

RadSee: See Your Handwriting Through Walls Using FMCW Radar

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Michigan State University

NDSS 2025



MICHIGAN STATE
UNIVERSITY

Background

- Can we see through the wall?

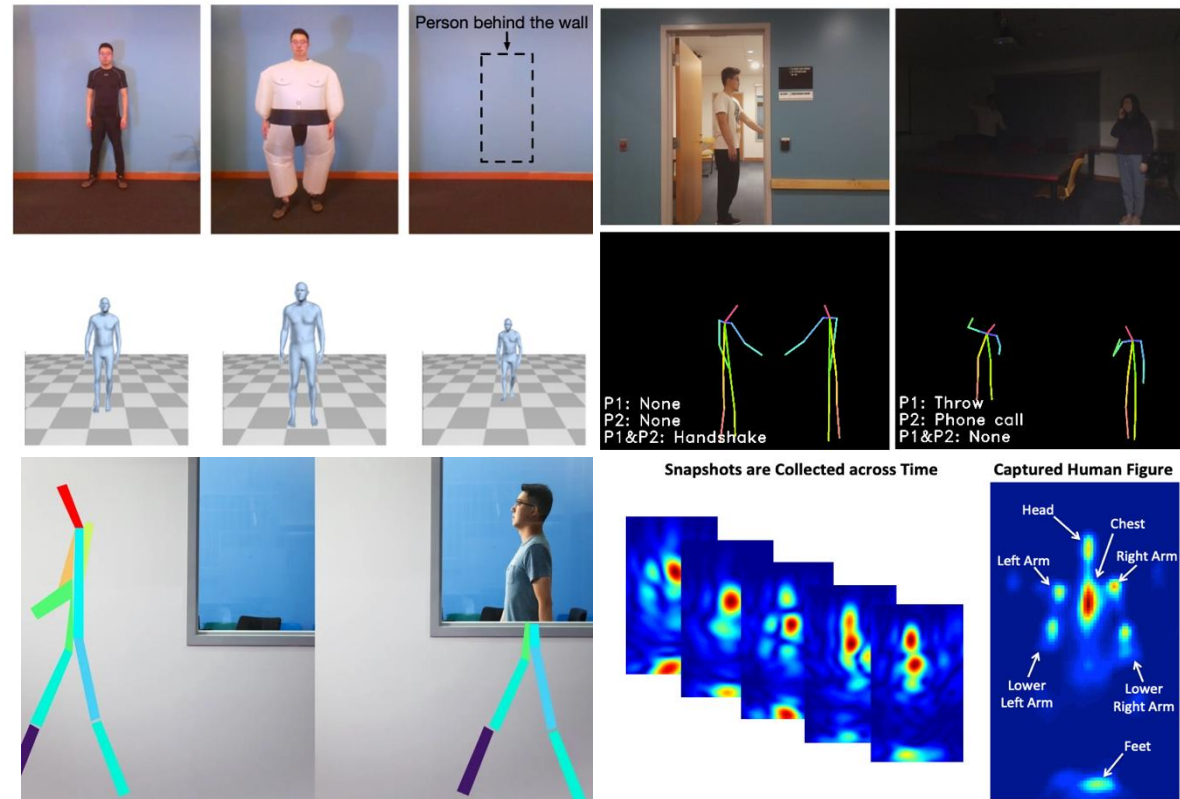
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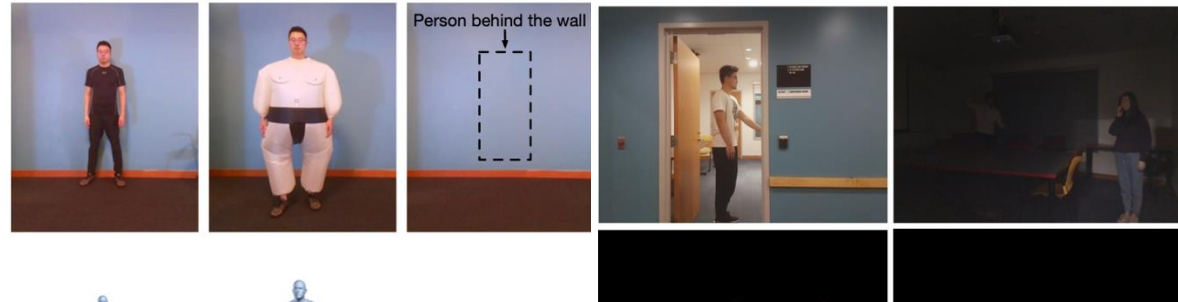
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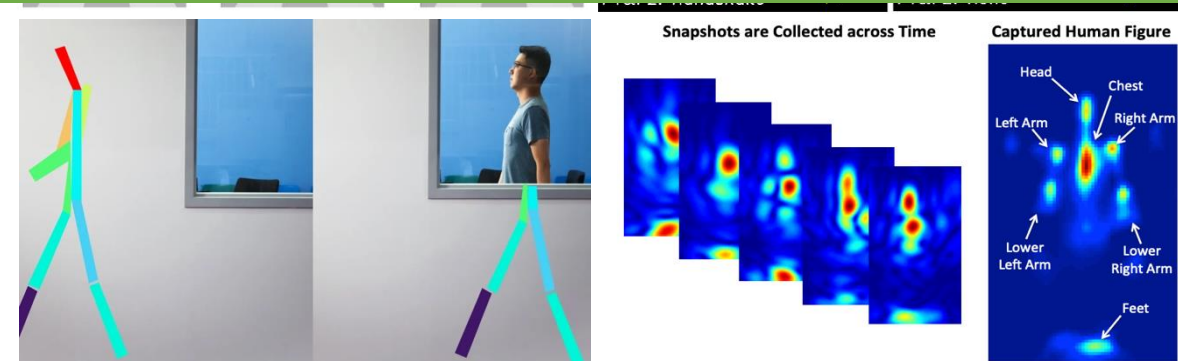
Existing work from MIT CSAIL

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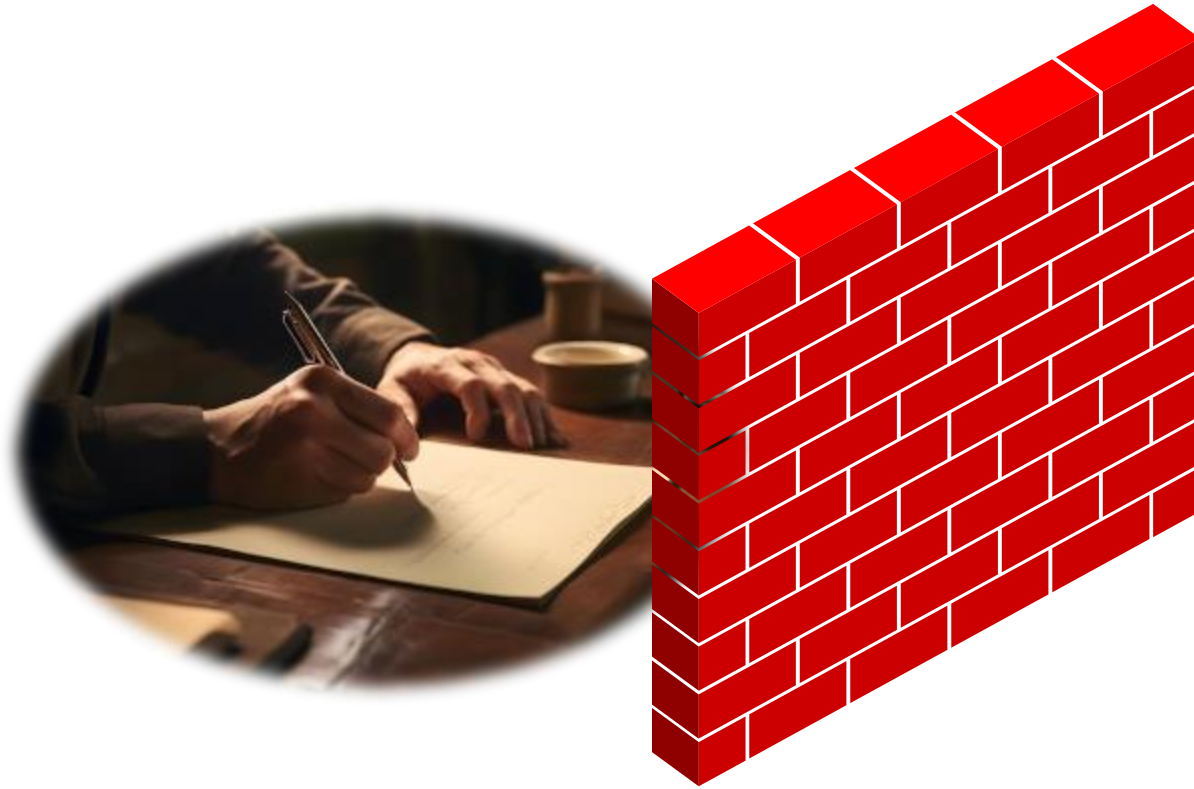
Can we get other information?



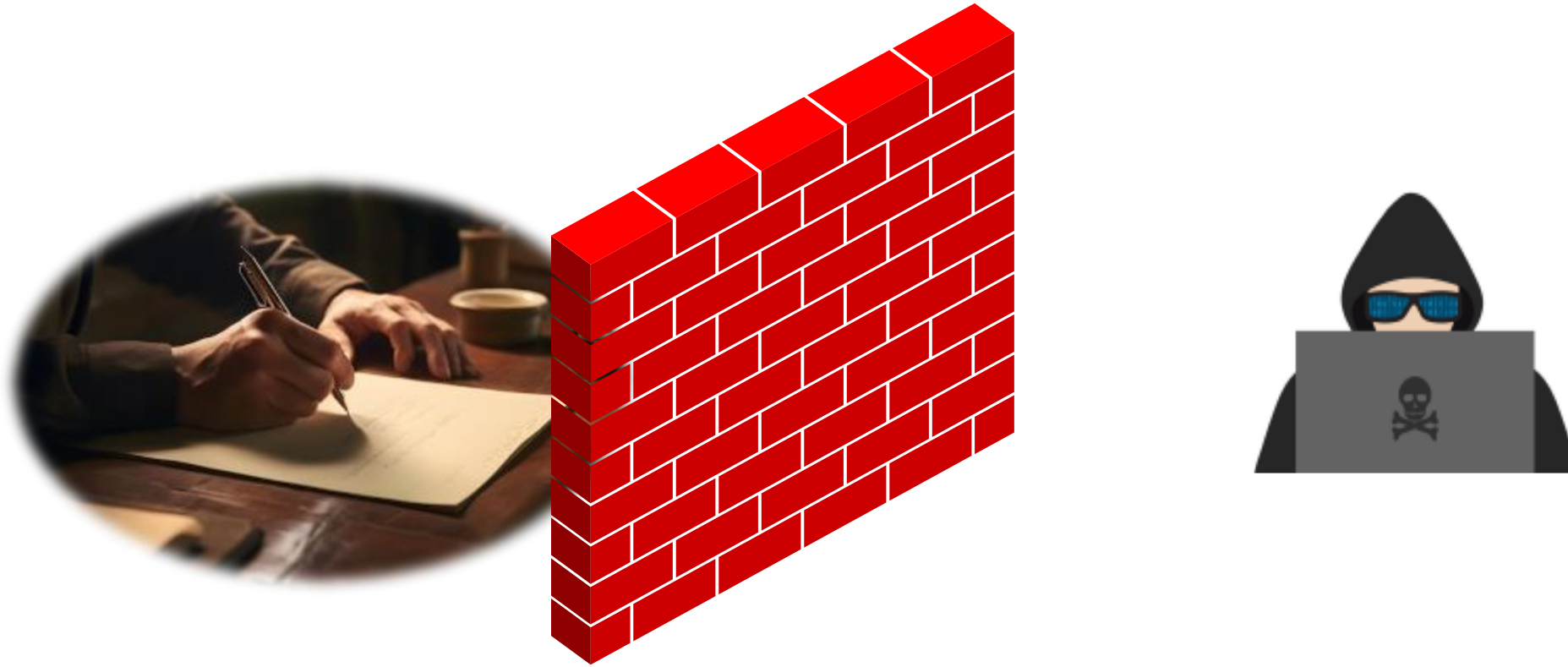
Existing work from MIT CSAIL

Attack Model

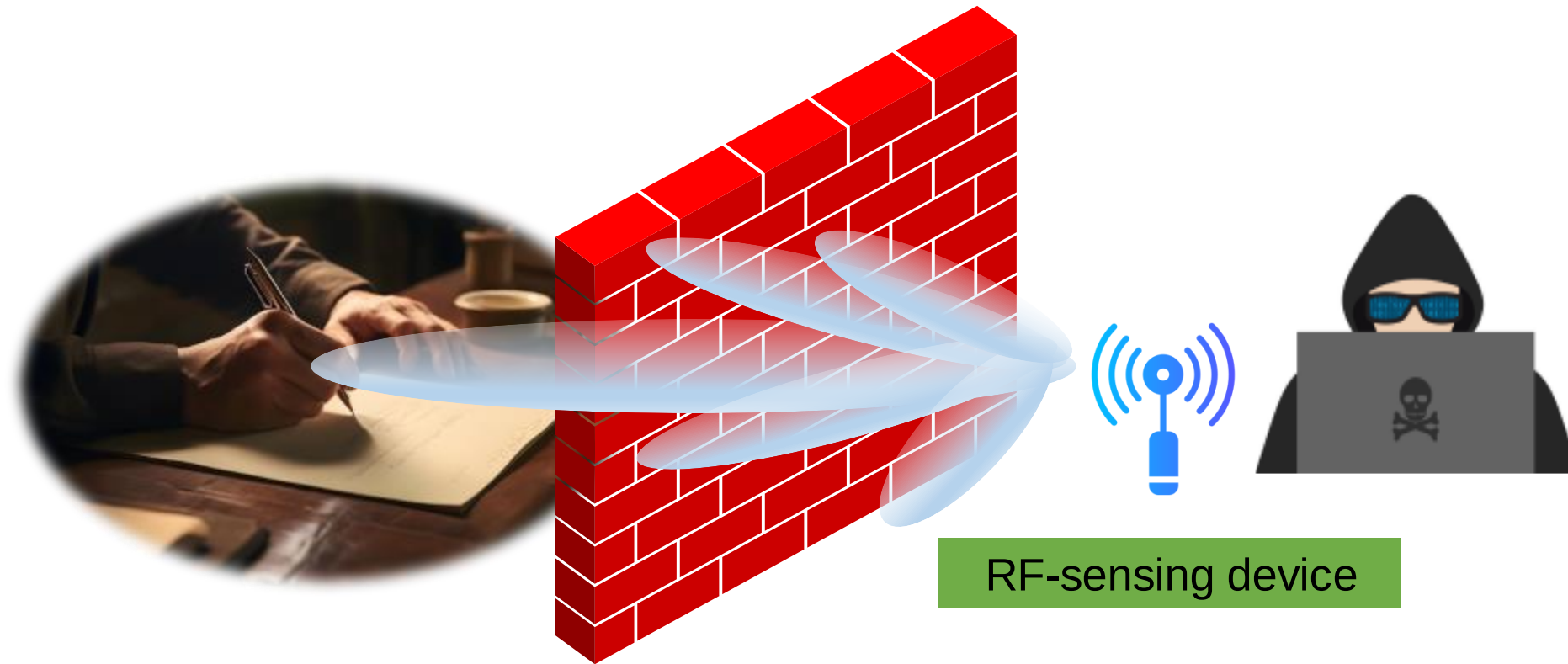
Attack Model



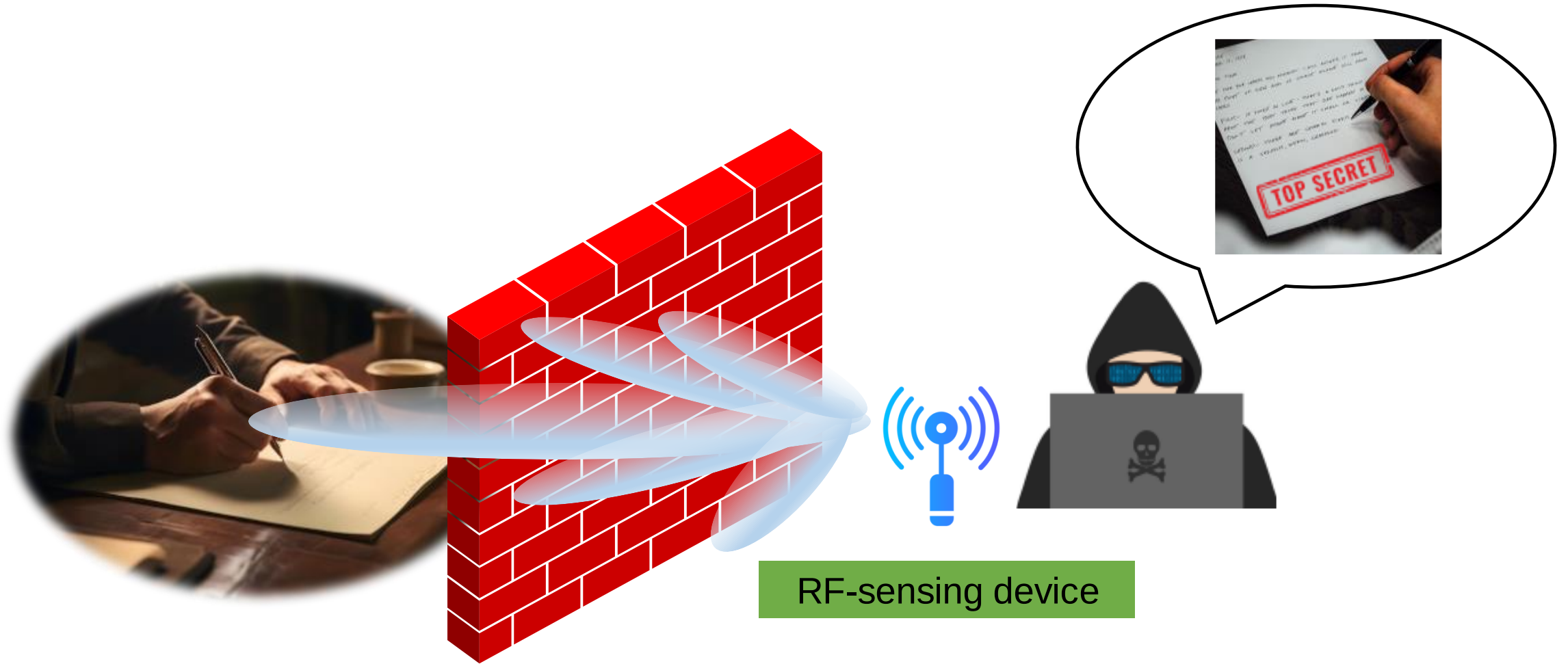
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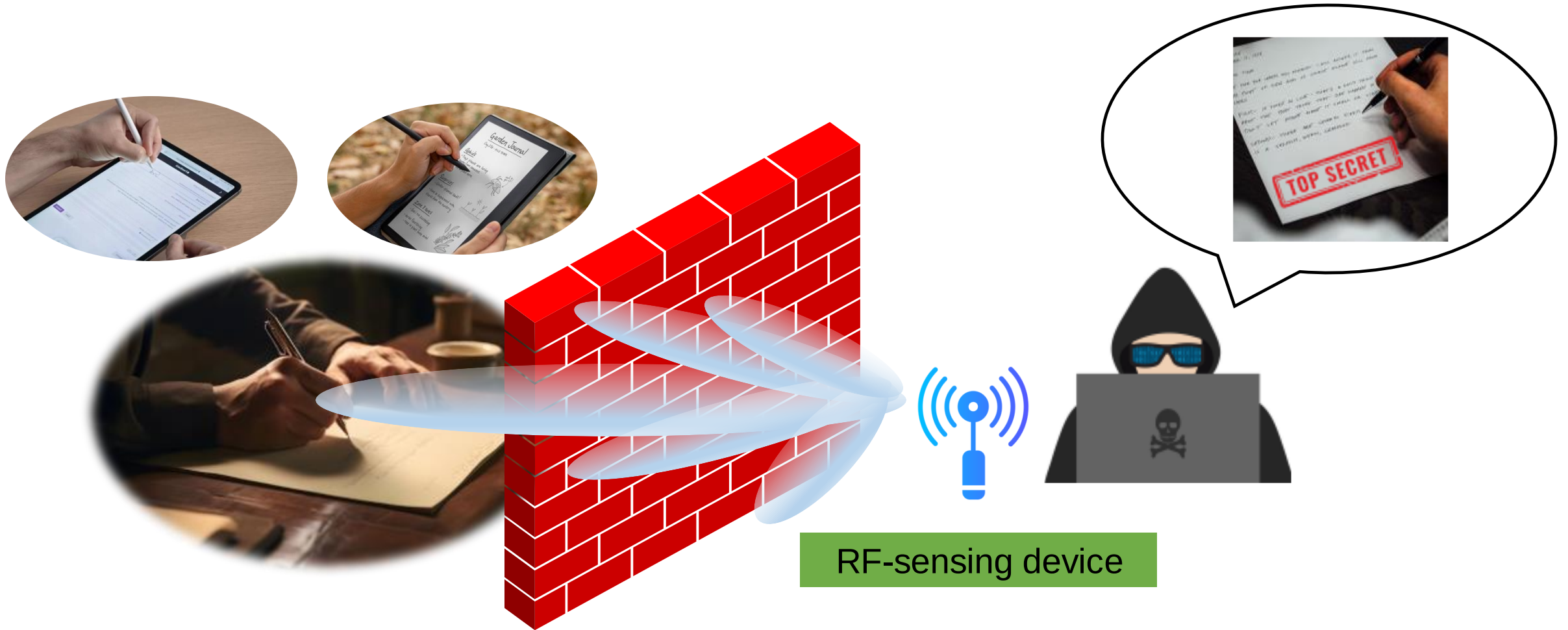
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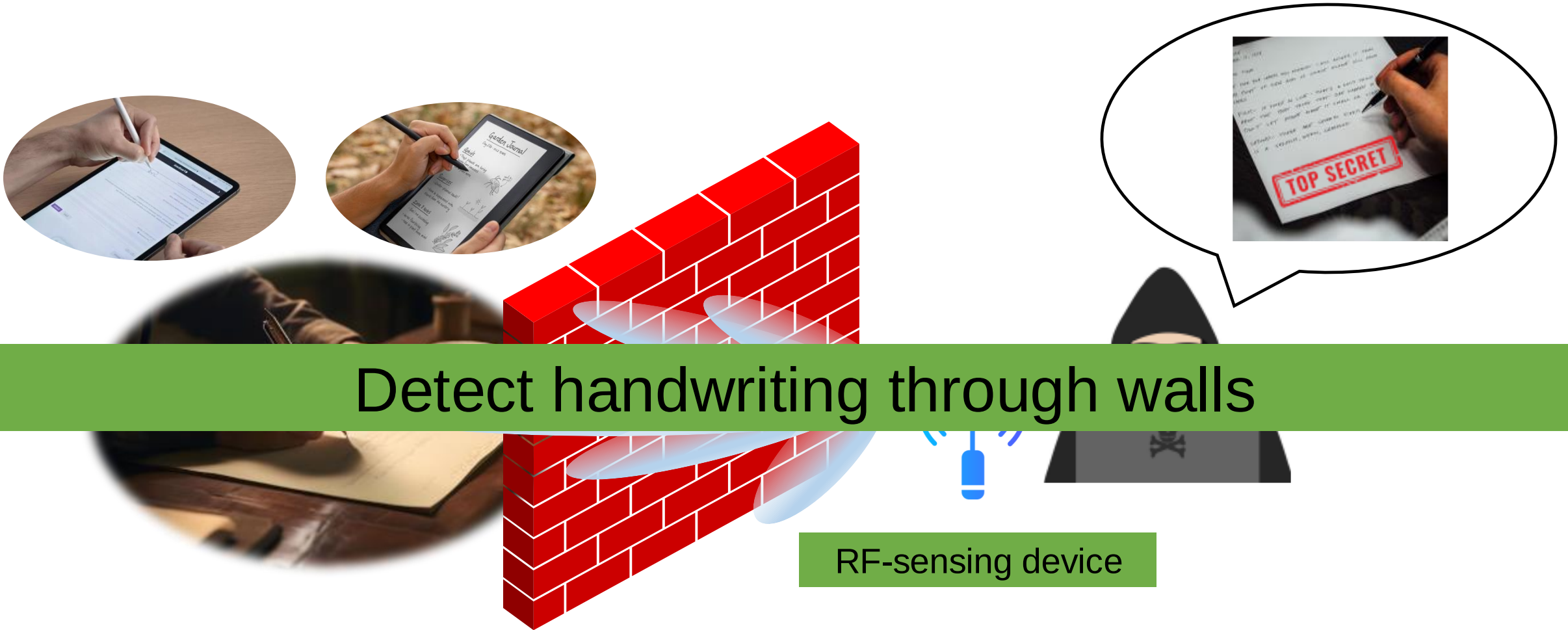
Attack Model



