# 1000BASE-T1:

# 3-Port Conversion/Balance Measurement for Cables and Components

April 1, 2014

Neven Pischl, Broadcom
Ahmad Chini, Broadcom
Mehmet Tazebay, Broadcom

# Foreword

- 4-port S parameters or S4P is commonly used to characterize cables and components.

- While S4P provides complete set of information to characterize a 4-port network, VNA measurement of S4P can be subject to errors induced by measurement tool or setup.

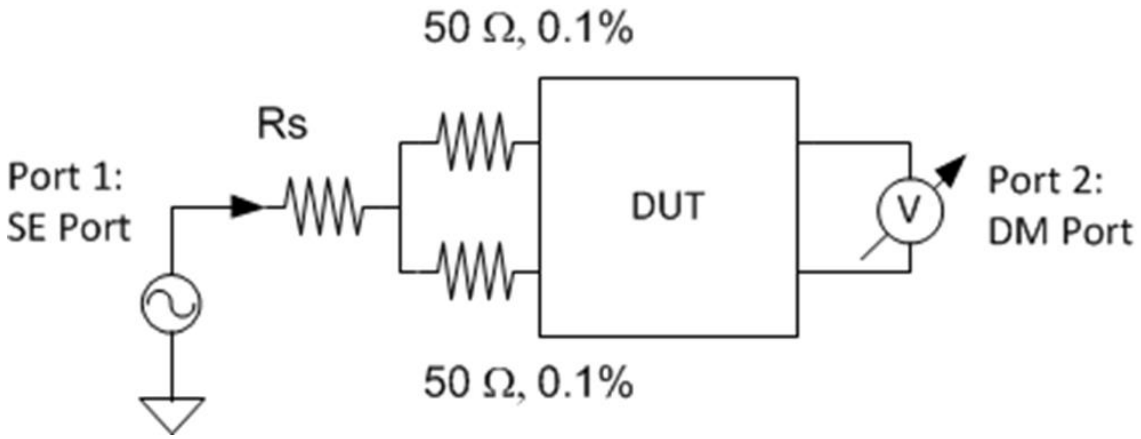
- In particular, low level mode conversion measurement may be affected by these measurement errors. In this document an alternative mode conversion measurement method based on 3-port S parameter measurement is introduced and compared with 4-port measurements.

# Difficulties with 4-port balance measurement

- Accuracy of initial calibration.
- Calibration drift over time.
- Phase stability of VNA cables (subject to bending).
- VNA scans four SE measurements in time sequence and combines results. Movements in the lab during that time, or just touching the VNA cable, easily affects measurement results.
- Need for more expensive coax connectors, e.g. “air-dielectric”.
- Difficulties cause inconsistent results across labs.

# Circuit for the 3-port balance measurement

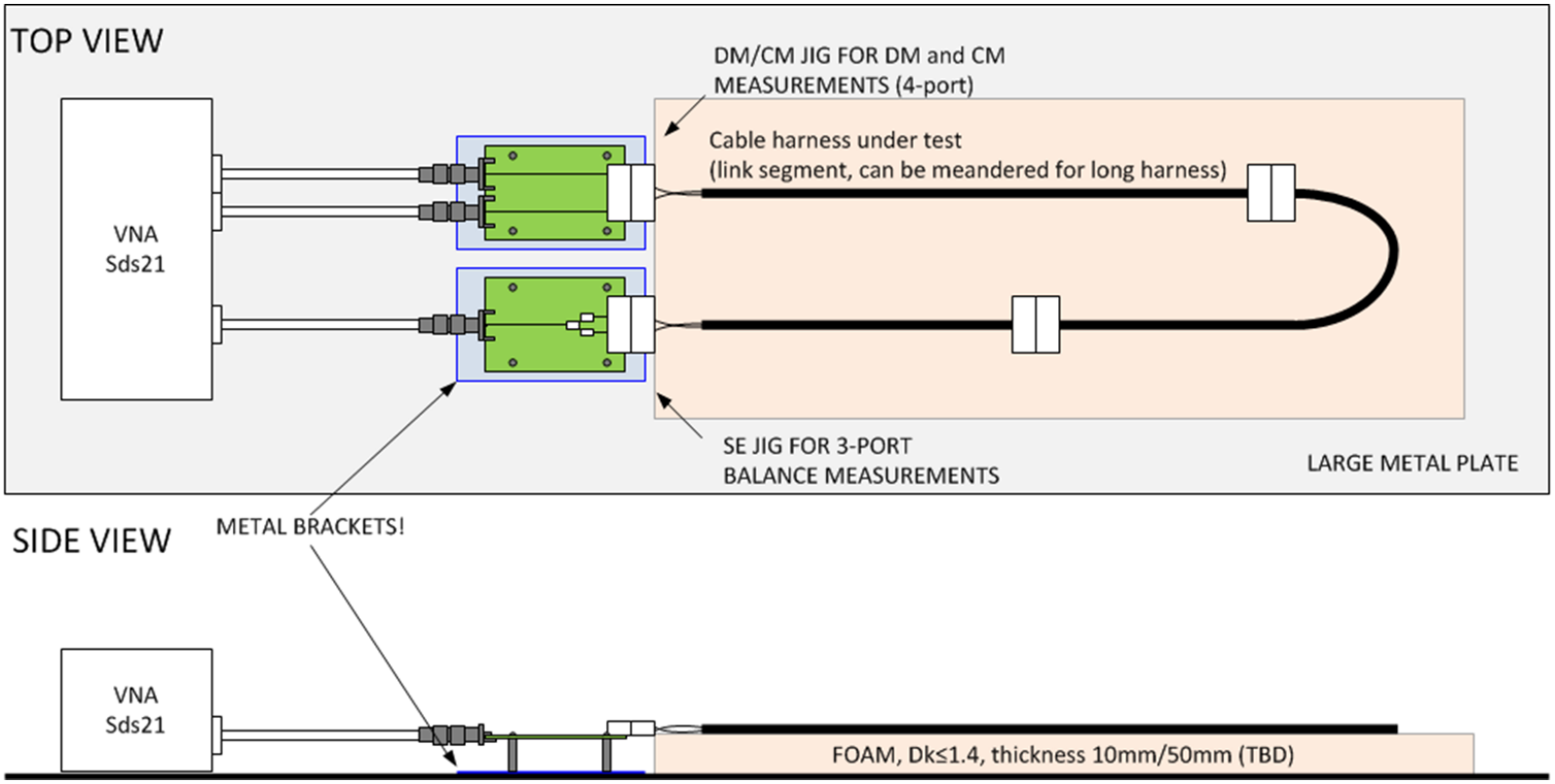
- Port 1 is a single-ended (SE) source.
- A precision resistive power divider splits the SE signal, provides true CM drive to the DUT.
- Port 2 measures the DM resulting from CM drive.
- The measured conversion parameter is Sds21.
- Critical, but easily achievable:
  - well-matched resistors
  - short connections between resistors and DUT



