Current Calibration Results

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MPP

July 3, 2025

Why calibrate?

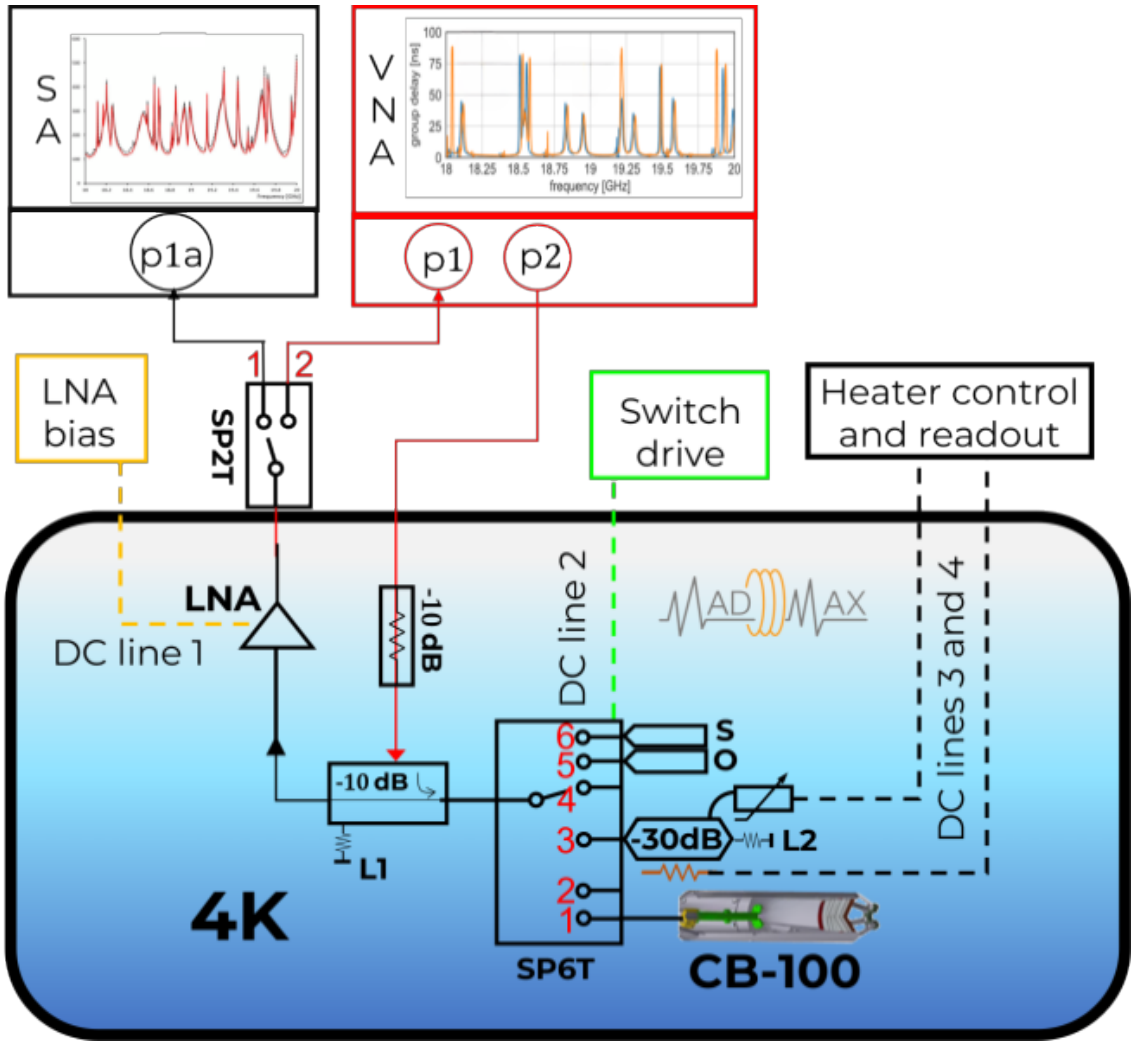


Figure: MADMAX setup used at Cryolab

One-port Calibration

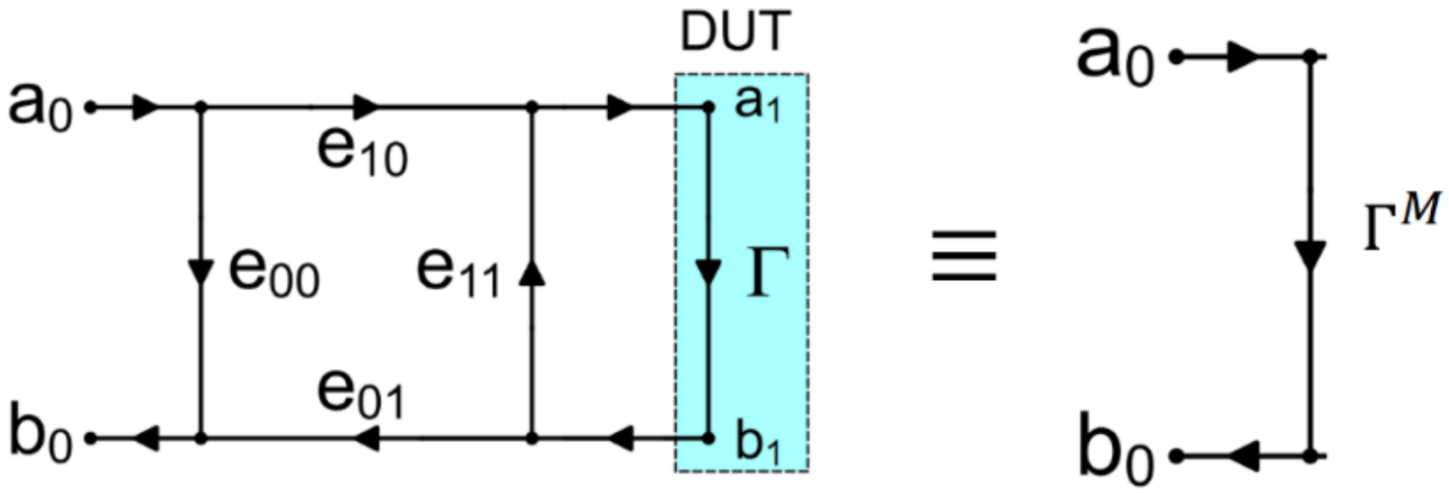


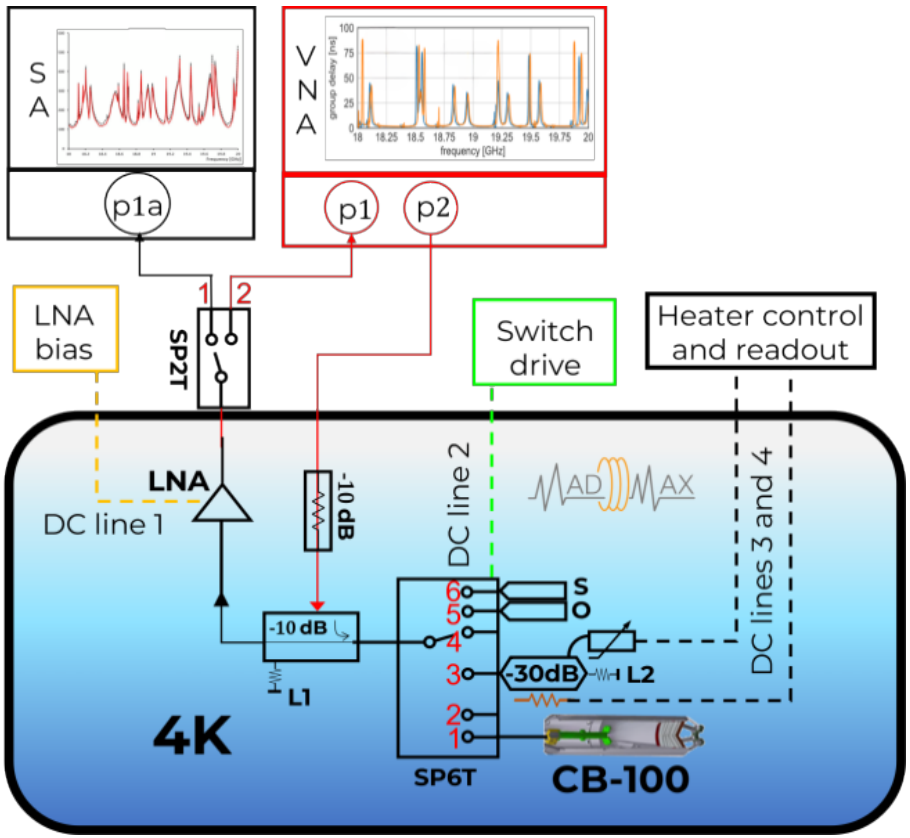
Figure: Γ^{M} **measured** reflectivity, Γ refelctivity of device under test.
Solving the equations below using three **well characterized, independent** standards allows to de-embed the unknown components.

$$\begin{bmatrix} 1 & \Gamma_1\Gamma_{\mathrm{M1}} & -\Gamma_1 \\ 1 & \Gamma_2\Gamma_{\mathrm{M2}} & -\Gamma_2 \\ 1 & \Gamma_3\Gamma_{\mathrm{M3}} & -\Gamma_3 \end{bmatrix} \begin{bmatrix} e_{00} \\ e_{11} \\ \Delta_{\mathrm{e}} \end{bmatrix} = \begin{bmatrix} \Gamma_{\mathrm{M1}} \\ \Gamma_{\mathrm{M2}} \\ \Gamma_{\mathrm{M3}} \end{bmatrix}$$

$$M \qquad E \quad = \quad \Gamma_{\mathrm{M}}$$

$$\Gamma = \frac{\Gamma^{\mathrm{M}} - e_{00}}{\Gamma^{\mathrm{M}} e_{11} - \Delta_{\mathrm{e}}}$$

