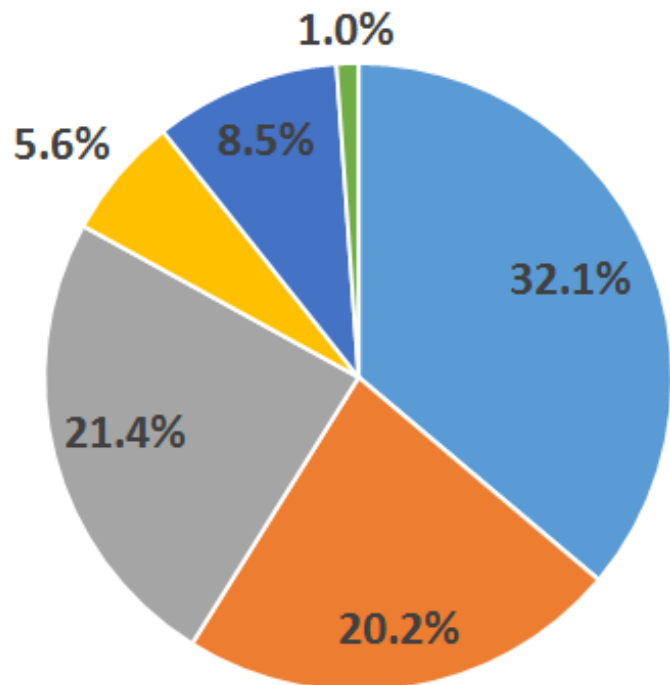


A Split Manufacturing Approach for Unclonable Chipless RFIDs for Pharmaceutical Supply Chain Security

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Pharmaceutical Supply Chain Risks



- No active ingredient
- Incorrect quantities of active ingredients
- Wrong ingredients
- Fake packaging
- High levels of impurities
- Copies of an original product

- **Counterfeiting**

- Fake or substandard medicines yielded an estimated revenue of \$75 billion in 2010 alone
- From 2010 to 2014, Interpol's Operation Pangea shut down 57,000 illegal online pharmacies and seized over 30.3 million units of counterfeit drugs

- **Theft**

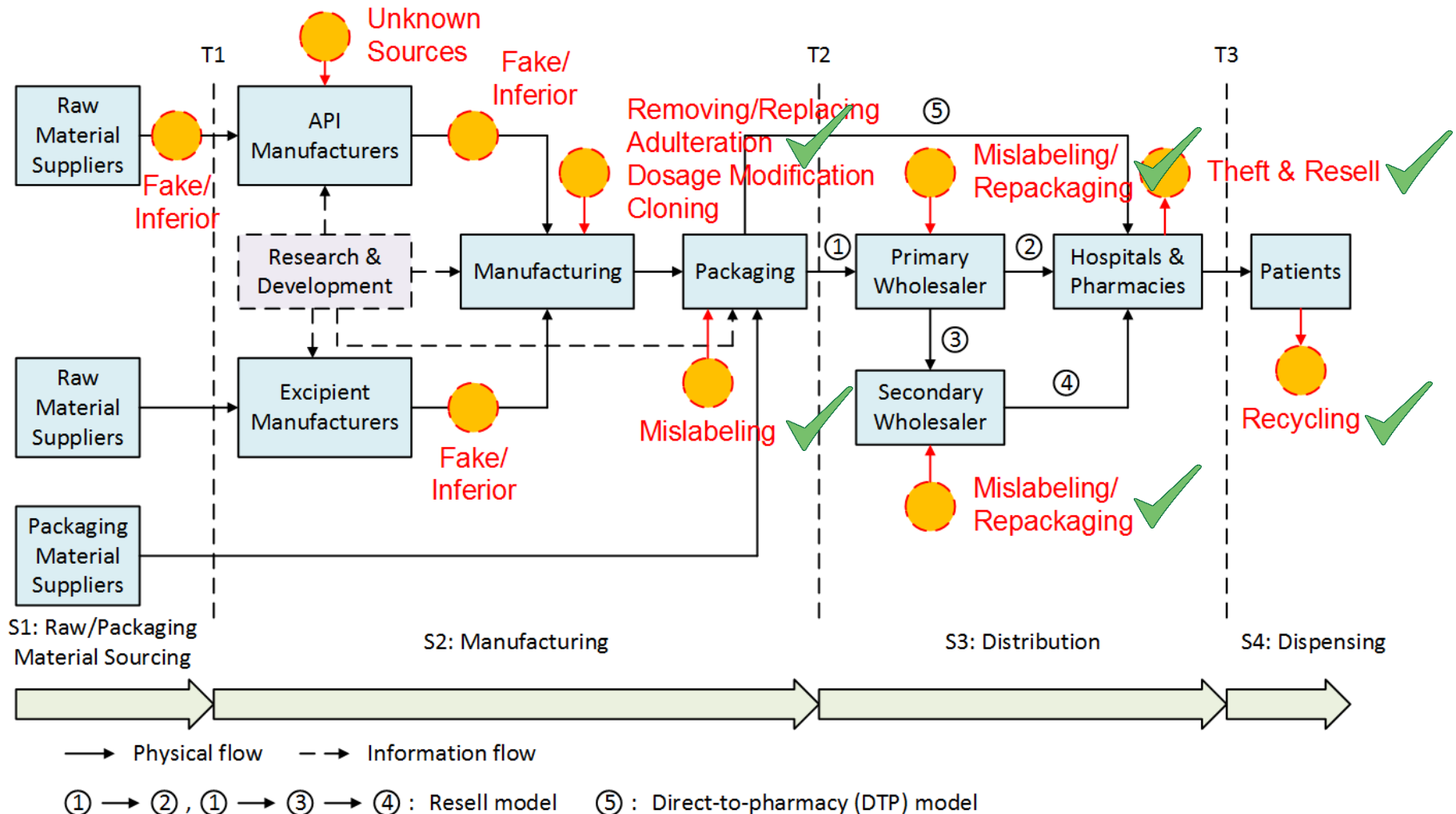
- In 2013, the average loss per pharmaceutical theft incident was \$261,819