Attack Model



Attack Model



Detect handwriting through walls

RF-sensing device

Attack Model

Attack Model

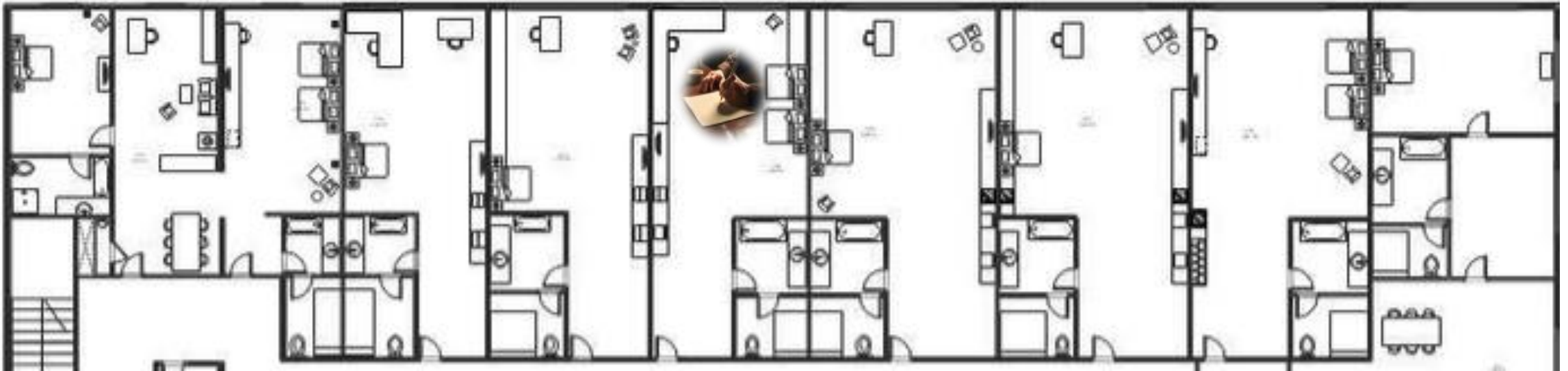
- Attacker's assumption
 - Has physical access to the space behind the wall

Attack Model

- Attacker's assumption
 - Has physical access to the space behind the wall
 - Knows the layout of the room and the approximate location of the victim

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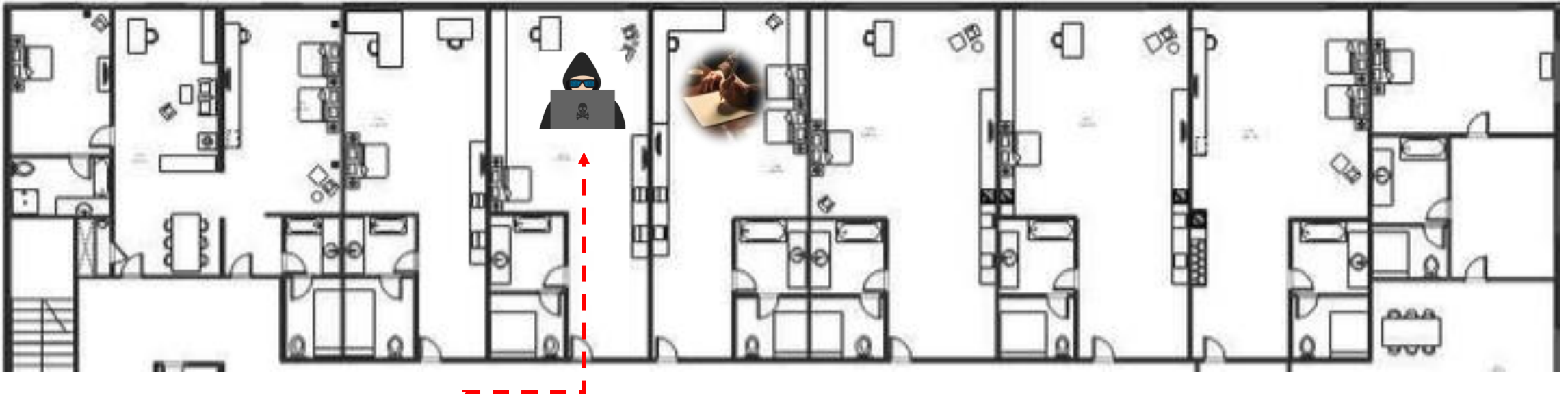
Attack Model

- Attacker's assumption
 - Has physical access to the space behind the wall
 - Knows the layout of the room and the approximate location of the victim



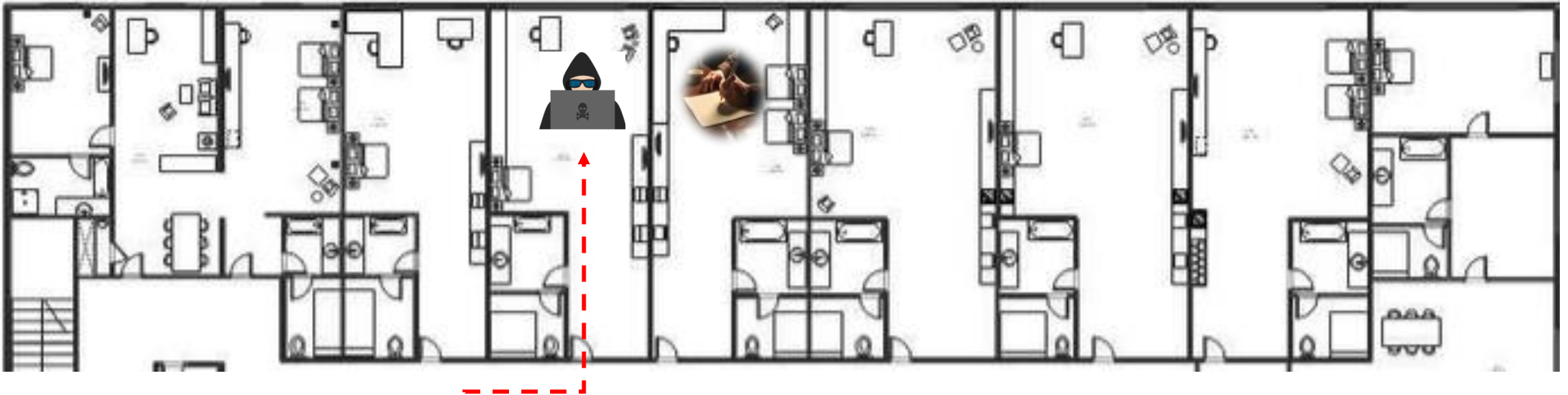
Attack Model

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Attack Model

- Attacker's assumption
 - Has physical access to the space behind the wall
 - Knows the layout of the room and the approximate location of the victim
 - No RF-shielding materials



Background

- Existing solution

Background

- Existing solution

Vision-based solution



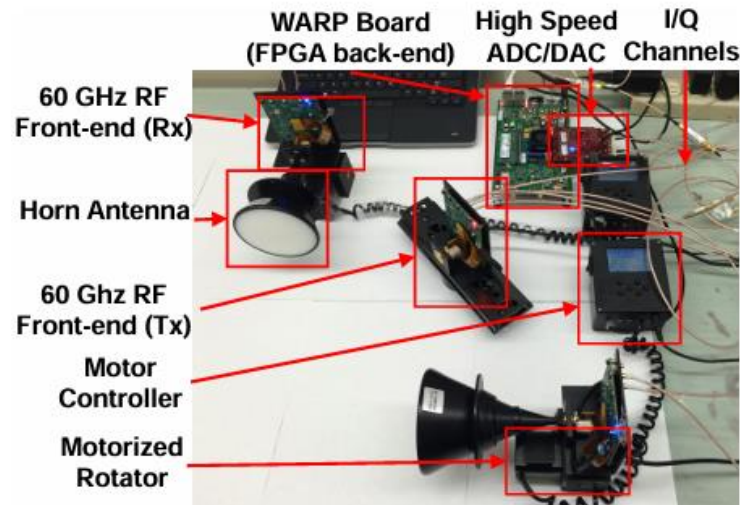
Background

- Existing solution

Vision-based solution



mmWave-based solution



(Wei et al. mTrack@MobiCom '15)

Not through-the-wall

Background

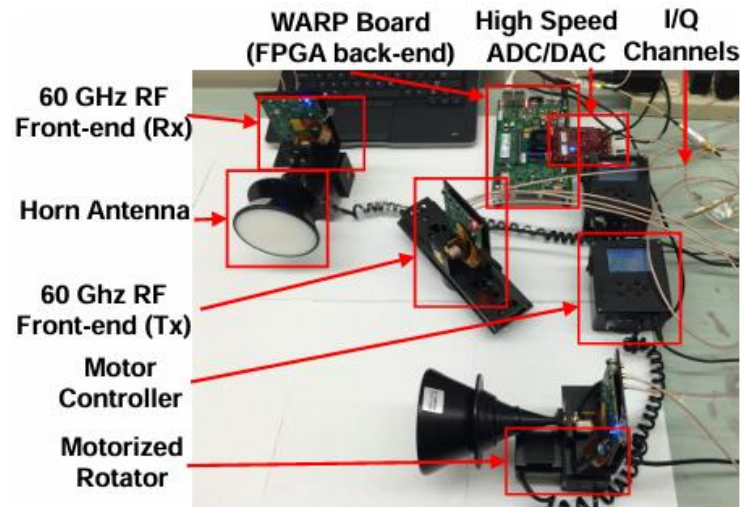
- Existing solution

Vision-based solution



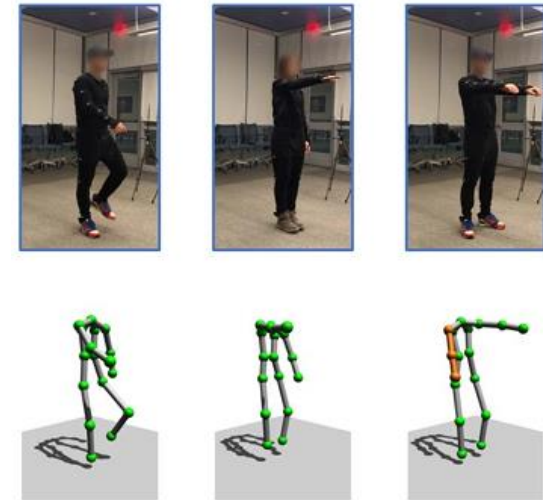
Not through-the-wall

mmWave-based solution



(Wei et al. mTrack@MobiCom '15)

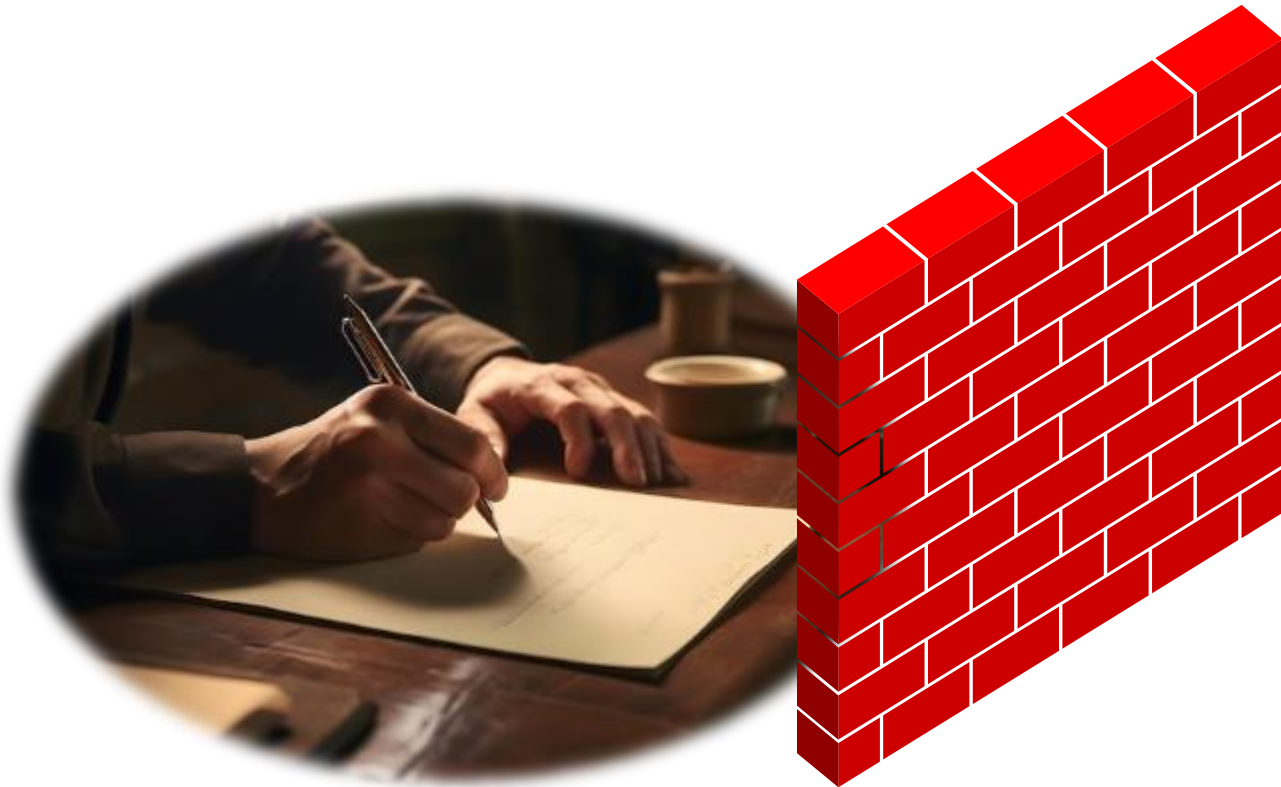
WiFi-based solution



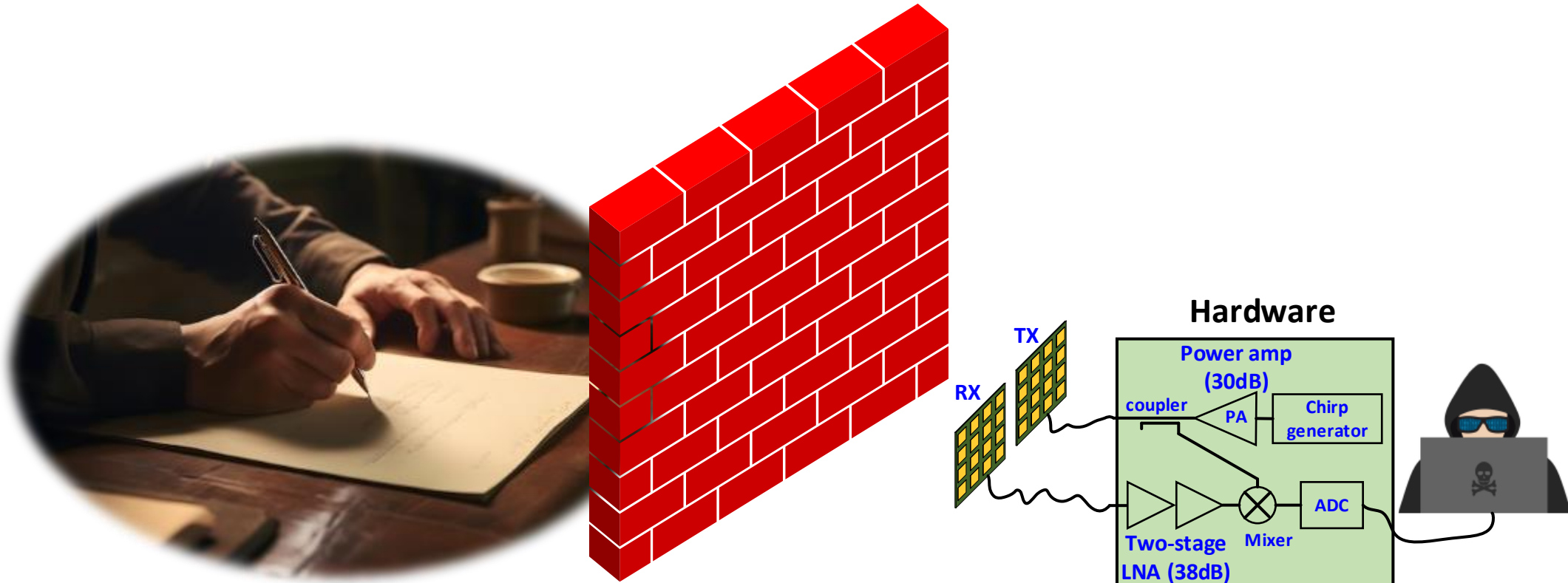
(Jiang et al. WiPose@MobiCom '20)

Not enough resolution

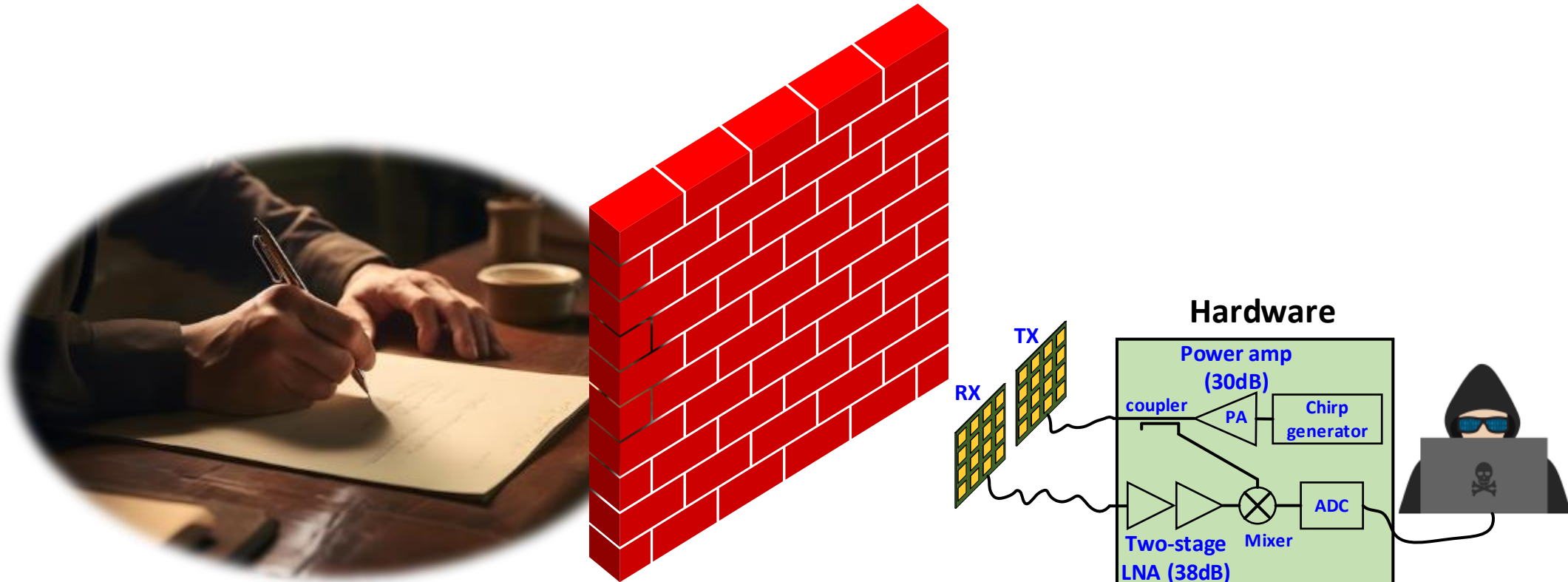
Our work: RadSee



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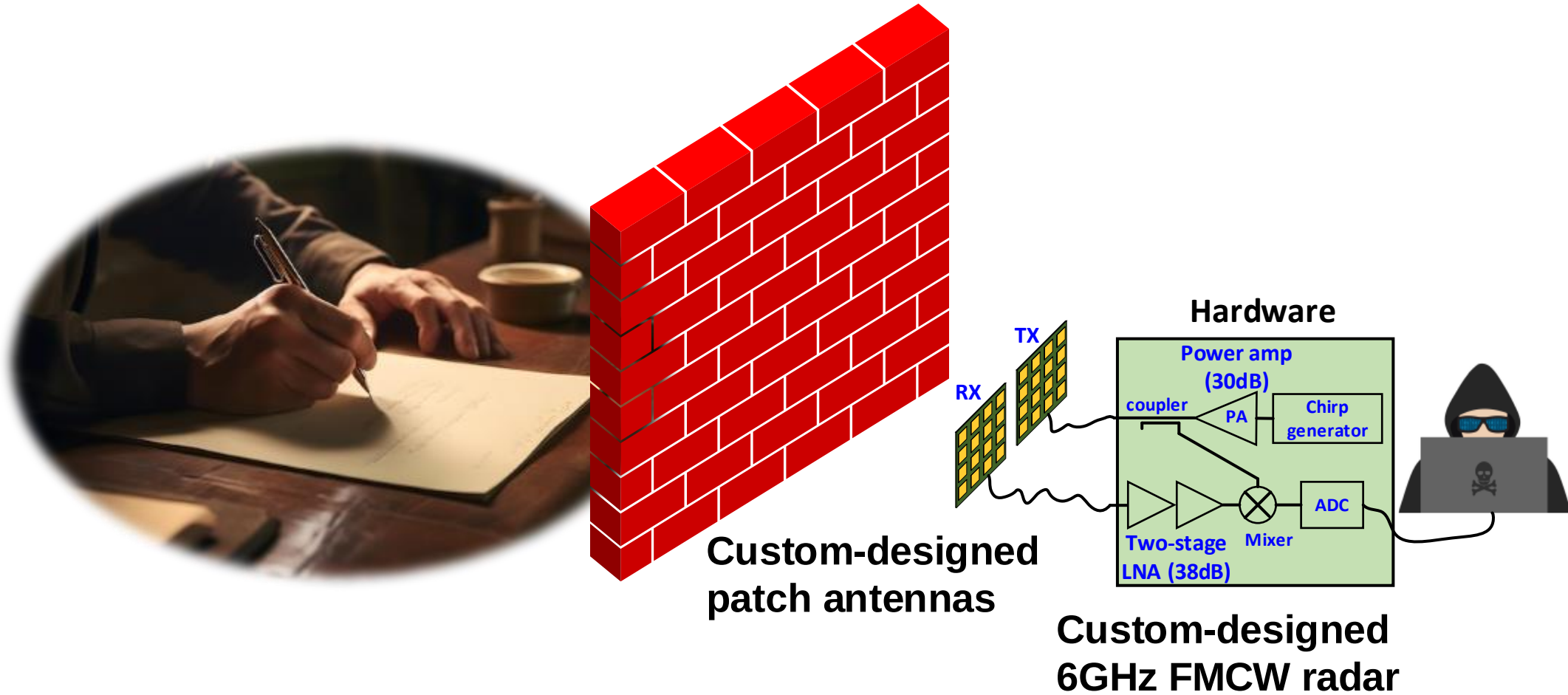


