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IoT enabled lifecycle tracking of good

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2. Introduction & Research question

“What is the most cost-efficiënt inventory management system for bottles with liquids using IoT technology?”

In this research we develop a inventory management system for a wine distribution center. The criteria for our resulting system are:

- Know what stock there is at any moment
- Tags per pallet or per bottle
- No certainty of orientation of tags
- Cost efficiënt
- Operate in presence of liquids

We will first investigate the different technologies we can use and then make a decision which one we will use. We calculate theoretic approximations of the limitations before we build the system.
Then we extensively test the limits of the system and compare this to the approximations we calculated. When differences are perceived causes of these deviation are mentioned and explained.

The biggest challenge to design a inventory management system using IoT is the presence of liquids. Radio frequency signals are heavily influenced by liquids or metals.
It is important that the design of our inventory management system is still financially realizable so that it is cost efficiënt for the wine retailer to implement and retain.

3. Market research

Before we go into deeper investigation it is helpful to know what is already on the market. In the following section we will investigate more what the competition is already selling on the market. Which technologies do they use? What is the cost model and where are they located?

3.1. Amazon go

Amazon Go uses a combination of cameras, sensors and deep learning algorithms to determine what is in the clients shopping basket.
NFC is only used when the shopper enters the shop to activate the application on their phone.

3.2. LinkLabs

LinkLabs is located in Annapolis, Maryland, East-coast of America.

AirFinder (division of LinkLabs) claims to have affordable Internet of Things technologies for asset tracking.
Their tracking system does not only rely on UWB, RFID or BLE beacons and infrastructure but also patented technology to keep complexity and costs down.

LinkLabs is the link between Symphony Link (Link Labs core product) and Bluetooth.
Symphony link resembles LoraWAN, which we will discuss in our technology research.
Not much can be found about their client or completed products

They do have a lot of documentation, whitepapers and webinars on their website which we will read through and summarise in following paragraphs.

Asset location Technologies & the selection process

[A]

Types of asset location

- Precision-based RTLS, these our not important for us.
- Proximity-based RTLS
  - 10 m^2 precision
  - detect presence of tag
  - tags (often BLE) to reader then to cloud
  - less expensive than precision based RTLS
- Outdoor location technologies, not important for us.

How proximity based RTLS works

BLE beacons are placed as reference points.

BLE beacon is programmed to listen for reference points. Tag processes own location and sends info to access point

Tags connect to BLE access points, placed every 100 feet (± 31m), sends info got from tag and resends it to the server. Connection to server can be cellular (LTE) or Symphony Link (LinkLab patented LoRa wireless network).
1 gateway can cover dozens of access points.

Benefits of proximity RTLS

- Open-source tags (iBeacons) $2 - $10
- secure, separation of existing WiFi network of enterprise
- Easy integration because of separation of existing network
- Scalable

5 types of tags available for Real-Time location systems [B]

1. Ultra Wide-Band Location Tags (UWB)

   Reader sends very wide pulse over GHz spectrum, then reader listens for answer (chirp) from tag, reader reports back to server.
   Low range
   Need to synchronise all the readers over stable IP network

2. WiFi Location Tags

   OK power efficiency because WiFi tags are no full TCP end points, only access points know how to process frames as 802.11 traffic.
   Can use existing WiFi infrastructure (can also be a downside because of integration, interference with already existing WiFi network at a company)

3. Infrared Location Tags

   Can be trusted more, less false positives because signal is send with light and not with radio waves. Disadvantage is that it can't go through walls so it won't be useful for our tracking system.
   Sometimes used in combination with WiFi or active RFID to increase their accuracy.

4. Passive Location RFID Tags

   Very short range and needs high-power readers. The tags are very cheap and the readers are more expensive, this is very suited for our tracking system since we need allot of tags and only a couple of readers.

5. Active RFID Location Tags

   Active RFID tags transmit (where passive tags use reflecting wave of sending readers) which get picked up by te reader.
   AirFinder uses iBeacon tags because they are easy to find on the market and cheap.
   Active RFID has more risk of false positives.

Cost-effective Solution for End-to-End manufacturing Visibility [C]

Only low cost BLE based infrastructure is needed, making it cheaper than traditional RFID or UWB systems.
Gateways connect through cellular so no IT system integration is needed.

BLE tags are cheapest tags of active transmitting tags. They wake up periodically, calculate their position by scanning the reference points and report to sensor network.
High tag density is possible since tags do not transmit very often.

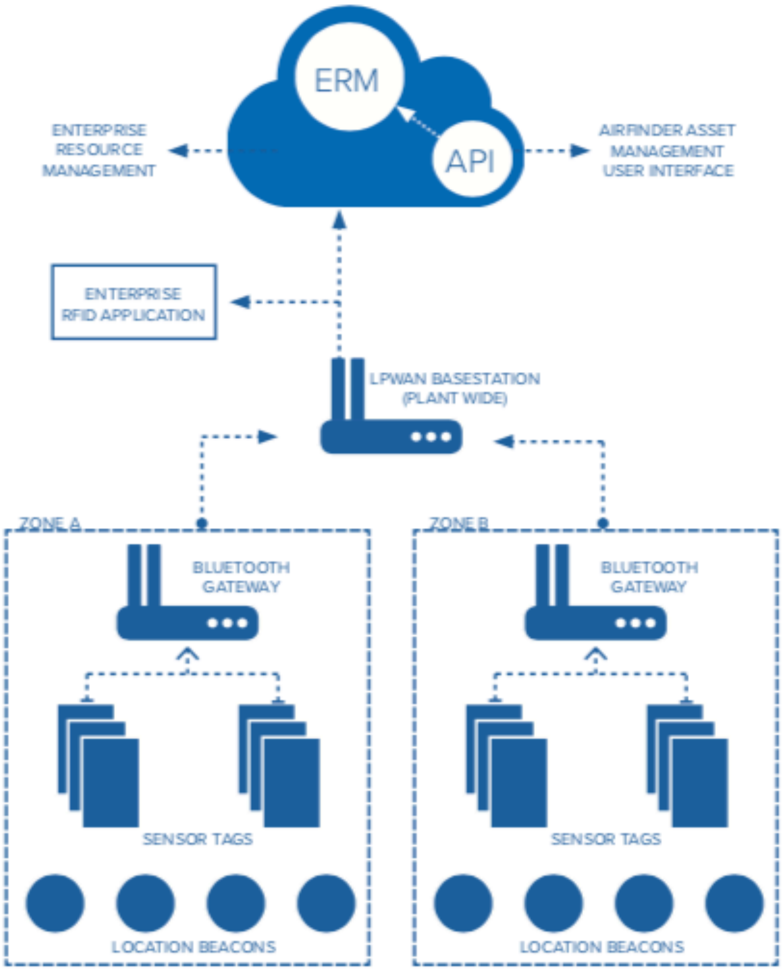


Figure 3. Solution Architecture

3.3. RFID 4U [2]

RFID 4U designs, builds and deploys business solutions using RFID, NFC, Barcode, GPS and NFC technologies.

Their HQ is based in Concord, California, America. They also have an office in India.

When we take a look at their clients we see some big names like Wehr (American drilling company), Dole (worldwide supermarket chain), Fitbit, Google, HP, NASA and Microsoft. Unfortunately their is no way to know what they actually delivered.

All their RFID solutions are based on TAGMATIKS, which is a cloud-ready, sensor adaptive network software platform that enables rapid deployment and integration of scalable, real-time visibility solutions for asset management, inventory control, warehouse management, access control, apparel tracking etc or simply a RFID Middleware.

Besides design and deployment they also have a webshop where they sell tags, readers, antenna's and RFID printers. The cheapest RFID Wet Inlays (tags with adhesive back to slab on the bottle) vary around $0,10, depending on the quantity you buy.

The most interesting for our project is their Inventory tracking solution. This solution uses a combination of RFID tags, RFID reader, barcodes, sensors and WiFi networks.

RFID, barcode and NFC is used to transfer data between items and inventory system. RFID labels are attached to the inventory items. There are fixed readers placed at all exits. Handheld readers are used for verification and order association.

Oil & Gas Inventory Management System [D]

RFID4U developed the Inventory Tracking System (ITS) using RFID tags and RFID handhelds as readers. The handhelds communicate with ERP (enterprise resource planning) system. Fixed RFID reader portals were used for inventory control.
Used UHF (ultra high frequency) RFID tags to track individual parts.

When a tag is read with a handheld device you get the serial number, last inspection date and days since inspection.
Important is to remark that if the system is deployed in multiple locations, the user still has to select the particular location before the tag can be read.

You can also create an inventory of scanned tags, it will display the total number of tags scanned. When finished the inventory can be sent to the ERP, the user has to select a work order. The work order provides the possibility to do multiple things with the scanned inventory, whether it is a check on the total amount of tags scanned vs the amount that should be scanned or the actual stock has to be adjusted without the scanned inventory.

If the user is offline, it is locally stored and sent to the database when connection is up again. The scanned inventory can be exported as a CSV file.

The last function of the ITS is the possibility to write to a tag so that you can store extra information with your unique item tag.
In our application this can for example be a destination of shipment or date of shipment. This extra information will also be sent to the ERP system.

3.4. Smartrac [3]

Smartrac is a global company that provides digitalisation of products and connect them to the Internat of Things for businesses.

Their headquarters are located in Amsterdam with further operations and production facilities in Asia, Africa and Amerika.

In 2018 they provided the FIFA world cup ball with NFC tags.
In 2017 they developed SPYDER's (ski clothing brand) first wearable technology enabled by NFC.

Not much Technical information is found on their patented technology.
Only thing we can conclude from the available information is that they use UHF RFID for tracking solutions using RAIN RFID tags.

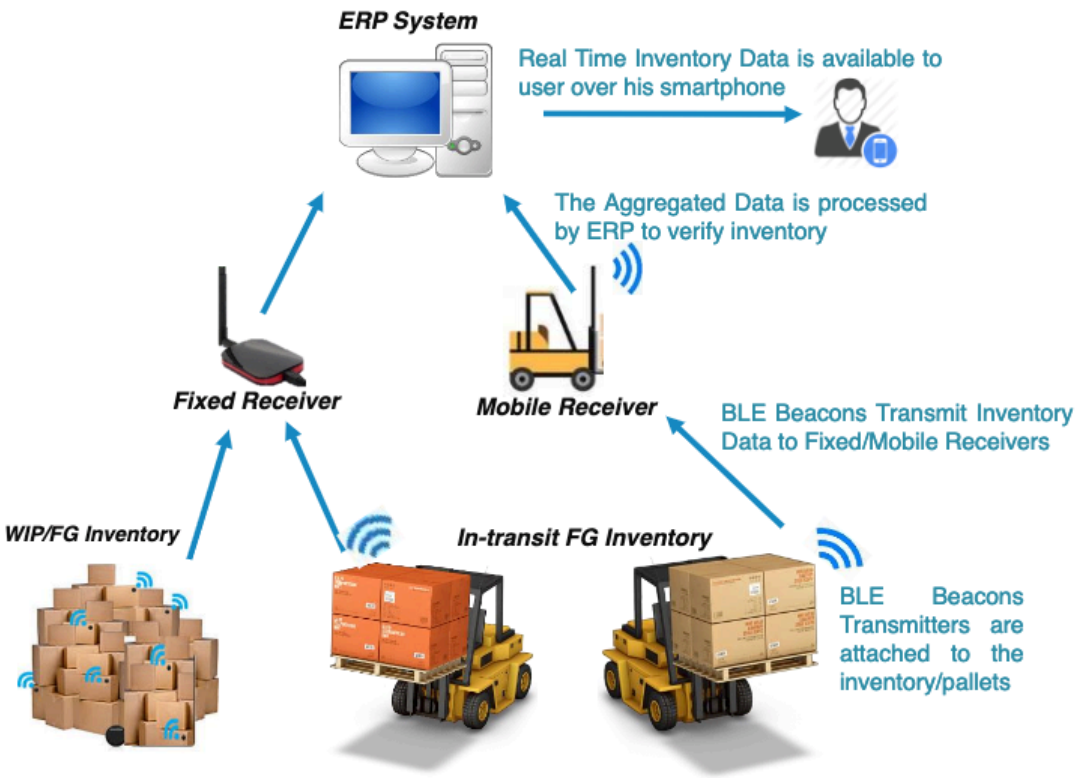
3.5. Cognizant [4]

Cognizant develops technology models for companies. Their HQ are located in the U.S. but they have offices all over the world. Cognizant is ranked 195 on the Fortune 500.
They are not specialised in IoT but have a much wider range of knowledge in technology.

They have an interesting presentation about IoT enable warehouses which we will investigate in the next paragraph.

IoT enable Smart Warehouse Solution [E]

The solution presented in the presentation is based on BLE.
They use forklifts with the BLE beacon attached to the pallets, so that when a pallet is loaded onto the forklift the transmitter beacon transmits the loaded inventory to the receiver when the forklift comes near enough to the receiver.
The receiver then processes the inventory information to the enterprise resource planning.



Their argument for using BLE is that it empowers bidirectional communication and it allows simultaneous integration with various sensors which makes BLE more versatile than RFID, Barcode (infrared) and QR codes.

3.6.Conclusion market research

We see that a lot of technology of our competition is patented and not much technical information is available.

We see 2 technologies that dominate the market. One is BLE (bluetooth low energy) and the other is RFID (Radio Frequency IDentification).
The BLE technology is more often used when location of the assets are of importance thus making it an asset tracking system. BLE seems to be based more on reusable tags since they cost more than RFID tags and are often made with hard polyester.

RFID is mostly used purely as an inventory management system since they don't use beacons to detect or determine positions of an asset. Mostly UHF (Ultra High Frequency) RFID is used because this has the longest range, highest bitrate and cheap but is the most sensitive to other radio interference.

All competition uses more or less the same cost model, we can divide this cost model is 3 big sections:

- Hardware cost

  Hardware cost consists of tags and readers. Readers are the bigger initial cost but since we need a lot of tags this reader cost is minimal in the long term.
  Tags are the biggest cost on the long term and we want to keep the price as low as possible by buying in large quantities or fabricating yourself (by use of a printer).

- Middleware cost

  The middleware cost is the software developed to communicate between the readers and the enterprise resource planning system. This cost depends on the complexity of the application and form of data storage.

- Service cost

  This includes system design, customisation, configuration and eventual update costs.

Almost no figures about the competition can be found on the price of middleware and service cost.
The hardware cost is dependent on the kind of technology used and quality. This we will discuss in more detail in next section where we will investigate and compare the different possible technologies.

4. Technology Research

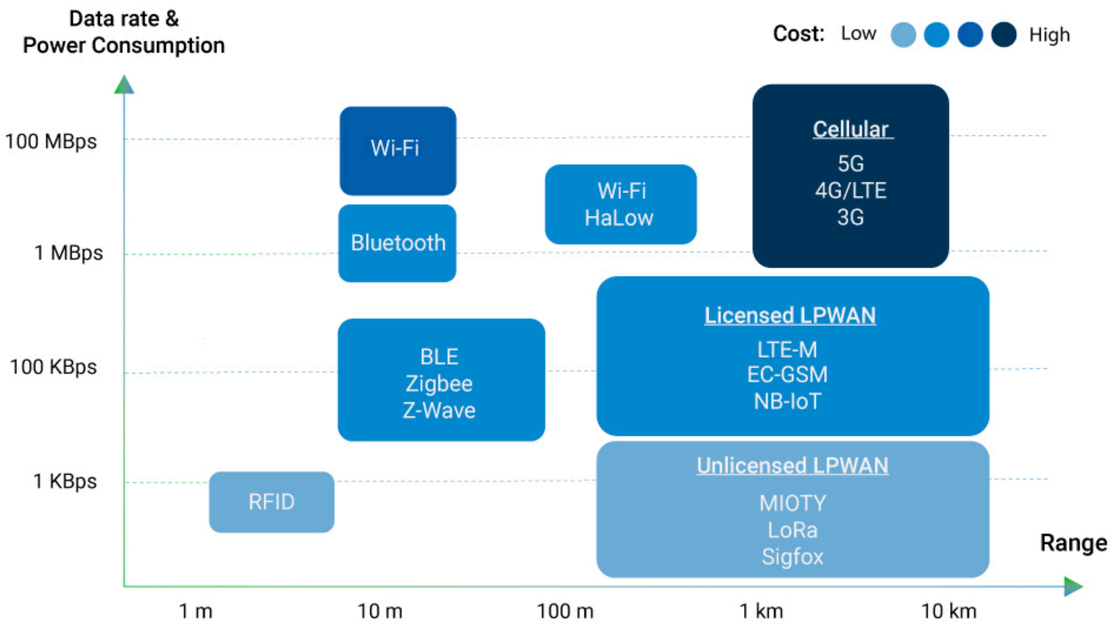
In this section we will compare the different possible technologies for IoT inventory management systems and conclude which are suited for our project.

The different technologies we have encountered in our market research are infrared, UWB, Wifi, BLE and RFID (active and passive). Based on the market research we can conclude that BLE and RFID are most likely the most interesting technologies to investigate in detail.

Technologies that did not come up in the market research but may be a possibility are Zigbee (IEEE 802.15.4) and Wifi HaLow (IEEE 802.11ah). WiFi HaLow is quit a new technology and was planned to be deployed by 2018.

Important properties we need to compare are range, sensitivity to interference, cost, data rate, power consumption and ease of integration.

A very basic overview of the possible technologies is given in the graph below. [5]



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

4.1.RFID [F] [6] [7]

There are two kinds of RFID, active RFID and passive RFID. It is important to note that RFID works in the unlicensed ISM frequency spectrum.

Active RFID

With active RFID the tags has its own energy supply, this can be a transponder tag or a beacon tag. With a transponder tag the reader will sent a signal to the tag and then the active transponder will reply the relevant information. Beacons tags will not wait for a message from the reader but send out its message every x seconds, making it more power consuming than a transponder tag.
The energy source in the tag has the consequence that these are more expensive (approximately between 10€ and 100€). The benefit of the tag having his own energy supply is that the energy can be used to achieve a longer range, up to 300m. Another consequence is that because of the energy source and use of more power in the tag the lifetime is more limited compared to passive RFID tags.

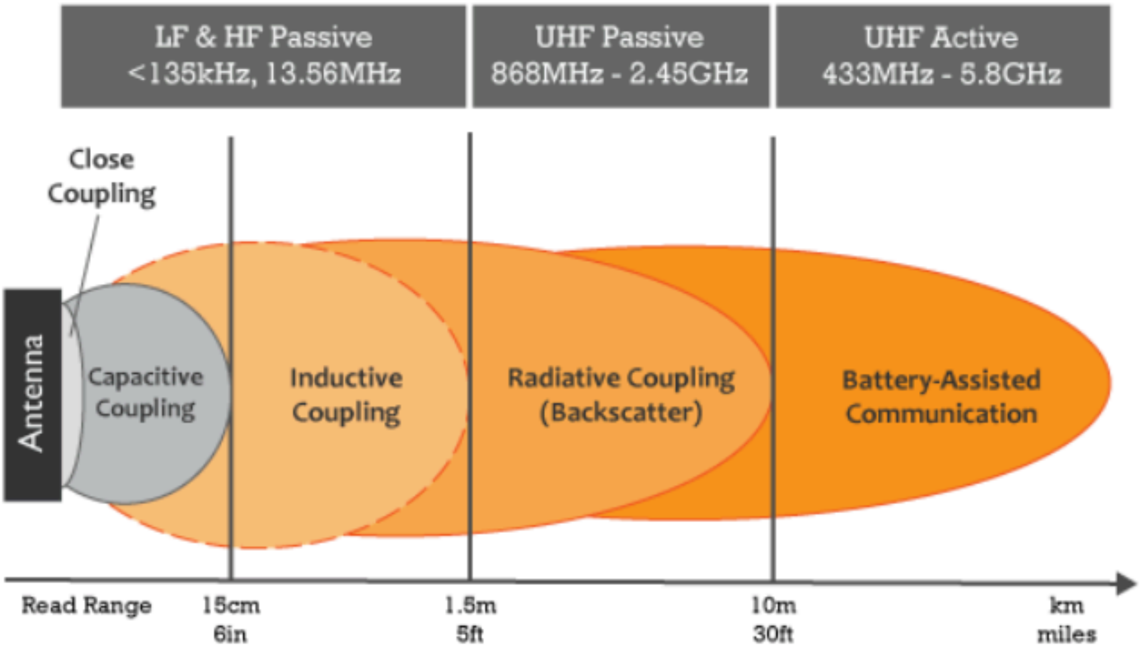
Passive RFID

Passive RFID tags have no power supply, in general they have a low data transfer capacity with a limited range. Because of the fact they have no power supply they have a longer lifetime, are more durable (heat resistant) and are much cheaper. The average price of a passive RFID tag is between 0,10€ and 10€. This price mostly varies depending of the type of tag, there are disposable tags and reusable tags which are more expensive than the disposable tags.

Passive RFID can be classified in 3 types based of frequency:

- Low Frequency (125 kHz - 134 kHz)
- High Frequency (13, 56 MHz)
- Ultra High Frequency (860 - 960 MHz)

- Reducing range
- Incresing data rate
- Increasing Interference sensitivity



Depending on the frequency used the coupling method between reader and tag differs.

At low frequency capacitive coupling is used to transmit data between reader and transponder (tag). Capacitive coupling is the phenomenon that the electric field in the reader influences the tag which gains enough power to answer back to the reader.

At high frequency inductive coupling is used to transfer data between reader and transponder. The reader creates a magnetic field which runs thrugh a coil on the tag and creates a current that can be used by the tag to answer its message.

At Ultra high frequency backscatter is used to transmit the data between tag and transponder. The electromagnetic waves send out by the reader are used to power up the tag.

Frequency	Read Range (Passive tag) [m]	Data transfer rate [Kbits/sec]	Environmental sensitivity (metal & water)	Directional
125-134 kHz (LF) Induction	< 1	2 - 4	Low	Not
13.56 MHz (HF) Induction	< 1.5	10 - 20	Limited	Hardly
868 – 870 MHz 902 – 928 MHz (UHF) Backscatter	2 – 4	20 – 150	High	More
2.45 GHz (UHF – µW) Backscatter	± 1	➢ 100	High	Very

Environmental sensitivity is an important factor. In above graph is said that UHF RFID is sensitive to radio wave interference by metal and liquids, two things present in the environment of our project. Multiple sources state that there are manufacturers that designed tags and antennas that keep the performance high in these difficult environments. Often RAIN RFID is mentioned as a technology that is suited for these hard environments. The RAIN RFID Alliance is founded by Impinj, Google, Intel and Smartrac to develop and promote the adoption of RAIN RFID technology. It is based on the GS1 UHF Gen2 protocol. The RAIN RFID alliance solely focuses on the UHF RFID band.

Conclusion RFID

We can conclude that RFID is a suited technology for the project we want to realise. To determine which class of RFID we can look at price, range and data rate.
Active RFID doesn't seem suited because of the price of the tags since tags won't be reusable in our project, also since the goal is to tag each box or bottle of wine making the total amount of tags needed too high for expensive tags.