# Description of the 3-port method

- **Port 1 is used as a true CM source to drive the DUT.**
- **Function of the resistive power divider network:**
  - Splitting of the source signal.
  - Precision match assures the worst-case conversion by the resistors is under -66dB.
  - 100Ω DM termination on the driven side.
  - CM termination on the driven side (includes source impedance) is (Rs+75)Ω.
- **Port 2 is made by two VNA ports, providing**
  - 100Ω DM termination.
  - Optional CM termination:
    - 25Ω CM “physical” termination, could be changed or converted by the VNA CM-impedance conversion feature.
    - Suggested corrected value for Port 2 CM impedance is in the 150Ω-250Ω range.
- **Issues related to the 4-port method such as port-scanning, cable bending, jig imperfections are reduced or eliminated.**

# Basic setup for channel measurement



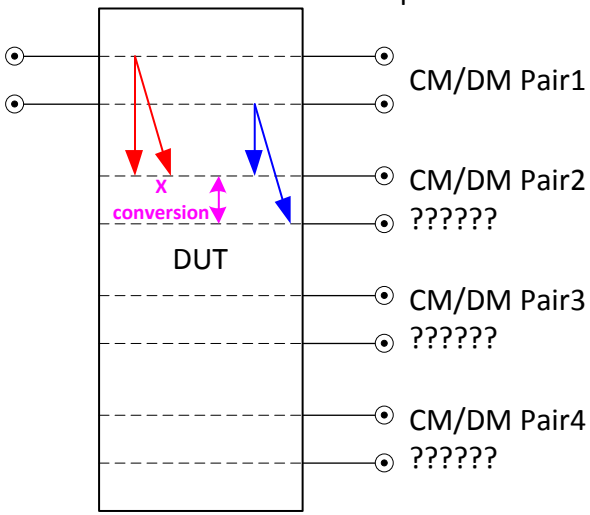

Notes:

1. The 50 Ω 0.1% resistors are RF-type SMD 0805 or smaller, e.g. Vishay FC series resistors.
2. Two DM/CM jigs are used for all “standard” 4-port differential and common mode measurements.
3. SE jig is used only for balance measurement.
4. Brackets provide reference “0V” for CM at the ends of DUT cable/harness.
5. The entire setup is on a large metal plate, which extends at least 10cm/50cm (TBD) beyond the setup.

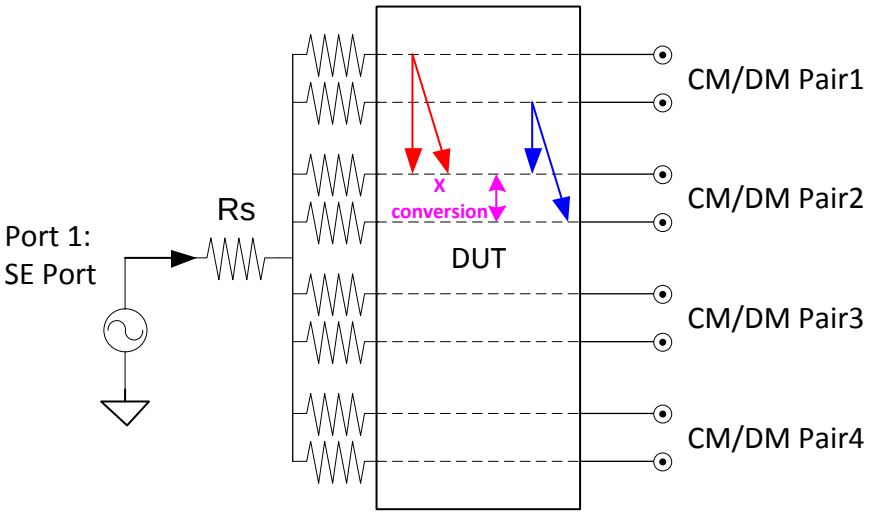
# Invaluable in multi-pair measurements

- **In multi-pair configurations , e.g. connectors, cross-conversion and cross-CM-coupling are very real and critical parameters.**
- **The 4-port method is not suitable because it does not provide true CM drive, and it does not capture true coupling between all lines.**
- **3-port method provides true CM drive, captures all valuable information.**

