TH1C-3

Low-IF Doppler Radar Using Delay- and Self-Injection-Locking Technology with Clutter Cancellation for Biomedical Monitoring

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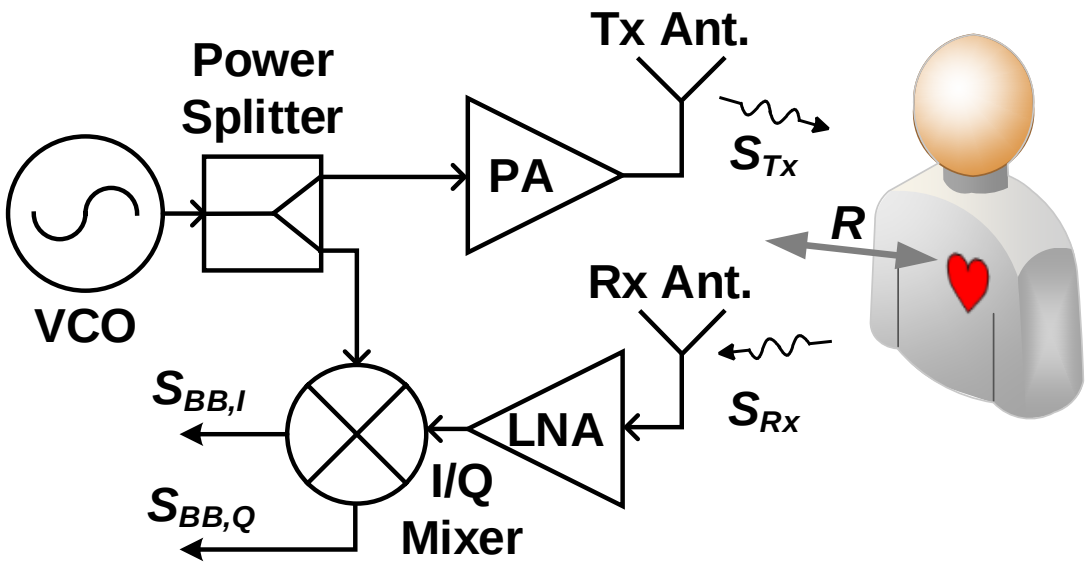
Outline

- Motivation
- Proposed Radar Architecture
- Operating Principle – Key Parameter
- Experimental Setup and Results
- Conclusion

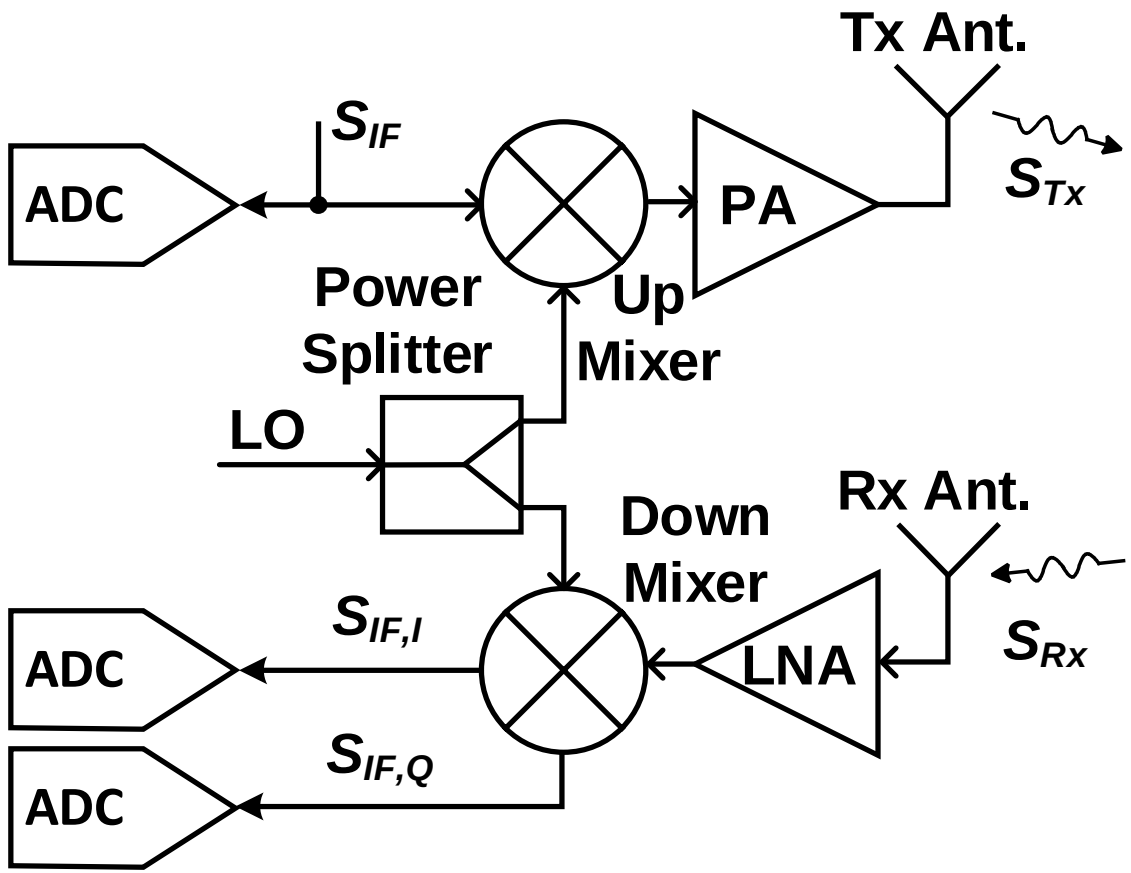
Direct-conversion Doppler Radar



Low-IF architecture

- **Advantages**
  - Simplicity structure
  - Micro-displacement detection
  - Human motions and vital signs surveillance
- **Challenges**
  - Vulnerable sensitivity
    - DC offset/flicker noise
  - Linearity within large displacement detection