Passive RFID is a much cheaper solution. More specifically the UHF RFID seems suited for our project. It has sufficient range and the most data transfer rate compared to other passive RFID technologies. The one downside and possible risk to be unsuited for this project is that UHF RFID is sensitive to water and metal, two things highly related to our project since we are working with trucks and wine. The actual numerical sensitivity has to be investigated and will be done later on.

Passive RFID	Range	Data rate	Sensitivity	Price	Power consumption
Performance	Ok	Ok	Risk	Good	Very Good

4.2. Bluetooth Low Energy [8] [G] [H]

BLE is a technology based on simple Bluetooth. It uses the unlicensed ISM band.

BLE is seen as to lowest power wireless technology (except for passive RFID of course). It uses a simple button cell which can power a tag for around 2 to 5 years.

There can be found a lot of different information about the range of BLE, depending of the beacon power. I've found number between 10 and 70 meters, but theoretical max is above 100m. The environment has an influence on the BLE radio frequencies, but since it radiates enough power it shouldn't impose any problems for our project. Nevertheless the influence should still be investigated should we use this technology.

Advertised data rate is high, reaching 1 to 2 Mbps but application throughput ranges between 0,27 and 1,37 Mbps, which is still more than enough for our needs.

BLE works with beacons and tags. Beacons keep sending out data, the tags wake op every x time and calculates his position based on the data it got from the beacons. The tag then sends his position to its gateway.

The tags and beacons are actually the same hardware but are programmed differently. These tags or beacons cost around 10€, but this highly depends on the quality of the hardware. This is still a high price as we need a lot of them for our projects. The only possibility to implement this technology for our project is if we use tags by pallet instead of per box and reuse the tags.

Because tags update their position it is often used in real time location systems. This is overkill for our project that comes with a higher price.

Conclusion BLE

It is possible to use the BLE technology for our project but costs will probably be too high and possibilities of BLE extends our needs since BLE is most often used for real time location systems. Therefor we will probably not use this technology.

BLE	Range	Data rate	Sensitivity	Price	Power consumption
Performance	Good	Good	Ok	Bad	Ok

4.3. ZigBee [9] [10] [I]

ZigBee is an open standard protocol (ISM) based on IEEE 802.15.4. It is often used in sensor networks and proces control and management. The technology is intended to be simpler and cheaper than other wireless personal area networks such as Bluetooth and Wi-Fi.

Something different from the technologies we have seen until now is that ZigBee networks are secured by 128 bit AES.

Data transfer rater depends on the frequency used, it can be used on 3 frequencies:
- 2,4 GHz : 250 kbps, 16 channels
- 915 MHz: 40 kbps, 10 channels
- 868 MHz: 20 kbps, 1 channel

The range varies between 10 and 70 meters.

Conclusion ZigBee

The statistics of the ZigBee protocol are good enough for our projects, although 250 kbps data rate is low for an active system (almost same as UHF passive RFID).

The protocol itself would be a suitable technology but there is very little support for what we want to do with it. ZigBee is completely focussed on sensor network and home/city automation by providing an ZigBee application layer where developers can build on. Because of this there is almost no suited hardware for our project, making ZigBee too hard to implement.

4.4.Wi-FI HaLow [11] [12] [13]

Wi-Fi HaLow is developed by the Wi-Fi Alliance based on the IEEE 802.11ah standard. It is focused for IoT by using lower frequency and this longer range and less power consumption. It uses the unlicensed 900 MHz frequency band.
It is important to note that WiFi HaLow is brand new and was predicted to be operational by the end of 2018.
WiFi Halow stations have predefined wake or doze periods. It uses 26 channels witch each of them providing 100 kbit/s throughput and can cover a 1km radius.

Besides this there is almost no information to be found. I did found one company called Morse Micro that is based in Australia which are working on IoT application for Wi-Fi HaLow. One of them is a logistic and asset management solution. They have a blog post about this but not much actual or numerical information can be found in it, only concepts are explained.

WiFi HaLow conclusion

This technology is still in its infancy making it very hard to implement for any application at this moment.

4.5.Conclusion technology research

As expected from our market research there are 2 viable technologies we can use, UHF RFID and BLE. Since UHF RFID is the cheapest technology that can satisfy the specifications this seems the best choice. All following research will be based on UHF RFID, should we encounter a limitation or reason why we can’t accomplish our project with UHF RFID we can fall back on another technology, probably BLE.

5. Thorough research passive UHF RFID [14] [15] [J] [16]

In this section we are going to do some deeper investigation about RFID. As RFID is still an evolving technology we are going to look into the different generations and classes of RFID.

We will also do research about the different antennas and tags we can find on the market and compare them to the hardware we already have available.

At this moment we are at the EPC Gen 2 Air interface protocol. Before that there was the EPC Gen 1.

5.1.Tags

The differences between the tags between the two generations can be summarised into the underneath table.

	Gen 1	Gen 2
# transistors	± 12 000	± 40 000
Global protocol	No	Yes (air-interface protocol)
Classes	0,1	0, 1, 2, 3, 4, 5

First thing that is important to mention is that the Gen1 is not compatible with Gen2. although Class-1 Gen-2 RFID tags are backward-compatible with Gen-1 Class-0 and Class 1 tags.
Since a Gen 2 chip on a tag requires a third of the transistors compared to Gen 1 they are cheaper.
Some other benefits compared to Gen 2 are:

- Faster and more flexible read speeds
- More accurate performance thanks to anti collision protocols
- Easier to deploy multiple readers at one time
- Enhanced security and privacy

Before the Gen2 air-interface protocol you needed different readers depending of the Gen1 class (class 0 or class 1), except if you had a multi protocol reader.
Gen2 uses the air-interface protocol which is an interoperable global standard and because of this all readers are compatible and can be used for all classes.
As already mentioned Gen1 had class 0 and class1, with Gen2 new classes of EPC tags were possible that focussed on higher level functions like reading active tags with sensors.

Classes	Functionality
Class 0	UHF read-only preprogrammed passive tag
Class 1	UHF/HF write once read many (WORM)
Class 2	Passive read-write tags that can be written at any point
Class 3	Semi-passive or active Read-write with onboard sensors capable (temperature, pressure,..)
Class 4	Active read-write with transmitters to communicate with other tags and readers
Class 5	Idem 4 but can supply power to other tags and can communicate with other devices than readers

Since tags will only be used once in our project we will need class 1 tags, which can be written once depending on which type of package the tag will be connected.

5.2. Protocol [K]

For the RAIN RFID we will find most information out of the official GS1 UHF Gen 2 EPCglobal documentation. It is standarized as ISO 18000-63.

Physical layer

The reader sends information to the tags by modulating the RF carrier by double-sideband amplitude shift keying (DSB-ASK), single-sideband amplitude shift keying (SSB-ASK), or phase-reversal amplitude shift keying (PR-ASK). This is used to write information to the tag.
The tags receive their energy from this modulated RF carrier.

The reader receives information from the tag by sending an unmodulated RF carrier and listens for backscatter reply. These tags modulate the amplitude or phase of the backscattered RF carrier.

The communication between tag and reader (also called interrogator) is half-duplex.

Tag identification layer

The interrogator (reader) has 3 operations on the tags:

- Select: choosing a tag population for inventory and access
- Inventory: operation to identify a tag. An Interrogator begins an inventory round by transmitting a Query command in one of four sessions. One or more Tags may reply. The Interrogator detects a single Tag reply and requests the PC/XPC word(s), EPC, and CRC from the Tag (see later).
- Access: operation for communication from interrogator to tag (read or write)

Protocol parameters

There are a lot of parameters for communication between interrogator (R) and tag (T). These can be divided in two sections:

- physical and MAC parameters: most important parameters falling under this category are frequency range, modulation, bit rate, bit rate accuracy, preamble.
- Logical - operating procedure calls: parameters used by the interrogator during the select, inventory and access operations. Examples are write sizes, transaction times, memory size (tag dependant).

R => T communication

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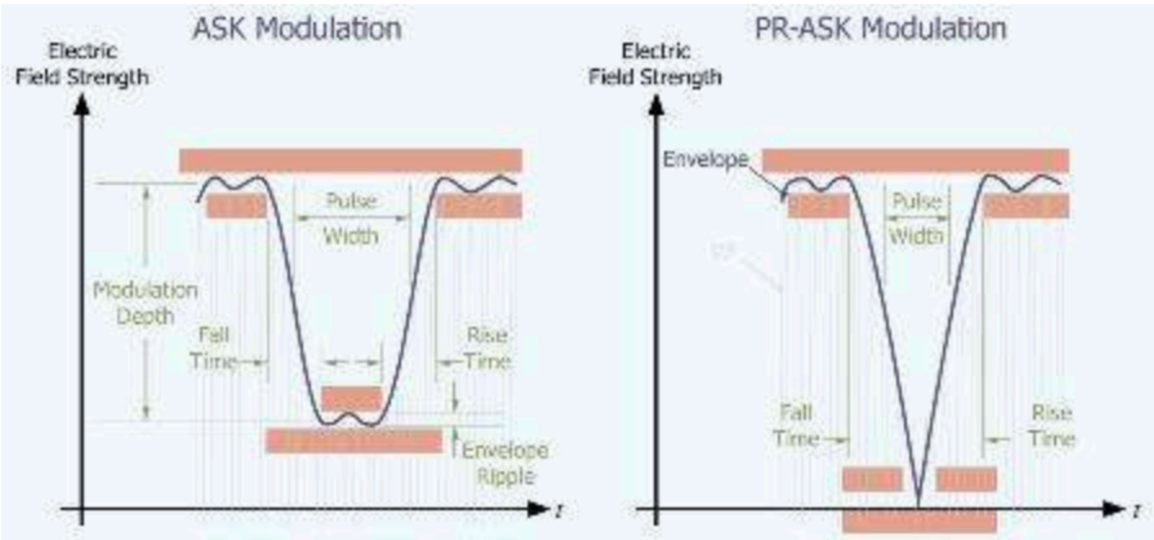
modulation [L]

Communication from interrogator to tag is by DSB-ASK (Double sideband amplitude shift keying), SSB-ASK (single sideband amplitude shift keying) or PR-ASK (phase reversal amplitude shift keying). Tags should me able to demodulate all three of these modulation techniques.



In research paper “ process tolerant analog ASK baseband for UHF RFID reader and implantable applications” is mentioned that PR-ASK or SSB-ASK are recommended for class 1 tags.

In the book ‘RFID design principles’ by Harbey lehpamer we find the following:

“The choice is essentially determined by performance requirements and cost. For example, ISO 18000 Type C (also know as EPC Gen2, Class 1) calls for DSB-ASK, SSB-ASK, and PR-ASK. ASK digital modulation are spectrally inefficient, requiring substantial RF bandwidth for a given data rate. Bandwidth efficiencies of 0.20 bit per hertz of RF bandwidth are not uncommon for DSB-ASK. It is possible to improve bandwidth efficiency using SSB-ASK. This is particularly important in European countries where bandwidth restriction may preclude DSB-ASK. The power efficiency of DSB-ASK and SSB-ASK is dependent on the modulation index. With a modulation index of 1, or on-off keying of the

carrier, the lowest carrier-to-noise (C/N) required to achieve a given bit error rate (BER) is obtained for DSB-ASK and SSB-ASK. Unfortunately, this also provides the least amount of RF power transport on the downlink to supply the tag with energy. Ideally, the off time of the carrier should be minimised so that the tag does not run out of power. The C/N requirements should also be minimised to maximise the ID read range. For many modulations these are conflicting requirements.

A modulation that can minimise the C/N requirement in a narrowband, while maximising the power transport of the tag is PR-ASK. Similar to a PSK signal, PR-ASK changes phase 180° each time a symbol is sent, PR-ASK also creates an amplitude modulation depth of 100% or a modulation index of 1, as the phase vector of the old symbol and the new symbol cross and briefly sum to a zero magnitude. This provides an easily detected clock signal as the amplitude briefly goes to zero, but minimises the time the carrier power is off, so power to the passive tag is optimised. PR-ASK has carrier to noise and bandwidth requirements that more closely match PSK than DSB-ASK, making it attractive for narrowband and longer-range applications.

DSB-ASK is the least bandwidth efficient modulation, but the easiest to produce by OOK of the carrier signal. ASK modulation specifications often have a modulation depth as well as rise and fill time requirements. The rise and fall time is typically related to the bandwidth filtering while the modulation depth is set by the attenuation difference between keying states."

PR-ASK and ASK are the 2 modulation options of our hardware (see later on).
The most important is tha PR-ASK is better than ASK because it has lower carrier to noise ratio and better power transport.

Data encoding

The R => T link uses PIE or pulse interval encoding. A Tari is the reference time interval for R => T signalling. The duration of a data-0 is exactly one Tari. A data 1 has the duration of 1,5 to 2 Tari.

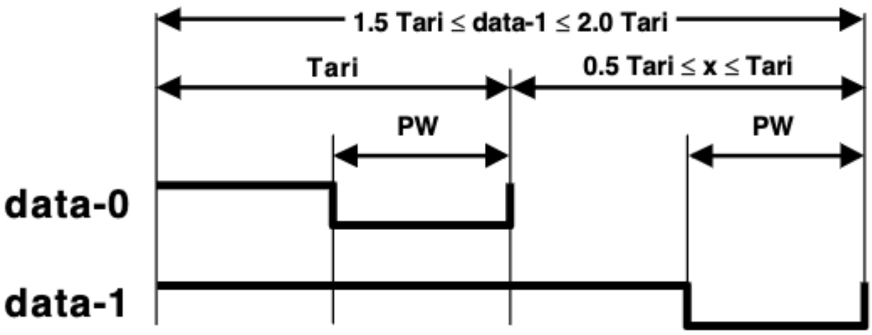


Figure 6.1 – PIE symbols

This Tari value ranges between 6,25 μs and 25 μs.

R => T preamble and frame-sync

The preamble precedes a Query command and implies the start of an inventory round.
All other signalling begins with a frame-sync.

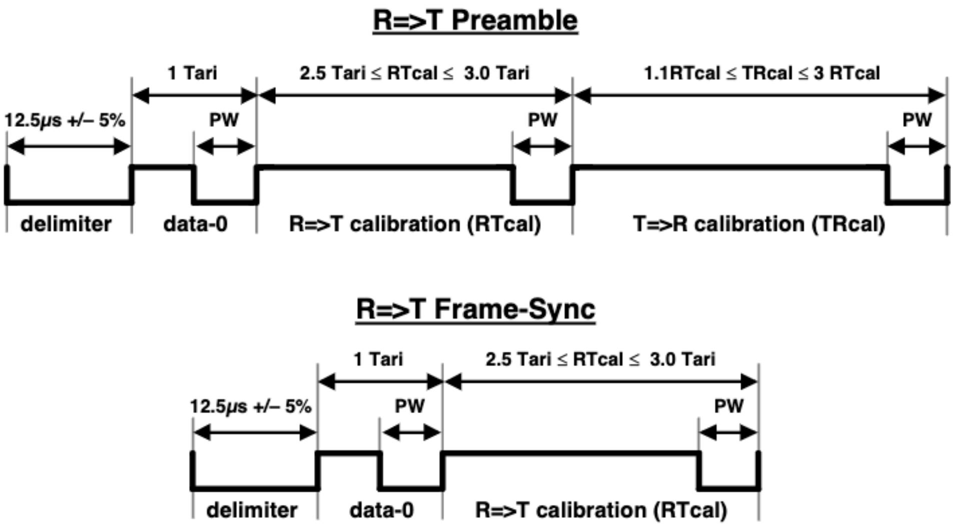


Figure 6.4 – R=>T preamble and frame-sync

RTcal has the length of a data0 + data , the tag then measures the length of the RTcal and compute the pivot (RTcal / 2). The tag now knows that signals shorter than this pivot determines a data0 and higher than the pivot determines a data1.

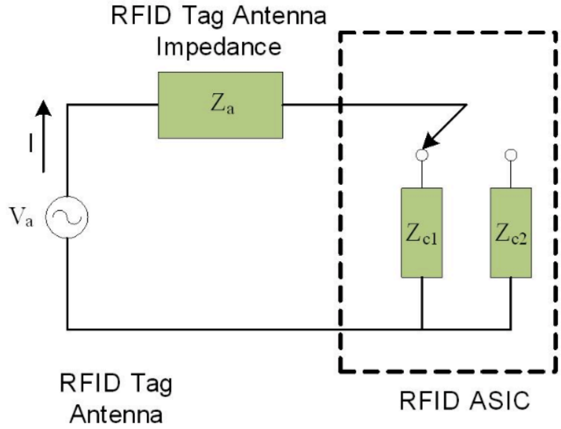
The TRcal (note that his is only present in the preamble frame) is a bit more complicated. The interrogator specifies the tag's backscatter link frequency (BLF) using the TRcal (which was already send) and the divide ratio (DR) to find the backscatter link frequency.

$$BLF = \frac{DR}{TRcal}$$

$$1.1 \times RTcal \le TRcal \le 3 \times RTcal$$

T => R communication [M]

Communication is based on backscatter modulation, the tag switches the reflection coefficient of its antenna between two states in accordance with the data being send, as shown below.



modulation

The backscatter is modulated in ASK and/or PSK, chosen by the vendor and the interrogator has to be able to demodulate both modulation types.

Data encoding

Backscattered data will be encoded in FM0 or Miller modulation of a subcarrier at the data rate.

FM0 (bi-phase space) baseband

Baseband phase gets inverted at every symbol boundary, with a data0 having a an additional mid-symbol inversion. The FM0 encoding has memory since the choice of sequences depends on prior transmissions. FM0 signalling always ends with a dummy data1 bit at the end of transmission.

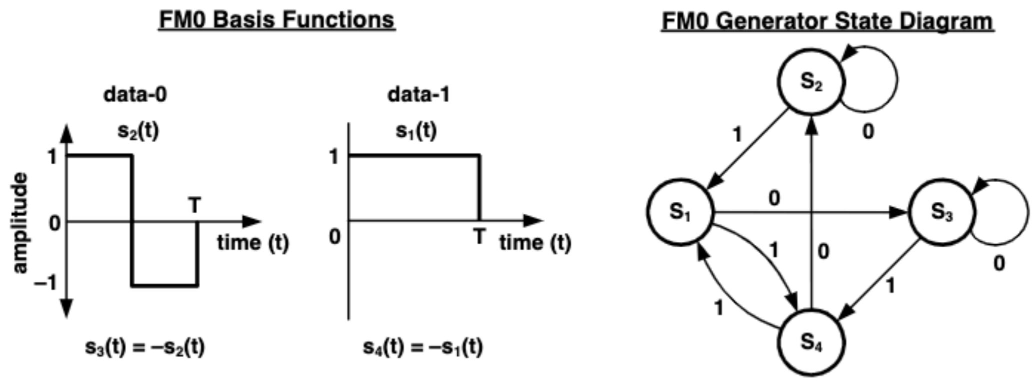


Figure 6.8 – FM0 basis functions and generator state diagram

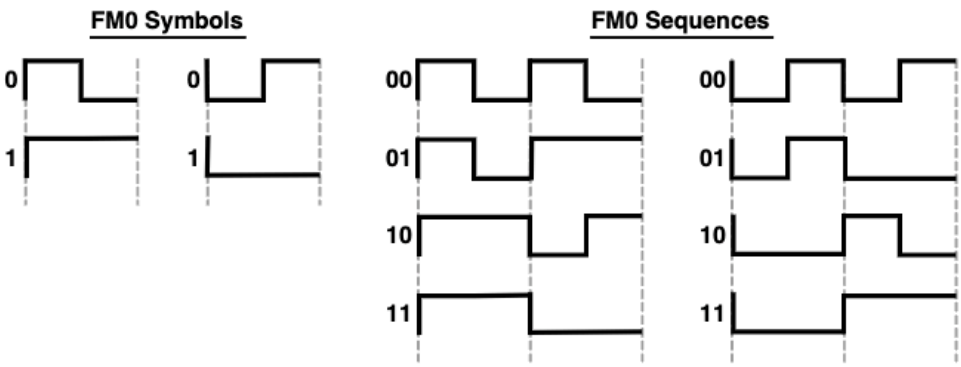


Figure 6.9 – FM0 symbols and sequences

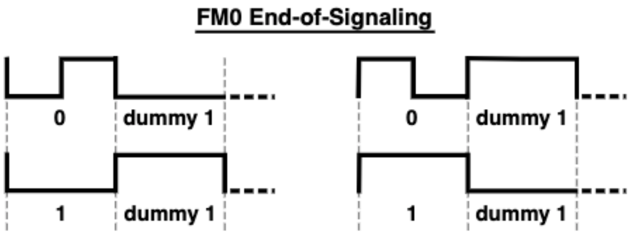


Figure 6.10 – Terminating FM0 transmissions

There are two kinds of FM0 preamble structures, the choice depends on the TRext bit specified in the query command initiated by the inventory round.

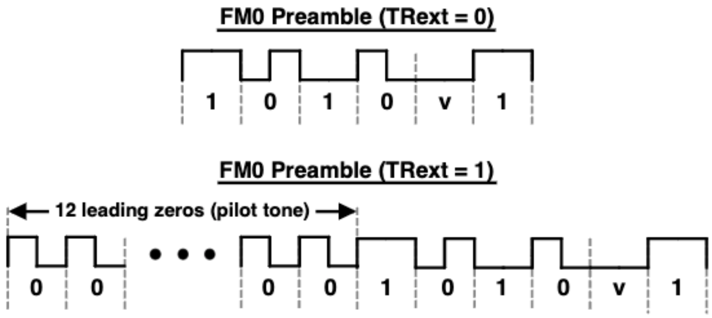


Figure 6.11 – FM0 T=>R preamble

Miller-modulated subcarrier

The baseband Miller inverts phase between two data0 in sequence and in the middle of a data1.

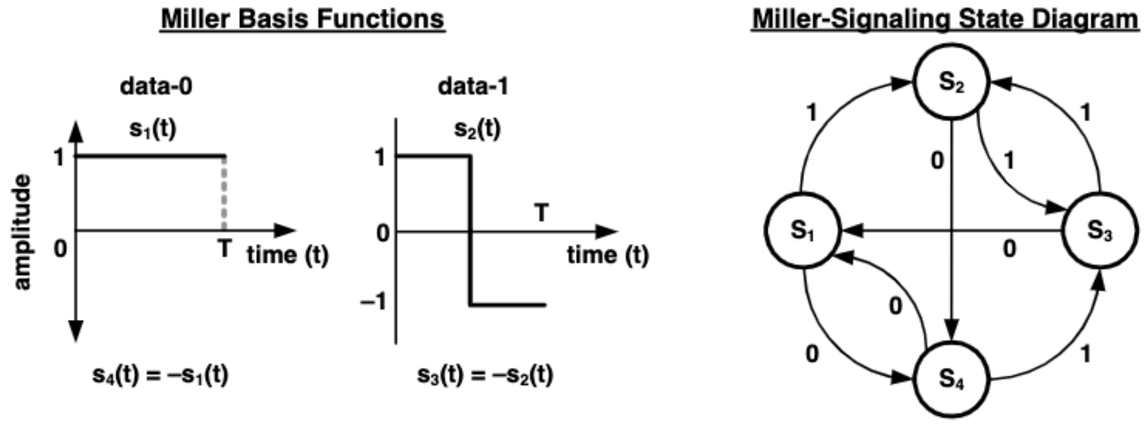


Figure 6.12 – Miller basis functions and generator state diagram

The Miller sequence has 2, 4 or 8 subcarrier cycles per bit depending on the value M specified in the query command. Just like FM0 the Miller signalling always ends with a dummy data1 at the end of transmission.

