RAIN RFID Lessons learned from the field

RAIN RFID Alliance
Whitepaper

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1 Introduction

A RAIN RFID system consists of items, tags, readers, software, and a network. Deployments have many parts and players with increasing complexity as the size and scope grows. The good news is that the technology, standards, and business eco-system have all evolved to such a level of maturity that successful deployments are routine around the world. We can learn from these successful deployments.

RAIN RFID *Lessons learned from the field* addresses system considerations that should be reviewed when designing, deploying, and using RAIN RFID systems.

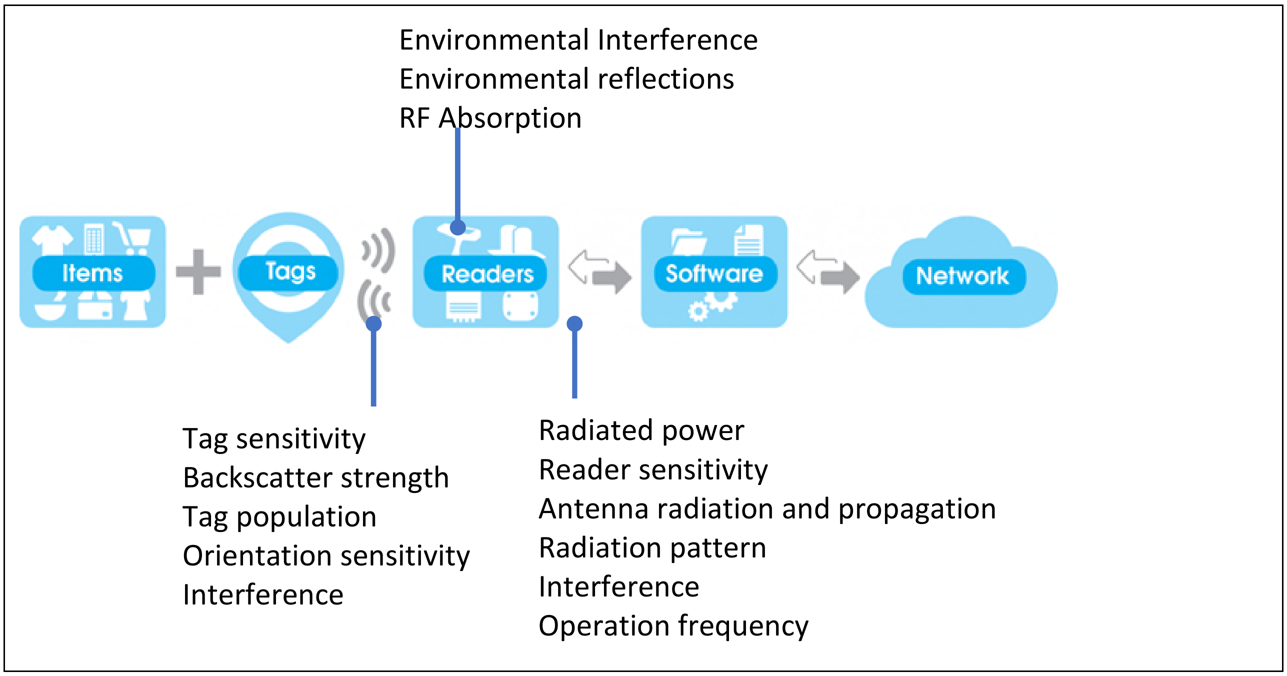


Figure 1: RAIN RFID System Overview

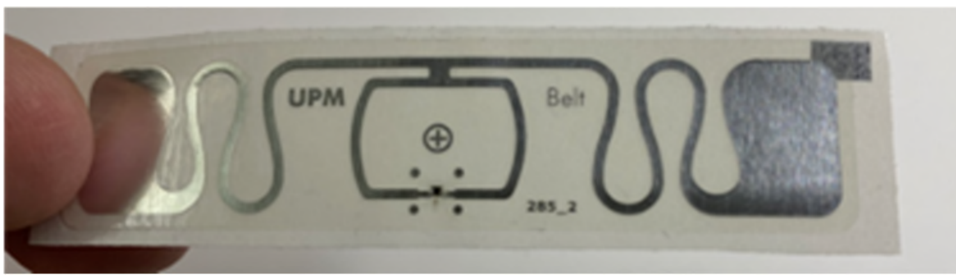
The following sections address avoidable pitfalls when deploying RAIN RFID technology, reducing the complexity and risks of deployment and operation. The target audience includes implementers of RAIN RFID technology, such as system integrators and advanced users.

2 RF characteristics

2.1 Handling tags - Avoid skin contact with RAIN tags while they communicate with a reader

Do not touch RAIN tags while they are interacting with a reader. Many RAIN tags can become detuned by the presence of water and humidity. For this reason, the high water content of the human body will negatively impact the operation (tuning) of a RAIN tag. If a tag must be held by human hands during operation, a fingertip pinch grip at the centre of the antenna will have the smallest detuning effect.

By contrast, touching the tag on its shorter side (i.e., at the edge of the dipole) is likely to cause significant detuning:



As a workaround when testing systems, (dry) wooden chopsticks or cloth pegs are an ideal, low-moisture substitute for fingertips, with contact preferably in the middle of the tag's symmetric side, which is in most cases the longer side.

Do not assume that UHF radio waves travel equally through all materials. Signals can be detuned when traveling through objects with water, metallic or high carbon content.

BEST PRACTISE:

⇒ Ensure that systems are designed to cater for tag read operations and a deployment's site-specific environment.

