

# Two Port Calibration Insensitive to Flange Misalignment

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Alexander Arsenovic<sub>\*</sub>, Robert M. Weikle II<sub>†</sub>, Jeffrey Hesler<sub>\*</sub>



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# Outline



Introduction

Numerical Simulation

Measurement Results

Conclusion

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## Context



- ▶ As waveguide measurements continue to push upwards in frequency, waveguide misalignment caused by mechanical tolerances becomes a severe problem[1].
- ▶ This creates measurement inaccuracies due to calibration error[2, 3].
- ▶ Two Solutions
  1. Improve flange → reduce misalignment
  2. Use a calibration routine tolerant of misalignment



# Why do this?



## Cons:

- ▶ A calibration insensitive to flange misalignment **will not** correct for the misalignment present in subsequent measurements.

## Pros:

- ▶ Eliminate flange misalignment as source of calibration error.
- ▶ Yield a direct measurement of the flange alignment.

## Theory (not much to it)



- ▶ **SDDRo**[4]<sup>1</sup> can tolerate misalignment on reflect standards
- ▶ **Unknown Thru**[5] can tolerate misalignment on the thru standard.

**SDDRo + UnknownThru = Misalignment Resistant Calibration (MRC)**

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<sup>1</sup>equation (17) has incorrect sign in the argument

# Requirments



To yield promised accuracy, **MRC** requires:

1. Misalignment is the only error mechanism
2. Two accurately known reflect standards
  - ▶ Flush Short (easy)
  - ▶ Radiating open (hard)

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# Numerical Simulation



Simulation of the calibration processing chain has been used for:

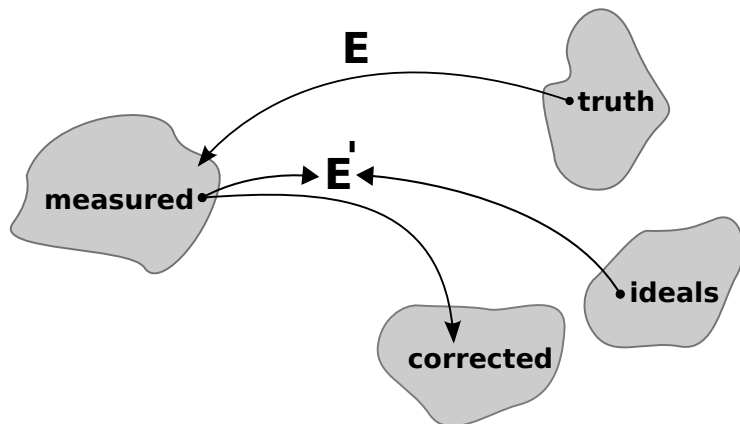
## 1. **Verification**

- ▶ Ensure the algorithm can accurately correct measurements given specified unknowns in the ideals.