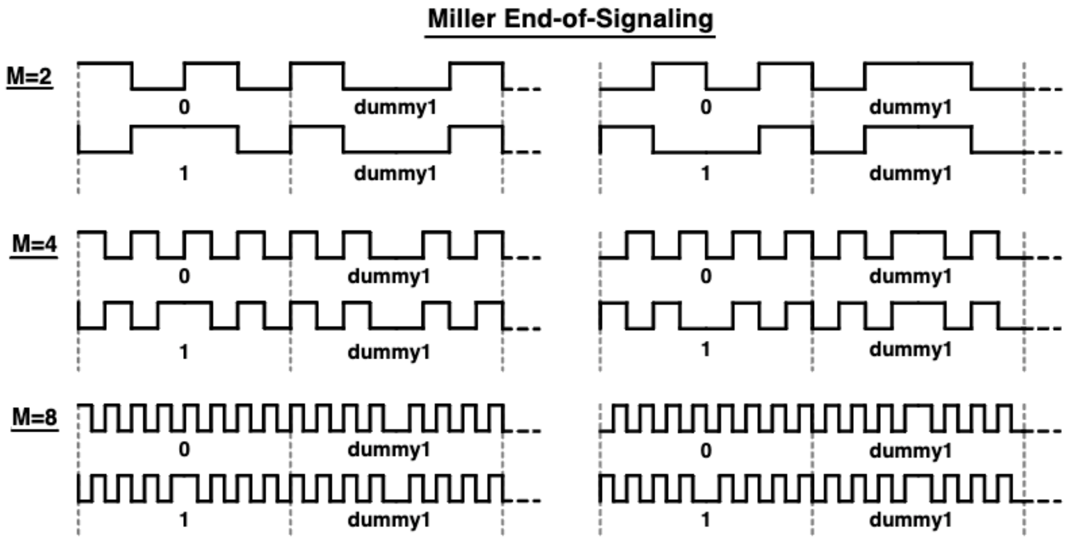


Figure 6.14 – Terminating subcarrier transmissions

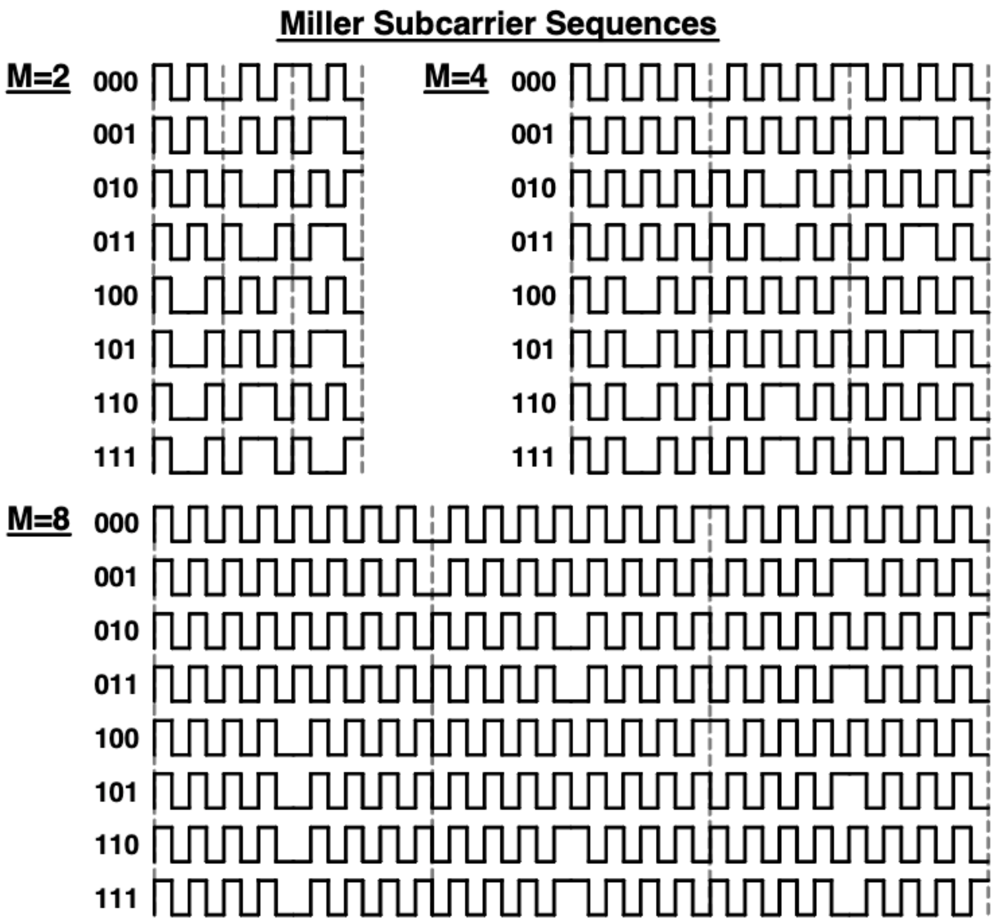


Figure 6.13 – Subcarrier sequences

Just like with FM0 there are 2 possible preambles with the miller modulation, specified by TRext bit in the query command that initiated the inventory round.

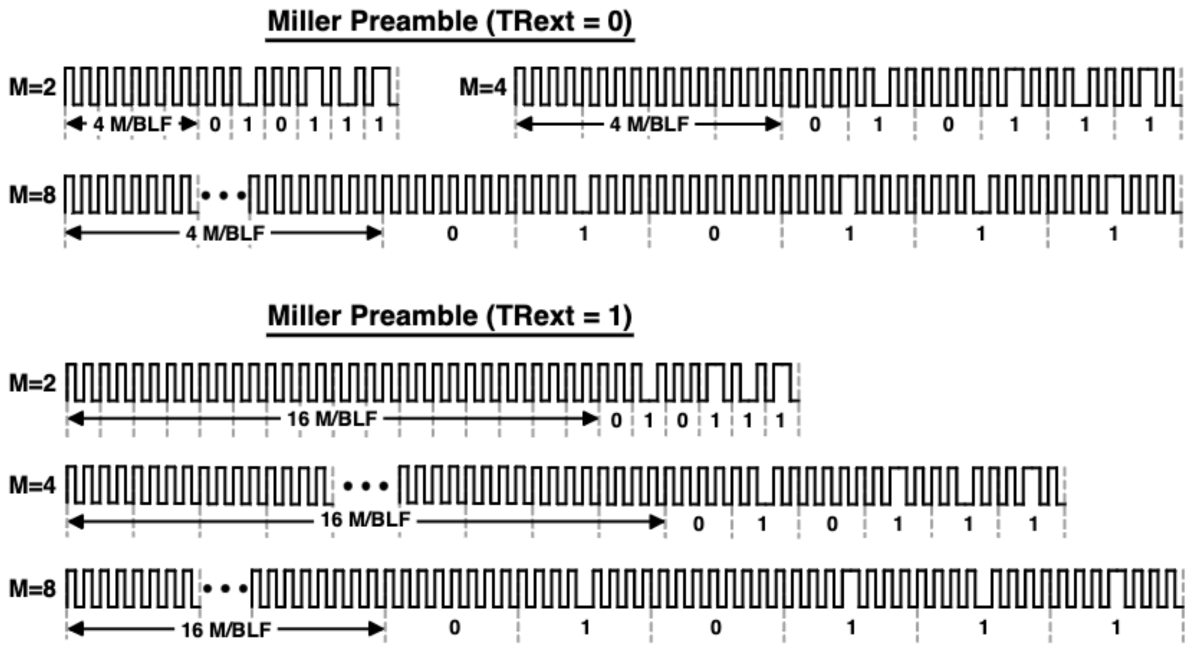


Figure 6.15 – Subcarrier T=>R preamble

Table 6.10 – Tag-to-Interrogator data rates

M: Number of subcarrier cycles per symbol	Modulation type	Data rate (kbps)
1	FM0 baseband	BLF
2	Miller subcarrier	BLF/2
4	Miller subcarrier	BLF/4
8	Miller subcarrier	BLF/8

Minimum operating field strength and backscatter strength

Tag manufacturer has to specify following things:

- Free-space sensitivity
- Minimum backscattered modulated power (ASK modulation) or change in radar cross-section or equivalent (phase modulation)
- Normal operating conditions

Transmission order

The communication of R => T and T => R is both Most Significant Bit first

Each message starts with most significant word first, also called big-endian.

Tag Memory

The tag memory has 4 separated partitions:

- Reserved memory: kill and access passwords if implemented
- EPC memory: contains a stored CRC + a code that identifies the object to the tag and XPC (extended protocol control) words if used.
- TID memory: Bit ISO/IEC class identifier and enough information for an interrogator to uniquely identify the custom commands and/or optional features the tag supports.
- User memory: optional

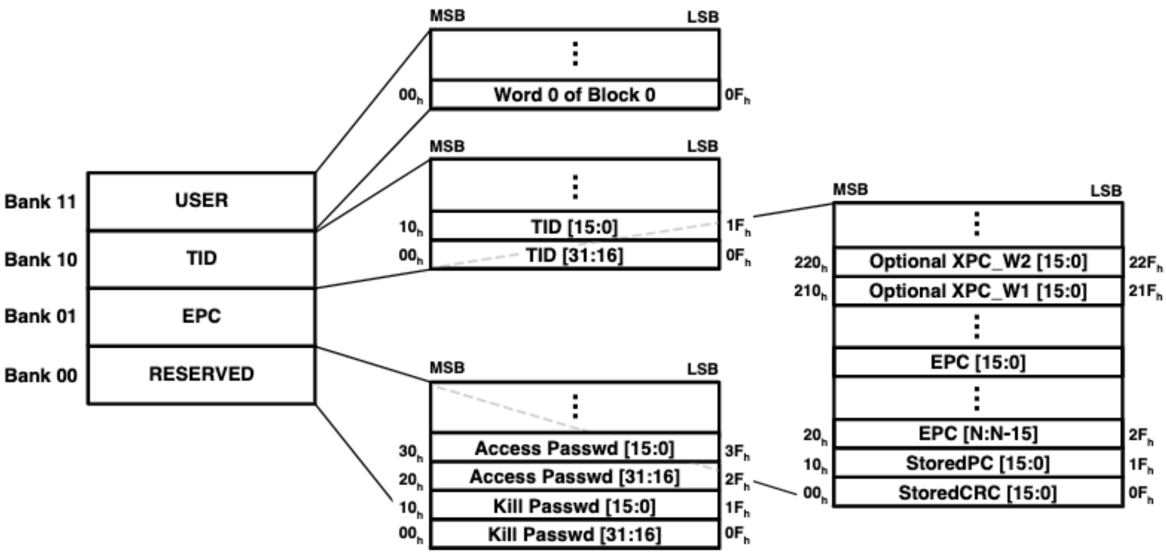


Figure 6.17 – Logical memory map

Interrogator commands and tag replies

Table 6.19 – *Select* command

	Command	Target	Action	MemBank	Pointer	Length	Mask	Truncate	CRC-16
# of bits	4	3	3	2	EBV	8	Variable	1	16
description	1010	000: **Inventoried** (S0) 001: **Inventoried** (S1) 010: **Inventoried** (S2) 011: **Inventoried** (S3) 100: **SL** 101: RFU 110: RFU 111: RFU	See Table 6.20	00: RFU 01: EPC 10: TID 11: User	Starting Mask address	Mask length (bits)	Mask value	0: Disable truncation 1: Enable truncation	

Table 6.21 – *Query* command

	Command	DR	M	TRext	Sel	Session	Target	Q	CRC-5
# of bits	4	1	2	1	2	2	1	4	5
description	1000	0: DR=8 1: DR=64/3	00: M=1 01: M=2 10: M=4 11: M=8	0: No pilot tone 1: Use pilot tone	00: All 01: All 10: ~**SL** 11: **SL**	00: S0 01: S1 10: S2 11: S3	0: *A* 1: *B*	0–15	

Table 6.33 – *Read* command

	Command	MemBank	WordPtr	WordCount	RN	CRC-16
# of bits	8	2	EBV	8	16	16
description	11000010	00: Reserved 01: EPC 10: TID 11: User	Starting address pointer	Number of words to read	handle	

Table 6.35 – *Write* command

	Command	MemBank	WordPtr	Data	RN	CRC-16
# of bits	8	2	EBV	16	16	16
description	11000011	00: Reserved 01: EPC 10: TID 11: User	Address pointer	RN16 ⊗ word to be written	handle	

Table 6.18 – Commands

Command	Code	Length (bits)	Mandatory?	Protection
QueryRep	**0**0	4	Yes	Unique command length
ACK	**0**1	18	Yes	Unique command length
Query	**10**00	22	Yes	Unique command length and a CRC-5
QueryAdjust	**10**01	9	Yes	Unique command length
Select	**10**10	> 44	Yes	CRC-16
Reserved for future use	**10**11	–	–	–
NAK	**110**00000	8	Yes	Unique command length
Req_RN	**110**00001	40	Yes	CRC-16
Read	**110**00010	> 57	Yes	CRC-16
Write	**110**00011	> 58	Yes	CRC-16
Kill	**110**00100	59	Yes	CRC-16
Lock	**110**00101	60	Yes	CRC-16
Access	**110**00110	56	No	CRC-16
BlockWrite	**110**00111	> 57	No	CRC-16
BlockErase	**110**01000	> 57	No	CRC-16
BlockPermalock	**110**01001	> 66	No	CRC-16
Reserved for future use	**110**01010 … **110**11111	–	–	–
Reserved for custom commands	**1110**0000 00000000 … **1110**0000 11111111	–	–	Manufacturer specified
Reserved for proprietary commands	**1110**0001 00000000 … **1110**0001 11111111	–	–	Manufacturer specified
Reserved for future use	**1110**0010 00000000 … **1110**1111 11111111	–	–	–

Interrogator command	T_{REPLY}	***Tag response***	
Write, Kill, Lock, BlockWrite, BlockErase, BlockPermalock (Read/Lock=1)	CW	Preamble	{0, handle, CRC-16}

Figure 6.22 – Successful *Write* sequence

This is certainly not a full list of all commands, not even all mandatory commands. This is a list of most usefull and important commands to understand the working of RFID class 1 Gen 2 protocol.

Tag state diagram

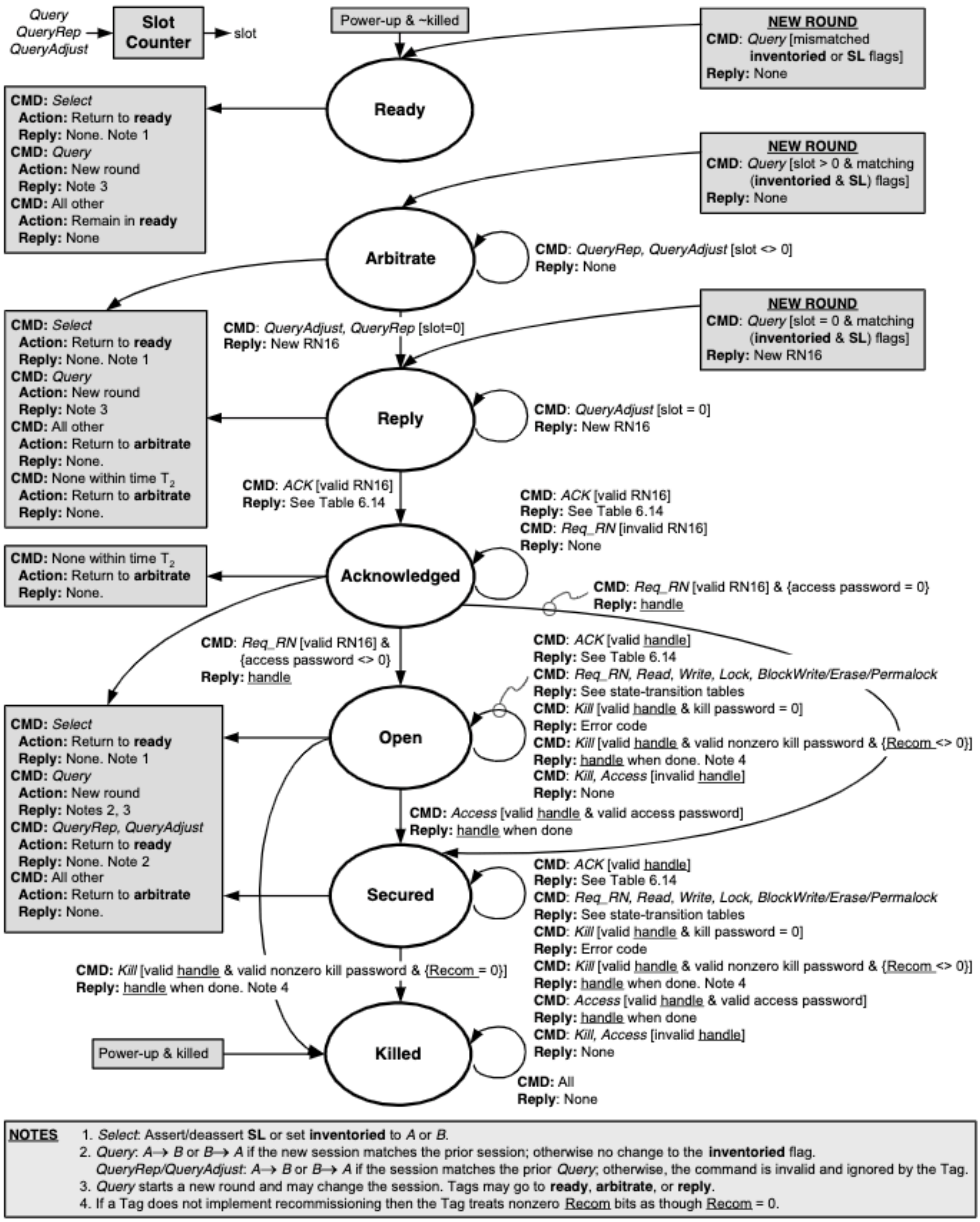


Figure 6.19 – Tag state diagram

6. Hardware research

In this section we will list which hardware we will use to realise this project. It is important to know that we already have some hardware available that we will use for testing. We will also look around on the market to compare our already available hardware to other hardware we could buy to possible improve results.

The different hardware components we need are a raspberry pi, an UHF RFID reader,an antenna and some tags.

6.1.Available Readers

NORDIC ID NUR-05WL2 [N] [O] [18]

RF Power	+27 dBm (500 mW) adjustable in 1 dB steps
Typical reading speed	200 tags / sec
RFID Protocol support	EPC class 1 gen2v2 (ISO 18000-63)

Antenna: 50 ohm / VSWR < 1.5:1

UART and USB 2.0 communication
Selectable receiver decoding, link frequency and transmitter modulation (ASK/ PR-ASK).

For software development there is the ID NUR API that provides full control in windows, linux and android OS.
Application can be written in C/C++, .NET and Java languages.

<u>Important note:</u>

Regulations have changed in Europe and now the effective radiated power (ERP) can be 33 dBm or 2W in the 868 MHz band. This could increase range and RSSI from the tag. There also is a ‘new’ band from 915 to 921 MHz where 4W ERP will be allowed in Europe. [R]

6.2.Alternative Readers

M6E NANO [17]

RF Power: 27 dBm
Typical reading speed: 150 tags/sec
Duration tag writing: ± 80 ms

Speedway RAIN RFID Readers [19]

Product Details	Speedway R420	Speedway R220	Speedway R120
Use Cases	Optimized for 4 read zone use cases Expandable to 32 read zones with Impinj Antenna Hubs Up to 1,100 tag reads per second	Optimized for 2 read zone use cases Up to 200 tag reads per second	Optimized for 1 read zone use cases Expandable to 8 read zones with optional Impinj Port Pack Up to 200 tag reads per second
Antenna Ports	4	2	1 (enabled)
Read Zones (maximum)	32 with Antenna Hubs	2	8 with Port Pack
Transmit Power (maximum without Antenna Hub)	FCC: 32.5 dBm AC/ 31.5 dBm PoE ETSI: 31.5 dBm AC/ 30.0 dBm PoE	FCC: 32.5 dBm AC/ 31.5 dBm PoE ETSI: 31.5 dBm AC/ 30.0 dBm PoE	FCC: 30.0 dBm AC and PoE ETSI: 30.0 dBm AC and PoE
Air Interface Protocol	GS1/EPCglobal UHF Gen2 (ISO 18000-63) or RAIN RFID		
Receive Sensitivity (maximum)	- 84dBm		
Return Loss (minimum)	10dB		
Reliability	Enterprise Grade		
Network Connectivity	10/100BASE-T Ethernet		

6.3.Available Antenna

Nordic ID Sampo S0 [P]

UHF RFID	
Frequency band	ETSI 865 - 868 MHz and FCC/IC 902-928 MHz
Gain	ETSI: 7.0 dBic/5.0 dBi
Beam width (-3dB)	80°
Polarization	RHCP
Input impedance	50 Ω
VSWR	< 1.5:1
Maximum input power	10 W (40 dBm)
Efficiency	87 %
Connector	SMA female
SIZE AND WEIGHT	
Dimensions	(W) 200 x (L) 260 x (H) 25 mm ((W) 7.9 x (L) 10.2 x (H) 1.0)
Weight	438 g (15.4 oz)
ENVIRONMENT	
Operating Temperature	-20°C to 55°C (-4°F to 130°F)
Storage Temperature	-40°C to 85°C (-40°F to 185°F)

RHCP: right hand circular polarisation. Lose of power compared to linear polarisation (3dB or half) but best used when orientation of the tag is unknown

Available Tags [20] [21] [22]

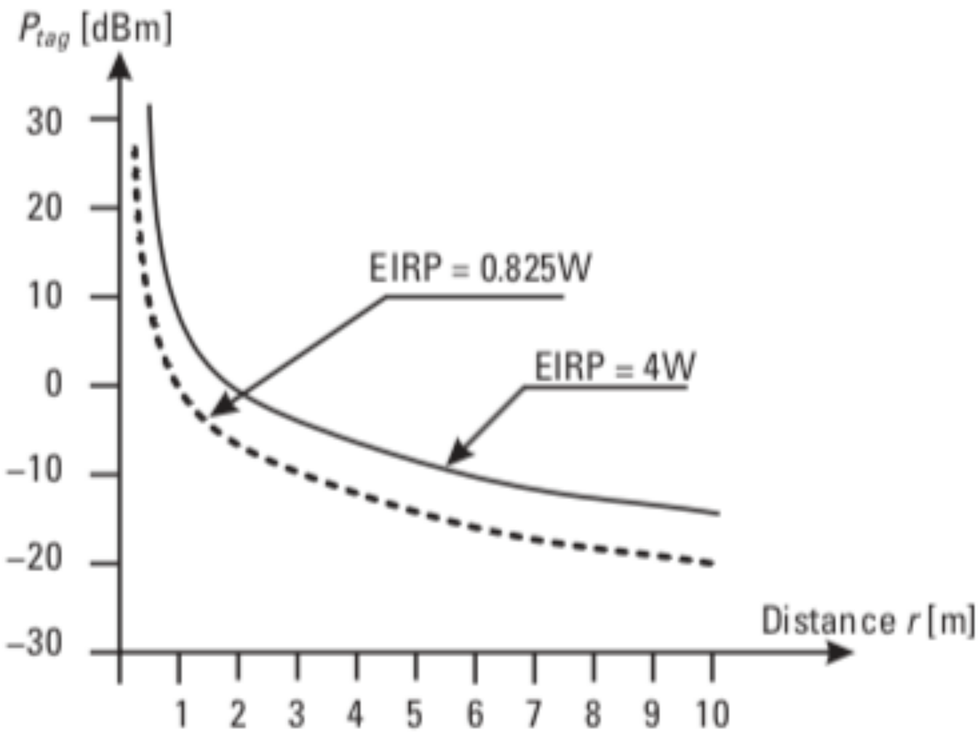
We hava two different tags at our disposal. Both are created from sparkfun and bought with at Antratek. There is the big issue that both tags don't have any datasheets, even after contacting Sparkfun support they couldn't provide me more information (Selectivity etc).