⇒ Anticipate how humans will interact with tags – intentionally as well as unintentionally – and develop workflows to minimise direct tag-to-person contact, as well as the presence of people in the interrogation zone (read zone), as much as possible.

⇒ Ensure that the design solution considers the likelihood of interference from human tissue in the interrogation zone (read zone).

2.2 Select the correct operating frequency

RAIN RFID readers **must** be configured to use the appropriate, approved frequency for the relevant country/region of operation, within a **locally regulated and enforced** subset of the 860 – 930 MHz (UHF) band. Operating a reader in the locally approved spectrum band is a legal obligation. Therefore, it is essential to specify the appropriate infrastructure for the intended geographic region and application.

Note that parts of the UHF band are also used by mobile phone service providers. Their systems automatically detect [location of] interference. A visit from their radio interference inspectors is, at a minimum, embarrassing, and may result in legal actions.

Furthermore, using unintended frequencies that are outside a tag's design may reduce its performance and read range, and may interfere with other systems.

Also, be aware that some readers allow user reconfiguration of RF parameters. Any change to these settings could negatively impact compliance with locally applicable radio regulations, as well as system performance.

BEST PRACTISE:

⇒ Ensure that the reader's RF parameters comply with local regulations prior to operation.

⇒ Only purchase and deploy readers that are approved by their manufacturer for the deployment's intended region.

⇒ Verify that tags have the required performance in the operating frequency band(s) of your readers.

⇒ Remember that tags may also move between different regions, where different regulations apply[1], with optimised performance required across the 860-930 MHz band.

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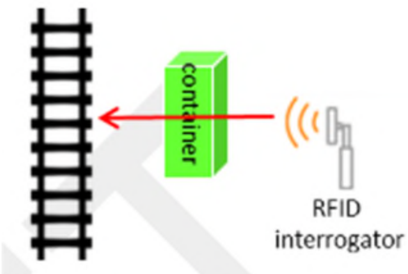
[1] Informal overview of UHF RFID frequencies globally: An informal overview is available under [6].

2.3 Be a good neighbour to European railway communications (GSM-R)

In Europe, fixed outdoor installations with antennas pointing towards railway tracks should, as a rule of thumb, maintain a minimum distance of 45 m from the closest track. This is to minimize risk of interference with the rail network's GSM-R.



