Reflective-Mode Phase-Variation Permittivity Sensors Based On Coupled Resonators

1 Port

Single frequency

Novel sensing strategy

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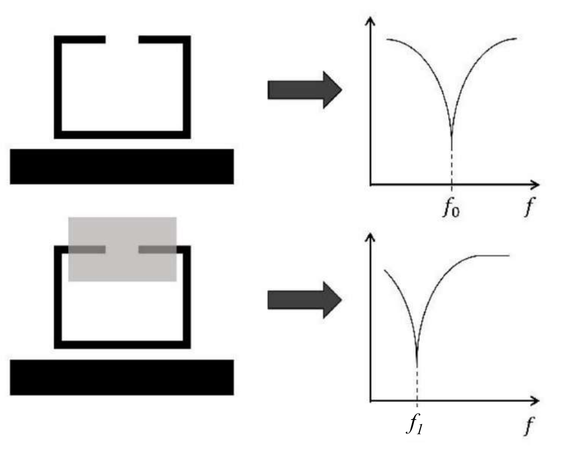
Planar Microwave Permittivity Sensors

Several types of planar microwave sensors:

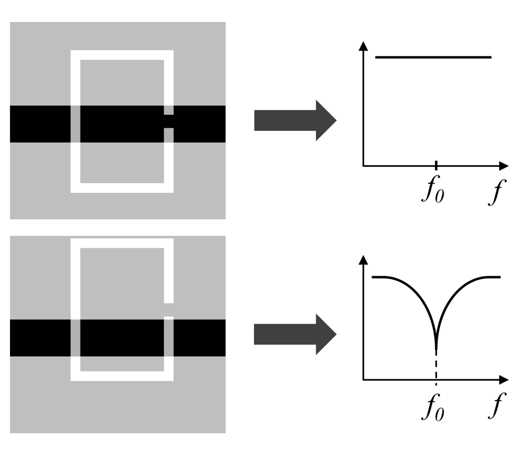
Frequency Variation



Complex permittivity

Wideband measure

Coupling Modulation

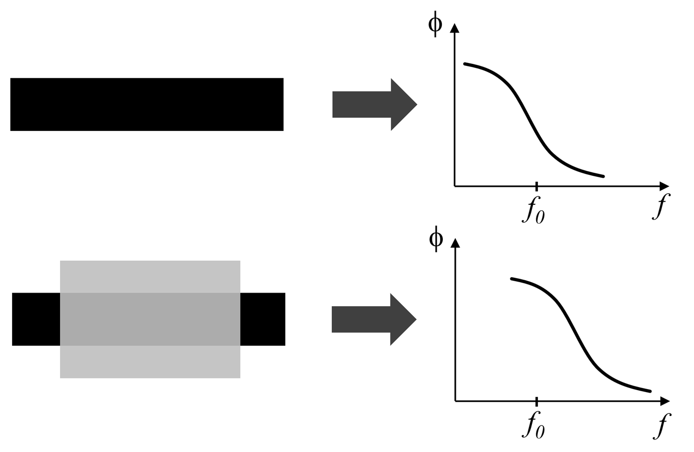


