RF-Wise: Pushing the Limit of RFID-based Sensing

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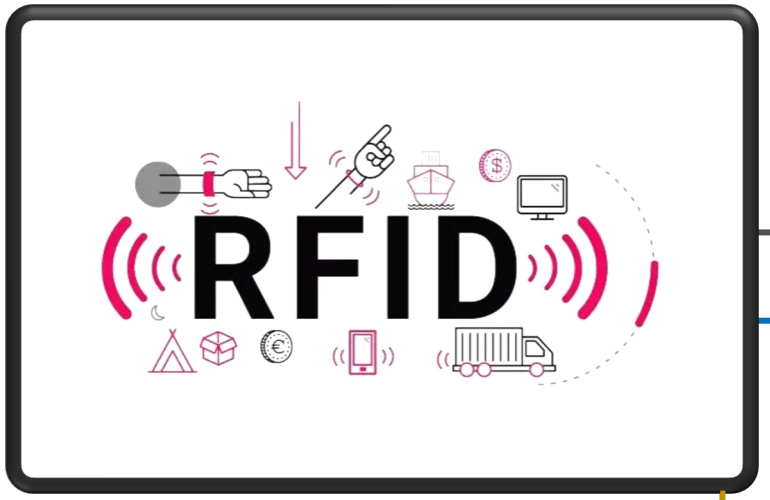
Content

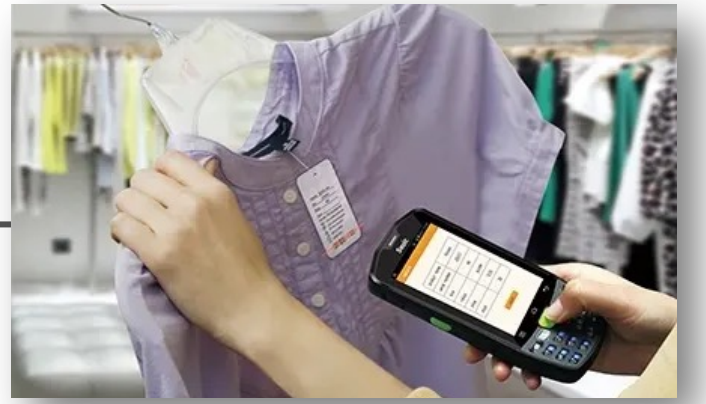
- **Motivation**
- **RF-Wise Design**
- **Evaluation**
- **Conclusion**

Motivation

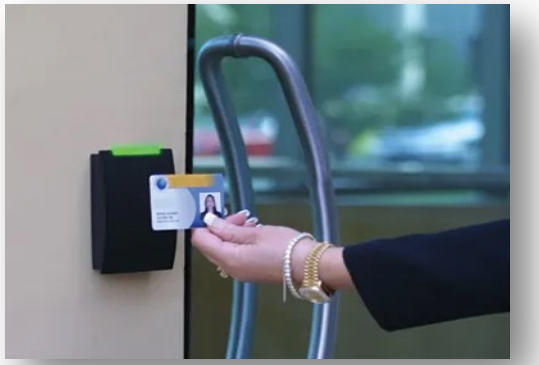


Radio Frequency Identification

Retail

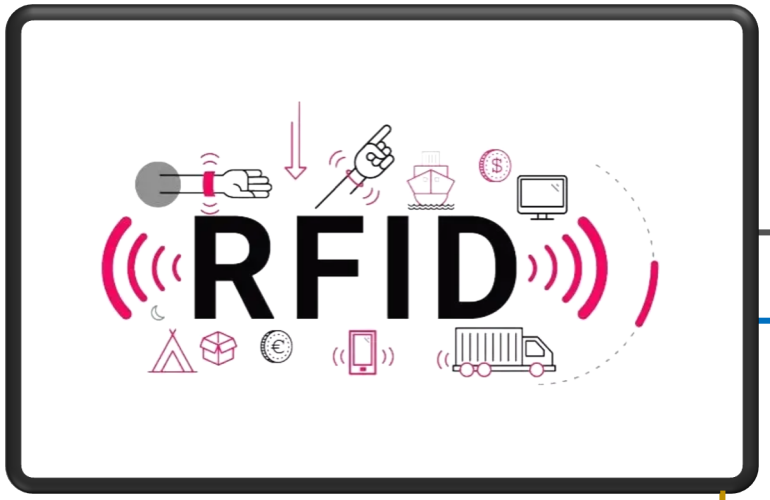


Access Control



Storage

Motivation



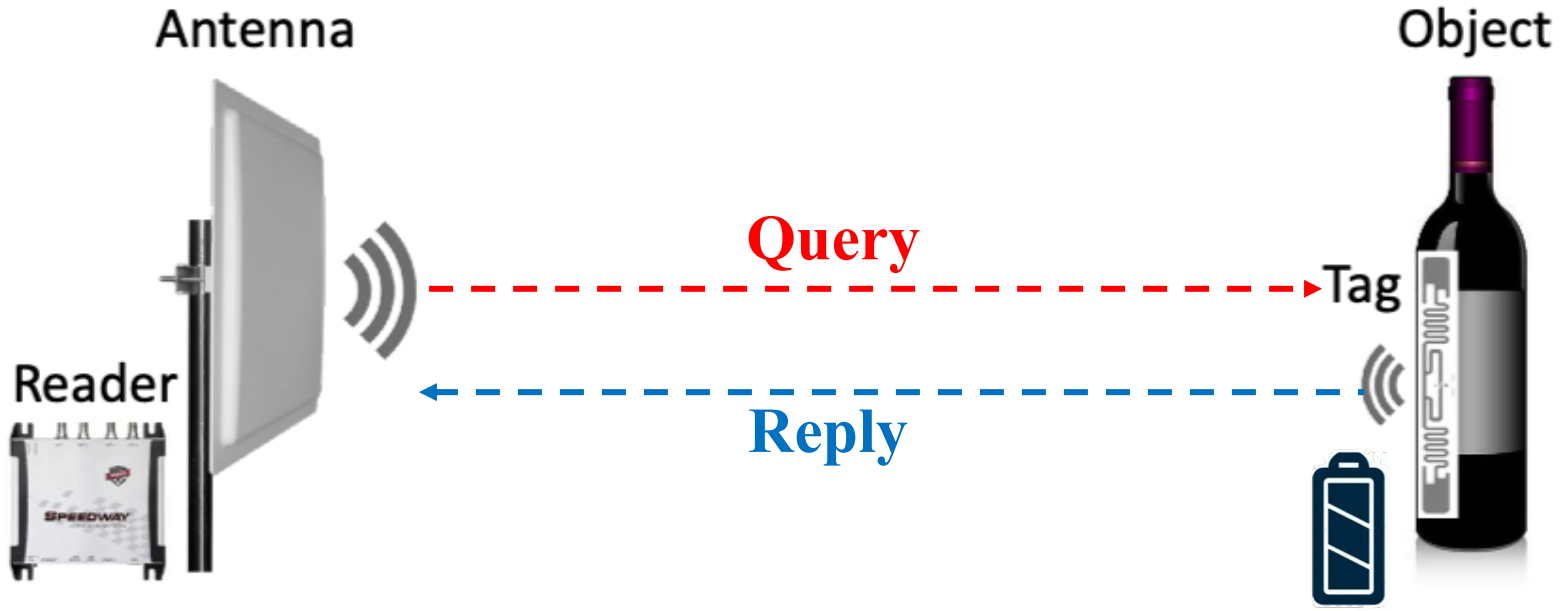
Radio Frequency Identification

Material identification

Localization

Gesture recognition

Motivation



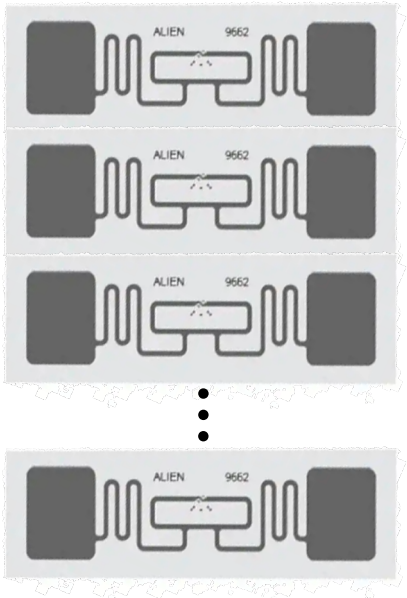
Single-dimensional sensing feature!