BEST PRACTISE:

⇒ If an outdoor system must be installed closer than 45 m from the railway track and GSM-R is used in that country [1], then the relevant railway organization should be consulted prior to deployment, to avoid unpleasant surprises.

3 System setup

3.1 Real life often deviates from the lab environment

Do not assume that results obtained from systems testing in a lab or test environment will be replicated when implemented in the field. While lab results can act as a guide, it is essential that all components are tested as a holistic solution in the intended environment to ensure a successful implementation.

BEST PRACTISE:

⇒ Regard lab results as best-case scenarios, rather than predictive of performance in the field.

⇒ Verify system performance in the actual implementation, on-site. In the absence of this, reference applications can serve as a rough rule of thumb, with the caveat that some implementation-specific variables (i.e., the environment, the process, etc.) might be overlooked and only become apparent on-site.

3.2 Tags should be locked

Do not leave tags unlocked in the deployed application. Leaving tags unlocked after encoding allows them to be rewritten, removing the original data. In the most basic of cases, this would mean a tag will either no longer be recognised in the system or be recognised as an entirely different item. Wider potential implications include miscounted inventory, mis-shipments, and manufacturing process errors.

BEST PRACTISE:

⇒ Ensure that tags are locked after encoding, using either a password protected reversible lock or permalock.

3.3 Select an existing encoding scheme conforming to a standard

Do not use proprietary data in MB01; this is the memory bank intended to hold the GS1 EPC (Electronic Product Code) or the ISO UII (Unique Item Identifier).

Note:

- MB01 is the first, and often the only, data read from the tag.
- MB01 contains other important information used in data interpretation and tag communication and may also be used for additional information about the tag and the tagged object.

Using proprietary, non-standardized encoding formats increases the risk of identifiers not being unique or recognisable, resulting in systems being flooded with unnecessary traffic, or confusing systems with unrecognised identifiers; this phenomenon is also known as "*acid RAIN*".

NOTE: A tag can contain GS1 or ISO data, indicated by the "Toggle" (or "T") bit 17h of MB01, within the PC bits.

BEST PRACTISE:

⇒ Please read the RAIN Technical note: Item Numbering and Information[2].

⇒ Only use GS1 (EPC) or ISO (UII) standard data structures; for details, see GS1's EPC Tag Data Standard (TDS)[3] and the ISO Data Constructs Register[4], respectively.

3.4 Expect tags from other applications to enter YOUR reading zones

RAIN tags are widely spread throughout many diverse applications, with billions of tags deployed over the entire globe. For this reason, systems should be designed to read only those tags that are expected to be identified by the application.

BEST PRACTISE:

⇒ Follow the recommendations of section 3.3.

⇒ Use readers which allow for tag filtering. Readers which support the RAIN Reader Communications Interface (RAIN RCI) or GS1 LLRP are recommended.

⇒ With a low-level reader, the *Select* command should be used to exclude "foreign" tags (i.e., not relevant to the application) wherever possible.

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[2] See rainrfid.org/resource-type/documents/ for RAIN publications

[3] See [5]

[4] www.aimglobal.org/registration-authority.html

3.5 Tags are tough, but not indestructible

Antennas and chips, as well as the chip-to-antenna interconnect, are not immune from cracks or fissures resulting from mechanical force or temperature extremes; such damage can result in detuning or complete loss of the tag.
BEST PRACTISE:

⇒ Choose a physical tag format appropriate (e.g., with tag encapsulation) for the application and the preceding supply chain.

3.6 Design the read zone to use shorter read ranges well within the limits of the tag and reader

Attempts to maximise or "stretch" the effective read zone can backfire by introducing unanticipated interference, in turn making it difficult to read tags at the extremities of the zone.
BEST PRACTISE:

⇒ Reduce reader-to-tag distance as much as possible for a given application.

