AN5807

Application note

Frequency hopping strategies for ST25RU3993

Introduction

This document shows how the tag inventory speed can be increased by applying different frequency hopping strategies on the ST25RU3939-HPEV board. This board is a high-power RAIN® (UHF) RFID reader system based on the integrated reader IC ST25RU3993.

For UHF RFID reader systems, it is of great importance to inventory a tag population as fast as possible, especially for warehouse or store deployments.

Being fast at discovering tags, the reader not only enables a higher update rate of the presence and location of items but offers other advantages too.

Shorter RF-ON times of the reader’s transmitter can lead to less congestion (interference) on the RF interface with other readers. For a local group of readers, this can mean a more efficient tag inventory. Saving energy is among the benefits of a fast tag inventorying reader too. A use-case, which does not demand for a high tag update rate but is sensitive to energy consumption. Then the shorter “RF-ON” times preserve energy since the most power-hungry part of a reader is typically the RF transmitter.

1 Description

Most countries and their respective radio frequency regulations define a number of frequency channels that may or have to be used by a UHF RFID reader. Additionally, frequency channel allocation times may be defined to limit the time a reader is allowed to transmit on a specific frequency channel. Some rulings such as the FCC extend these requirements these aim for a balanced usage of the frequency channels.

A common approach of UHF RFID readers is to stay on a frequency channel for the maximum allowed time. When this time is used up the reader ceases RF transmission, tunes its VCO to another channel frequency and powers-up the RF transmitter again to continue tag inventory. In some reader configurations it can make sense to change this frequency hopping approach to a dynamic allocation time of the frequency channels.

Before going into detail of dynamic allocation times the properties of the conventional frequency hopping approach shall be discussed.

The next two sections below explain why a fixed channel allocation time might limit the inventory speed of a reader.

2 Reader to reader interference

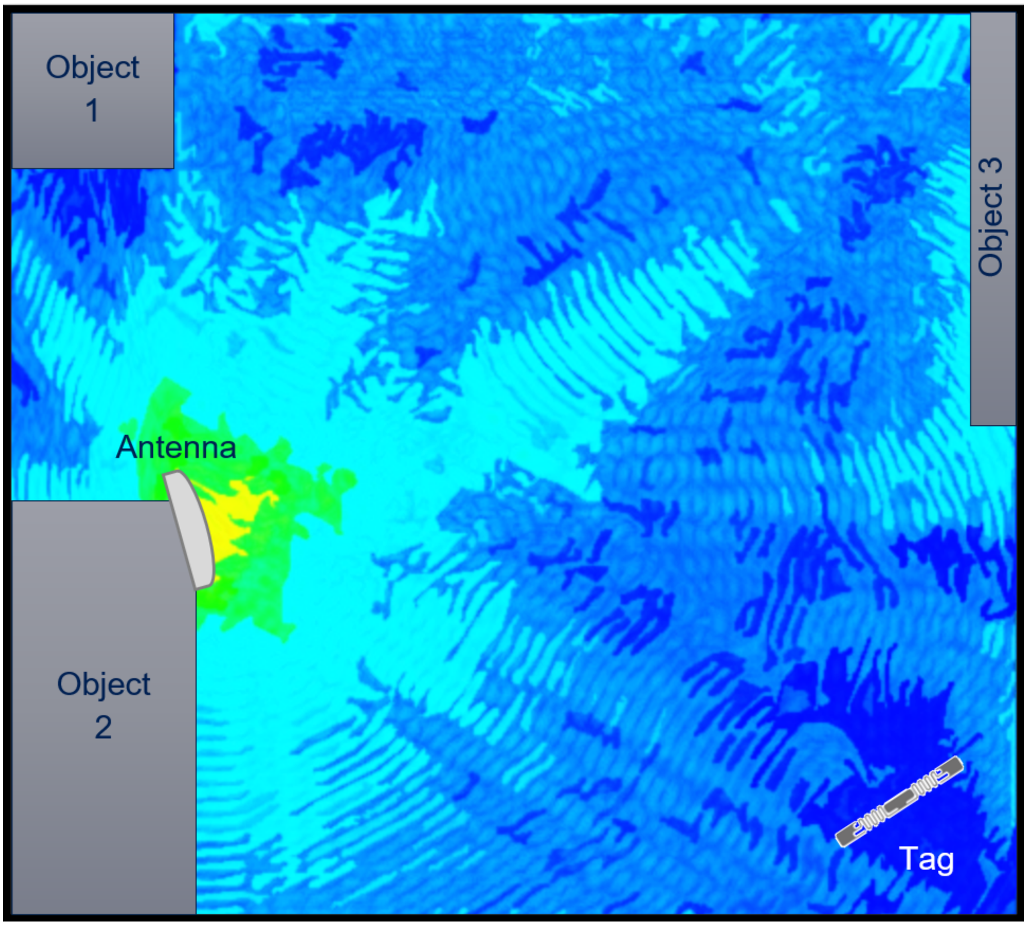
Consider a deploying of several UHF RIFD readers in one location for simultaneous inventorying tags. Since UHF RFID readers typically (pseudo-) randomly pick a frequency channel for their transmission, some degree of collisions is expected.