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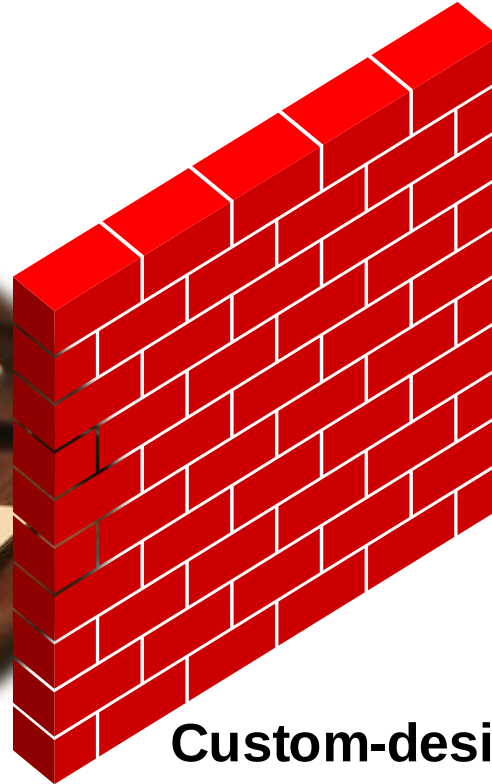


Custom-designed
6GHz FMCW radar

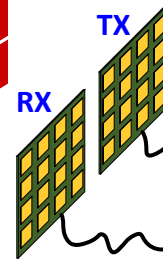
Our work: RadSee



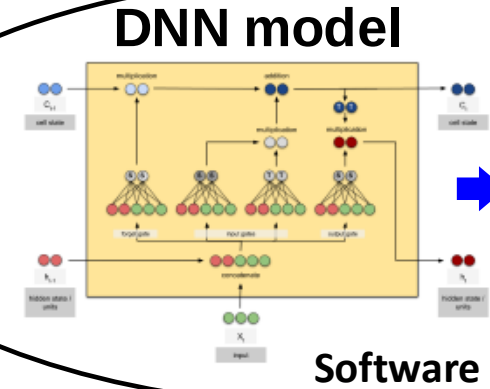
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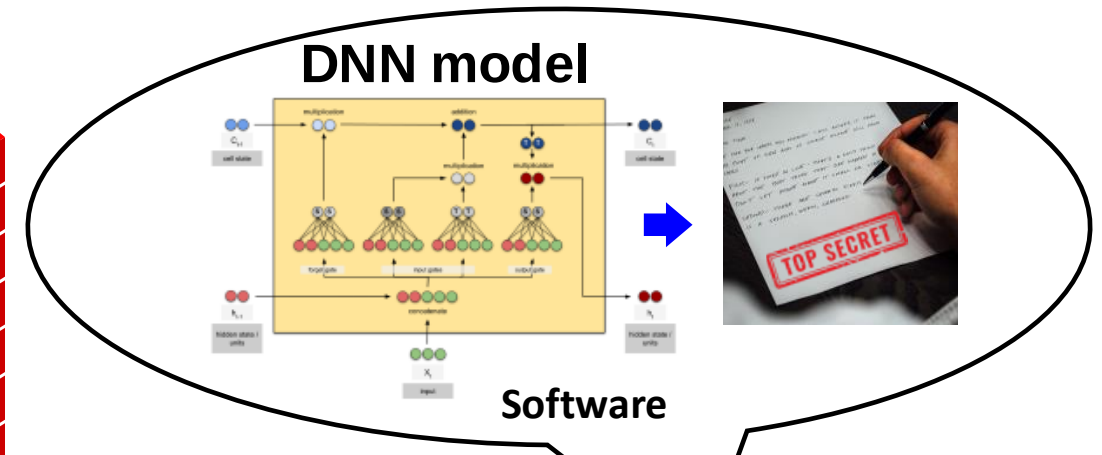
Custom-designed
patch antennas



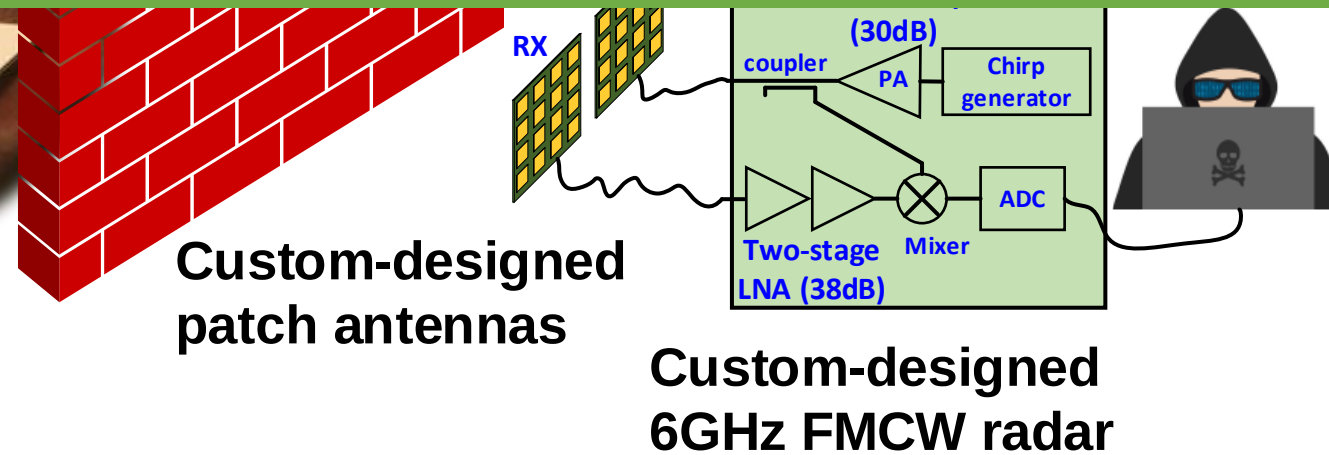
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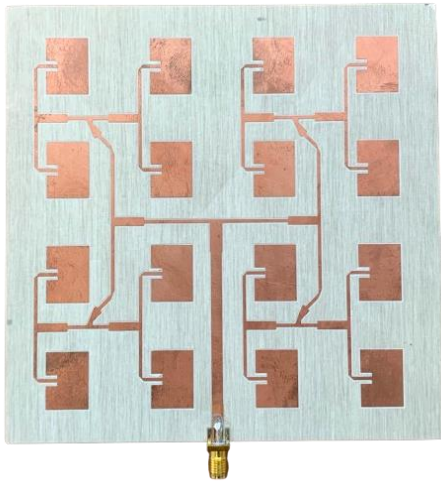
Hardware + Software!



Hardware

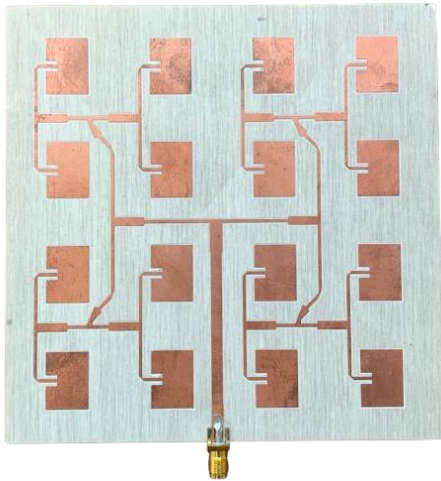
Hardware

- Patch antenna



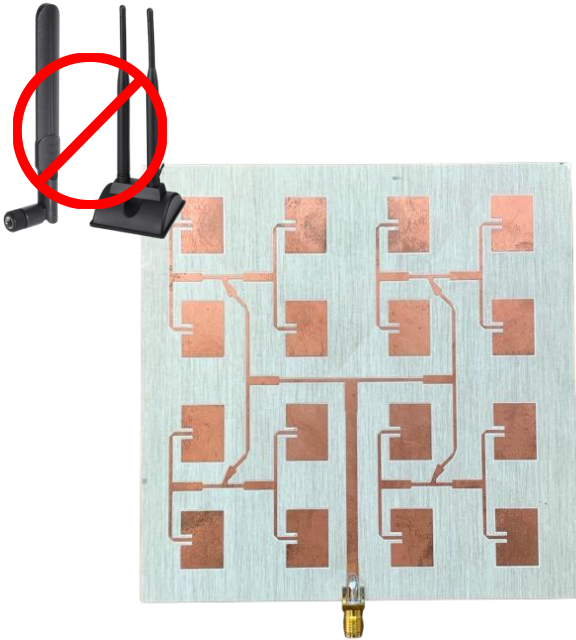
Hardware

- Patch antenna
 - 18dBi antenna gain



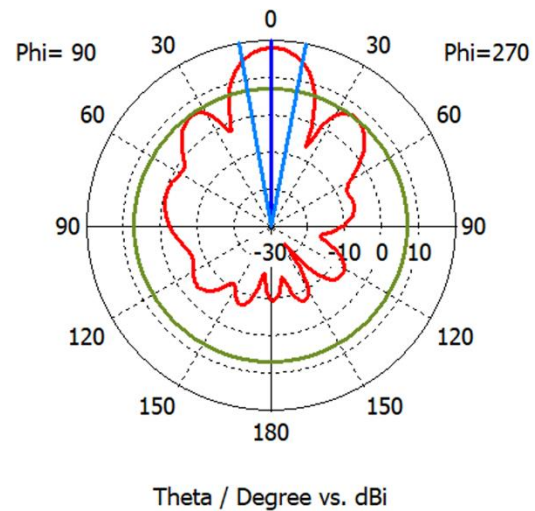
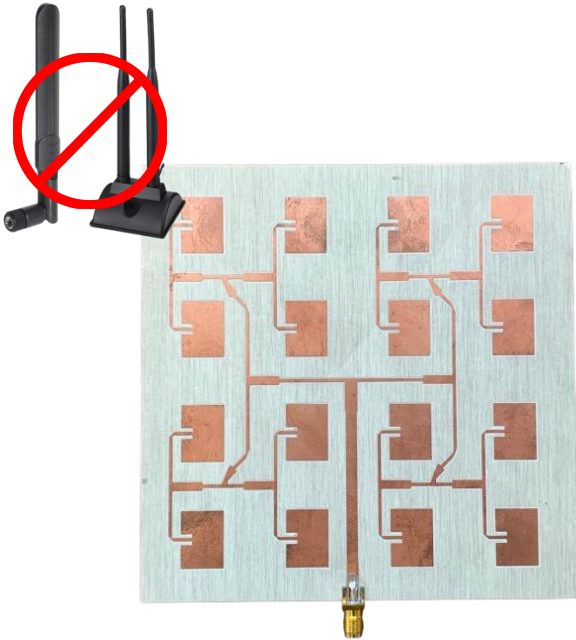
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Hardware

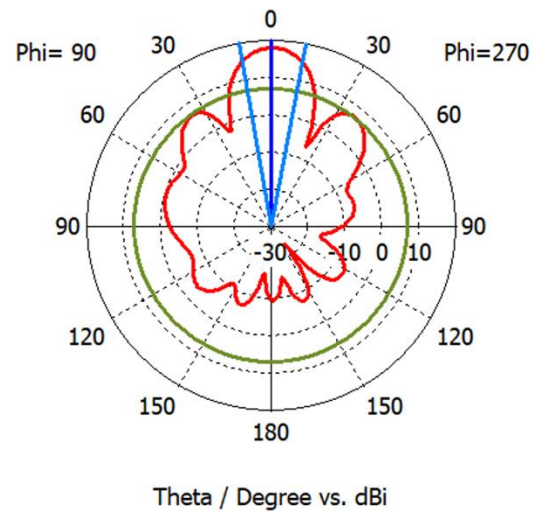
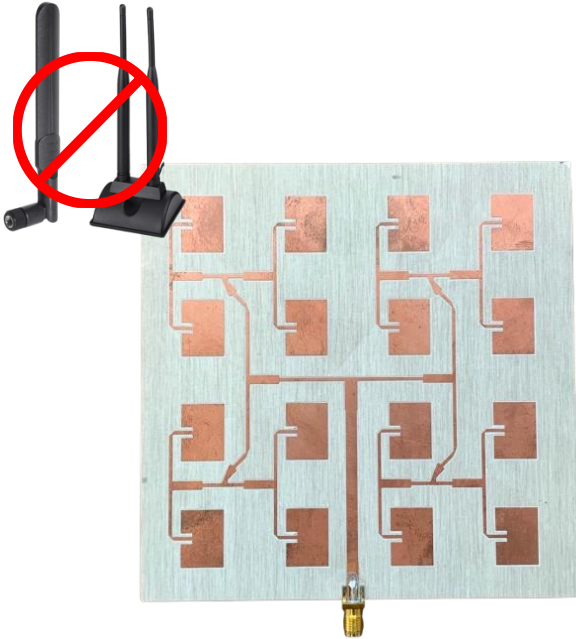
- Patch antenna
 - 18dBi antenna gain
 - Angular filter



Gain pattern of patch antenna

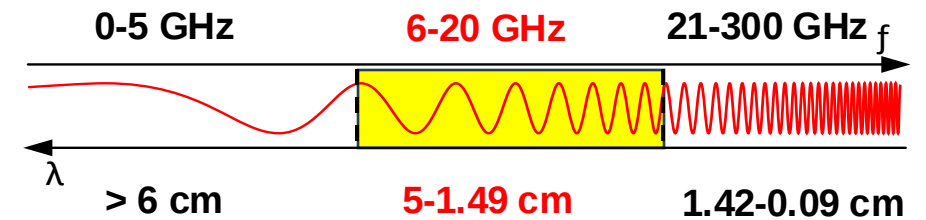
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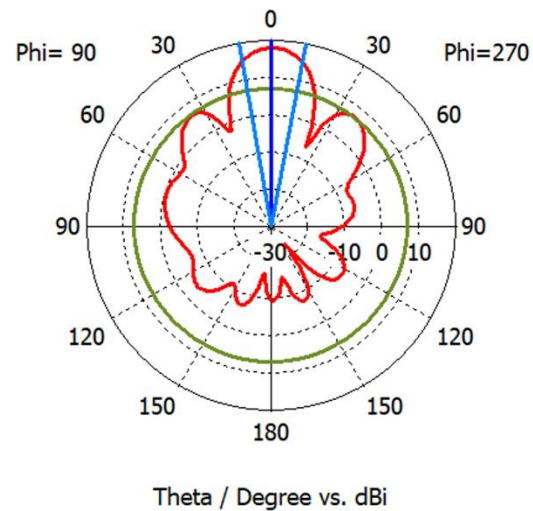
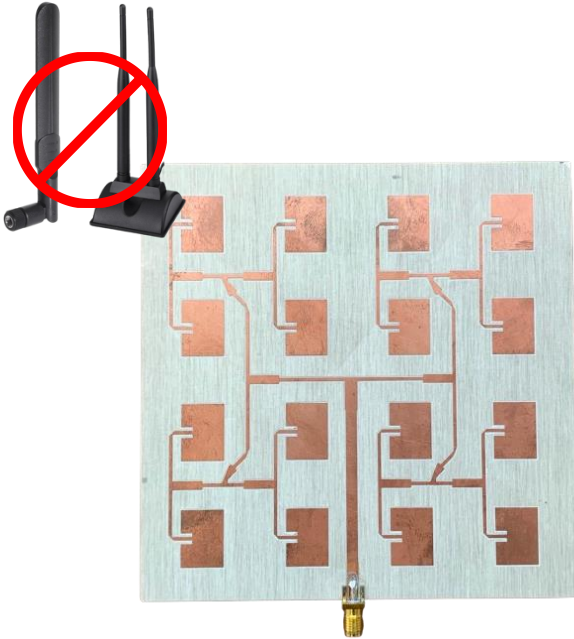
Gain pattern of patch antenna

- 6GHz FMCW radar



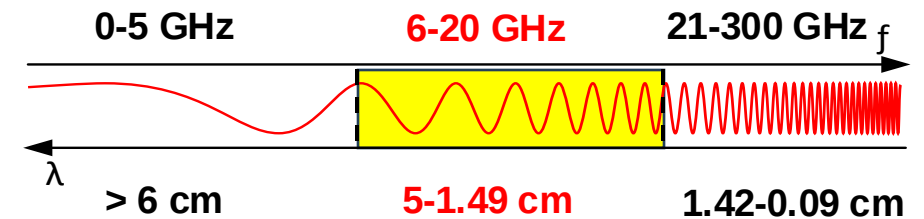
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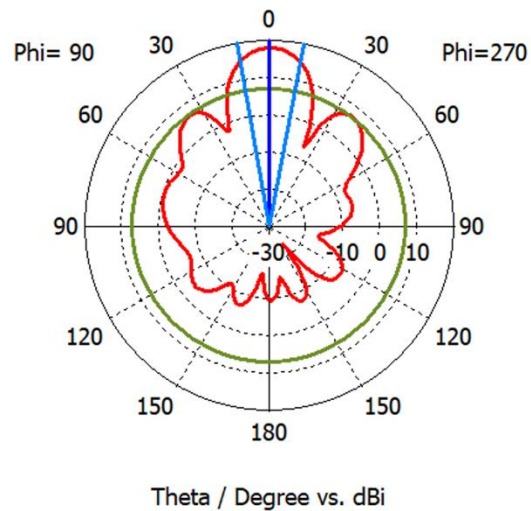
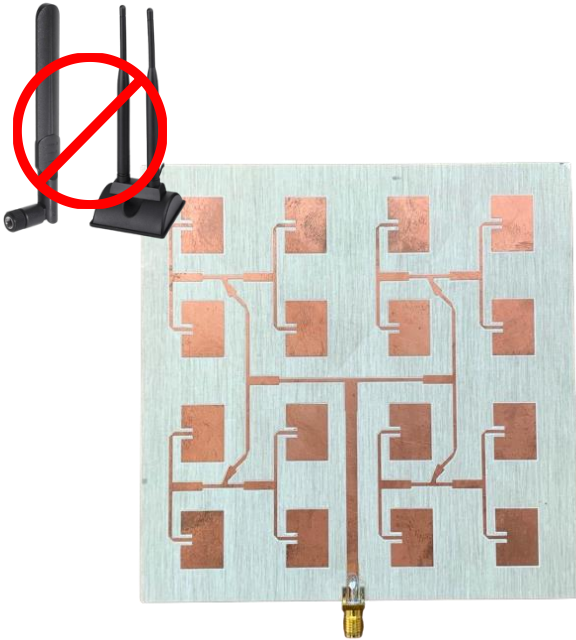
Gain pattern of patch antenna

- 6GHz FMCW radar
 - 6 GHz enables the ability to penetrate through walls



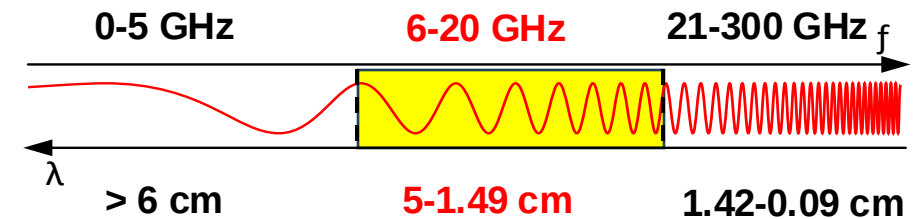
Hardware

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 - Angular filter



Gain pattern of patch antenna

- 6GHz FMCW radar
 - 6 GHz enables the ability to penetrate through walls
 - FMCW serves as distance filter



Hardware

- Patch antenna

- 18dBi antenna gain
- Angular filter

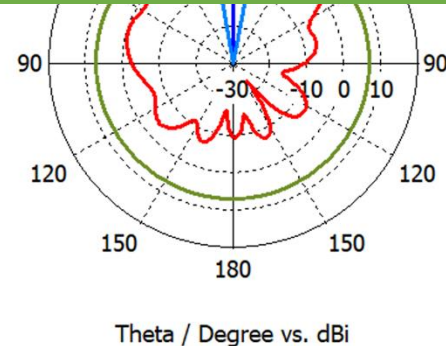
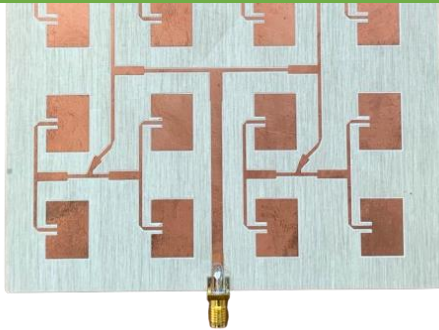


- 6GHz FMCW radar

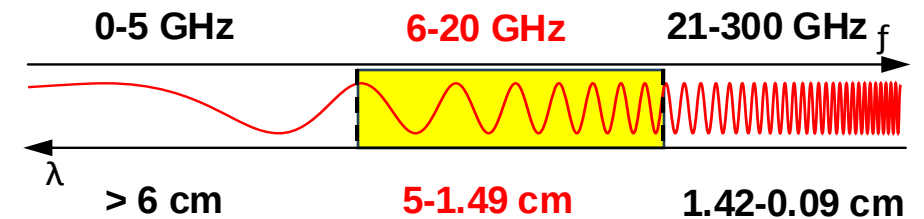
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Through-the-wall detection



Gain pattern of patch antenna

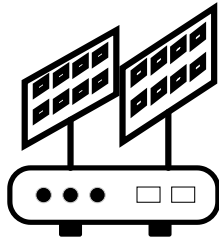


Hardware

- The effect of *patch antenna* + *6GHz FMCW* radar!

