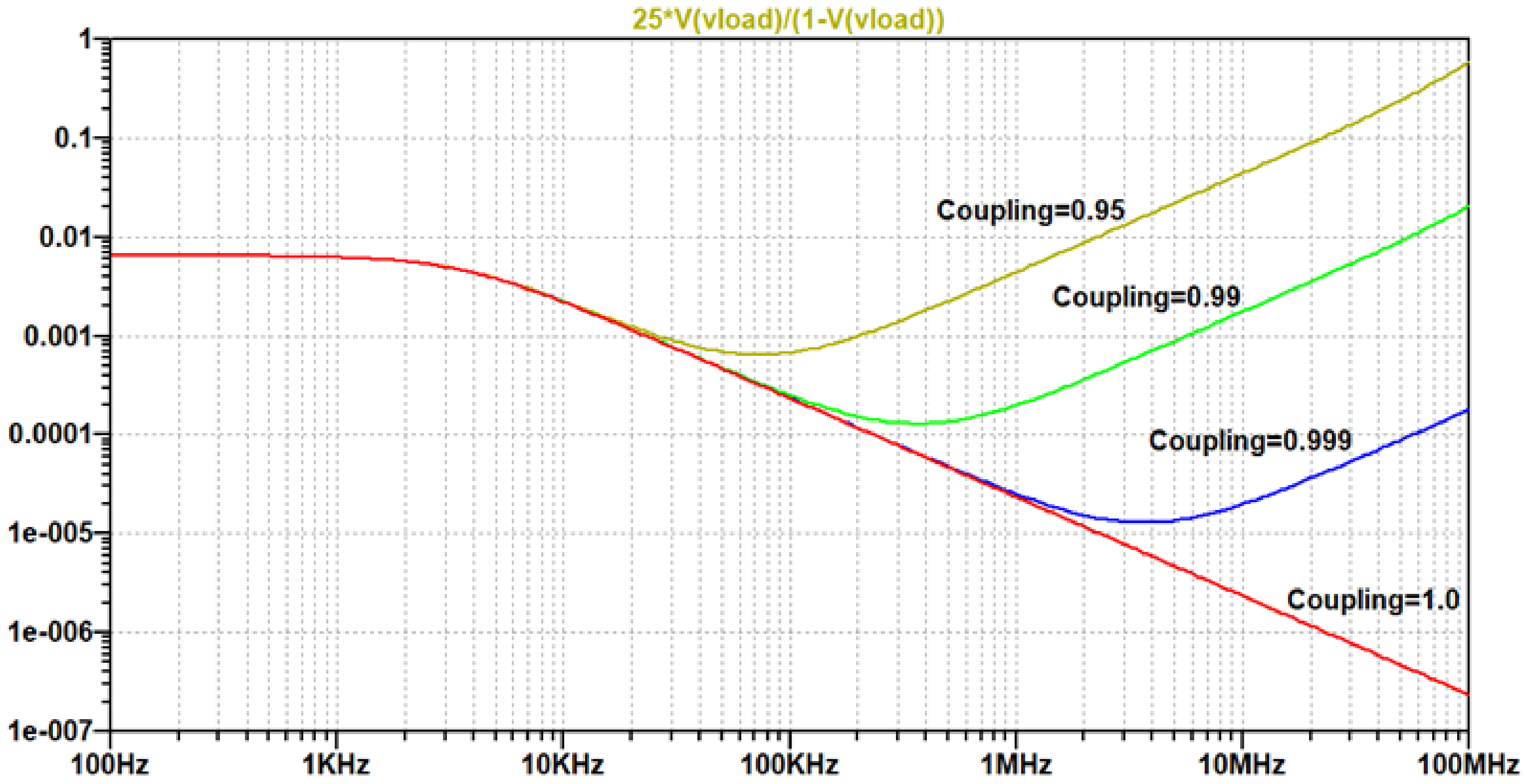
Simulations and Correlations

Simulated impedance reading with different cable impedances by sweeping cable capacitance.



Simulations and Correlations

Simulated impedance reading with different coupling coefficients of cable braid and cable center-wire inductances.



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Acknowledgement

Special thanks to

- Joe Curilla of Electronics Consulting Laboratory for making the quadraxial test fixture available.
- Keysight and Picotest for providing loaner equipment
  - https://literature.cdn.keysight.com/litweb/pdf/5990-4392EN.pdf
  - https://www.picotest.com/
- Simulations were done with Analog Devices' free LTSPICE

Summary and Conclusions

- Finite transfer impedance of cables creates errors in SI and PI measurements.
- Error shows up when shields of two measurement cables form a loop and the measured quantity is low at low frequencies.
- In SI measurements this happens when we measure crosstalk on printed circuit boards or bundled cables. It can lead to incorrect low-frequency extrapolations when frequency-domain response is transformed into time-domain.
- In PI measurements this happens when we measure low impedances with two-port shunt-through scheme.
- For cables with good shield, the low-frequency error monotonically drops above the cable braid cutoff frequency.
- For cables with weaker shields the error reaches a minimum, followed by an upslope.
- The error at medium frequencies is not the result of the interaction between the two cables through the air, rather it is a lumped phenomenon confined to within the cable and it is driven by the loosening coupling between the inductances of the center wire and the braid.
- With ideal tight coupling the coupled inductance gradually 'translates' the common-mode error created by the cable braid loop to differential signal and this common-mode to differential-mode conversion gets weaker with non-ideal coupling between the inductances.

THANK YOU!

Any Questions?