Phase /RSS/Doppler shift

Motivation

Antenna Array

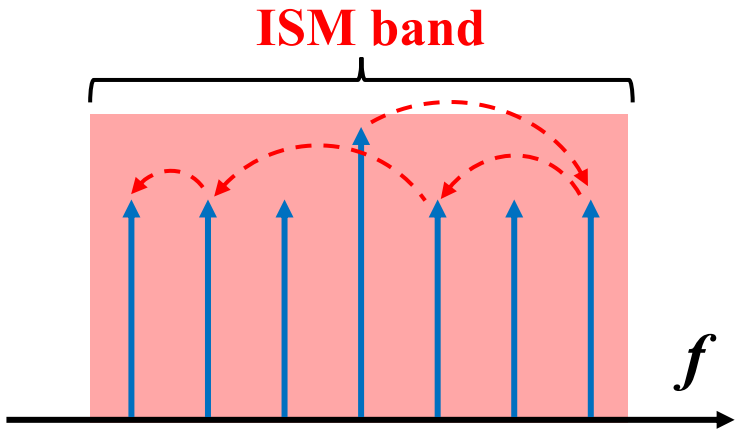
Higher cost



Tag Array

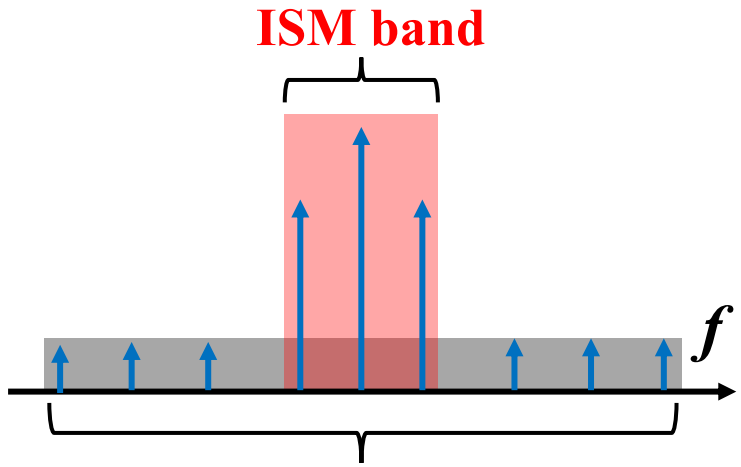
Collision

Motivation



Frequency hopping

Large latency



Wide band sensing

Large overhead

Motivation

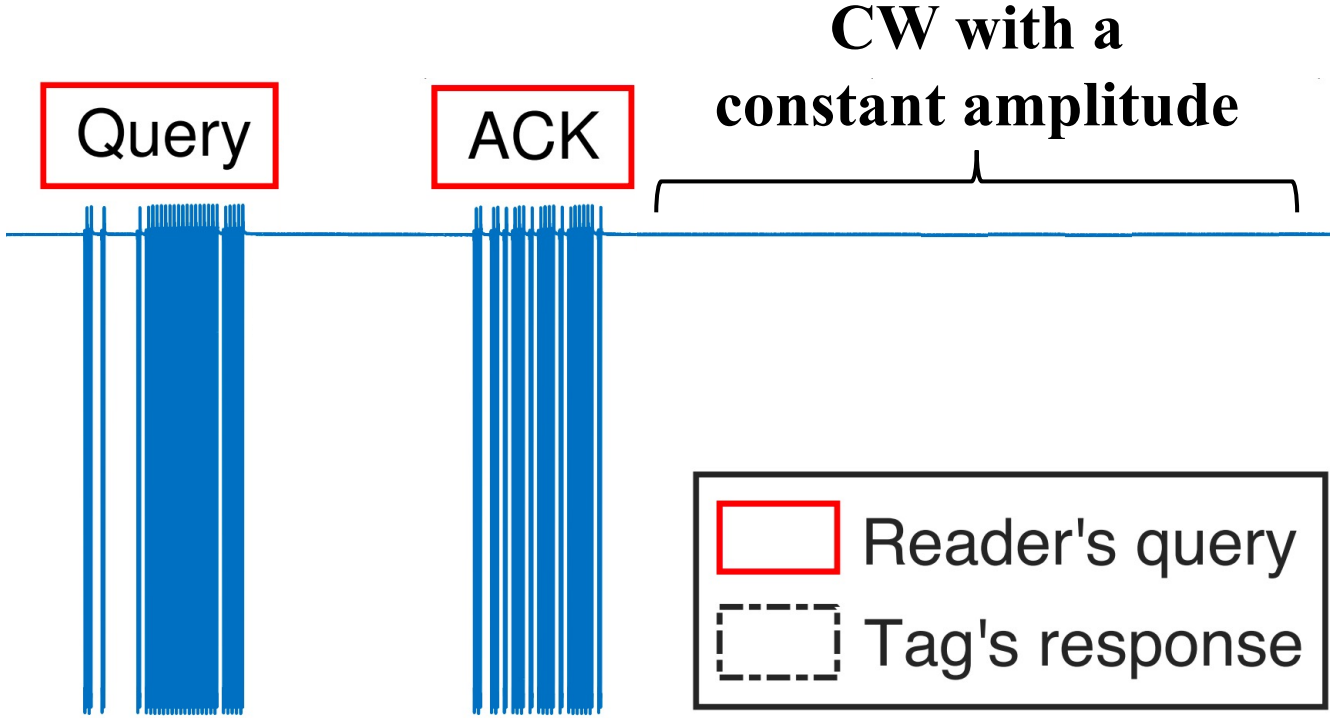
Can we improve RFID sensing without such extra costs and overhead?

RF-Wise brings a positive answer!

- **Multiple-frequency sensing**
- **No extra devices**
- **One tag only**
- **Within the ISM band**