Low-IF Doppler Radar

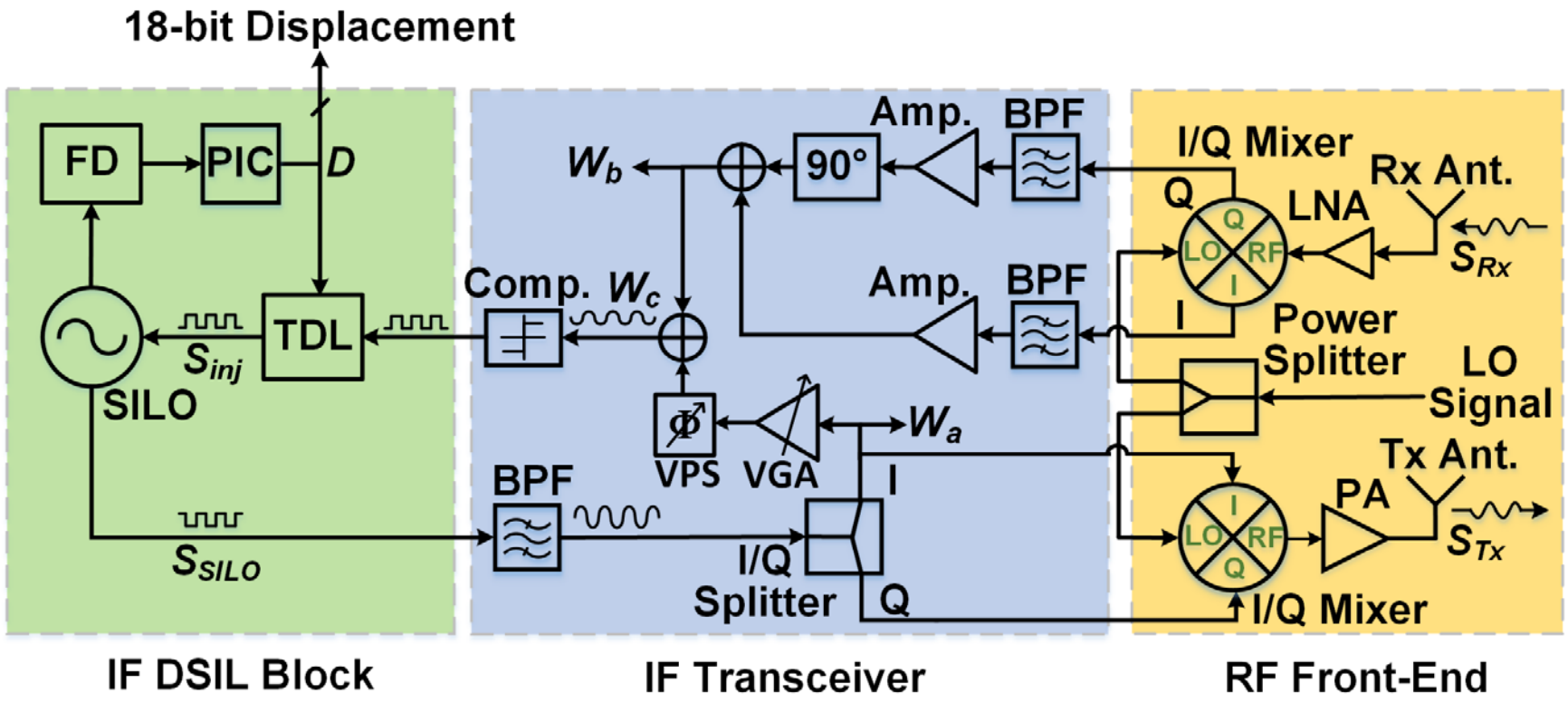


- **Requirement**
  - High image rejection
  - High sampling rate
- **Sophisticated signal processing**
  - I/Q mismatch
  - DC offset compensation
  - Arctangent demodulation
  - Phase unwrapping

ASIC

Proposed Radar Architecture

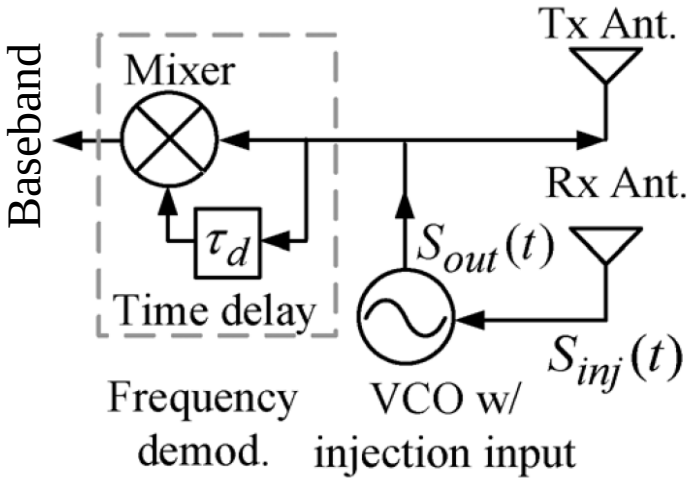
Digital self-injection-locked (DSIL) based low-IF Doppler radar



