We3A-5

Impedance Standard Substrate Characterization and EM Model Definition for Cryogenic and Quantum-Computing Applications

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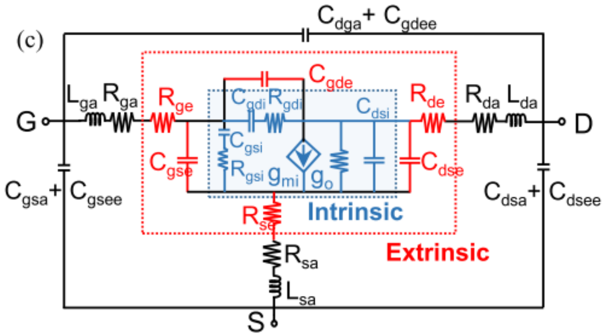
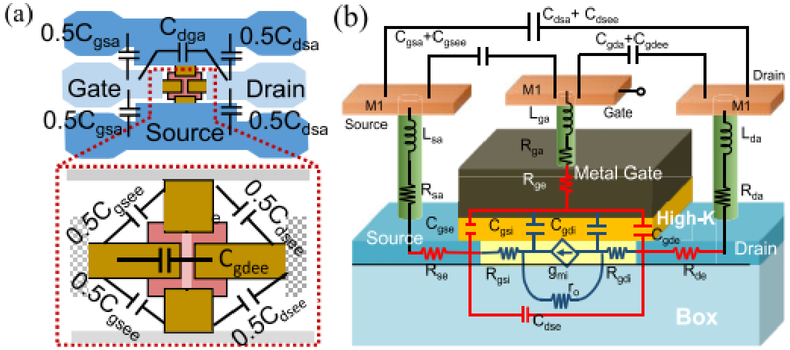
Outline

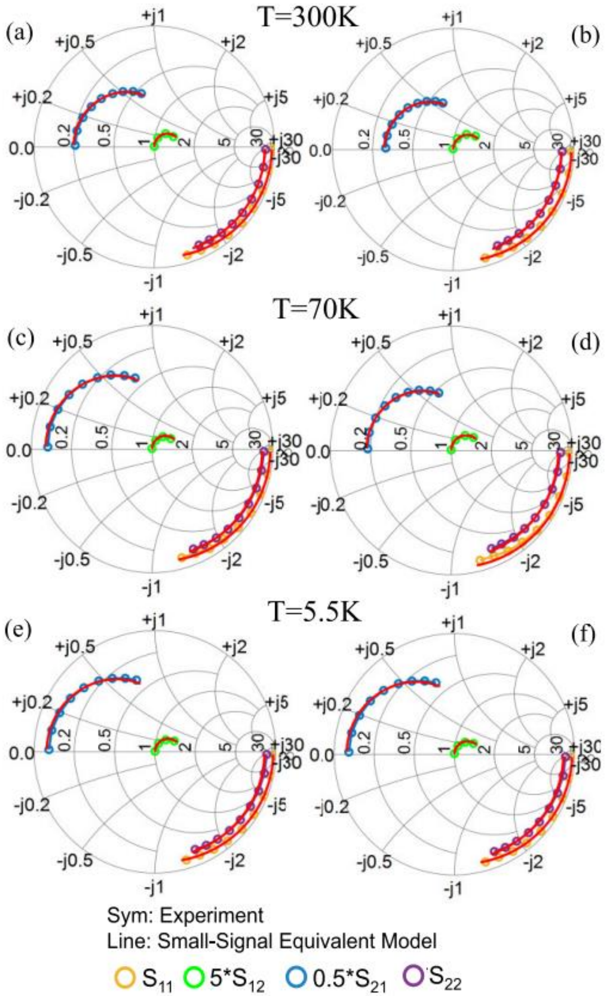
- Introduction and motivation
- Modelling of on-wafer calibration structures
  - Dimensions measurements
  - Cryo EM and mechanical characteristics of ISS
  - Load compensation method
- Measurement results
- Validation
- Conclusion

Introduction and motivation

Cryogenic applications, such as quantum computing, is gathering more commercial interest, and cryogenic device modeling is an essential part of research progress which requires Wide-band measurements.





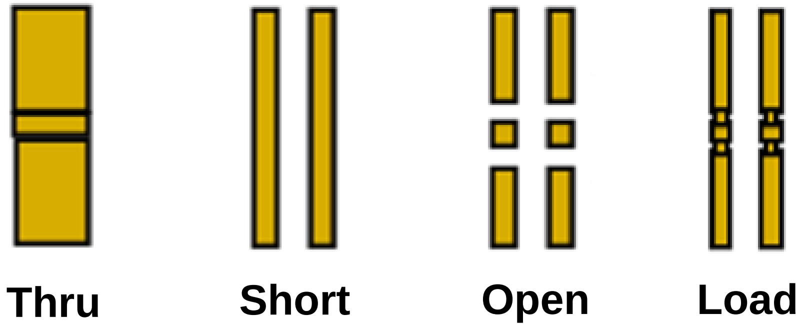


[1]

[1] Chakraborty, Wriddhi, et al. "Characterization and Modeling of 22 nm FDSOI Cryogenic RF CMOS." IEEE Journal on Exploratory Solid-State Computational Devices and Circuits 7.2 (2021): 184-192.