RF-Wise Design

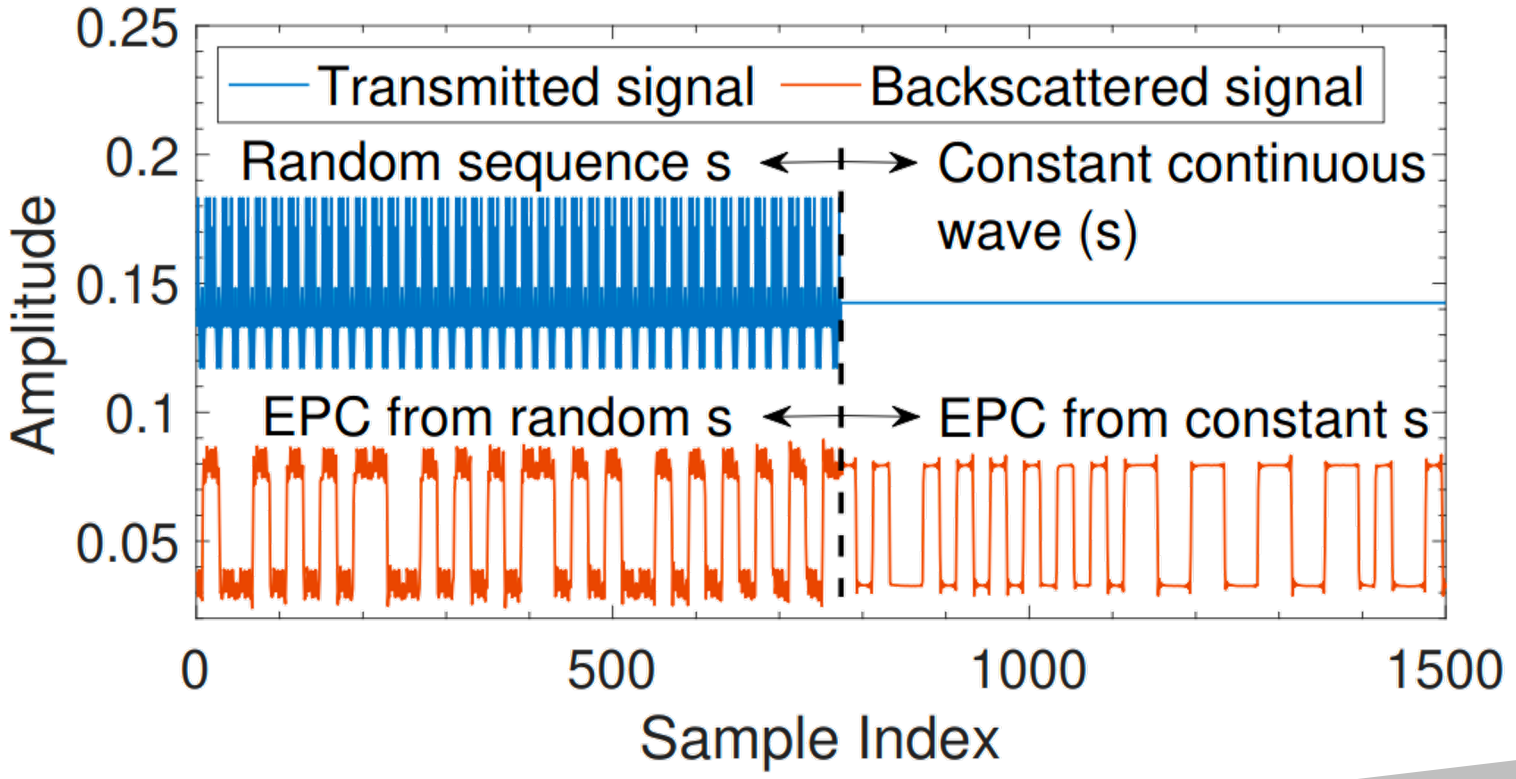
- **RFID communication**



RF-Wise Design

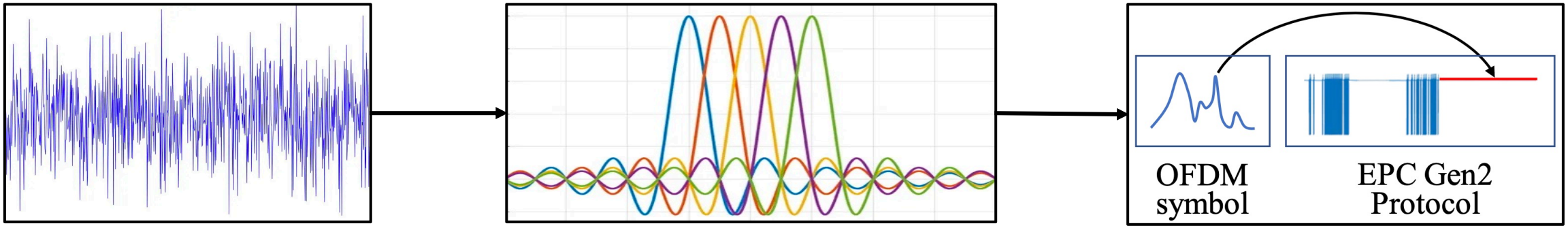
➢ Observation

- **Tag's backscattering is not sensitive to the waveform format of the continuous wave.**



RF-Wise Design

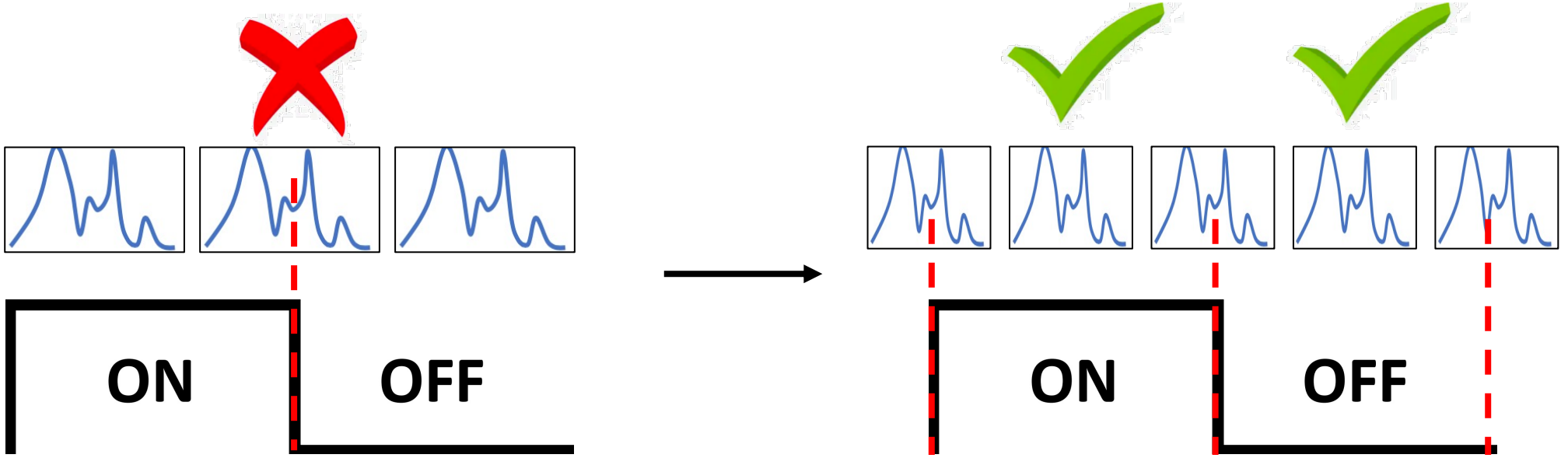
- **Signal customization**



Random sequence **OFDM symbol** **Customization**

RF-Wise Design

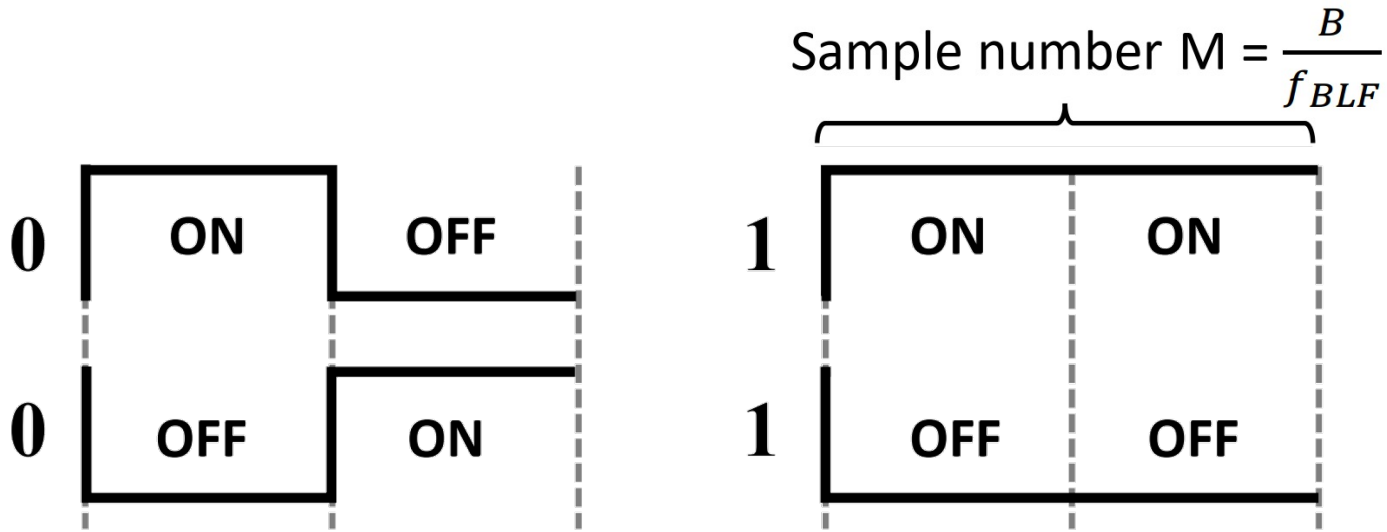
- **Signal customization**



RF-Wise Design

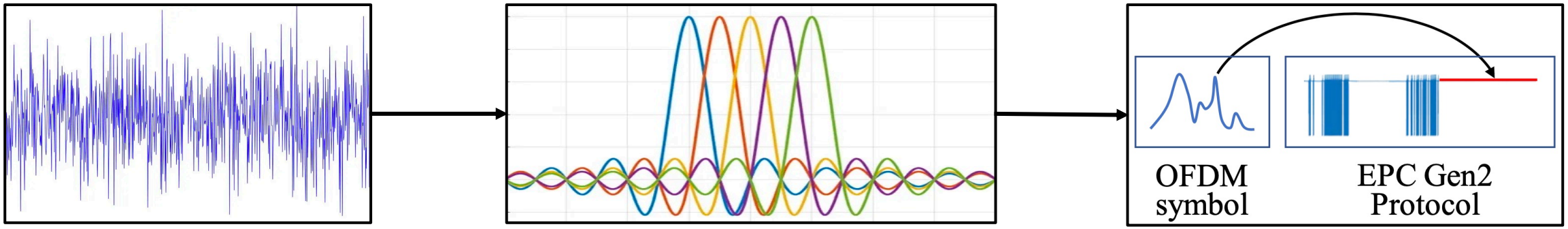
➢ Signal customization

$$L_{OFDM} < \frac{B}{2f_{BLF}} \longrightarrow L_{OFDM} < \frac{B}{\mu f_{BLF}}, \begin{cases} \mu = 2 & for\ bit\ 1 \\ \mu = 4 & for\ bit\ 0 \end{cases}$$