Single frequency

Affected by noise

This Work

Phase Variation

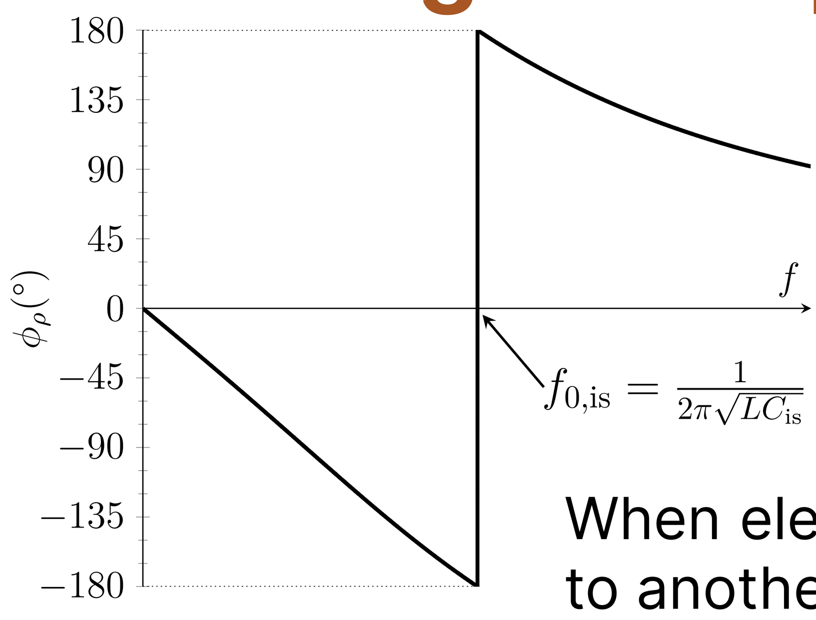


Single frequency

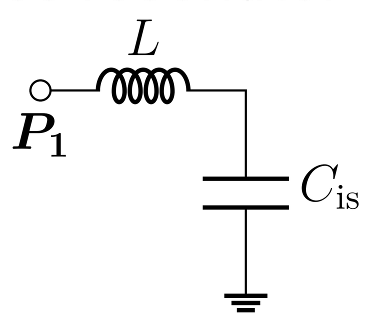
EMI and noise tolerant

The permittivity of the Material Under Test (MUT) alters the output signal.

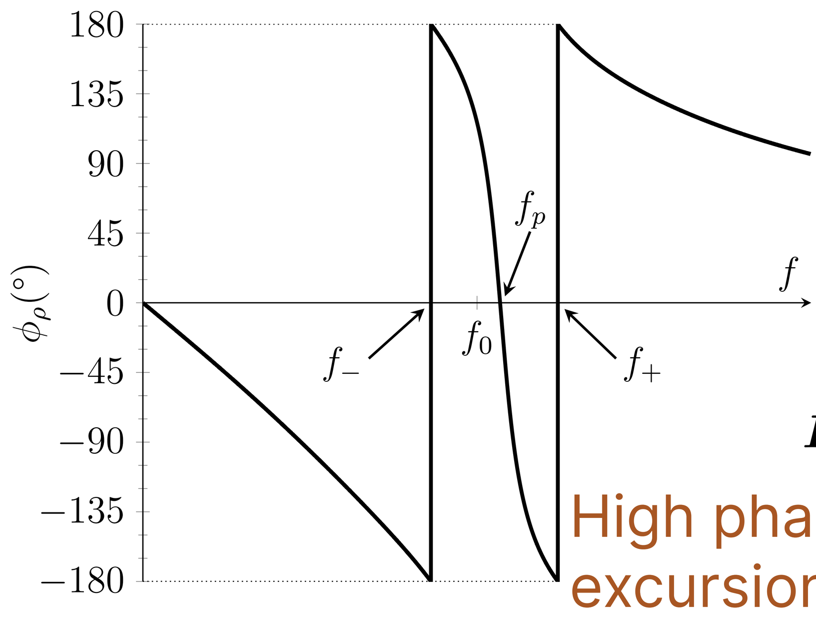
1. Sensing Concept

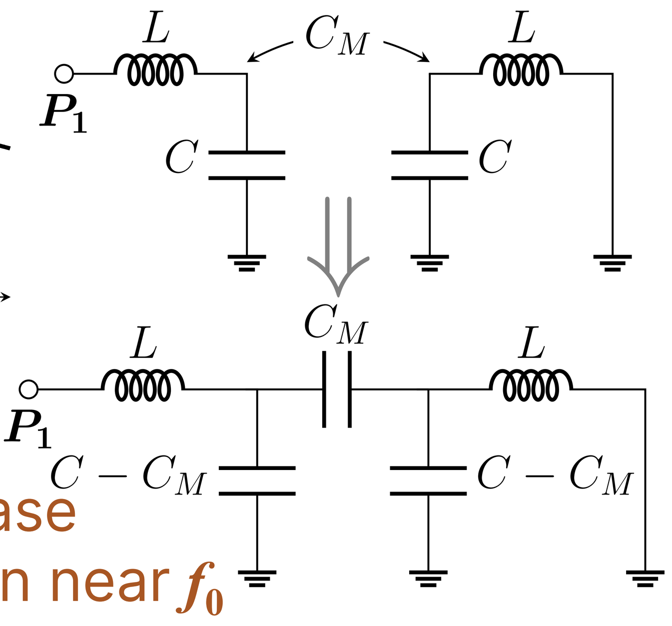


Isolated series resonator



When electrically coupled to another resonator:



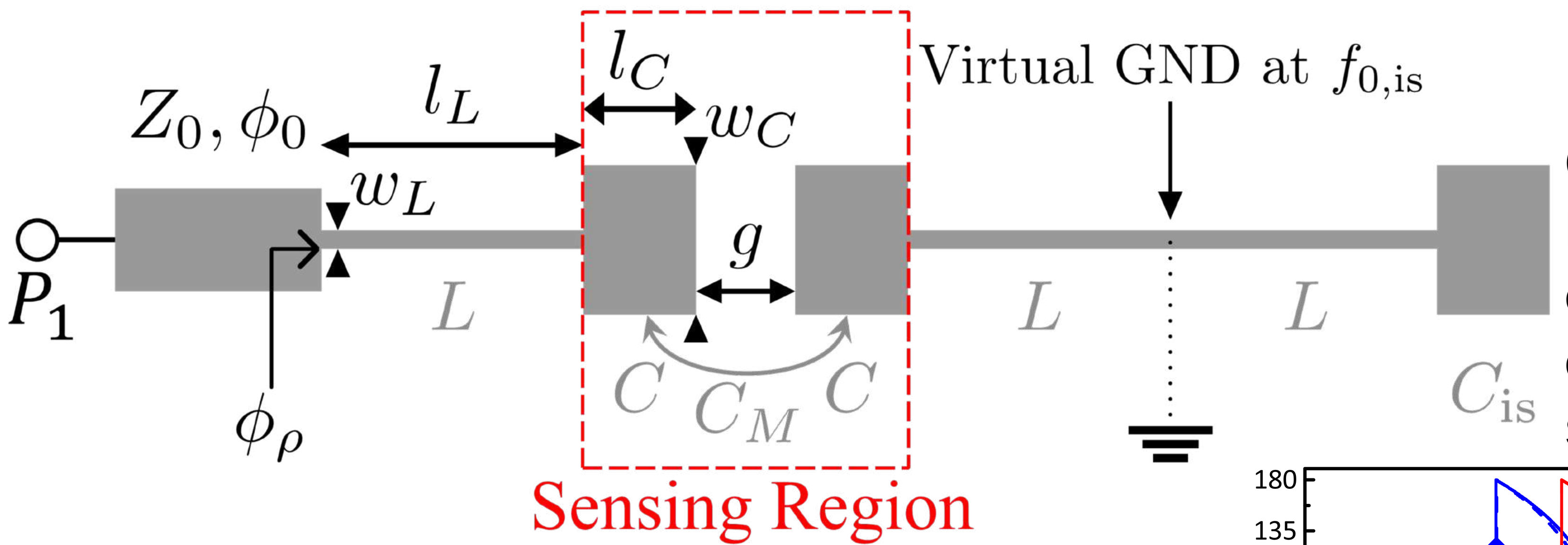


High phase excursion near f_0

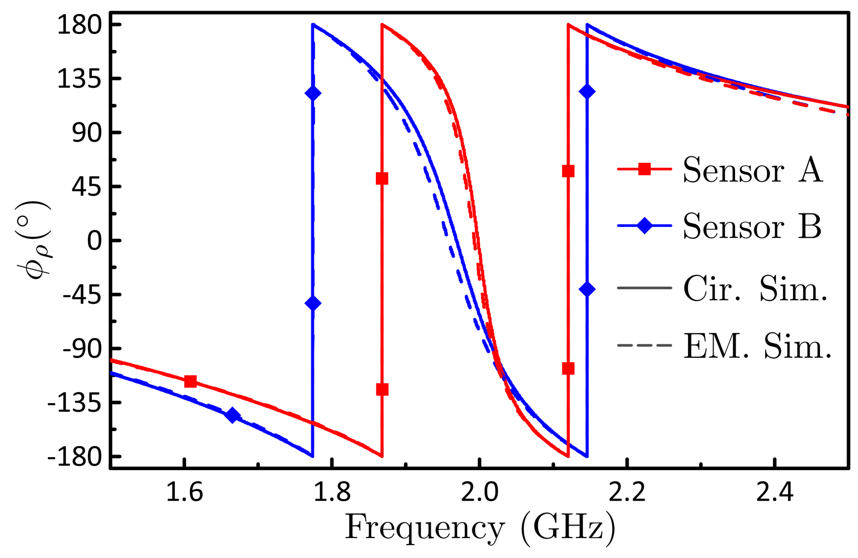
Weaker coupling provides higher sensitivity since f_- and f_+ are closer.

No need to add High/Low impedance sections like in [1], in order to increase the sensitivity.

2. Sensor Design and Implementation



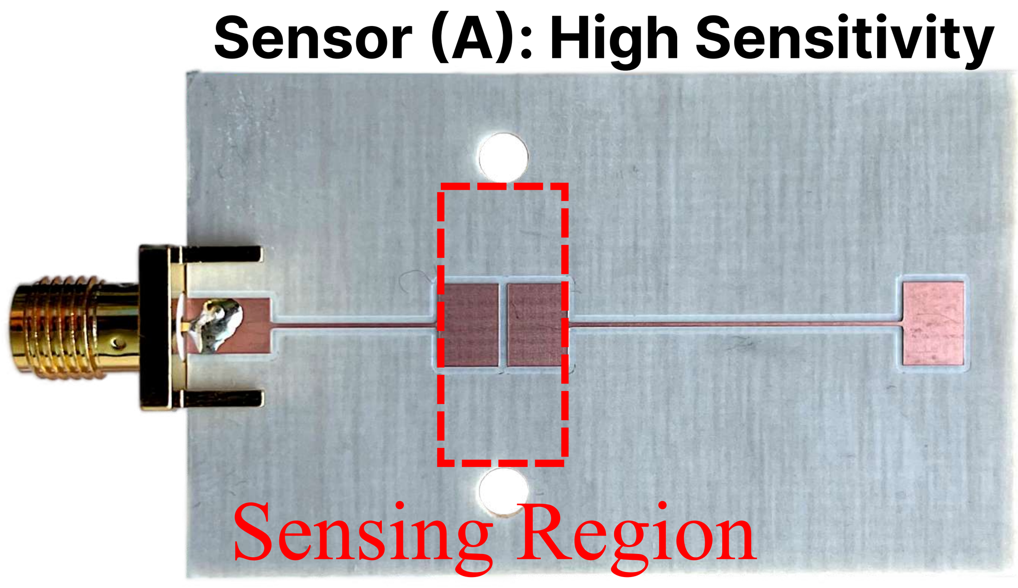
Good agreement between the circuit model and electromagnetic simulation.