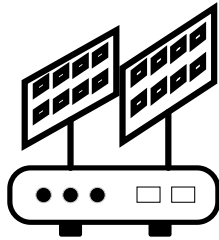
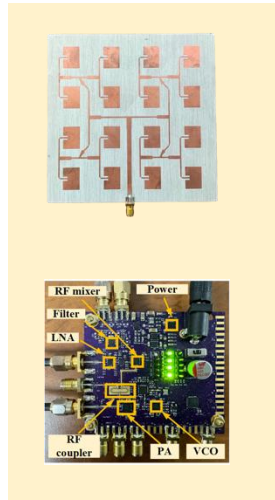
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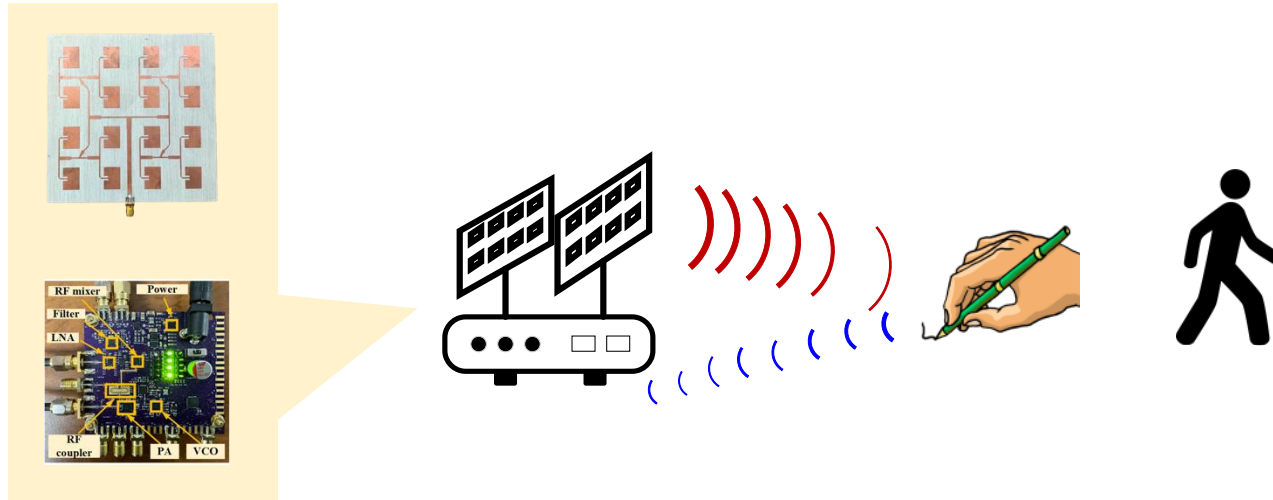
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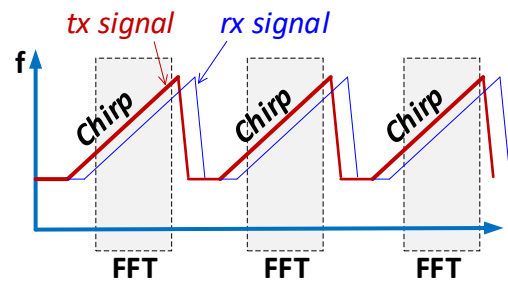
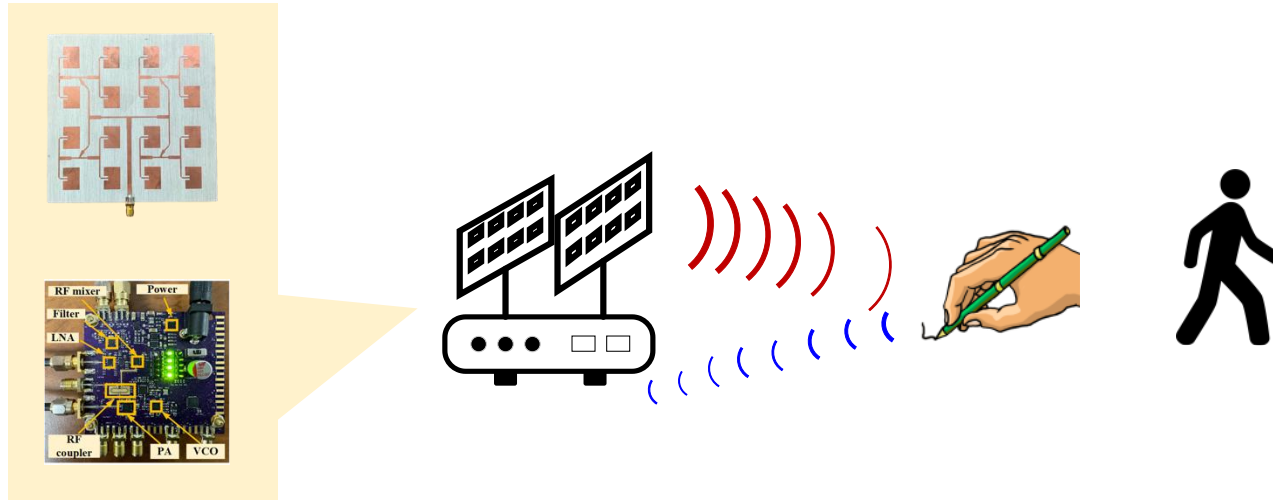
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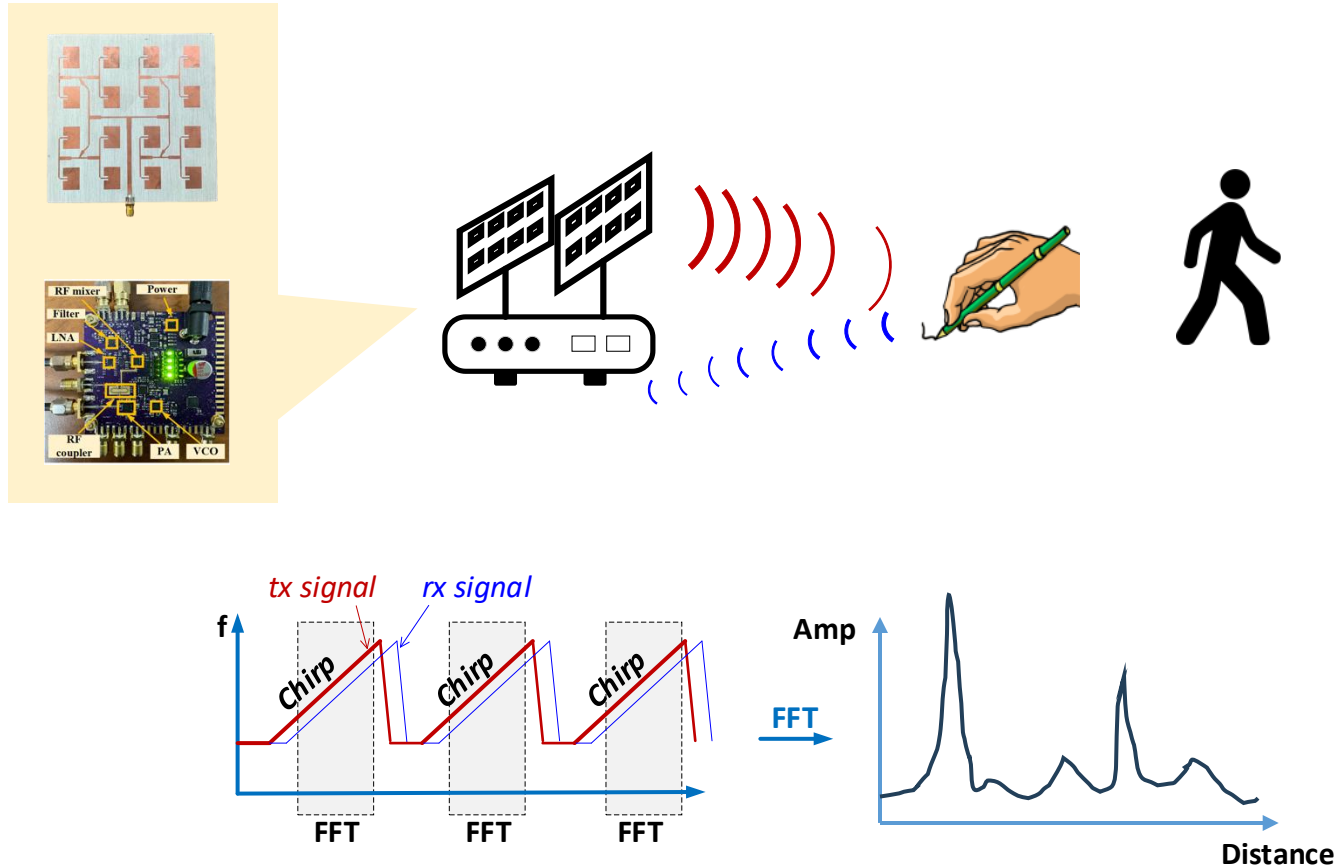
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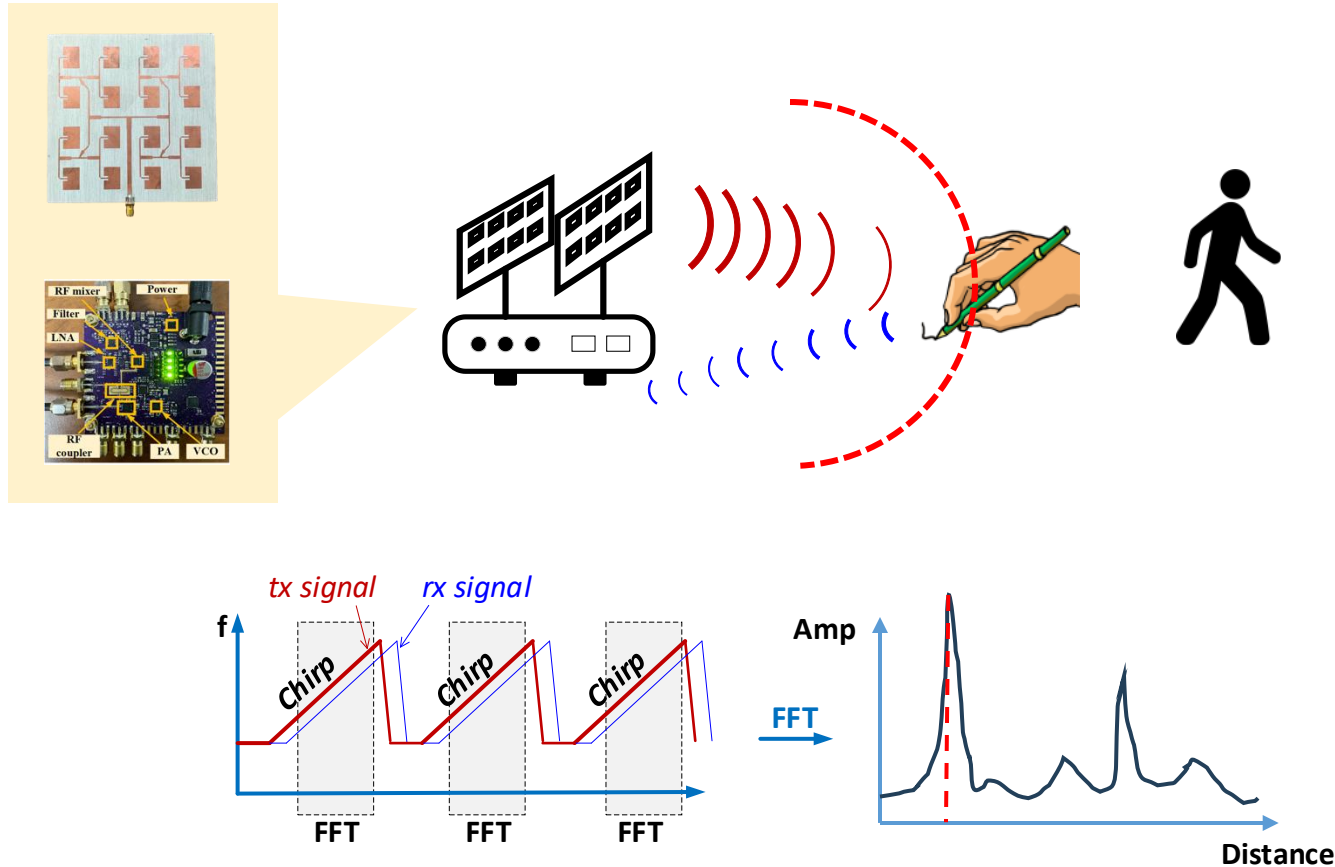
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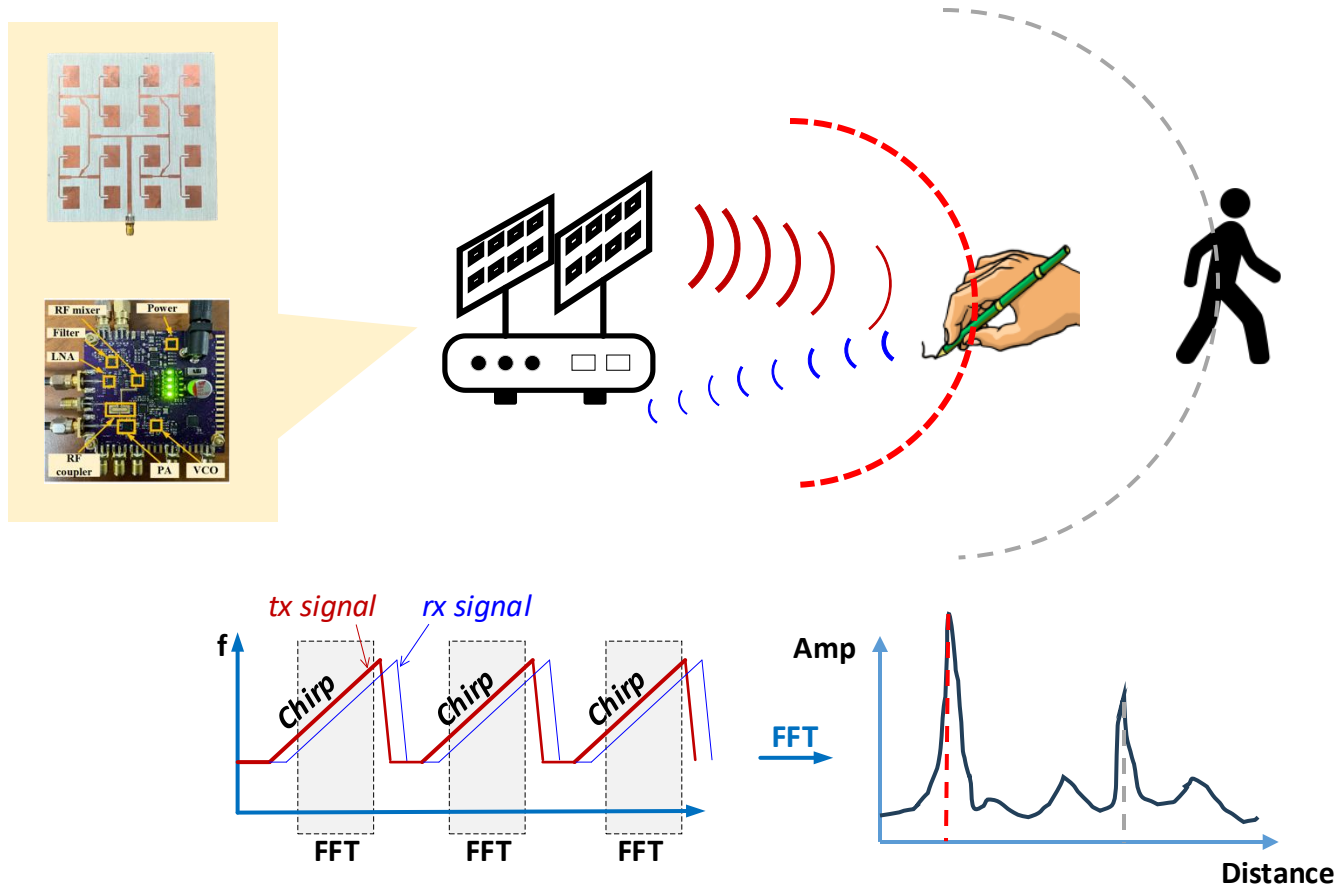
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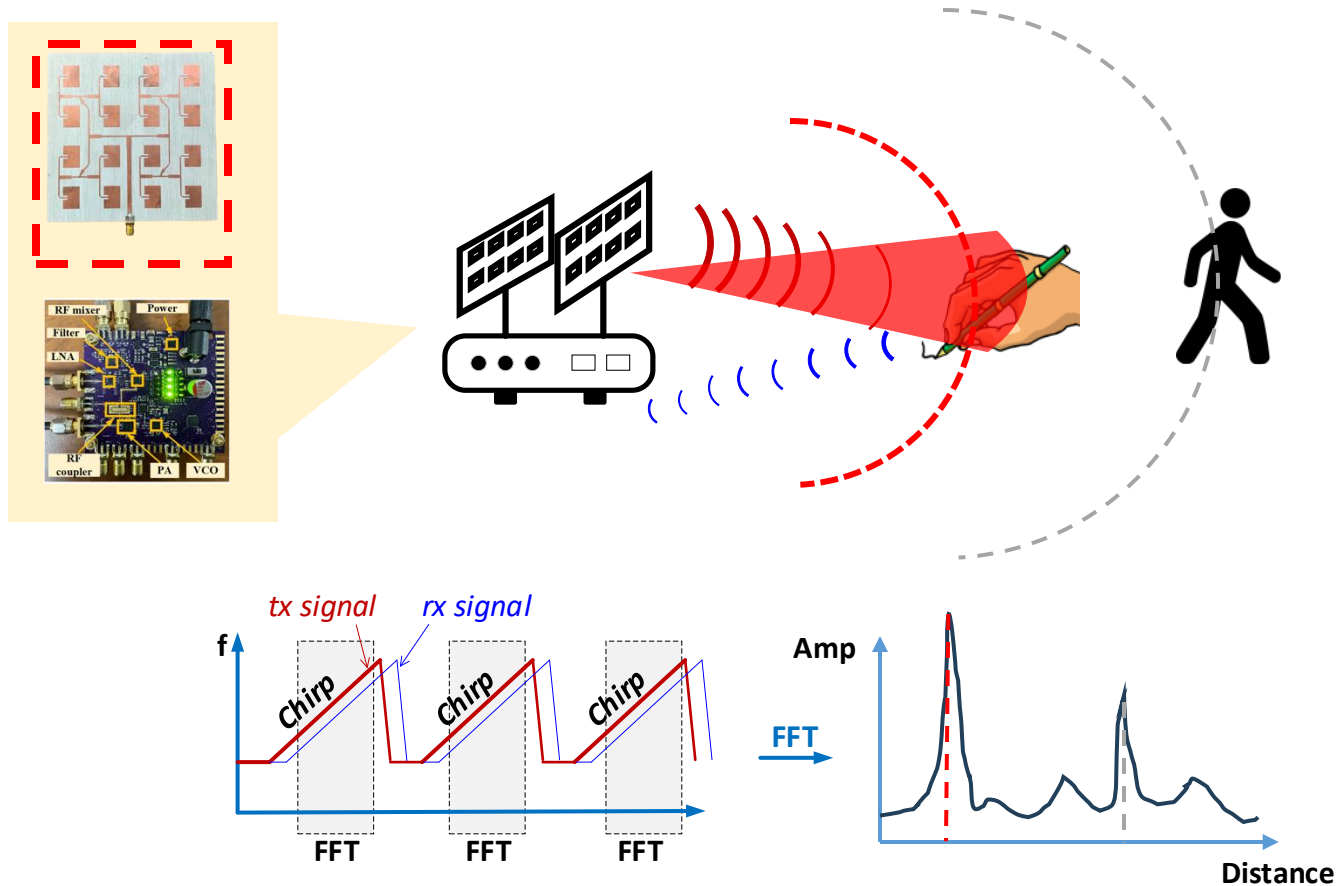
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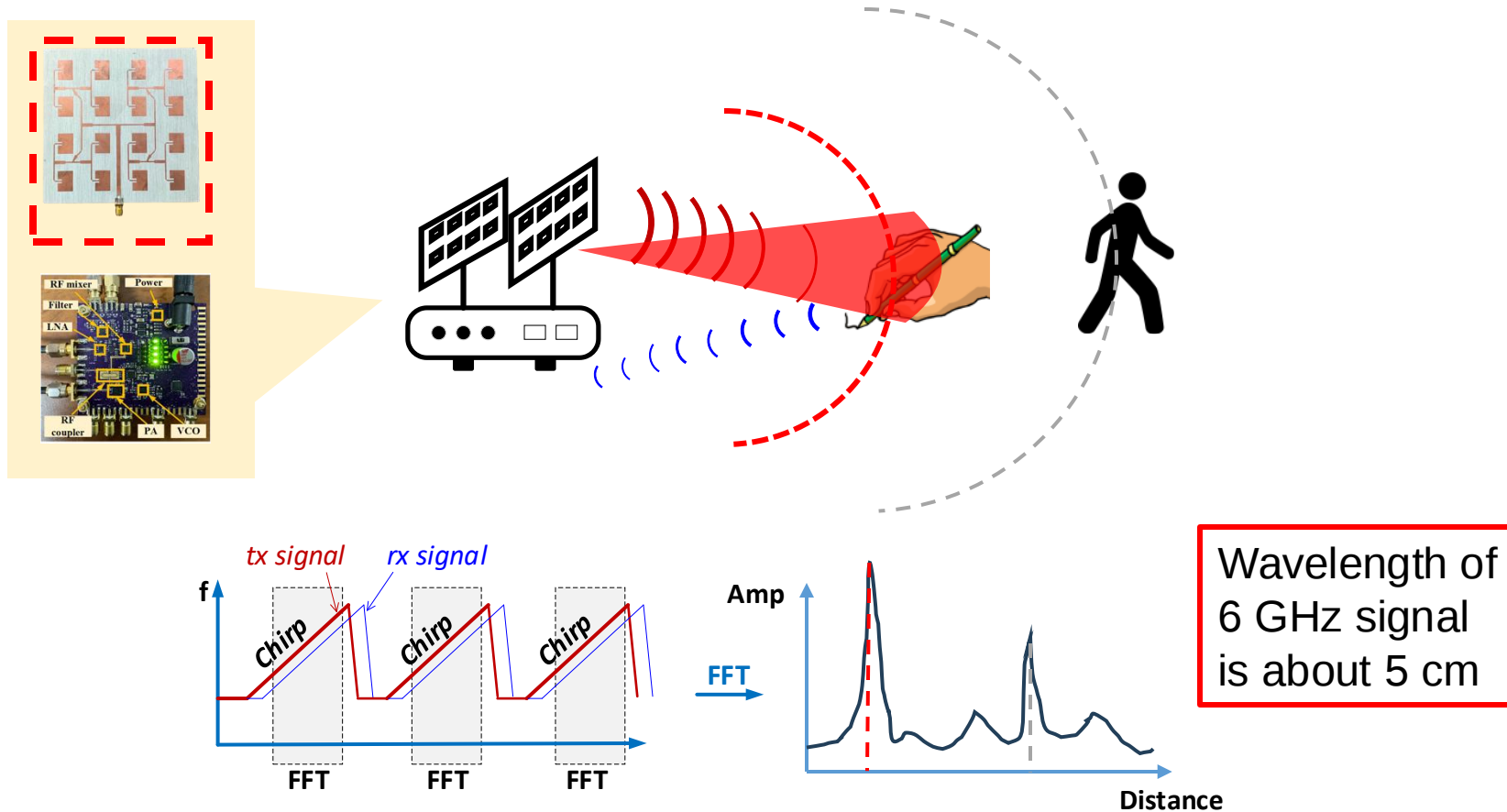
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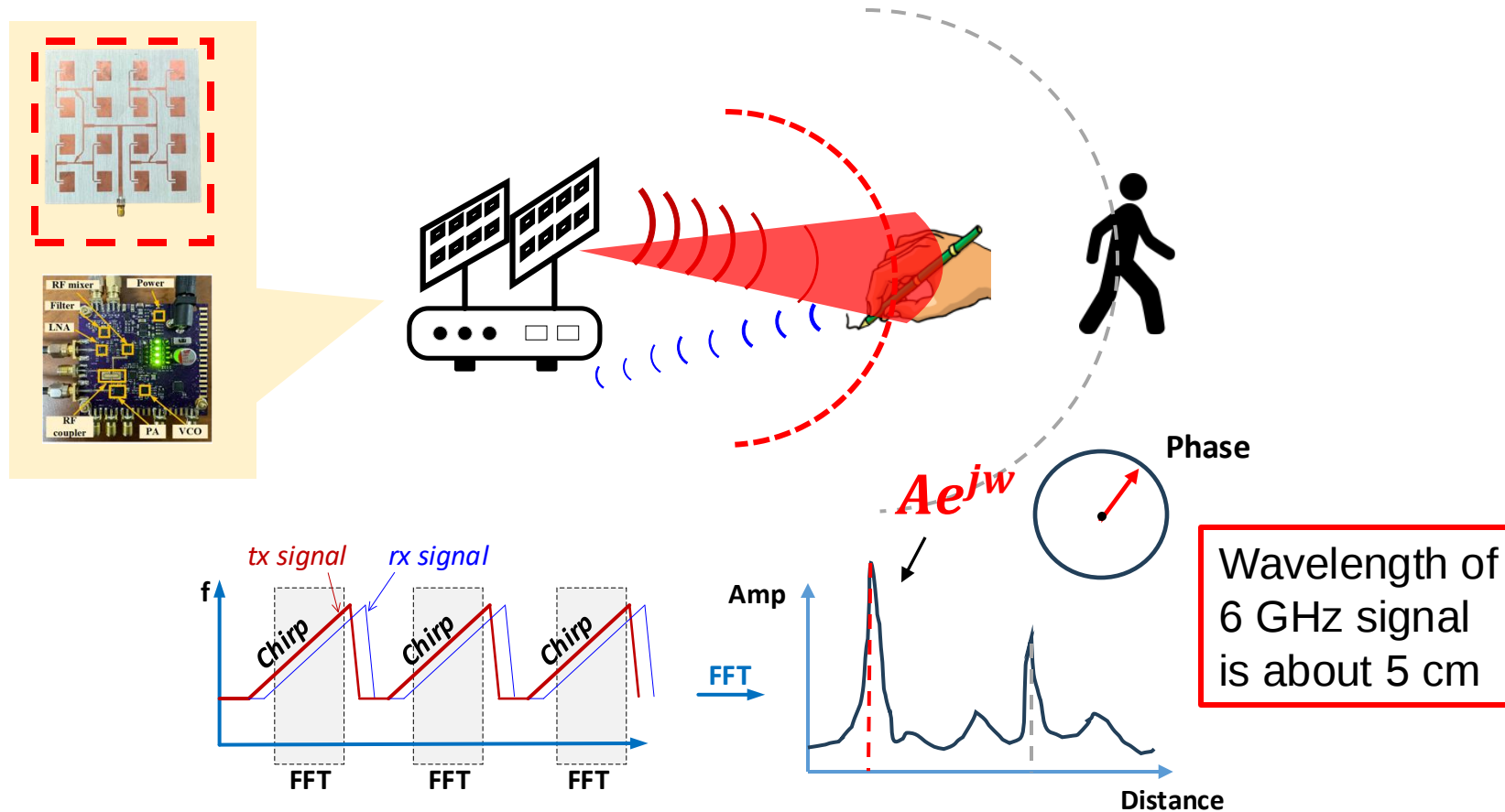
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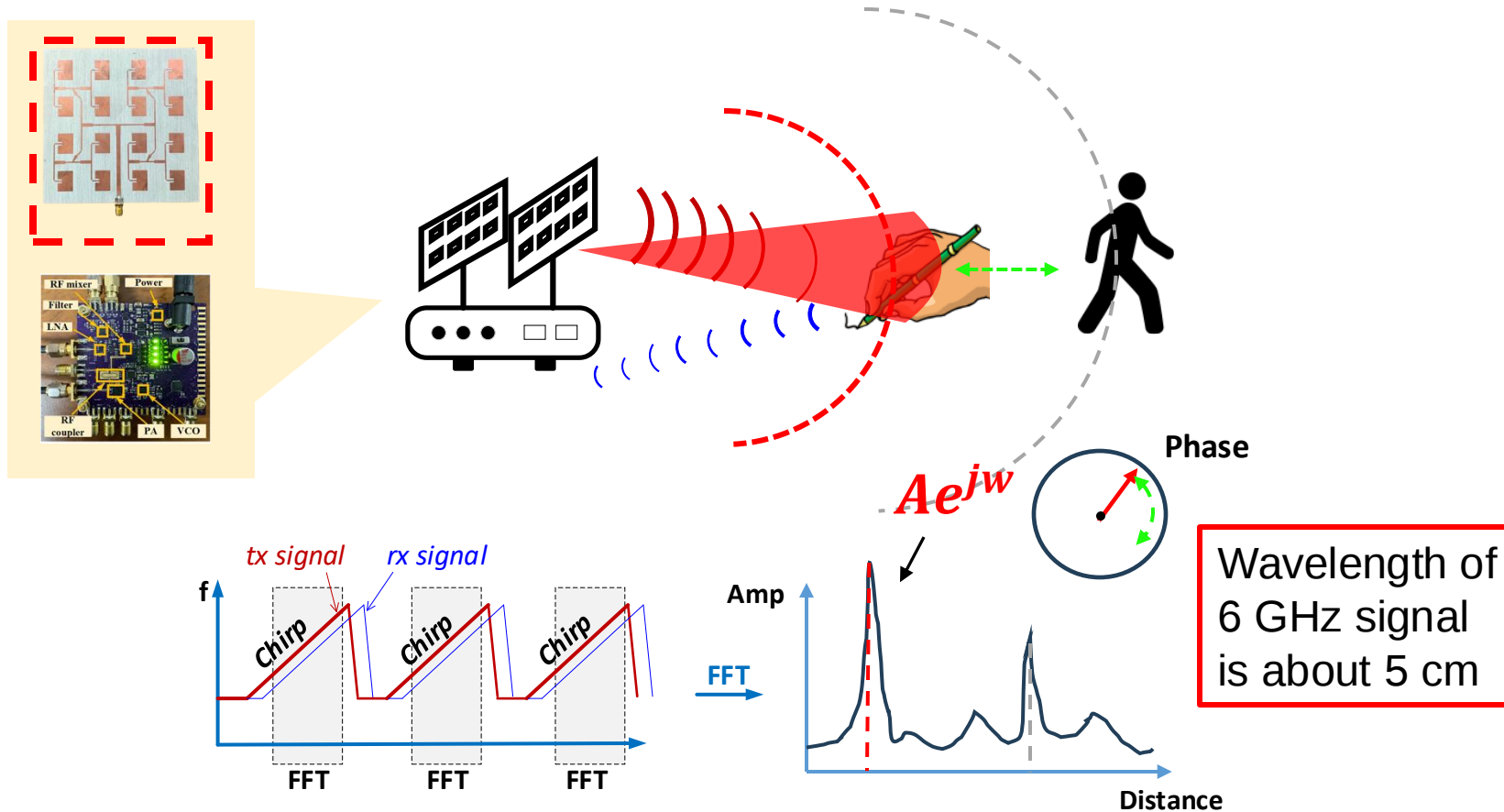
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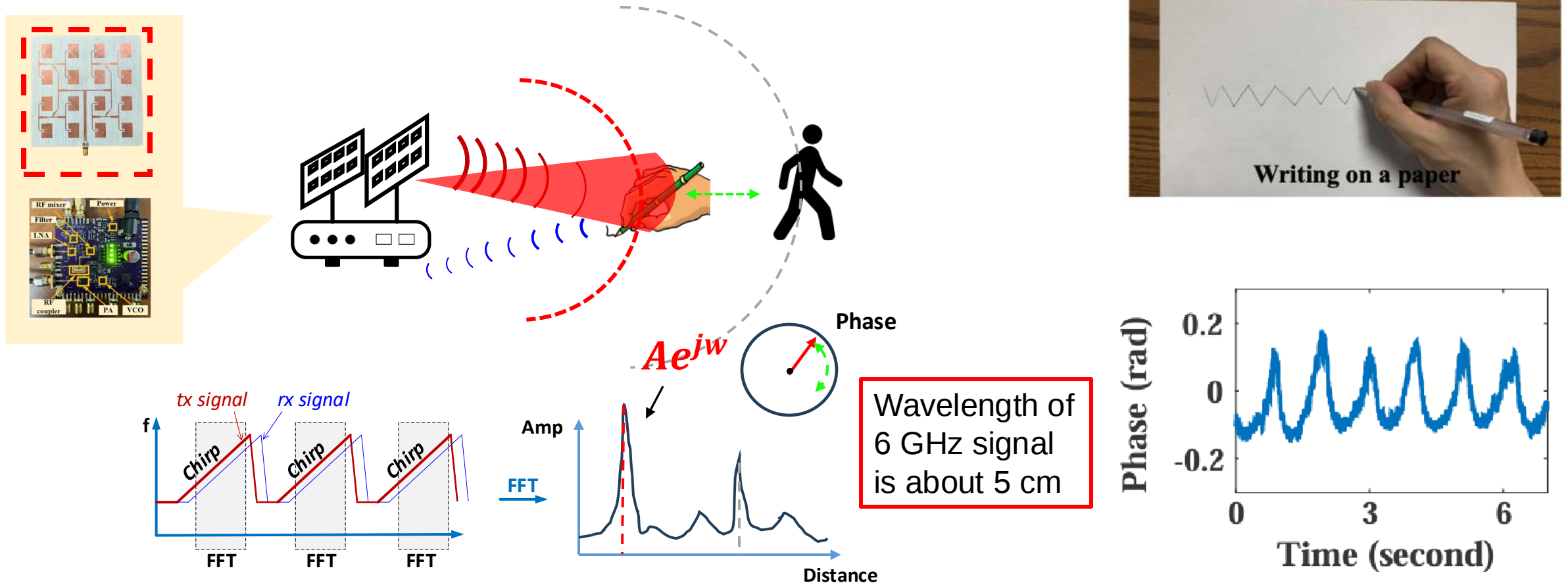
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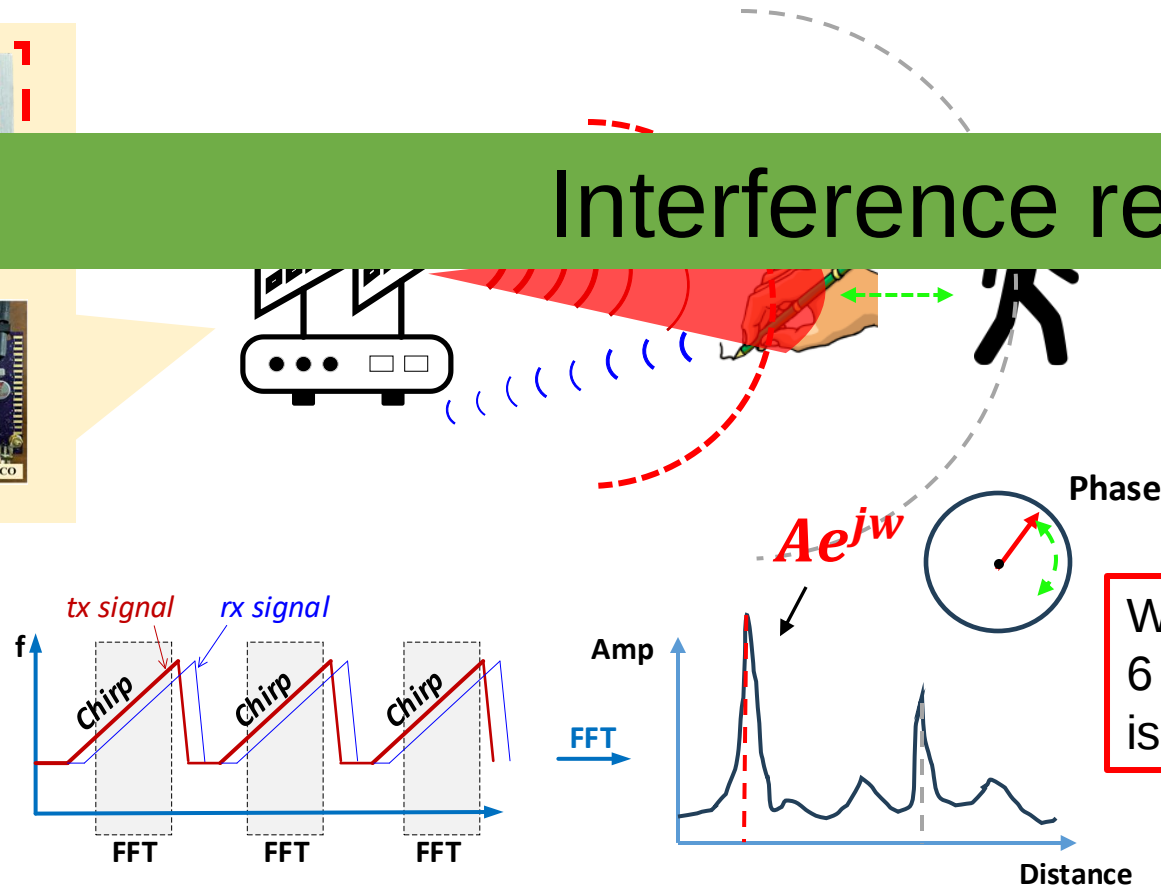
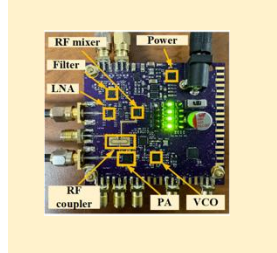
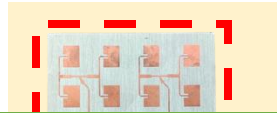
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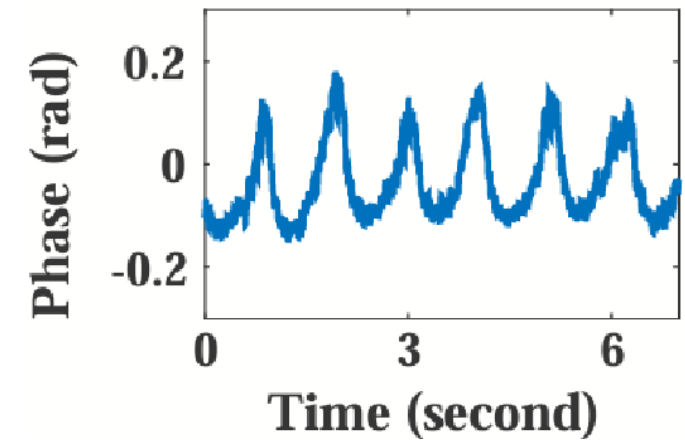
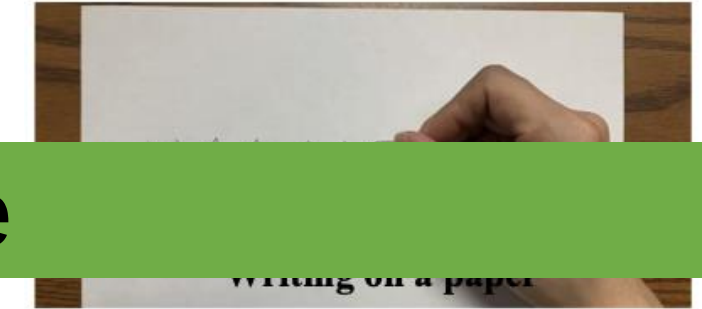
Hardware