RF-Wise Design

- **Signal customization**

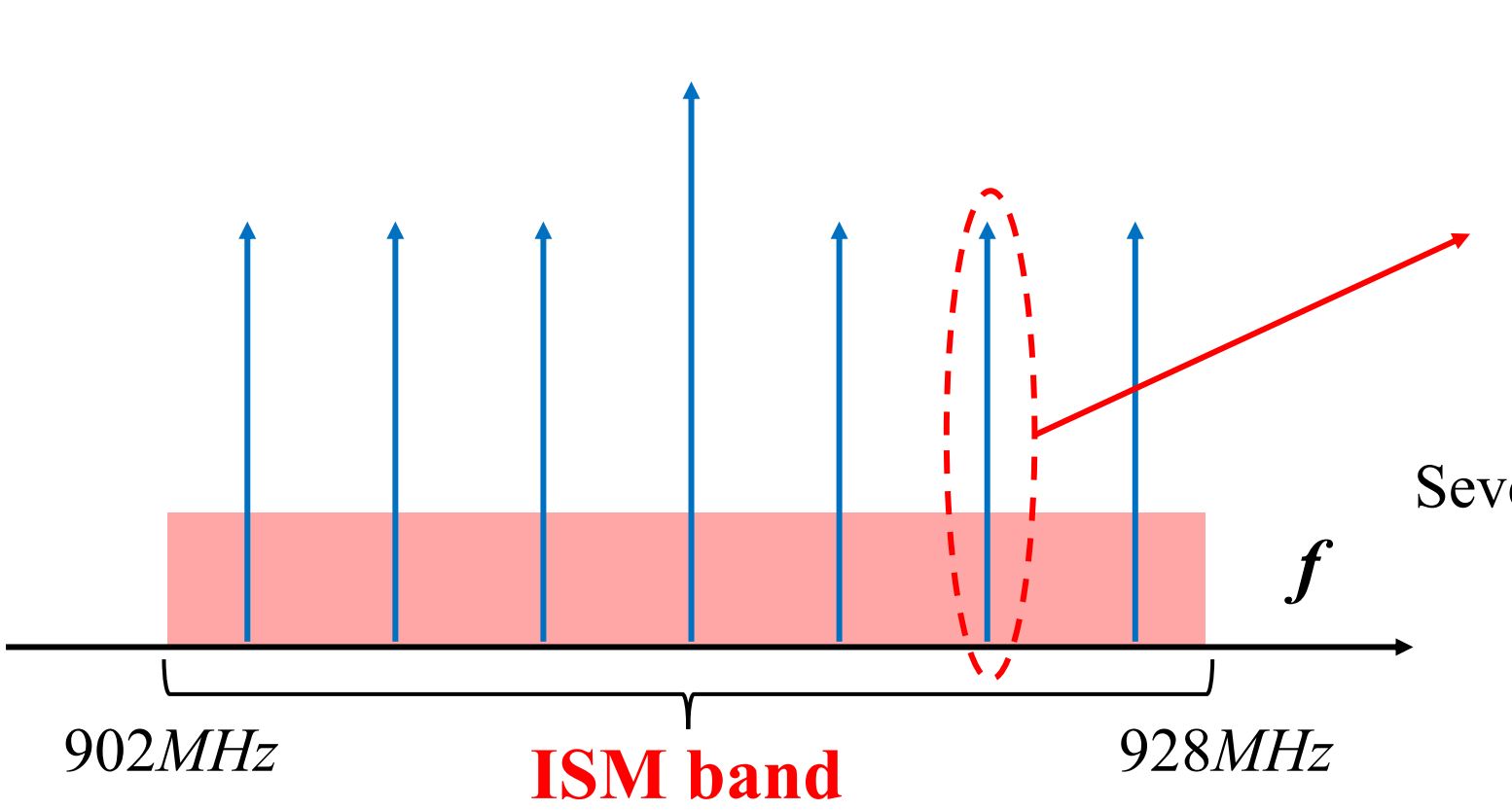


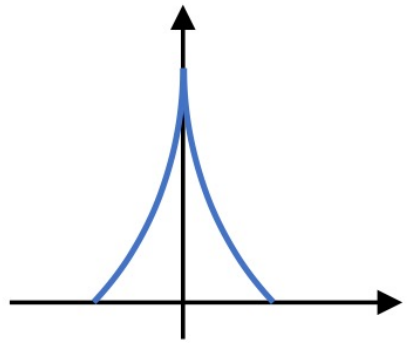
Random sequence **OFDM symbol** **Customization**

- $E_{OFDM} < E_{require}$ → No tag's reply
- $\alpha \cdot E_{OFDM} > E_{require}$ → Tag's reply cannot be decoded
- $\beta \cdot E_{OFDM} + E_{CW} > E_{require}$ → Tag functions well

RF-Wise Design

- **Harnessing wider band**





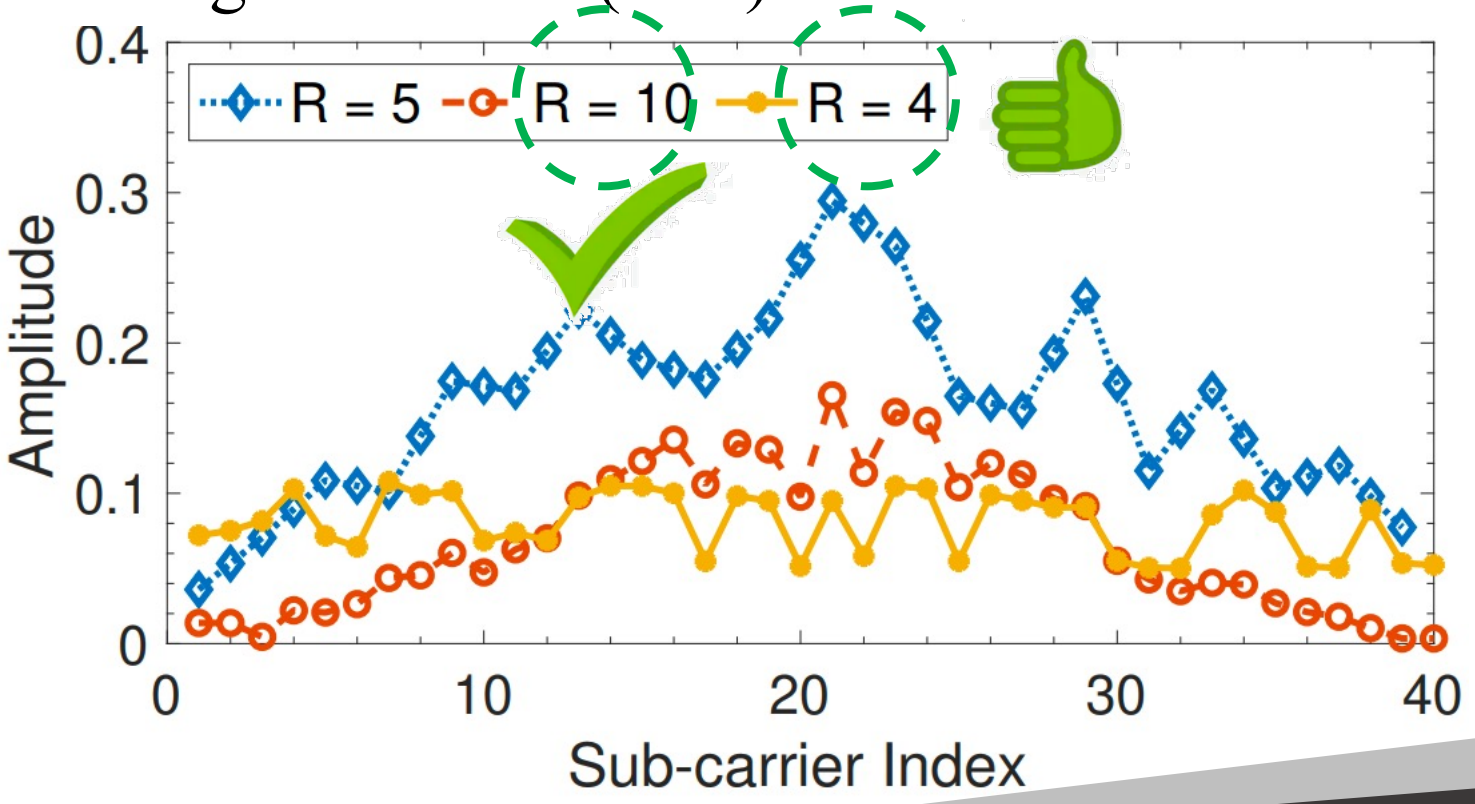
Narrow Band

Several hundreds of kHz

RF-Wise Design

➢ Harnessing wider band

- Inappropriate bandwidth
  - → integrator-comb (CIC) roll-off



RF-Wise Design

➢ Harnessing wider band

- Inappropriate bandwidth
  - → integrator-comb (CIC) roll-off
  - → RFID parameters

$$\max_{\{\theta_B\}} \ B,$$
$$s.t. \ ① B \leq B_u,$$
$$② \frac{r}{B} \in \{2^i\}, \ i = 1, 2, \ldots,$$
$$③ L_j(B, \theta_B) \in N_+, \ j = 1, \ldots, 4,$$