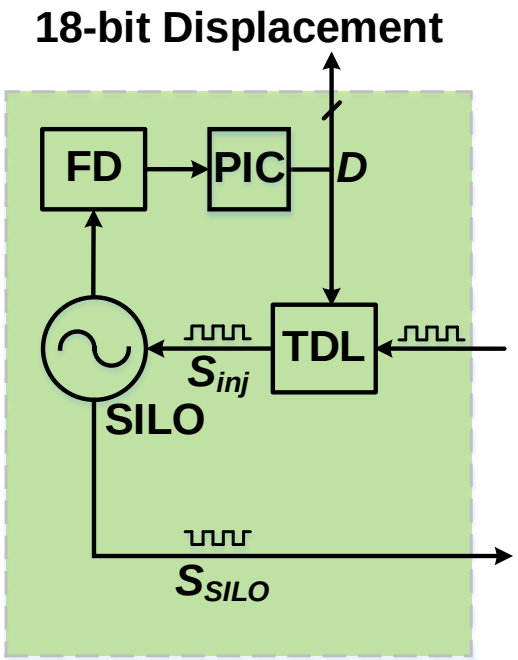
- RF front-end
  - High IRR
- IF transceiver
  - Clutter canceller
- IF SDIL unit
  - High linearity benefits from a DLL-controlled digital TDL
  - High Doppler sensitivity

Key Parameter of Doppler Sensitivity

Sensitivity		
Analog	Carrier freq.	
	Locking range	
	Delay line in FD	
Digital	Carrier freq.	
	Locking range	
	Delay line in FD	
	IF freq.	
	System clk	



[1]



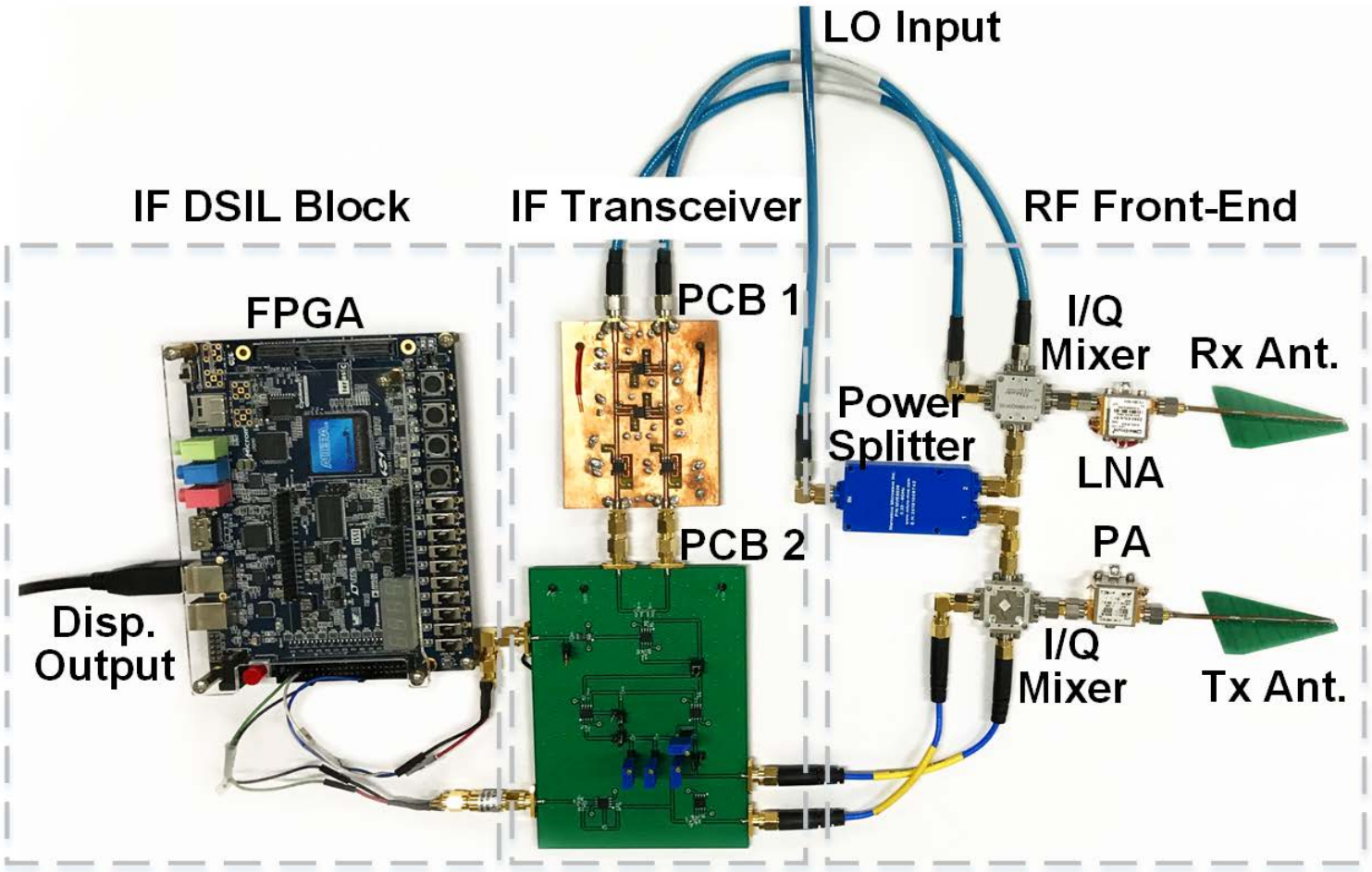
$$G_{SNR}(s) = \left| \frac{\omega_{LR} \cos \alpha_{inj}}{s} \right|^2$$

$$\Delta D_{\min} = \frac{f_{IF} T_{CLK} c}{2 f_{RF}}$$

Analog SIL radar | **Digital SIL radar**

[1] F.-K. Wang *et al.*, "A novel vital-sign sensor based on a self-injection-locked oscillator," *IEEE Trans. Microw. Theory Techn.*, vol. 52, no. 12, pp. 4112-4120, Dec. 2010.