Example:
4-ports only drive one pair at the time and thus only measure self-properties for each pair.
Considerable interaction between pairs and resulting cross-conversion and CM-CM transfer are not captured.




Example:
3-port method drives all pairs together, and properly captures the total conversion (self&cross) and CM-CM transfer in multi-pair DUTs. It captures real-life conditions.



# Advantages of the 3-port method

- Simplifies the test procedure and improves accuracy.
- Applicable to various components.
- Invaluable in multi-pair applications.
- VNA cable bending (phase stability) and connectors are no issue on the SE side.
- Calibration is not as critical as for 4-port balance measurement.
- Measurement is not sensitive to movement in the lab.

- Results are very stable and easier to reproduce between labs.

# Applicable to various components

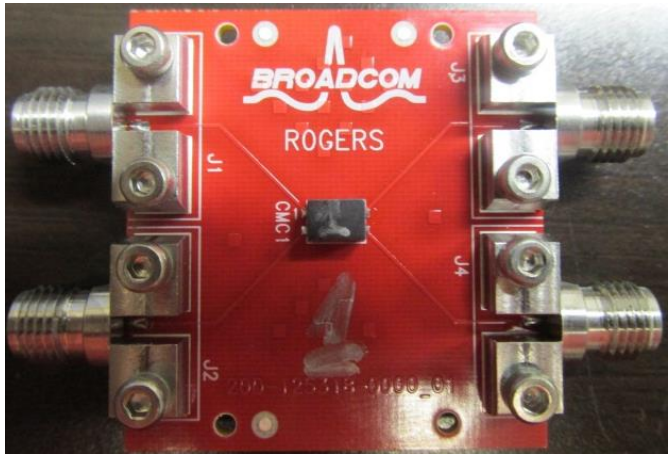
- **The method is very much applicable not only to the whole channel measurements, but to the individual components, such as:**
  - Cables
  - Connectors
  - CM chokes
  - Filters
  - Transformers etc.

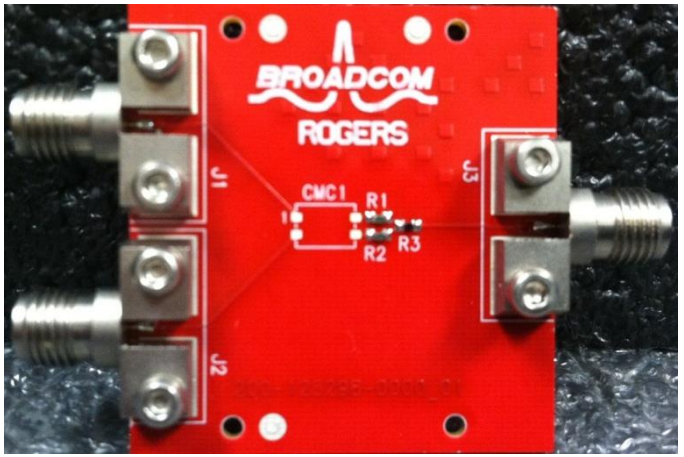
- **Precautions:**
  - The SE jig must be balanced from the resistors to the DUT terminals (short traces).
  - The DM/CM jig must have reasonable balance compared to the measured levels.
  - The jigs should use 50Ω single-ended traces.
  - The VNA reference plane should be extended to the DUT pins on the DM side.

