Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Influence of LO cable movements on VNA measurements using Frequency Extensions

Einfluss von LO-Kabelbewegungen auf VNA-Messungen mit Frequenz-Erweiterung

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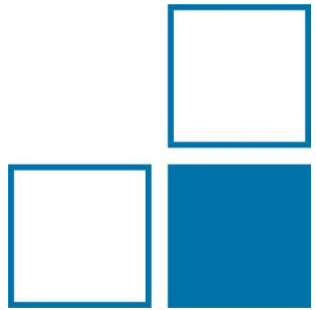
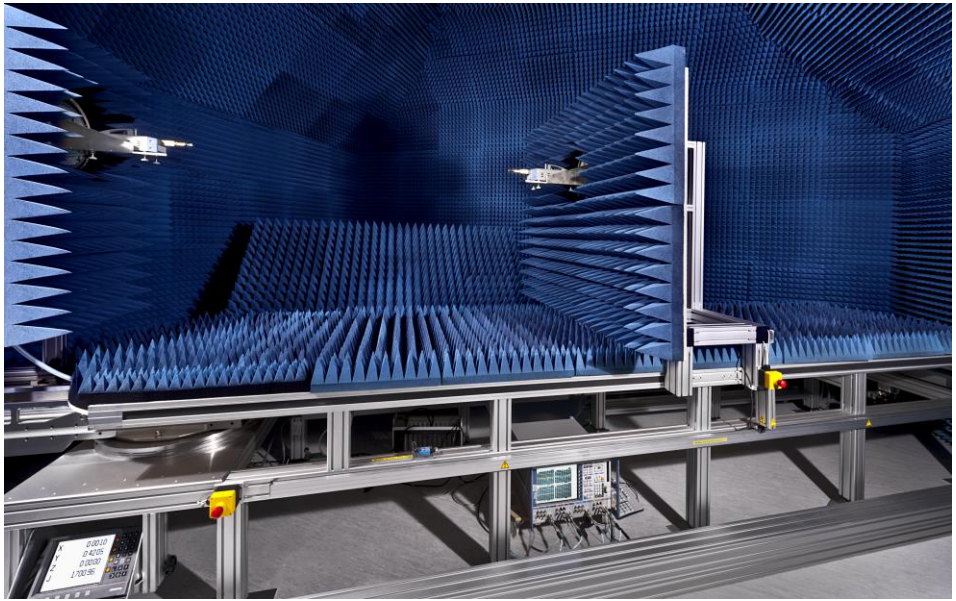


Outline

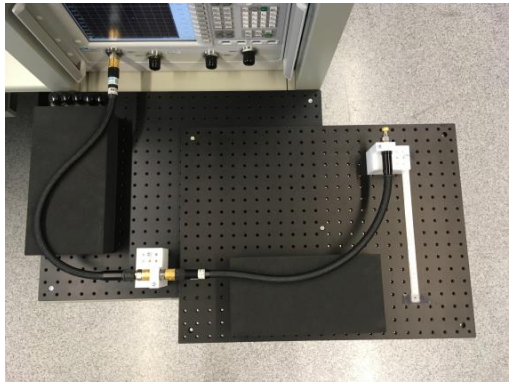
- Problem and Motivation
- Operational Principle
- Measurement Setup
- Results
- Solutions and corrections
- Impact on drift
- Conclusion and outlook

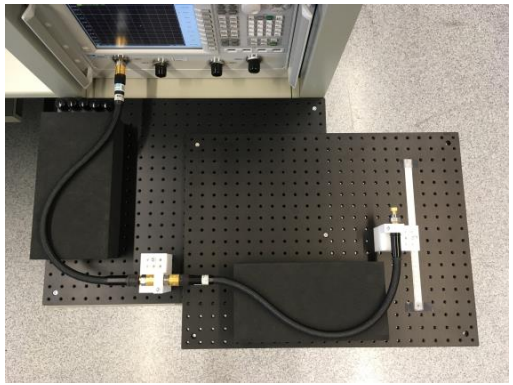
Motivation

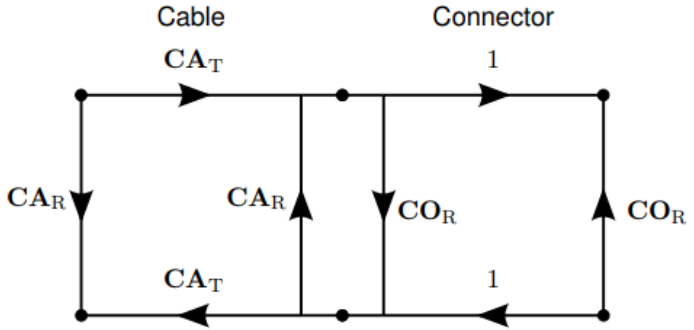
- Measurements at high frequencies
- Often a TRL calibration is performed
- Cable movements are sometimes not avoidable
- Antenna measurements