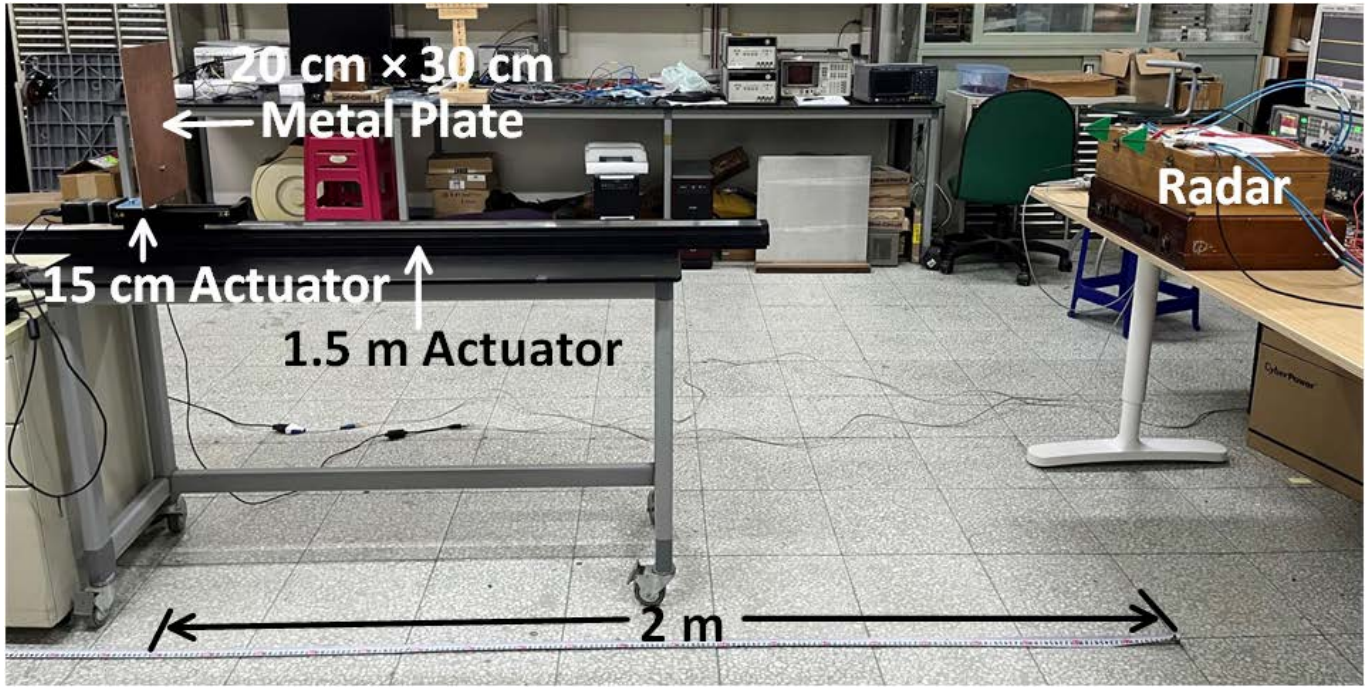
Implementation of the Radar



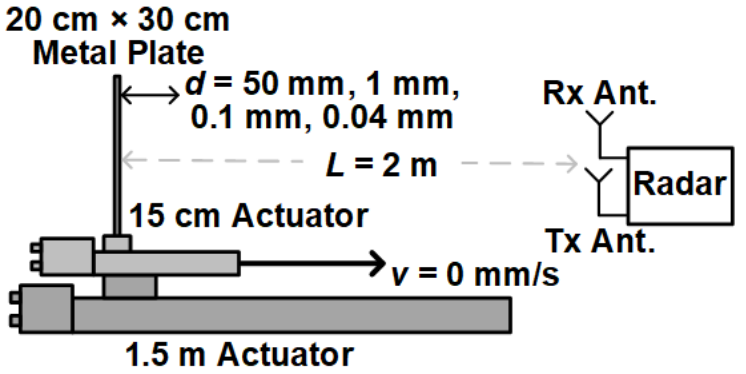
Tx freq.	5.8 GHz
IF freq.	40 kHz
Tx power	0 dBm
Total IRR	~76 dB
Total harmonic distortion	< 1.2 %
Displacement resolution	20.7 µm