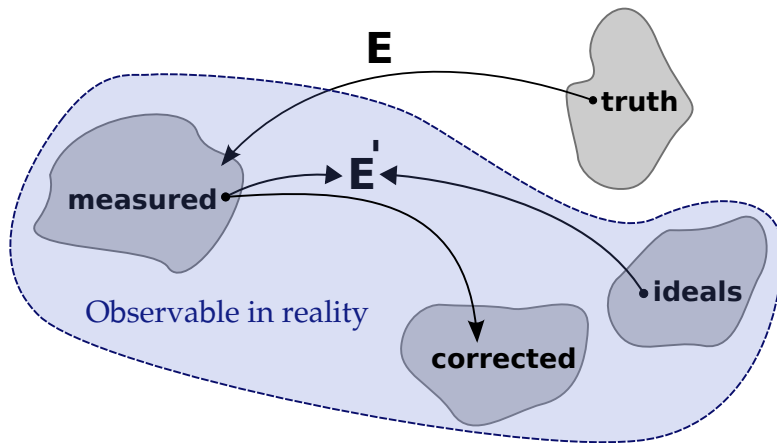
## 2. **Modeling**

- ▶ Heuristically determine causes of measurement artifacts

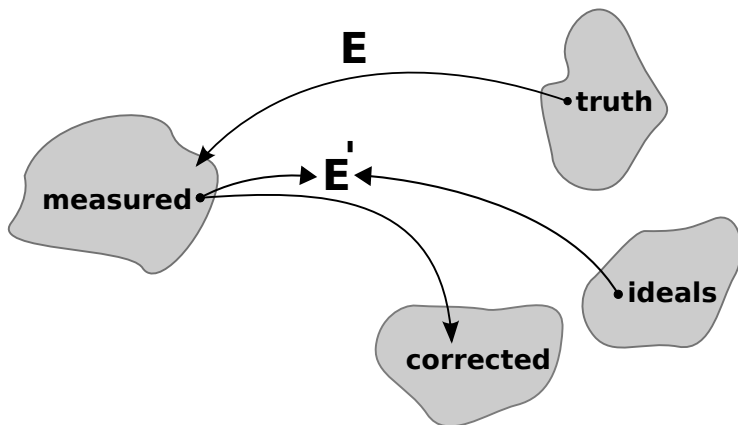
# Calibration Processing Chain



# Calibration Processing Chain

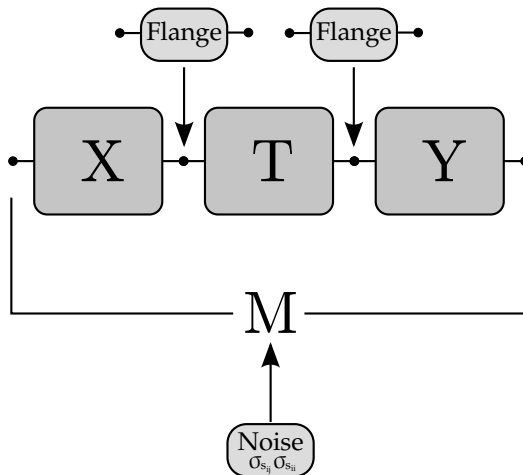


# Calibration Processing Chain



In simulation everything is observable  $\rightarrow$  verification is possible.  
Details of verification can be found in the test-suite of scikit-rf[6].

# Generating Measurements

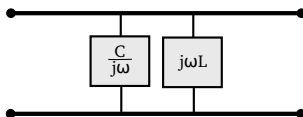


►  $\sigma_{\angle S_{ij}} = .8^\circ$  ,       $\sigma_{\angle S_{ji}} = .2^\circ$

# Flange Model



Circuit model used to approximate a misaligned flange



►  $C = 2\text{fF}, \quad L = 4\text{nH}$

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# Experimental Setup



Flange pins removed.

Alignment holes reamed out to  $.0066'' (= .2a)$

Center dowels used in Thru



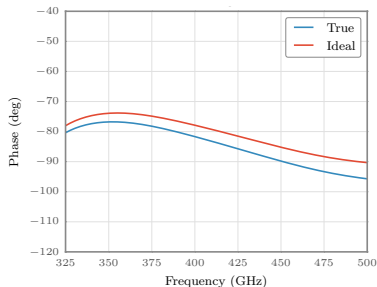
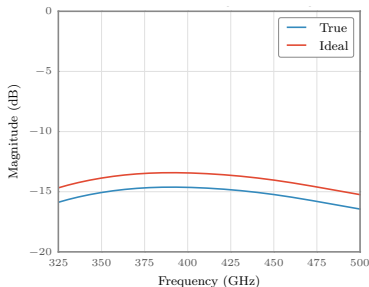


# Results

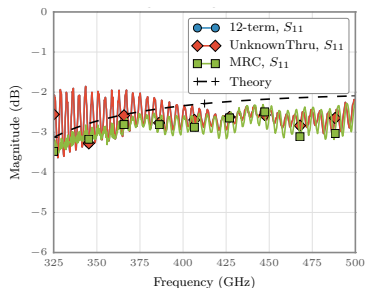


The following simulation results differ from paper.

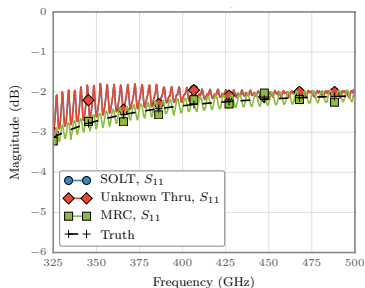
These results include error in ideal definition for the radiating open model.