Setup at room temperature



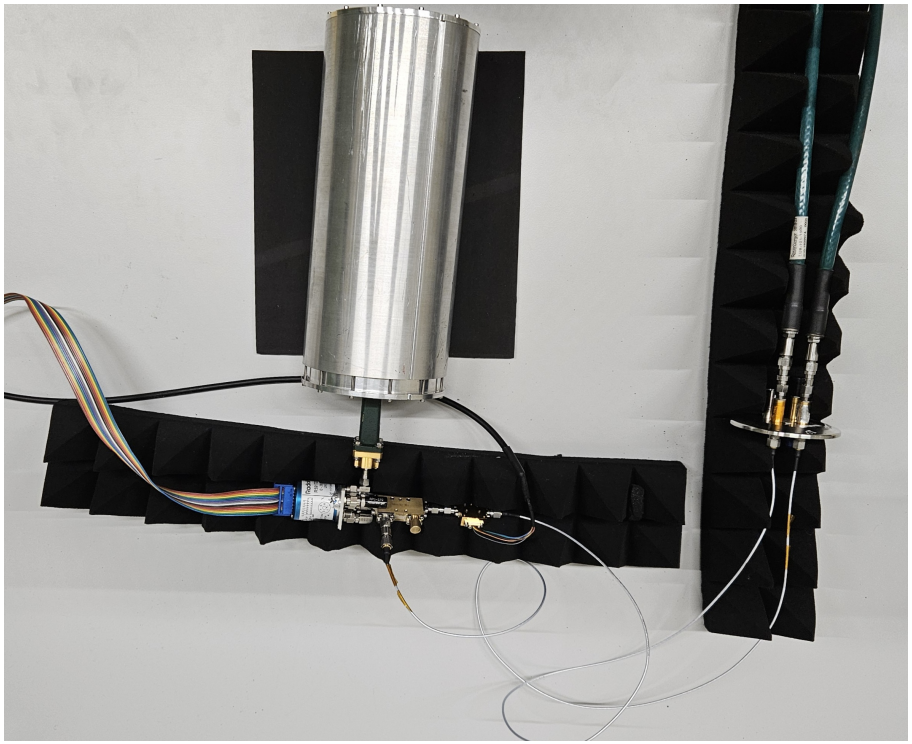


Figure: recreated MADMAX setup at room temperature

Setup at room-temperature

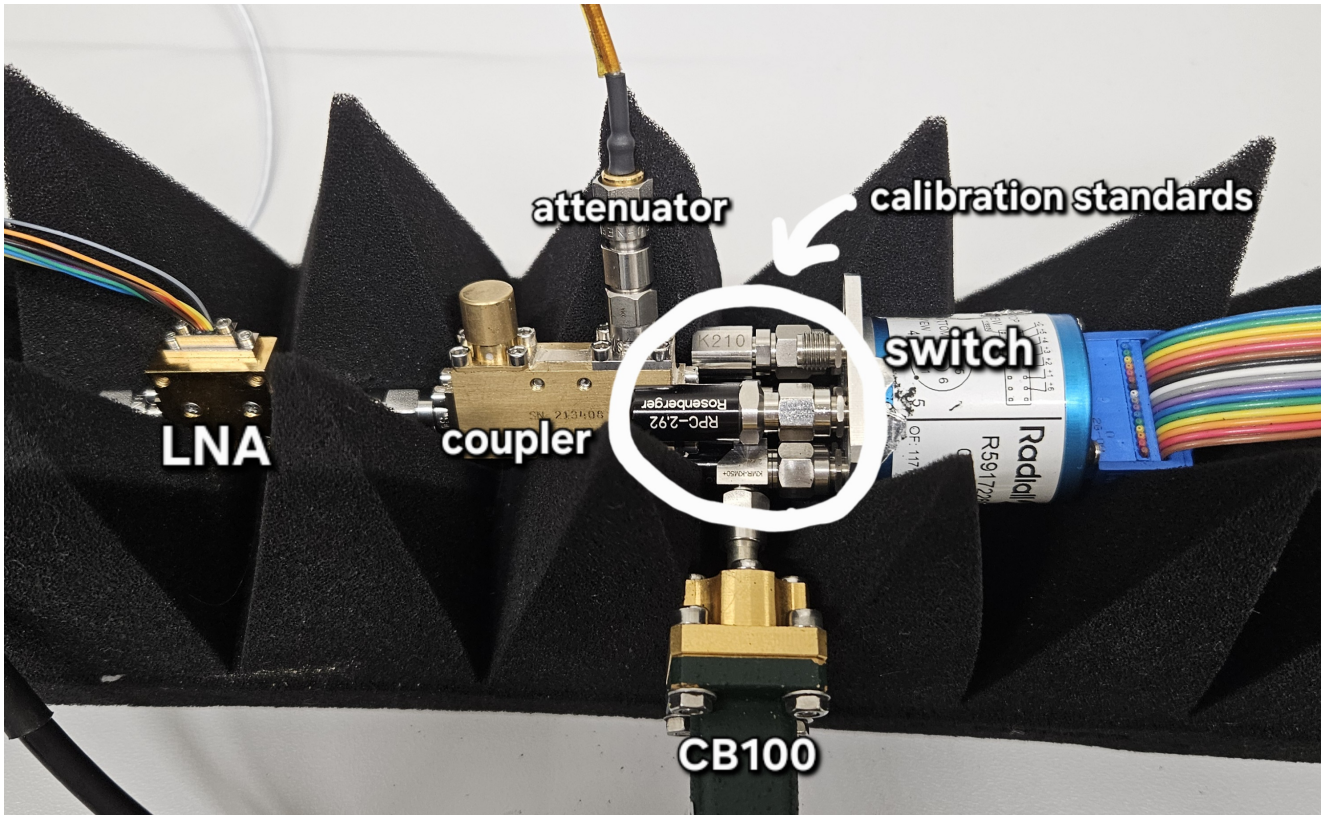


Figure: Close-up photo of the main components in the setup

Data

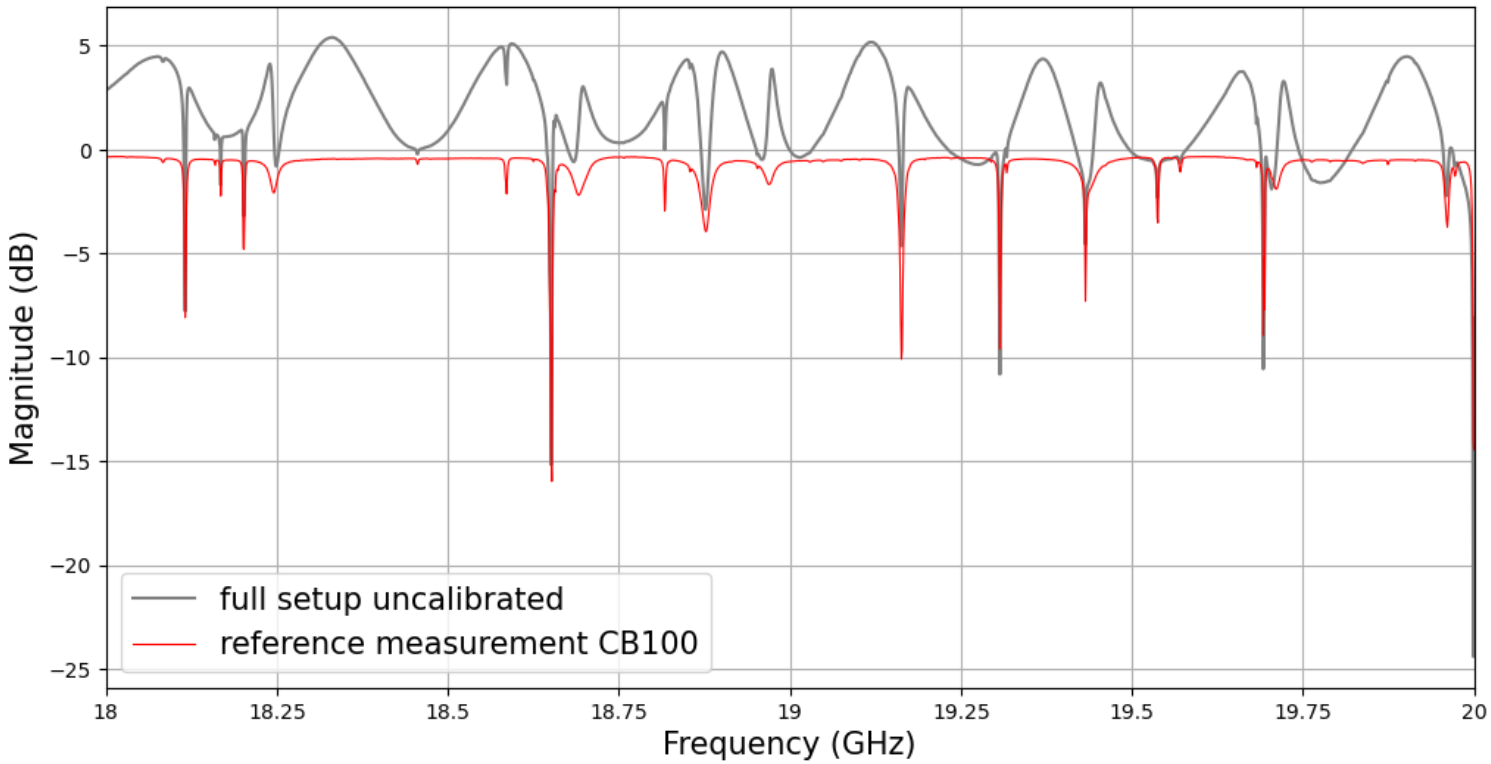


Figure: Reference refelctivity Γ_{DUT} (CB100 connected directly to the VNA cable) compared to uncalibrated reflectivity Γ^{M} of the full setup