RF-Wise Design

➢ Harnessing wider band

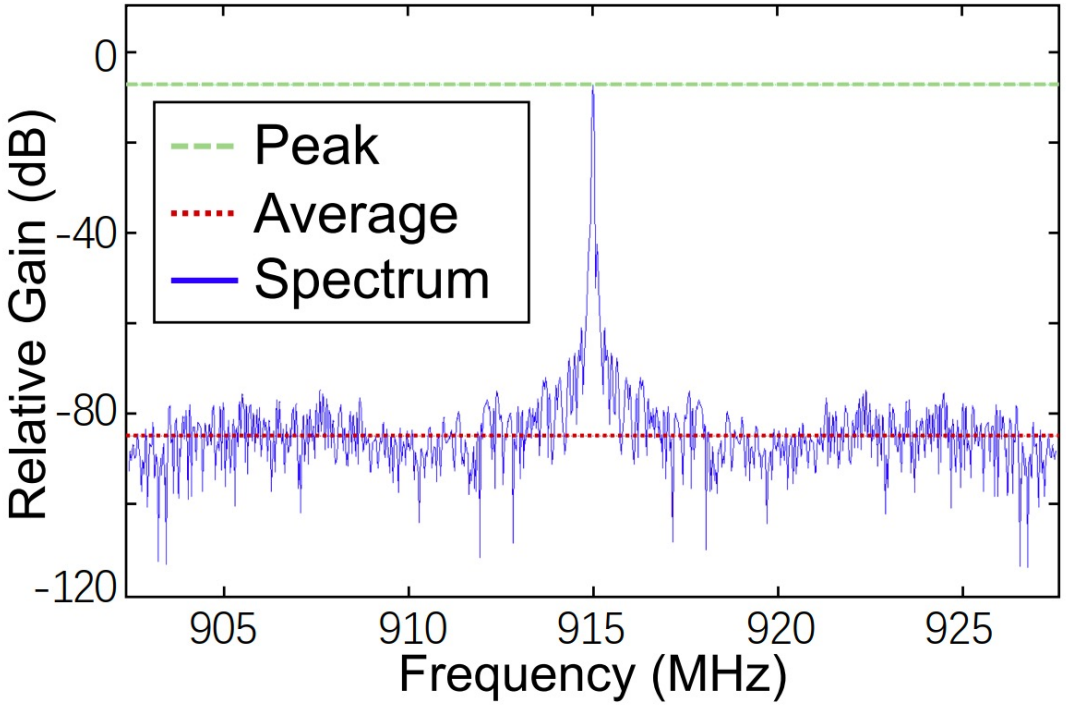
- Inappropriate bandwidth
  - → integrator-comb (CIC) roll-off
  - → RFID parameters

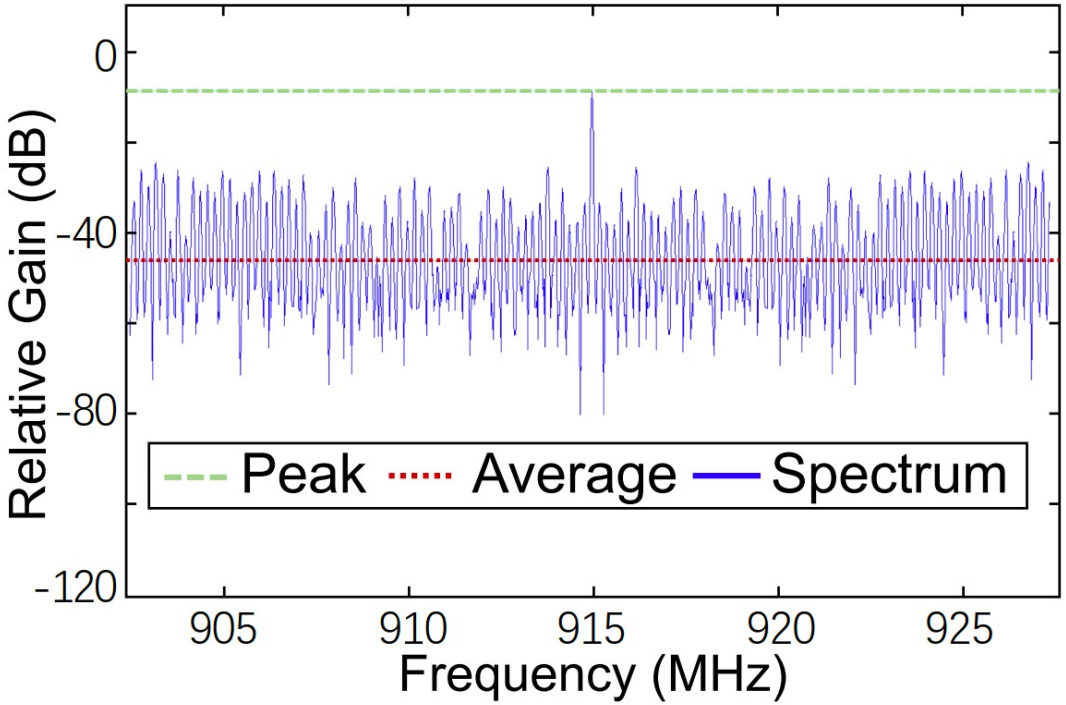
SETTING OF RFID'S META PARAMETERS USED IN RF-WISE. THE CENTRAL FREQUENCY OF RFID COMMUNICATION IS SET TO 915 MHZ.

f_{BLF}	P_{TRcal}	P_{RTcal}	P_{Tari}	P_{T_1}	P_{T_2}	P_{DC}
50 KHz	160 μs	60 μs	20 μs	180 μs	380 μs	90 μs

RF-Wise Design

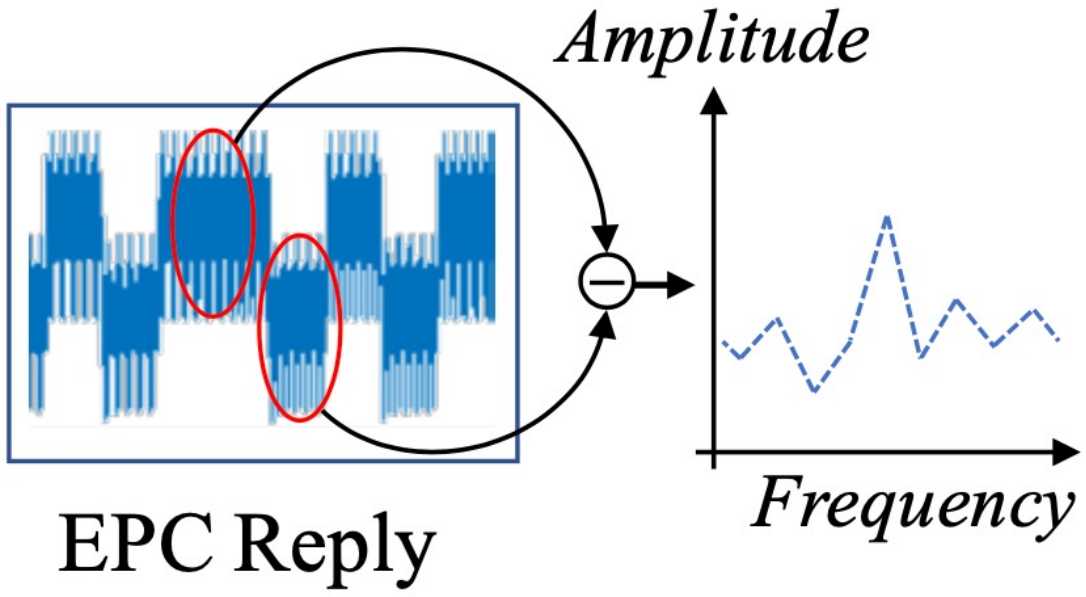
- **Harnessing wider band**





RF-Wise Design

➢ Feature extraction



$f_{target} + f_{env}$ $\qquad$ f_{env}

$$\mathcal{F}_{sta} = \frac{1}{q_1}\sum_{i=1}^{q_1} H_i^1(on) - \frac{1}{q_2}\sum_{j=1}^{q_2} H_j^1(off)$$

