Universiteit Antwerpen

26 June 2019

Faculty of Applied Engineering

Bachelor thesis:
IoT enabled lifecycle tracking of goods

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Company/internship provider: Inuits

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Promotor UAntwerpen: Weyn Maarten

Bachelor of Science in the industrial sciences: elektronics-ICT

Universiteit Antwerpen

inuits

OPEN SOURCE INNOVATORS

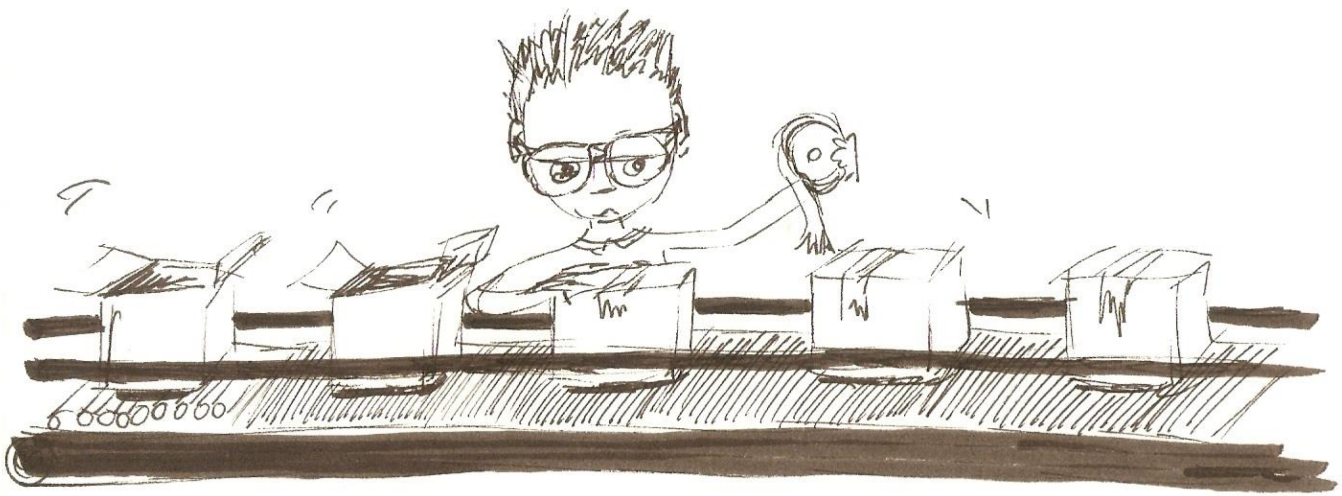
Introduction

Is there a cost-efficiënt way to automate inventory management of liquid products on a large scale with Internet of Things?

Overview & approach

1. Importance
2. Market research
3. Technology comparison
4. Theoretical maximum range
5. Theoretical reading speeds
6. Practical maximum range
7. Influence of liquids
8. Solutions
9. Conclusion

Figure 1. Profit. Retrieved from
http://solopracticeuniversity.com/2019/03/06/revenue-is-sexy-but-profit-pays-the-bills-the-law-firm-profit-margin-formula/



2. Market Research

LinkLabs (AirFinder): BLE

RFID 4U (TAGMATIKS): RFID

Smartrac: NFC

Cognizant: BLE

2. Market research

Radio Frequency Identification

Bluetooth Low Energy

3. Technology Comparison

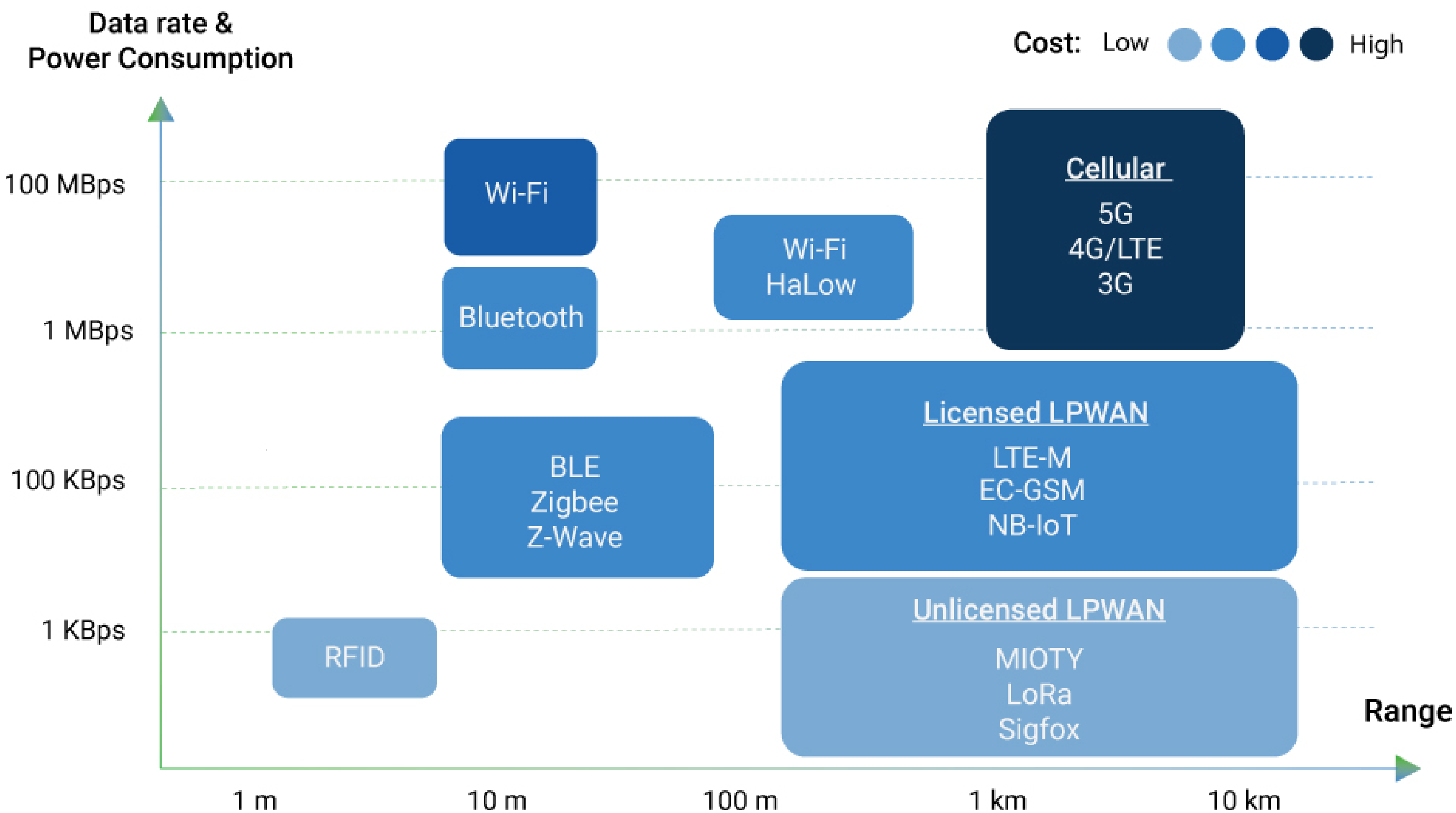


Figure 4. Comparison of IoT technologies. Adapted from “Mobile Communications WPAN-RFID-NFC”, By Prof. Weyn, M. W., & Bellekens, B. B. (2019).Retrieved from
https://blackboard.uantwerpen.be/bbcswebdav/pid-1931690-dt-content-rid-18962961_1/xid-18962961_1

3. Technology Comparison

IoT Asset Tracking Technologies Summary			
Features	Passive RFID	Active RFID	Bluetooth
Lifetime Use	20 years	3-5 years	2-5 years
Tag Cost	$0.10	$20	$20
Reader Cost	$10k - $20k	$500-$2000	$25

Figure 5. Comparison RFID vs BLE. Retrieved from https://www.bastiansolutions.com/comparing-internet-of-things-iot-based-asset-tracking-technologies-rfid-vs-ble/

4. Theoretical maximum range

$$r = \frac{\lambda cos(\theta)\sqrt{\frac{PrGrGt(1-(\Delta p))^2}{Pth}}}{4\pi}$$

where λ = wavelength [m]

θ = angle tag with reader plane
Pr = reader power [mW]
Gr = gain reader
Gt = gain tag
Pth = minimum tag threshold power [mW]
Δp = power reflection coëfficiënt