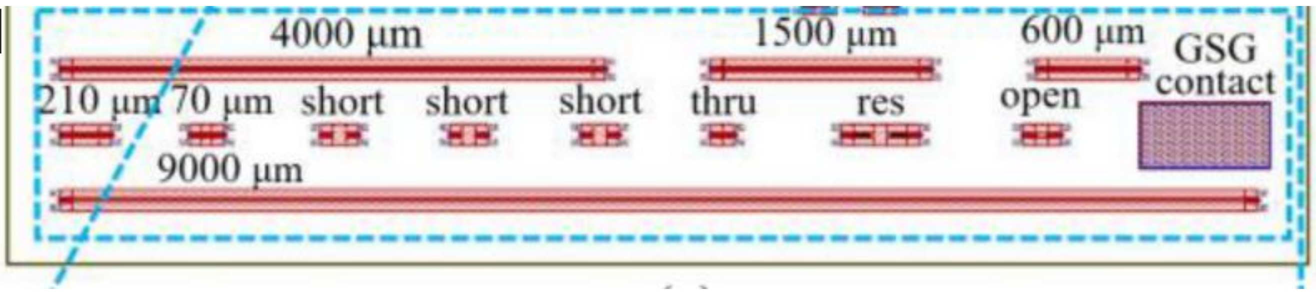
Introduction and motivation

Wide-band calibration algorithms (e.g., SOLR) require knowledge of standards.

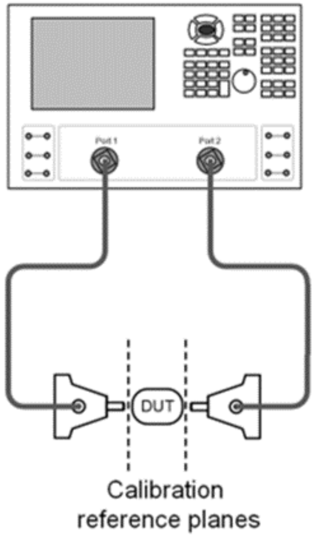


Requires knowledge of standard

[1]



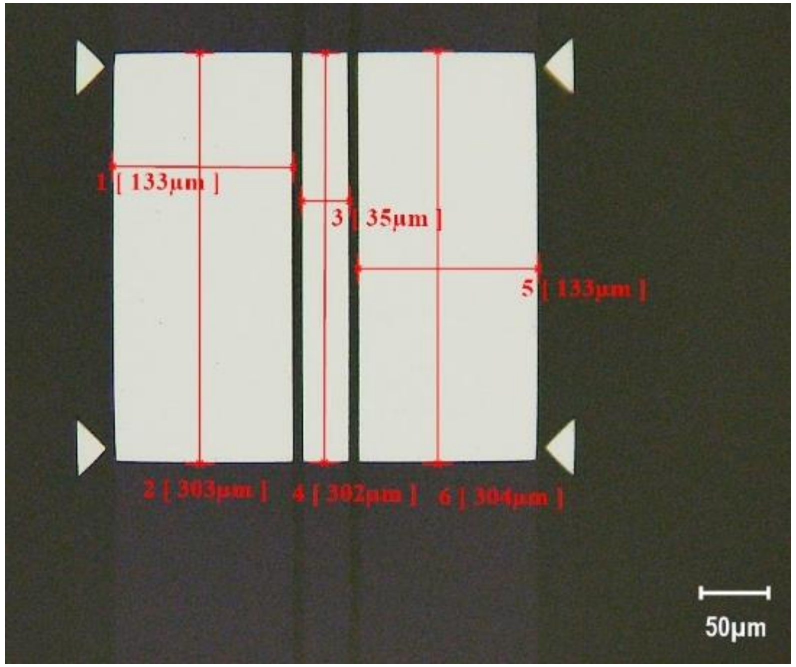
Requires Z_0 of the line



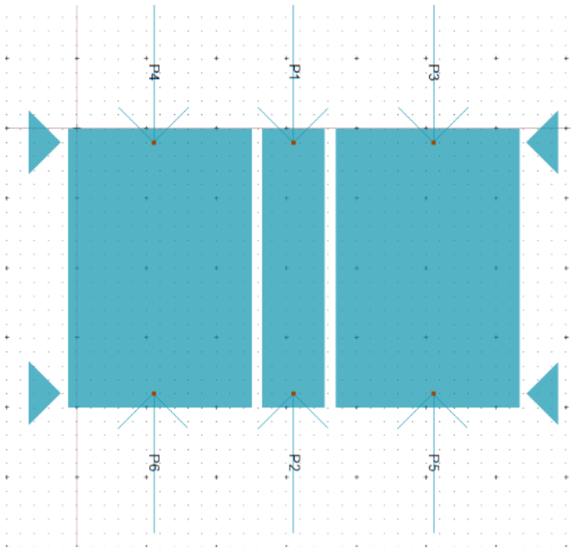
[1] Williams, Dylan F., et al. "Calibrations for millimeter-wave silicon transistor characterization." IEEE transactions on Microwave Theory and Techniques 62.3 (2014): 658-668.