They are EPCglobal Gen2 tags with 800 bits of memory and 512 of them as user bits. They have a 64 bit TID and 32 bit access and kill passwords.

7. Calculations of Range [L] [Q]

In this section we will determine the range we can achieve with our hardware and tags. We will also look into what influences the read rates of the tags and how many tags/s is realistic. We will first calculate the read range in ideal situation, then from a more realistic perpective by taking into account losses and polarization mismatch and at last we will try to calculate the maximum read range if the medium of transmission becomes wine instead of free space.

The relation of the power at the tag with the distance can be visualized as underneath.



It is important to know the difference between EIRP and ERP. EIRP stands for Effective isotropic radiated power, which is the power the antenna will radiate is it radiates equally strong in all directions around it. Or in other words that ERP compares the acual antenna to a half-wave dipole antenna, while EIRP compares it to a theoretical isotropic antenna. The relation between EIRP and ERP is EIRP = ERP + 2,15.

Underneath table gives us an idea of the power at a tag when the antenna is at a certain distance.

Table 5.1
Received UHF RFID Power for Various Distances

f [MHz]	λ [m]	*r* [m]	*P* Reader [W]	*P* Reader [dBm]	Reader Antenna Gain	Tag Antenna Gain	$\Delta\rho$	σ [m^2]	*P* Received [μW]	*P* Received [dBm]	Power Ratio [dB]
915.00	0.33	1.00	2.00	33.01	1.60	1.60	0.50	0.0055	1.5185	−28.19	−61.20
915.00	0.33	2.00	2.00	33.01	1.60	1.60	0.50	0.0055	0.0949	−40.23	−73.24
915.00	0.33	4.00	2.00	33.01	1.60	1.60	0.50	0.0055	0.0059	−52.27	−85.28
915.00	0.33	8.00	2.00	33.01	1.60	1.60	0.50	0.0055	0.0004	−64.31	−97.32
433.00	0.69	1.00	2.00	33.01	1.60	1.60	0.50	0.0244	30.2793	−15.19	−48.20
433.00	0.69	2.00	2.00	33.01	1.60	1.60	0.50	0.0244	1.8925	−27.23	−60.24
433.00	0.69	4.00	2.00	33.01	1.60	1.60	0.50	0.0244	0.1183	−39.27	−72.28
433.00	0.69	8.00	2.00	33.01	1.60	1.60	0.50	0.0244	0.0074	−51.31	−84.32

We also have a table with expected read range depending on the output power of the reader.

Table 5.4
Read Range for Different UHF Reader Powers and Reflection Coefficients

f [MHz]	λ [m]	*P* Reader [W]	*P* Reader [dBm]	Reader Antenna Gain	Tag Antenna Gain	$\Delta\rho$	Angle [°]	Tag Threshold Power [dBm]	Tag Threshold Power [mW]	Read Range [m]
915.00	0.33	0.50	26.99	1.64	1.64	0.40	0.00	−10.00	0.10	2.7731
915.00	0.33	0.50	26.99	1.64	1.64	0.50	0.00	−10.00	0.10	2.6203
915.00	0.33	0.50	26.99	1.64	1.64	0.60	0.00	−10.00	0.10	2.4205
915.00	0.33	2.44	33.87	1.64	1.64	0.40	0.00	−10.00	0.10	6.1259
915.00	0.33	2.44	33.87	1.64	1.64	0.50	0.00	−10.00	0.10	5.7884
915.00	0.33	2.44	33.87	1.64	1.64	0.60	0.00	−10.00	0.10	5.3471

The output power of the reader is regulated depending on which region you use the RFID RF signal. We already discussed this before but we can have a maximum of 2W ERP in the 868 MHz in Europe but there also is a 'new' band at 915 to 921 MHz which will allow 4W ERP in Europe.[R]

Table 5.3
RFID Power Limitations Based on the Region and Frequency

Frequency Band	Power, Limitations, and Region
125 kHz	Inductively coupled RF tags
1.95, 3.25, and 8.2 MHz	Inductively coupled theft tags, worldwide
13.56 MHz	Inductively coupled RFID tags, worldwide
27 and 40 MHz	0.1W ERP, Europe
138 MHz	0.05W ERP, duty cycle < 1%, Europe
402–405 MHz	Medical implants, 25 μW ERP (–16 dBm)
433.05–434.79 MHz	25 mW ERP, duty cycle < 10%, Europe
468.200 MHz	0.5W ERP, Europe
869.40–869.65 MHz	0.5W ERP, duty cycle < 10%, Europe*
902–928 MHz	4W EIRP, America
2400–2,483.5 MHz	ISM band, 0.5W EIRP Europe; 4W America, Bluetooth
5,725–5,875 MHz	25 mW EIRP

Note: EIRP = equivalent isotropic radiated power; ERP = equivalent radiated power.
*To accommodate concerns over the ability of Gen 2 RFID systems to perform under the European regulations, Europe has already increased its available frequency spectrum from 2 to 8 MHz, allowable power output level from 0.5W to 2W, and replaced its 10% duty-cycle restriction with a listen-before-talk requirement. Even with these improvements, work is still under way to further alleviate European regulatory constraints.

For the calculations we had to make quit a lot of assumptions because there aren't any datasheets available of the tags we have to know the sensitivity and the minimal power needed to activate the tag. Most assumptions we made correspond to the assumptions made in "RFID design principles" [L].

7.1.Read Range in free space with no losses

The minimum power needed to activate a tag Pth is typically between 10 μW (-20 dBm) and 50 μW (-13 dBm).
The gain of a tag is typical 2 dBi.

To calculate the maximum read range r we use the Friis equation for free space:

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

where λ = wavelength [m]

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

$\lambda = \frac{c}{f}$ where c = speed of light = 3.108 [m/s]

f = frequency = 866,6 [MHz]

λ = 0,346 [m]

Gr = 5 dBi = 3,16
Pr = 27 dBm = 500 mW
Gt = 2 dBi = 1,6
Δp < 0,5
10 μW < Pth < 50 μW

We first calculate the maximum read distance with optimal values.

θ = 0
Δp = 0
Pth = 0,01 mW

Filling in the Friis equation gives us r = **13,8 m**

When we don't use optimale values we will get a more realistic read range.
We still assume optimale angle between tag and reader since this is the case in our project.

θ = 0
Δp = 0,5
Pth = 0,05 mW

We then get a maximum read range r = **5,36 m**

7.2. Read Range in free space with losses

To get a more realistic reading range we have to take into account losses. We do this by calculating the link budget.

We have several kinds of losses we take into account in our link budget.
The polarization mismatch is typical -3dB
We also have to take into account noise.
There are two kinds of noises, thermal noise and a noise figure.
Noise figure is also called receiver noise and has a typical value of -3 dB
For thermal noise N we use the formula:

$N = kTB$ where B is the bandwidth
T is the temperature
k is the Boltzmann constant = 1,38*10-23

We assume a room temperature of 20 degrees, giving T = 293,15.
The bandwidth in Europe for UHF RFID is 200 kHz.

$N = 1{,}38.10^{-23} * 290{,}15 * 200.10^{3} = -150{,}9dBm$ = 8,13.10-23 W

Then the link budget looks as follows

Transmitter power

27 dBm

Cable and connector losses

-3 dBm
=> 30 dBm

Reader antenna

+5 dBi
-3 polarization mismatch
=> 32 dBm

Free space path loss

?

Tag antenna

+2 dBi

Tag sensitivity treshold

-13 dBm

We now have a link budget with free space path loss as a variable, by using the Friis equation we can get the maximum read range based on the maximum free space path loss to still have a valid link budget.

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

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

$$FSL = 40{,}85$$

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

Inserting our found FSL value from our link budget and transforming the equation to d gives:

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

This is the distance for the forward link budget.

There is no need to calculate the backscatter link budget because well-designed passive systems are always limited by the tag sensitivity (-13 dBm) and not by the readers sensitivity (-90 dBm)

The calculated range can be less than the measured range due to the fact of constructive interferences!

7.3.Tag read speed

In multiple sources is stated that UHF RFID reaches 200 tags per second in Europe.
An overall formula for the amount of tags that can be scanned in a certain amount om time is as follows:

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

If we want to take into consideration multiple tags with collision avoidance (ALOHA algorithm for example) the formula becomes:

$Tr > (Tc + Td) * N$ where N is the amount of tags

Tc can also be written as $Tc = Acn * (\frac{Dv}{Dr})$ where Acn = average read/write operations
Dv = data volume
Dr = data transfer rate

Our frequency divided by the amound of clocks per bit (RF/32 or RF/16, meaning 32 or 16 clock signals per bit) gives us the amount of kbps.
This typically is 40 kbps.

Our tags have 800 bit memory meaning that operation time Tc = Acn * (800 / 40).
Typical detection time is 0,055s.
There is no know value for the average read write operations but "RFID design principles" sais that for a tag of 100 bytes (800 bit) the time for each tag is 0,7 seconds.

To know how fast the tags may pass the reader we can assume that
$Tr = \frac{L}{v}$ with L the distance of the operational area and v the speed of the tag

For N amount of tags we get the following equation for the amount of tags that may pass our reader in a certain time period.

$$\frac{L}{v} > 0{,}7N$$

For a concrete example of a 4x4x4 array of tags the time needed to scan al 64 tags is 44,8s

The maximum speed must be $v < \frac{L}{44{,}8}$

If we assume that the operational area is 2 meters in front of the truck we load into:

$$v < 0{,}045[m/s]$$

Or Tc is typically 0,7s (Lehpamer, 2012).
So we become:

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

In case we take as example a pallet op 4x4x4 boxes of wine with 6 bottles each with tag:

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

The pallet needs to stay 268,8s or 4 minutes and 29 seconds in the detection area of the antenna.
This is quit long so a tag per box would give is a more practical solution.

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

7.4.Read Range with wine as medium [L]

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

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 $A = \dfrac{\lambda}{4pi}$

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

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

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.

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

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

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

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).

There are different possible causes for the result to be unrealistic.
One can be that I made wrong assumptions for the variables in the formula.
It is also possible that I used a formula that is only ment to be used in free space and that it is not mentioned in my sources.
Another possible cause is that in reality there are much more factors to be taken into account like Brewster angle and the fact that the curved bottle refracts a lot of the RF signal since the angel of incidence is not constant.

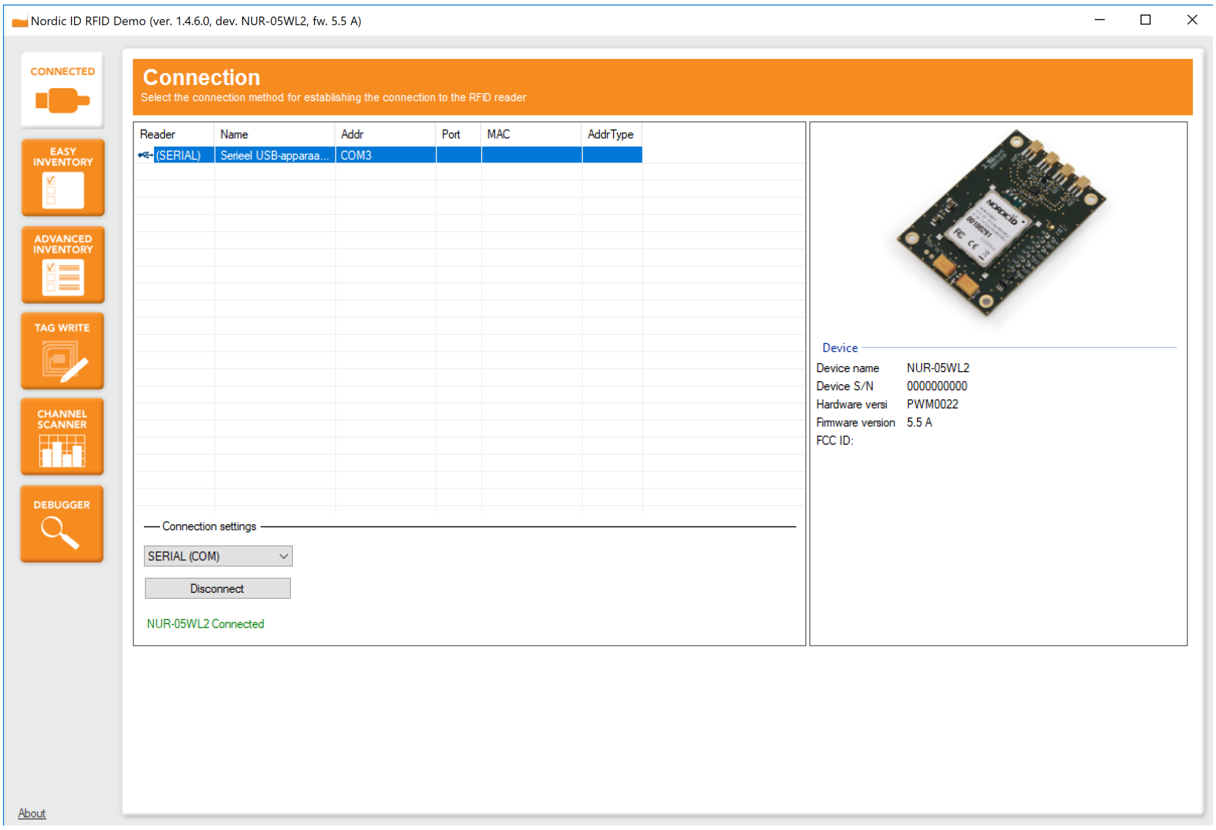
8. Hardware Implementation

8.1. Windows OS

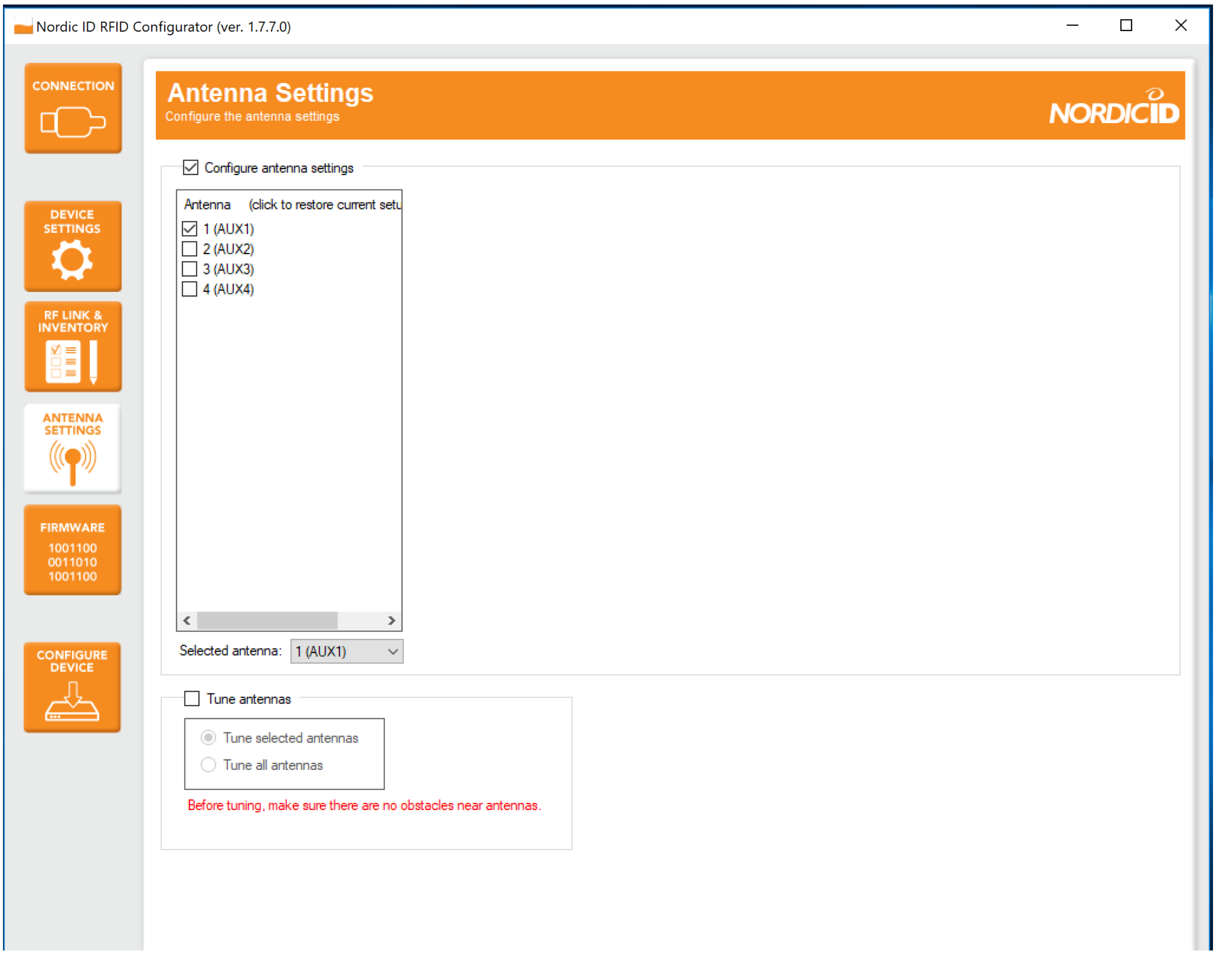
Nordic ID has developed some applications for Windows OS that can be found in the support section of their website [23]

The applications gives a very easy interface to configure your reader and visualise the read data of the tags.

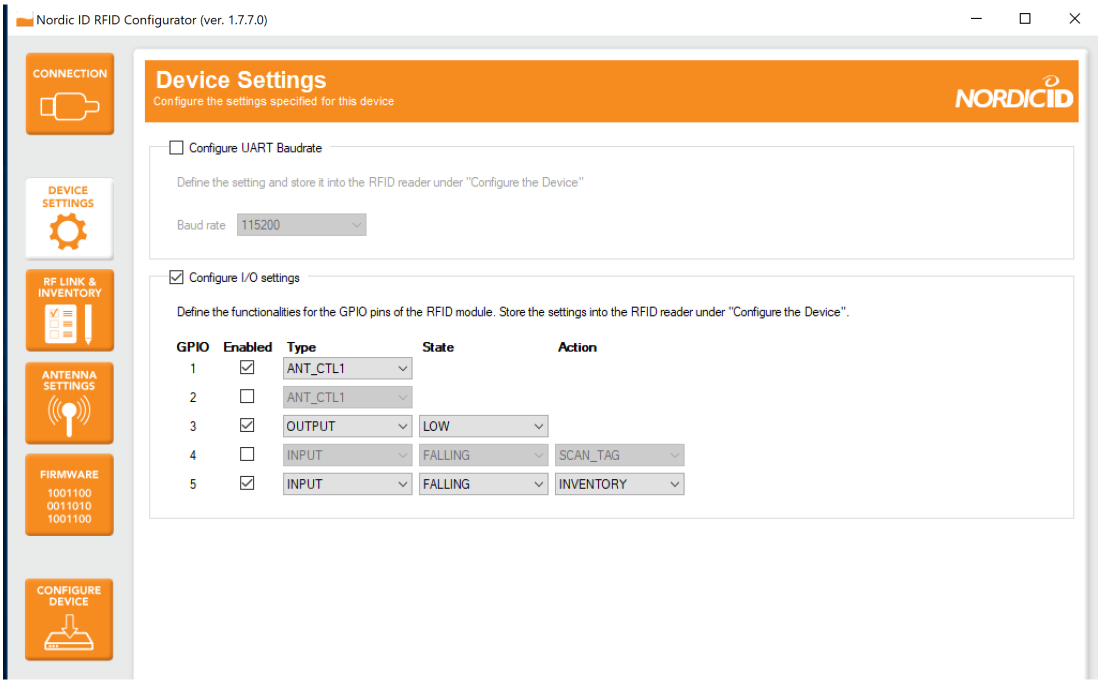
Firstly you must connect your reader.



After that we adjust our antenna settings. Since we only use one antenna in this setup we disable the other 3 antennas.

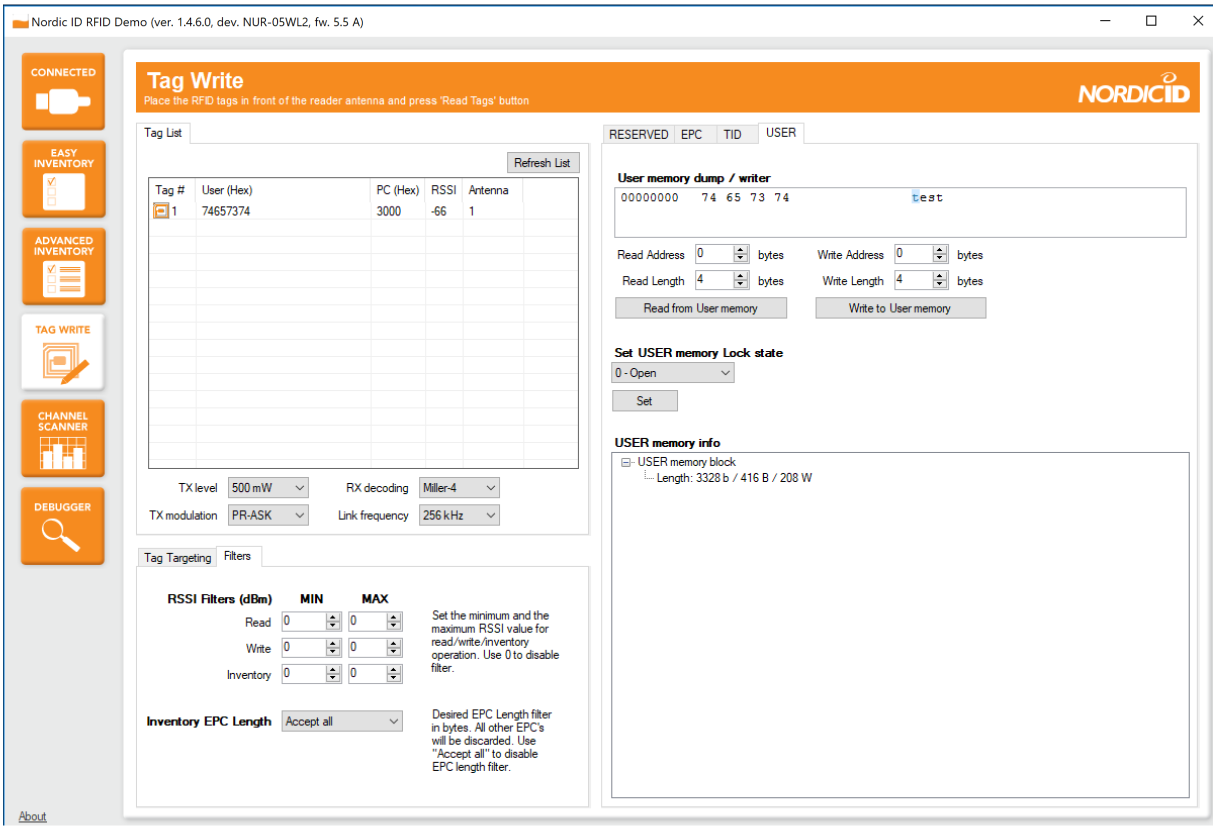


We can also change the device settings as shown in the screenshot below.



