STANDARD OPERATING PROCEDURE

Calibration & Liquid Permittivity Extraction for SIW C-Band Resonators

DOCUMENT TITLE:	**SIW C-Band Resonator SOP**	**DOC NUMBER:**	SOP-SIW-001
TARGET HARDWARE:	Substrate Integrated Waveguide / C-Band (4-8 GHz) Fluidic Cell	**REVISION / DATE:**	Rev 1.0 / Sep 16, 2026
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1. Purpose & Scope

This Standard Operating Procedure (SOP) defines Vector Network Analyzer (VNA) 2-port calibration, microfluidic channel loading, and complex permittivity extraction ($ arepsilon_r', arepsilon_r''$) for Substrate Integrated Waveguide (SIW) and Substrate Integrated Suspended Line (SISL) C-band resonator sensors. SIW resonators provide high Quality Factors ($Q_0 > 250$) and electromagnetic shielding for high-precision dielectric characterization of liquids.

2. Required Test Equipment & Calibration Standards

• **2-Port Vector Network Analyzer (VNA):** Keysight FieldFox N9918A ($300\text{ kHz to }26.5\text{ GHz}$).
• **VNA Calibration Kit:** Precision N-type 50-ohm SOLT (Short-Open-Load-Thru) mechanical calibration kit.
• **Precision Torque Wrench:** 3.5 mm SMA connector torque wrench ($5.0\text{ in-lbs} \pm 0.2\text{ in-lbs}$).
• **Reference Calibration Liquids:** Deionized water ($\varepsilon_r' = 78.4$ at 25°C), Ethanol ($\varepsilon_r' = 24.5$), and Isopropanol ($\varepsilon_r' = 18.3$).
• **Microfluidic Syringe Pump:** Syringe driver ($0.1\text{--}10.0\ \mu\text{L/min}$ flow rate) and PTFE tubing.

3. Step-by-Step Calibration & Permittivity Extraction Procedure

3.1 VNA 2-Port SOLT Calibration & Thermal Stabilization

1. Power on VNA and allow 30 minutes for internal reference oscillator thermal stabilization.
2. Set frequency sweep range: $4.0\text{ GHz to }8.0\text{ GHz}$ (1601 points, 100 Hz IF bandwidth, $+0\text{ dBm}$ power).
3. Connect precision SOLT standards to Port 1 and Port 2 cables. Execute 2-port SOLT calibration. Verify $S_{11}, S_{22} < -45\text{ dB}$ across band.

3.2 Unloaded Air Baseline Verification (Q_0 & f_0)

1. Connect SIW resonator sensor board to VNA test cables using torque wrench (5.0 in-lbs).
2. Measure S_{21} transmission response with empty microfluidic channel.
3. Record unloaded resonant frequency $f_0 \approx 5.80\text{ GHz}$ and peak $S_{21} \ge -3.5\text{ dB}$. Calculate 3-dB bandwidth Δf_0 and unloaded Quality Factor $Q_0 = f_0 / \Delta f_0$. Confirm $Q_0 \ge 250$.

3.3 Liquid Sample Injection & Dielectric Inversion

1. Inject $15.0\ \mu\text{L}$ of reference liquid into the SIW etched slot channel at $2.0\ \mu\text{L/min}$. Ensure zero air bubbles in sensing region.
2. Record shifted resonant frequency f_r and loaded Quality Factor Q_L.
3. Calculate real permittivity ε_r' and loss tangent $\tan\delta$ using perturbation equations:
   $\frac{f_0 - f_r}{f_0} = A (\varepsilon_r' - 1)$ and **$\Delta \left(\frac{1}{Q}\right) = B \cdot \varepsilon_r''$**

4. Quality Control & Temperature Correction

Substrate permittivity changes at $-0.0015/^\circ\text{C}$. Measure ambient temperature during sweep and apply quadratic thermal compensation to f_r. Flush microfluidic channel with methanol between samples and verify f_0 returns to within $\pm 2\text{ MHz}$ of air baseline.