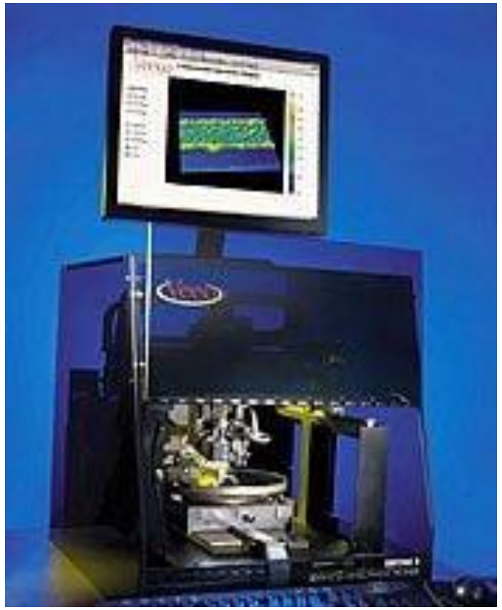
Calibration structure modeling

Accurate models of calibration structures are made in ADS based on dimension measurements.



lateral dimensions using a microscope



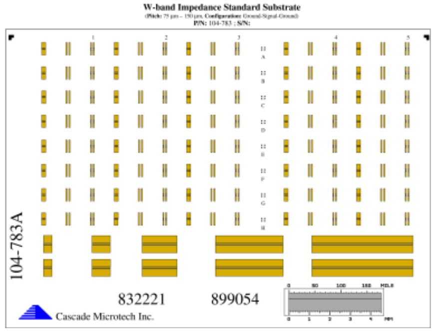


Veeco Stylus profiler dektak 8 for layer height measurements

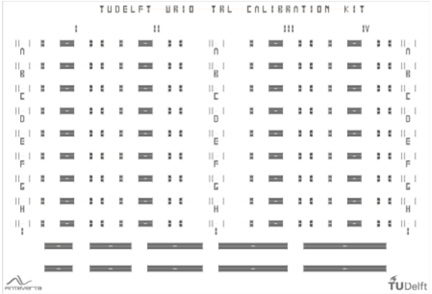
ISS characteristics

Two different ISS (Impedance Standard Substrate) are modelled in room temperature and 4K,Fused Quartz from IMS® and Alumina from FormFactor®

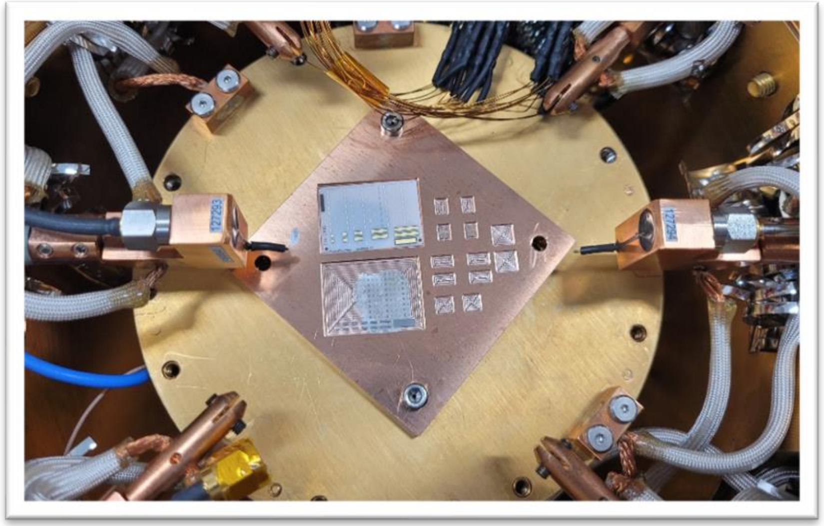
Substrate Material	Thermal contraction (ΔL/L0) (293K to 4K)	Relative electrical permittivity	Loss tangent(tan δ)	Top Metal
Alumina	0.063%	9.9	1e-4	GOLD(Au)
Fused Quartz	0.015%	3.81	4e-4	Aluminium(Al)



