Student Paper Finalist

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Displacement Monitoring Using Phase- and Quadrature Self-Injection-Locked (PQSIL) Radar

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Outline

- Introduction

- System Architecture

- Detection Principle

- Experimental Result

- Conclusion

- **Self-injection-locked (SIL) radar**

  — Inject the received signal into the SIL oscillator (SILO)

  — Doppler phase shifts the output frequency of the SILO

  — Demodulation with noncoherent frequency demodulator

  ✓ **Clutters immunity and good SNR**

  ✗ **Null points, electromagnetic interference (EMI), and nonlinear distortion problems.**

■ SNR– signal-to-noise ratio

Literature Review

- **Phase- and SIL (PSIL) radar**

  — Combine the SIL technique with a PLL circuit

- **Frequency-offset SIL (FOSIL) radar**

  — Use two SILOs to cancel the frequency shift

- **Quadrature SIL (QSIL) radar**

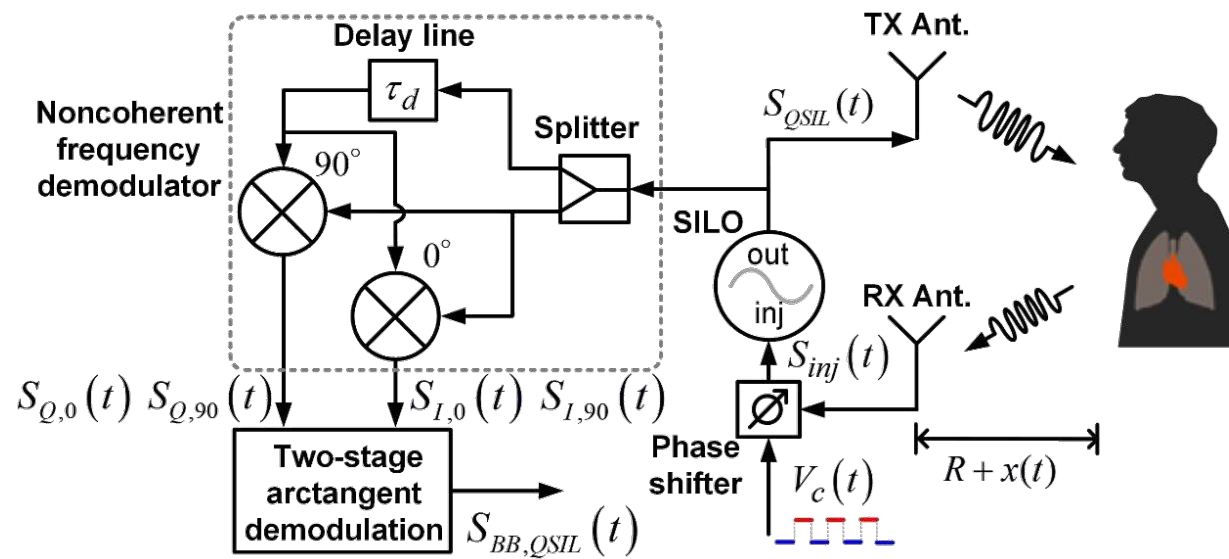 — Use an additional phase shifter in the injection path

Radar	Null points issue	EMI issue	Nonlinear distortion issue
PSIL	No	No	Yes (SIL phenomenon)
FOSIL	No	No	Yes (SIL phenomenon)
QSIL	No	Yes	Yes (EMI)