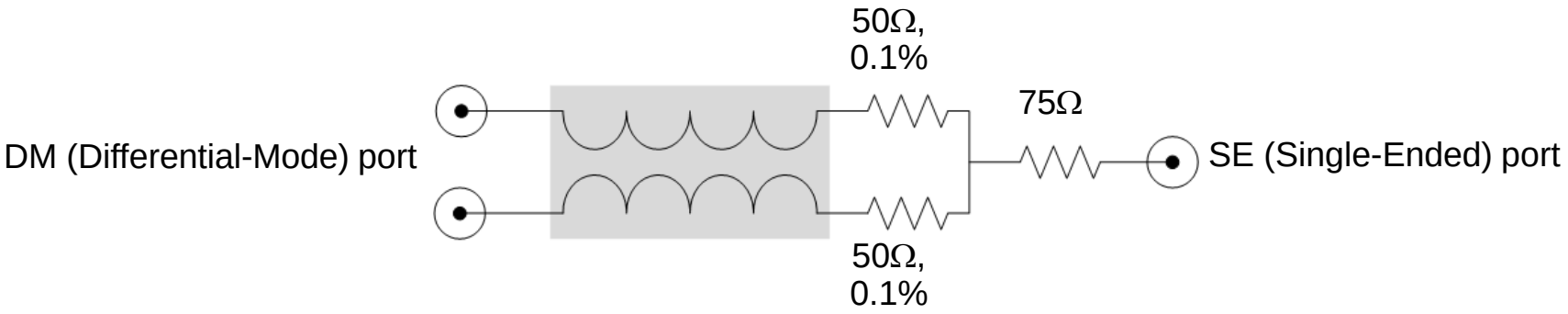
# APPENDIX

- Relation between 3-port and 4-port mode conversion measurements using VNA is described.
- 3-port mode conversion measurement provides convenience and accuracy in some measurement aspects, as previously described.
- This Appendix shows how 3-port and 4-port are related in a single-pair measurement application.
- Comparison is made for a sample CMC (relatively simple DUT) and a 2m UTP cable with additional effects e.g. resonances.

# 4-port and 3-port jigs used for CMC measurements

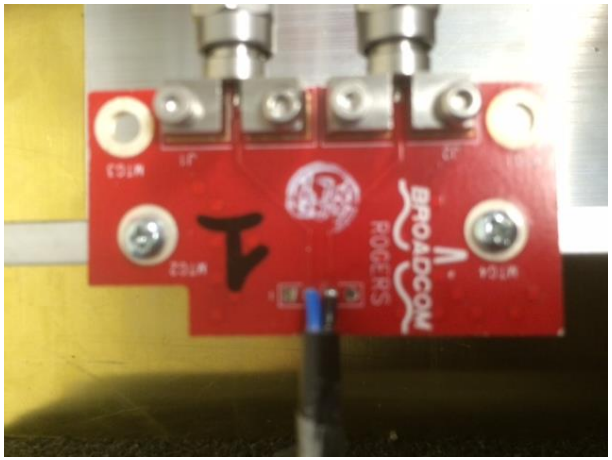


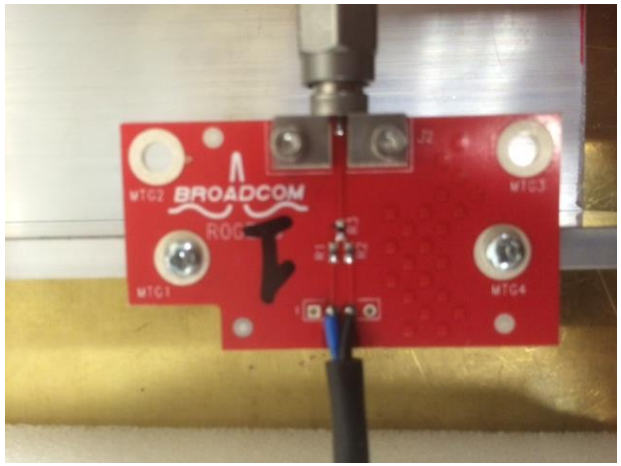



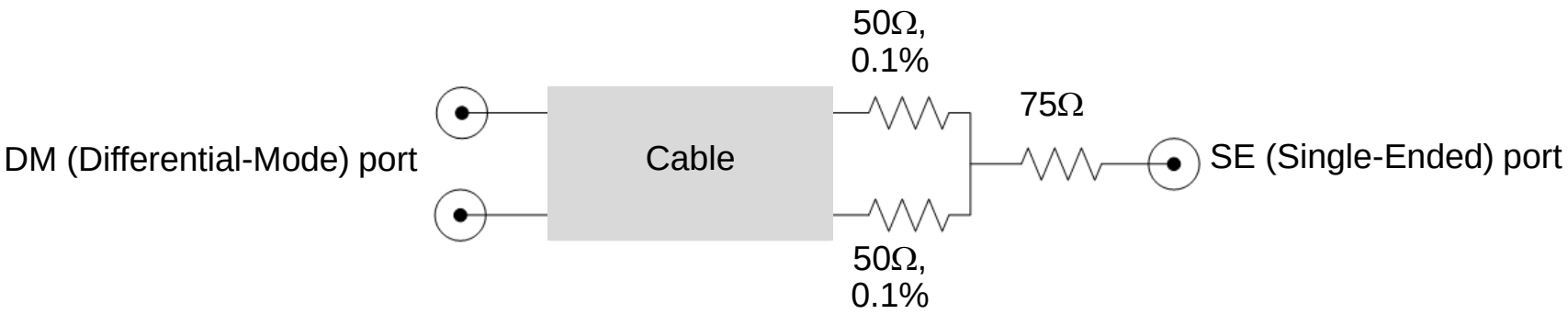




3-port and 4-port measurements with and without port extension for a sample automotive CMC are used in analysis.