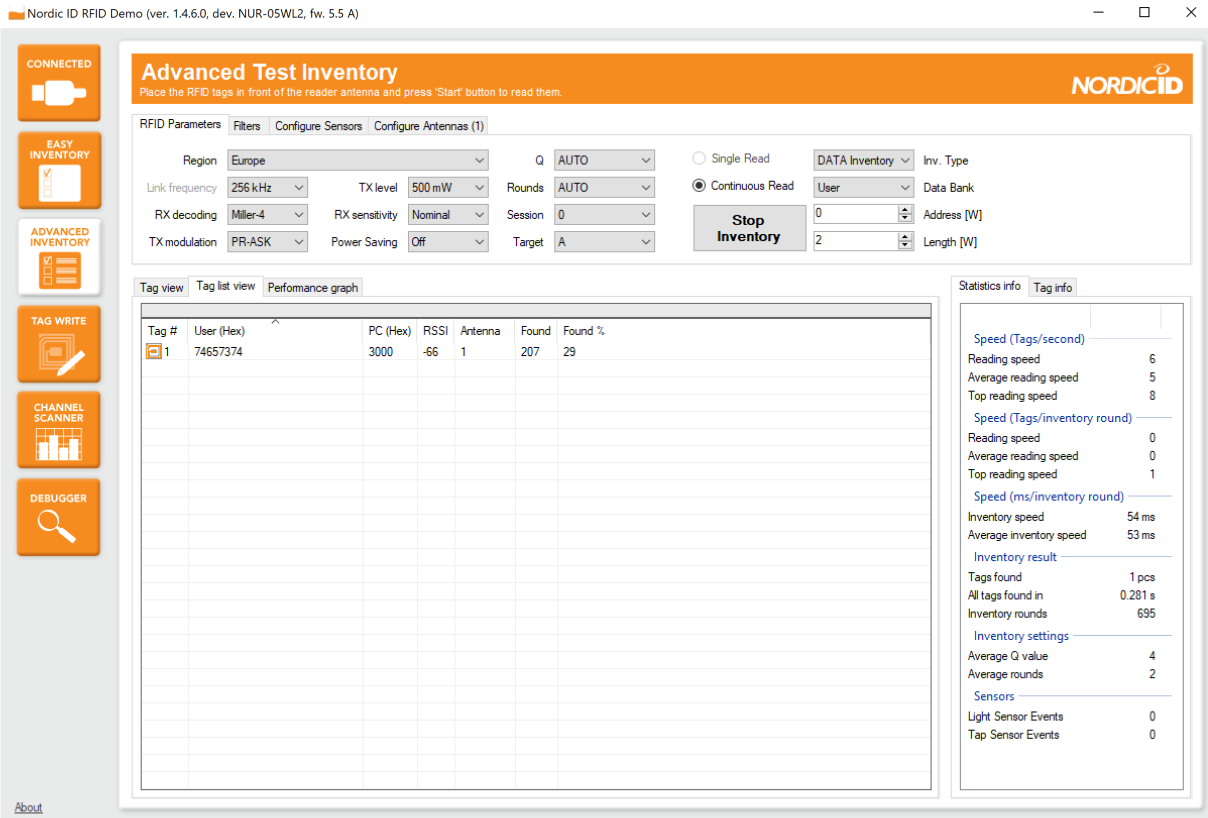
Now let’s try to write some data into our tag and visualise it when reading.

As mentioned before in our UHF RFID reasearch the tag has 4 memory banks. For example we want to write the string “test” (hex: 74 65 73 74) into our user memory starting at the first byte of the user memory.



We must first select the tag, if not present you should refresh the list until the reader picks up the presence of the tag.
Then select the tag, the content of the 4 memory banks will be shown on the right.
The reason why the data is represented in pairs of 2 hexadecimal numbers is that 1 hexadecimal number is 4 bit, so the representation is per byte.
It is also important to mention that you can only write or read in multiples of 2 bytes, or 4 hexadecimal number or 2 ASCII character (each ASCII character is 1 byte), the reason for this is that the memory space is divided into ‘slots’ or also called words. Each word is 2 byte and it is not possible to write halve a word into memory.

When we read the tag using an inventory command from the reader we indeed get our hexidecimal form of our “test string”.
It is also in this advanced inventory round where we can select how the data is encoded and decoded for the inventory round as well as the power output from the reader, named TxLevel. The TxLevel has the biggest impact on the detection of the tag, with 500 mW (or 27 dB) being the maximum. We can also select which tag have to be listed based on the inventory type. If for example you have a new tag with just an EPC (Electronic Product Code), which is an identifier, the tag will not be listed If we scan for data since no data has be written to it.
The user must also select which data bank has to be read (displayed), as also the first word and the length or amount of words to be read (2 byte for each word as mentioned above).



For our project we won’t use a windows OS to run these applications on but it is much easier gaining insights by using these applications.
It is also easy to adjust the configuration or write data at a specific place, therefor we will often still use the applications for quick configuration or writing data during the reasearch to gain time since it is all more complicated to figure out how we implement the hardware on a linux OS, as we will see in the next section.

8.2.Raspbian (Raspberry pi)

Norid ID has a SDK for the raspberry pi which can be found on their github. [24]

First we clone the nur_sdk repository.
It is noted in a README that we shoud create a “NurApiDotNet.dll.config” in the running directory to find the correct library, which contains the following:

```
<configuration>
        <dllmap dll="NurApi.dll" target="libNurApiRaspi.so"/>
</configuration>
```

The only thing we need to adjust to the makefile is the LIBDEF, which first is defined as -lNurApix64 but needs to change to -lNurApiRaspi since this is the correct library for our raspberry pi.

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
```

We then make the file with make -f Makefile command.

Then we execute the make command which runs the Makefile included in the NurApiExample folder. At first this gives some errors with the basic stl library.

The reason given is that input of min and max functions do not match, in other words, the SDK defines a min and max functions but this gives problems with the standard library. To resolve this we #undef min and #undef max in the header files.

Executing make run starts the example, in which we can do multiple things la a scan_tag or inventory round but also change the TxLevel. The output of these functions is shown below.

```
Fetch tags from module...
Fetch tags from module...
2 unique tags found
Tag info:
  EPC: [da1200014816940001000003]
  EPC length: 12
  RSSI: -71
  Timestamp: 5
  Frequency: 867500
  PC bytes: 3000
Tag info:
  EPC: [e200688d0405060708090a0a]
  EPC length: 12
  RSSI: -69
  Timestamp: 13
  Frequency: 867500
  PC bytes: 3000

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 notification (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
```

We first see 2 EPC's appearing, while onlu e20068.. is our tag, meaning da12000.. is from another source. To prevent this source to be reached we set the TxLevel high(low power output) and see that the object doesn't show up anymore after another inventory scan.

The next step for is to also show the user memory data bank in which we wrote "test" with the windows application.

```
// 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
    }
```

There are 2 functions defined in ReadWriteExample.cpp to do this named 'ReadTagUserMemory and ReadTagUserMemoryByEPC'.
Before we can use these functions we still need to make a header file for this cpp file so that we can include it into our main example.

readData is a struct which is more extended than tagData which does not containt user memory fields.

This code gives us the following output after a new inventory round.
Where we can see our "test" string at the bottom.