- **Impact**

- 81 people were killed in the 2008 case of counterfeit blood thinner heparin
- During late January 2012, tainted cardiac medicines killed more than 200 people in Pakistan and sickened around 1000

Pharmaceutical Supply Chain Risks

✓ : Risks that can be addressed by pill-level UCR



Conventional Solutions

- **Barcode and QR code**
 - Easy to duplicate
 - Require individual scanning
 - Need direct line-of-sight and close proximity to scanner
- **IC-based RFID tag**
 - Price is high
 - Tag information is possible to be overwritten by attacker



Barcode



QR code



IC-based RFID tag

Existing Chipless RFID Tags

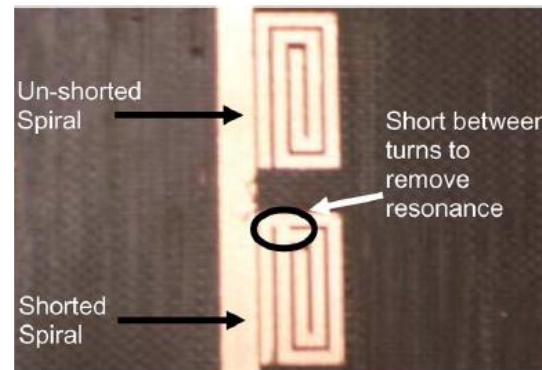
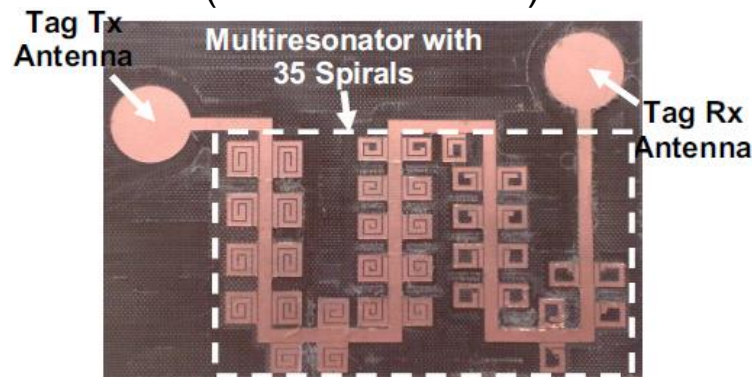
• Merits

- Extremely low price (as low as 0.1 cents)
- Near-zero power consumption
- Printability
- Elimination of tag memory
- Insensitivity to ambient temperature variation

• Shortcomings

- Complex manufacturing process
- Large tag area
- Small ID size
- Vulnerability to cloning attack

35-bit chipless RFID tag
(88 mm × 65 mm)



[2] Stevan Preradovic and Nemai C Karmakar. Design of fully printable planar chipless RFID transponder with 35-bit data capacity. In Microwave Conference, 2009. EuMC 2009. European, pages 013–016. IEEE, 2009.