3.7 Use one reader per read zone

A tag chip can only talk to one reader at a time; tags attempting to communicate with multiple readers simultaneously may get confused (reader-to-tag interference), negatively impacting performance. Note that a reader may have more than one antenna, though only one antenna will be active at a given time. Do not use antennas from different readers within the same read zone.
BEST PRACTISE:

⇒ Design read zones to use one reader, possibly with many antennas.
⇒ Design multiple read zones and keep their distance.
⇒ Ensure that a tag is closest to the reader with which it needs to communicate in the context of a given business process step at that point in time, even if the other readers are part of the same application. This will make it easier for the tag to understand the intended reader.

3.8 Note the impact of large metal surfaces close or within the read zone.

Large metal surfaces strongly reflect signals, causing signal multi-paths. This can result in localised areas of signal cancellation in the expected read zone. Multi-path signals can also unintentionally extend the read zone to unexpected areas.
Tagging of metal objects, such as a vehicle or shipping container, requires careful consideration. On-metal tags are designed to work on conducting layers like metal (and even carbon) sheets and wire mesh. However, pointing a reader antenna face-on at an on-metal tag will result a high-power signal reflection, especially at close range, which will blind/swamp the reader, possibly preventing the reader from detecting the tag.
BEST PRACTISE:

⇒ Evaluate the application setup, removing or displacing large metal surfaces if possible.
⇒ Try to avoid metal surfaces perpendicular to the main beam lobe of reader and tag antennas.

⇒ Carefully consider the antenna angles when tagged objects have large metal surfaces.

3.9 Consider on-metal tags for metal surfaces

While large metal surfaces strongly reflect signals, causing signal multi-paths, a variety of specialised RFID tags are designed for a metal surface.
It is important to note that on-metal tags are directional in nature, typically perpendicular away from the metal surface.
BEST PRACTISE:

⇒ Select on-metal tags for application/mounting directly on a metal surface.

⇒ Avoid on-metal tags for non-metallic surfaces, as the anticipated metal is an important factor of optimal tag tuning.

3.10 Read range is only one of many parameters for tag performance.

Typically, a long read range necessitates a narrow radiation aperture. Narrow apertures often result in suboptimal orientation of reader and tags with respect to each other's beam, increasing the likelihood of a misread.
On the other hand, a narrow reader antenna beam may be beneficial by reducing interference.
BEST PRACTISE:

⇒ A wide tag radiation aperture with a reduced read range is often better than an increased read range with a narrow aperture.

3.11 Consider how to best use antenna polarisation

Signal polarisation has similarities to polarised sunglasses: effective at eliminating glare, but sometimes with the unintended side effect of blocking out LCD displays (which are also polarised). When two polarized lenses are aligned along the same principal axis, no light passes through when one of the lenses is rotated 90° along its vertical axis.
Light and RFID signals behave similarly in this regard. In RF, where "glare" manifests itself as unwanted reflected signal, antenna polarisation may improve read performance. Long, thin tags are typically polarised in the direction of the longest edge. Reader antennas may appear square but are polarised.
BEST PRACTISE:

⇒ For applications in which tag orientation is predictable as the object moves through the read zone, using linear polarised reader antennas may be beneficial in reducing RF noise and unwanted tags.

⇒ For applications in which tag orientation is not predictable, a circular reader antenna is recommended.

3.12 RAIN tags are direction sensitive

RAIN tags are typically dipoles, which are direction-sensitive. The field characteristics can be roughly estimated by looking at a tag. The more surface area of a dipole antenna is visible, the

more efficient it will be. When viewed from the long edge, signal reception is good. When viewed from the short edge, signal reception is weak.
BEST PRACTISE:
⇒ Carefully consider tag orientation in the read zone by visually assessing its orientation and angle to line-of-sight.
⇒ Apply ISO/IEC 18046-3 for standardised tag performance tests.