Cable Movements in VNA Guide





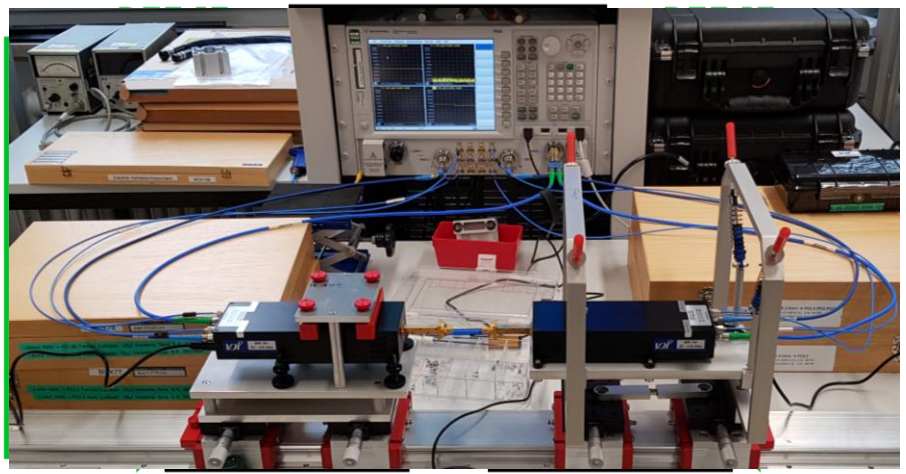


- Cables are reciprocal
- Uncertainties for cable movement
- Short and Load standards are used
- A generous envelope is defined

From: Guidelines on the Evaluation of Vector Network Analysers (VNA), EURAMET Calibration Guide No. 12, Version 3.0 (03/2018)

VNA Extender Measurements

- Block diagram
- Local oscillator often with a splitter
- Cable movement changes LO of one extender
- Effects of cable movements are modelled to be reciprocal



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VNA Extenders

- Data for R900 (WR10) Extenders
- 64.9 GHz to 115 GHz
- Multiplier RF is 3
- Multiplier LO is 6
- RF Power :
  0 dBm ± 3dBm
- LO Power :
  10 dBm ± 3dBm

Image: https://www.vadiodes.com/images/Products/VNA/imgrotate/VNAXpix7Final.png

LO Cable Movement

- LO for only one extender changes
- Minor impact on Reflection measurements
- Introduces non-reciprocity
- Commonly used model for cable movement is reciprocal