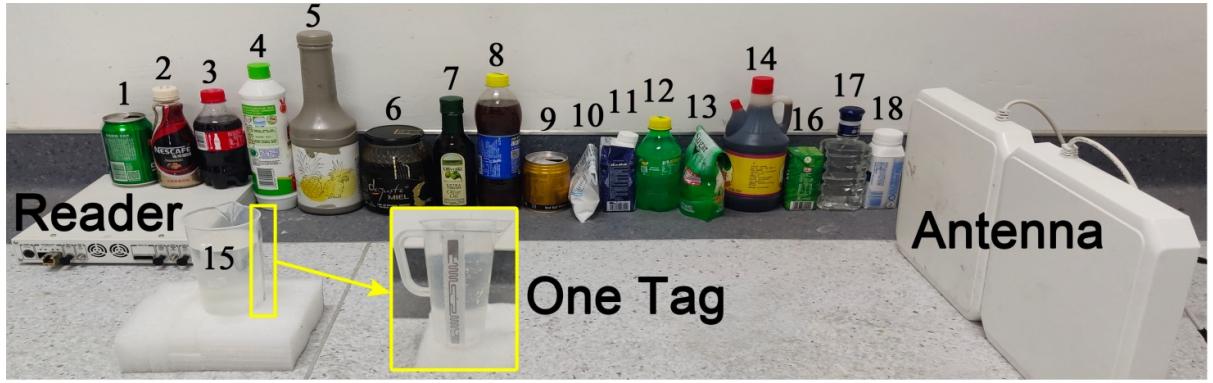
$$\mathcal{F}_{dyn} = \mathcal{H}^{0/1} = \{H_i^{0/1}\}_{i=1}^{q_3}$$

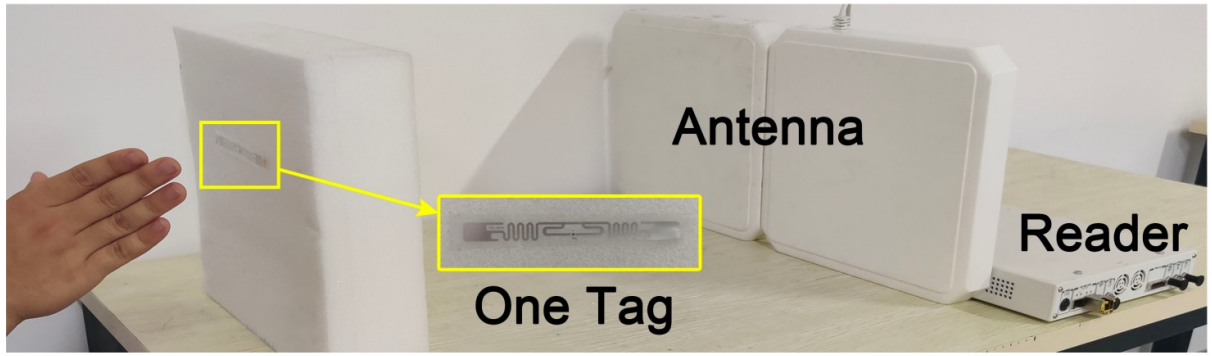
Evaluation

- Hardware:
  - USRP X310 with SBX-40 daughterboard
  - Laird S9028PCR antenna
  - Alien 9640 RFID tag
  - X520-DA1 network adapter
  - 10 Gigabit Ethernet Cable

- Software:
  - GNU Radio 3.7
  - UHD 3.15
  - Ubuntu 18.04

Liquid classification

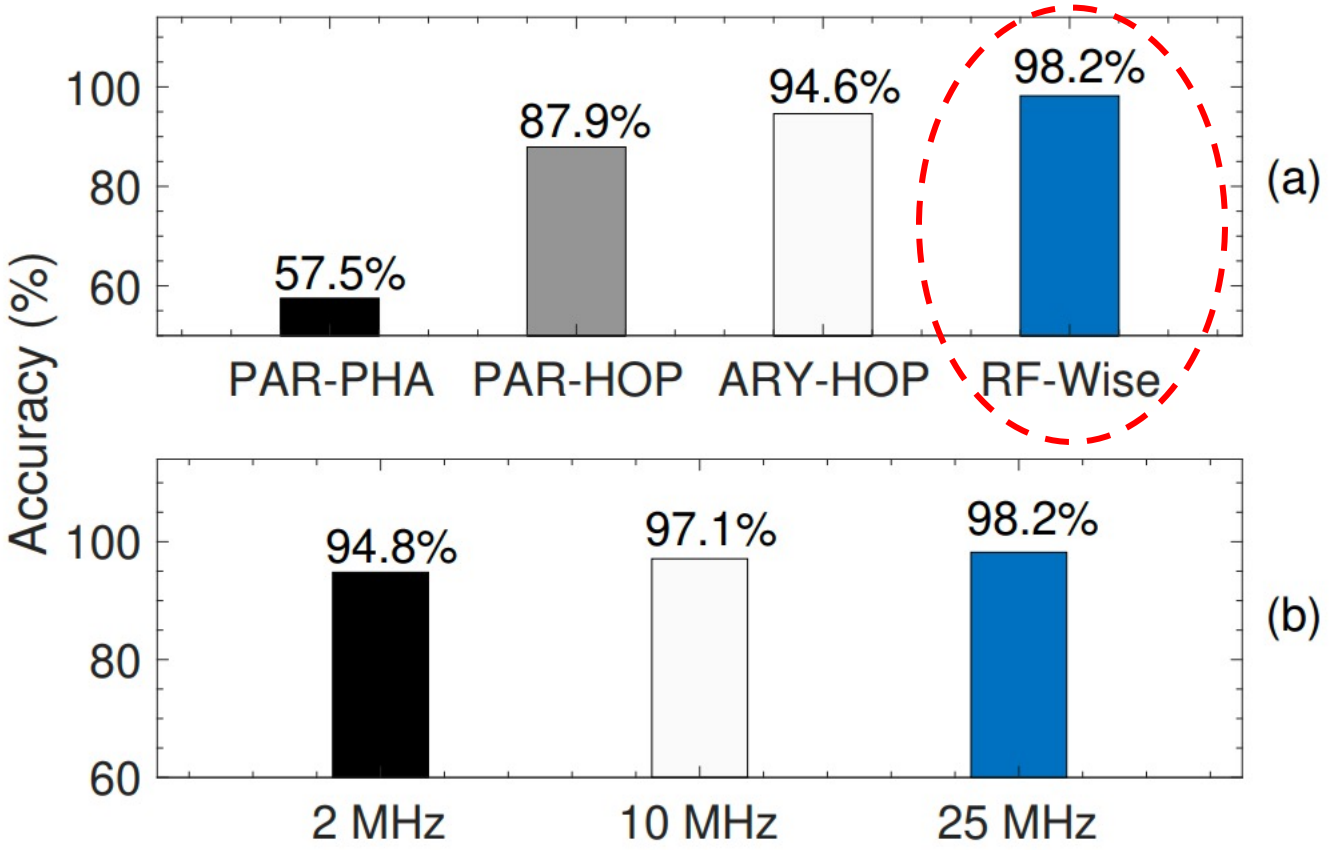




Gesture recognition

Evaluation

➢ Liquid classification



① **PAR-PHA**: one pair of tags (PAR) and signal's phase information (PHA)

② **PAR-HOP**: one pair of tags (PAR) with frequency hopping (HOP)

③ **ARY-HOP**: tag array (ARY) and the frequency hopping (HOP)

④ **RF-Wise**: one tag, frequency multiplexing and 25 MHz bandwidth

Evaluation

➢ Liquid classification

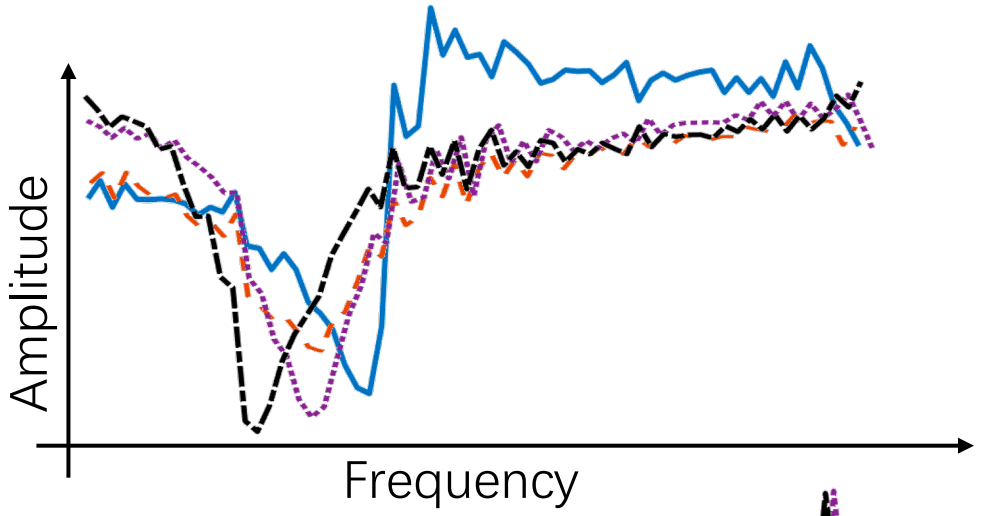
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Liquids
1	1																		1 Beer
2		0.95										0.02	0.02			0.01			2 Coffee
3		0.003	0.96					0.017				0.01	0.01						3 Coke
4				0.98										0.007		0.01	0.003		4 Detergent
5				0.01	0.99														5 Juice
6		0.007				0.99											0.003		6 Honey
7							0.99										0.01		7 Oil
8	0.01		0.02					0.96				0.01							8 Pepsi
9				0.003		0.003			0.99				0.003						9 Red Bull
10										0.99			0.01						10 Saline water
11								0.003			0.98					0.017			11 Skimmed milk
12			0.01									0.98				0.01			12 Sprite
13												0.013	0.98		0.007				13 Sweet water
14				0.013	0.007									0.98					14 Vinegar
15	0.01														0.99				15 Water
16					0.003						0.02		0.003			0.97		0.003	16 Whole milk
17																	1		17 Wine
18																		1	18 Yogurt