```
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 unigue 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(]
```

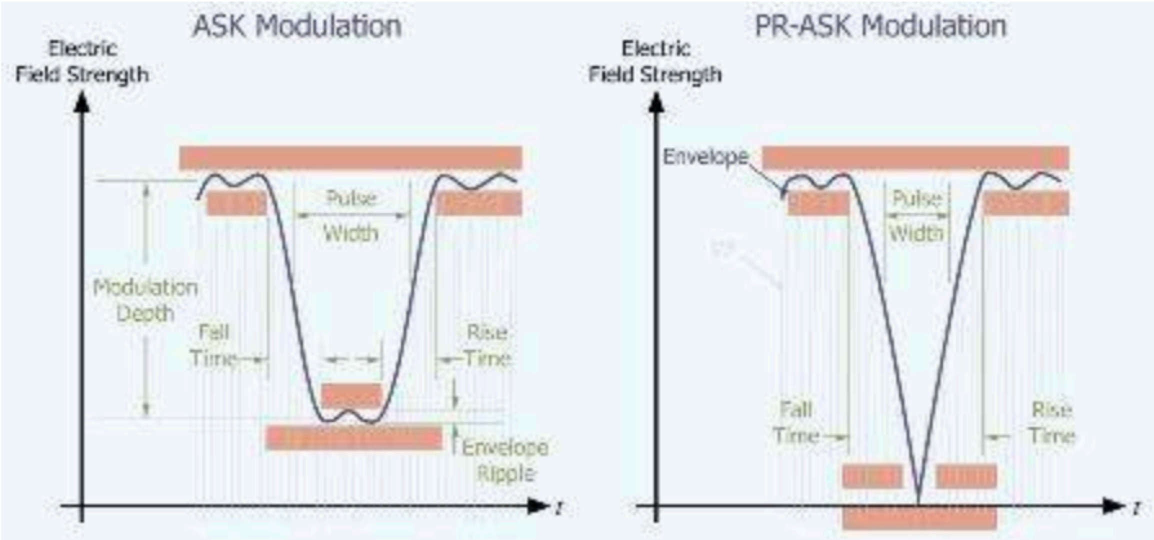
9. Measure maximal range

Important note [25] [26]:

All tests have been done with the available hardware.
Certainly the RF power of the reader could be a lot better under new regulations.
The NUR-05WL2 has a RF power of 27 dBm (500 mW) but the new regulations permit RF power up till 33 dBm or 2W which is fourfold the transmirtted signal strength and thus the read range and RSSI. It's even possible to use a 4W reader when using the 915 to 921 MHz band.

All tags used start with E20000, tags starting with other EPC fields are from unknows devices (DA…).

PR-ASK has 'deeper' modulation, with the consequance that the electric field strength has a lower top (surface under both graphs are still the same). Because of this the range increases.



The RSSI that is shown is a measure for the received signal strength. It is a value between 0 and 255 and is not in dBm.
Some relation between dB and RSSI are:

high quality: 90% = -55dB
medium quality: 50% = -75 dB
low quality: 30% = -85 dB
no usable signal: 8% = -96 dB

The RSSI is $(\frac{percentage}{2}) - 100$

Lower quality ofcourse results in less probability for the tag to be read.

9.1.Tag only

We make sure that the antenne is lifted of the ground to minimize the effect of multipath and interferences.

All reading are done with the following settings:

256kHz link frequency
miller-4 encoding
PR-ASK modulation
TX level of 500 mW

Also set the RSSI filter to the minimum, which is -90 RSSI to receive weak signals from the tag. Doing this also has the consequence of reading devices which weren't intended to be read.

At a distance of 5.507m we still get a decent signal to say that the tag is detected. As you can see above we then get a relative signal strength of -71 RSSI with the tag being found 14% of the time.

It is important to say that the directivity of the antenna to the tag was optimal, which we tested with a laser. When the tag was moved left or right there was almost never detection of the tag at 5,5m. The tag was also in the optimal direction with the antenna.

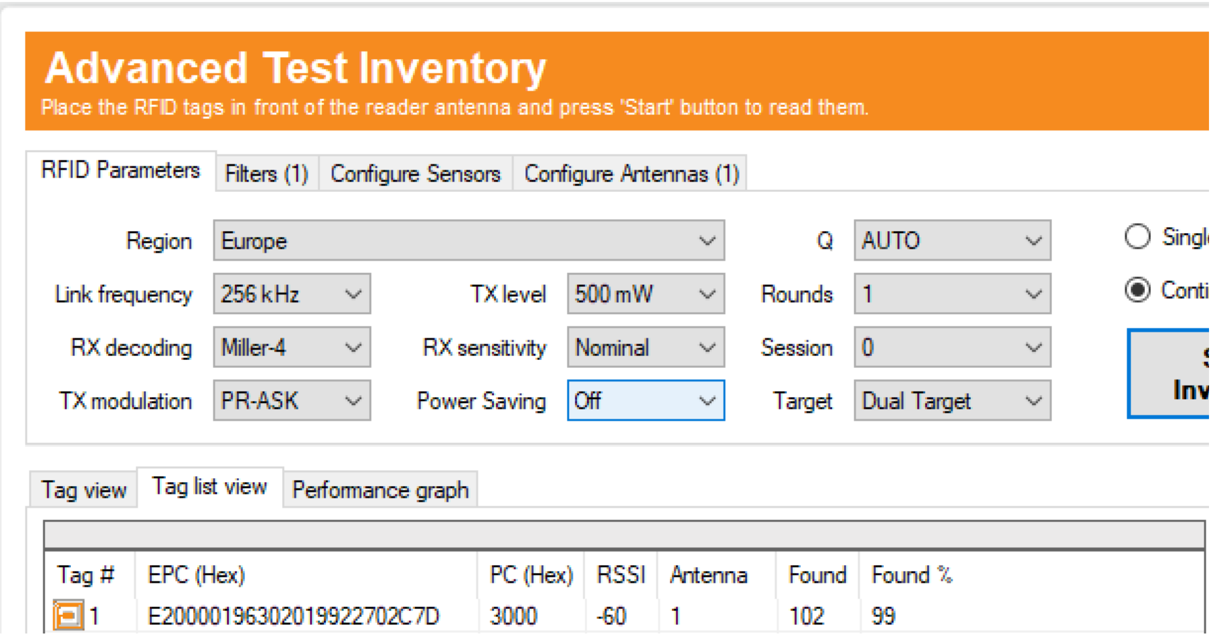
When we compare these results whit the read range we calculated (3,03m) we see that this is more. A cause for this can be constructive interferences. Also since the directivity was so precise it is possible that we come at 5,5m, if we change the position of the tag slightly is isn't detected anymore.

9.2.Influence of wine on measurements

Antenna in front of boxes

To test the influence of wine on the detection of the tags we wanted a good received signal strength without any wine in front of the tag.

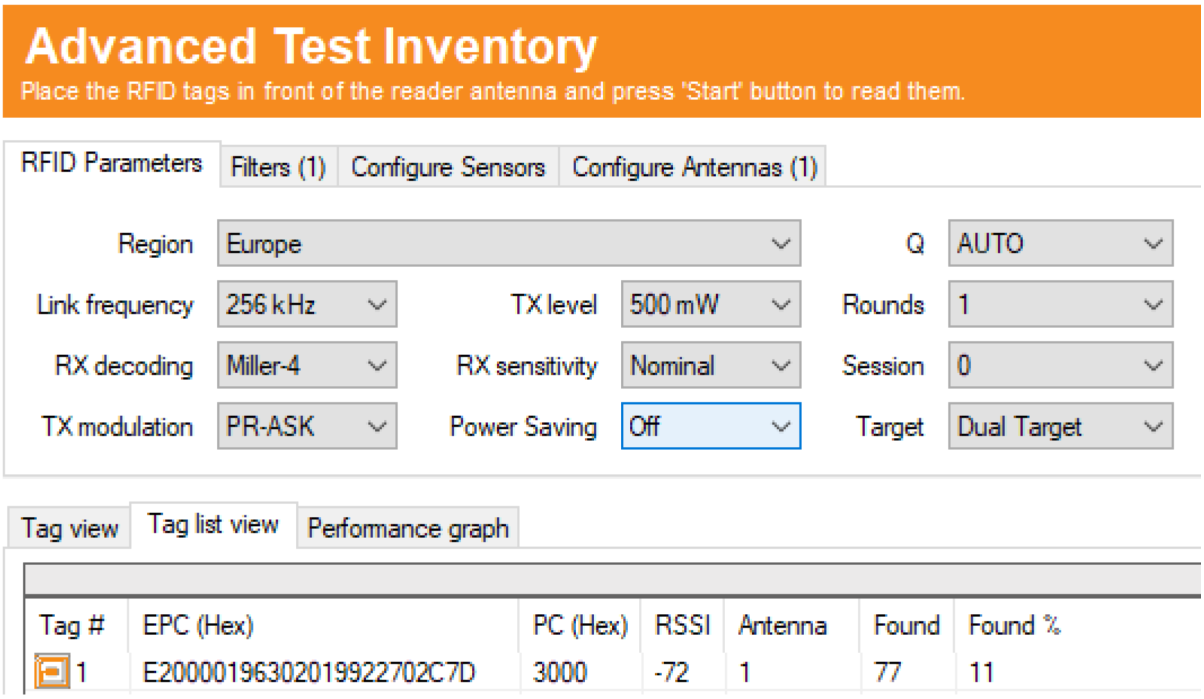
At a distance of 2 meters we had a signal of -60 RSSI with a 99% find accuracy.



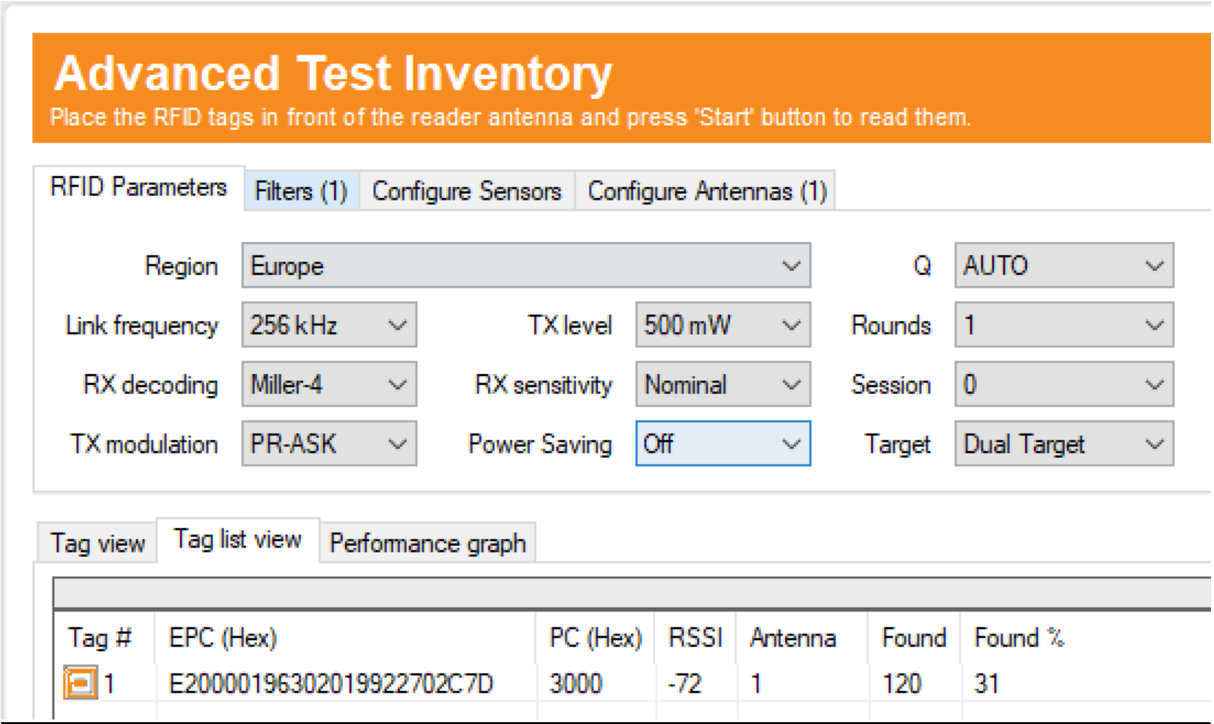
We start placing wine boxes in front of the tagged box on wine in different formations.

We start with the setup as above, increasing the amount of wine boxes in front of the tag.

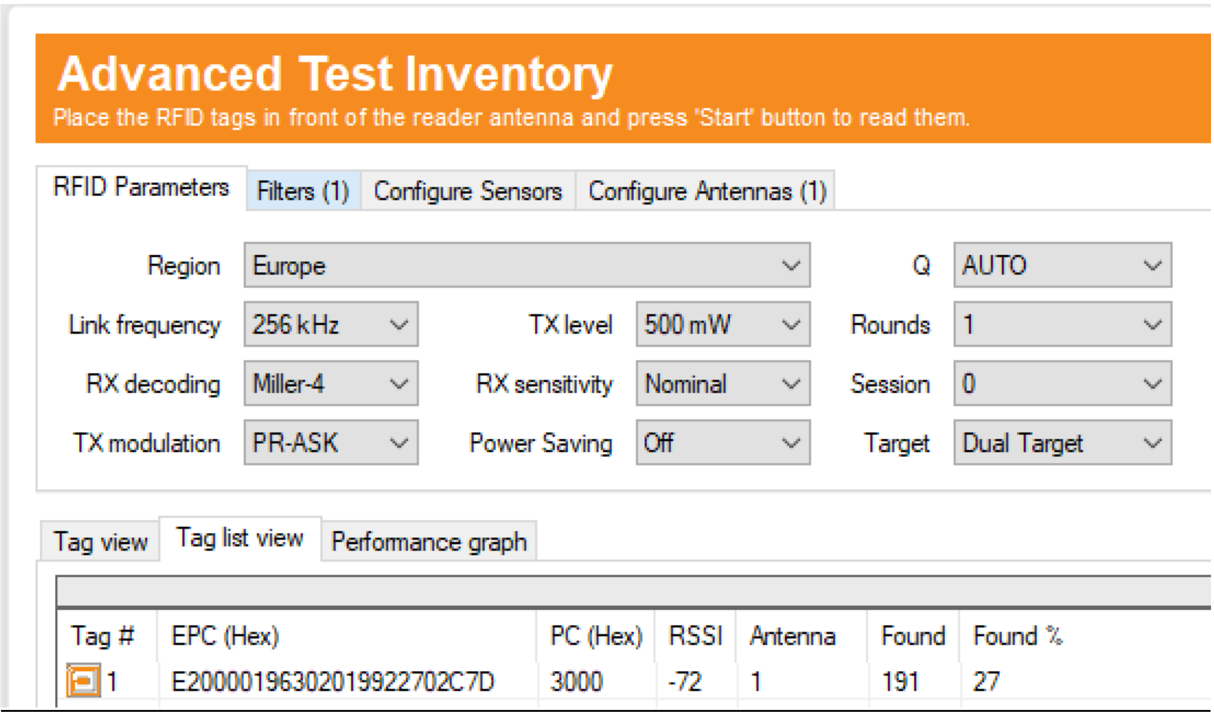
One box



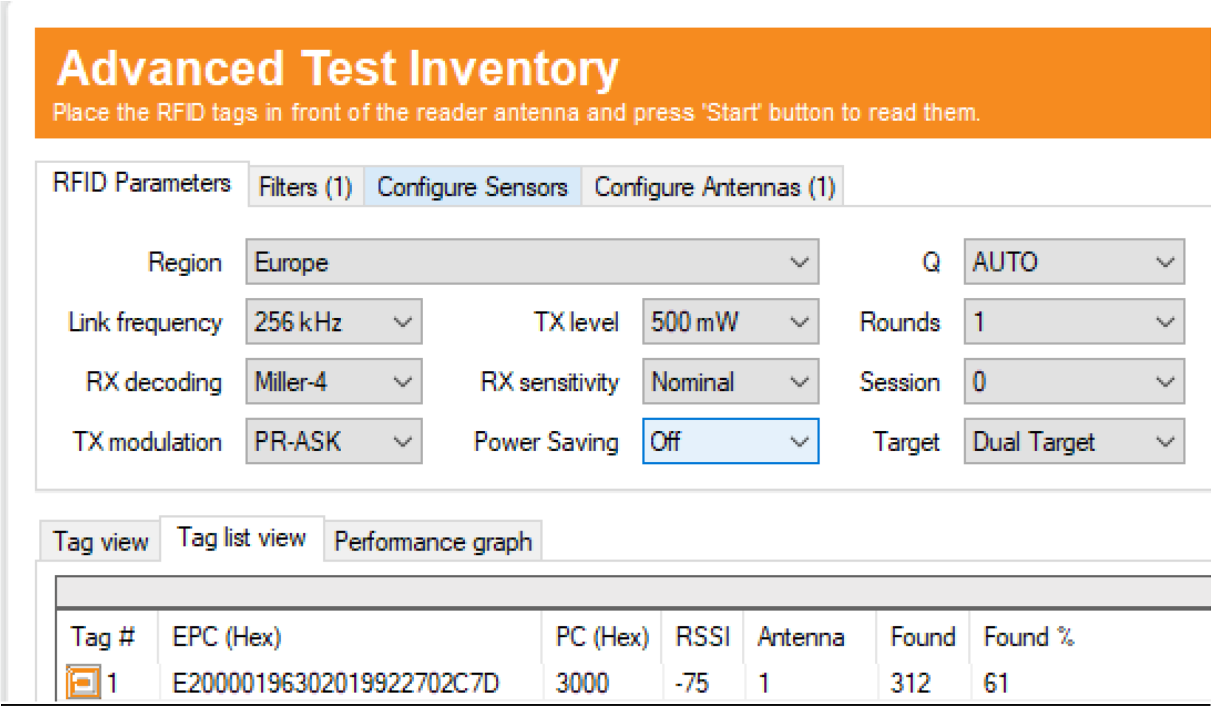
Two boxes



Three boxes



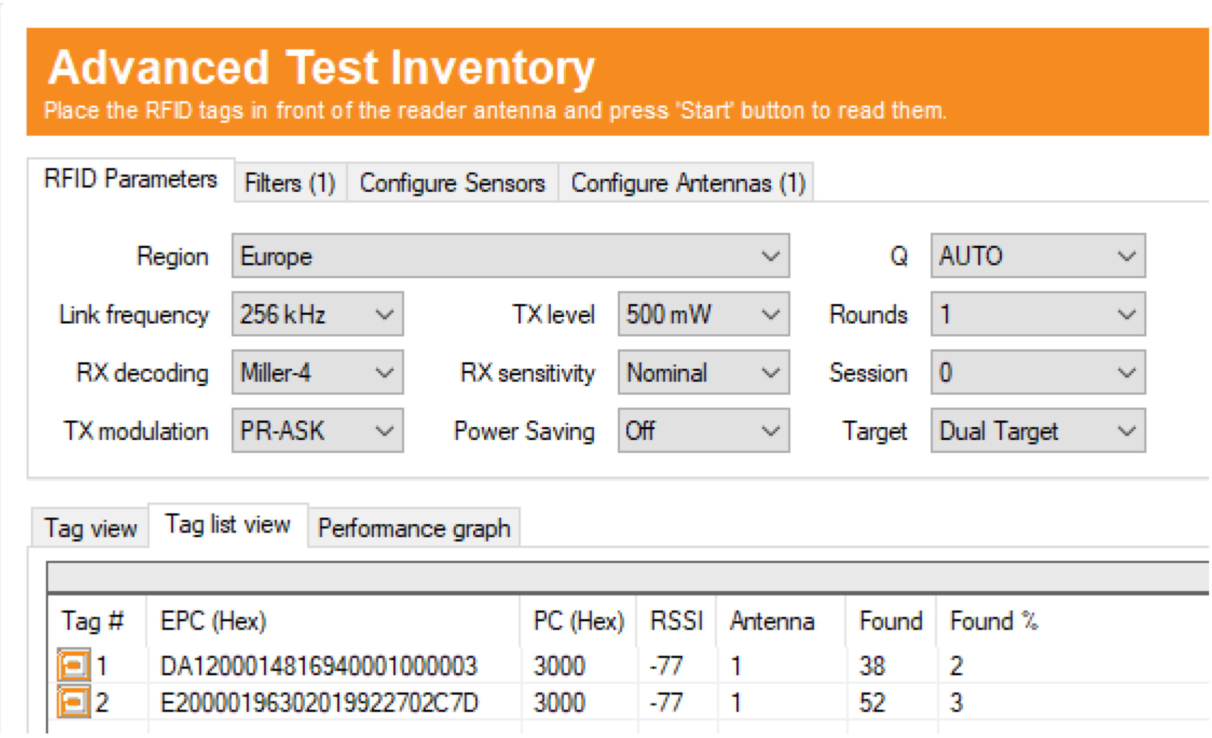
Four boxes



As you can see in the above pictures, there isn’t much difference RSSI, this is probably because of directivity of the antenna (which is slightly above the boxes most in front).

Next we want to investigate the received signal when we put an array of boxes in front. We will always show the picture of the setup first with the screenshot of the result underneath.

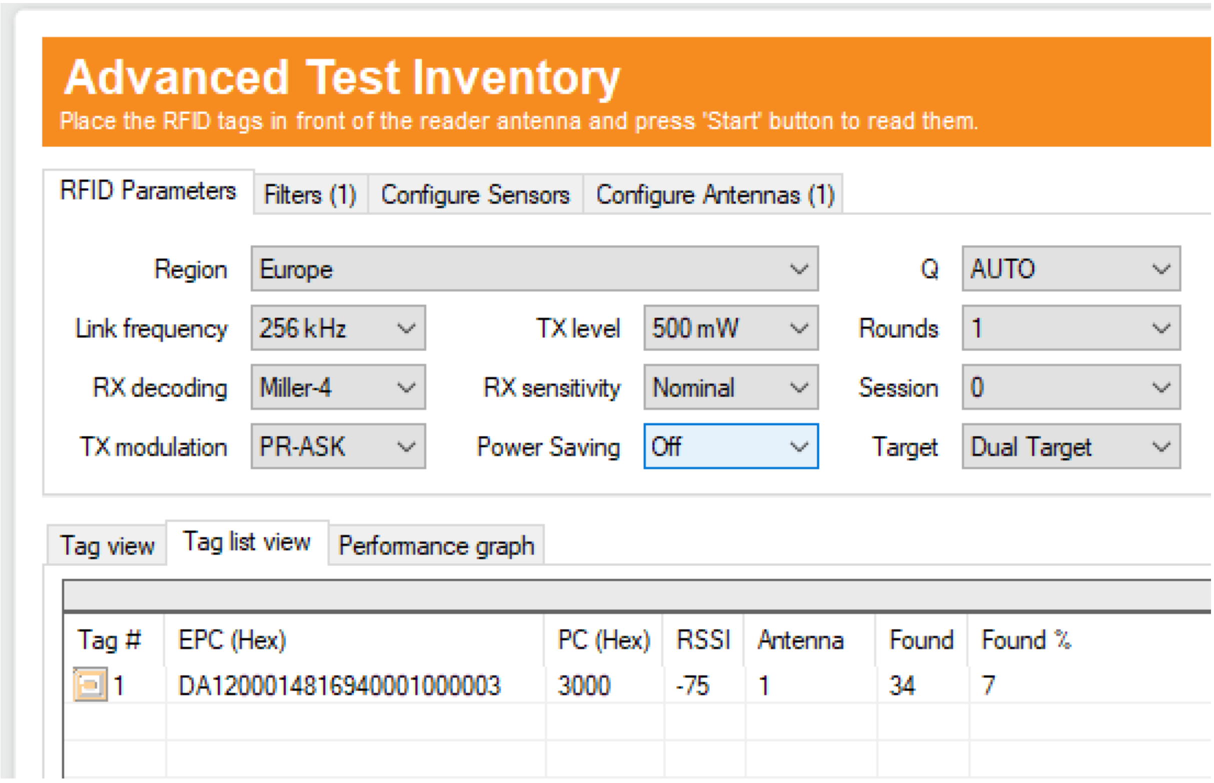
1 wide 2 high 1 deep



Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	DA1200014816940001000003	3000	-77	1	38	2
2	E2000019630201992270 2C7D	3000	-77	1	52	3

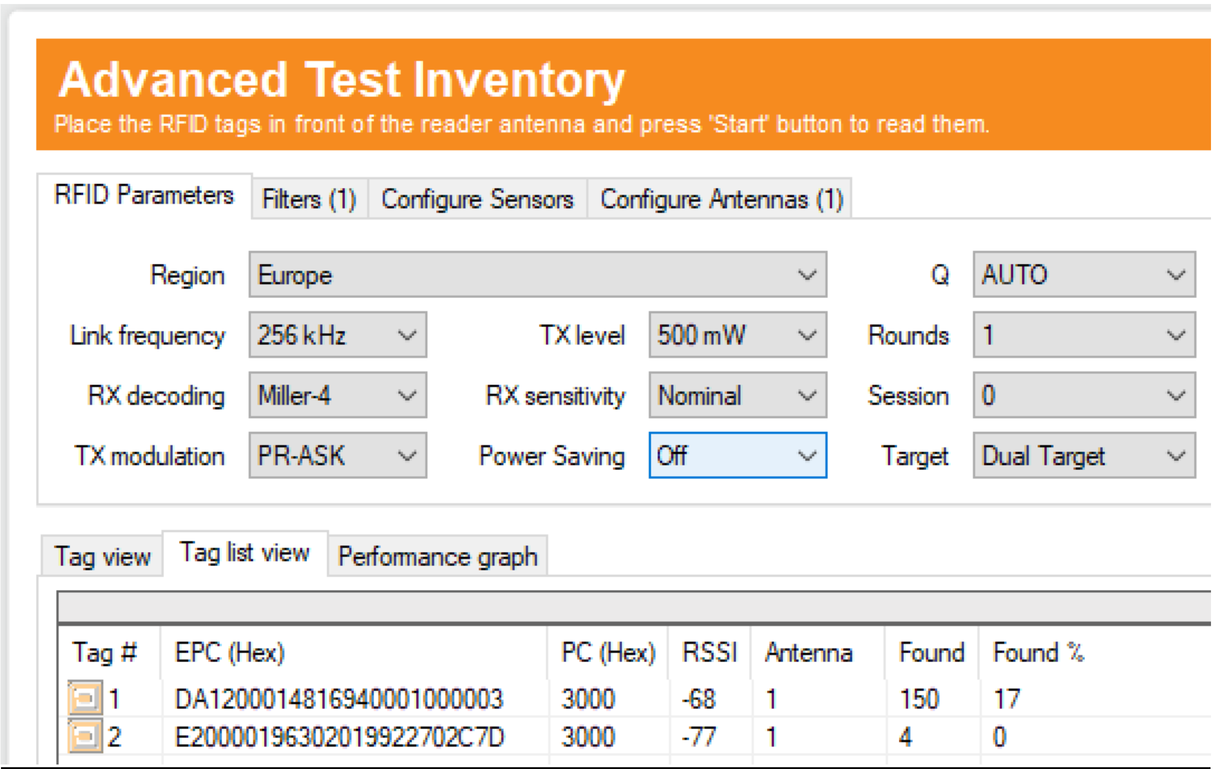
=> detected

1 wide 2 high 2 deep



=> not detected

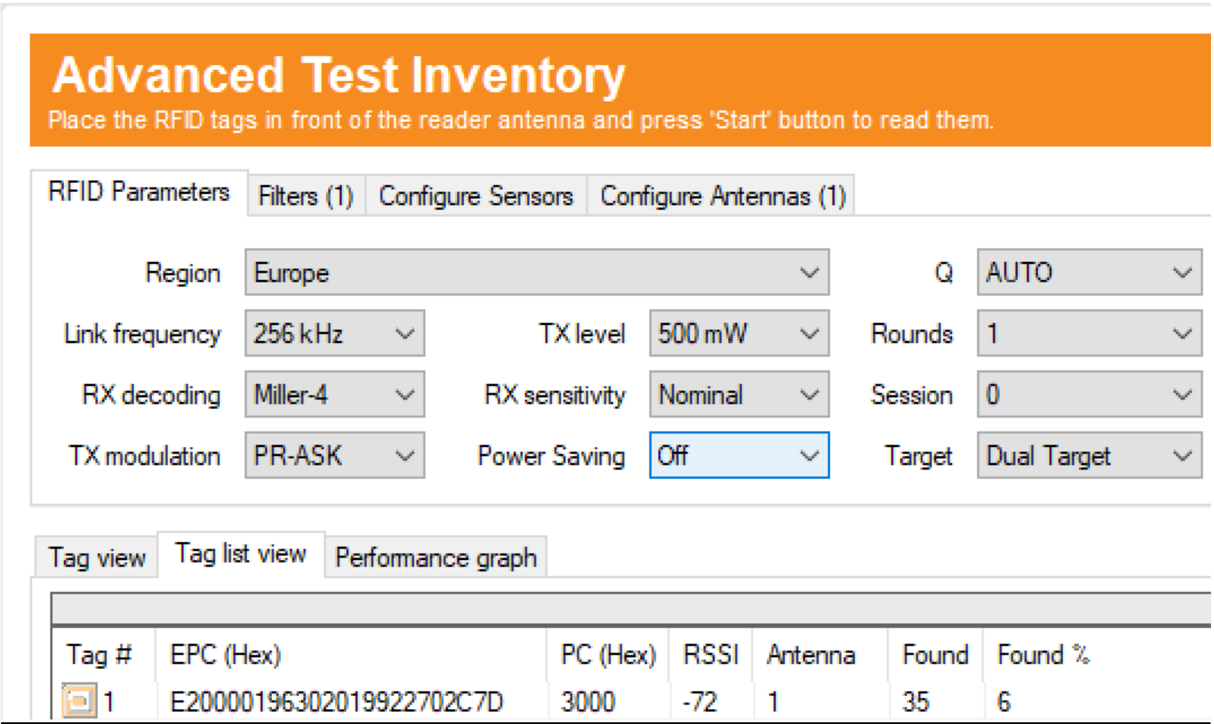
2 wide 2 high 1 deep



Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	DA1200014816940001000003	3000	-68	1	150	17
2	E2000019630201992270 2C7D	3000	-77	1	4	0

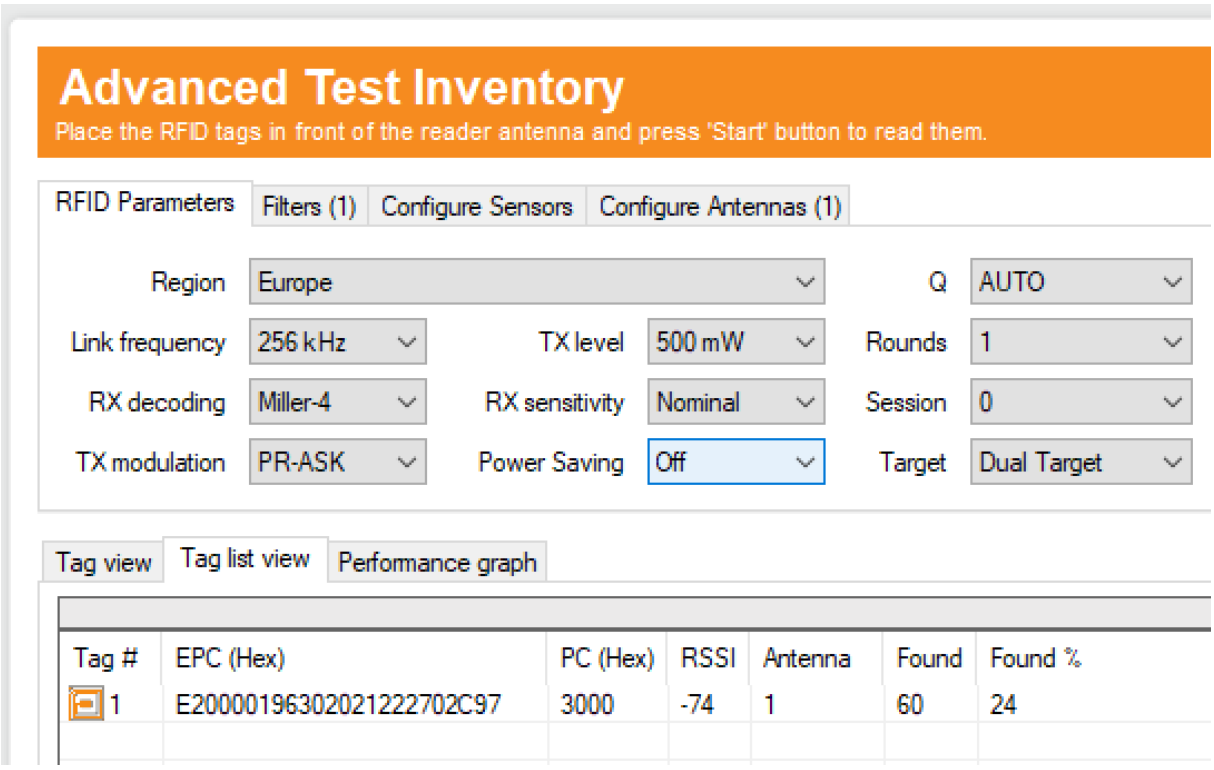
=> weak, uncertain detection

2 wide 1 high 1 deep



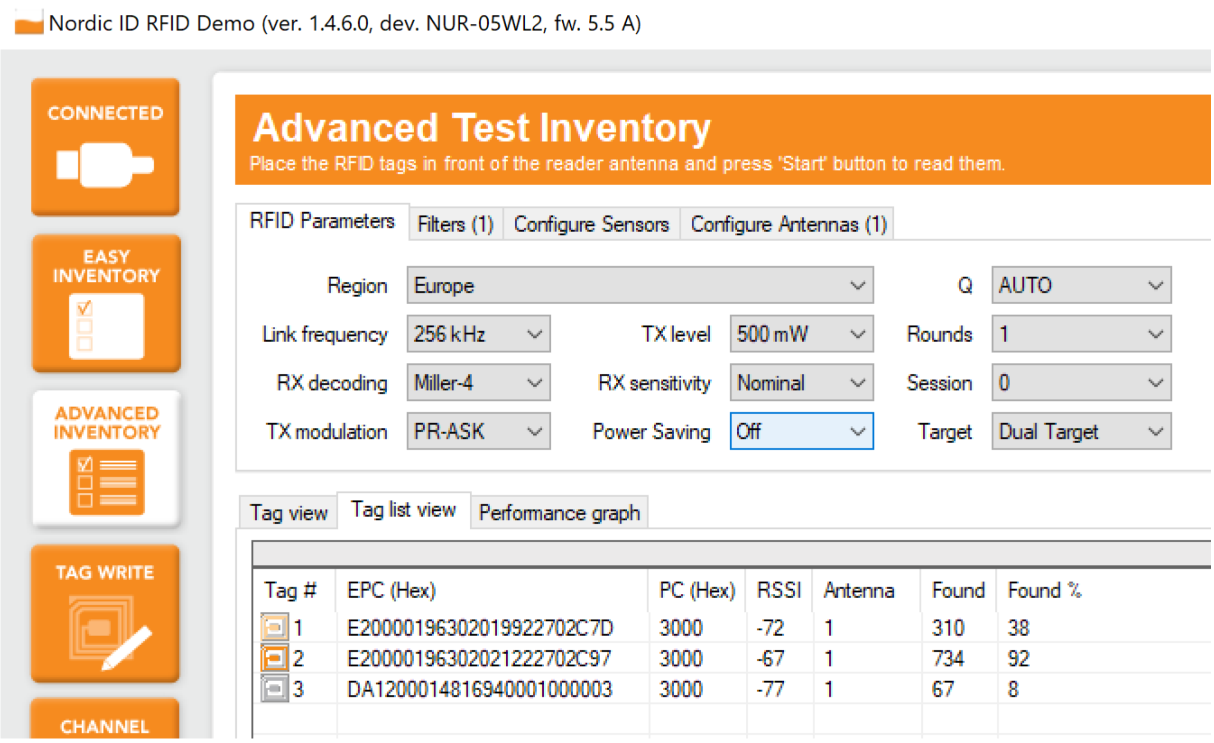
=> detection

1 wide 2 high 2 deep two tags



=> tag on top box detected, tag on box below not. Probably because of directivity.

1 wide 3 high 2 deep with empty space two tags



=> detection of both, top one much stronger.

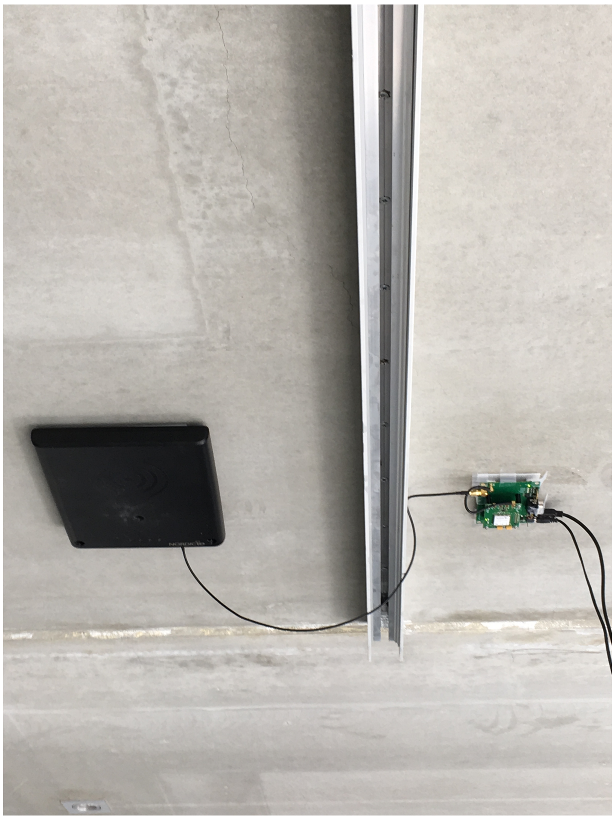
Antenna on ceiling

We do the same tests but now with the antenna put on the ceiling.

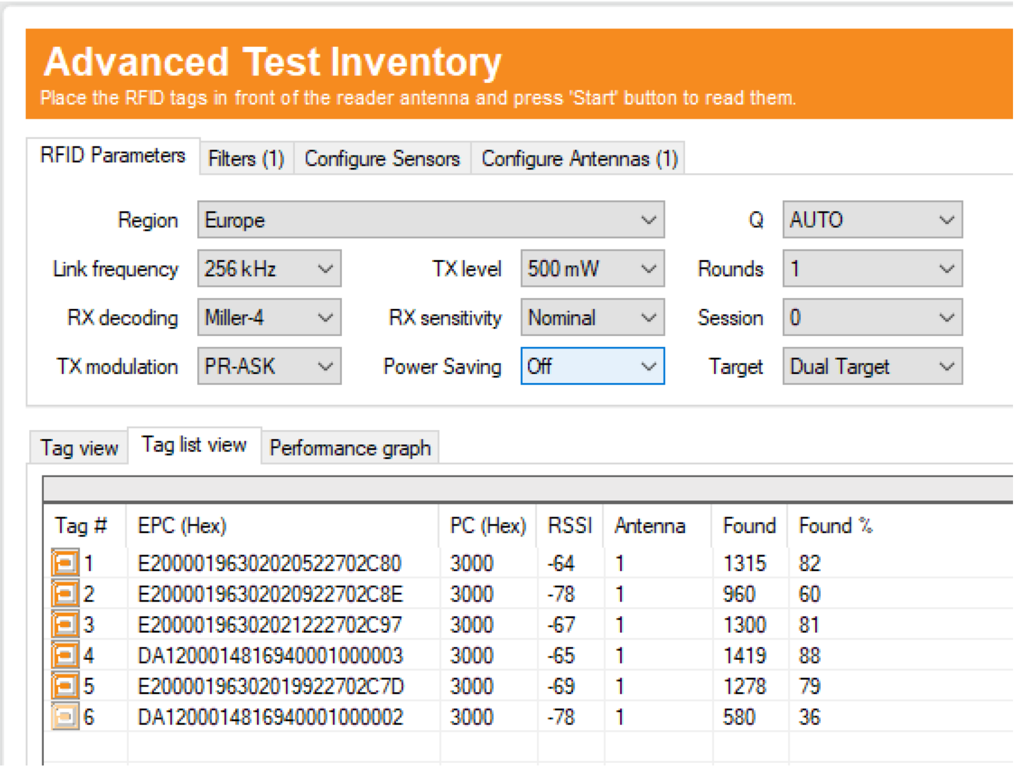
the distance from antenna to floor is: 2m70
from antenna to top of box is 2m30.

We put 2 tags on the top of a box in different orientations. (2m30)

tag ending 86: bottom of box
tag ending 7D and 96 top of box
tag ending 80: short side of box
tag ending BE: long side of box



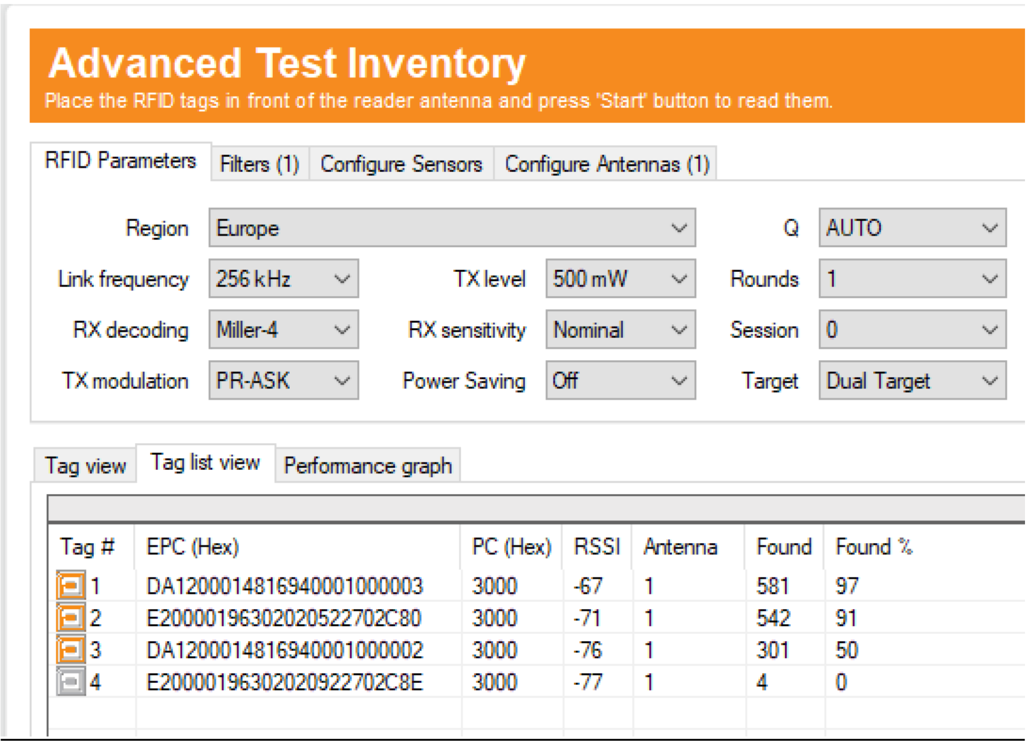

97
7D
BE
80



Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	E20000196302020522702C80	3000	-64	1	1315	82
2	E20000196302020922702C8E	3000	-78	1	960	60
3	E20000196302021222702C97	3000	-67	1	1300	81
4	DA1200014816940001000003	3000	-65	1	1419	88
5	E20000196302019922702C7D	3000	-69	1	1278	79
6	DA1200014816940001000002	3000	-78	1	580	36

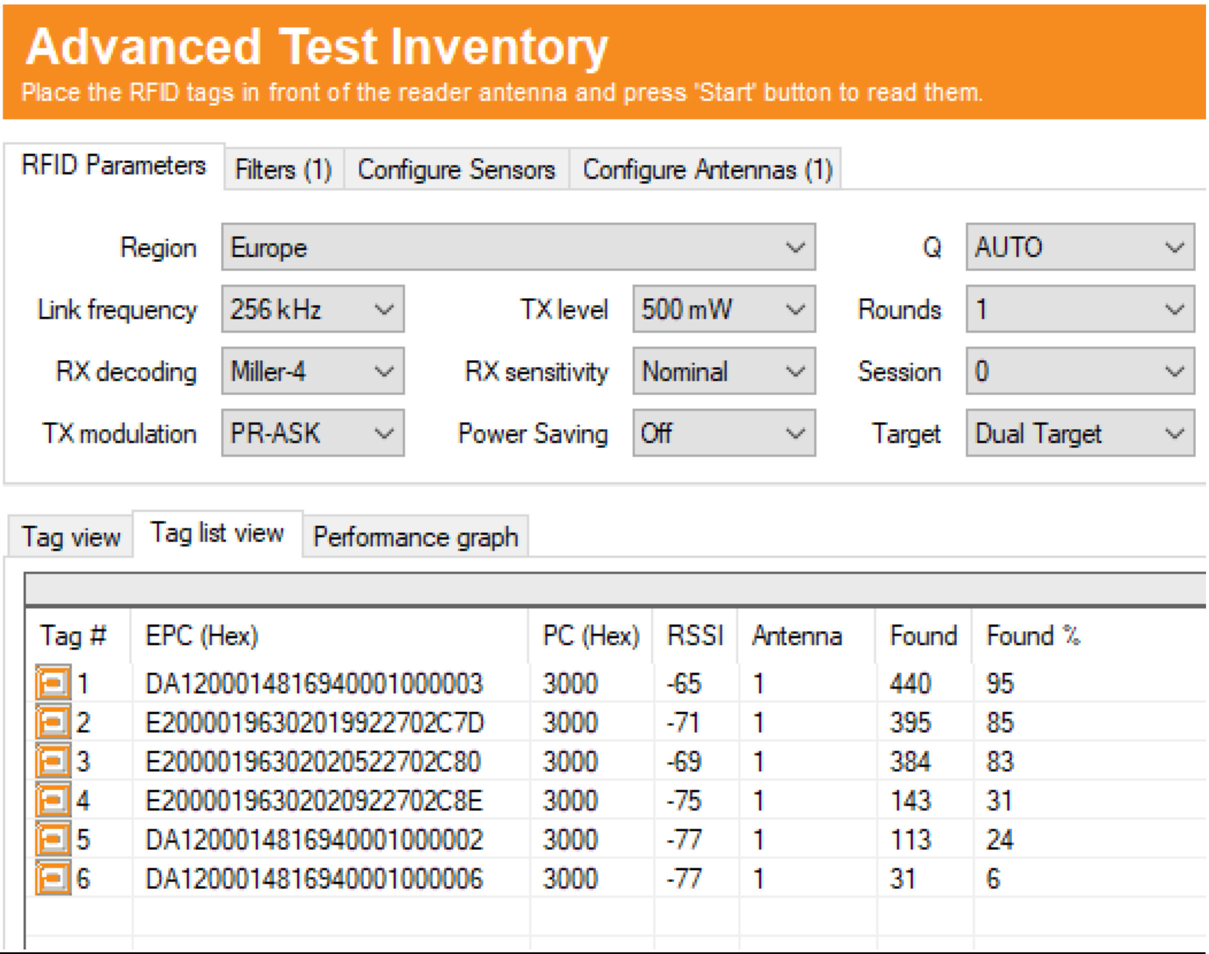
=> all tags detected except bottom one.

1 box in top (only 2 top tags)



=> only tags on side detected, mostly tag on short side

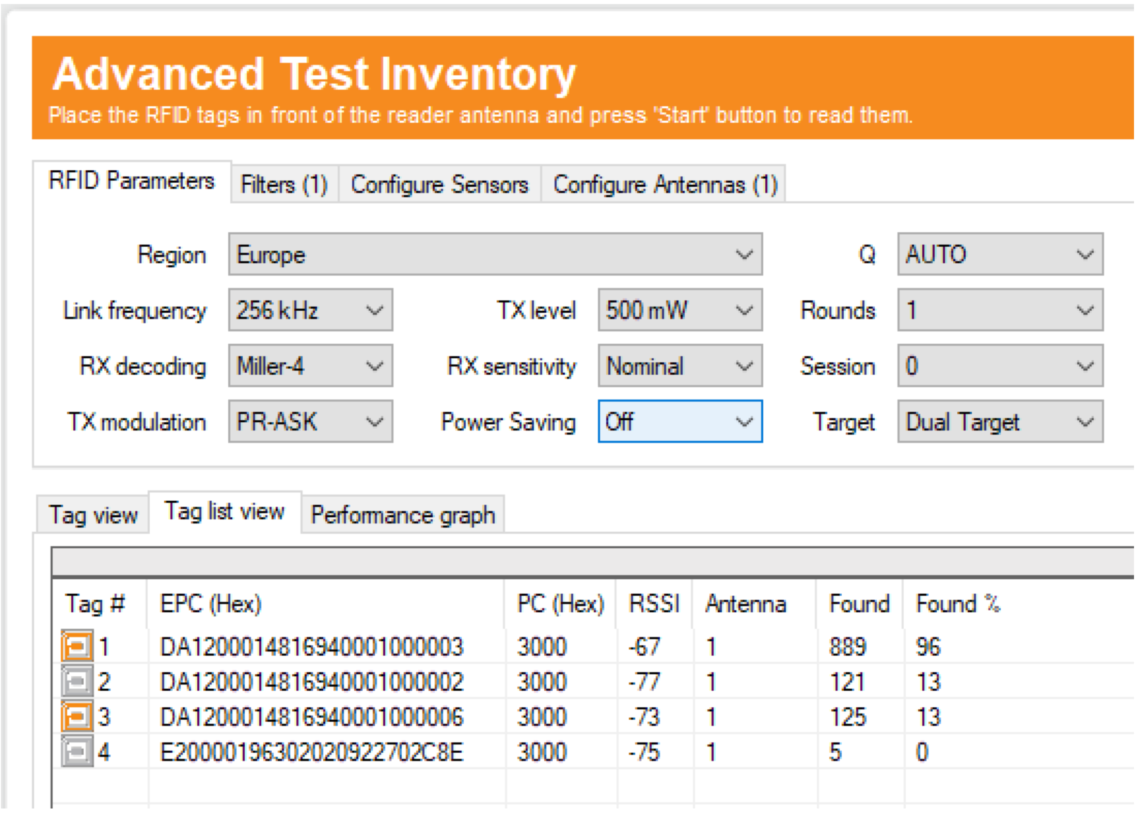
2 box 1 bottle removed above a tag



Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	DA1200014816940001000003	3000	-65	1	440	95
2	E20000196302019922702C7D	3000	-71	1	395	85
3	E20000196302020522702C80	3000	-69	1	384	83
4	E20000196302020922702C8E	3000	-75	1	143	31
5	DA1200014816940001000002	3000	-77	1	113	24
6	DA1200014816940001000006	3000	-77	1	31	6

=> 2 sidetags detected and tag just underneath the removed bottle.

Extra boxes on short side



Advanced Test Inventory

Place the RFID tags in front of the reader antenna and press 'Start' button to read them.

RFID Parameters | Filters (1) | Configure Sensors | Configure Antennas (1)

Region	Europe			Q	AUTO
Link frequency	256 kHz	TX level	500 mW	Rounds	1
RX decoding	Miller-4	RX sensitivity	Nominal	Session	0
TX modulation	PR-ASK	Power Saving	Off	Target	Dual Target

Tag view | Tag list view | Performance graph

Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	DA1200014816940001000003	3000	-67	1	889	96
2	DA1200014816940001000002	3000	-77	1	121	13
3	DA1200014816940001000006	3000	-73	1	125	13
4	E20000196302020922702C8E	3000	-75	1	5	0

=> tag on the short side is not detected anymore.

Replace box on top with t-shirts

Advanced Test Inventory

Place the RFID tags in front of the reader antenna and press 'Start' button to read them.

RFID Parameters | Filters (1) | Configure Sensors | Configure Antennas (1)

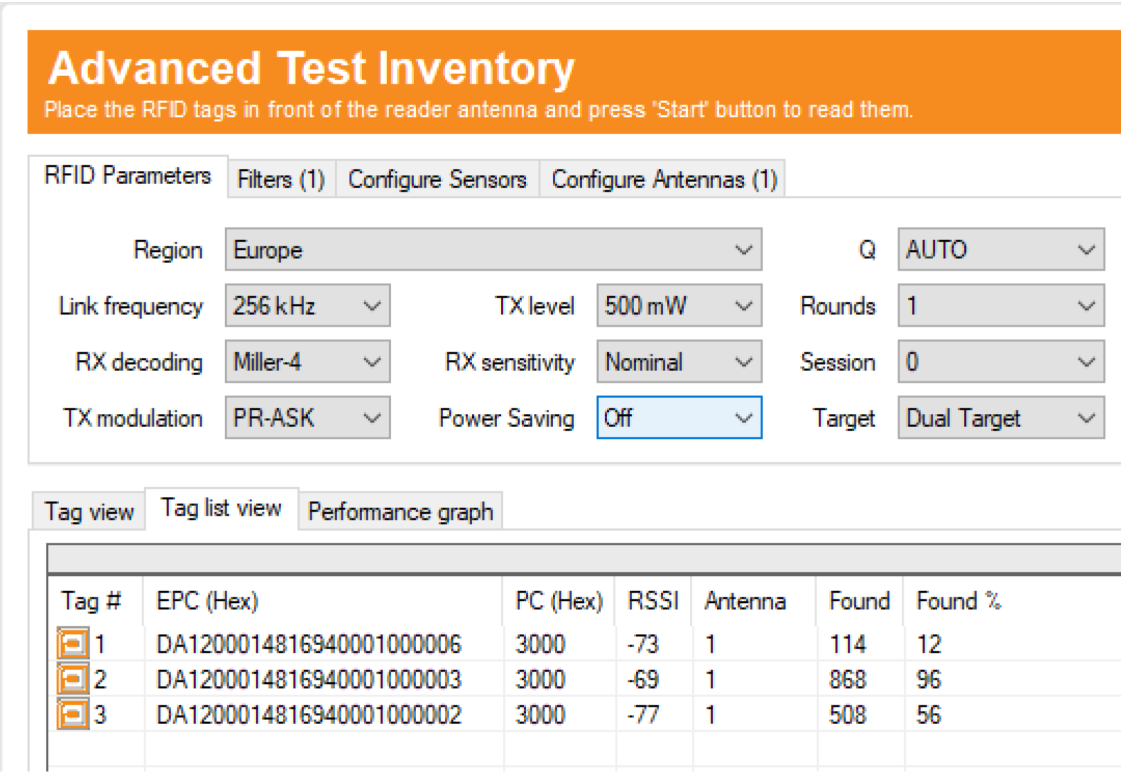
Region	Europe			Q	AUTO
Link frequency	256 kHz	TX level	500 mW	Rounds	1
RX decoding	Miller-4	RX sensitivity	Nominal	Session	0
TX modulation	PR-ASK	Power Saving	Off	Target	Dual Target

Tag view | Tag list view | Performance graph

Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	E2000019630202122270 2C97	3000	-63	1	302	92
2	E20000196302020522702C80	3000	-73	1	164	50
3	E20000196302019922702C7D	3000	-69	1	223	67
4	DA1200014816940001000006	3000	-77	1	21	6
5	DA1200014816940001000003	3000	-63	1	305	92
6	E20000196302020922702C8E	3000	-77	1	98	29
7	DA1200014816940001000002	3000	-75	1	37	11

=> all tags except bottom one detected! (wine has influence but t-shirts don't)

Put box with tags higher (1m70) with one box on top



Advanced Test Inventory

Place the RFID tags in front of the reader antenna and press 'Start' button to read them.

RFID Parameters | Filters (1) | Configure Sensors | Configure Antennas (1)

Region	Europe			Q	AUTO
Link frequency	256 kHz	TX level	500 mW	Rounds	1
RX decoding	Miller-4	RX sensitivity	Nominal	Session	0
TX modulation	PR-ASK	Power Saving	Off	Target	Dual Target

Tag view | Tag list view | Performance graph

Tag #	EPC (Hex)	PC (Hex)	RSSI	Antenna	Found	Found %
1	DA1200014816940001000006	3000	-73	1	114	12
2	DA1200014816940001000003	3000	-69	1	868	96
3	DA1200014816940001000002	3000	-77	1	508	56

=> tags on top not detected

9.3.Conclusion influence of Liquids on signal

We can conclude that liquids have very strong influence on our signal. In general we can say that when antenna reads from front the signal is still strong enough to pass 1 box of wine (or 2 bottles). When we put the antenna on the ceiling we get worst results, with the signal not being strong enough to pass 1 box of wine (1 bottle vertical).

It is also very clear that distance has much less impact on the RSSI than the presence of liquids since we tried moving the tags closer to the antenna with no different results.

Liquids have much more influence on the RF signal than other materials, like t-shirts. Probably due to high refraction and phase shifting causing multipath.
'RFID Technology for Medical Applications' also states at p 247 that glass has not much influence when the angle of incidence is 90* but when the angle of incidence differs from 90* the signal is refracted more, which is the case with bottles of wine since the are always round.

We became the same results when testing with different modulation en decoding techniques.

A possible solution could be a stronger antenna, for example a reader with 33 dBm or 2W output power.
In general a lower frequency, and longer wavelength has better penetration capabilities. With lower frequency also comes more power consumption.
Lowering the frequency and still using RFID technology is not a solution since passive Low Frequency RFID and High Frequence RFID use inductive and capacitive coupling, which don't have the range we need (max 1,5m in free space).
Most other alternative IoT technologies at lower frequencies have to high power consumption or are to expensive to implement as seen in our technology research.

In the next chapter we will be looking for solutions and if it is possbile

10.Research solution for influence of liquids

10.1. CapTag research [28] [29] [30] [31] [32]

Our research on the CapTag solution for the absorbance of RF signals by liquids is based on the patent on the tag and converstations with Dave Mapleston, the creator of CapTag.

Patent GB 249 3996A [S]

CapTag uses low cost near-field tags and transform them into a long range far field tag by using the metal capsule cover used on wine bottles.

The near field tag has no antenna. It is just a loop of metal.
The tag must be placed partly over the capsule and partly over the glas of the bottle.
This results in RF coupling through stray (parasitic) capacitance.

RF coupling is to put 2 inductor close together and let them interact with each other.
Stray capacitance is when 2 electrical conductors at different voltages are close together.

High level of backscatter modulation depth aids.

Magnetig field is very strong close to the read antenna but dies away at a cube of the distance .
Electric field dies away at just the square of the distance from the antenna and so longer ranges can be achieved at low RF power using electric field

The capsule is used to turn the H field tag (near field tag) into an electric field tag.
Since H field penetrate liquids easier than E fields.

The electric field of a standard RFID antenna is captured by the capsule foil. A portion of the tag is capacitive coupled to the foil and the other part is capacitieve coupled to the fluid of the bottle.
Part of loop is connected to the E field on the foil, other part grounded by the absorption of RF by the fluid.
This causes high frequency AC current flow int the loop at a voltage adequate to power up the RFID chip.