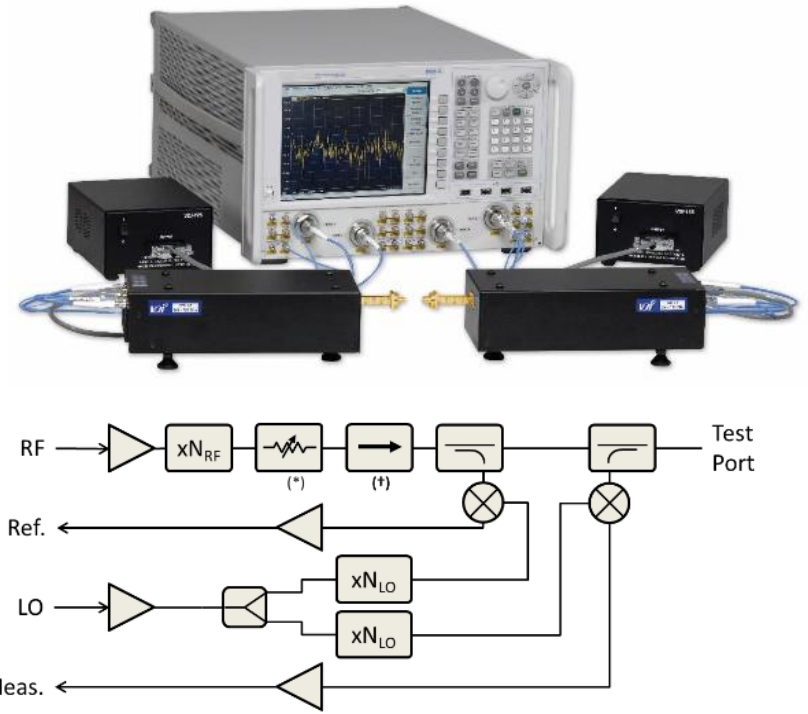
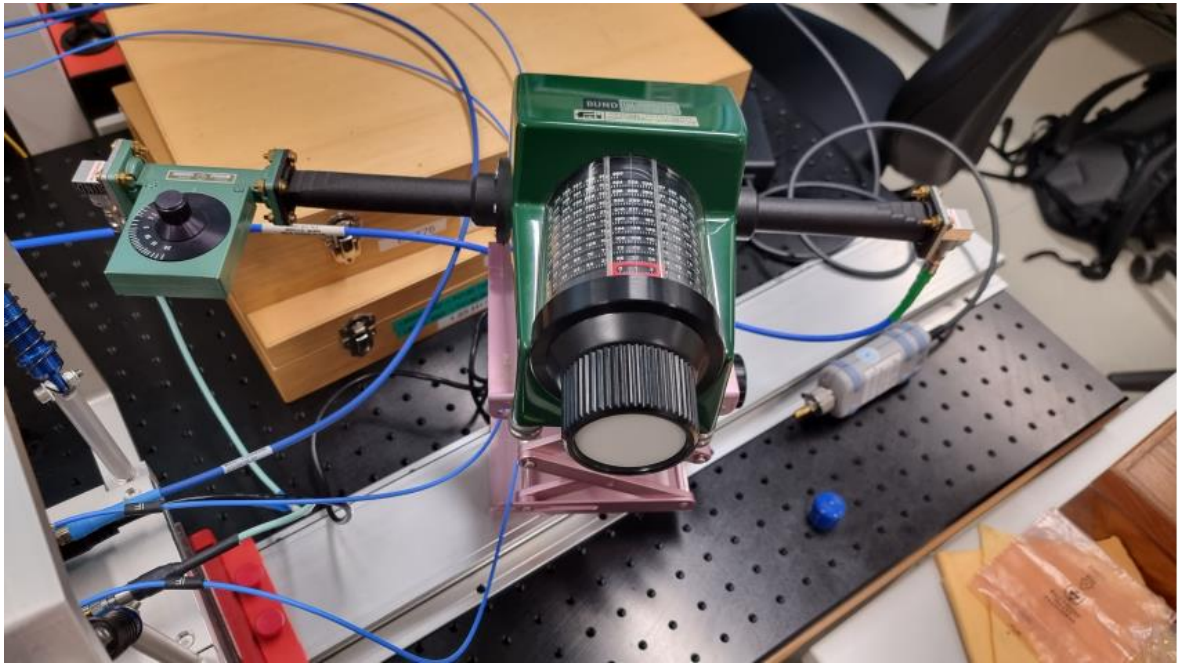
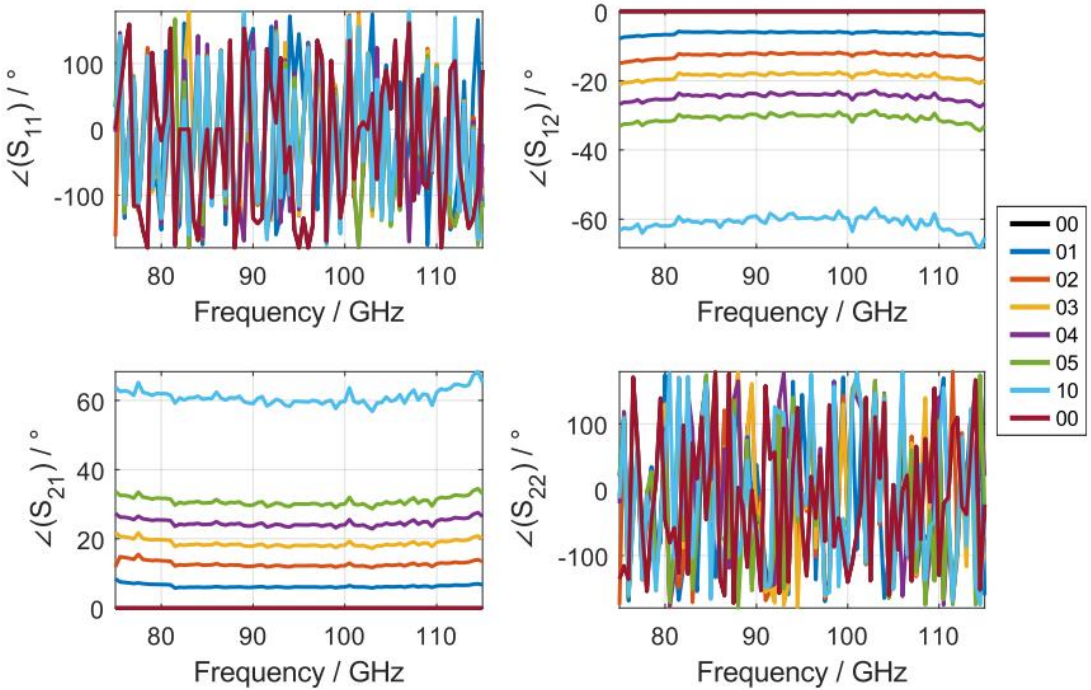