Unclonable Chipless RFID (UCR) Tag

- **Merits**

- ID is unique and unclonable
- Large ID size (10 analog values)
- Small tag area
- Does not require post-processing to encode data
- Short manufacturing time
- Low manufacturing cost

- **Shortcomings**

- Does not establish an inseparable connection with the object being identified and thus is ***vulnerable to split attacks***
- Cannot provide a ***pill-level traceability*** for protecting the pharmaceutical supply chain

UCR tag (radius: 10 mm)



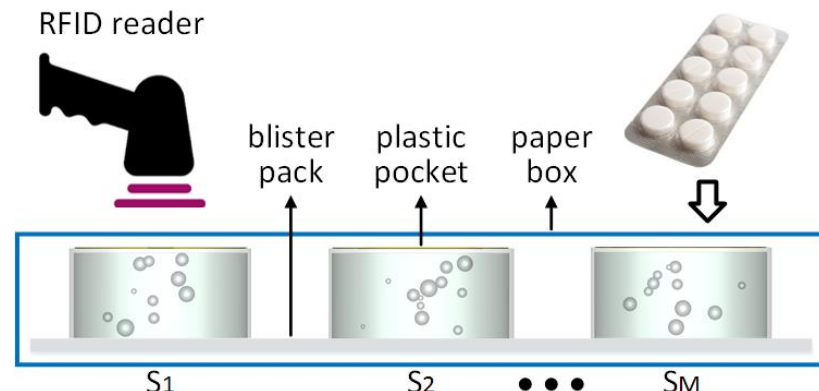
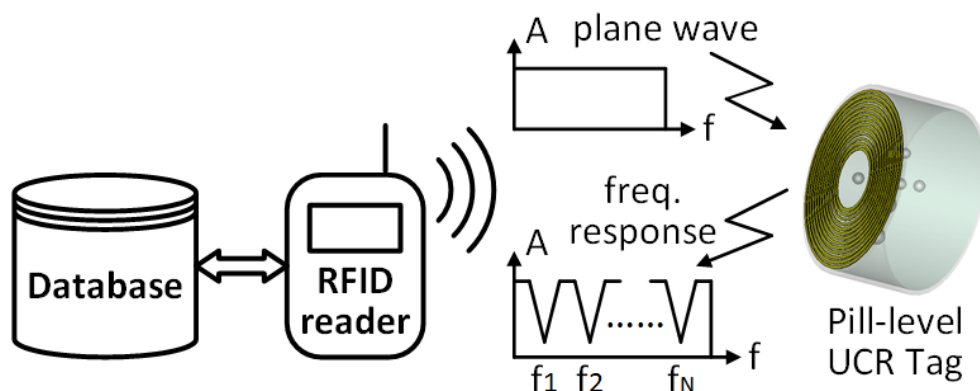
Shortcomings of existing solutions

- Expensive
- Inconvenient
- Unreliable
- Insecure
- Large tag area
- Small ID size
- Box-level traceability

Pill-level UCR

- Low cost
- Easy to access
- Reliable
- Unclonable
- Small tag area
- Large ID size
- Pill-level traceability

Pill-Level UCR System



Drug authentication without necessarily opening the package

- **Pill-level UCR tag**

- A certain number of concentric ring slot resonators integrated on the external surface of each plastic cavity or pocket of blister pack
- Nontoxic silver particles of random quantity with random diameters filled in random places of each pharmaceutical tablet

- **Excitation signal**

- A swept-frequency continuous-wave signal (i.e., plane wave)

- **RFID reader**

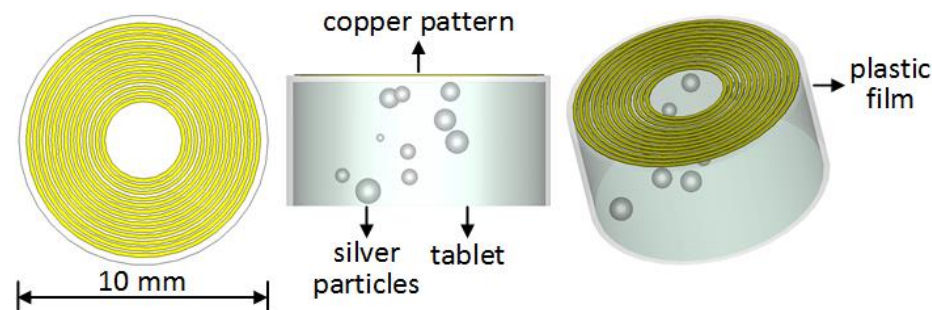
- Provides the plane wave and captures the signature (i.e., frequency spectrum)

The signatures (S_1, S_2, \dots, S_M) of all tablets within the same blister pack will be bound together to add one more layer of security to be resistant to illegal tablet replacement