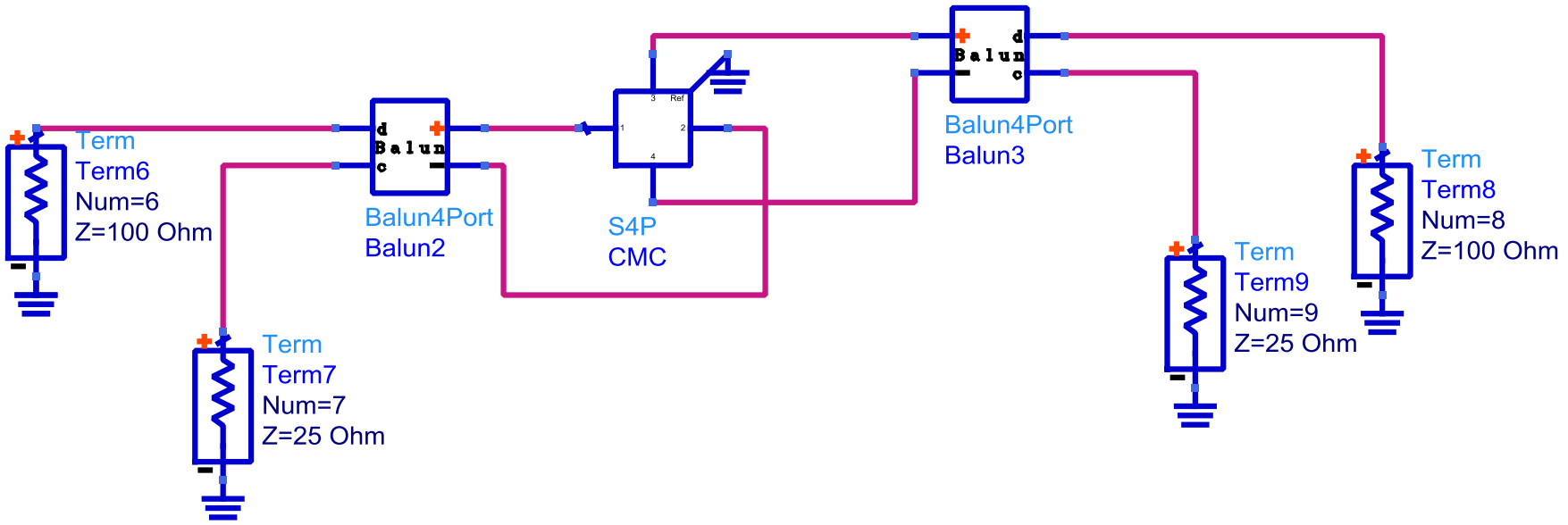
# DM and CM Jigs used for 3-port Cable measurements