With optimal values: θ = 0, Δp = 0 , Pth = 0.01 mW

r = 13,8 m

With more realistic values: θ = 0, Δp = 0.5, Pth = 0.05 mW

r = 5,36 m

4. Theoretical maximum range

Transmitter power	Cable and connector losses	Reader antenna	Free space path loss	Tag antenna	Tag treshold
27 dBm	-3 dbm	5 dBi -3 polarization mismatch	Searched	2 dBi	-13 dBm

Table 1. Link Budget

$$FSL = Pr + Gr + Gt - \sum losses - Pth$$

$$FSL = 27 + 5 + 2 - (3 + 3) - (-13)$$

$$FSL = 40{,}85$$

$$FSL = 10log(\frac{4\pi df}{c})^2 = 20log(d) + 20log(f) - 27{,}55$$

$$d = 10^{\frac{191-31{,}2}{20}} = 3{,}03m$$

5. Theoretical reading speeds

$$Tr > (Tc + Td) * N$$

where Tr is the time a tag is in the operating area
Tc is the operation time of reader to tag
Td is the time for detecting existing tag

$$Tr > 0{,}7N$$

$$Tr = 0{,}7 * (4 * 4 * 4 * 6) = 268{,}8s$$

$$Tr = 0{,}7 * (4 * 4 * 4) = 44{,}8s$$

6. Practical maximum range

Nordic ID NUR-05WL2 RFID module (reader)

- 500 mW RF Power

Nordic ID SAMPO S0

- 5 dBi gain
- Circular polarisation

SparkFun UHF RFID EPC Gen 2 tags

Alien H3 EPC Gen 2 UHF RFID adhesive tags

6. Practical maximum range

Makefile

Bestand Bewerken Zoeken Opties Hulp

```
CC = g++
RM = rm -f

SRC = $(wildcard *.cpp)

INCLUDE = -I ../../../include
LIBDEF = -L ../../../linux -lNurApiRaspi -lm -lpthread
CFLAGS = -g -Os

OUTPUT = nurexample
all:
	$(CC) $(INCLUDE) $(CFLAGS) $(SRC) -o $(OUTPUT) $(LIBDEF)

clean:
	$(RM) $(OUTPUT)

run: all
	LD_LIBRARY_PATH=../../../linux ./nurexample

sudorun: all
	sudo LD_LIBRARY_PATH=../../../linux ./nurexample
```

Figure 6. Makefile for Raspberry pi implementation

6. Practical maximum range

```
NurApiExample - Main Menu
Please make your selection
 p - Ping module
 v - Print module version
 1 - Perform inventory
 2 - Start / Stop inventory stream
 3 - Configure sensor notifigation (SAMPO)
 4 - Configure TxLevel
 5 - List physical antennas
 6 - Perform tag tracking
 7 - Network device discovery
 q - QUIT
STATE: Connected
4
Configure TxLevel...
[0 - 19 = MAX - MIN]: 19
TxLevel is now 19
1
Perform inventory...
Perform inventory..
Round: 1, Tags: 1 / 1
Fetch tags from module...
Round: 2, Tags: 0 / 0
Round: 3, Tags: 0 / 0
Round: 4, Tags: 0 / 0
Round: 5, Tags: 0 / 0
Fetch tags from module...
1 unique tags found
Tag info:
  EPC: [e200688d0405060708090a0a]
  EPC length: 12
  RSSI: -75
  Timestamp: 9
  Frequency: 867500
  PC bytes: 3000
```

Figure 7. Result of inventory round on Raspberry pi

6. Practical maximum range

```
// Loop through tags
for (idx = 0; idx < tagCount; idx++)
{
    error = NurApiGetTagData(hApi, idx, &tagData);

    if (error == NUR_NO_ERROR)
    {

        EpcToString(tagData.epc, tagData.epcLen, epcStr);

        //EpcToString(readData.data, readData.dataLen, epcStr);                                 //added myself
        ReadTagUserMemory(hApi, readData.epc, readData.epcLen, readData.data, readData.dataLen); //added myself
        ReadTagUserMemoryByEPC(hApi, tagData.epc, tagData.epcLen, readData.data, readData.dataLen);


        // Print tag info
        _tprintf(_T("Tag info:\r\n"));
        _tprintf(_T("  EPC: [%s]\r\n"), epcStr);
        _tprintf(_T("  EPC length: %d\r\n"), tagData.epcLen);
        _tprintf(_T("  RSSI: %d\r\n"), tagData.rssi);
        _tprintf(_T("  Timestamp: %u\r\n"), tagData.timestamp);
        _tprintf(_T("  Frequency: %u\r\n"), tagData.freq);
        _tprintf(_T("  PC bytes: %04x\r\n"), tagData.pc);
        _tprintf(_T("  user data length: %d \r\n"), readData.dataLen);          //added myself
        _tprintf(_T("  user data string: [%s] \r\n"), readData.data);          //addded myself
    }
```

Figure 8. Code adaption to read user memory

6. Practical maximum range

```
STATE: Connected
NOTIFICATION >> Transport connected
1
Perform inventory...
Perform inventory..
Round: 1, Tags: 1 / 1
Fetch tags from module...
Round: 2, Tags: 1 / 1
Fetch tags from module...
Round: 3, Tags: 1 / 1
Fetch tags from module...
Round: 4, Tags: 1 / 1
Fetch tags from module...
Round: 5, Tags: 1 / 1
Fetch tags from module...
Fetch tags from module...
1 unique tags found
NOTIFICATION >> LOG: <E>NurApiReadSingulatedTag32() error: 5 (0x5) (Invalid command parameter(s); Invalid function parameter(s))
Tag info:
  EPC: [e200688d0405060708090a0a]
  EPC length: 12
  RSSI: -68
  Timestamp: 12
  Frequency: 866900
  PC bytes: 3000
  user data length: 36
  user data string: [test(]
```