The requirements of frequency hopping target a fair usage of the available frequency channels and are trying to minimize collisions on the air-interface among readers. If it happens that two readers are trying to transmit on the same frequency channel, then potentially none of the readers involved can successfully communicate with a tag for the remainder of their respective channel allocation time. Therefore, a portion of the allowed allocation time is wasted. In this case it would have been more efficient, for the readers involved, to try a different frequency channel as soon as a collision situation became evident. If the congested frequency channel is released earlier, another reader can use it again and the collided readers, due to the pseudo randomness of the hopping, can select an unoccupied frequency channel themselves.

3 Multipath fading

Multipath fading is a challenging property that resides in the nature of electromagnetic waves at an ultra-high frequency. When the electromagnetic waves are radiated inside a building, they travel from the antenna onwards into the surrounding space, and eventually encounter matter (wall, ceiling, object, etc.). An electromagnetic wave is then either reflected or absorbed inside this room. Depending on the dimensions of the room and the objects inside, the involved material properties as well as the wavelength, the electromagnetic waves reach certain locations via different paths. For instance, one location can be reached by the electromagnetic wave via a direct line, but also via a reflection off a wall or ceiling. The various rays of electromagnetic waves reaching this location interfere with each other. Depending on the instantaneous phase of the various electromagnetic-waves, constructive or destructive interference occurs. In other words, the electromagnetic field density is increased or decreased. Looking at the volume inside a room, multipath related interference of electromagnetic waves causes a specific pattern of nonuniform electromagnetic field density with locations with an abundance of energy or in the other extreme, very low field energy for a UHF RFID tag.

Figure 1. Multipath fading visualization



For passive UHF RFID tags, which do not have an energy source of their own, this can be quite problematic. In order for the tag IC to be operational, a certain minimum level of the electromagnetic field density is necessary from which energy can be drawn.

Easy to understand that if, for instance, a tag resides at a location where the electromagnetic-field density is at its lowest, then this tag is unable to operate and therefore never responds to a reader. It is said that this tag is in a “dead-spot” or a “reading-hole”. If only something would change the inference pattern of the electromagnetic field density, then the tag might be lucky enough to get out of the dead-spot, start-up, and be ready to communicate with a reader.

The interference pattern can be changed by a different reader position, orientation, a different transmit frequency, by moving an object inside the room, or more general by changing the geometry of the volume inside the room.

Note: *If anything of the above is happening, the dead-spots only shift their position. For a different tag in another position, this shift could mean the end of its power supply and is therefore rendered inoperative.*

In order to shift the dead-spots, the parameter a reader can most easily change is the transmit frequency. So, by changing the transmit frequency additional tags might be powered-up while at the same time the others lose power and shut down.