Ideal vs measured standards

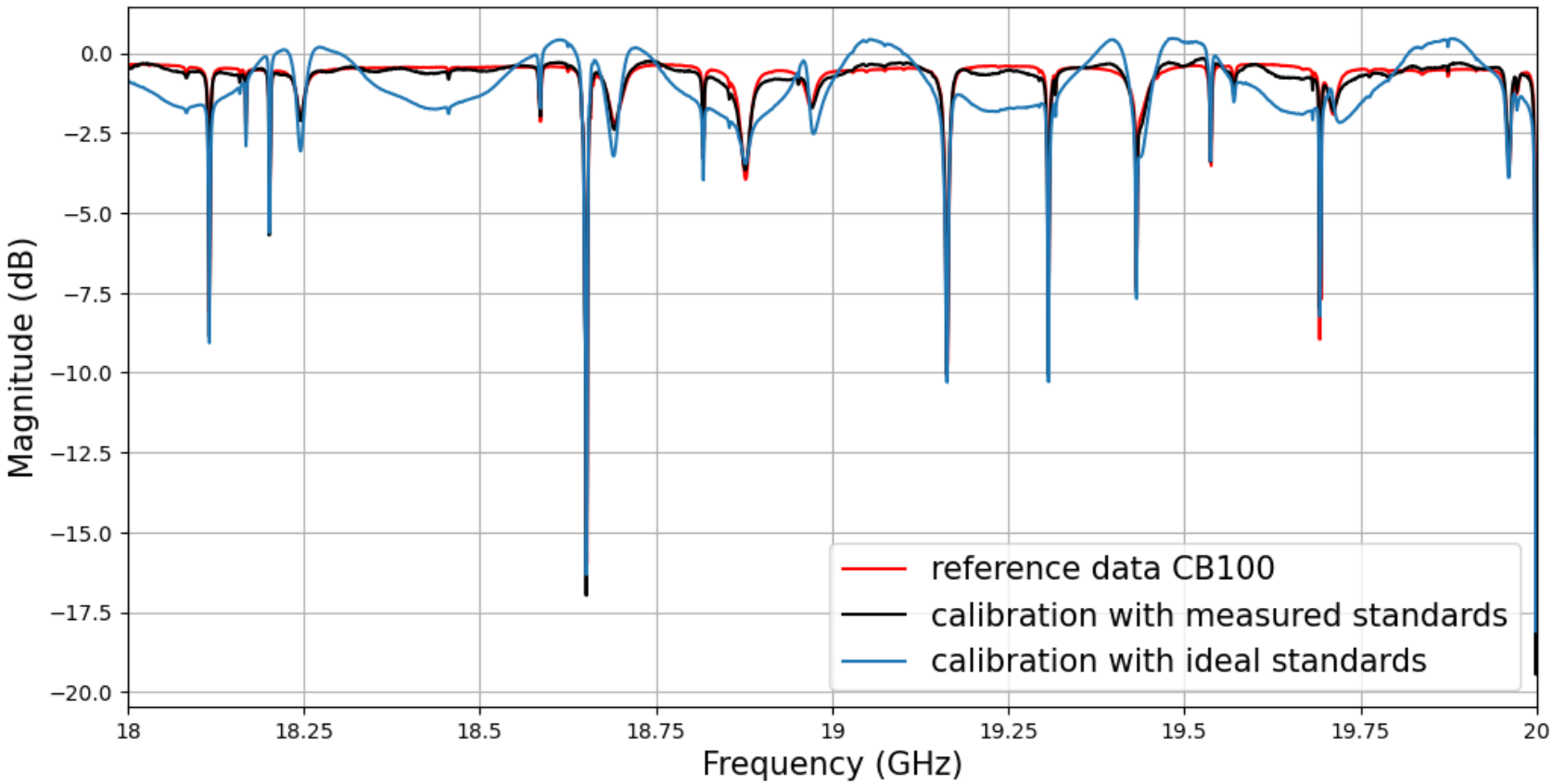


Figure: Calibration with standards assumes as "ideal" ($\Gamma_{\text{short}} = -1$, $\Gamma_{\text{open}} = 1$, $\Gamma_{\text{load}} = 0$) compared to calibration with measured standards.

Uncertainties

In order to estimate the uncertainties of the calibration, I applied a **Monte-Carlo method**:
Uncertainties from switch and VNA:

- phase: 2.062°
- magnitude: -44.655 dB

Assuming **uniform distribution**
→ deliberately introduced deviations within bounds
→ performed calibration → 2000 times.
This led to average uncertainties of the calibration:

- phase : ≈ 4°
- magnitude: ≈ -31 dB

Calibration

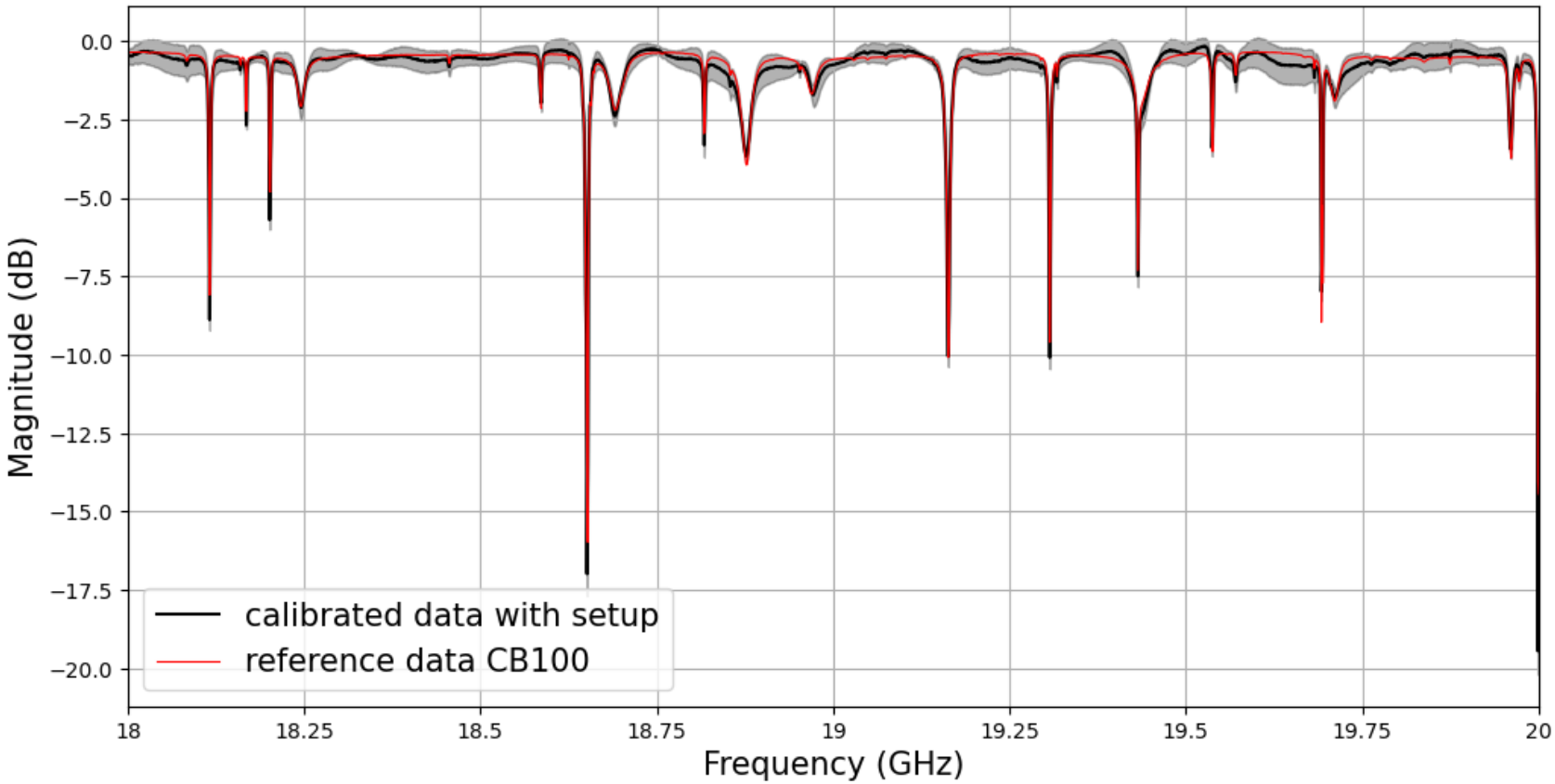


Figure: Calibrated CB100 