Figure 9. Visualisation of written user memory on Raspberry pi

6. Practical maximum range

RSSI sensitivity set at -90 RSSI

TxLevel at 500 mW

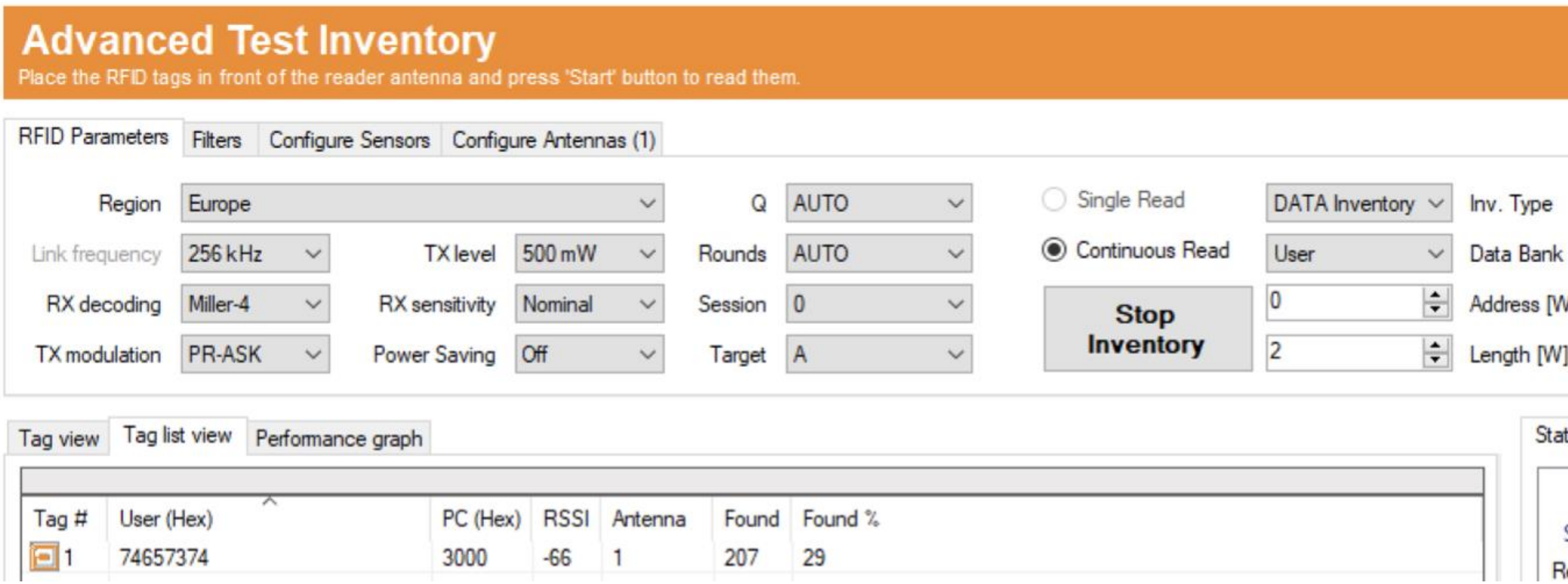


Figure 7. Example of tag reading with windows application

6. Practical maximum range

Lowest sensitivity

Maximum power

Optimal directivity

Gives us 5,5m range

- -71 RSSI
- Find percentage of 14%

At 4m the find percentage is 70%

$\Leftrightarrow$ 5,36 m theoretic (Friis equation) and 3 m link budget

7. Influence of liquids

Figure 8. Setup for measurement from side

Figure 9. Setup for measurement from top

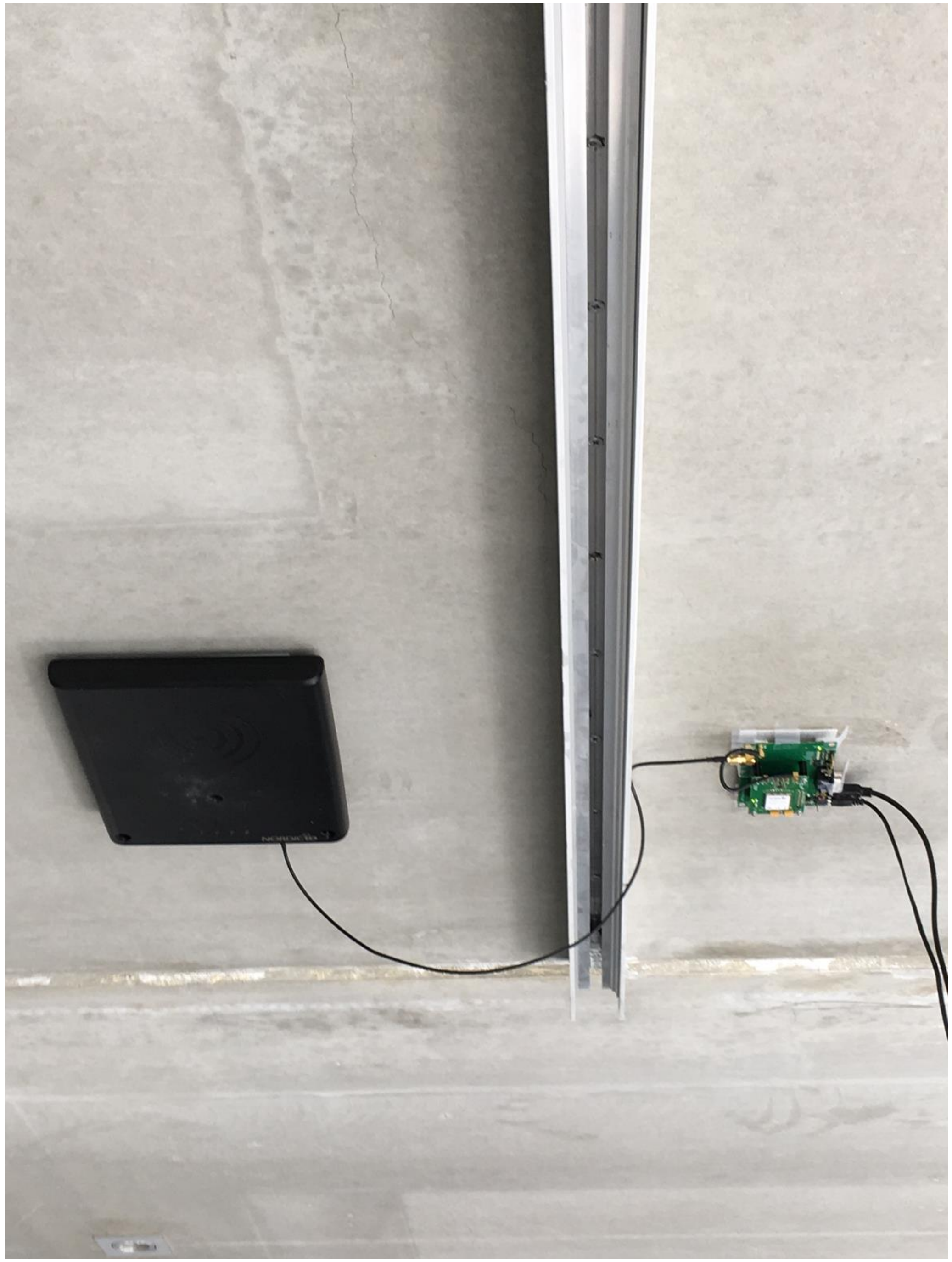
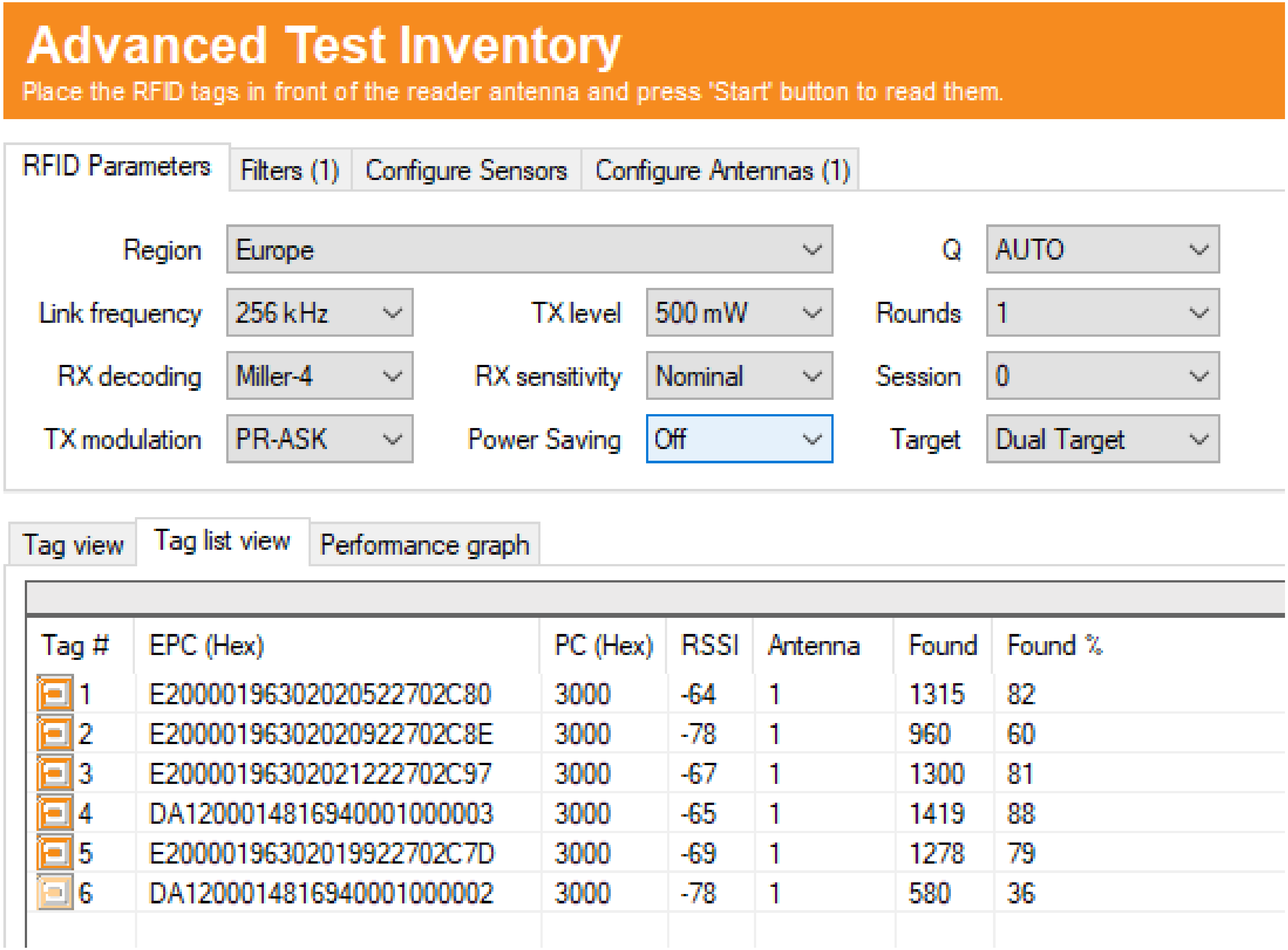