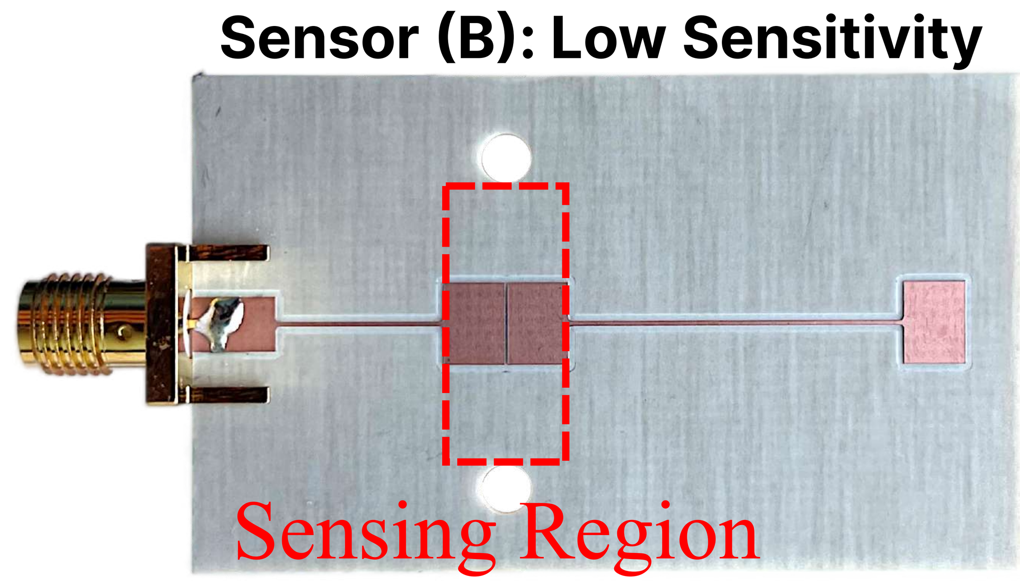
Two implementations:

Change of the sensitivity only by modifying the coupling, altering the gap (g), between the capacitive region of the Stepped Impedance Resonators (SIRs).