Pill-Level UCR Tag

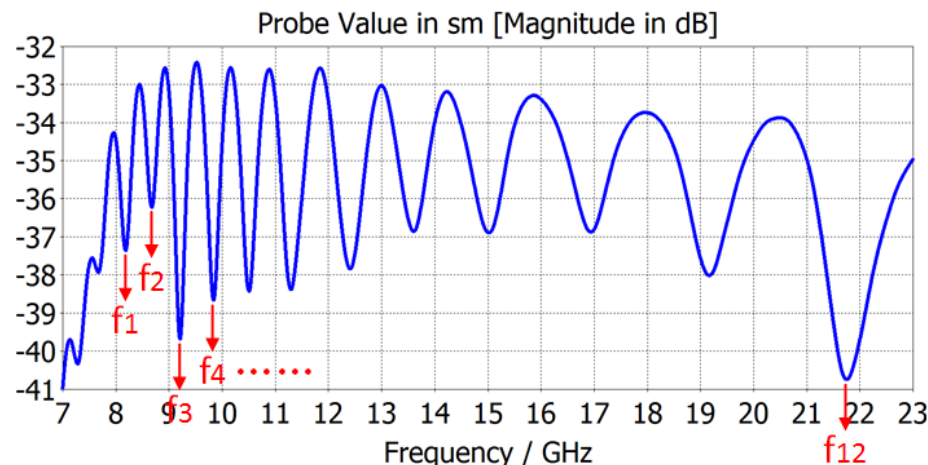
ID

- The vector (f_1, f_2, \dots, f_N) composed of fundamental resonance points in the frequency response spectrum



Entropy sources

- Process variations during copper pattern manufacturing
- Randomnesses of silver particles



[3] Silvers valence is + not ++ and therefore it does not oxidize into a toxic form.

[4] University of Florida. Tattletale pills: Engineers design pill that signals it has been swallowed, 2010.

Entropy Sources

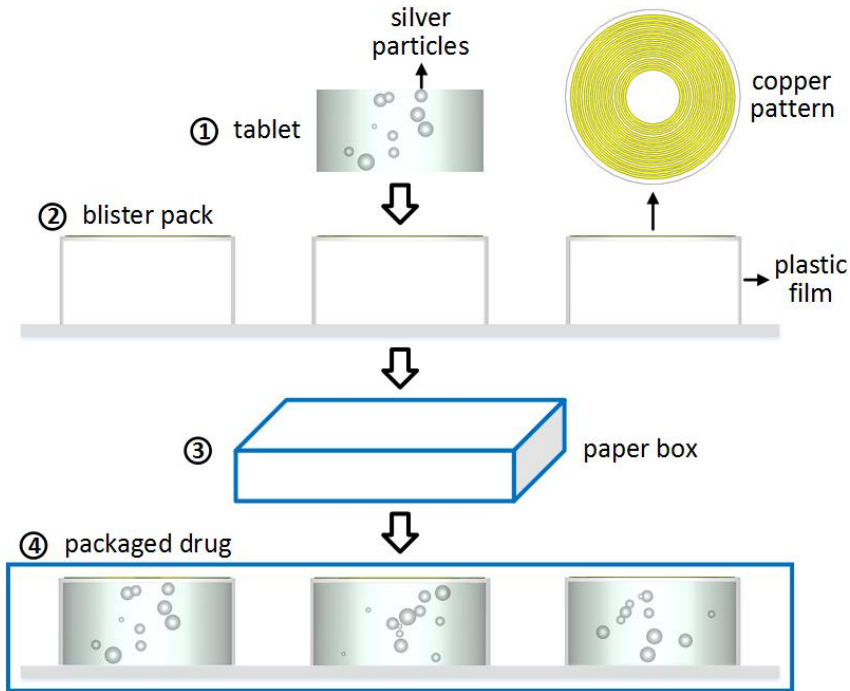
PCB Manufacturer	Trace Width / Air Gap Tolerance	PCB Thickness Tolerance
Advanced Circuits	max (+/-20%, +/-0.002")	max (+/-10%, +/-0.005")
Sunstone	+/- 20%	+/- 10%
Sierra Circuits	+/- 0.0001"	+/- 10%
Precision PCBS	+/- 20%	+/- 0.005"
RUSH PCB	+/- 0.005"	+/- 10%

Process variations during copper pattern manufacturing

- For the trace width and air gap, the maximum deviation between design value and measured value can be as large as 20%
- PCB thickness will typically have a tolerance of 10%

Randomnesses of silver particles

- Random quantities, diameters, positions, and sphericities



Step 1: Filling silver particles of random quantity with random diameters in random positions of tablets