Figure 10. Hardware attachment to ceiling

Figure 11. Position and last 2 EPC character of tags on box



Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	E2000019630202052270 2C80	3000	-64	1	1315	82
2	E200001963020209227 02C8E	3000	-78	1	960	60
3	E2000019630202122270 2C97	3000	-67	1	1300	81
4	DA120001481694000100 0003	3000	-65	1	1419	88
5	E2000019630201992270 2C7D	3000	-69	1	1278	79
6	DA120001481694000100 0002	3000	-78	1	580	36

Figure 12. Results of inventory rounds without other boxes of wine

Figure 13. One box with bottles of wine on top of box with tags

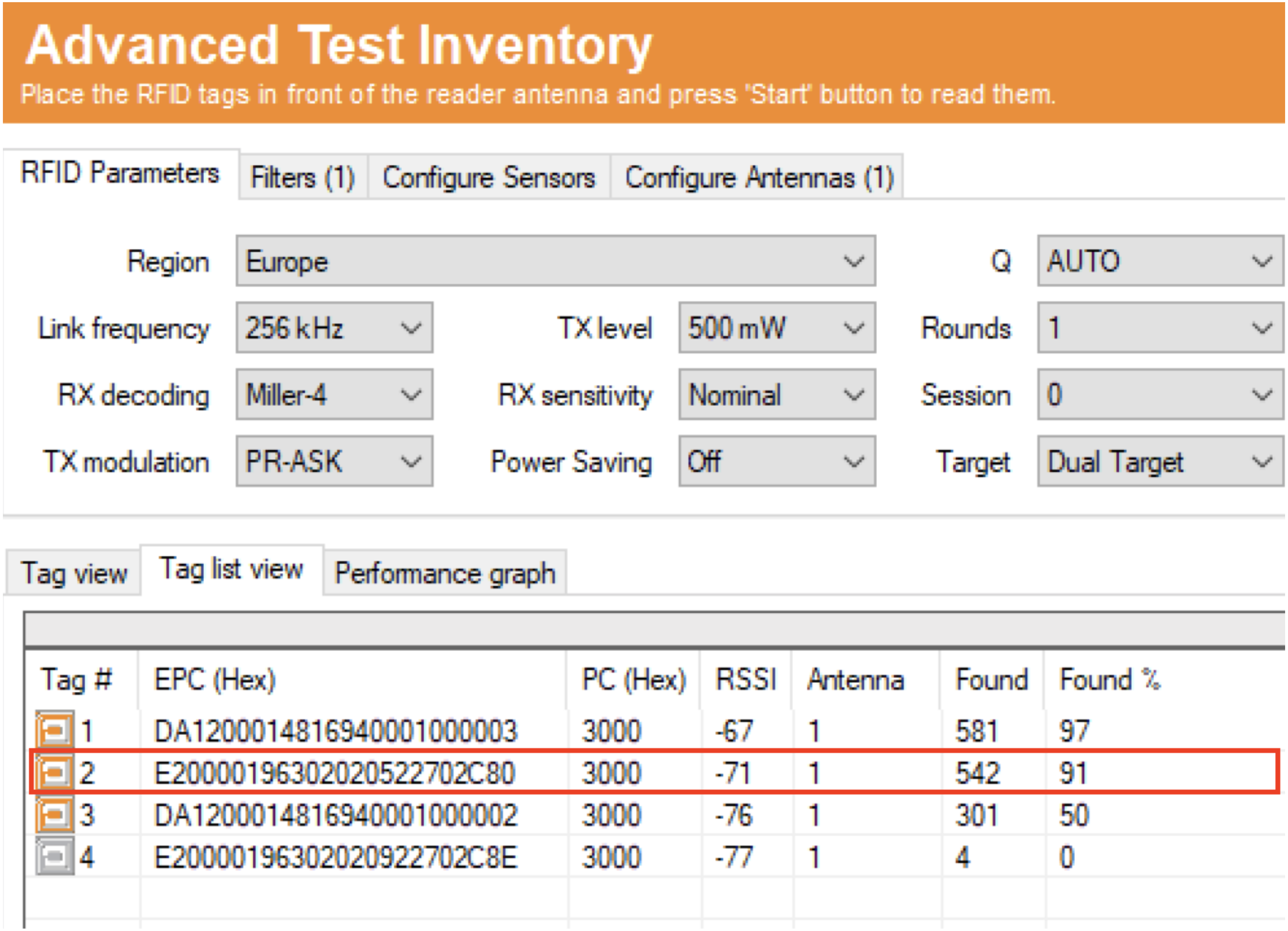


Figure 14. Result from top reading with one box of bottles on top of tagged box

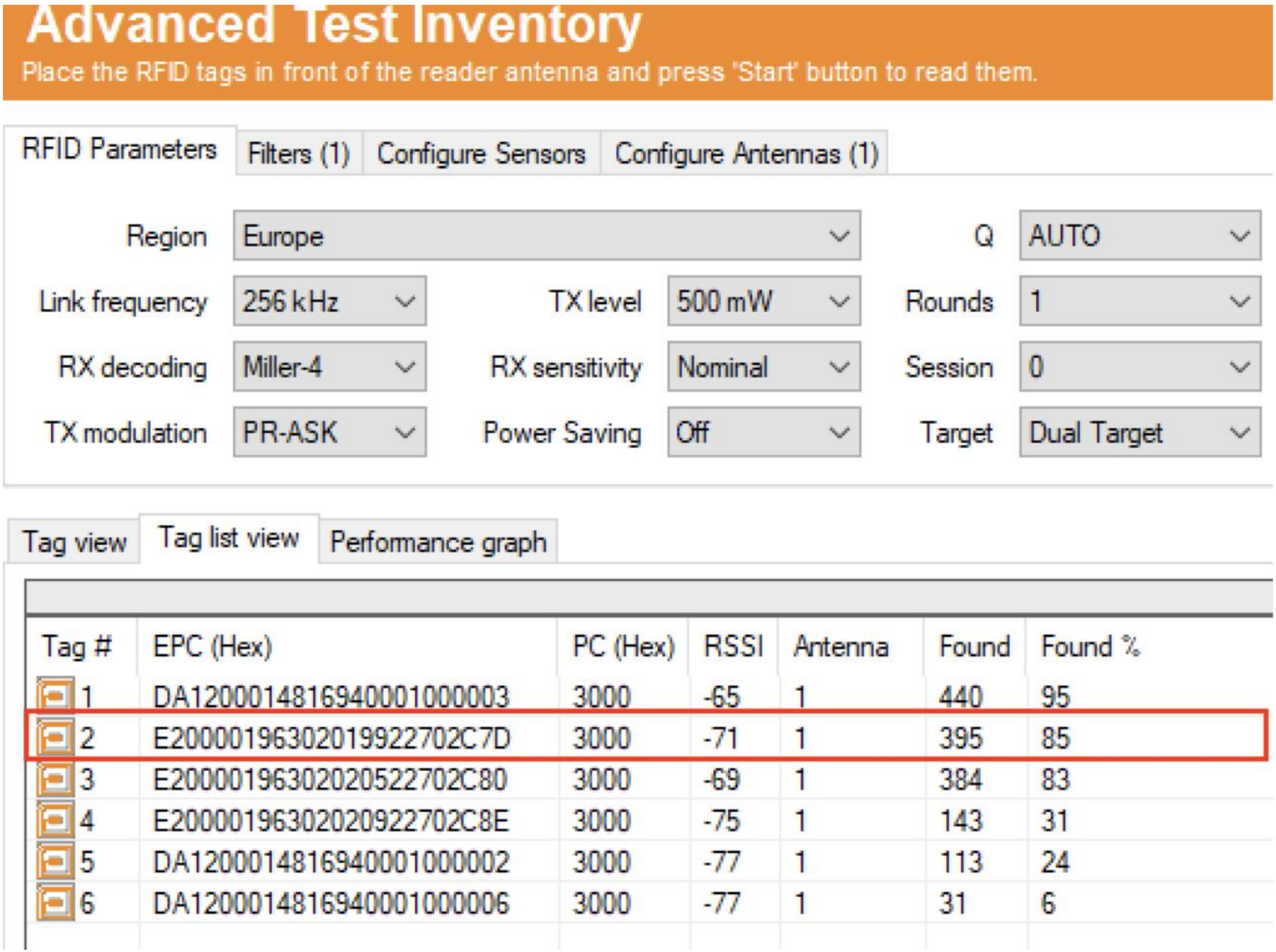


Figure 15. Result from top reading with one box of bottles on top of tagged box, the bottle above the 7D tag is removed

7. Influence of liquids

Possible causes:

- Absorption E field of RF signal by liquid
- Refraction

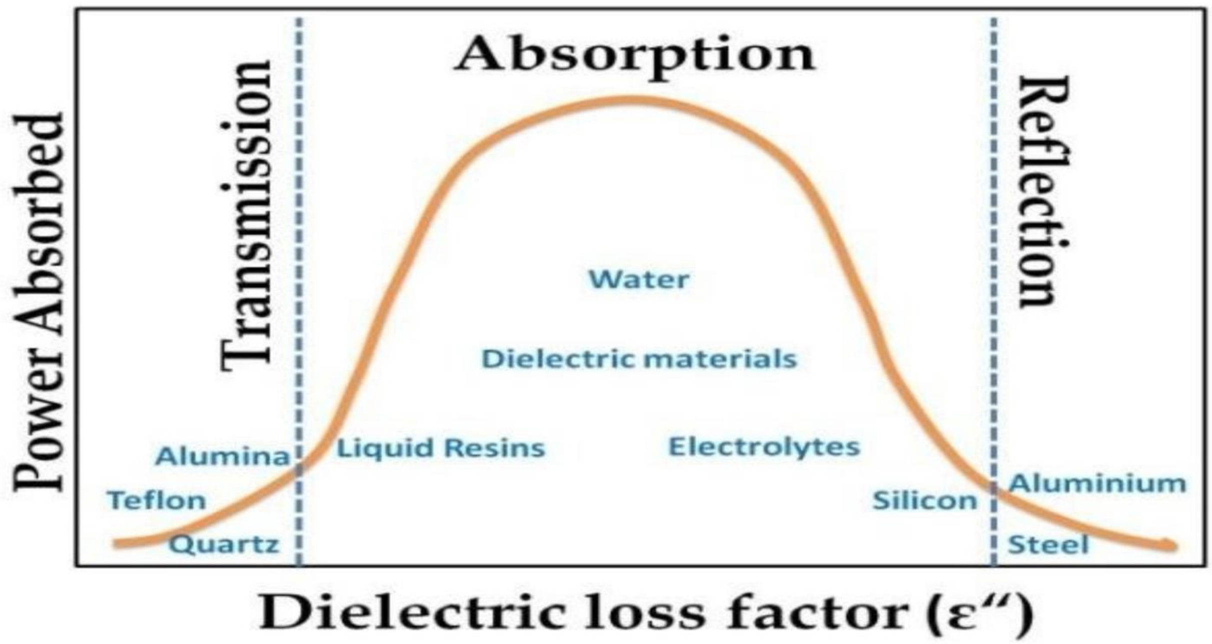


Figure 16. Absorbed power in functiondielectric loss factor. By Jesus Prado-Gonjal. Retrieved from

https://www.researchgate.net/publication/263023052_Microwave_-
assisted_synthesis_and_characterization_of_inorganic_materials/figures?lo=1

8. Solutions

2 or 4 W ERP

Omni-ID

Solution for on-bottle tagging

Dual Frequency

Solution penetration RF signal through liquids

CapTag

Solution on-bottle tagging

8.1 Omni-ID

Spacing technique

Plasmonic structure (patented)

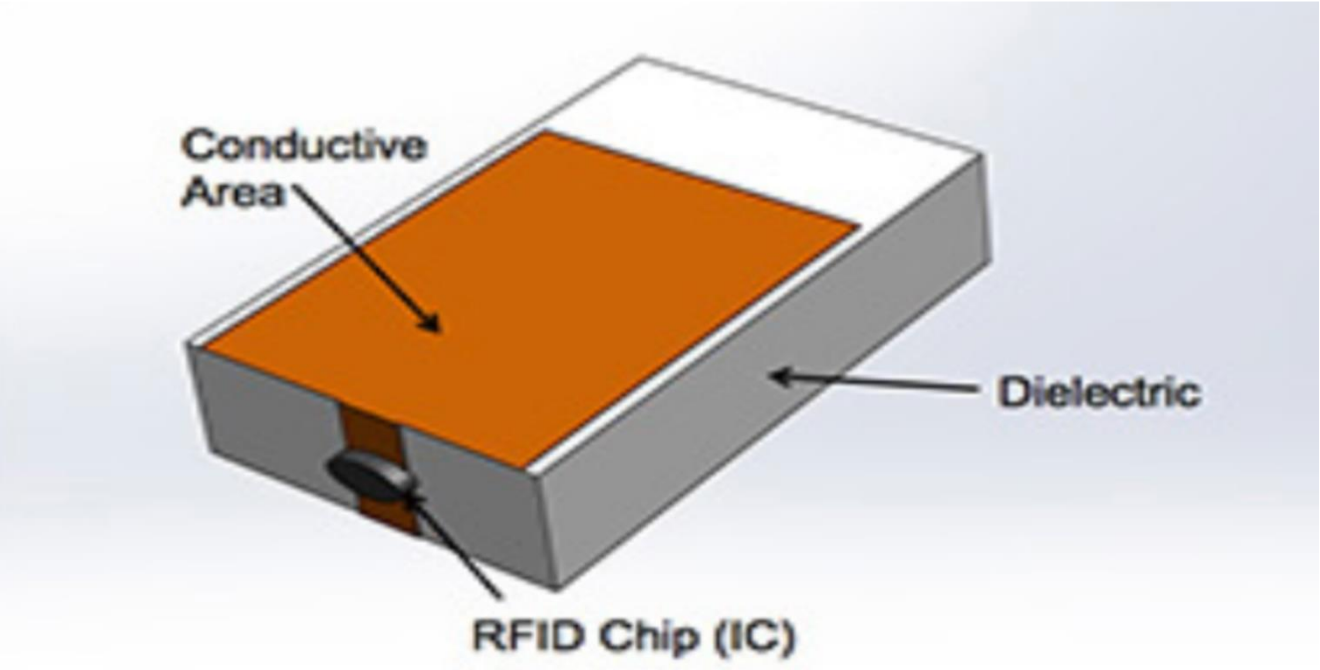


Figure 19. Plamonic structure from Omni-ID tag. Retrieved from

https://www.omni-id.com/rfid-tag-technology/

8.1 Omni-ID

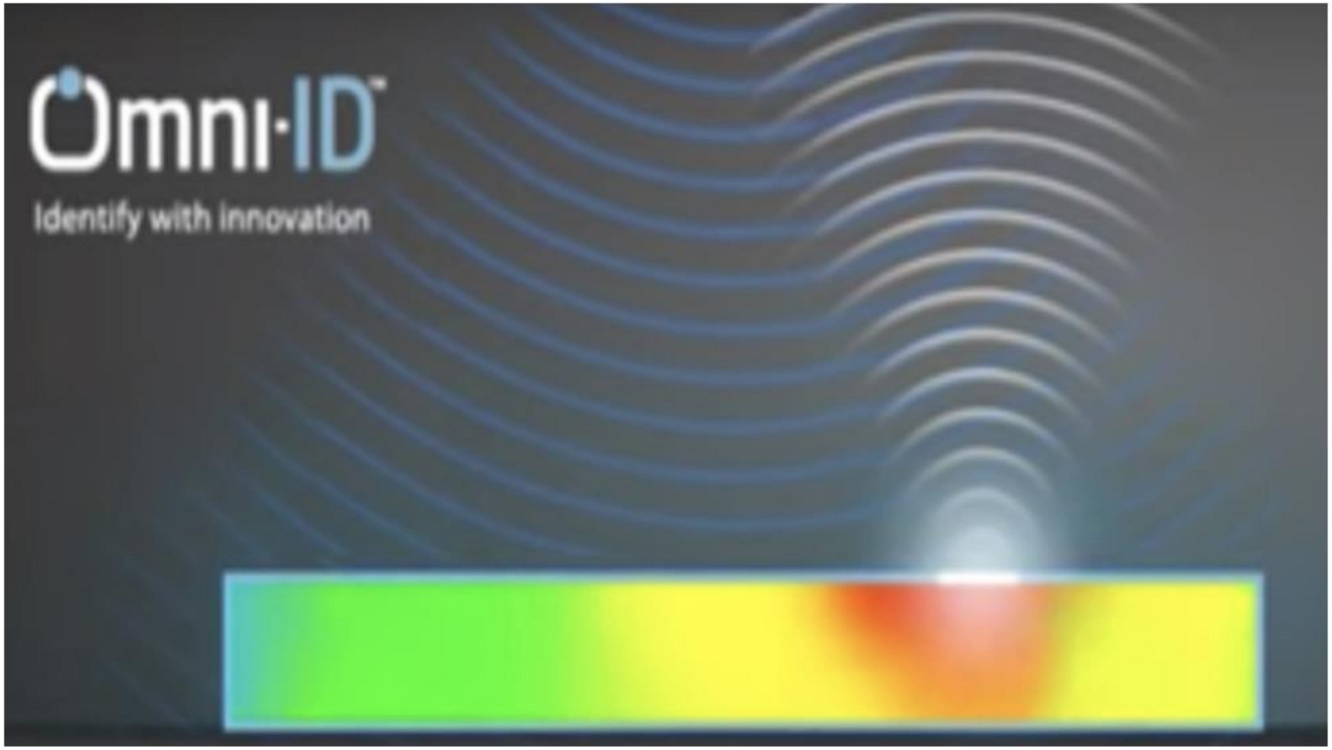


Figure 20. Energy concentration in plasmic structure. Retrieved from https://www.omni-id.com/rfid-tag-technology/