- The effect of *patch antenna* + 6GHz FMCW radar!

Interference resilience



Wavelength of
6 GHz signal
is about 5 cm

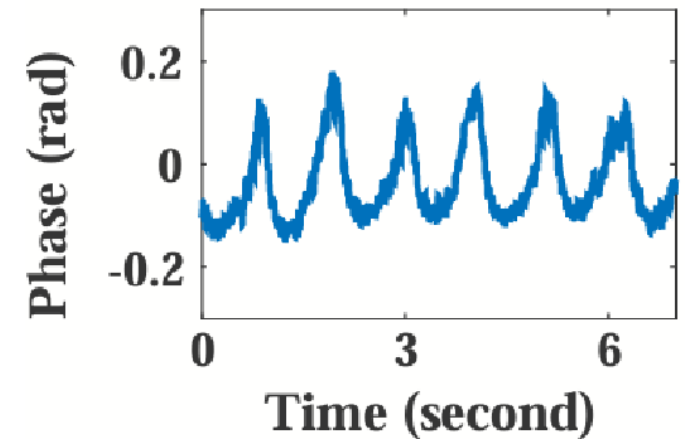
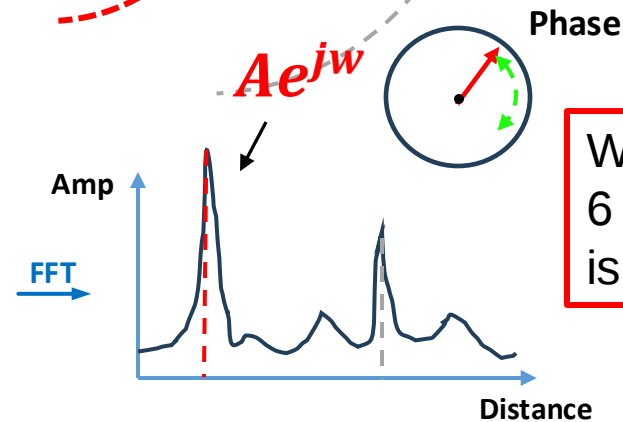
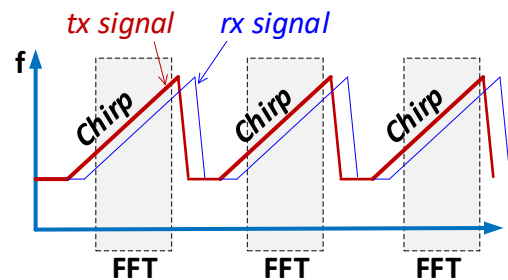


Hardware

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Interference resilience

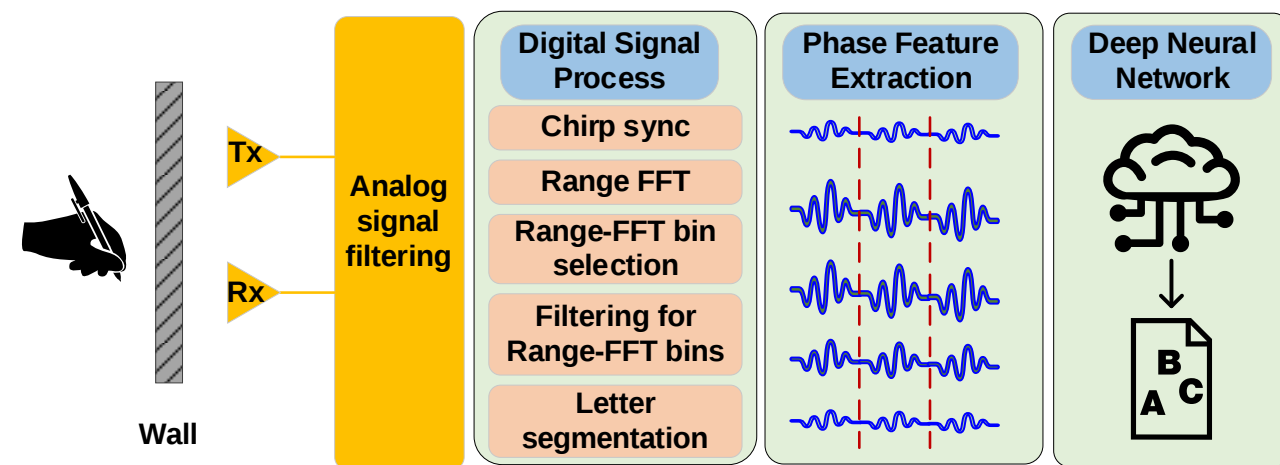
Millimeter-level hand movement detection