Proposed System

- **Phase- and quadrature SIL (PQSIL) radar**

  — Stabilize the output frequency of the SILO with a PLL circuit

  — Switch the injection phase delay

  — Use one stage AD to obtain the Doppler phase

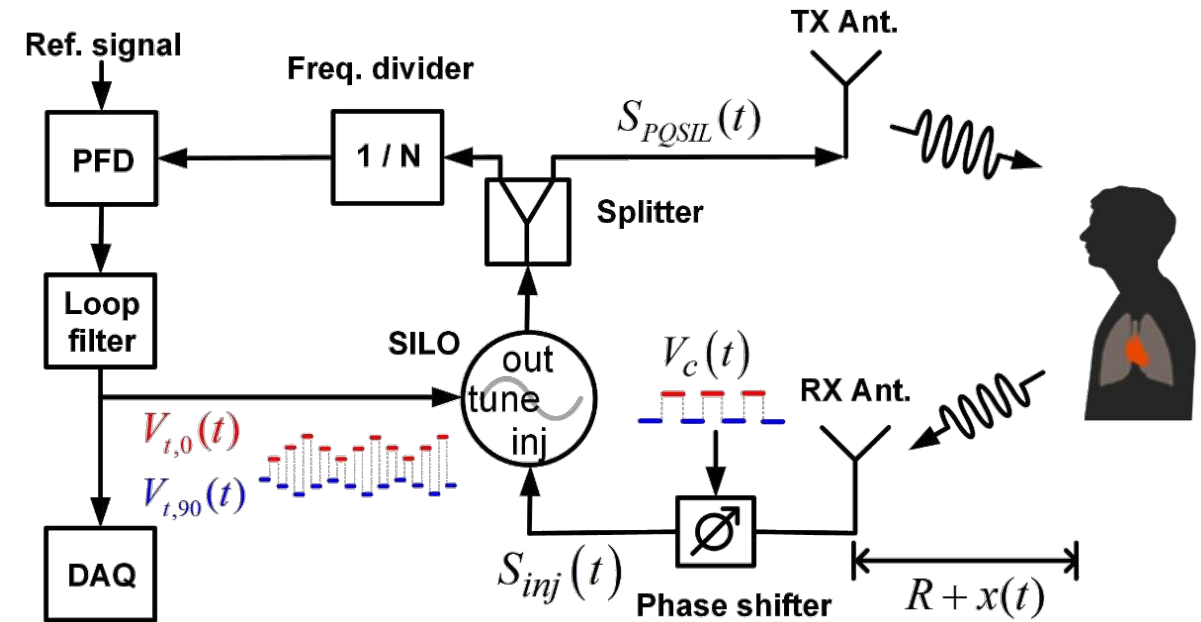 ✓ Solves null points, EMI, and nonlinear distortion problems.

■ AD- Arctangent Demodulation

QSIL radar

Noncoherent frequency demodulator

PQSIL radar

PLL circuit

- **QSIL radar**

— Instantaneous output frequency

$$\begin{cases} \omega_{QSIL,0}(t) = \omega_{osc} - \omega_{LR} \sin \alpha_{QSIL,0}(t) \\ \omega_{QSIL,90}(t) = \omega_{osc} + \omega_{LR} \cos \alpha_{QSIL,90}(t) \end{cases} \quad (1)$$

— Doppler phase

$$\begin{cases} \alpha_{QSIL,0}(t) = \dfrac{2\omega_{QSIL,0}(t)}{c}(R+x(t)) \\ \alpha_{QSIL,90}(t) = \dfrac{2\omega_{QSIL,90}(t)}{c}(R+x(t)) \end{cases} \quad (2)$$

$x(t)\uparrow,\ \Delta\omega_{QSIL}(t)\uparrow$
Nonlinear distortion

— Demodulated baseband signal

$$S_{BB,QSIL}(t) \propto \tan^{-1}\frac{\sin \alpha_{QSIL,90}(t)}{\cos \alpha_{QSIL,0}(t)}. \quad (3)$$

$$\omega_{LR} = \frac{\omega_{osc}}{2Q} \cdot \frac{E_{inj}}{E_{osc}}$$

- **PQSIL radar**

  — Output frequency

  $$\omega_{PQSIL}(t) = \omega_{osc} - \omega_{LR}\sin\alpha_{PQSIL}(t) + K_v V_{t,0}(t) = \omega_{osc} \quad (4)$$

  — Doppler phase

  $$\alpha_{PQSIL}(t) = \frac{2\omega_{osc}}{c}\left(R + x(t)\right) \quad (5)$$

  $x(t)$ ↑, stable freq.
  No nonlinear distortion

  — Tuning voltage

  $$\begin{cases} V_{t,0}(t) = V_i - \dfrac{\omega_{LR}\sin\alpha_{PQSIL}(t)}{K_v} \\[3mm] V_{t,90}(t) = V_i + \dfrac{\omega_{LR}\cos\alpha_{PQSIL}(t)}{K_v} \end{cases} \quad (6)$$

  — Demodulated baseband signal

  $$S_{BB,PQSIL}(t) = \tan^{-1}\left(\frac{-(V_{t,0}(t) - V_i)}{V_{t,90}(t) - V_i}\right) = \alpha_{PQSIL}(t) \quad (7)$$

QSIL radar

PQSIL radar

QSIL radar

PQSIL radar

- **Displacement monitoring (Δd =10 mm – 125 mm)**

CW: Δd ⬇ , SNR ⬇, RMSE ⬆

QSIL: Δd ⬆ , RMSE ⬆

    (Nonlinear distortion)

PQSIL: for all Δd, RMSE<1%

■ RMSE – root-mean-square error

Conclusion

This work proposed a phase- and quadrature self-injection locked (PQSIL) radar system, which has a SILO, a phase shifter, and a PLL circuit, to monitor the displacement of a moving target.

- It solves the problems of EMI, null point, and nonlinear distortion.

- Experimental results- RMSE values are smaller than 1% with different displacements.

- It can detect the frequency and displacement of the subject's chest movement.