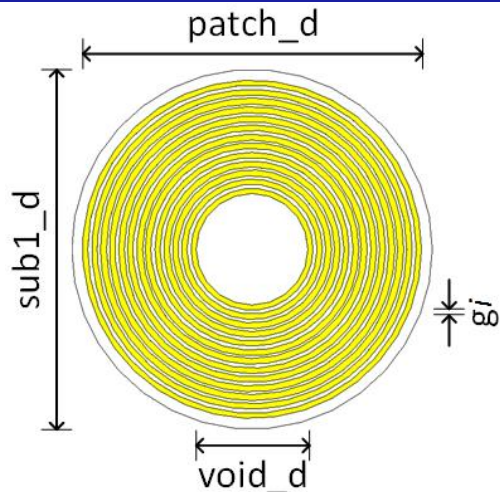
Step 2: Integrating copper pattern on the external surface of each plastic pocket

Step 3: Filling tablets into plastic pockets of blister pack and packaging blister pack

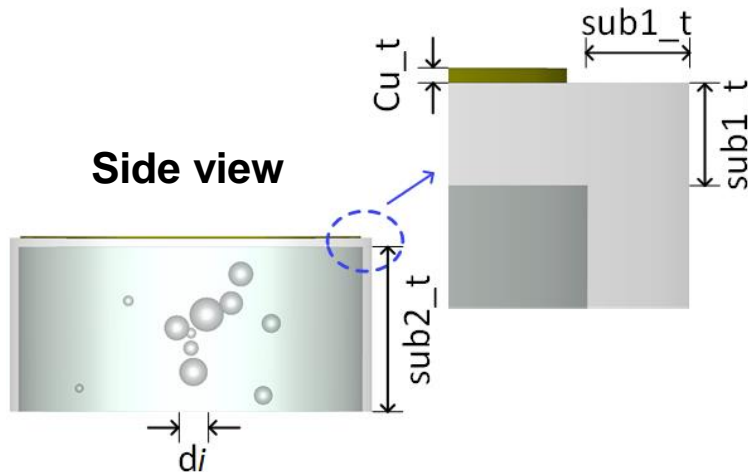
Significance

- Preventing untrusted tag manufacturer from recording frequency spectra of all tags and performing replay attack