2W ERP is not sufficient for ranges up to 2m.

Extra range can be achieved by putting a bigger part of the loop further under the capsule.
This tunes the loop to a higher resonate frequency.

These are the criteria to achieve maximum range:

The loop loop must tune to the the used frequency
The loop must form a complex congregate match to the RFID chips input impedance so the transfer rate of energy into the RFID chip is efficient.
An experiment is needed to find the point of maximum performance is where the loop tunes and still has a good impedance match (between metal seal and tag.

Due to high RF power used for the application (2W) reflections from other metal causes large RF nulls and so the environment should be carefully controled.

More power than 2W is needed to achieve distances with magnetic field.

For the tags we can cut the loop from a gen 2 tag and the capsule and bottle will be used to form an antenna.

Mail conversations with Dave Mapleston

I contacted Dave Mapleston, director CapTag, for help.
The following mail conversation occured.

From me to Dave Mapleston.

Dear,

I'm a engineering student at the University of Antwerp.
I'm currently doing a thesis on the influence of liquids on UHF RFID signals.

During my research I found an article on foil-CapTag, which is based on patented technology by ePix.
Is there any possibility to get more information about the technology?

Of course a sample of the tag would be great for us at the university but I completely understand if it's not possible due to made agreements or patents.

Thanks in advance.

Greetings,
Cédric Plouvier

Reply from Dave Mapleston

Hi Cédric

Please take a look at www.CAPTAG.Solutions

To study what happens to radio waves in fluid you will need to understand relative permeability, permittivity and loss angle of water and other fluids (some pure oils don't have a los angle and so don't affect UHF rfid). For example the Er of water is 80 rather than 1 in air and so the fluid absorbs the electric field; however, there is still a good proportion of magnetic 'H' field energy which penetrates the liquid.
The H field disperses as the cube of distance rather than the E field which disperses at the square of distance. So, although H-field penetrates fluid it takes more than 1W of power just to reach 7cm into the fluid.

You will need to study Gen 2 RFID which is mostly for tags working with the electric field; however, learning more about UHF near field will be very helpful to you when water is present in an application.

UHF E-field range drops by about 12% when used in the rain as the E-field is reflected, polarised and absorbed

When people talk about NFC (near field) they are usually talking about 13.56MHz; however, we work with the same principle at GEN 2 which is 866MHz in Europe and 915 MHz in the USA. A new exciting band in Europe has just been announced at 4W ERP.
You will need to fully understand the difference between ERP and EIRP.

It would be an advantage to understand radio polarisation (circular and Linear).

I have attached some examples based on E field RFID.

When an electromagnetic wave hits fluid the loss angle of the water absorbs energy from the wave turning it into heat; however, some radio energy is reflected from the surface of the water just like sunlight it gets polarised as it leaves the surface. Look up the David Bruster angle.

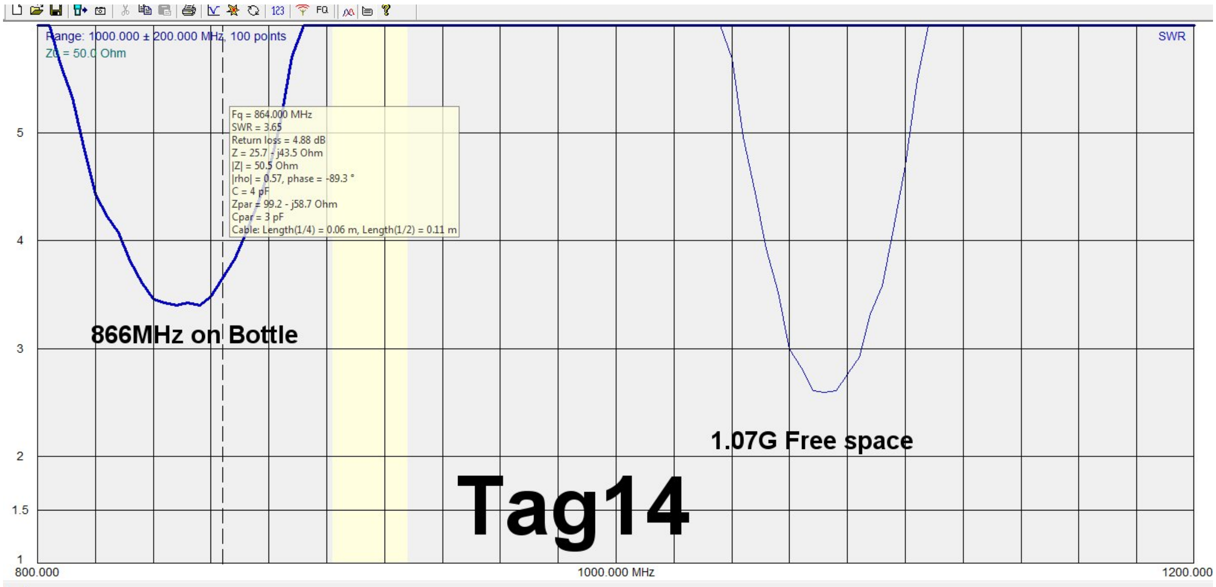
I have attached a picture of a near field tag which is at 1 GHz in free space but gets pulled down to 866MHz when on a bottle. This is the effect of the Glass layer Er=5 and the fluid ER=80.

The patent for the Bottle tag sold by CapTag is GB2493996. This is a granted patent so feel free to use any information from this publication. Six other patents are pending.

I have added a couple of meters which are available from CapTag. (Student discount applies).

Note that if you cut the loop from a normal gen 2 tag this will work as a near field tag when used with a Near field antenna. It won't be perfectly in tune as in the tag it functions as a transformer to provide a congregate match between the antenna and the chips input impedance. This is another area in which you will need to become an expert.

I hope the above information is useful to you and helps you focus your direction. The RFID industry needs new people who actually understand the technology, so let me whish you the very best of luck for your future.



Regards
Dave.

ePix ltd
Director CapTag.
CTO Rebound tag
Director GigRig ltd.

Reply from me to Dave Mapleston

Hi Dave,

Thank you very much for the extensive reply!

I’ve been looking into near-field antenna’s but only seem to find antenna’s with read ranges less than 30cm.
What’s is the approx. possible max range for using near-field coupling?

Something that isn’t clear for me is once the magnetic field reaches the tag, the capsule is used to turn the H field tag into an electric field tag.
How does the antenna capture the electric field response from the tag since this also passes the liquid? Or does the antenna detects the electric field because it has much lower sensitivity and that a well designed passive system is always limited by the tags sensitivity?

At this moment I only have access to a 0.5W reader with 5 dBi gain, tests without liquids have gone well and match my calculations using the Friis equation.

I’m now calculating if it is possible for the electric field to power up the tag using 2 or 4W ERP through liquid before purchasing one. And should it be possible also determine the maximum read distance through fluids. I’m starting from the power flux density (E^2 / wave impedance) and then calculating the Power at the tag which is the power flux density times effective aperture. Unfortunately I keep getting wrong results, mostly because I cannot find any way to accurately calculate the electric field at the tag. Is this something I should keep pursuing or is it too hard to determine?

Kind regards,
Cédric Plouvier

Reply from Dave Mapleston to me

Hi, Cédric; answers in [ ]

Thank you very much for the extensive reply!

I’ve been looking into near-field antenna’s but only seem to find antenna’s with read ranges less than 30cm.
What’s is the approx. possible max range for using near-field coupling?

[Near field is the magnetic field and so you need to understand the Cube law associated with magnetic coupling. At 866MHz the best range is about 8cm at the maximum power 2W. It easy to think you have done better however this is usually due to E field leakage. At lower frequencies 1 meter or more can be achieved]

Something that isn’t clear for me is once the magnetic field reaches the tag, the capsule is used to turn the H field tag into an electric field tag.
How does the antenna capture the electric field response from the tag since this also passes the liquid? Or does the antenna detects the electric field because it has much lower sensitivity and that a well designed passive system is always limited by the tags sensitivity?

[Yes, this is correct; actually the range is a function of the power taken by the tag to power up. You can read any tag at 30meters once it is powered.]
[Yes, again; the CapTag has huge range, 8 meters when the bottle is upright. This is due to a few factors; but the simple answer is that the capsule catches the electric field (Radar capture area) and this electric field is taken to ground (the fluid is the ground) it passes the tuned loop (cavity) so it excited current flow around the loop. This is now mostly H field around this loop so not affected by the glass or fluid very much. So CapTag is basically a mono pole antenna. As you can guess if the bottle has no stopper and the wine bottle is on it's side then the fluid goes into the capsule which greatly reduces the range.

If the bottle has no capsule then the tunes squiggle antenna tunes to the transmitted frequency and so performs the same function as the capsule.
To understand how these impedances work you will need to study complex congregate matching.]

At this moment I only have access to a 0.5W reader with 5 dBi gain, tests without liquids have gone well and match my calculations using the Friis equation.

[Well, unfortunately the Friis equations doesn't work for RFID Gen 2; unless you factor in the power required to power up the tag. So, only if you use the Friis equation or simple field theory to estimate the range from your antenna to get the level of power to excite the tag will you be close. If your measuring the range(which should be about 5 Meters) you will get 30% more range than calculated due to constructive interference; with circular polarisation or horizontal linear you will see large dead spots at about 2 meters. So you can only verify your results in a test chamber, otherwise you will be +- 30%]

I'm now calculating if it is possible for the electric field to power up the tag using 2 or 4W ERP through liquid before purchasing one. And should it be possible also determine the maximum read distance through fluids. I'm starting from the power flux density (E^2 / wave impedance) and then calculating the Power at the tag which is the power flux density times effective aperture. Unfortunately I keep getting wrong results, mostly because I cannot find any way to accurately calculate the electric field at the tag. Is this something I should keep pursuing or is it too hard to determine?

[I think you are on the right track and you are obviously aware of the limitations of the maths due to the many variable involved.

[In the fluid the magnetic field prevails. Almost all the electric field is dissipated due to the Er and the loss angle. Basically the same as a microwave oven which heats the food by resonating the H2O molecules between two stable states creating heat.] So for fluid penetration you should be looking at the theory of magnetic coupling.

[A single turn for the transmitter will be a maximum of 4cm, above this it will self resonate. The receiving loop (See Alien Technology Sit TAG) will be about 1cm diameter so calculating the power transfer to the single loop tag will give you the range. The maximum range can be approximated 1.6(d1+d2) so in the above example this is 8cm. Now you are probably thinking 'Well what about the Power' ???? In fact due to the double cube law the range you get using 2W rather than 500mW will only be about 12%. So at 500mW you should get 5cm to 6cm penetration.]

Unfortunately, I can't give you some of the details because we have many patents pending in this area; however, I am very pleased to help a fellow European. Like most scientist, I am also ignoring Brexit.

To help with your studies:
Experiment-1 Try heating a bottle of Johnson's baby oil in a microwave.
Experiment-2 Put a conventional Gen 2 tag on the baby oil and another Tag on a bottle of water and measure the difference in range.
This proves that all fluids are not the same.

Hope the above is helpful and moves you forward in your RF fluid research.
My research colleague Dr Brian Weeks and I will be interested in any findings you make.

You have a lot to study and test Cédric.

I will try to answer any further questions and whish you success in your understand in this difficult area.

Dave
ePix Ltd
CapTag Solutions

<u>Reply from me to Dave</u>

Hey Dave,

Sorry to bother you again.

I've discussed several possible solutions I could try out with my professors and were very interested by the CapTag solution.
Now they want me to recreate this to proof the concept works.

There is one thing I'm still confused about.
Do you use a far field antenna where the E field gets dissipated but the H field of the electromagnetic field still penetrates or do you use a near-field antenna at 868 MHz?

If I cut the loop from a normal tag I have to use a near-field antenna, are there near-field tags that can be used with a far field antenna?