spectrum between 18 and 20 GHz

Calibration

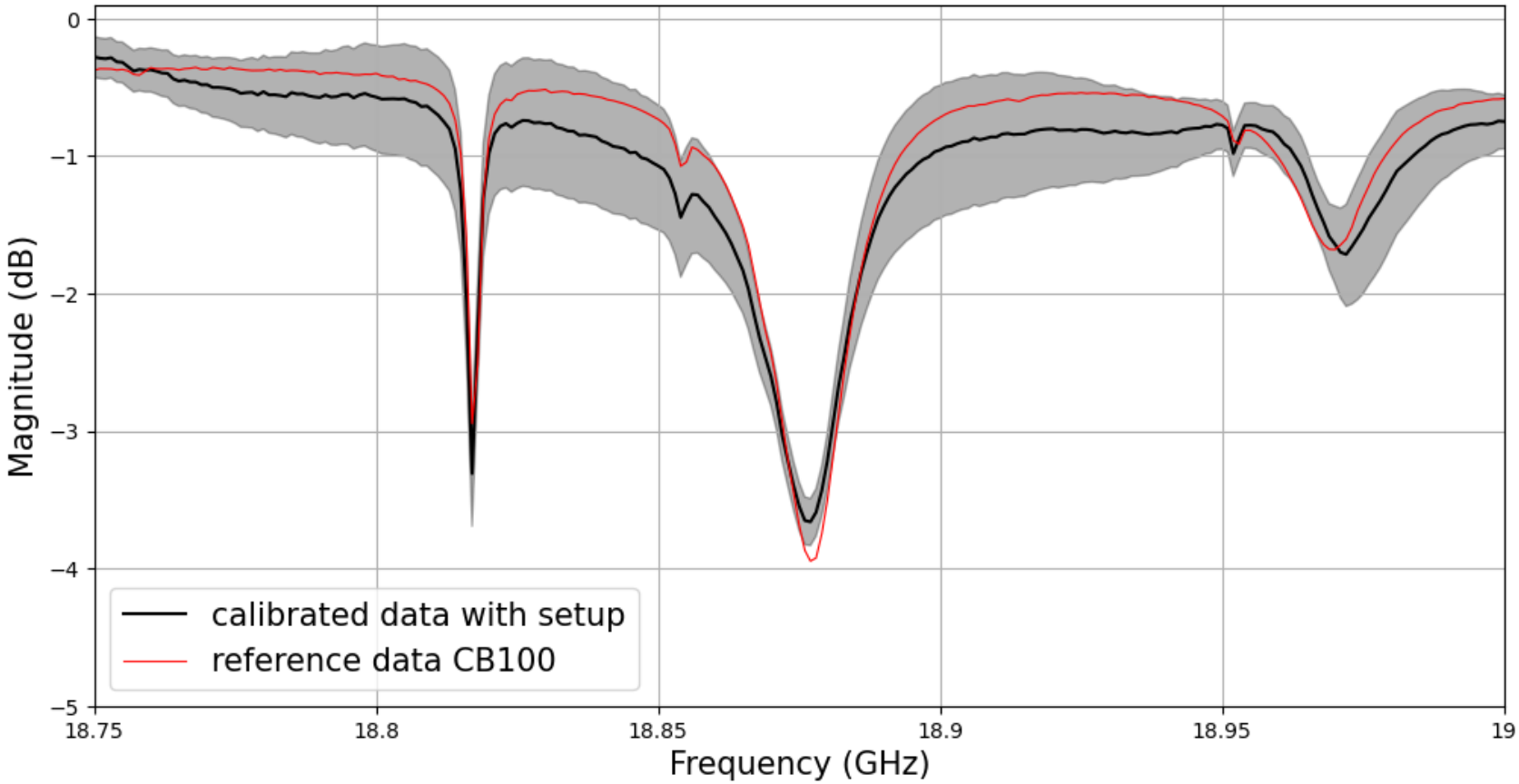


Figure: Calibrated data in