Image: https://www.vadiodes.com/images/Products/VNA/Product_Manual/VDI-707.1-VNAx-Product-Manual.pdf

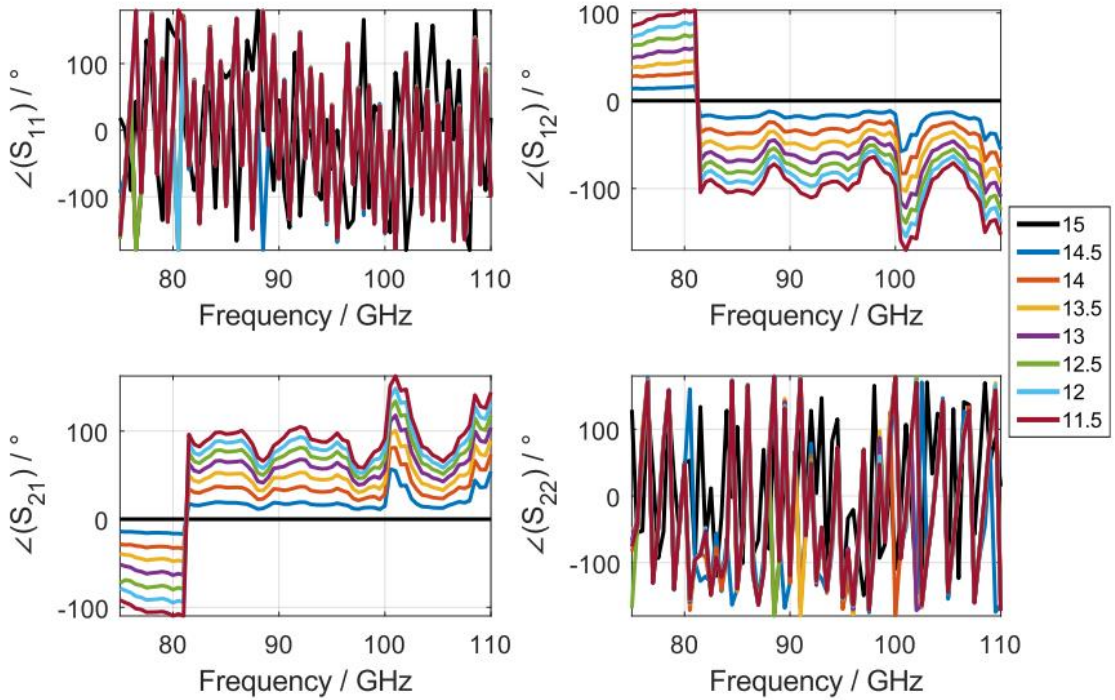
Measurement Setup



Measurement Results Phase Shift



Measurement Results Amplitude



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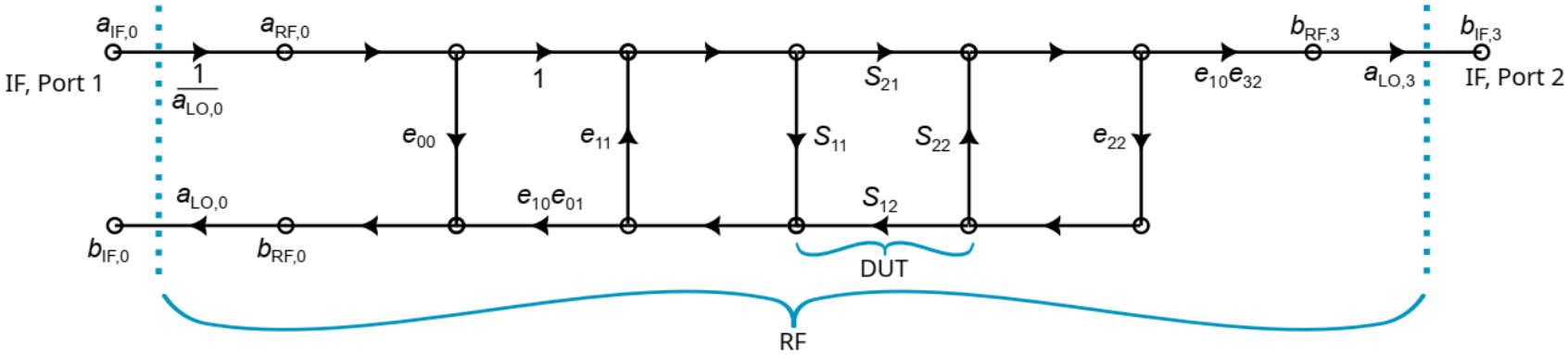
Cable movement effect



$$S_{11}^{M} = \frac{b_{IF,0}}{a_{IF,0}} = \frac{b_{RF,0} \cdot \delta a_{LO,0}}{a_{RF,0} \cdot \delta a_{LO,0}},$$