Performance Evaluation

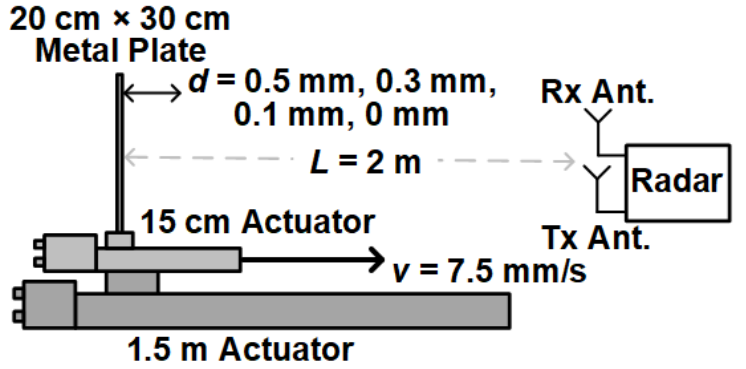
Experimental Setup



1) Clutter cancellation & vibration sensitivity



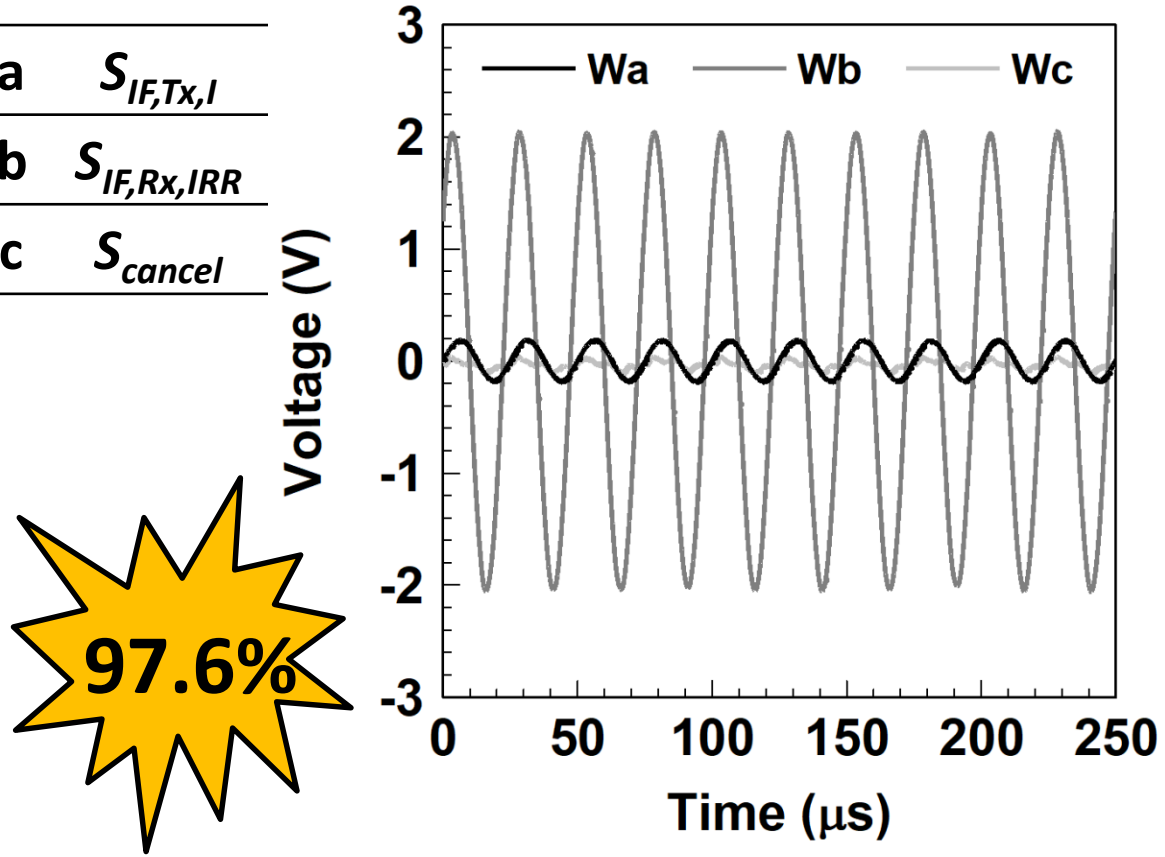
2) Vibration sensitivity under 1-D constant velocity motion



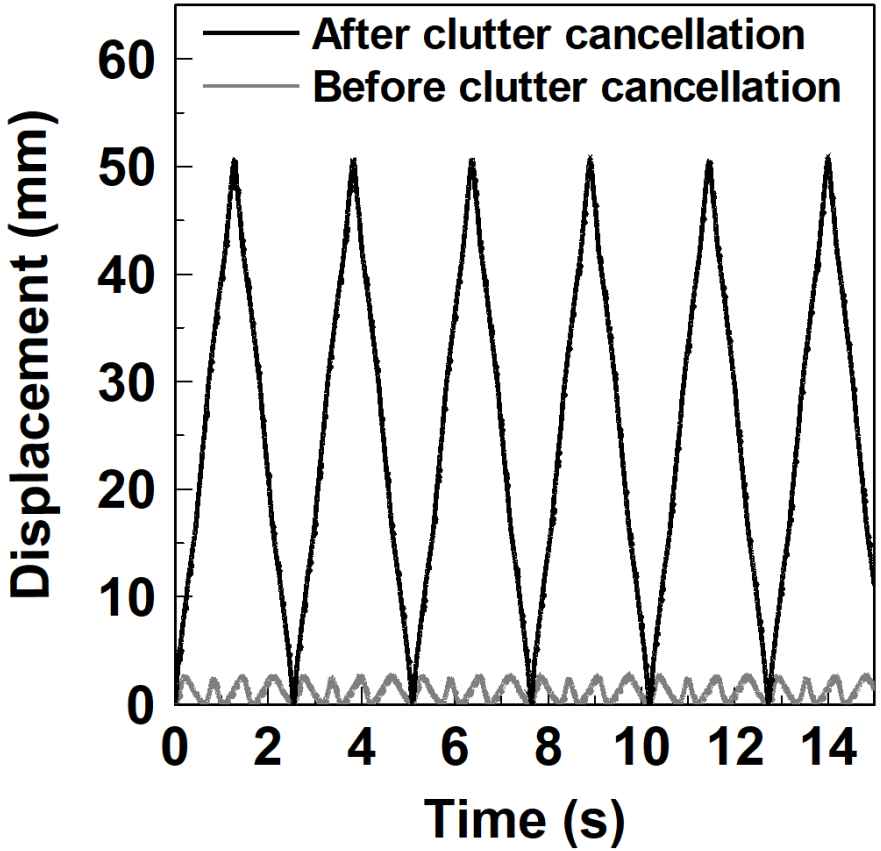
Evaluation Result (1-I)