Software

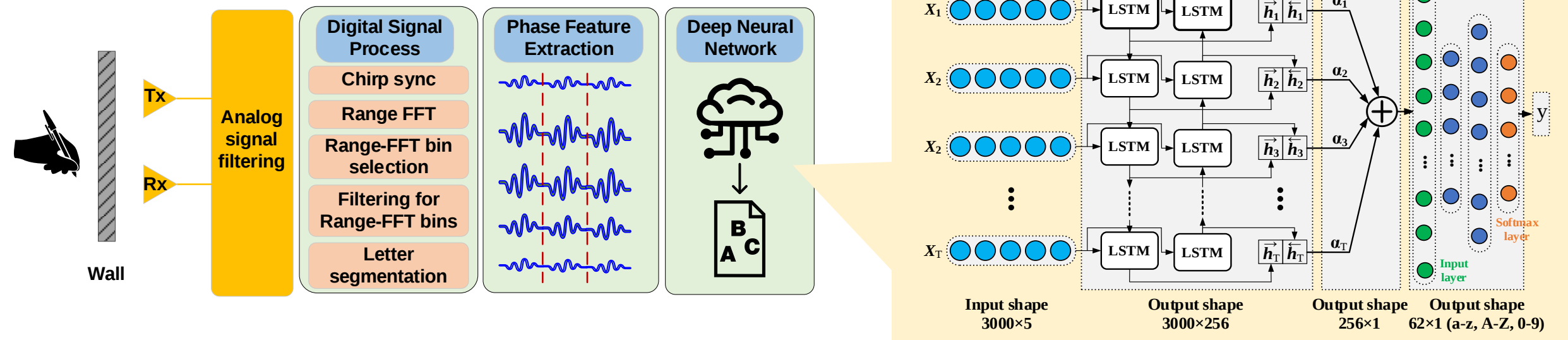
Software

- Signal processing pipeline



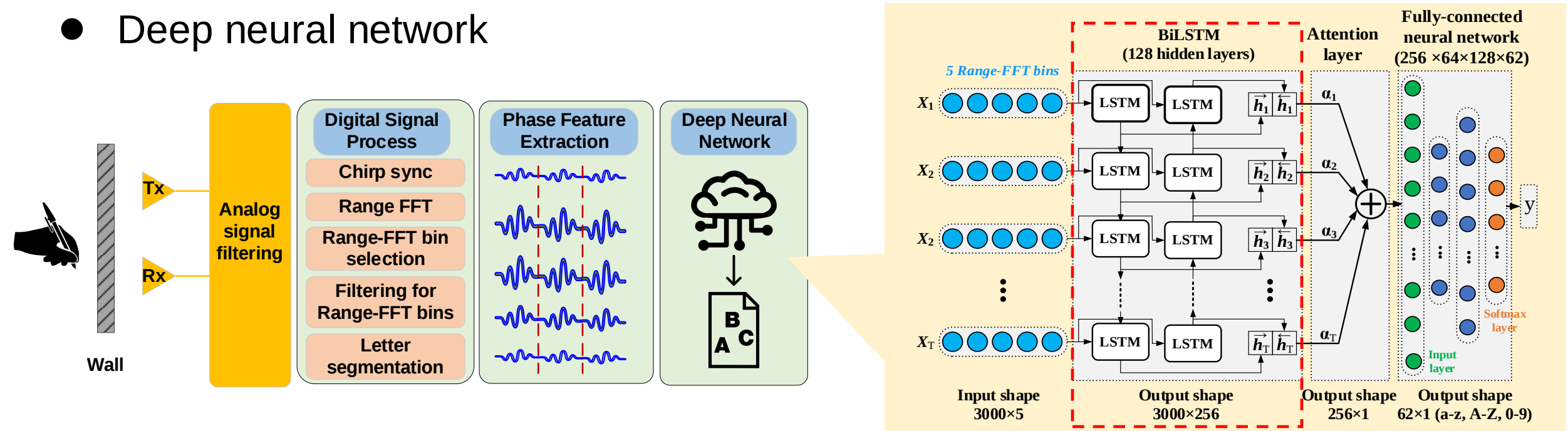
Software

- Signal processing pipeline
- Deep neural network



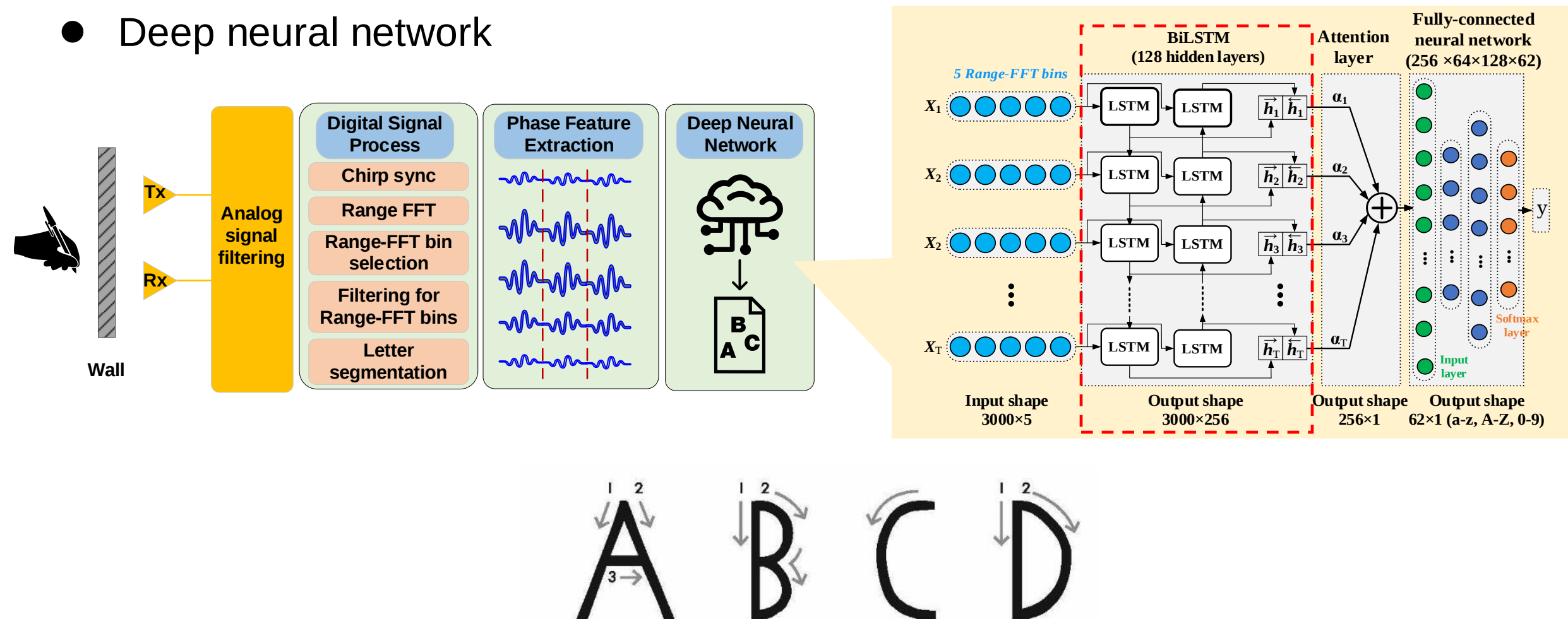
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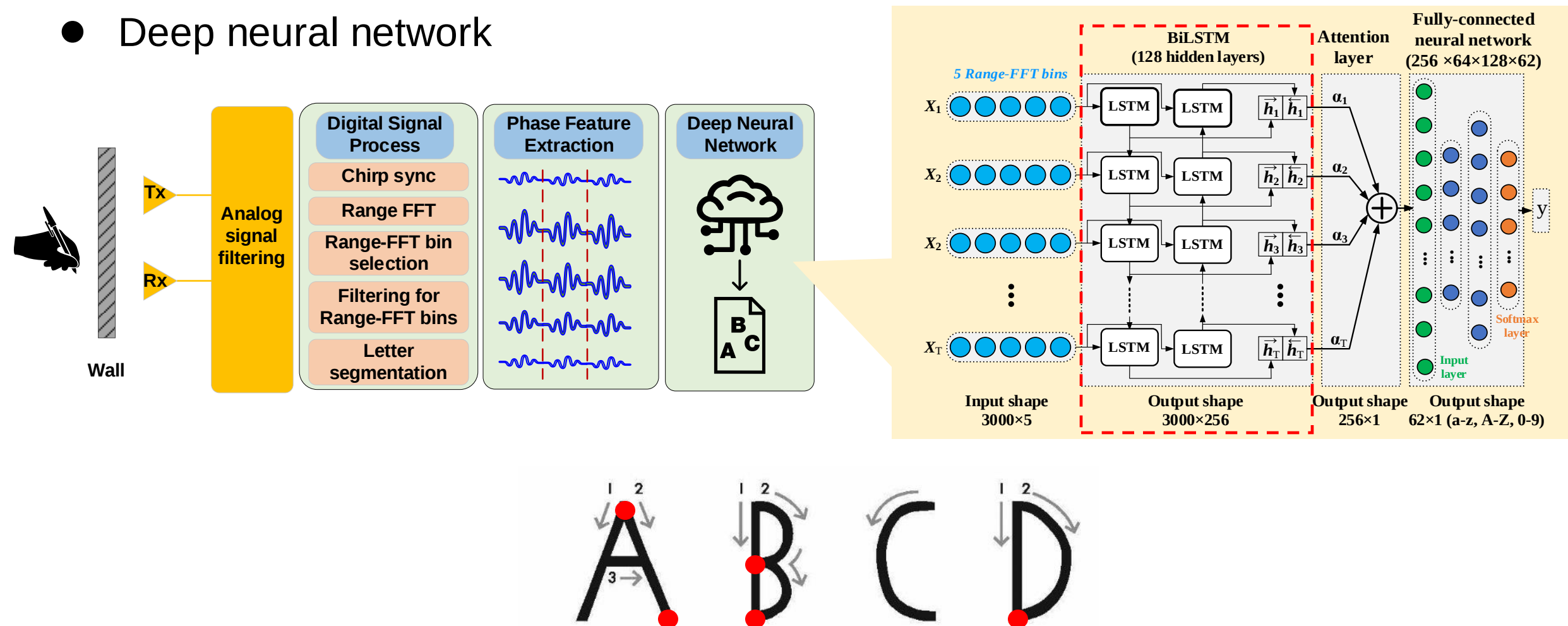
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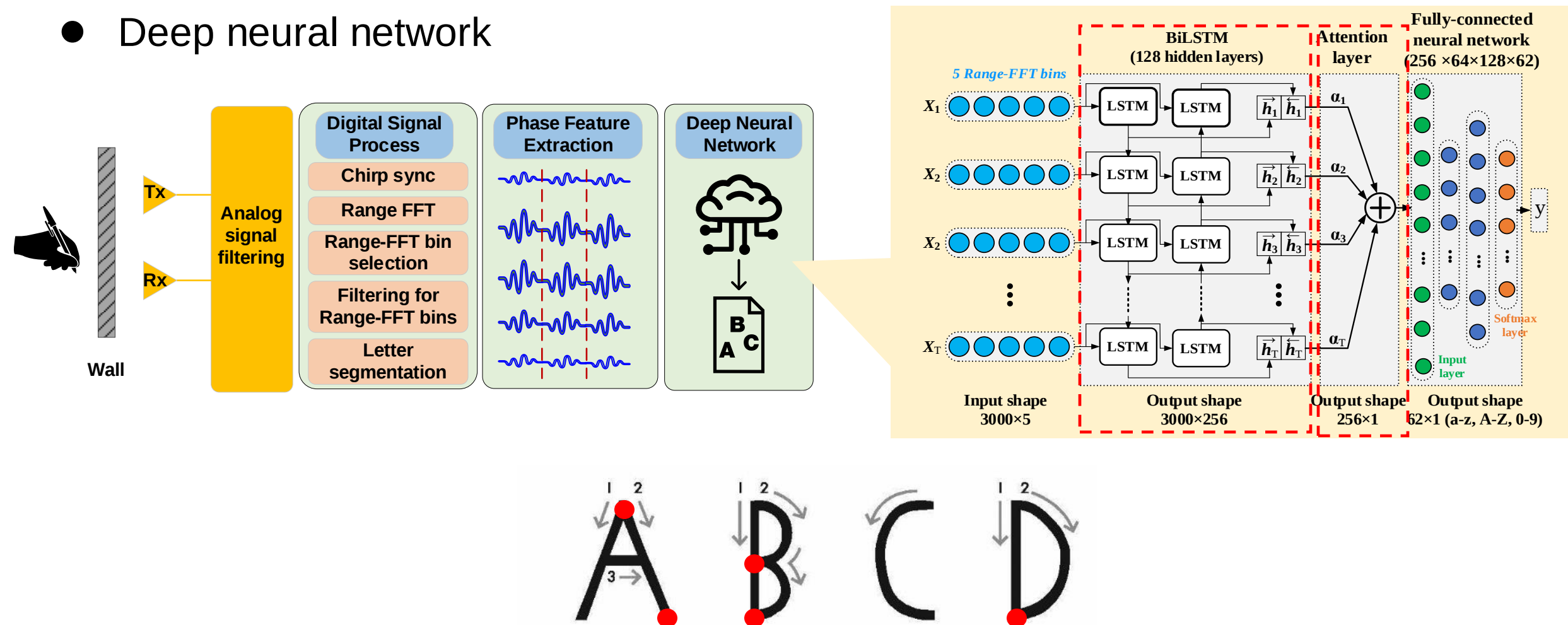
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- Signal processing pipeline
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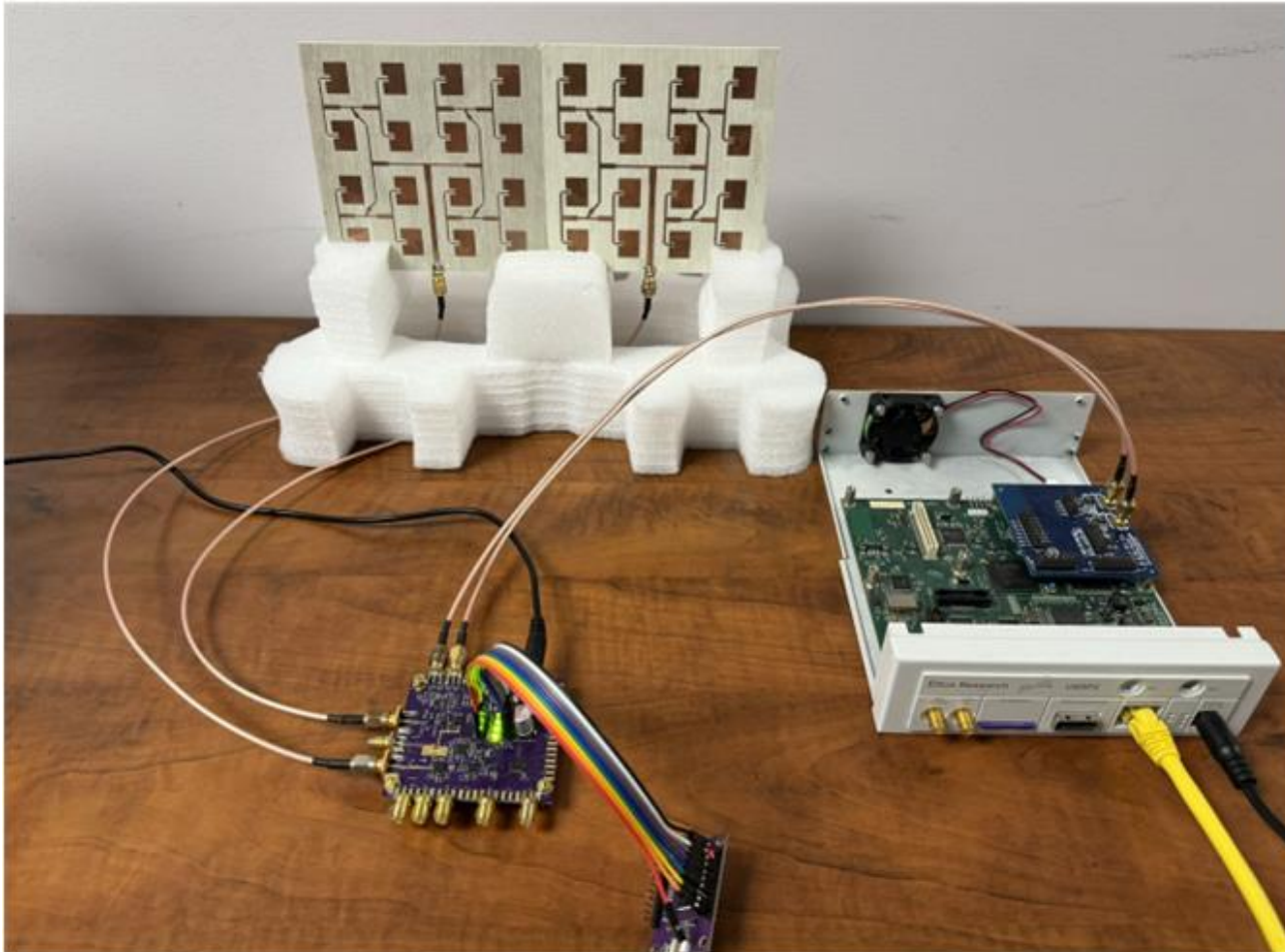