Alumina

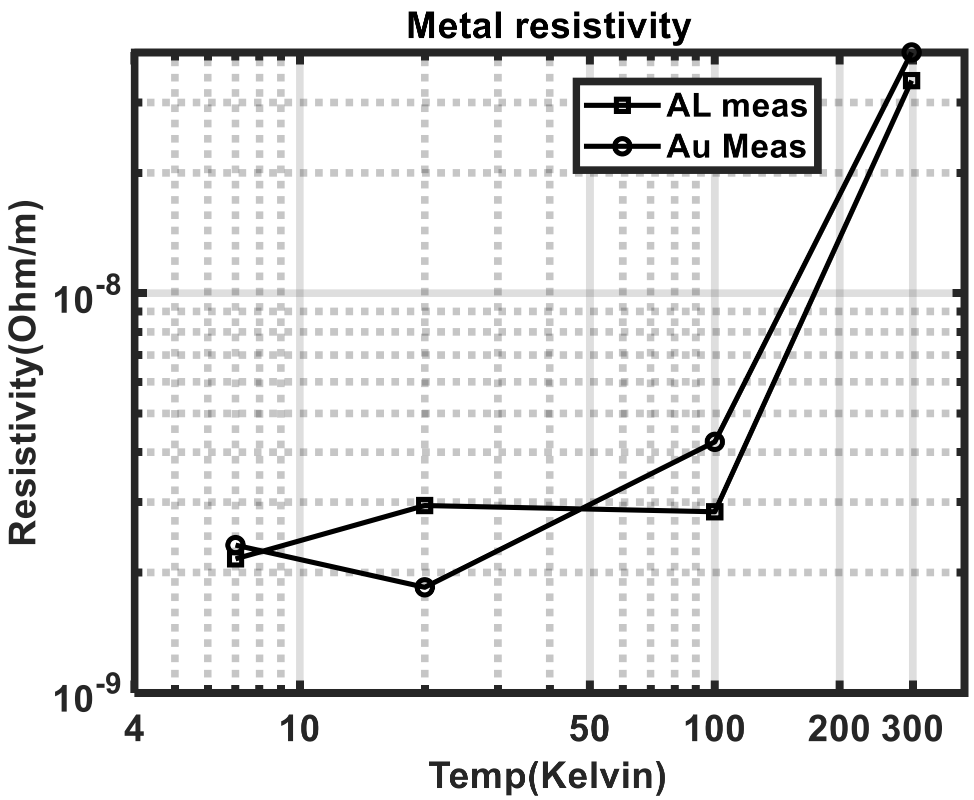


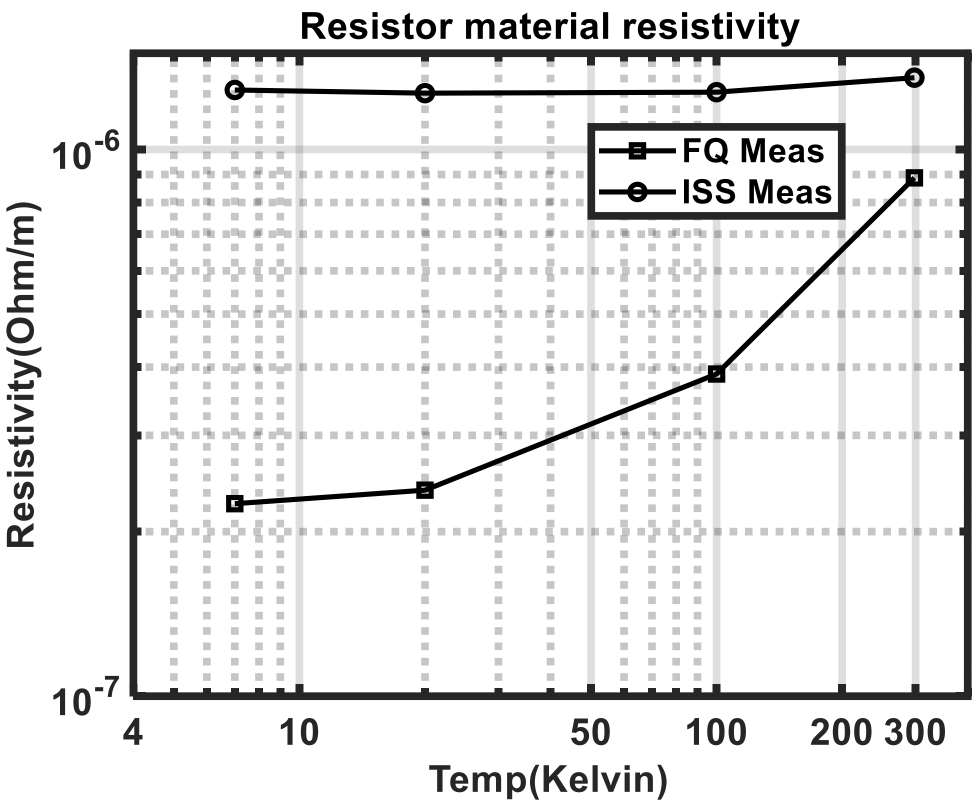
Fused Quartz



Materials characterization

In order to have accurate STD definitions, all the models are updated via new calculated dimensions and measured resistivity of conductive layers.