3.13 Antenna duty cycle plan

For multi-antenna read zones, the reader needs to switch between antennas; the default antenna selection might not suit the application.
BEST PRACTISE:
⇒ Start with an equally distributed antenna utilisation, which would be 25% in the case of 4 antennas. Make duty cycle dependent on tag presence, provided that tags can be prevented passing other antennas during those cycles. The use time for each of the antennas should be at least 10%, unless no tags are identified.
⇒ Local radio regulations sometimes provide a helpful framework for this approach. For example, FCC regulations require a channel hop after no later than 400 ms; this hop would lend itself to a simultaneous antenna switch. In contrast, in Europe a channel may be used for up to 4 seconds, which is too long to serve as an effective antenna switching interval.

3.14 Use full transmit power only if really needed

High power equates to increased read range. However, in some applications this results in reading unwanted tags and unwanted reflections. Furthermore, higher power might result in increased interference to other readers in the vicinity.
BEST PRACTISE:
⇒ Set reader power to reliably read all tags in the read zone. Additional power is likely to degrade performance, due to reader self-jamming and increased interference between multiple readers.

3.15 Know your antenna cable lengths and specs

Antenna cables are available in a wide variety of lengths and, importantly, specifications. These two factors must be considered and balanced when implementing a RAIN RFID system.
All RF cables will lose power over their length between the reader output to the antenna input; this attenuation will depend on the length and structure of the cable. Typical options for cables used in RFID applications, in ascending order of loss tolerance, are the types LMR240, LMR400 and LMR600. Typically, the less attenuation from a cable, the more expensive and less flexible the cable will be.
All antenna cables may lose performance over time, especially when they are exposed to mechanical forces and the elements (e.g., extremes in temperature and humidity).
BEST PRACTICE:
⇒ Use good quality cable.
⇒ Never step on a cable or bend it sharply.

⇒ Install cables in a way to reduce vibrations, other mechanical forces, and exposure to the elements. Avoid sharp bends and mechanical stress on RF cables and connectors.
⇒ Ensure that the chosen cable has a tolerable level of loss for the required length of cable and compensate for losses by increasing the reader output power, as far as allowed by local radio regulations.

4 Protocol related

4.1 Session Times and Flags - Session times might be longer than expected, and tags do not always enter a read zone unpowered and/or with their *Inventoried* flags set to A

Session flags S2 and S3 have no limitation on their maximum activated time. For all temperatures, but especially for low temperatures, typical session time may be 100 to 1,000 times longer than the minimum of 2 seconds required by the RAIN RFID air interface standard[5]!
BEST PRACTISE:
⇒ Use session flag S1, if tag persistence needs to be kept as short as possible.

4.2 Successful write - Proactively verify that a tag has been successfully written, even if the tag has already confirmed successful execution of a write operation

A *write* command may be interrupted at any time. Depending on the memory technology of the chip it could even mean that memory locations that have already been set are subsequently re-set, or vice-versa.
BEST PRACTISE:
⇒ A *write* (as well as *blockwrite* and *lock*) command should always be verified by a *read* (or other suitable) command.
⇒ It is strongly recommended to not power down before doing this, unless it can be ensured that only the intended tag is present in the interrogation zone, or that this tag can be unambiguously selected by a *select* command.

4.3 Tag read speed - Manage read rate expectations realistically

Do not expect read rates of 1,000 tags/second. It is important to understand protocol limitations and recognising hundreds of tag singulations within a few seconds is excellent performance!
For example, when Tari = 12.5 µs, M=4, BLF = 320 kHz, then the read rate will be in the range of 200 tags/second for a 96-bit EPC.
BEST PRACTISE:

[5] RAIN Air interface standard means [2] and [3]

⇒ Reconsider your requirements if the speed demand exceeds 200 tags/second, or when large amounts of data need to be read.

NOTE: While speed improving custom commands reading EPC+TID in shorter time are available, please note that these are IC-vendor-proprietary and not standardized.

4.4 Tag readability - Multiple query commands will increase visibility of tags in the zone

According to the protocol a single Query command would allow all the tags to be read; however, real-world RF environment does not support this reliably. Do not assume that all tags in the zone will respond to a lone query command.