8.2 Dual Frequency

Downlink 13,56 MHz or 125 kHz

Uplink 868 MHz

Easier penetration of fluids with lower frequency to power up te tag

Not tested

Aucxis informed that this method does not work as well as claimed based on own

8.3 CapTag solution

On liquid tagging

Up to 10 meter range

Capacitive coupling causing high frequency AC current flow to power up tag

Electric field captured by metal capsule

Design real tags confidential

8.3 CapTag solution

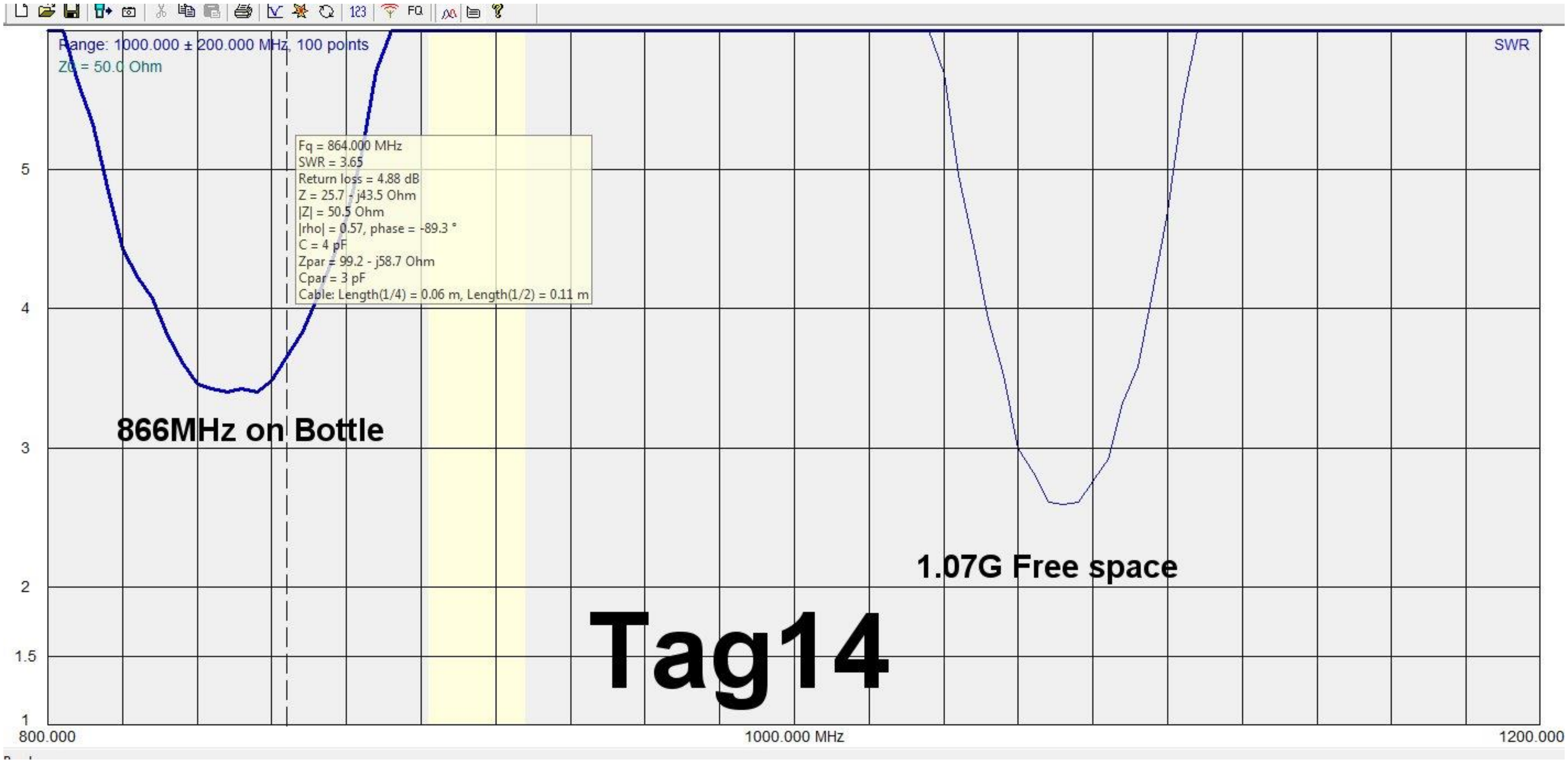


Figure 20. Frequency pulled-down by glass bottle with liquids.
From D. Mapleston of CapTag Solutions, personal communication on 11 april 2019

8.3 CapTag solution

On liquid tagging

Up to 10 meter range

Capacitive coupling causing high frequency AC current flow to power up tag

Electric field captured by metal capsule

Design real tags confidential

8.3 CapTag solution

Test concept by using near-field tag

Tag partially on glass and part on metal capsule

Fluids work as ground

Bottle "needs" to be upwards

8.3 CapTag Solution

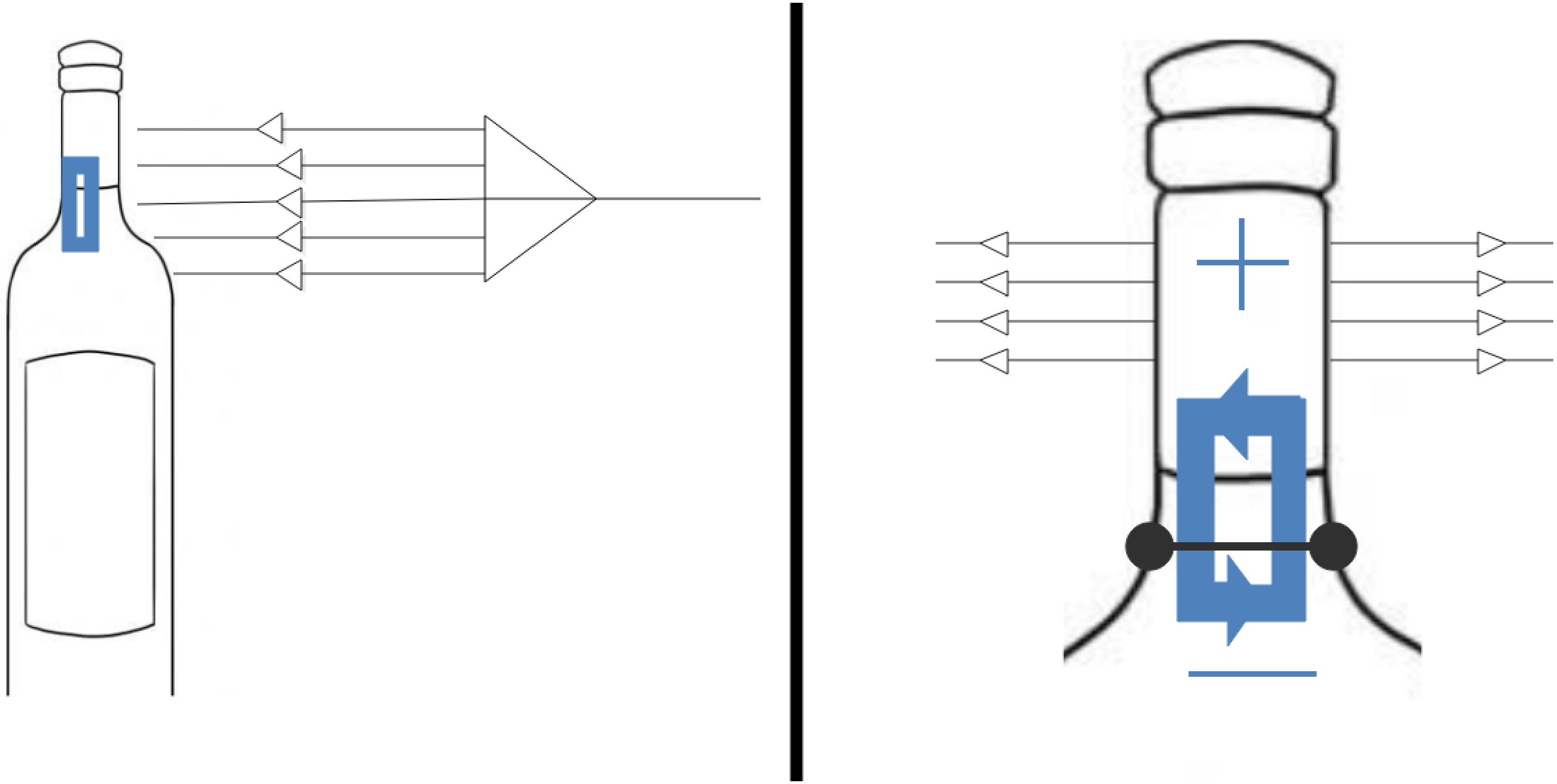


Figure 23. Representation of CapTag solution with near-field tags

8.3 CapTag solution

Figure 24. Position of tags on bottles.