the Booster-Peak region

Phase

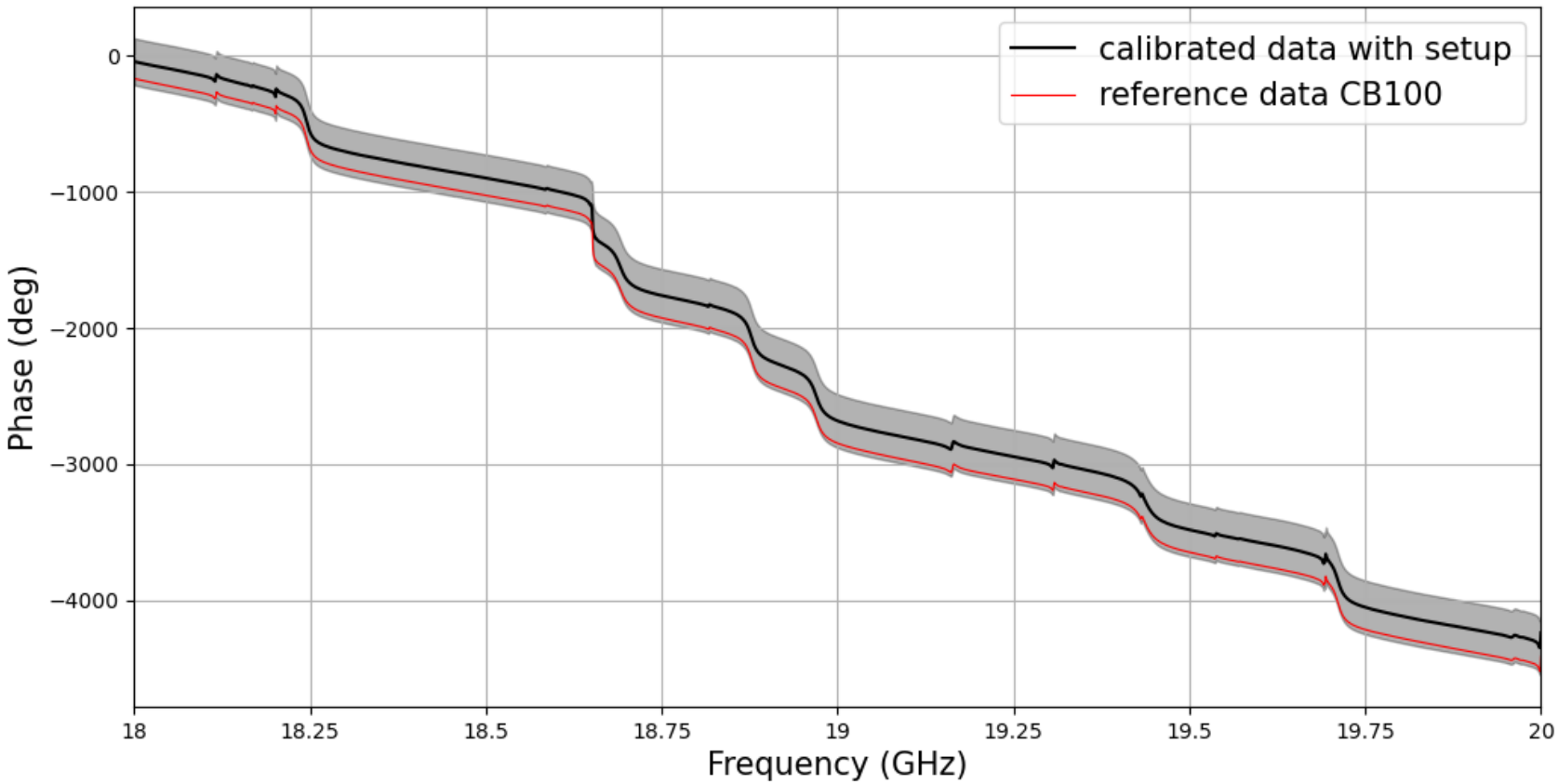
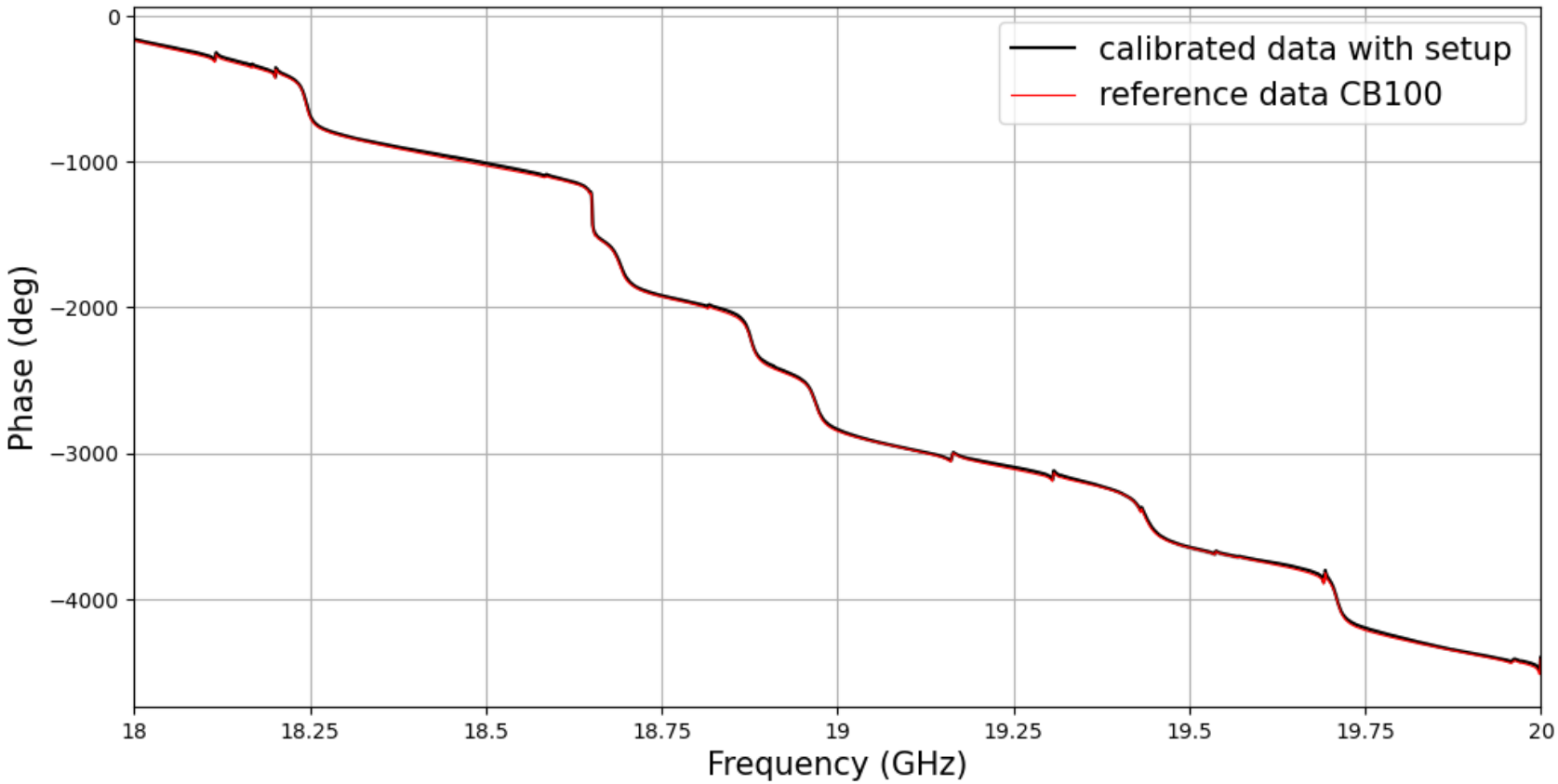