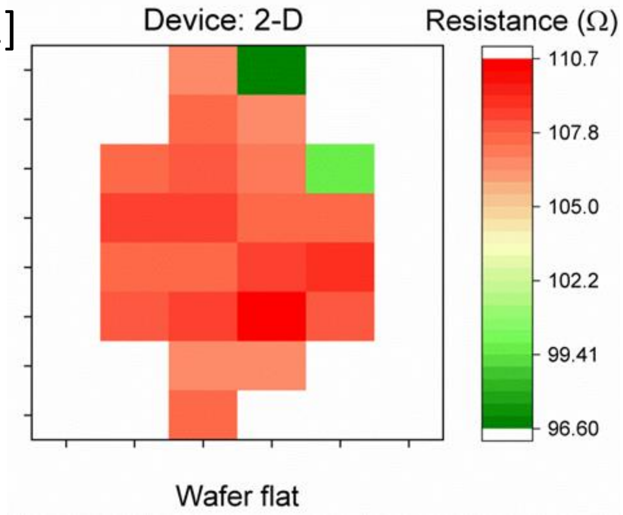


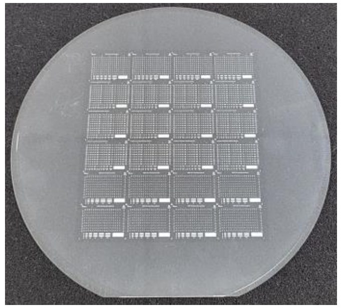


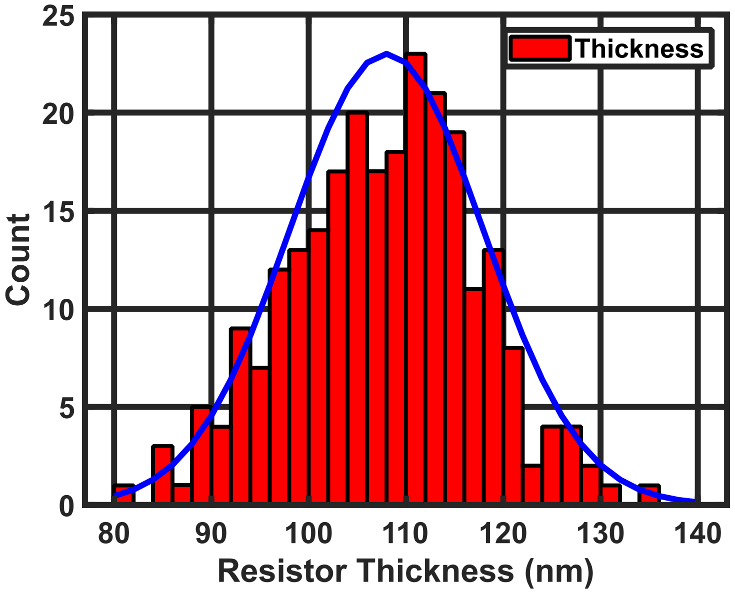
Process variation impact on load

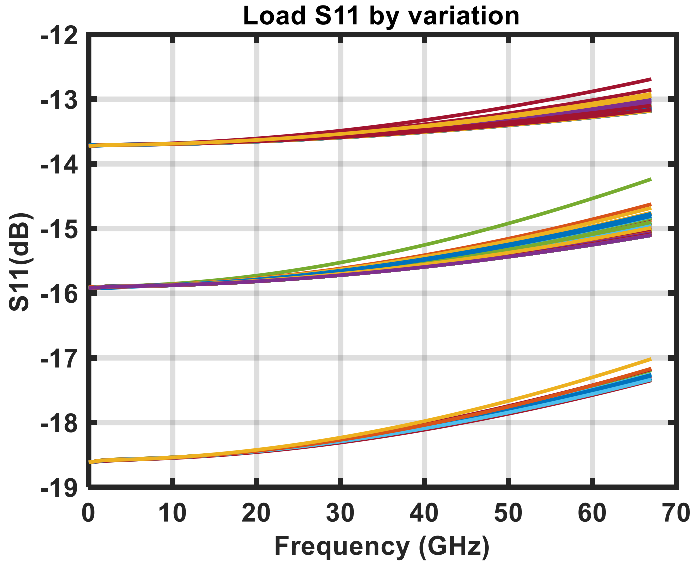
The impact of process variation is strongly noticeably on the load standard.

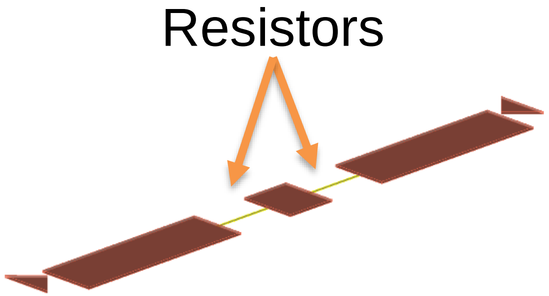
[1]











[1] L. Galatro et al., "Towards Commercially Available Quartz Calibration Substrates," 2020 95th ARFTG Microwave Measurement Conference (ARFTG), 2020, pp. 1-5.

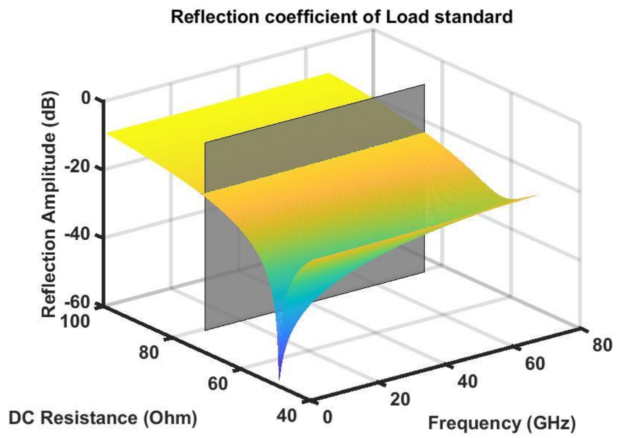
Load Compensation Algorithm

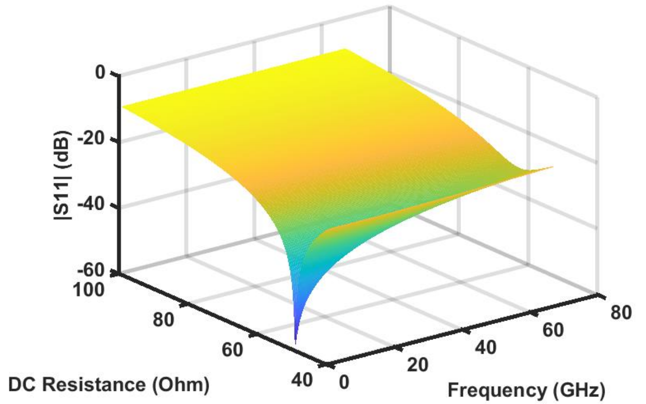
Extract DC resistance of Load structure

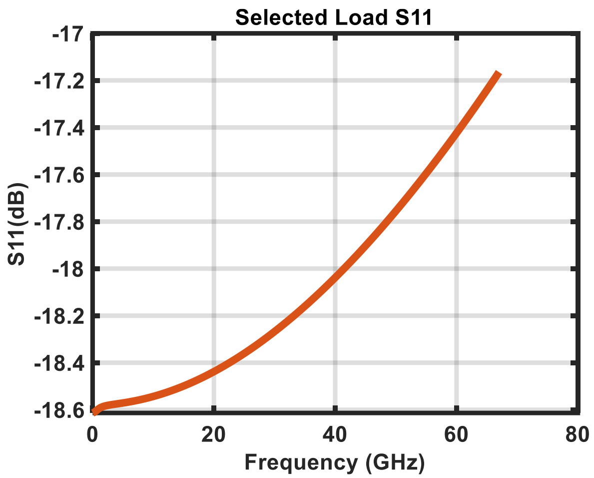
Extract DC resistance of Short structure