Consider a situation in which a reader has discovered all powered tags on a certain frequency channel and there is still plenty of channel allocation time left. Unless nothing changes the interference pattern of the electromagnetic field density it is pointless for the reader to continue transmitting on this frequency channel. It might make more sense to change the transmit frequency channel in the hope that additional, yet undiscovered tags, power-up, and respond back to the reader.

The two points described above, the reader-to-reader interference and multipath fading can render the conventional frequency hopping with a fixed frequency channel allocation time inefficient. For the remainder of this document, the term channel allocation time is replaced by the term sending time. Therefore, frequency hopping strategies that handle the frequency channel sending time dynamically are introduced in this application note.

The section below describes the conventional frequency hopping strategy as well as the dynamic ones.

4 Frequency hopping strategies

4.1 Wait mode (default)

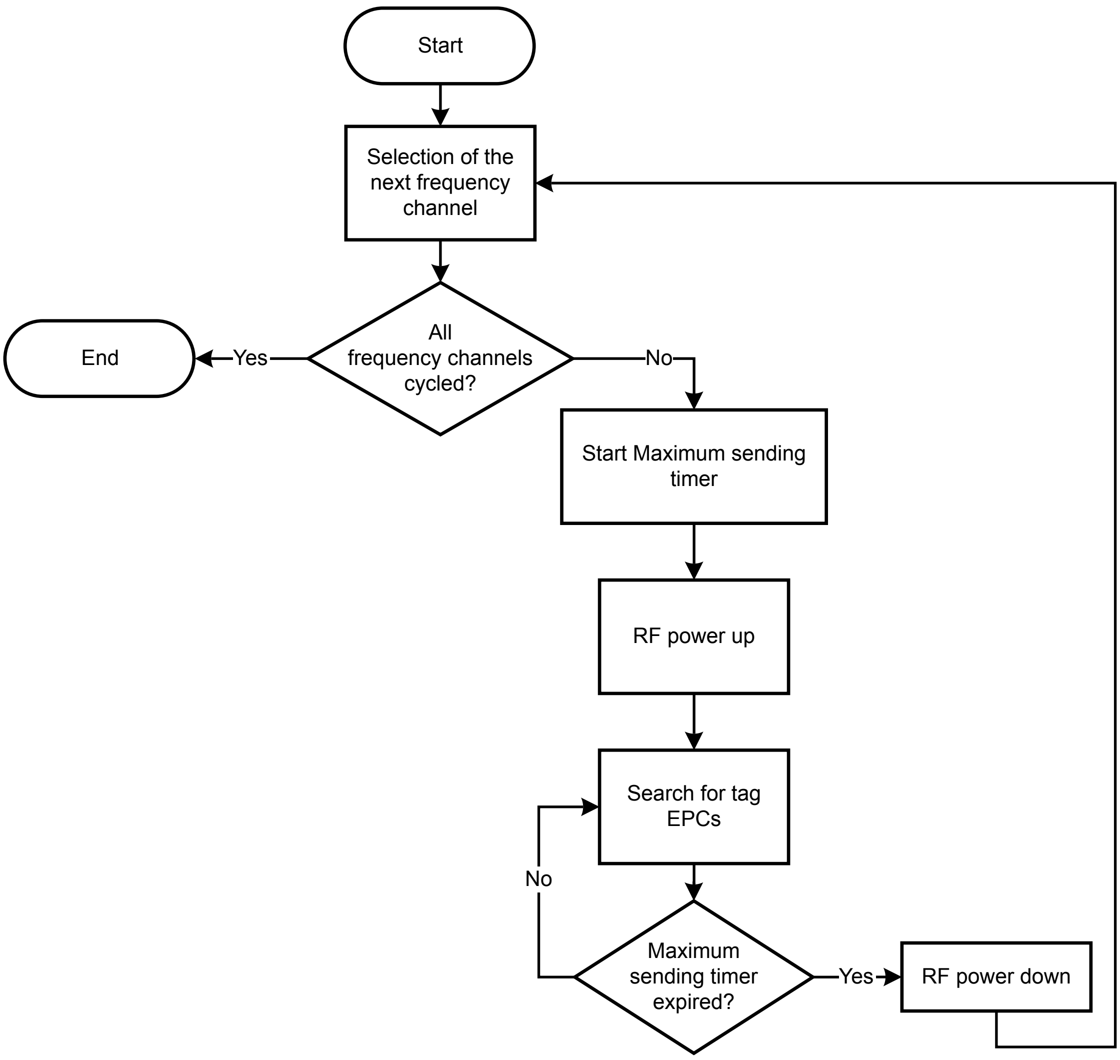
This mode represents the conventional frequency hopping strategy. The reader transmits on a frequency channel for a fixed user defined sending time. For ETSI frequencies, the maximum sending time is set to 4 seconds per default, but this value can be adjusted if required. For the FCC frequencies, the maximum sending time is fixed to 400 ms.