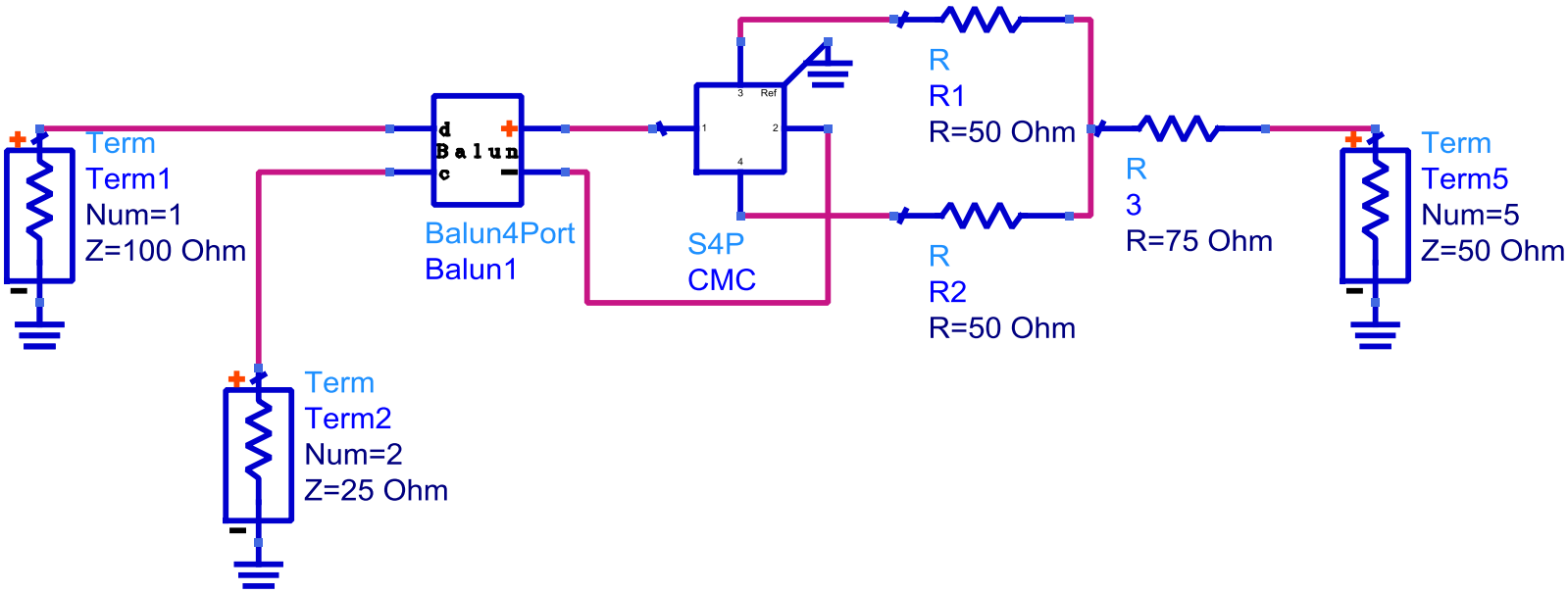



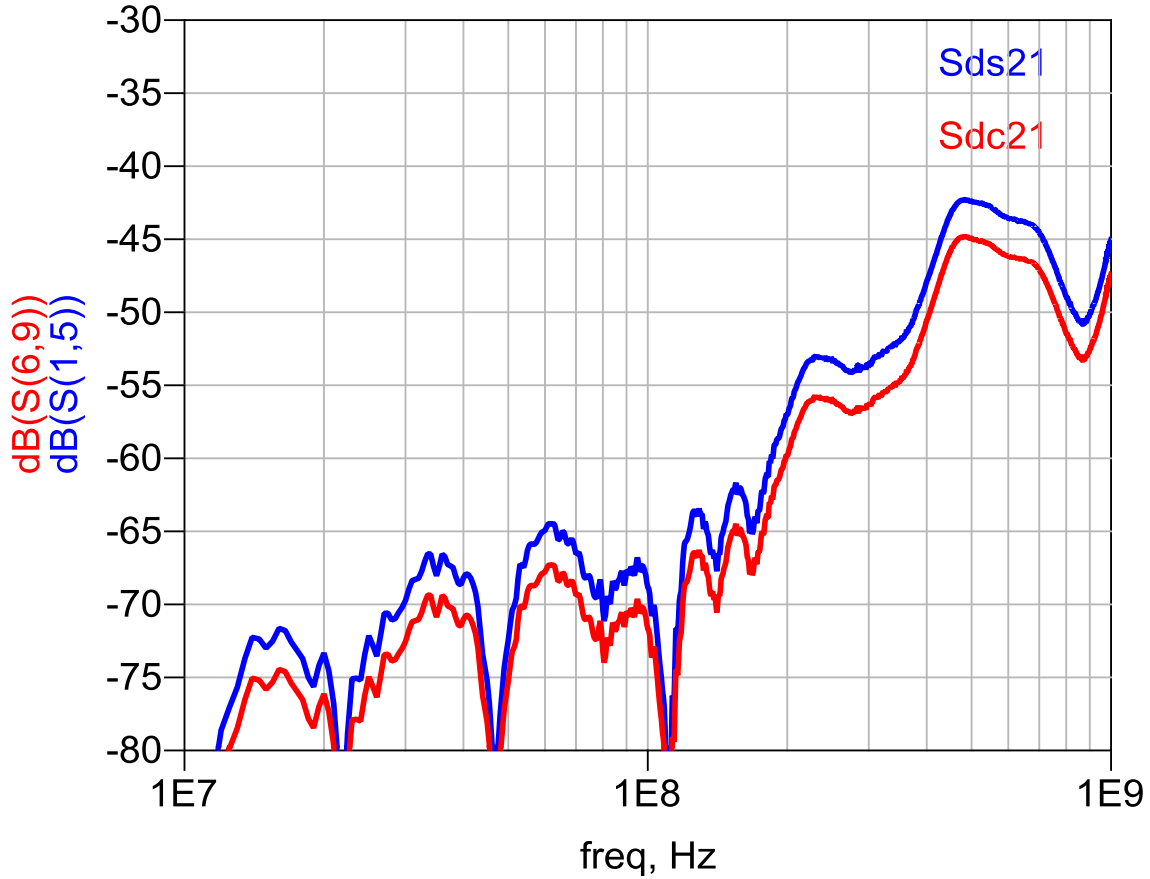
# 4-port ADS model using 4-port VNA measured S4P