Calculate resistor value from difference

Select the corresponding response from EM simulation dataset







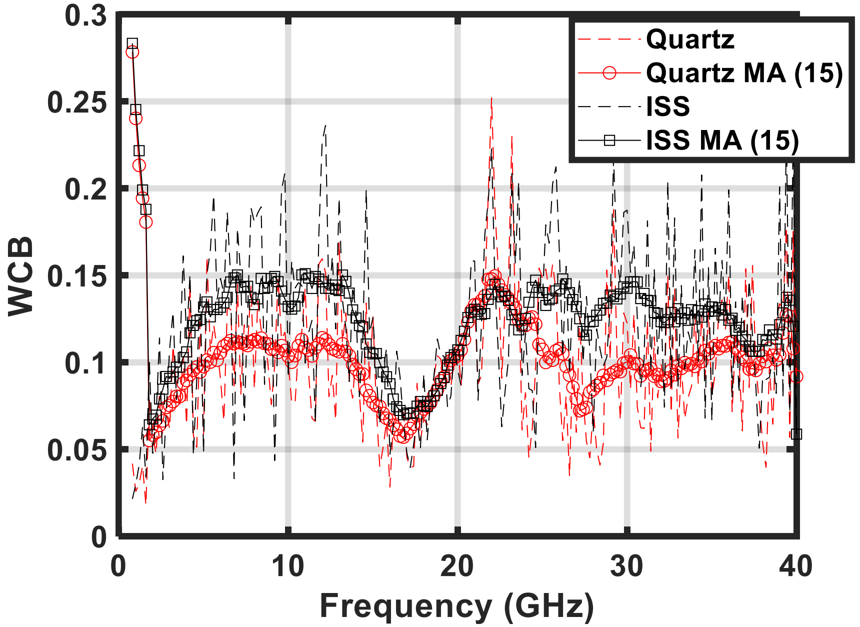
Use the response as calibration standard

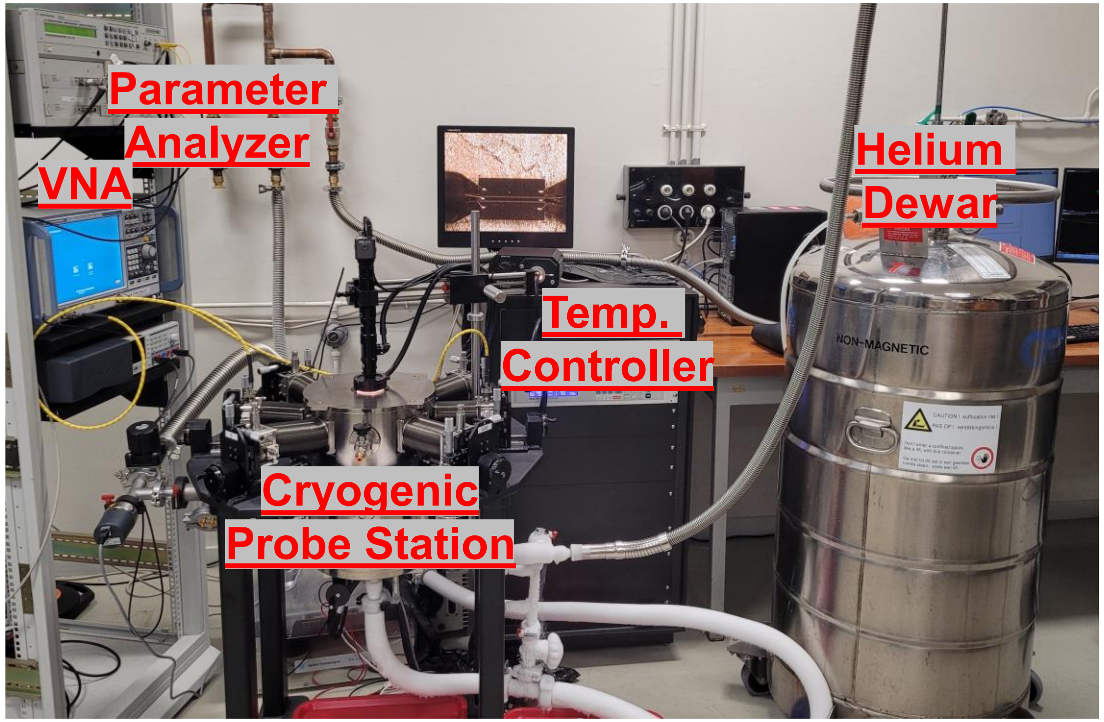
Calculate Error-terms

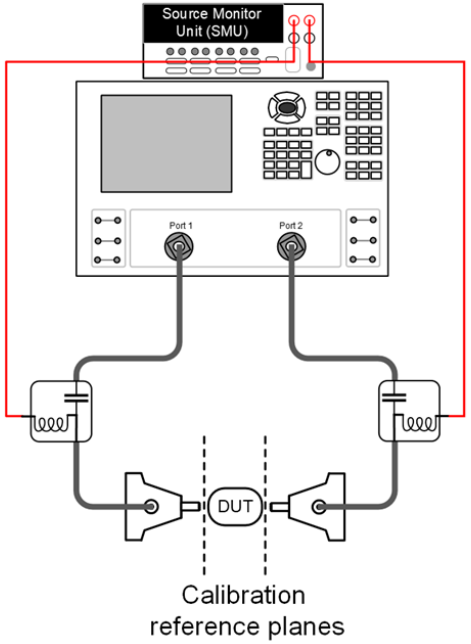
Room temp. Calibration quality

The room temperature behavior of the test-bench is acquired and used as a reference for the cryogenic measurements.