Evaluation

➢ Liquid classification

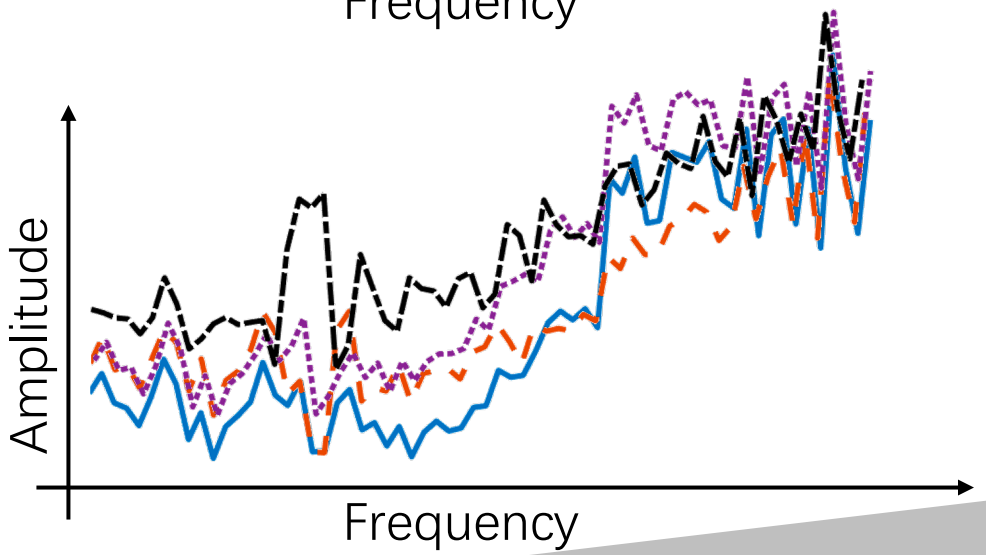
Fresh Milk

After 1 hour
After 2 hours
After 4 hours



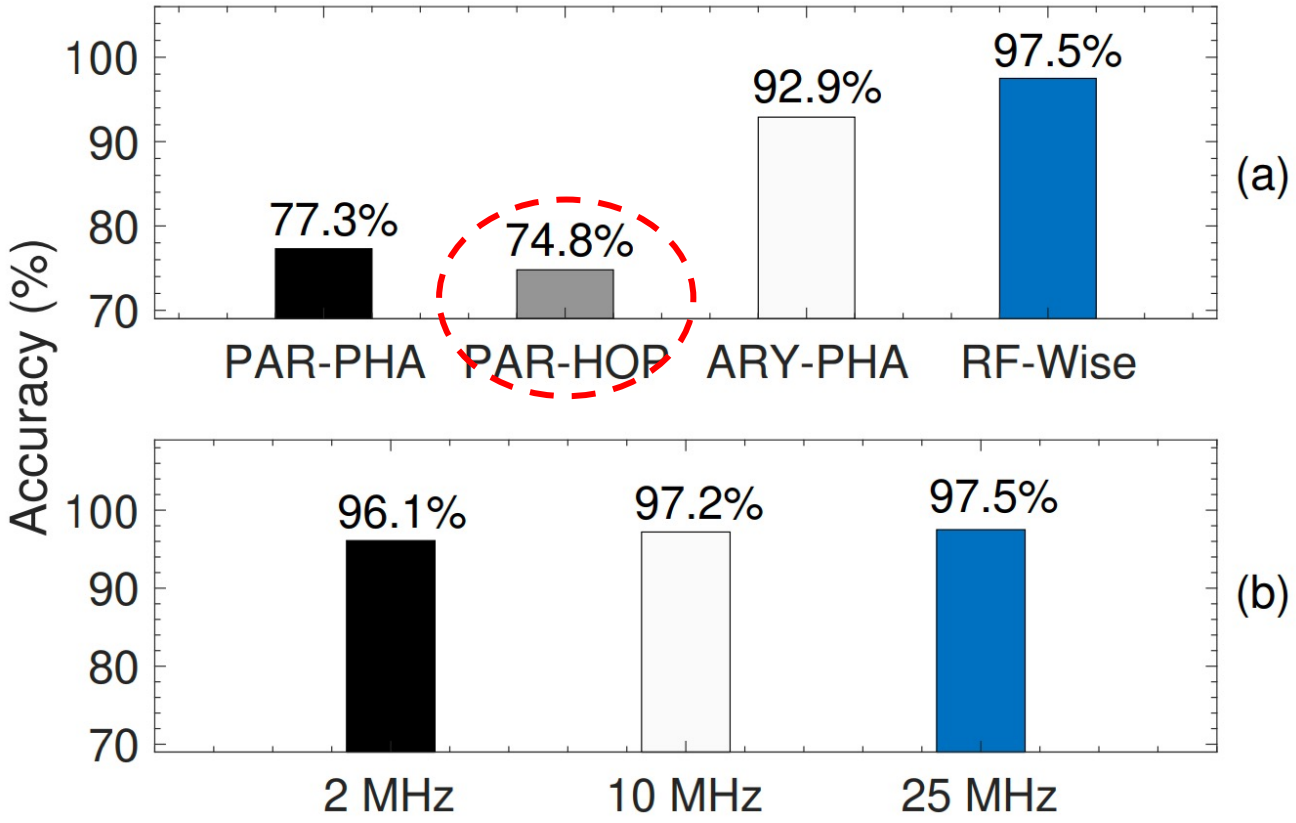
Wine

w/ 2.5% water
w/ 5.0% water
w/ 7.5% water



Evaluation

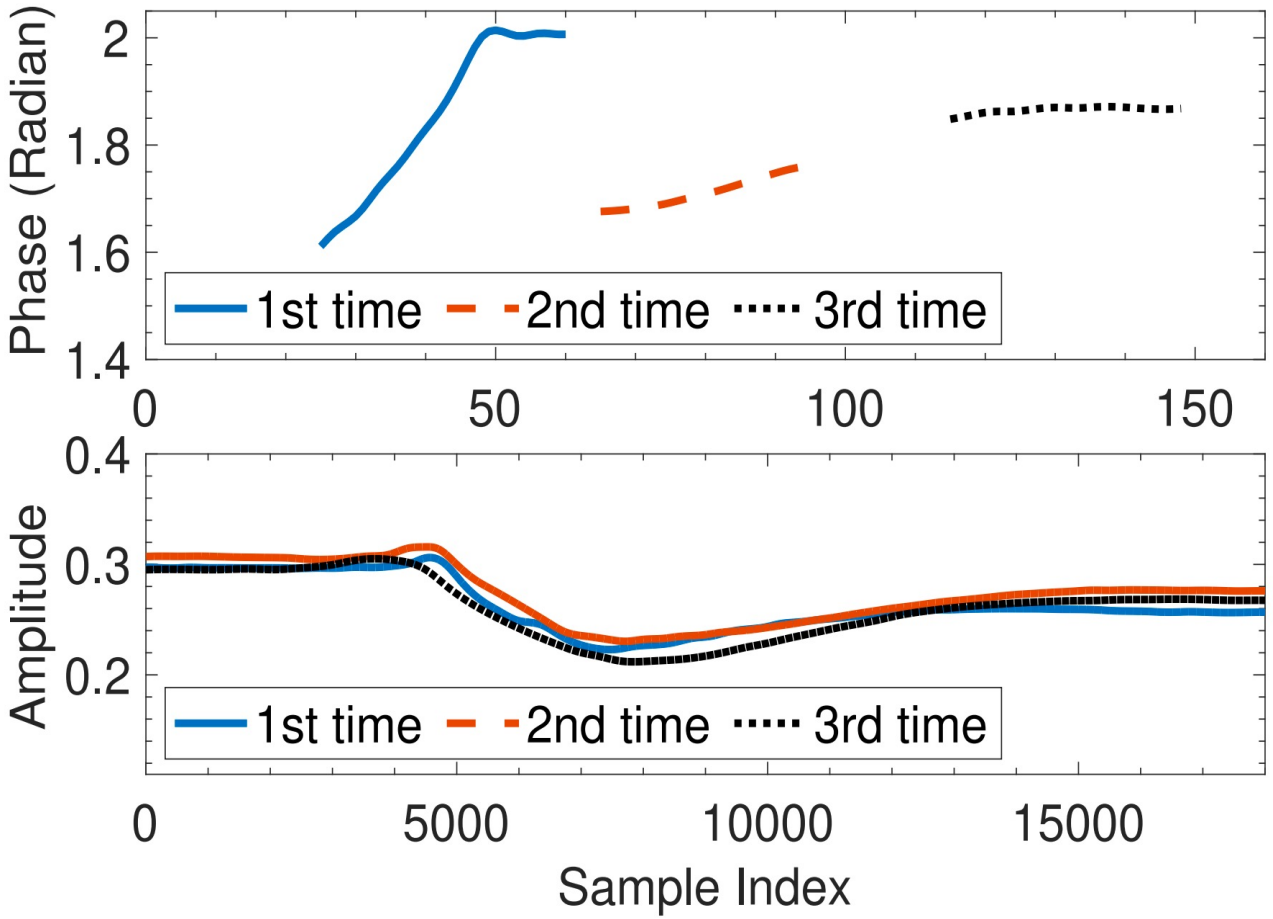
➢ Gesture recognition



- **PAR-PHA**: one pair of tags (PAR) and the phase information (PHA)
- **PAR-HOP**: one pair of tags (PAR) with frequency hopping (HOP)
- **ARY-PHA**: tag array (ARY) and signal's phase information (PHA).
- **RF-Wise**: one tag, frequency multiplexing and 25 MHz bandwidth

Evaluation