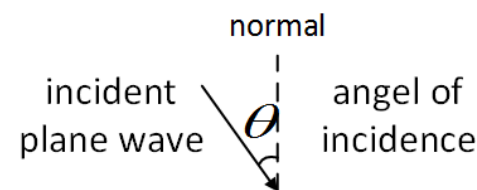
Evaluation Model



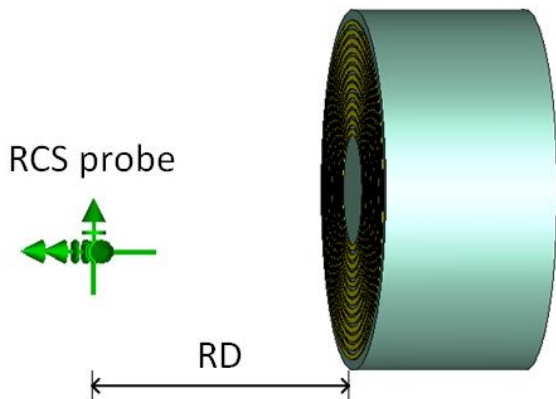
Top view



Side view



Angle of incidence



Distance between RCS probe and tag

- **Pill-level UCR tag**

- 12 concentric ring slot resonators
- Silver particles

- **Metallic pattern material**

- Pure copper

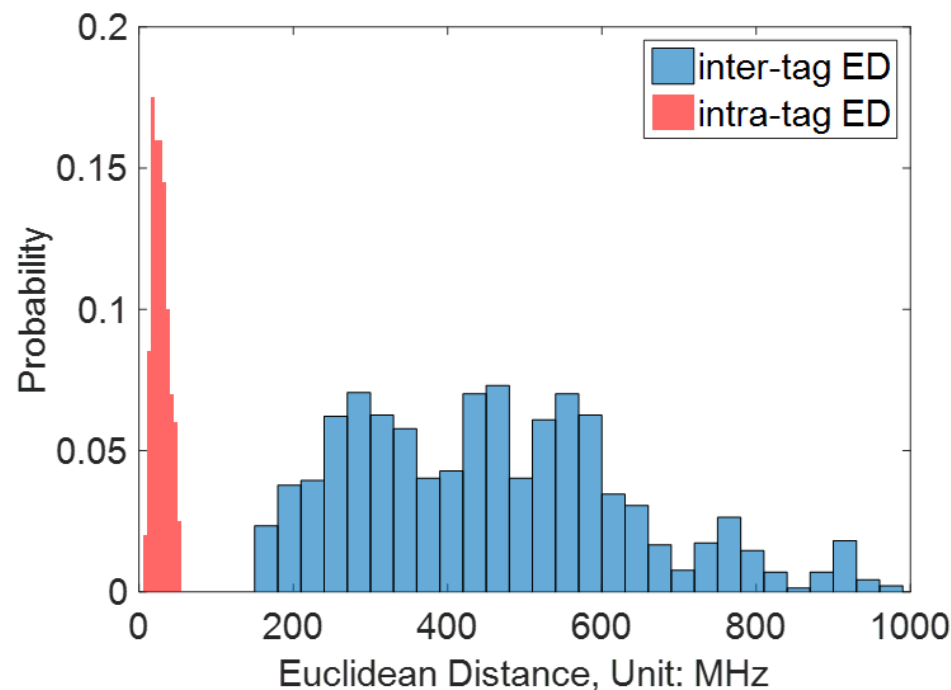
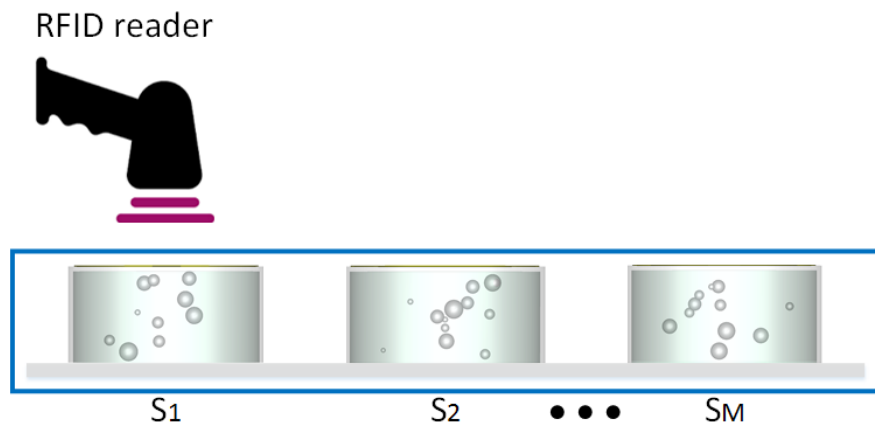
- **Excitation signal**

- Circularly polarized plane wave
- The radio cross-section (RCS) probe is used to detect the backscattered signal

Simulation Parameters

Category	Variable	Parameter	Value
Copper pattern	patch_d	Patch diameter	9.4 mm
	void_d	Central void diameter	3.1 mm
	g_i	Air gap i ($i=1, \dots, 12$)	N (0.1 mm, 0.0169 mm)
	Cu_t	Copper thickness	0.035 mm
Plastic film	sub1_d	Substrate I diameter	10 mm
	sub1_t	Substrate I thickness	0.25 mm
		Substrate I dielectric constant	2.8
Tablet	sub2_t	Substrate II thickness	N (5 mm, 0.1667 mm)
		Substrate II dielectric constant	2.42
Silver particles	n_p	Number of particles	U{0, 20}
	d_i	Particle i diameter ($i=1, \dots, n_p$)	U(0.2 mm, 1 mm)
Setup	RD	Reading distance	50 mm

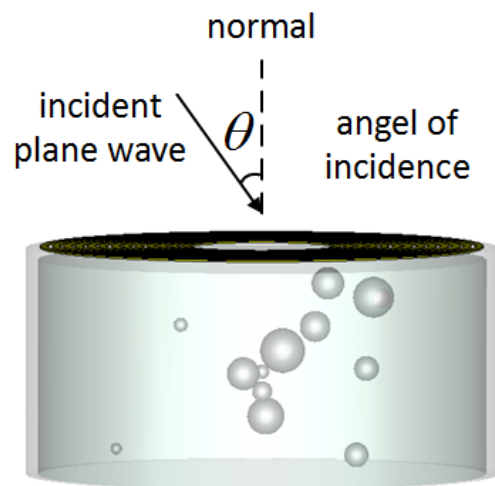
Euclidean Distance Based Tag Recognition