Implementation

- Hardware

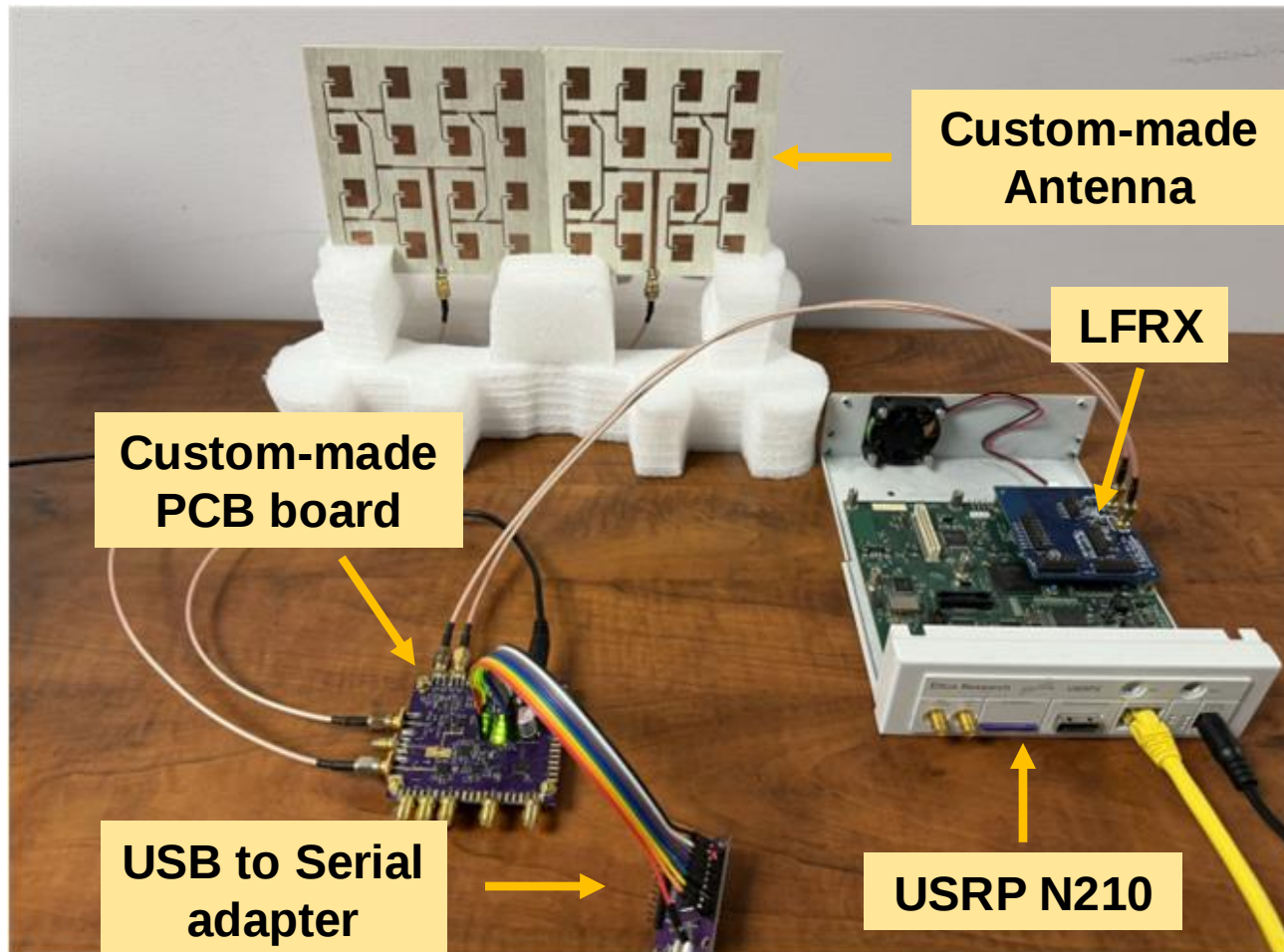
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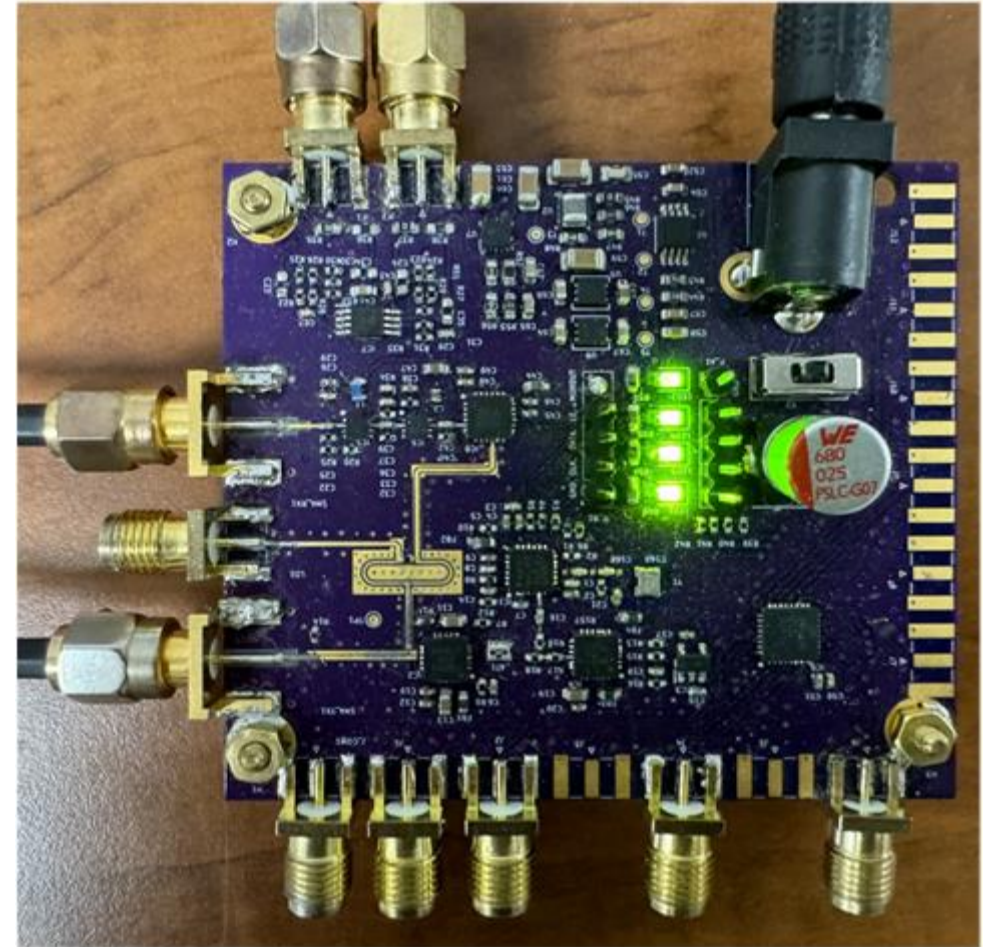
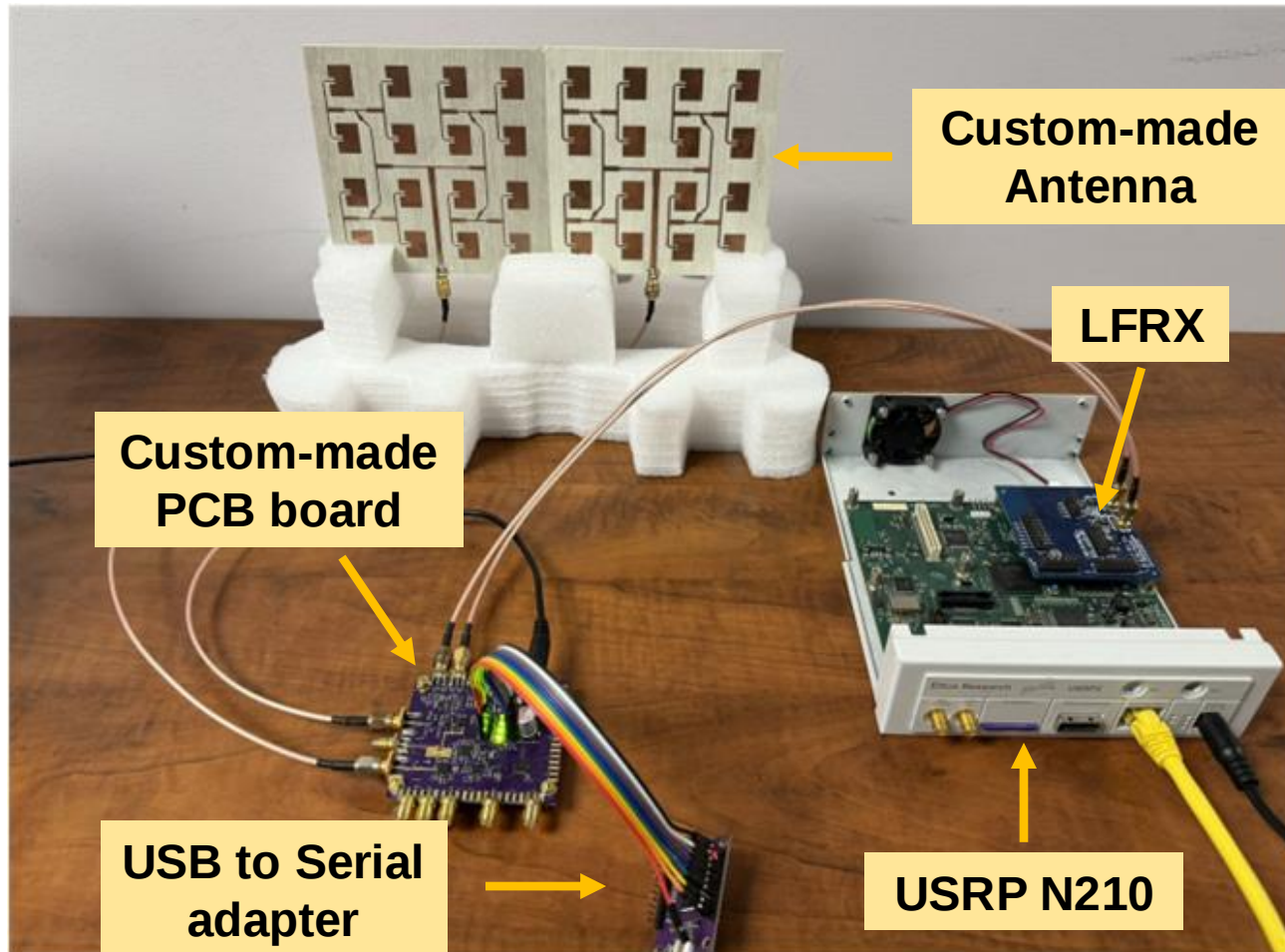
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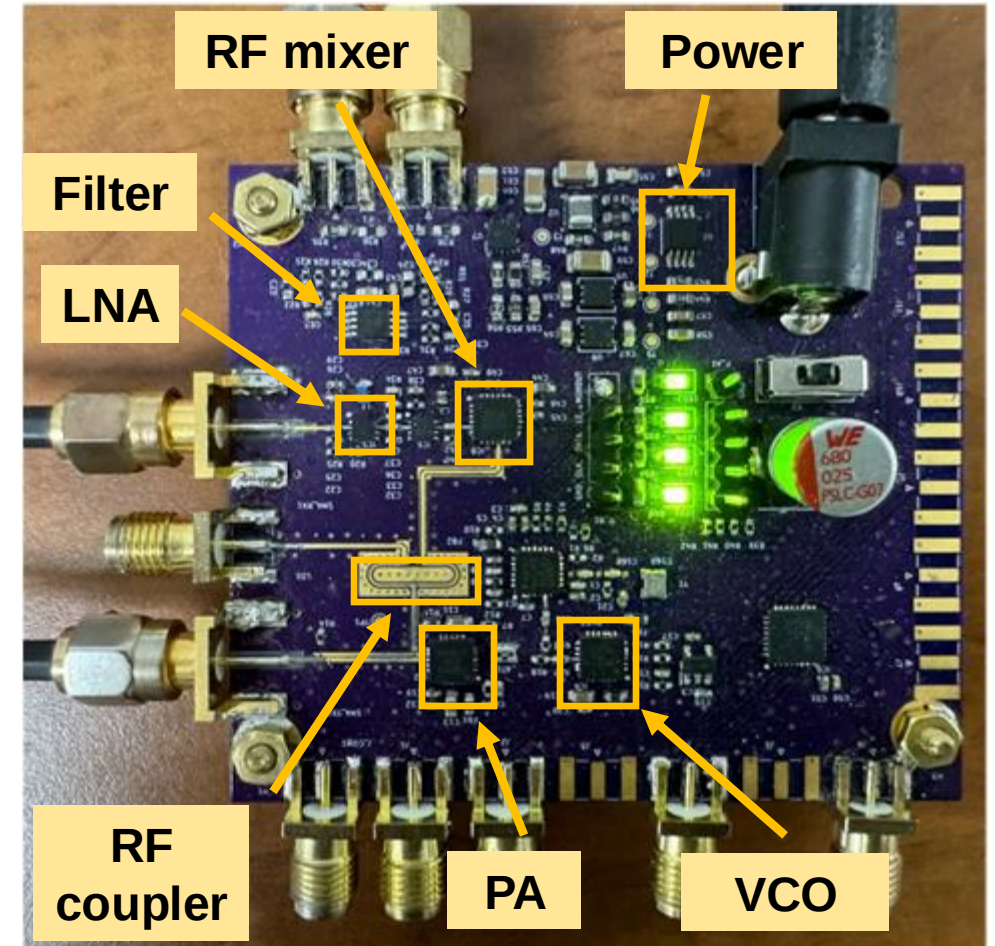
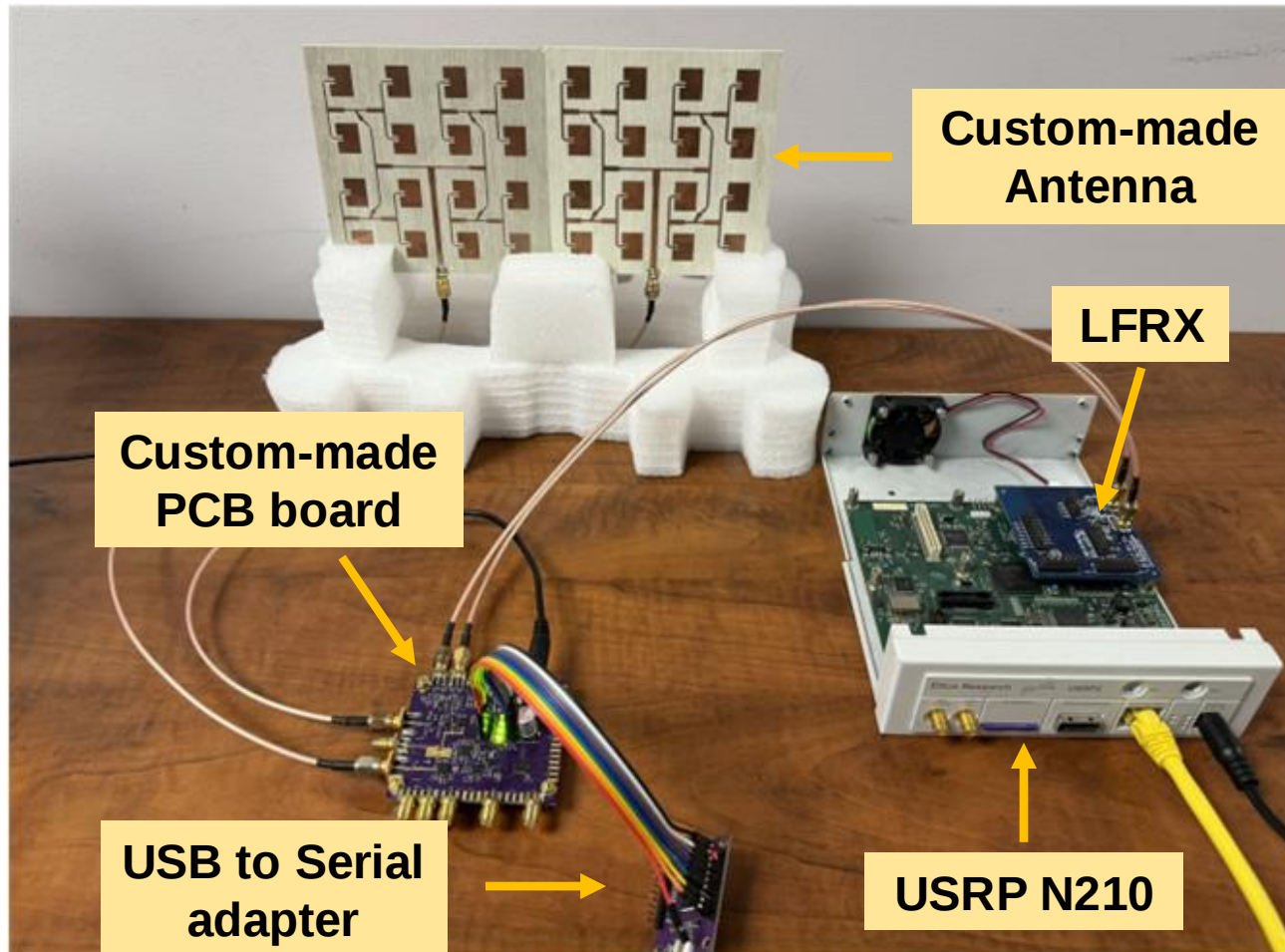
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Implementation

- Hardware



Evaluation

Evaluation

- Data collection
 - Participants are from different countries
 - Wiring in print or cursive style with different handedness

Evaluation

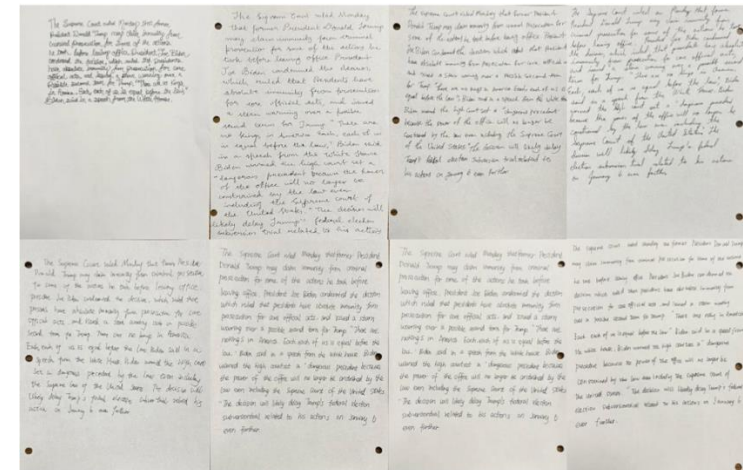
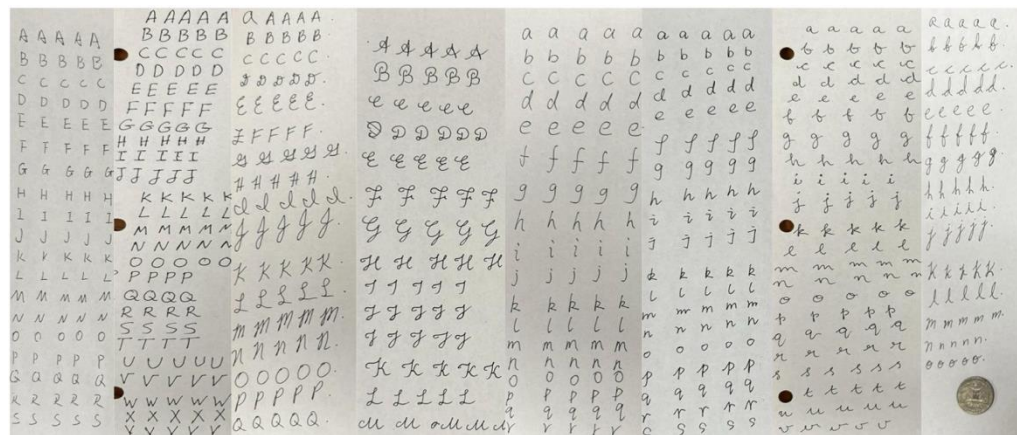
- Data collection
 - Participants are from different countries
 - Writing in print or cursive style with different handedness

	Participants for training				Participants for test			
Handedness	Right-handed		Left-handed		Right-handed		Left-handed	
Writing style	Print	Cursive	Print	Cursive	Print	Cursive	Print	Cursive
# of participants	11	5	1	1	7	3	1	1

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- Data collection
 - Participants are from different countries
 - Writing in print or cursive style with different handedness

	Participants for training				Participants for test			
Handedness	Right-handed		Left-handed		Right-handed		Left-handed	
Writing style	Print	Cursive	Print	Cursive	Print	Cursive	Print	Cursive
# of participants	11	5	1	1	7	3	1	1