$$S_{21}^{M} = \frac{b_{IF,3}}{a_{IF,0}} = \frac{b_{RF,3} \cdot \delta a_{LO,3}}{a_{RF,0} \cdot \delta a_{LO,0}} = \frac{b_{RF,3}}{a_{RF,0}} \cdot \delta \quad \text{and} \quad S_{12}^{M} = \frac{b_{IF,0}}{a_{IF,3}} = \frac{b_{RF,0} \cdot \delta a_{LO,0}}{a_{RF,3} \cdot \delta a_{LO,3}} = \frac{b_{RF,0}}{a_{RF,3}} \cdot \frac{1}{\delta}.$$

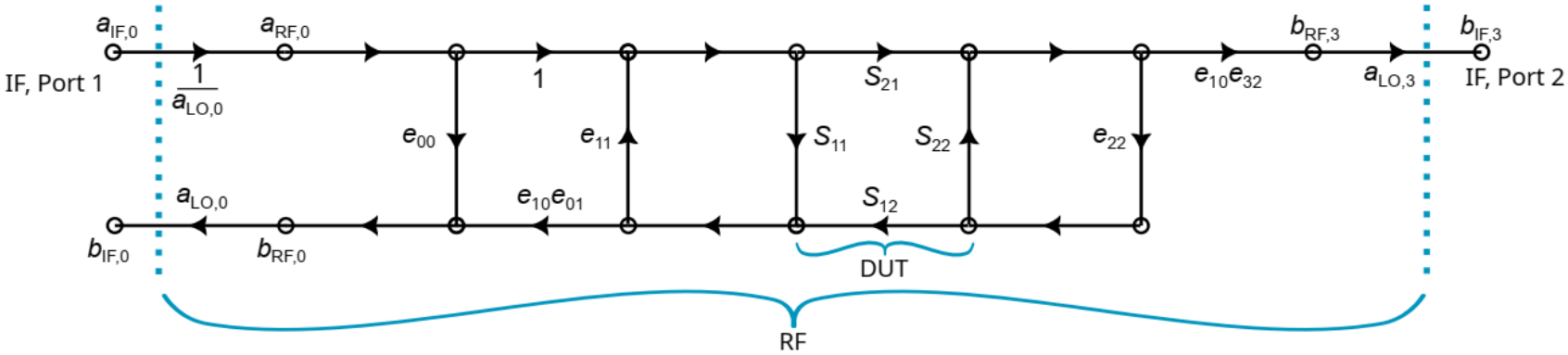
Correction of calibrated VNA data

- LO cable change after calibration
- Make calibrated result reciprocal for reciprocal DUTs

$$\delta S_{12} = \frac{1}{\delta} S_{21} \quad \Leftrightarrow \quad \delta = \pm\sqrt{\frac{S_{21}}{S_{12}}} = \begin{cases} +\sqrt{\frac{S_{21}}{S_{12}}} \\ -\sqrt{\frac{S_{21}}{S_{12}}} = \mathrm{e}^{j\pi} \cdot \sqrt{\frac{S_{21}}{S_{12}}}. \end{cases}$$

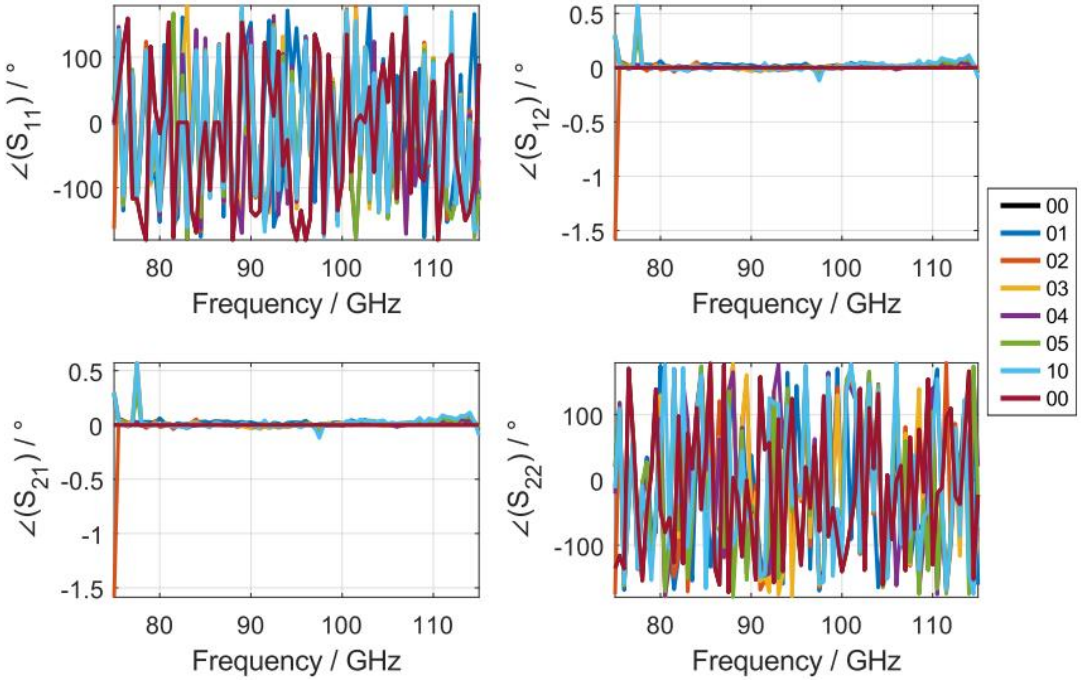
- Measure reciprocal DUT
- Apply correction for non-reciprocal DUTs

