Standard Operating Procedure: Interdigital Capacitor (IDC) Sensor

Planar Dielectric Characterization and Quality Factor (Q) Optimization

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1. Principle & Geometry Design

Interdigital capacitors (IDCs) utilize multi-finger periodic copper conductor traces on microwave substrates (e.g., RT/Duroid) to generate intense near-field fringing electric fields across narrow gap spaces (S). They provide high sensitivity for small-volume dielectric measurements.

- **Geometric Parameters:** Number of fingers ($N = 4 ext{--}10$), finger width ($W = 0.5 ext{--}2.0 ext{ mm}$), finger length ($L$), and gap spacing ($S = 0.5 ext{--}2.0 ext{ mm}$). Copper thickness is standardized at $0.032 ext{ mm}$.
- **Operating Frequency:** High Quality Factor (Q) peak is optimized at **600 MHz**.

2. Mathematical Model & Permittivity Inversion

The total capacitance C (in pF) is modeled as a function of substrate relative permittivity ($ arepsilon_r$), finger count ($N$), and finger geometry constants (A_1, A_2):

$C = (arepsilon_r + 1) l \left[(N - 3)A_1 + A_2 ight]$

Increasing finger width (W) or finger count (N) increases total capacitance, but degrades the Quality Factor (Q) due to increased reactive resistance and parasitic inductance dissipation. Gap width (S) controls local field confinement.

3. Calibration & Test Protocol

1. **Unloaded Air Calibration:** Measure air baseline capacitance C_0 and unloaded Q-factor (Q_0) at 600 MHz on a calibrated LCR meter or Vector Network Analyzer.

2. **Sample Interface Registration:** Place microliter liquid sample or thin dielectric film directly across the active interdigital fingers.

3. **Permittivity Extraction:** Record shifted capacitance C_m and calculate dielectric constant $ arepsilon_r$. Track Q-factor drop to quantify dielectric loss tangent ($ an\delta$).

4. Quality Control Limits

Parameter	Specification / Formula	Tolerance
Operating Frequency	Optimal Q-factor peak	600 MHz ± 5 MHz
Finger Width (W)	Proportional to C; test range 0.5–2.0 mm	± 0.02 mm (etching tol)
Finger Gap (S)	Proportional to C & field strength; 0.5–2.0 mm	± 0.02 mm
Substrate Material	RT/Duroid low-loss microwave laminate	$ arepsilon_r = 2.20 \pm 0.02$