IF signal waveform during the clutter cancellation process

Wa	$S_{IF,Tx,I}$
Wb	$S_{IF,Rx,IRR}$
Wc	S_{cancel}

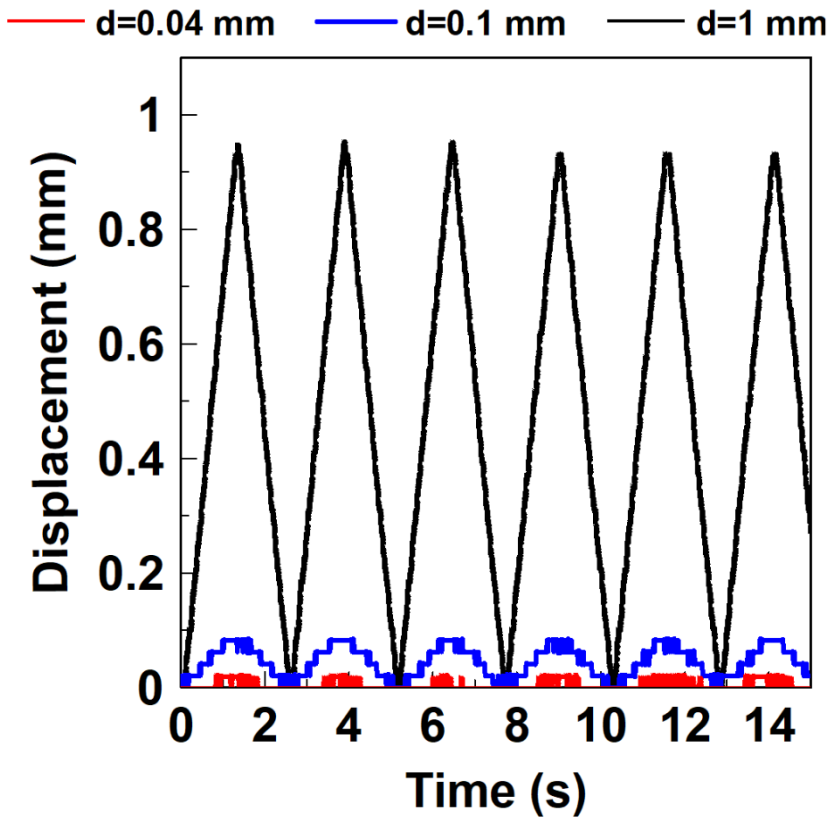


Baseband displacement waveform before/after cancellation

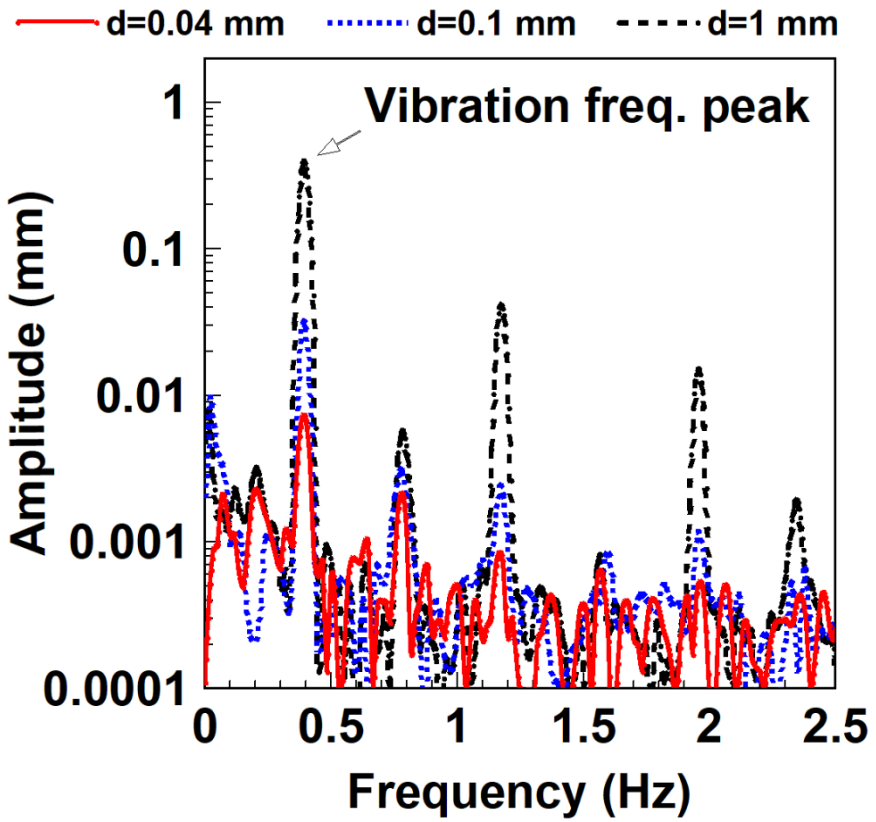


Evaluation Result (1-II)