Correction in raw VNA data



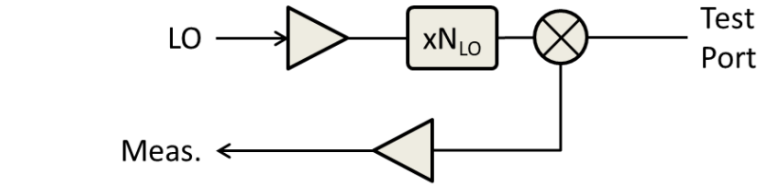
- Consider system error correction
- Influence on corrected data the same as raw data, if leakage is negligible
- Measure a reciprocal DUT after each cable movement

Same Measurements with Correction



RxTx-Extenders for this correction

- There are “mini modules”
- Rx or Tx extenders only
- S_{12} and S_{21} are both needed for this correction



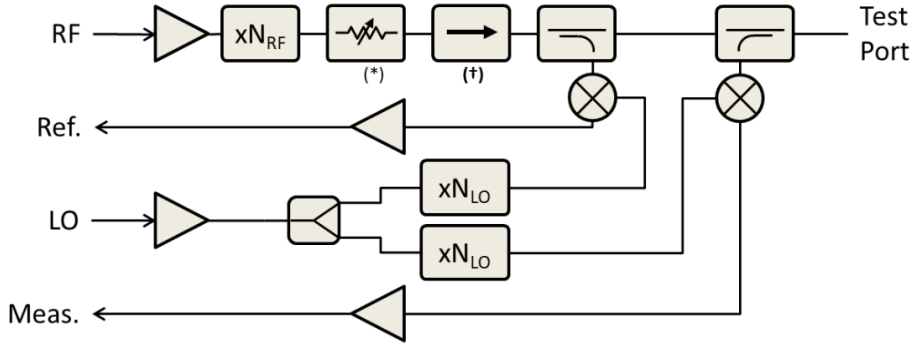


Image: https://www.vadiodes.com/images/Products/VNA/Product_Manual/VDI-707.1-VNAx-Product-Manual.pdf