Sensor (A): High Sensitivity



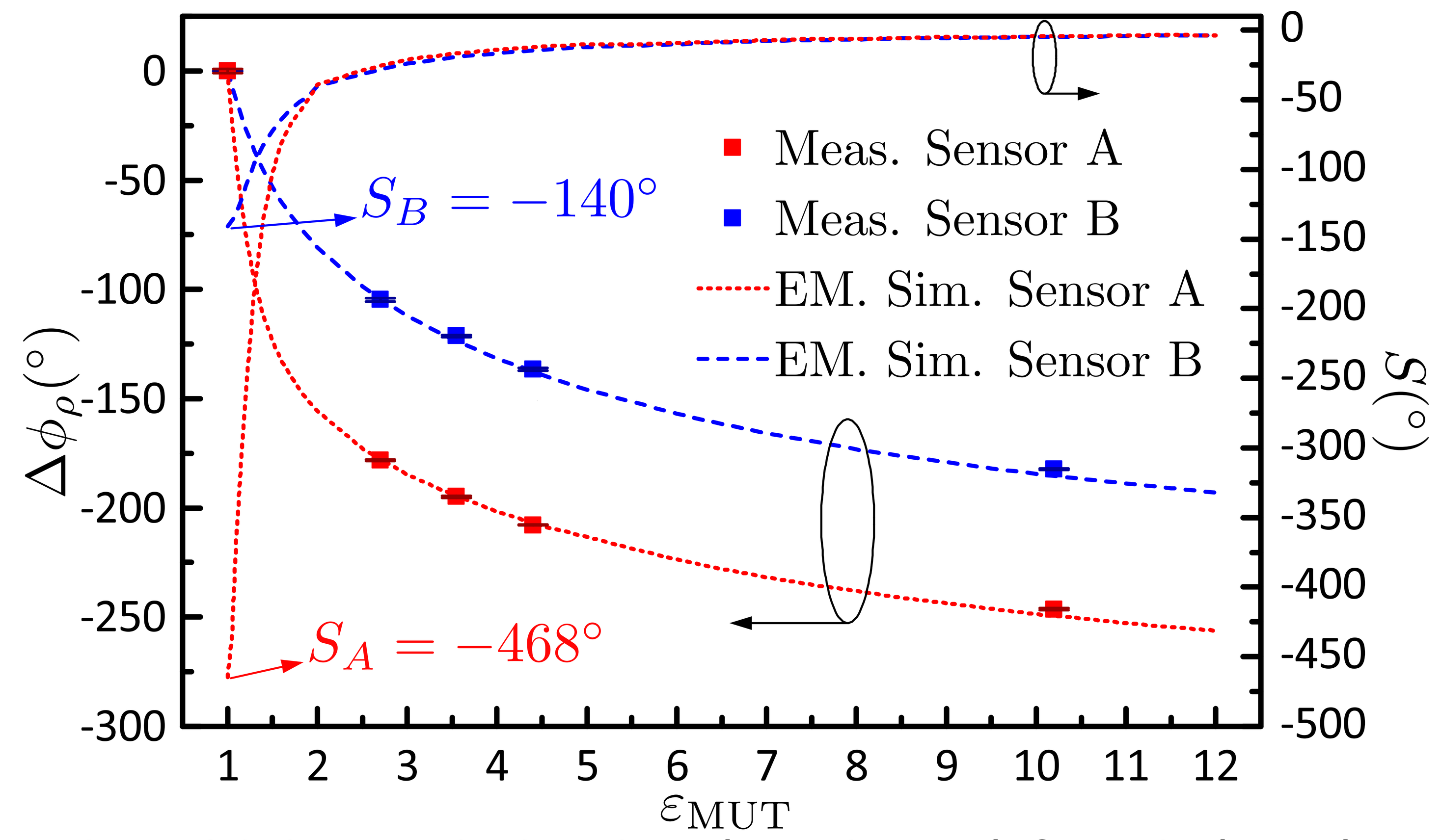
Sensor (B): Low Sensitivity



Substrate: *Rogers RO4003C* ($\varepsilon_r = 3.33$, $h = 1.52$ mm, $\tan\delta = 0.0023$)

3. Results

Solid MUT samples ranging from $\varepsilon_{\text{MUT}} = 1$ to 10.2: Air ($\varepsilon_r = 1$), PLA ($\varepsilon_r = 2.8$), *RO4003C* ($\varepsilon_r = 3.33$), *FR4* ($\varepsilon_r = 4.4$), *RO3010* ($\varepsilon_r = 10.2$).



Sensitivity optimization (maximum) for Air ($\varepsilon_r = 1$).

4. Highlights

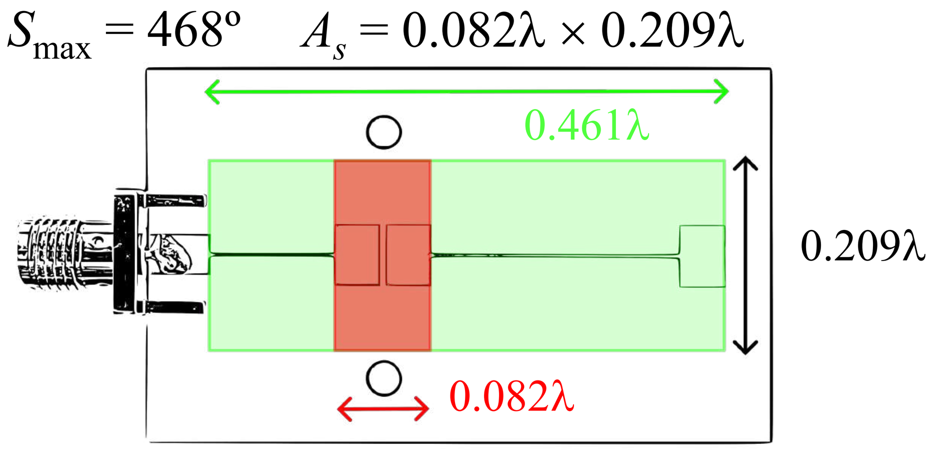
Novel sensing strategy for one-port reflective-mode phase-variation sensors by **coupling SIR structures.**

Sensitivity enhancement by **weakly coupling** the resonant elements.

$\text{FoM}_A = S_{max}/A_s = \mathbf{27419°/\lambda^2}$

An unprecedented **FoM** regarding sensitivity and sensing area as well as the overall sensor area.

$S_{max} = 468°$ $\quad A_s = 0.082\lambda \times 0.209\lambda$



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[1] J. Muñoz-Enano, P. Vélez, L. Su, M. Gil, P. Casacuberta, and F. Martín, "On the sensitivity of reflective-mode phase variation sensors based on open-ended stepped-impedance transmission lines: theoretical analysis and experimental validation", *IEEE Trans.Microw. TheoryTechn.* vol. 69, no. 1, pp. 308-324, 2021.

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