$$WCB(f) = max\left|S'_{ij}(f) - S_{ij}(f)\right|$$

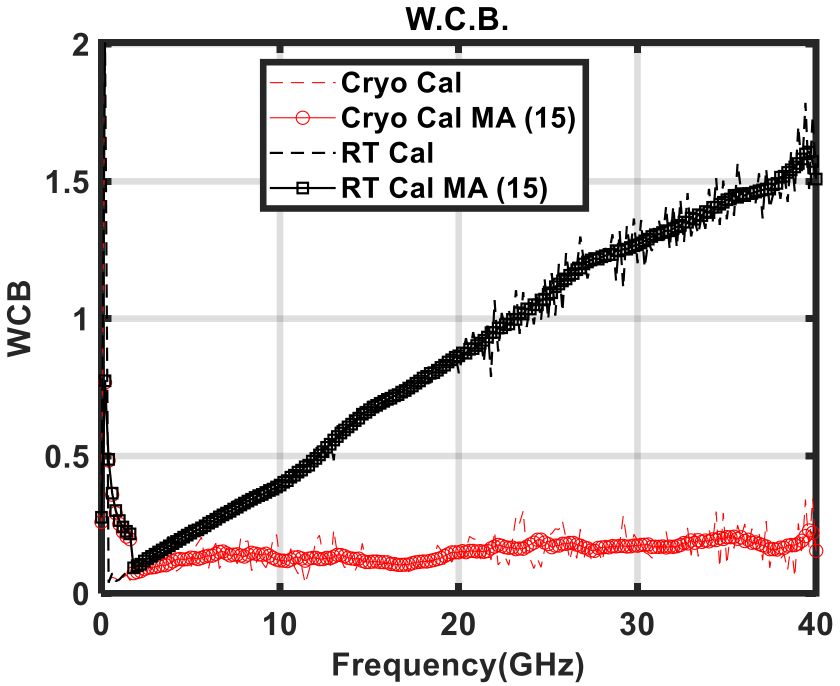


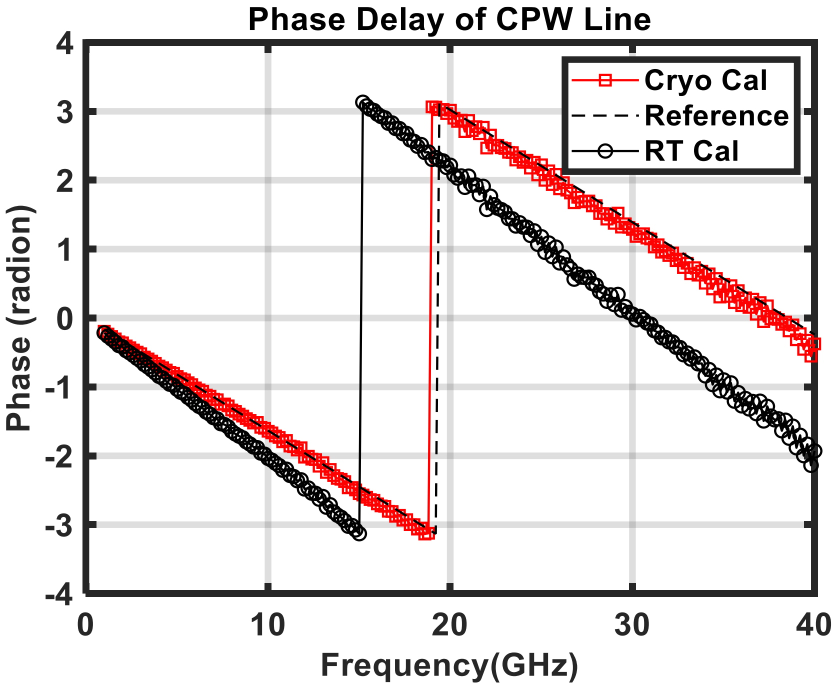




Cryo measurement
RT models vs Cryo models

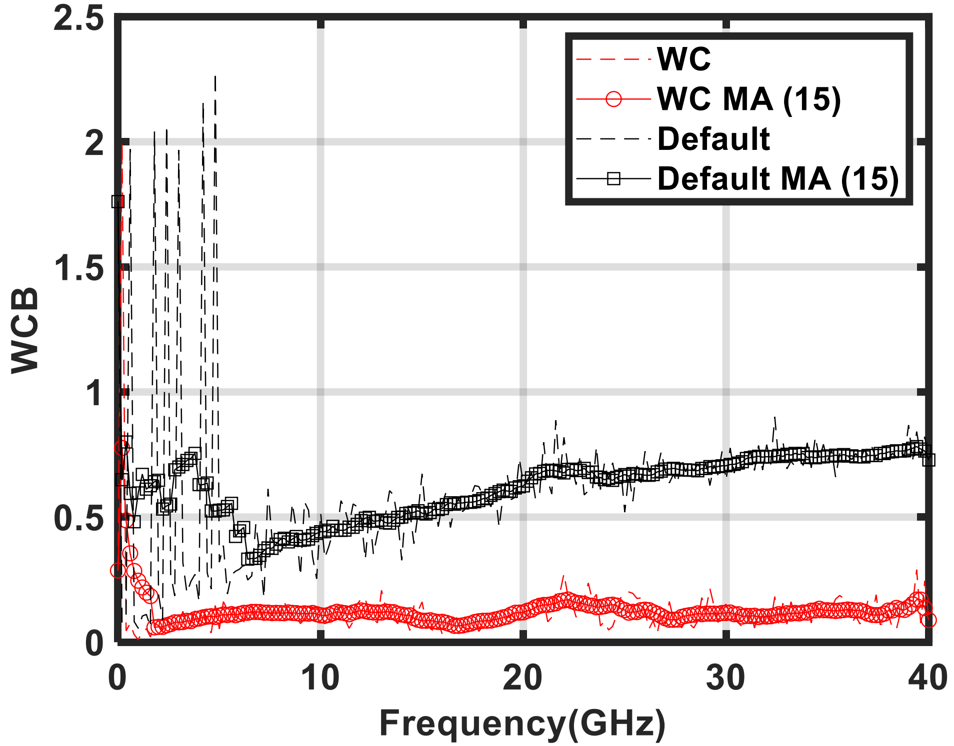
WCB of CPW line on an **Alumina substrate** measured at 7K using calibration definition for the standards derived from RT response (RT – black line) and from cryogenic temperature responses (Cryo Cal – red line).