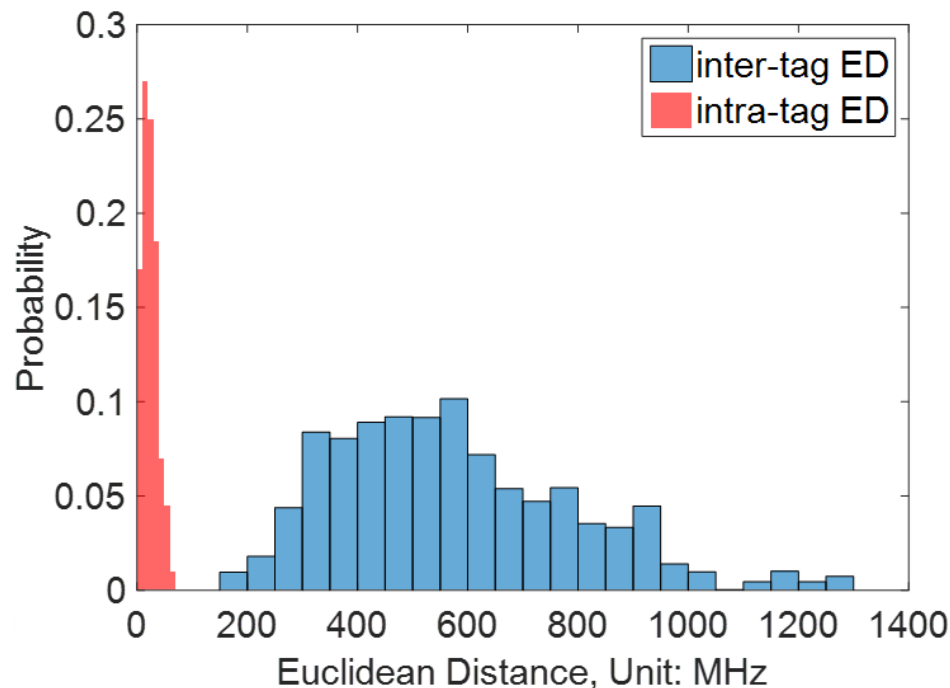
ED distributions of pill-level UCR tags in the presence of WGN with a SNR of 20 dB

- Number of tag samples: 20
- Measurements per tag sample: 5
- The margin between minimum inter-tag Euclidean distance and maximum intra-tag Euclidean distance reaches approximately 103.6 MHz

Euclidean Distance Based Tag Recognition



Angle of incidence



ED distributions of pill-level UCR tags when angle of plane wave incidence varies from 0° to 20°

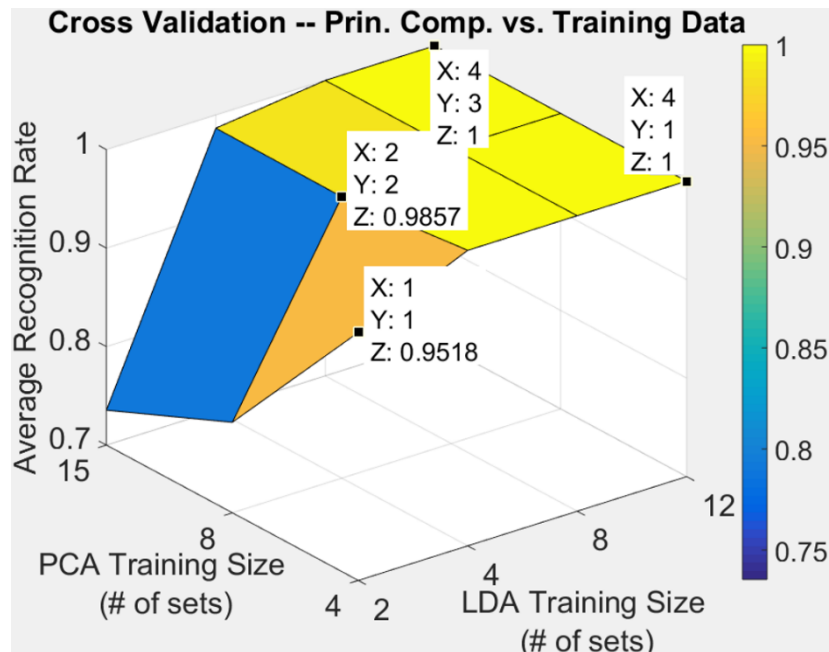
- Number of tag samples: 20
- Measurements per tag sample: 5
- The margin between minimum inter-tag Euclidean distance and maximum intra-tag Euclidean distance reaches approximately 110.5 MHz

Unsupervised recognition performance comparison

Classification Technique	Recognition Rate
Lorentzian Distance	95.56 %
Manhattan Distance	92.65 %
Normalized Correlation Coefficient	92.65 %
Wavelet Transform Manhattan Distance	98.67 %