Vibration sensitivity test under various displacement



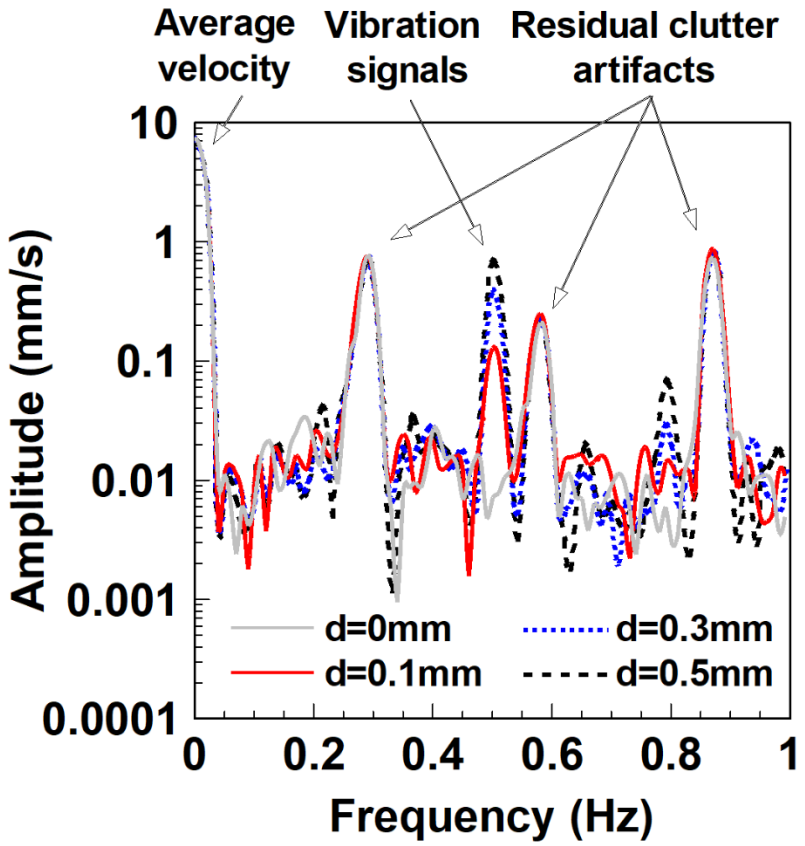
FFT

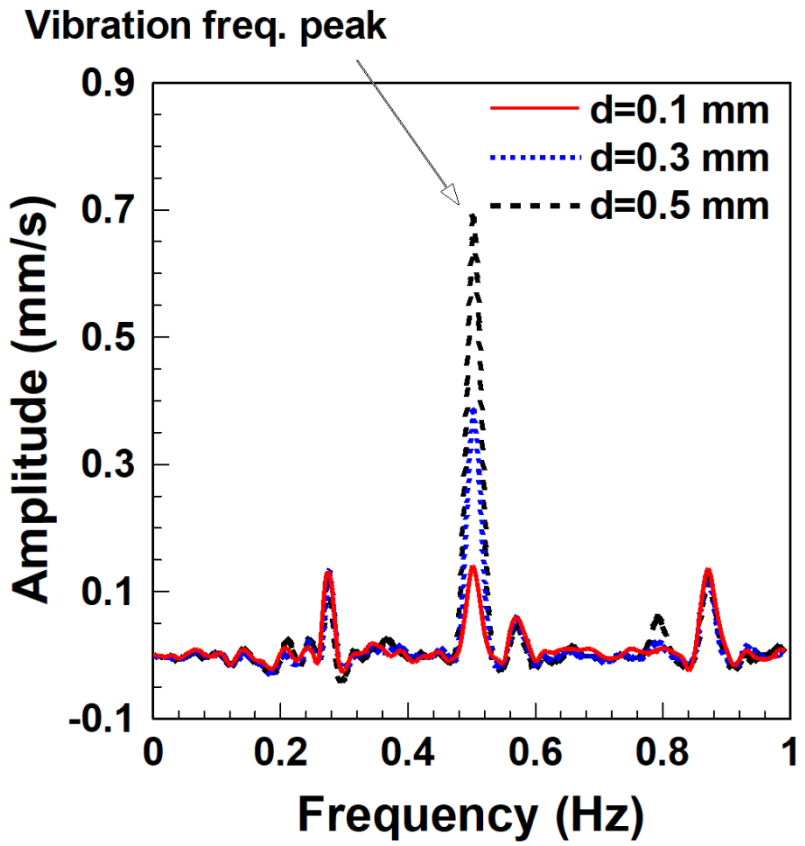


- **Theoretical**
  $\Delta D_{\min} = 20.7\ \mu\text{m}$
- **Measured**
  $\Delta D_{\min} = 40\ \mu\text{m}$
- **Quantization noise/jitter**

Evaluation Result (2)

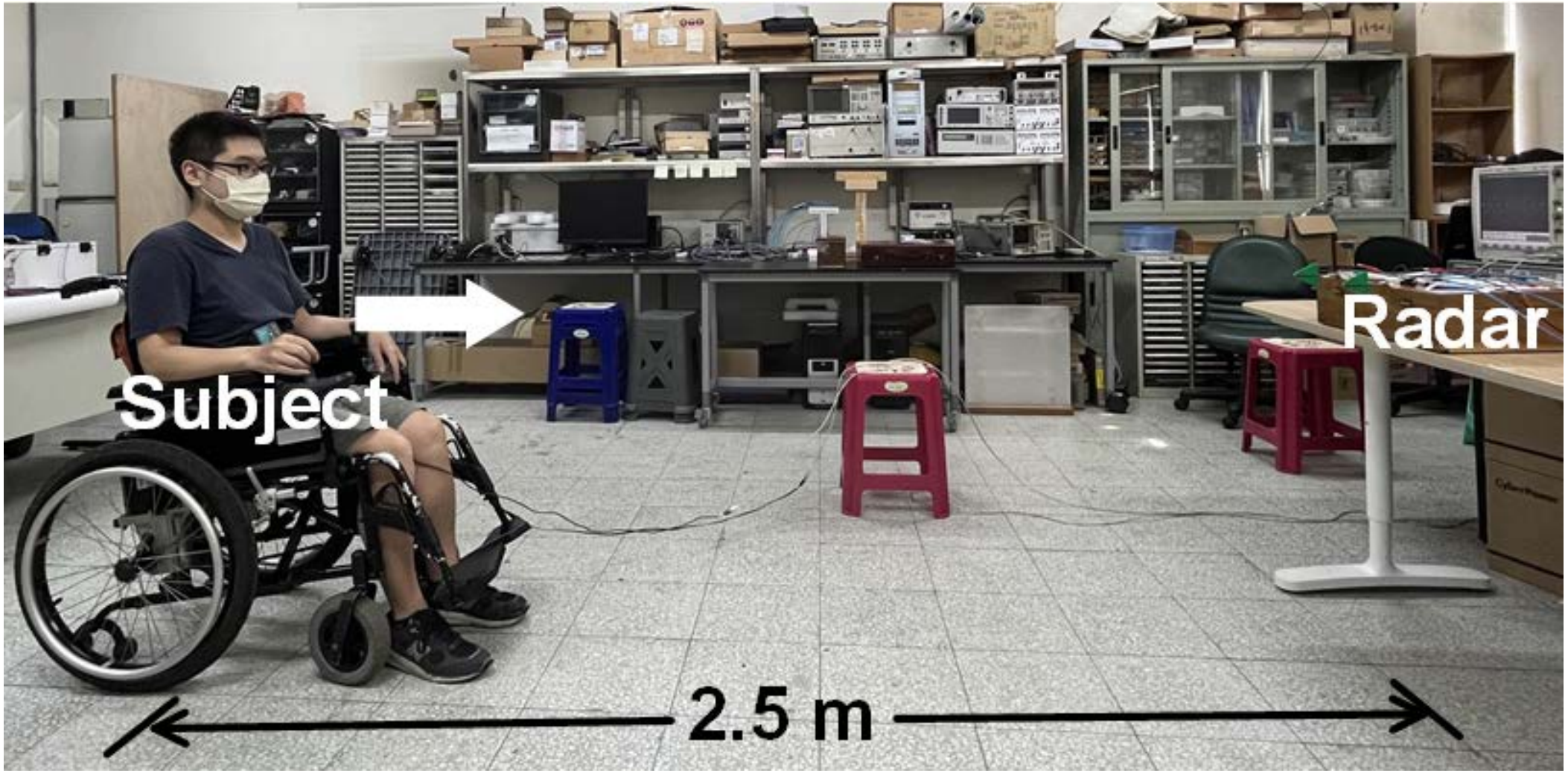
Vibration sensitivity test with various displacement under 1-D constant velocity motion