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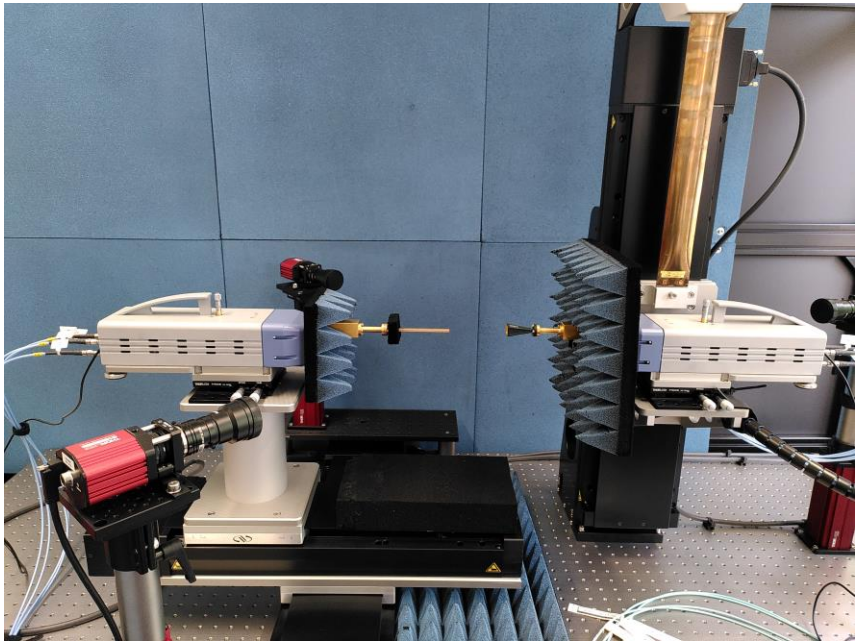
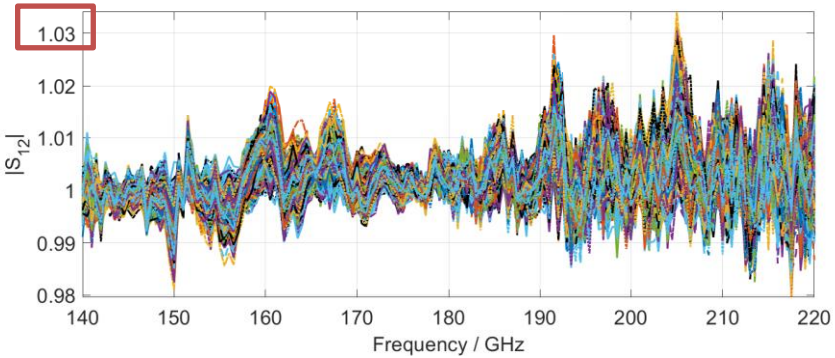
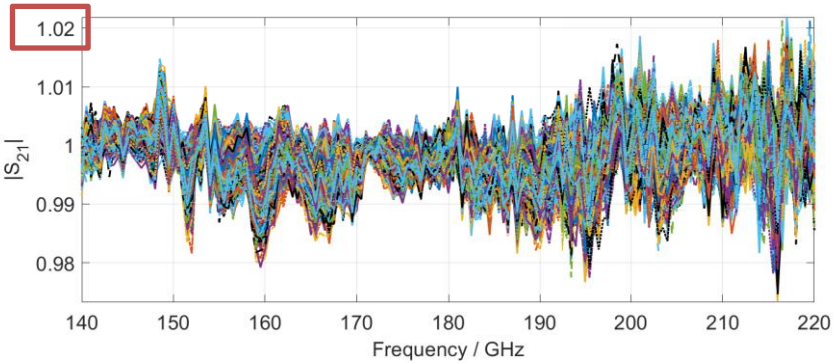
Impact on Drift

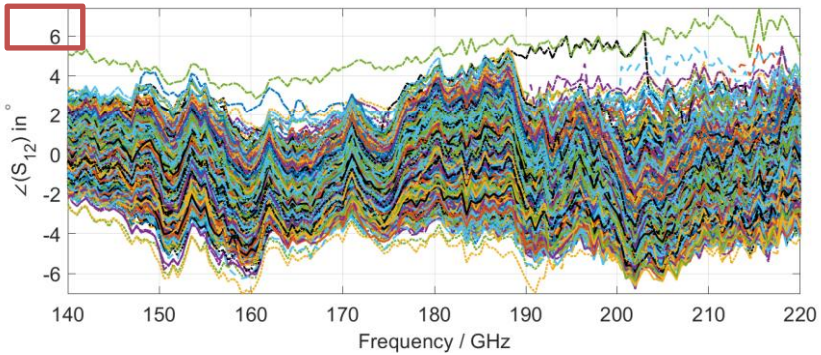
- Drift also influences the LO signal
- Will this reciprocity correction affect drift?
- Direct Thru setup
- Measure transmission over 24 hours every minute
- Do not touch the setup