➢ Gesture recognition

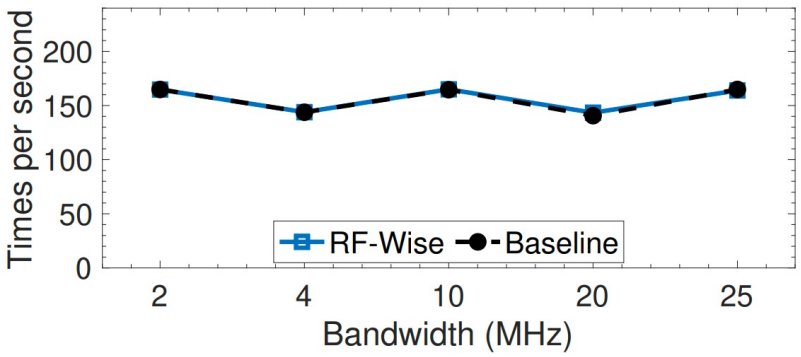


(a) Features from Frequency Hopping

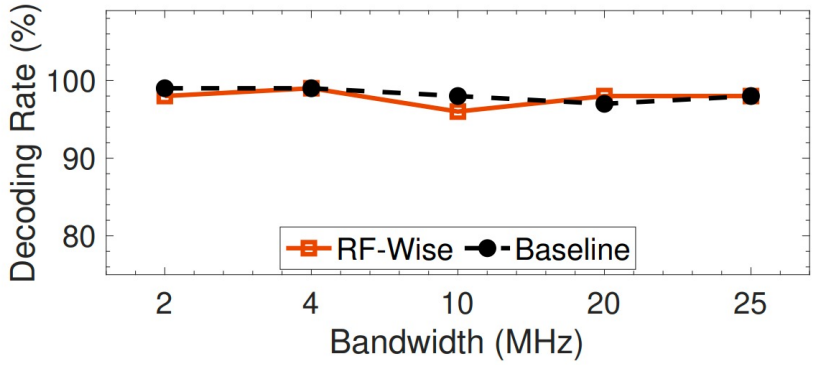
(b) Features from RF-Wise

Evaluation

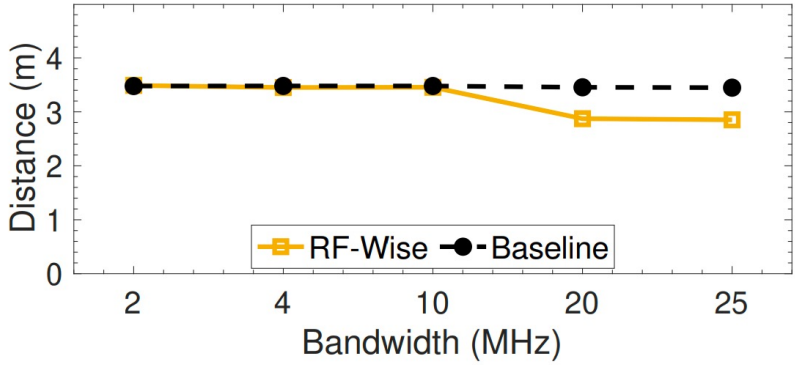
➢ Compatible to RFID communication



(a) Reading rate v.s. Bandwidth



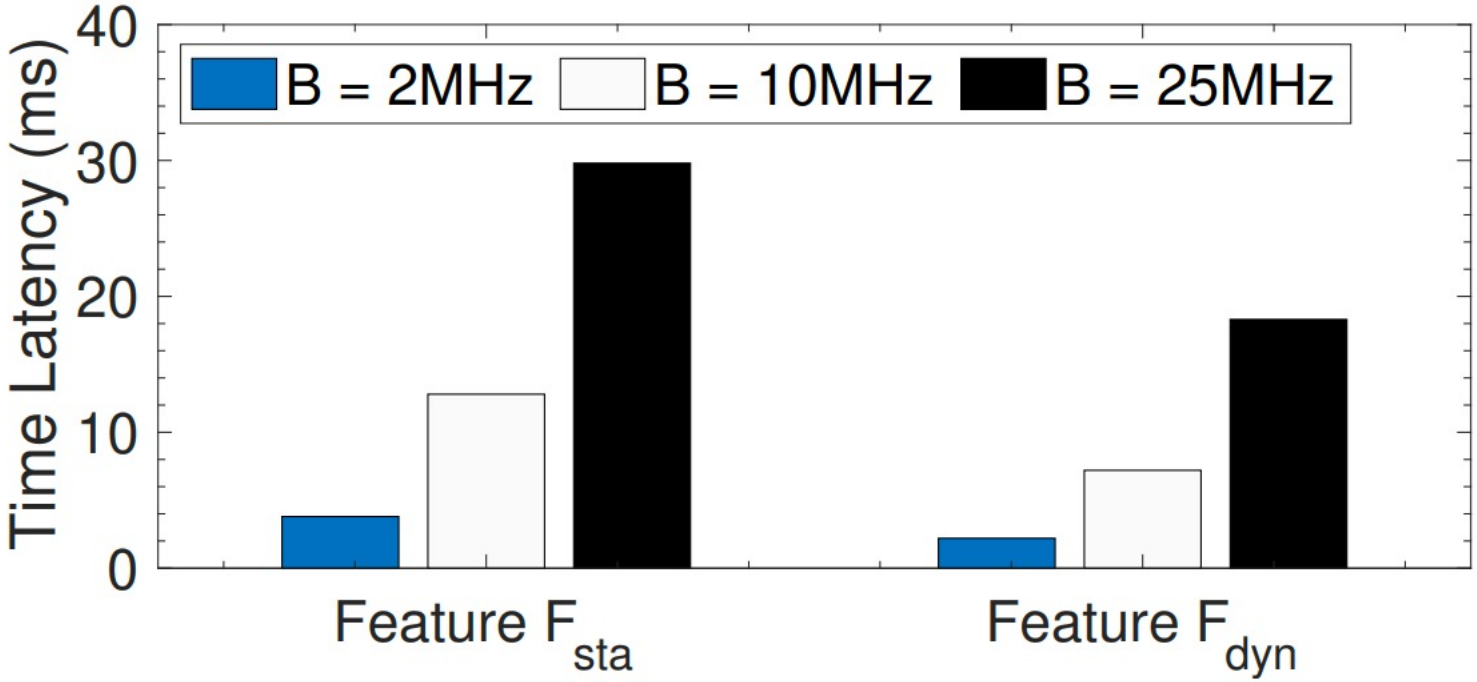
(b) Decoding rate v.s. Bandwidth



(c) Reading distance v.s. Bandwidth

Evaluation

- **Latency**



Conclusion and Q&A

- First work to collect the fine-grained CSI-like sensing features from the RFID signal.
  - https://cui-zhao.github.io/RF-WISE/