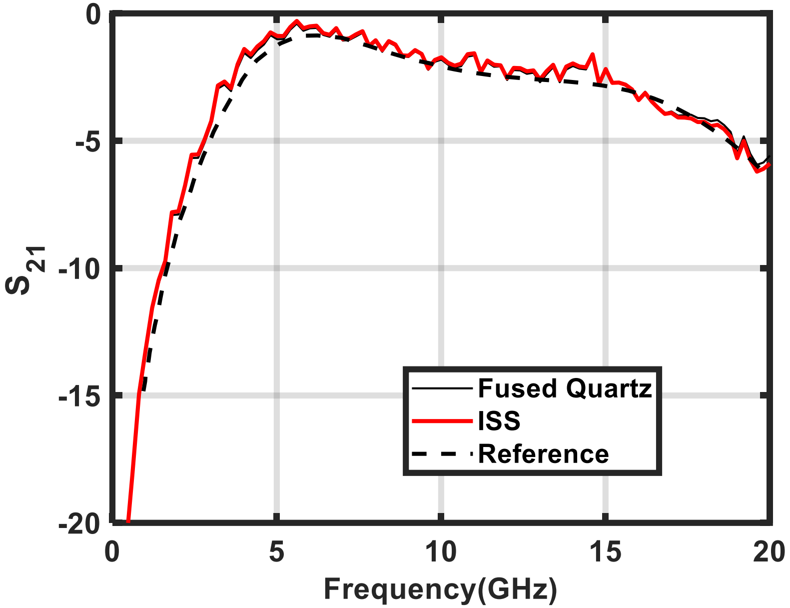
Load compensated (Cryo) standards vs default (Cryo) standards

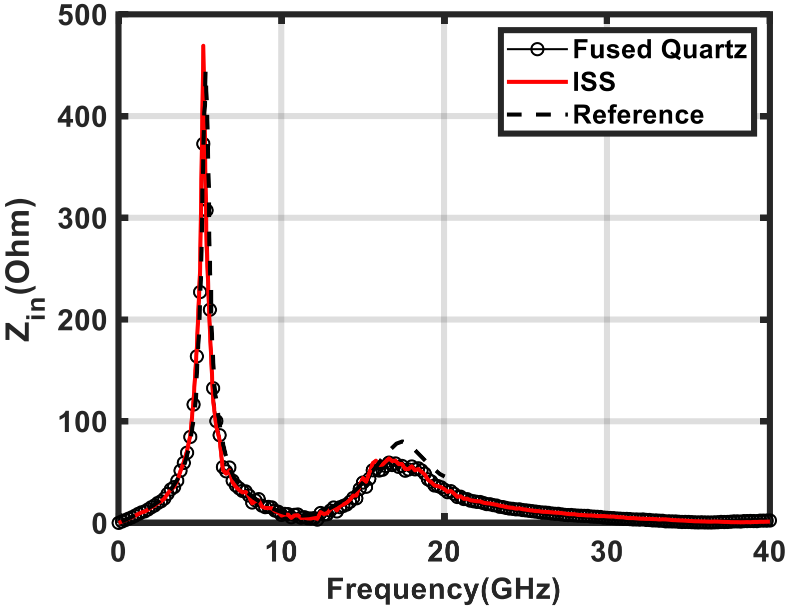
WCB on Fused Quartz substrate of a 1320 micron CPW on Quartz substrate using: (Default) calibration set employing default Cryo parameter response (i.e., nominal conductivity) and (WC) load response matching the measured device DC resistivity.

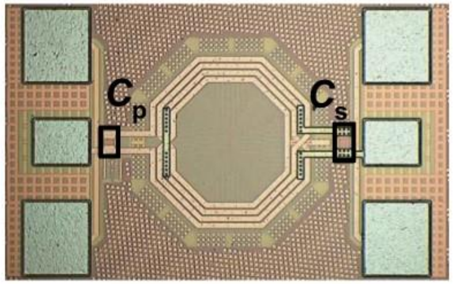


Validation on a CMOS passive device

To verify, a transformer-based resonator with cryogenic model is measured [1] and corrected via both calibrations and compared.







transformer-based resonator realized in CMOS

[1]B. Patra, M. Mehrpoo, A. Ruffino, F. Sebastiano, E. Charbon and M. Babaie, "Characterization and Analysis of On-Chip Microwave Passive Components at Cryogenic Temperatures," in IEEE Journal of the Electron Devices Society, vol. 8, pp. 448-456, 2020

Summary

- Discussed the necessity of cryogenic modelling of calibration structures
- Demonstrated modelling of two ISS structures based on measurements
- Introduced load compensation method to deal with process variation
- Demonstrated results of measurement
- Validation on a CMOS transformer-based resonator

Thankyou for you attention

Backup slide – stability

Gamma of an offset open was measured in Cryo setup at RT and in a reference setup to compare stability of setups.