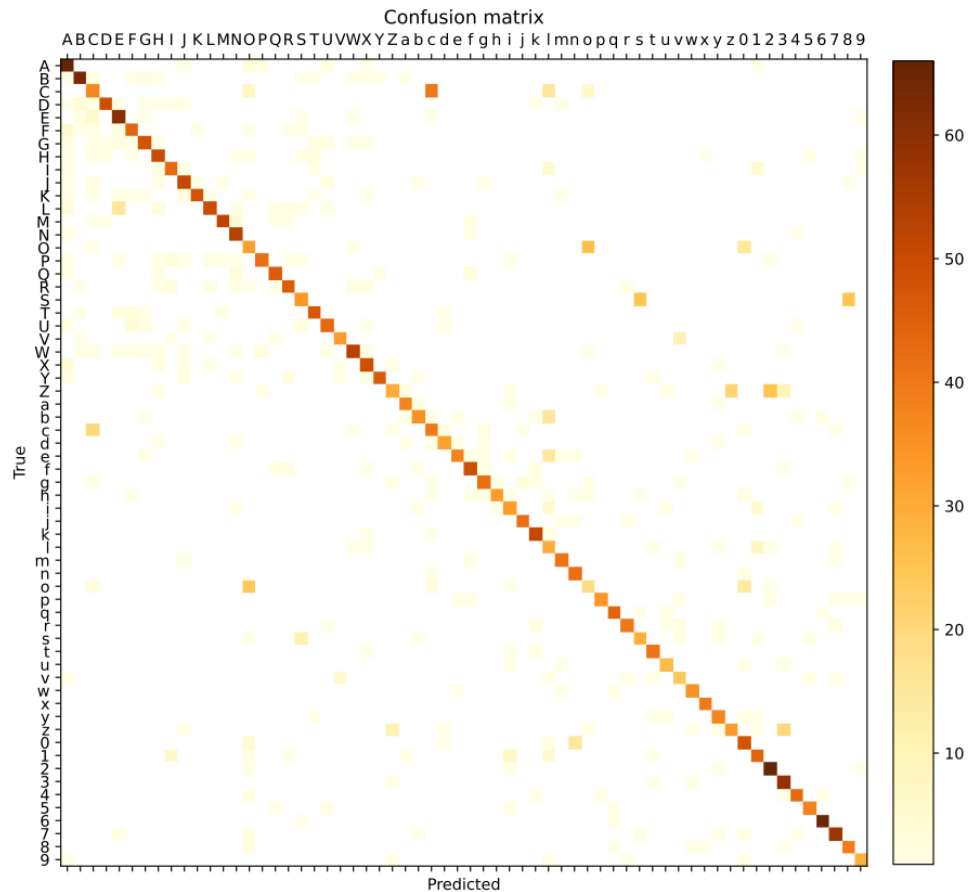


Evaluation

- Letter recognition accuracy

Evaluation

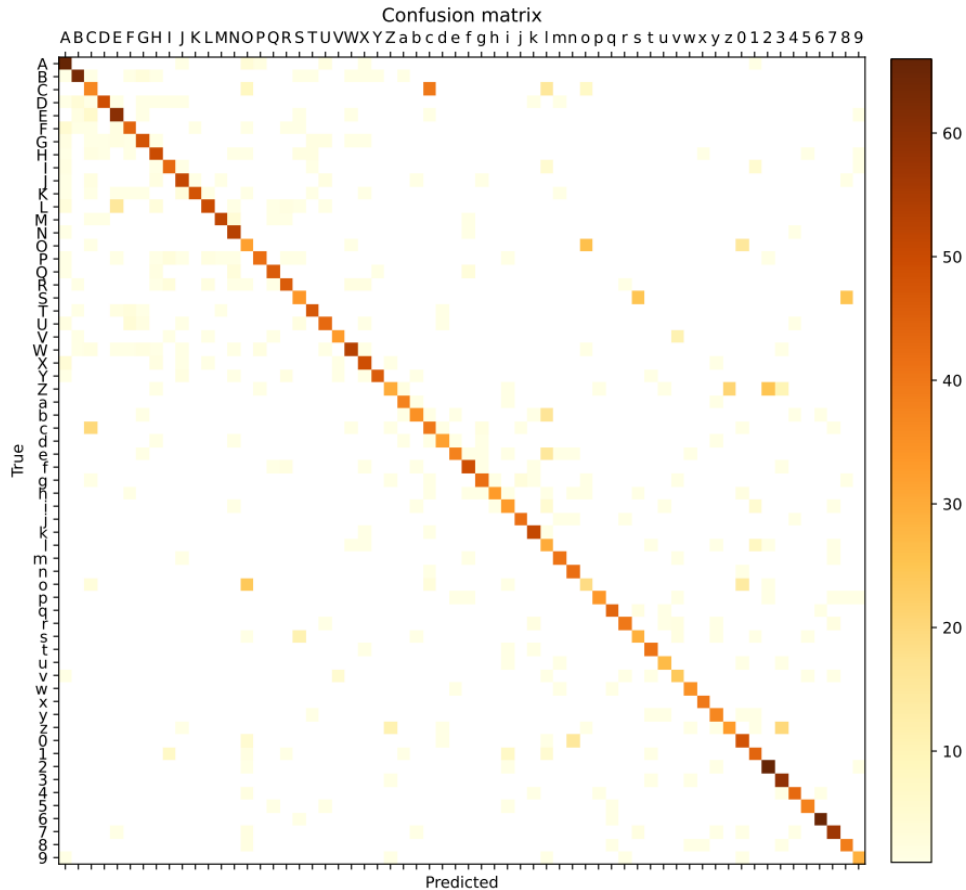
- Letter recognition accuracy



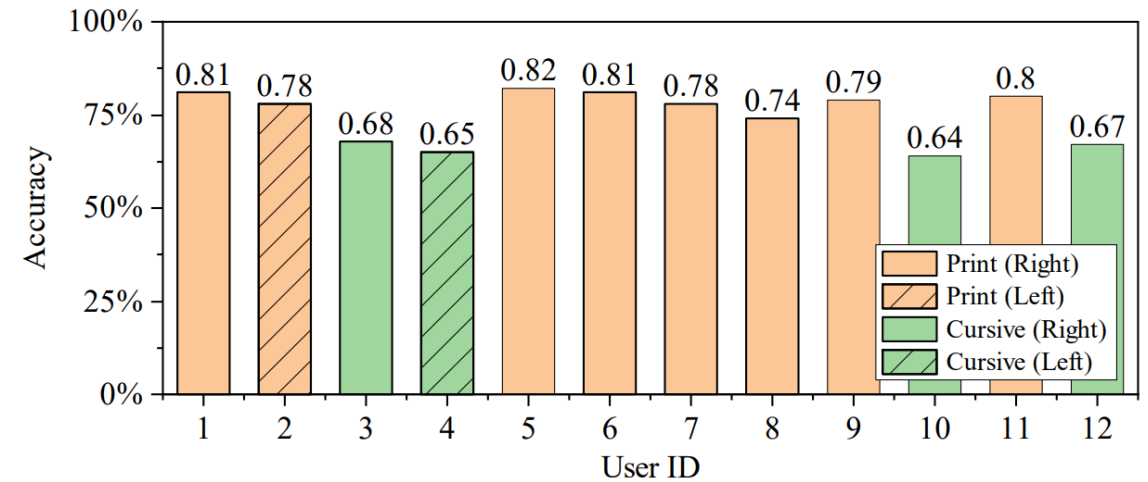
75% letter recognition accuracy

Evaluation

- Letter recognition accuracy



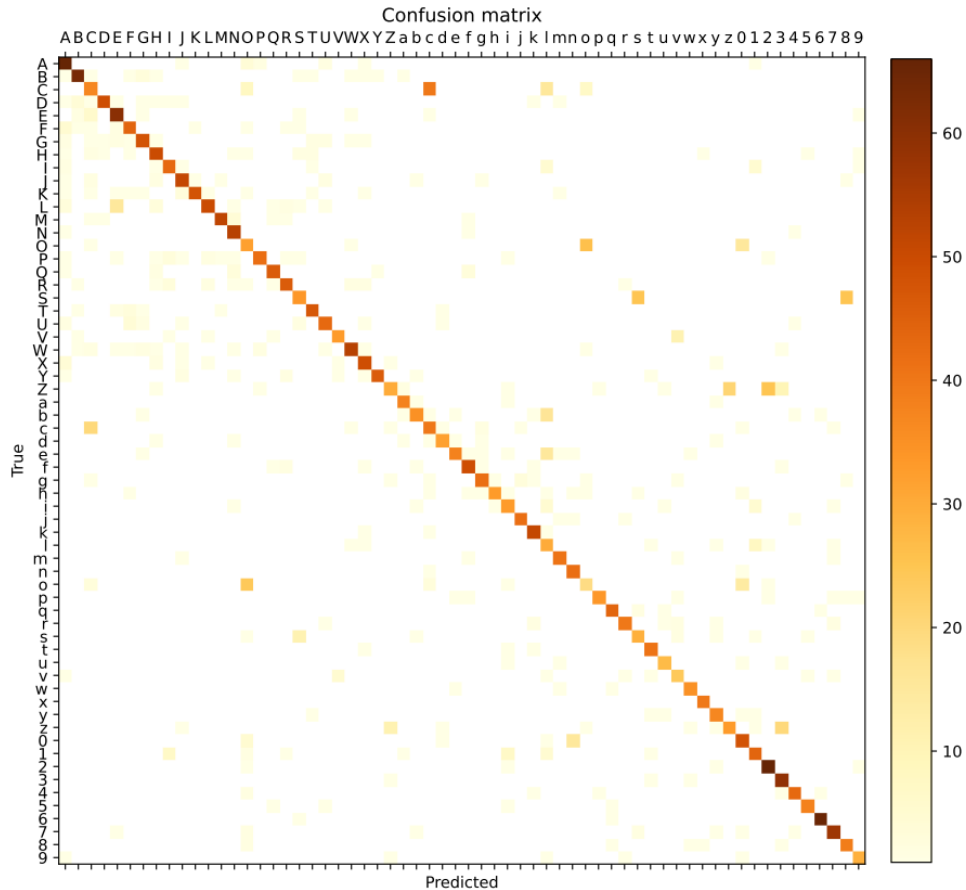
75% letter recognition accuracy



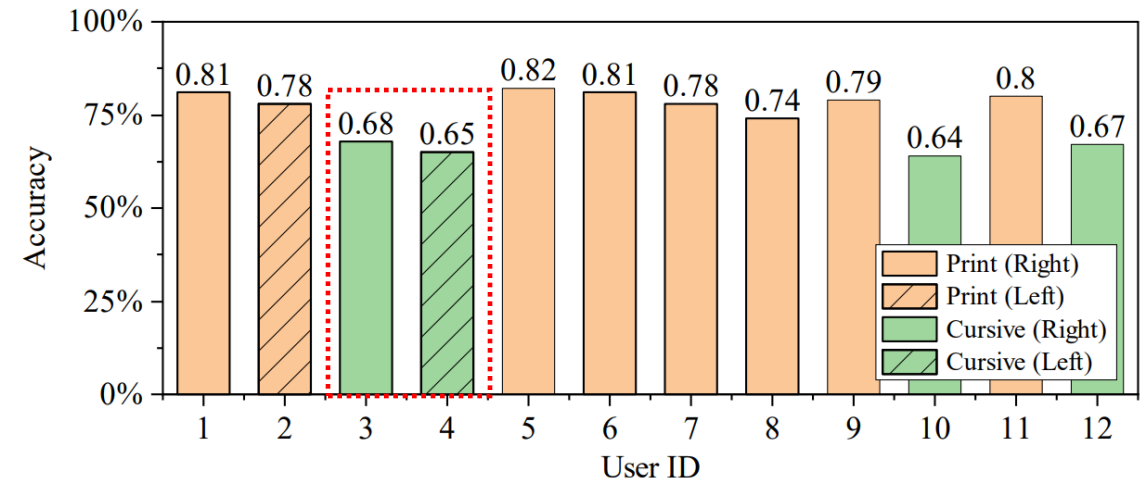
Lower accuracy when writing in cursive

Evaluation

- Letter recognition accuracy



75% letter recognition accuracy

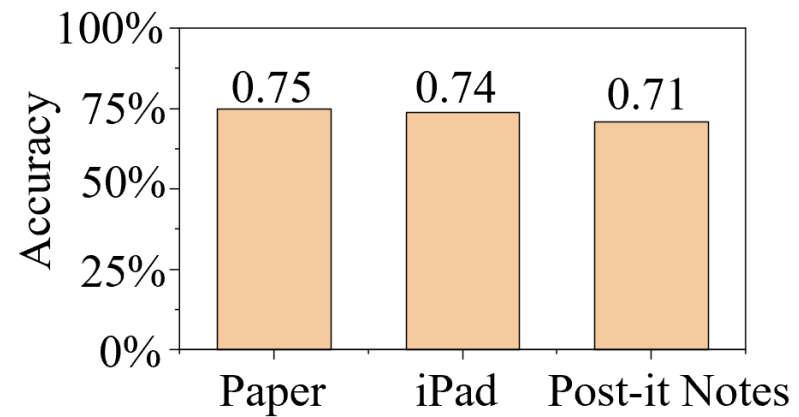
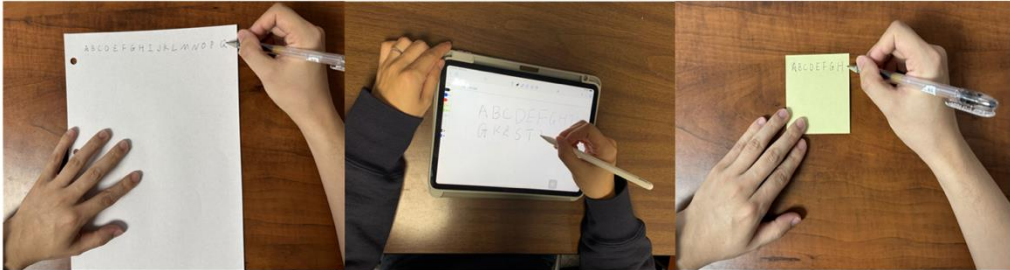


Lower accuracy when writing in cursive

Evaluation

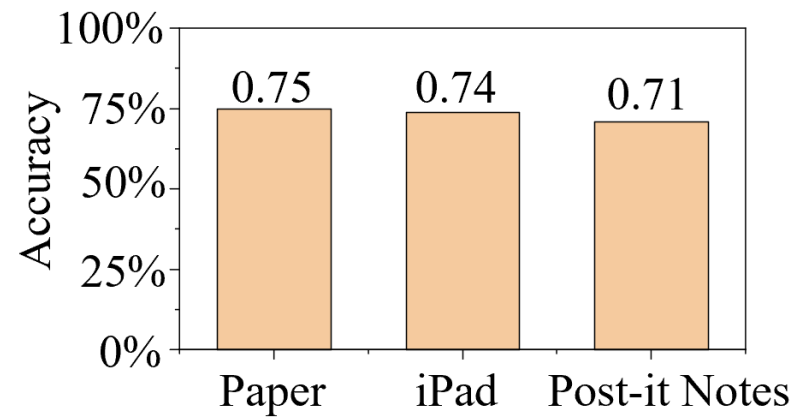
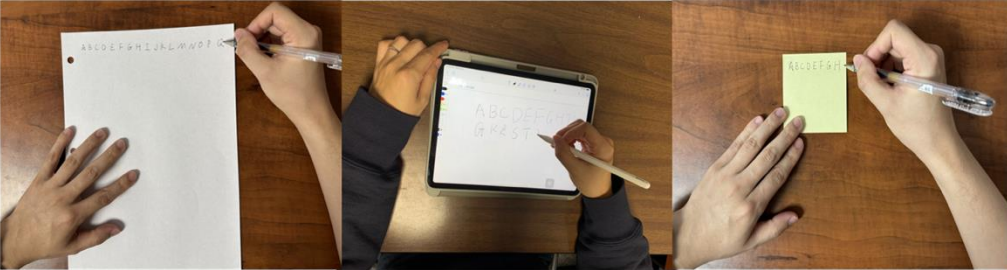
Evaluation

- Writing on different media



Evaluation

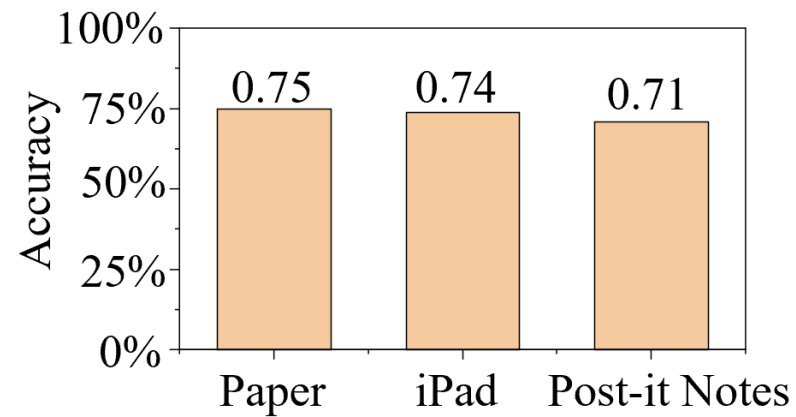
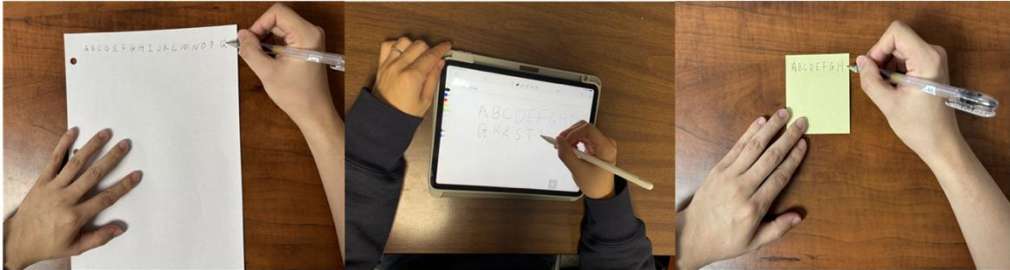
- Writing on different media



Similar accuracy across different writing media

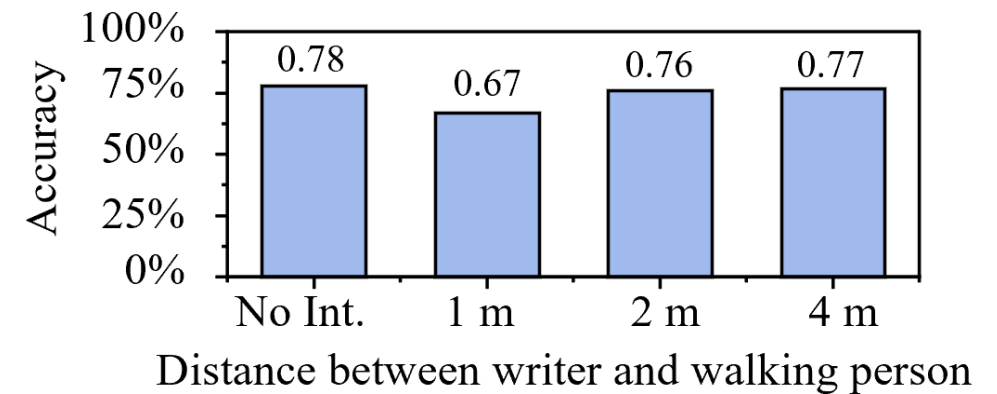
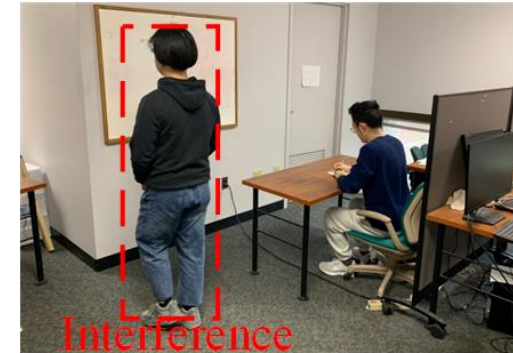
Evaluation

- Writing on different media



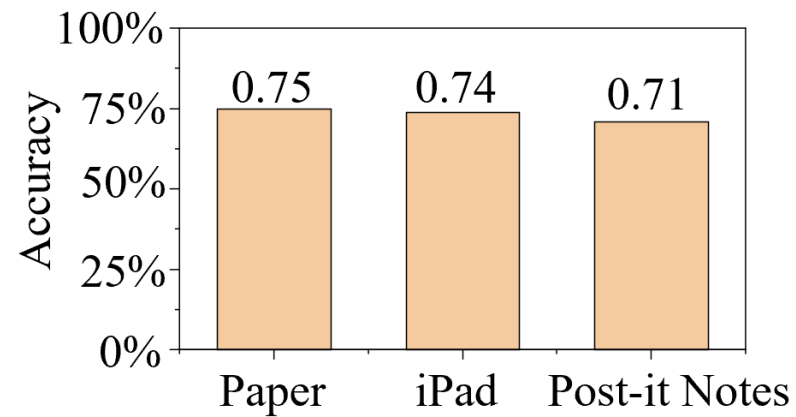
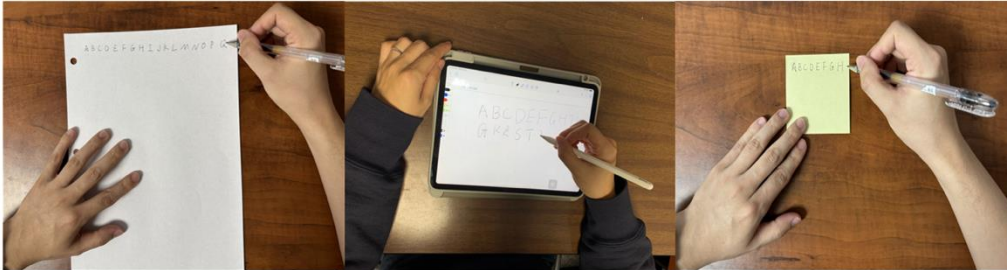
Similar accuracy across different writing media

- Writing under interference



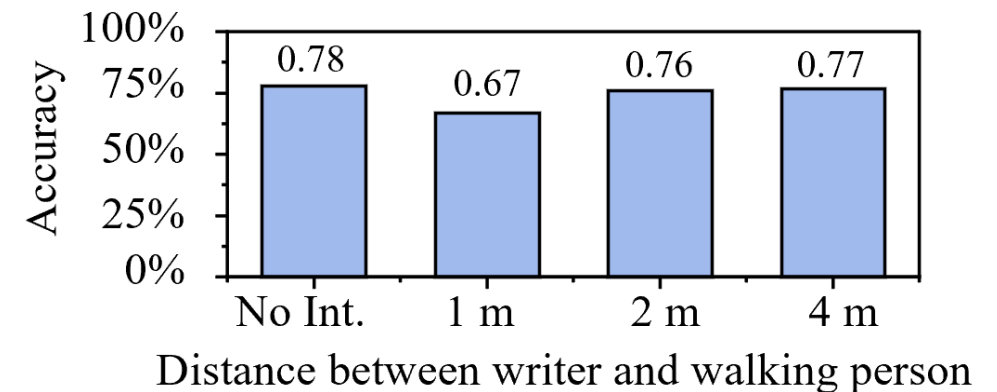
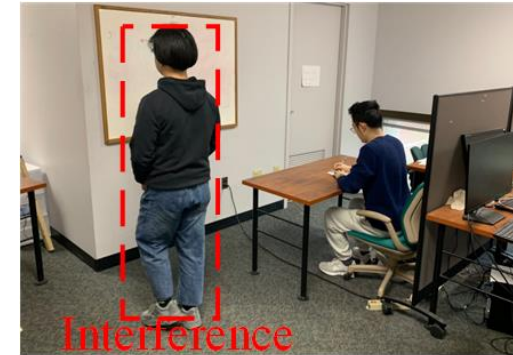
Evaluation

- Writing on different media



Similar accuracy across different writing media

- Writing under interference

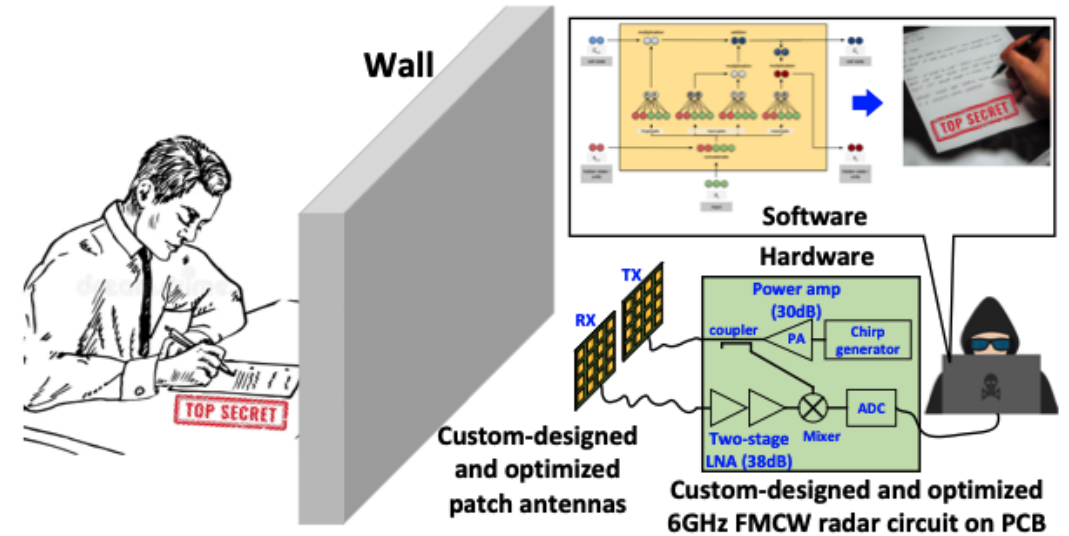


Resilient to interference when the distance > 1m

Summary

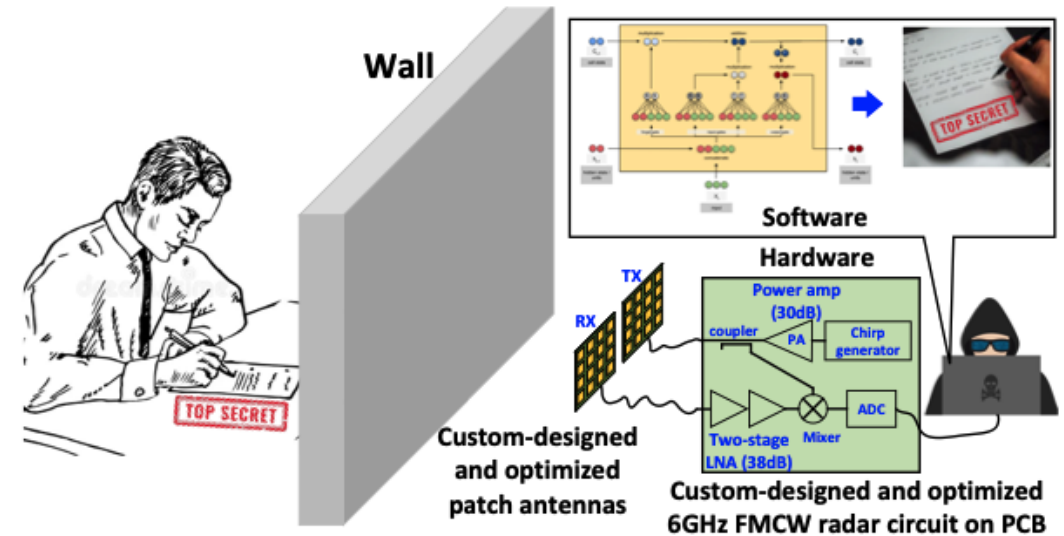
Summary

- RadSee is a 6 GHz FMCW radar device featuring an integrated software and hardware design.



Summary

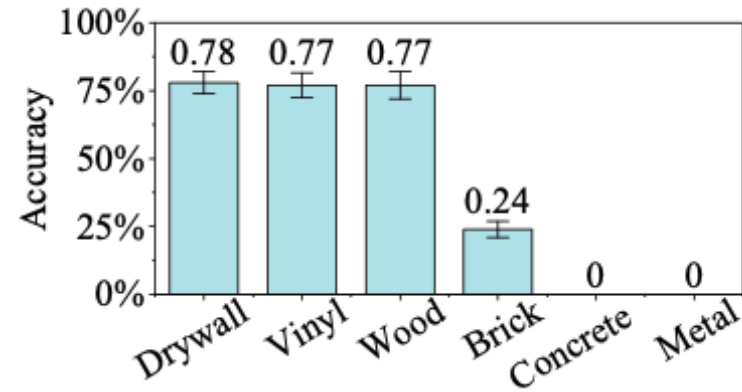
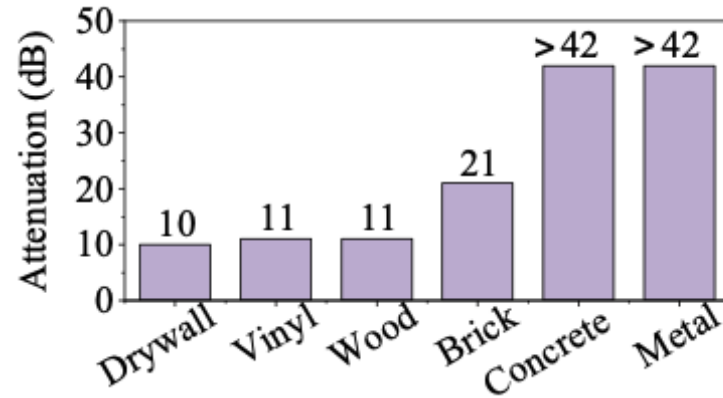
- RadSee is a 6 GHz FMCW radar device featuring an integrated software and hardware design.
- It can detect mm-level movements and letters written behind walls accurately, with low power and strong resistance to interference.



Thank you!

Backup Slides

- Impact of Different Wall Materials



Drywall



Vinyl wall



Wood wall



Brick wall



Concrete wall



Metal door