# 3-port ADS model using 4-port VNA measured S4P

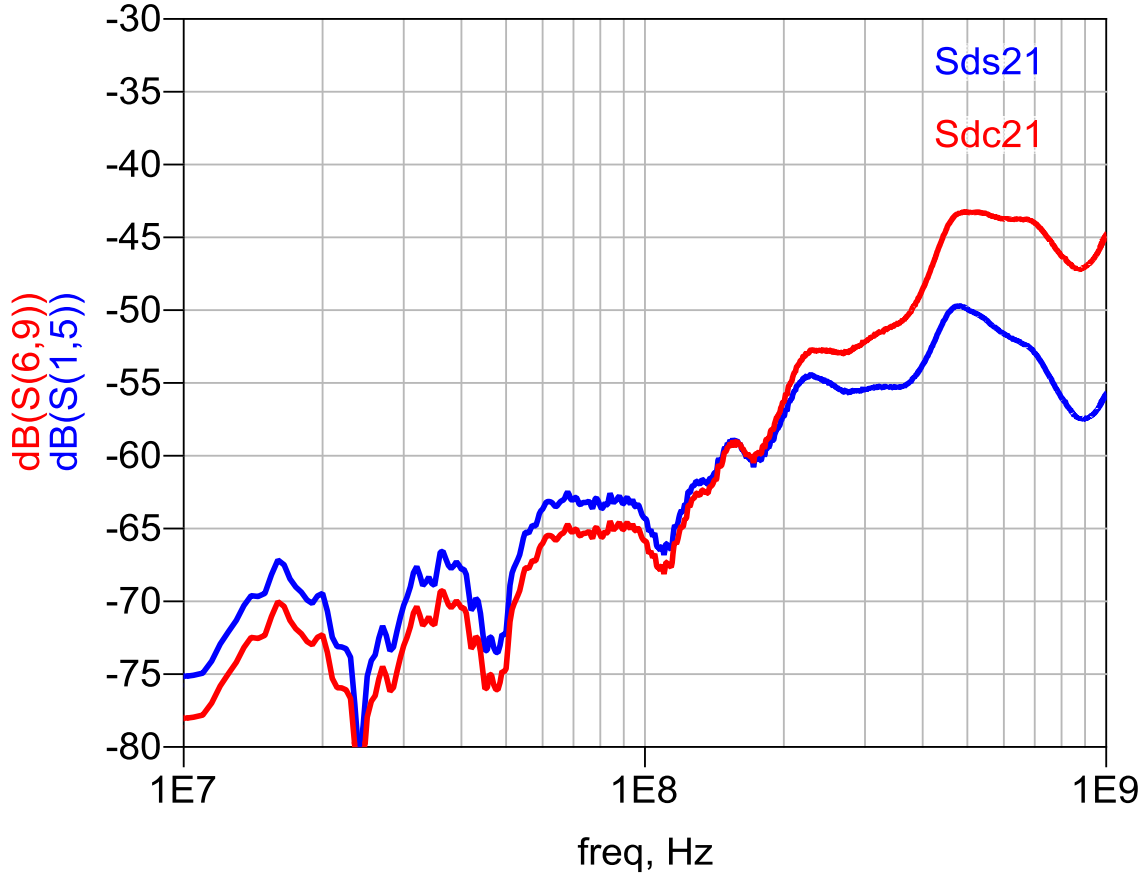


# $S_{ds}21$ vs. $S_{dc}21$ on a CMC, with port extension



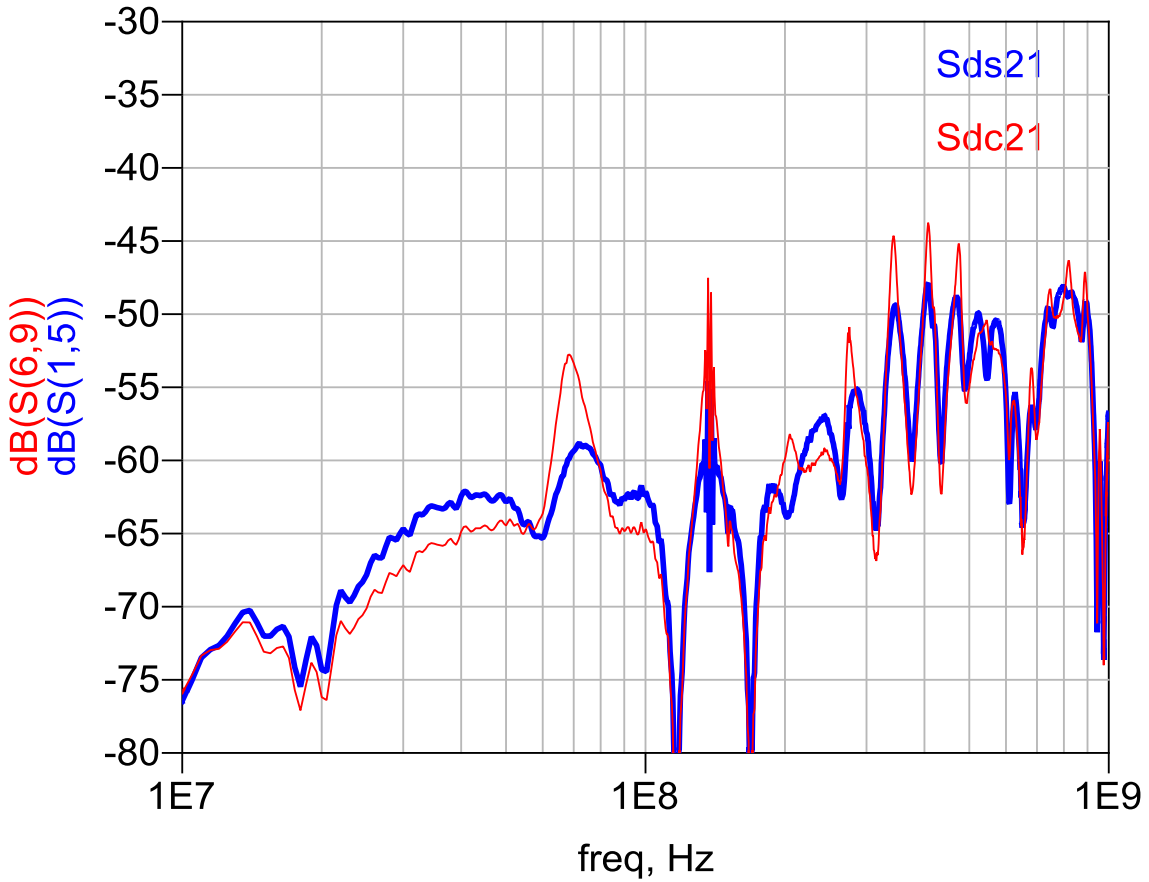

- Sds21 is similar in shape and about 3dB higher than Sdc21 when 4-port VNA measurement with port extension is used to generate 3-port mode conversion (Sds21).
- The 3dB higher value for Sds21 can be explained given CM is measured on 50Ω as compared to Sdc21 measured on 25Ω.