BEST PRACTISE:

⇒ Use multiple loops of Query commands to read all tags during an inventory round.

4.5 Reading more data from the tag requires more time

When a tag is detected, it delivers the data from MB01, which should contain at least the EPC/UII. All other data to and from the tag is transferred with separate commands. Tag security will require extra communications.

To move additional data between reader and tags requires additional time and energy. This necessarily reduces tag throughput and may also reduce read range. Do not expect to read (or write) all data 100% of the time, especially for moving tags, or when additional memory access is required.

BEST PRACTISE:

⇒ Reduce the amount of data that is actually read during collision arbitration (the process in detecting a tag) as far as possible. Furthermore, identifiers and other data stored in MB 01 (EPC/UII) should be as minimal as possible to make the read process as fast and robust as possible.

⇒ It is prudent to plan back-end user systems (consuming tag data for workflow and business applications) so that the data on the tag is useful and unambiguous, even if only part of the data is read.

5 Encoding

5.1 Ensure the tags are encoded for your application correctly

GS1 and ISO provide standardised encoding schemes. Proprietary encodings should be avoided wherever possible and restricted to closed loop applications.

BEST PRACTISE:

⇒ Make use of established data encoding standards.

⇒ Ensure that you can identify your own tags by means of standardised inventory operations (per RAIN RFID air interface[5]).

5.2 Identifiers in memory bank MB01 should be unique, unambiguous, and adhere to standardised encoding schemes.

The tag inventory process cannot easily distinguish between tags which have the same data encoded in MB01. For example, it is not possible to accurately inventory a population of uncoded (i.e., EPC/UII is all zeros) tags.

5.3 Memory bank MB01 of supplied tags needs to be correctly encoded in the context of the user's business application.

MB01 of supplied tags might be unencoded or might have been encoded by the IC/inlay manufacturer for its own internal production/QA purposes. MB01 must be encoded with a unique and unambiguous identifier (per section 5.2) in the context of the user's business application, by (or for) the user, at the user's tagging site.
BEST PRACTISE:

⇒ Verify tag data content after encoding at the user's site

5.4 Consider the potential presence of "foreign" tags in the read zone

As more RAIN tags are being used in many applications, "foreign" tags (i.e., from other applications) are increasingly likely to be present in any given read zone.
BEST PRACTISE:

⇒ In order to minimise the interference of "foreign" tags, make use of standardised *select* operations to ensure only tags from the intended application are included in *inventory* operations.

6 References

[1] CEPT ECC ERC Recommendation 70-03 Relating to the use of Short Range Devices (SRD)

[2] GS1 EPC Radio-Frequency Identity Protocols Generation-2 UHF RFID Specification for RFID Air Interface Protocol for Communications at 860 MHz – 960 MHz

[3] ISO/IEC 18000-63, Information technology -- Radio frequency identification for item management -- Part 63: Parameters for air interface communications at 860 MHz to 960 MHz Type C

[4] RAIN RFID Relevant Standards (www. rainrfid.org/resources/)

[5] GS1 EPC Tag Data Standard (TDS) www.gs1.org/standards/epc-rfid/tds

[6] Overview of UHF RFID allocations www.gs1.org/docs/epc/uhf_regulations.pdf

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7 Background and Contributors

This document was developed within the RAIN RFID Technical Workgroup. While frequently updated drafts were available for comment to the entire Workgroup, the following contributors played a major role in shaping the final document:

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ABOUT RAIN RFID ALLIANCE

The RAIN RFID Alliance is an organization supporting the universal adoption of RAIN UHF RFID technology. A wireless technology that connects billions of everyday items to the internet, enabling businesses and consumers to identify, locate, authenticate, and engage each item. The technology is based on the EPC Gen2 UHF RFID specification, incorporated into the ISO/IEC 18000-63 standard.

Join the RAIN RFID Alliance to enable connectivity for your business and consumers: identify, locate, authenticate, and engage items in our everyday world. For more information, visit www.RAINRFID.org.

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