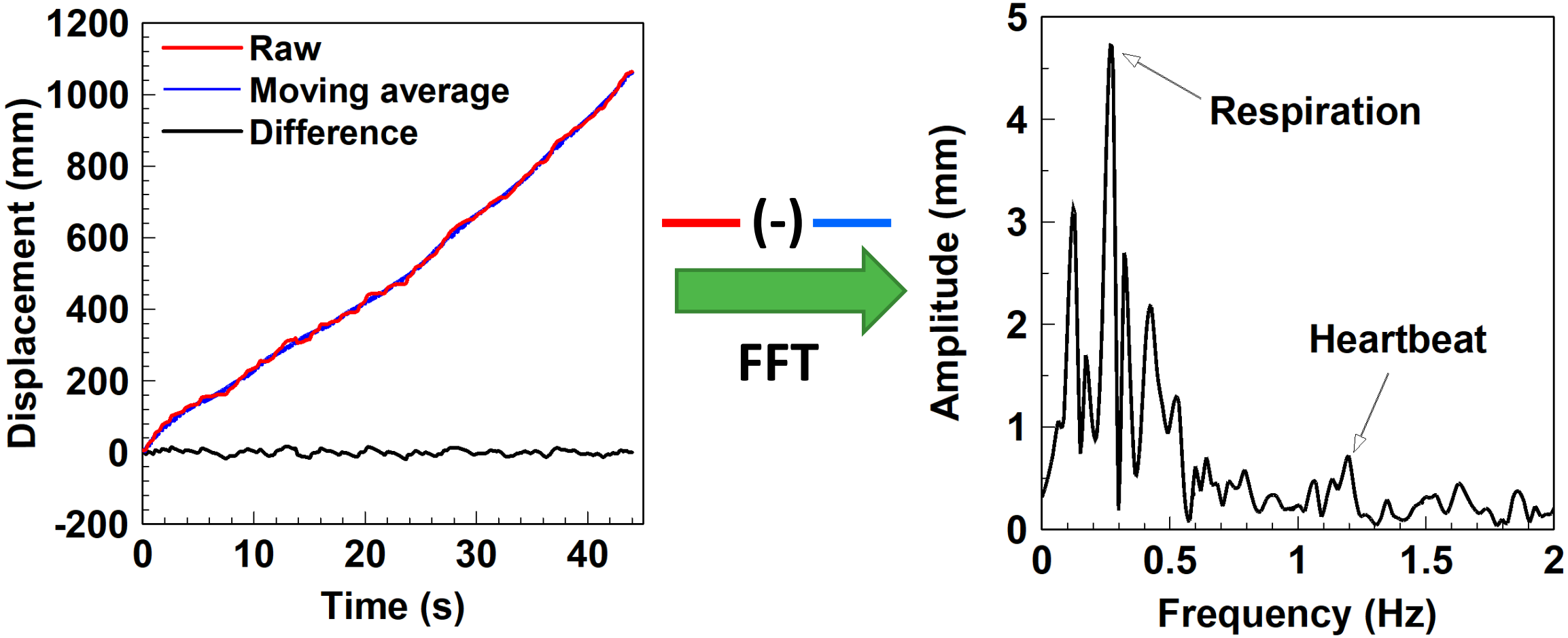


- Detectable displacement can be smaller than 0.1 mm while moving several wavelengths
  - High linearity
  - High sensitivity

Vital Signs Monitoring for A Moving Subject



Experimental Result



Conclusion

- This work introduces the clutter canceller into the low-IF digital SIL radar to deal with the strong environment clutter from using a wide beamwidth antenna
  - The clutter cancellation ratio is up to 97.6%
  - Recover the distortion due to the clutter
  - High linearity and high sensitivity

- The proposed low-IF digital SIL radar successfully monitors the vital signs of a human subject when he moves at a constant velocity for several wavelengths