# $S_{ds}21$ vs. $S_{dc}21$ on a CMC, without port extension



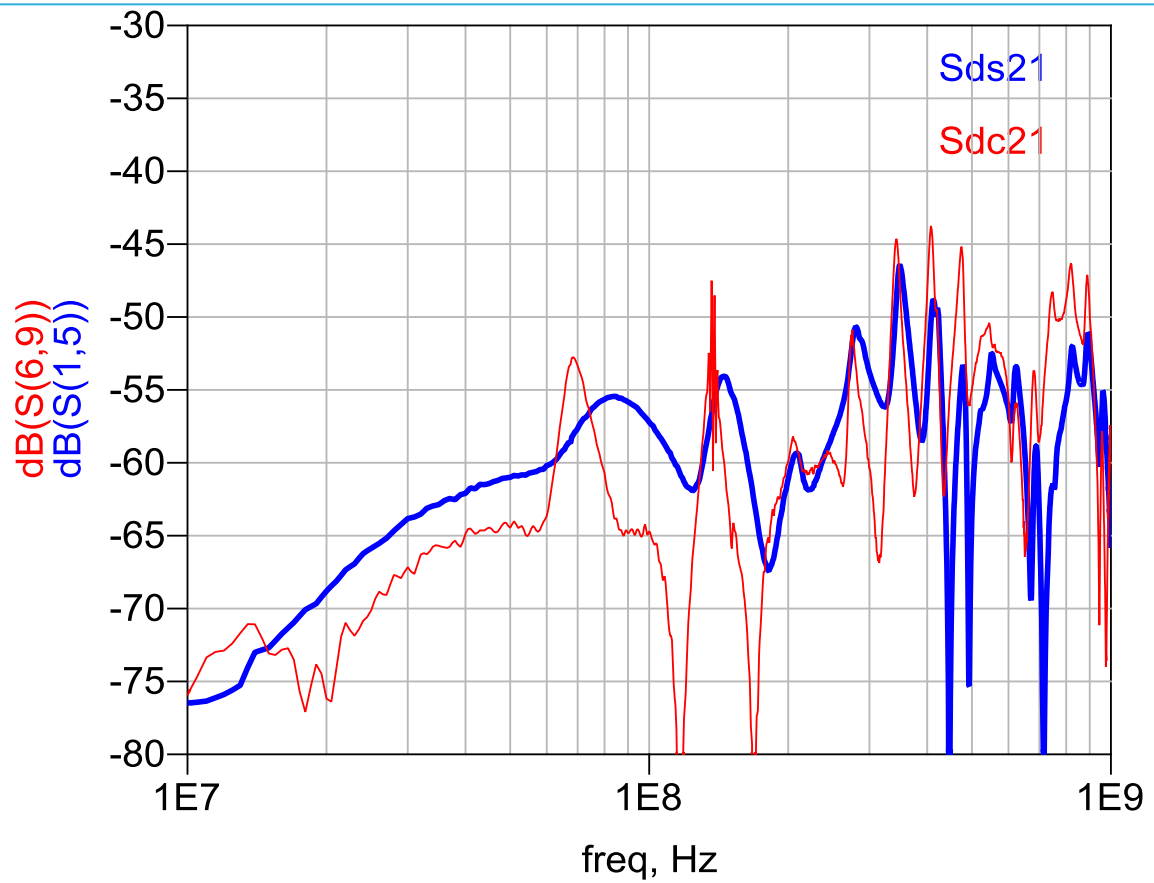

- Sds21 is different in shape to Sdc21 when 4-port VNA measurement without port extension is used to generate 3-port mode conversion (Sds21).
- The different shape can be explained given the test jig trace effect is not removed here.

# $S_{ds}21$ vs. $S_{dc}21$ on a cable, with port extension




- Sds21 shows diminished values at resonance frequencies as compared to Sdc21.
- At other frequencies Sds21 could be higher by up to 3dB.
- The 3dB difference comes from Sds21 measuring CM on 50Ω instead of 25Ω.
- Reduction at resonance frequencies is due to CM termination provided by150Ω resistor network.

# $S_{ds}21$ vs. $S_{dc}21$ measured on a cable




- Sds21 measured shows diminished values at resonance frequencies as compared to Sdc21.
- This is due to CM termination provided by the 150Ω resistor network.

# Appendix Summary

- In order to obtain accurate S4P data using 4-port VNA measurements, the test jig trace effect needs to be removed. This can be done effectively using VNA port extension.
- 3-port mode conversion measurement represents true mode conversion if the combining resistors are placed close to DUT.
- 3-port mode conversion measurement for CMC produces 3dB higher value than 4-port measurement. Therefore passing a mode conversion limit line with 3-port measurement guarantees passing the same limit line for 4-port mode conversion (Sdc21).
- When 3-port measurement is performed for cable mode conversion, the values are expected to pass the same limit line used for 4-port measurement with some margin (3dB?) to consider for diminished resonances.