# 1" Straight Waveguide + Flush Short

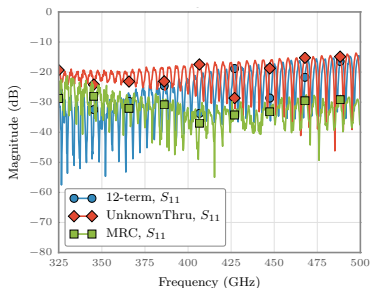


(a) Measurement

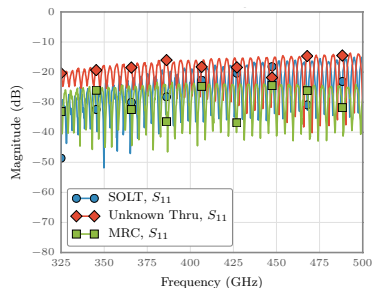


(b) Simulation

# 1" Straight Waveguide

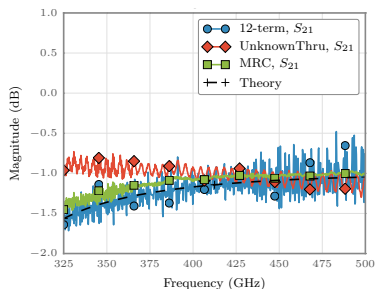


(c) Measurement

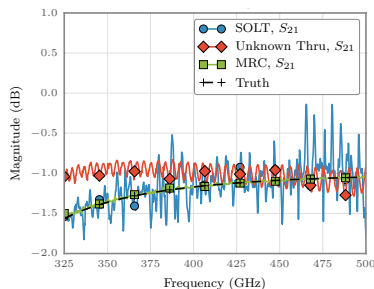


(d) Simulation

# 1" Straight Waveguide

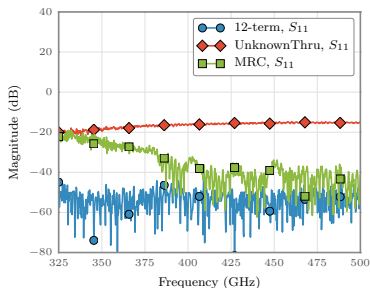


(e) Measurement

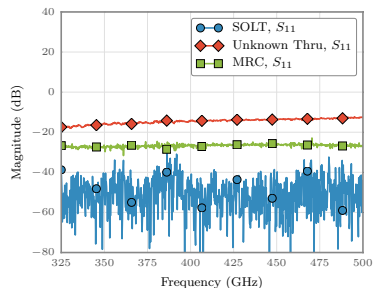


(f) Simulation

# Flush Thru

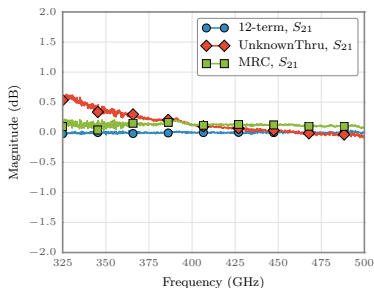


(g) Measurement

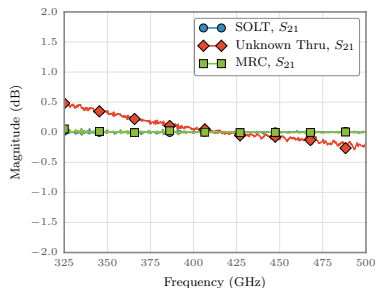


(h) Simulation

# Flush Thru



(i) Measurement



(j) Simulation

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# Conclusion



- ▶ A two-port calibration resistant to flange misalignment has been constructed → **MRC**
- ▶ Numerical simulations have been used to
  - ▶ verify algorithms works
  - ▶ model measured results
- ▶ The simulated and measured performance indicate accuracy of radiating open model is likely a limitation.

This last point is missing from paper.



## Availability



# scikit-rf

Open Source RF Engineering

**SDDL** and **MRC** Algorithms have been implemented in the open source python module scikit-rf ([www.scikit-rf.org](http://www.scikit-rf.org))

# The End



## End Of Line

# Bibliography



- [1] E. W. A. R. Kerr and N. Horner, "Waveguide flanges for alma instrumentation," Nov 1999.
- [2] A. Arsenovic and R. Weikle, "Comparison of competing designs for delay-short calibration standards at wr-1.5," *International Conference on Infrared, Millimeter, and Terahertz Waves*, September 2012.
- [3] D. F. Williams, "500 GHz - 750 GHz rectangular-waveguide vector-network-analyzer calibrations," *Terahertz Science and Technology, IEEE Transactions on*, vol. 1, pp. 364 –377, Nov. 2011.
- [4] Z. Liu and R. Weikle, "A reflectometer calibration method resistant to waveguide flange misalignment," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 54, pp. 2447 –2452, June 2006.
- [5] A. Ferrero and U. Pisani, "Two-port network analyzer calibration using an unknown 'thru'," *IEEE Microwave and Guided Wave Letters*, vol. 2, no. 12, pp. 505–507, 1992.
- [6] scikit-rf Development Team, "scikit-rf: Open source rf engineering," 2009-present.  
<http://www.scikit-rf.org>.

# SDDL by cross ratio



$$z = \frac{(a-b)(c-d)}{(a-d)(c-b)}$$

$$z = \frac{(a-b)c}{a(c-b)}$$

$$z - zbc^{-1} = \frac{a-b}{a}$$

$$\Im(z - zbc^{-1}) = 0$$

$$\Im(z) = \Im(zbc^{-1})$$

$$\Im(z) = \frac{1}{2j} (bzc^{-1} - \bar{b}\bar{z}\bar{c}^{-1})$$

$$b = j \frac{\Im(z)}{\Re(zc^{-1})}$$