8.3 CapTag solution

Position	Front range (m)	Back range (m)
1FE: full UHF RFID tag on the bottle	0,38	0,42
BF0: loop full on capsule	Not found	Not found
7B2: loop full on capsule	0,61	0,85
6FC: loop half on bottle, half on capsule with bottle half full, chip on capsule	0,28	0,32
AB4: loop half on bottle, half on capsule with bottle filled till capsule, chip on capsule	0,32	0,58
C49: loop half on bottle, half on capsule with airgap between capsule and wine, chip on capsule	0,52	0,85
AA9: loop half on bottle, half on capsule with airgap between capsule and wine, chip behind wine	1,68	1,84
00BF0: loop half on bottle, half on capsule with airgap between capsule and wine, chip on airgap	1,6	1,78
2ED: Loop half on bottle, half on capsule with bottle fille till capsule, chip behind wine	0,84	1,63

Table 2. Results of testing CapTag solution with near-field tags

8.3 CapTag Solution

Concept works

➔ Quadrupled range vs on bottle UHF RFID

Better results with tag at back of bottle

No improvement for reading tags through liquids

➔ Able to read all bottles in one box

9. Conclusion

Absorption of RF signal through liquids too high for passive UHF RFID

No cost-efficiënt way of inventory management for liquid product in large quantities

→ Wait for cost reduction of BLE or active RFID

→ Other cost-efficiënt technology to be developed

→ Load trucks box by box instead of pallet

10. References

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10. References

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10. References

D. Mapleston van CapTag, persoonlijke communicatie, 11 april 2019

Nordic ID. (2018). NORDIC ID SAMPO S0 (V1010). Retrieved from https://www.nordicid.com/nordic-id-sampo-s0_datasheet_eu_v1010/

Nordic ID. (2017). NORDIC ID NUR-05WL2 RFID MODULES (V1006). Retrieved from https://www.nordicid.com/nordic-id-nur-05wl2-rfid-module_datasheet_eu_v1006/

11. Answers to possible questions

11. Tag read speed

Lehpahmer p 162

Tc + Td = 0,12 example

But if 100 bytes => 0,7 seconds per tag

Data transfer rate of ± 7,8 kbps

Tc = Acn * (Dv/Dr)

Very inconsistent (tag)

RF/32: 32 clock signals per logic 1 or 0

11. Collisions

tag-tag: collision avoidance (singulation of EPC)

- Tag random delay for response
- Deterministic (silent TWA)
- probabilistic (TDMA => slotted ALOHA, substring ID)

reader-tag: reader and tag different frequencies

Reader-reader: TDMA (colorwave, color represents time slot)

11. EPC

8 bit header: EPC version

28 bit EPC manager: manufacturer identification

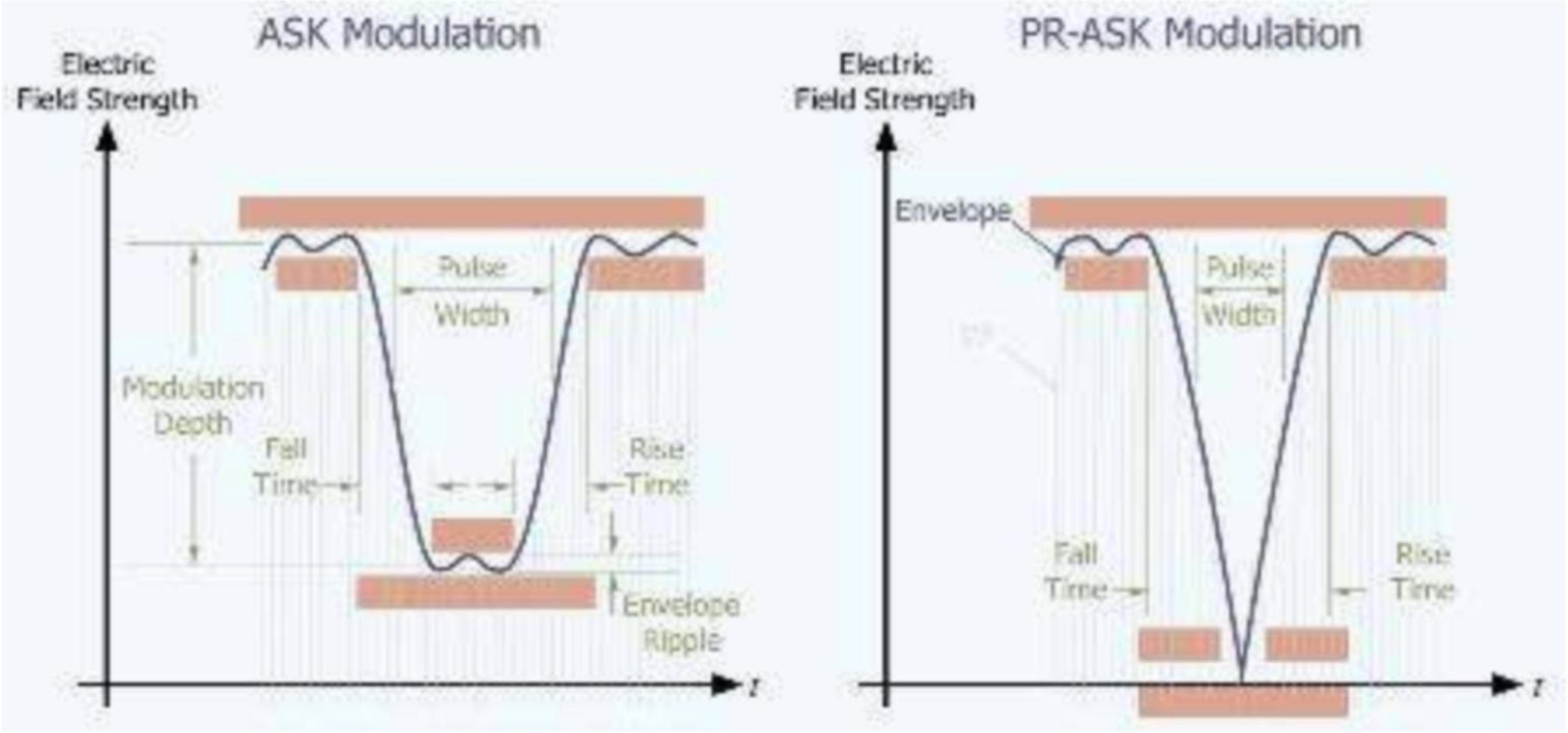
24 bit object class identifier: type of product

36 bit serial number: unique identification

11. Other RFID challenges (p67)

- IP issues
- Lack of precedents (historic data)
- Data security
- Large data volumes
- Spectral congestion
- Lack of expertise