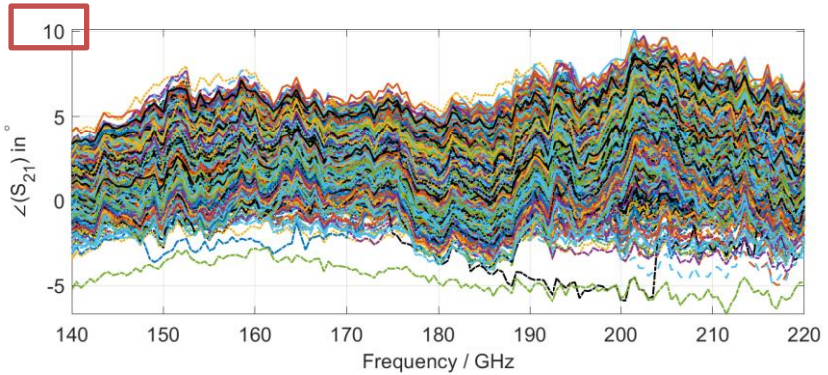


Drift Measurement Result

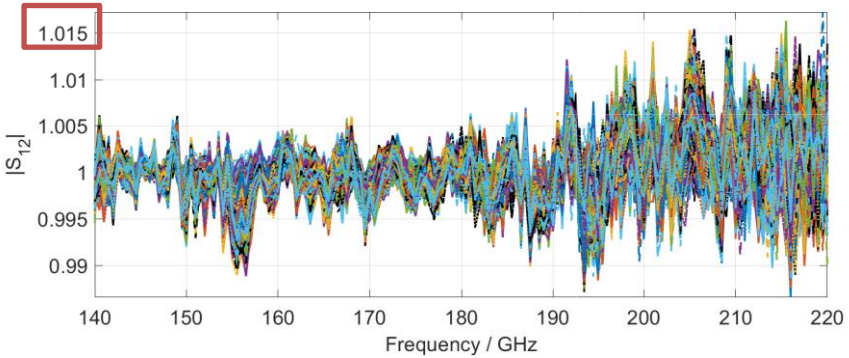


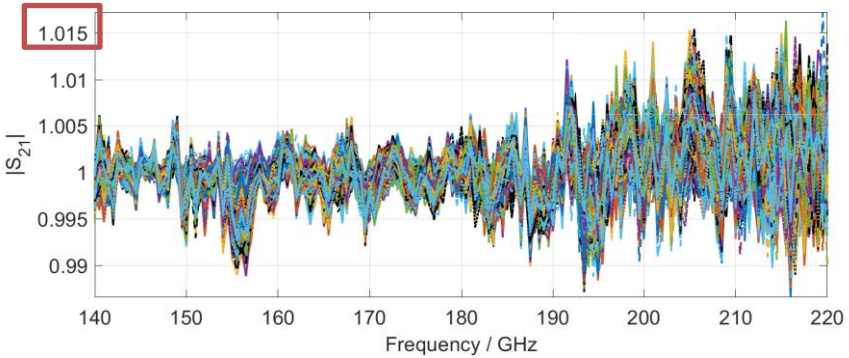


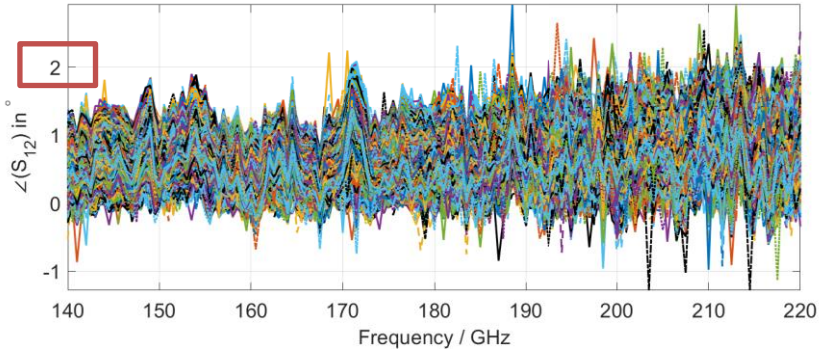


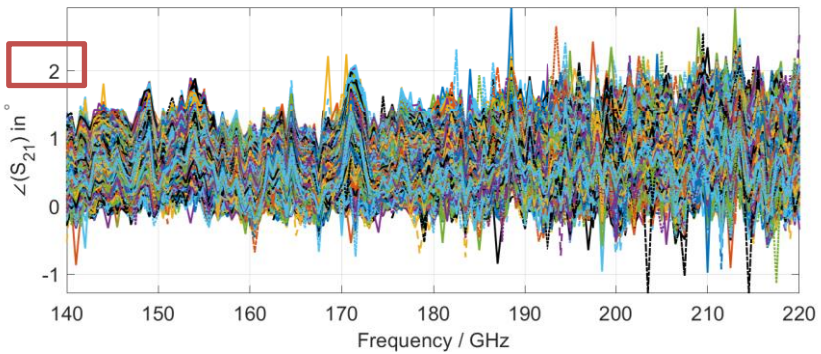


Drift Measurement Result Corrected









Conclusion

- Local oscillator cable movements can have a significant influence
- It affects transmission measurements
- The effect can (and should⁉) be considered and corrected
- Often reflection measurements are used to test the impact of cable movements
- For antenna characterization with NFFF- transformation RxTx-extenders are needed
- Include LO cable movements in the EURAMET calibration guide
- Asymmetry term in cable model needed
- Correction can also significantly reduce drift

Literature

- EURAMET Calibration Guide No. 12, version 3.0, 2018
- Doug Rytting, Network Analyzer Error Models and Calibration Methods, Agilent Technologies, 2004
- Koul, S.K., Kaurav, P. (2022). Electronic Sub-Terahertz VNA Measurement Techniques. In: Sub-Terahertz Sensing Technology for Biomedical Applications. Biological and Medical Physics, Biomedical Engineering. Springer, Singapore.
- VDI product manual: https://www.vadiodes.com/images/Products/VNA/Product_Manual/VDI-707.1-VNAx-Product-Manual.pdf
- Gellersen, Ulm, Rausche, Schramm, Kuhlmann, Influence of LO cable movements on VNA measurements using Frequency Extensions, 2024, *Advances in Radio Science* , Vol. 22, p. 47-52

Questions

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