Figure: Unwrapped phase calibrated CB100 data between 18 and 20 GHz

What causes phase shift?

Figure: Radiall R591 switch: ports have slightly different internal lengths
$\Rightarrow$ causes phase shift

De-embedding seperate switch ports



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De-embedding seperate switch ports

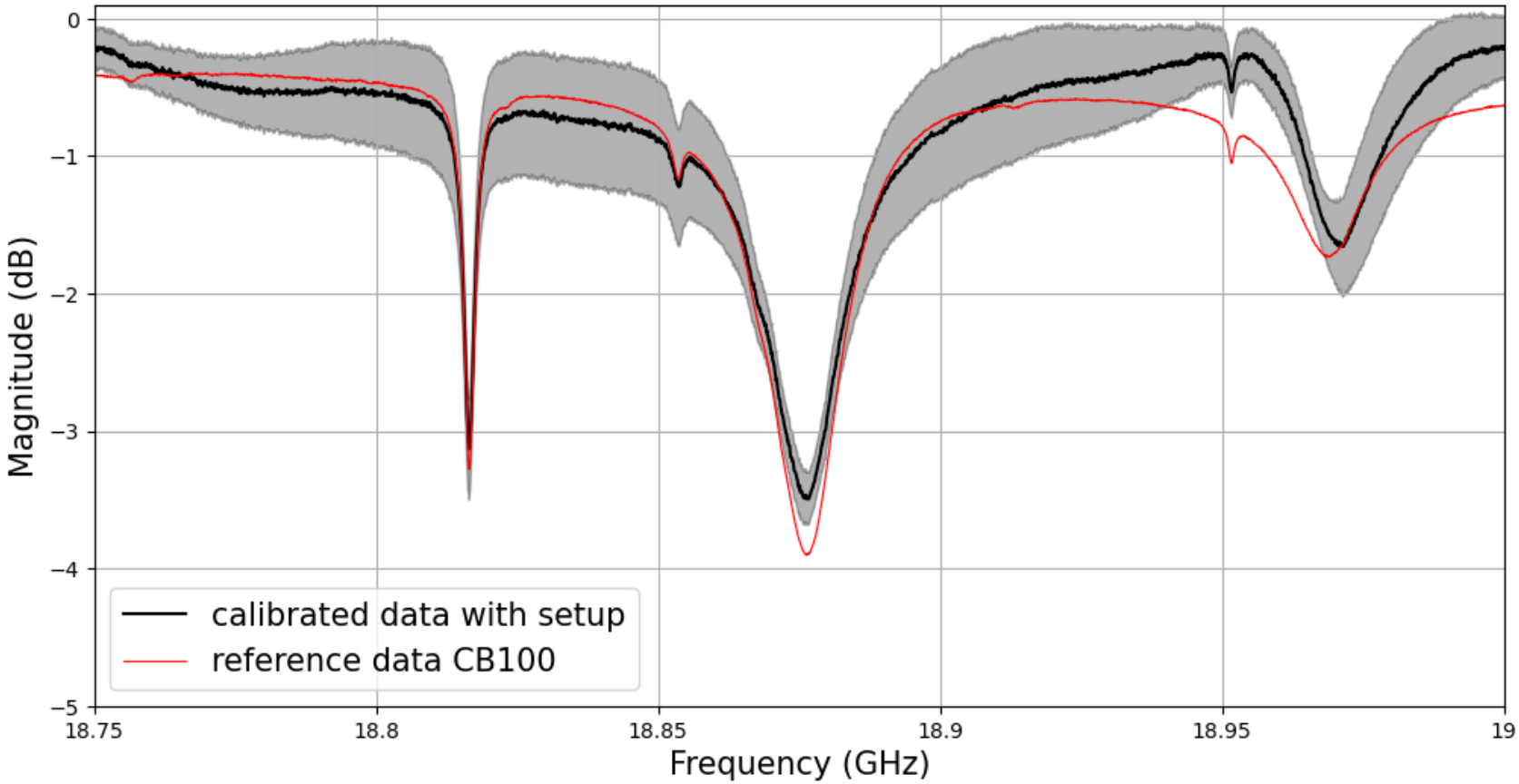

Figure: Calibrated data with de-embedding switch ports.
De-embedding too many components might accumulate errors.