11. Modulation techniques



11. CapTag tag types

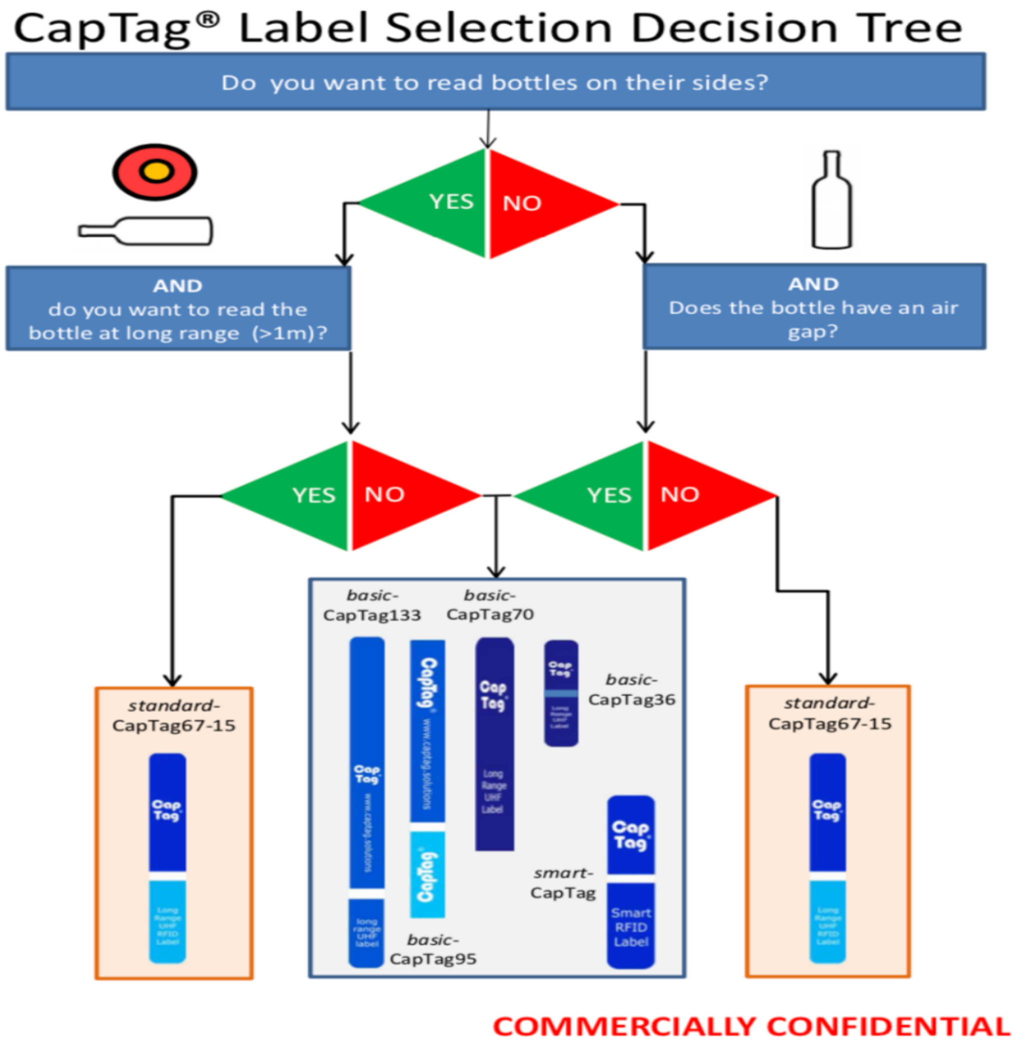


Figure 21. CapTag selection tree. From CapTag Solutions, personal communication on 3 may 2019

11. Tag memory architecture

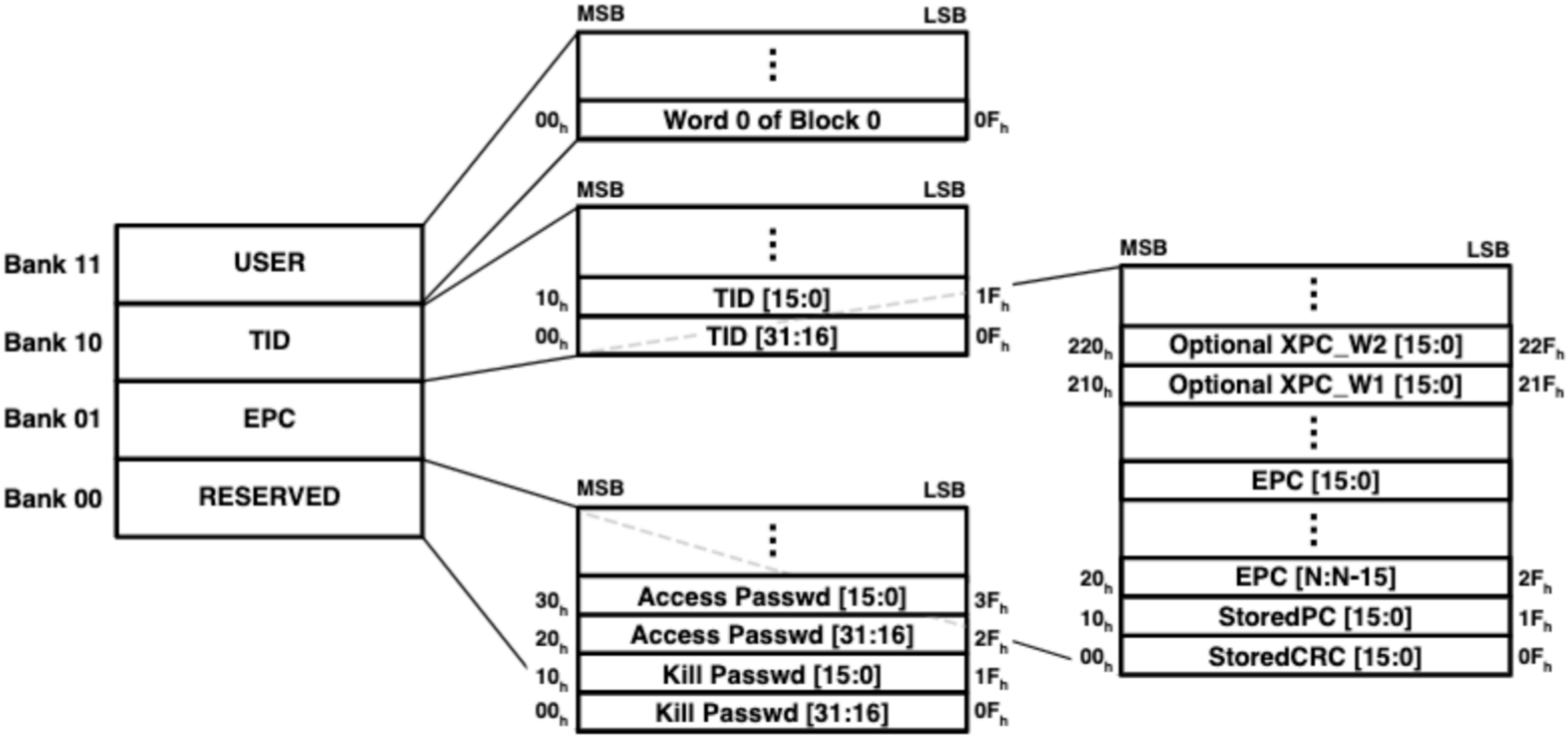


Figure 6.17 – Logical memory map

11. EIRP vs ERP and dBm vs dBi

EIRP ±= ERP + 2,15

dBi ±= dBm + 2,15

11. Failed read range calculations with wine as medium

$$S = \frac{E^2}{Z} \qquad S = \frac{Pr}{4 * pi * r^2}$$

where S = nondirectional power flux density

E = electrical field
Z = wave impedance(120pi in free space)
Pr = power of the reader [mW]

For isotropic antenna wit apperture $A = \frac{\lambda}{4pi}$

The power of the tag $Pt = \frac{S * \lambda^2}{4pi}$

And $Z = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu r * \mu 0}{\varepsilon r * \varepsilon 0}}$ with μ0 = 4pi*10^{-7} , ε0 = 8,85*10^{-12}

and for water μr = 0,999992 and ε0 = 80,2

This gives us Z = 42.

We took the relative permeability and relative permitivity for water since no accurate values are found for wine.

We now calculate the elctrical field E at the tag by combining the 2 formules for nondirectional flux density.

$$\frac{E^2}{Z} = \frac{Pr}{4 * pi * r^2}$$

We take for the distance r 2 meter since this is the minimum distance we need for our project.

11. Failed read range calculations with wine as medium

$$E = \sqrt{\frac{500 * 42}{4pi * 2^2}} = 20{,}44 \text{ [V/m]}$$

$$S = \frac{E^2}{Z}$$ gives us S = 9,45 [mW/m²]

$$Pt = \frac{S * \lambda^2}{4pi} = \frac{9{,}45 * (0{,}346^2)}{4pi}$$ = 0,09 mW = 90 µW.

We say in 7.1 that we need 50 µW for the tag to be powered, this means that the tag should be powered through 2 meters of liquids with a 0,5W reader. This is not at all a realistic result since we know that it isn't possible to read the tag through 2 meters of liquid (see tests later).

11. Positives of thesis

Methodology

Reaching out to other companies/ qualified people

Thorough testing

Extensive documentation

11. Workpoints

Start testing sooner => more solutions to test

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