Kind regards,
Cédric Plouvier

<u>Reply from Dave to me</u>

Hi, Cédric

We have some information on the CapTag website; you can even find a video of me doing a demonstration.

If you type CapTag solutions into YouTube, you will see the demonstrations and my ePix video. CapTag is a spin off company from ePix ltd.

Feel free to ask CapTag for tag samples.

Your question is simple; however, the answer is very complicated.

First of all you are correct; the electric E-field is collected at the top of our tag and the bottom of the tag is held at ground. Well, not really a ground as it's a fluid. The tag then becomes a monopole antenna, either using the capsule to collect the E field or the squiggles to collect the E field.
So, we get current flowing from the top of the antenna into the fluid which must go past the resonant cavity and chip.

In normal tags the chip loop is designed as a transformed to provide a congregate match between the dipole antenna and the chips input impedance (about 1K and .4pF).

In our case the resonant cavity is tuned very high so that when the tag is on the bottle it is pulled down to the resonant frequency 866MHz, 915MHz or somewhere in-between. (we don't use this loop as a matching transformer.
Our loop is excited by the current flow at the bottom of our monopole antenna. The chip matching is not perfect; but good enough for 10 meters range with upright bottles. I can't disclose too much as we have patents going through the system all the time.

One very interesting effect is that the range is twice as good when the tag is at the back of the bottle rather than the front. This is due to the absorption of the E-field which is much more effective at the back as the E-field cannot pass through the fluid and so when the tag is at the back the ground is more effective. We measure about 4dBi gain.

Hypothesis:
We also think that the AURORA BOREALIS effect may be playing a part in this forward gain. Take a look at new theories which explain why the northern lights appear at the opposite side of the earth to the sum. Recent discoveries show that as the magnetic field lines try to cross each other a large E-field (electrons) are fired back at the opposite side of the earth to the sun.
Other theories are due to skin effect lensing; however, E-field shielding is the most accepted answer to this effect.

https://captag.solutions/captag-technology

Hope you find this interesting.

Dave.

From Dave to me

Cédric, if you would like some CapTag samples, please contact CapTag Solutions. I have asked David to provide you with free samples and data.

Contact
david.potter@captag.solutions

Regards
Dave.

From me to Dave

Hey David,

I did some test today with cut out loops from normal uhf tags and results where better than expected.
Read tags up to 1,80m (quadruple of normal tag) by placing the loop partially over the metallic capsule and bottle with an air gap in between and the chip underneath the air gap (upright bottle of course).

Regards,
Cédric Plouvier
Reply from Dave to me

Hi Cedric.

The only reward I need is to see you progress. No gift necessary; but very kind of you to offer.

Well done with your experiment.

See if you can get twice the range when the tag is at the back of the bottle and the reader is at the front. This structure has a forward gain of about 3dBi to 4dBi.

Our tags on an uptight bottle give over 8,0 meters. When the bottle is on its side then the range will drop to 0,4 meters. This is because the fluid is taking all the RF E field from the top of the capsule; in effect shorting out the tag.

We have made some advances with horizontal bottles however, the range is always lower than upright bottles.

Remember that your transmitter antenna (patch for example) produces H field un-polarised at .1 meters. This means you will always read the tag at close range.

Hope this is helpful.

Regards
David Mapleston
Director CapTag.solutions
Director ePix research
Director TheGigRig ltd.

10.2. Omni-ID research

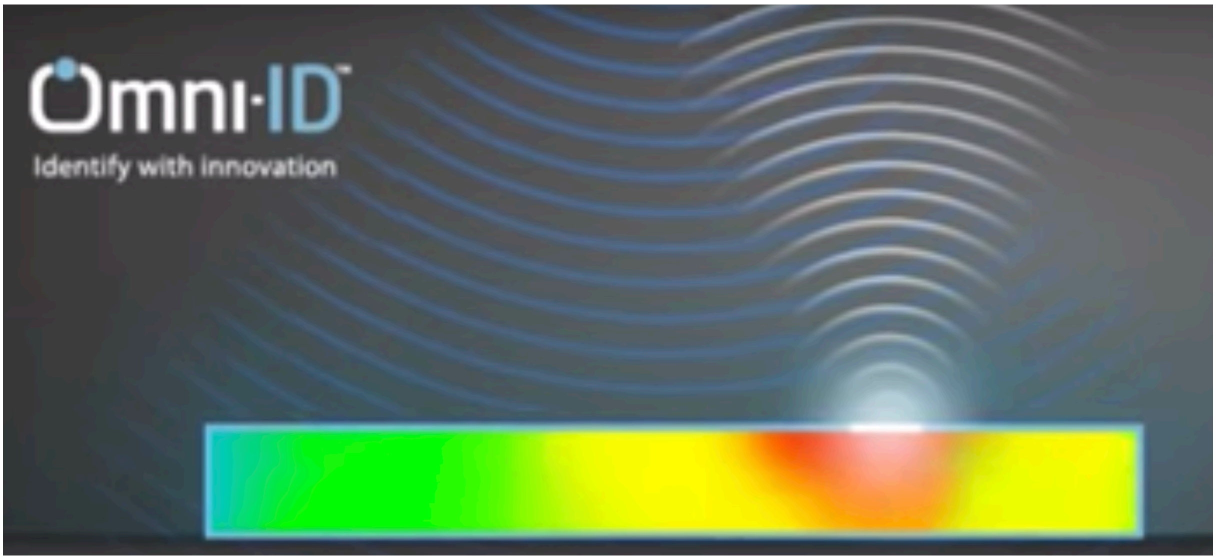
Plasmonic structure [27]

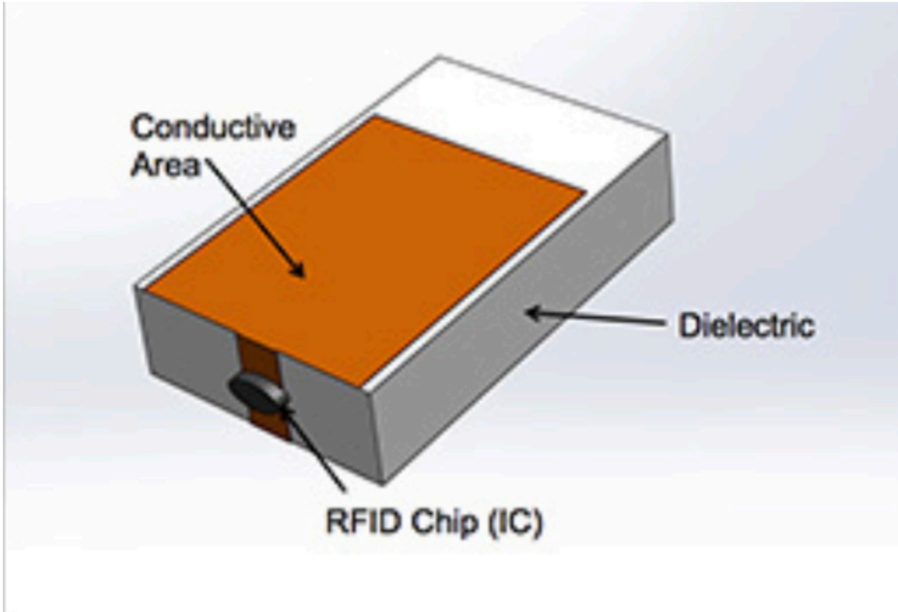
Patents: US7880619 [T] / US7768400 [U]

Omni-ID is an on-metal or near liquids solution.

The solution uses layers of conductors and dielectrics to isolate the RF from the tag's surrounding environment, which ensures the tag performs near liquids.

Plamsonic structure captures RF waves and concentrates the energy from them around the integrated circuit, outside materials do not interfere.
The concentrated energy is most concentrated under the RFID microchip, because of how the structure is engineered, which activates this chip and allows the tag to respond.





Omni-ID white paper: The Technology of On-Metal RFID

The plasmonic structure impacts the oscillations within an electromagnetic field to generate a reflection.

The captured waves oscillate within the plasmonic structure, building up over time. After some time a region of high concentrated energy is developed which activates the microchip.

Because the high energy field in the dielectric isolates the RFID tag from the structure the tags can be read independant of the material they are on.
This technique is also called spacing but hasn't been as effective before.

The tag structure produces a frequency response that has two peaks rather than one (like with conventional tags).

They have three different tags adjusted to different needs.

Omni-ID Max Pro: optimization for on-metal instead of balanced performance extends the read range.

Omni-ID Max HD: greater durability, polycarbonate case, broadband performance (2 peaks of frequency) so that one tag can be used globally. Works in extreme weather conditions. Works as well for on as off metal material.

Omni-ID Ultra: passive UHF RFID tag with on metal 30m read range.

Conclusion

This technology is also patented and probably aren't allowed to copy it.

The downside of it is that the tag is thicker due to the spacing with dielectric.
The tags can not be bought seperately since Omni-ID only sells on demand solutions for companies. The do sell test rolls of the tags which cost 100$ for 99 tags.

10.3. Falken Secure Networks IPICO Dual Frequency RFID

Falken Secure Networks provide a solution based on the use of dual frequencies.
The frequencies are such that tags are not screened by human bodies or conducting material.

They designed a semi-passive tag that can be attached at the bottom of a wine bottle.

The uplink (tag to reader) operates at 6,8 MHz (in Europe this will be 13,56 MHz) and the forward link is 125 kHz.
The reason that the forward link frequency is much lower is because that it is much harder to power up the tag.
Lower frequencies means longer wavelength and easier penetration of lossy mediums.
The limitation of lower frequencies is that the data rate also is much lower.
In our technology research we found values of around 2 to 4 kbits per second.
Hower according to an article from RFID Journal it can transmit 128 kbits/s at reading ranges from 30 cm to 3m.

The IPICO tags us the IP-X TM anti-collision algorithm, which allows fro 120 tags to be read simultaneously at a rate of 30 tags per second, according to Falken Secure Networks.

11. Testing CapTag solution

In this section we are going to test the CapTag solution.
In the first part we will use our own created tags.
After that we will do the same tests with the CapTag tags.

11.1.CapTag solution with own created tags

We create the tags simply by cutting out the loop from a simple UHF RFID tag.
The tags can be mount in multiple ways to the capsule or bottle.
First we test what is the best way to mount the tags to get the longest range.

The pictures below show the positioning of the tags with their corresponding last 3 digits of their identification number.
They are already ordered from worst to best range performance from left to right.

We assume a tag is found during the tests when the RSSI is above -75 and is found more dan 50% of the time.

There is a difference when the tag is mounted at the back (furthest from antenna) or front of the bottle. This is due to better shielding of the ground part of the loop (part on the bottle and not the capsule).

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

These results show that it is important that the chip of the tag is not on the capsule.
We achieve the best results when there is an airgap between the capsule and where the wine starts in the bottle.
The best result is achieved when there is an airgap and the chip is located behind the wine.

In the next part we do some test with the tags by putting liquids on front of the tagged bottles.
We tested with 6 bottles (1 box) where the tags are placed optimal according to above results.

Without any liquids on front of the box we can not tag the back middle one (2 rows of 3 bottles). We interchanged bottles kept having the same results, we did not found any reasonable explenation for this.

We placed 2 boxes of cava on top of each other in front of the tagged bottles.
With the tagged bottles at 1m40 we did read 2 out of the 6 tags but very inconsistently, with a 5% found rate.

Next we moved the tagged bottles closer but always with the same results.

Conclusion testing CapTag solution with selfmade tags

The concept of the CapTag solution of turning the capsule of the bottle into a monopole antenna by placing a near-field tag half on the capsule and half of the bottle is proven for on-liquid tagging. With results of 1,80m range achieved compared to 0,40m is we place a normal UHF RFID tag on a bottle containing liquid. This is a quadruple of the range!

The CapTag solution does not provide a solution in case their are other liquids in front of tagged bottles. This is as expected since the electromagnetic signal from the reader to the tag still gets absorbed by the liquids in front on the tagged bottles.

12.Conclusion

From our research we concluded that UHF RFID is the only cost-efficiënt IoT technology that we could use for inventory management on large scale. We test the technology and observed that liquids have a very destructive influence on our UHF RFID signal. Making it impossible to read tags through liquids or get an acceptable range to read tags when attached straight onto the bottle. From the 3 different solutions we found only one had the intention to solve the problem of reading a tag though liquids. This was the dual-frequency band solution. Despite efforts we could not test it ourselves due to the lack of hardware and resource but from a market investigation we concluded that this technology does not work well.
Omni-ID solution and CapTag both provide a solution to read tags attache on a bottle from decent ranges. We only tested the CapTag solution which indeed seems to work well. Giving us a read range of 1,80 meters with self-made tags while the real CapTag tags can reach a range of 10m according to them. Other technologies like active RFID or BLE would probably work to read tags through liquids but are too exepensive for applications on very large scale.

13.Future perspective

The IoT market is in constant development so their is always the possibility that a new technology can tags liquids bottles through liquids and be cost-efficiënt at the same time. Wi-Fi HaLow could be one of these technologies which is already on the verge of coming onto the market.
Another possibility is that already existing technologies that can tag though liquids like active RFID or BLE but are too expensive at the moment for large scale application will become cost-efficiënt. It is expected that is will drop in price over time as seen with all other technologies but there is no telling at which point in time this will be.

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