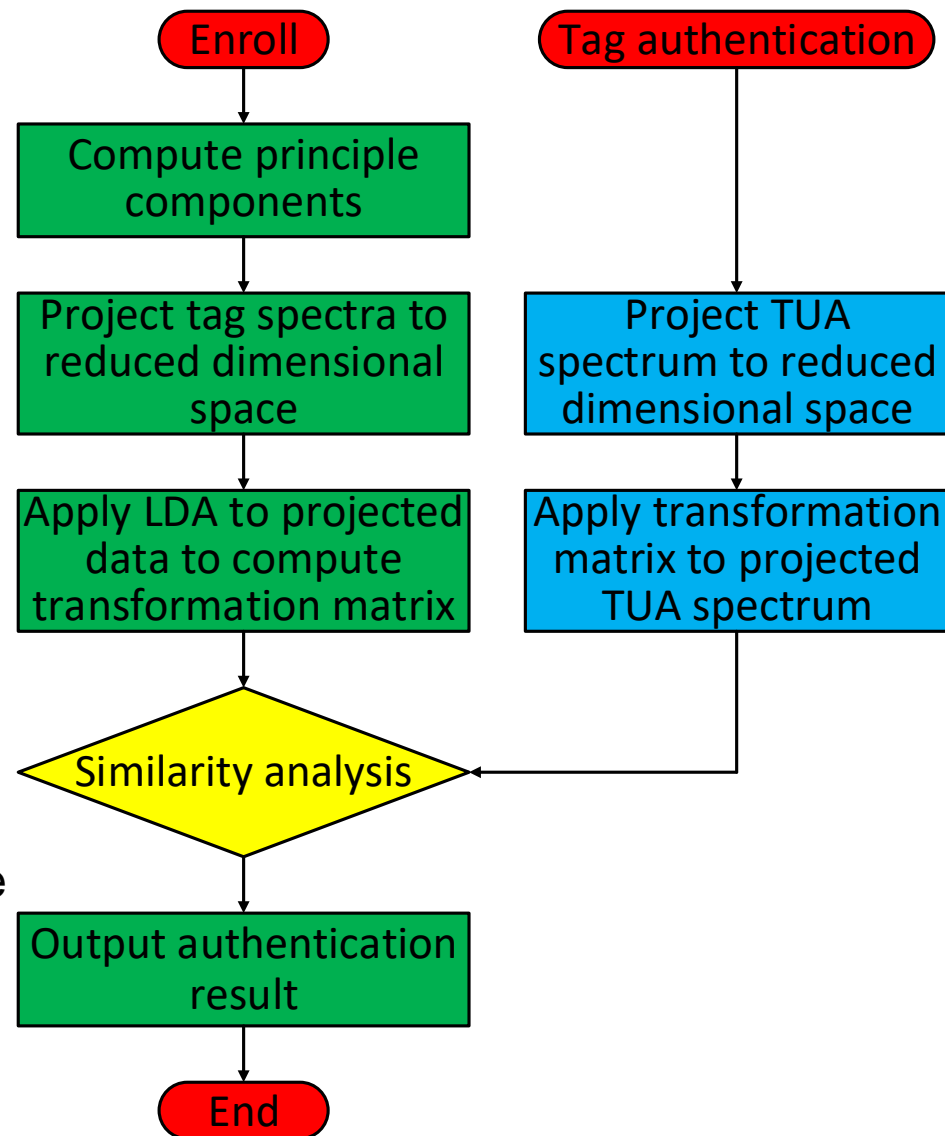
- Evaluation method
 - Selected a group of tag measurements to serve as the gallery (enrolled) set and then use the remaining tags to serve as the probe (verification) set
- Data set
 - 15 tags, 15 measurements for each tag
- Total number of classification attempts: 3,375
- All the scores are above 90% which means that out of the 3,375 classification attempts there were more than 3,037 correct identifications

Machine Learning Based Tag Recognition



Overall recognition performance for (15T, 15M, 8000S)

- Supervised technique outperforms unsupervised techniques as long as the classifier is trained on more than 2 sets of measurements
- Nearly all of the scores in the upper region are close to 100% recognition



Attack	Countermeasure
Cloning	Uncontrollable process variations during tag fabrication cannot be easily modeled
Split attacks	Establishing an inseparable connection between tag and identified object
Illegal tablet replacement	Binding the signatures of different tablets within the same blister pack
Overwriting tag memory	Elimination of tag memory
Replay attack	Split manufacturing

- Split attacks
 - Separating tag from product
 - Swapping tags
- Multi-parameter tag manufacturing prevents untrusted tag manufacturer from recording the frequency response spectra of all UCR tags and performing replay attack during tag authentication.

Merits of pill-level UCR system

- **Low cost**
- **Easy to access**
 - Drug authentication without necessarily opening the package
- **Reliability**
 - Multiple entropy sources enlarge the margin between inter-tag and intra-tag signature distributions
- **Security**
 - ID is unique and unclonable
 - Resistance to split attacks and illegal tablet replacement

Future work

- Fabricate pill-level UCR tags and test them in a real-world scenario
- Design a hardware to track the elapsed time since manufacturing to combat out-of-date commodities

*Thank
you*