Note: To comply with FCC rules, a frequency channel is reused once the reader has transmitted on all available frequency channels for 400 ms. Since the maximum sending time is limited to 400 ms, and the reader is hopping through 50 frequency channels, a reuse does not happen before 20 seconds.

The reader stops transmission a few milliseconds before the max. sending time is reached to ensure a complete last tag communication on this frequency channel avoiding a violation of the max. sending time definition.
Once the max. sending time is reached the reader ceases transmission and resumes transmission on the next pseudo-randomly chosen frequency channel and the process repeats.

The flow chart below shows the process flow for one cycle through all frequency channels for the WAIT frequency hopping mode.

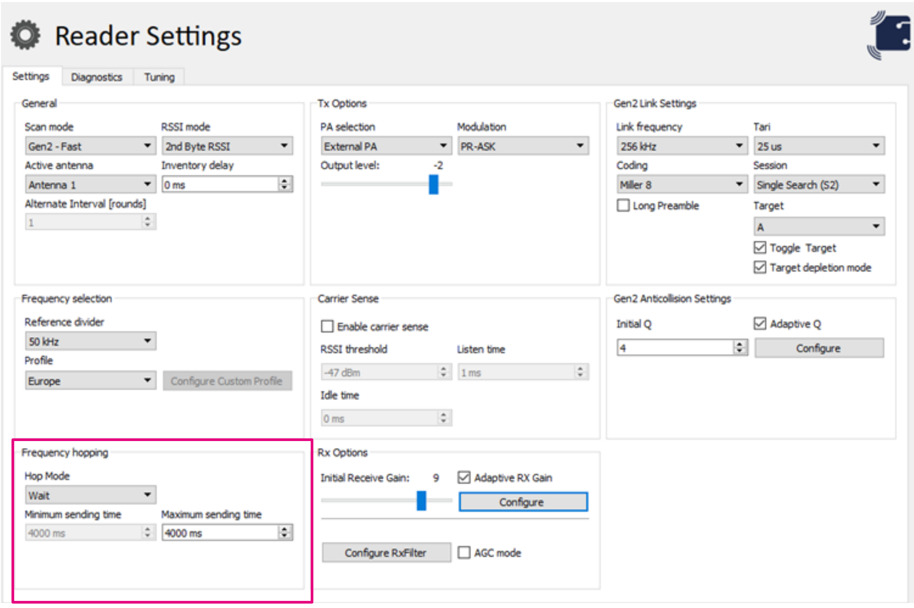
Figure 2. **Flow chart - Wait for frequency hopping mode**



The wait frequency hopping mode is the default mode in the ST25RU3993 reader suite.

To use a different frequency hopping mode, open the Reader settings dialog in the ST25RU3993 reader suite, and change the Hop mode in the frequency hopping section.

Figure 3. Frequency hopping modes in the ST25RU3993 reader suite

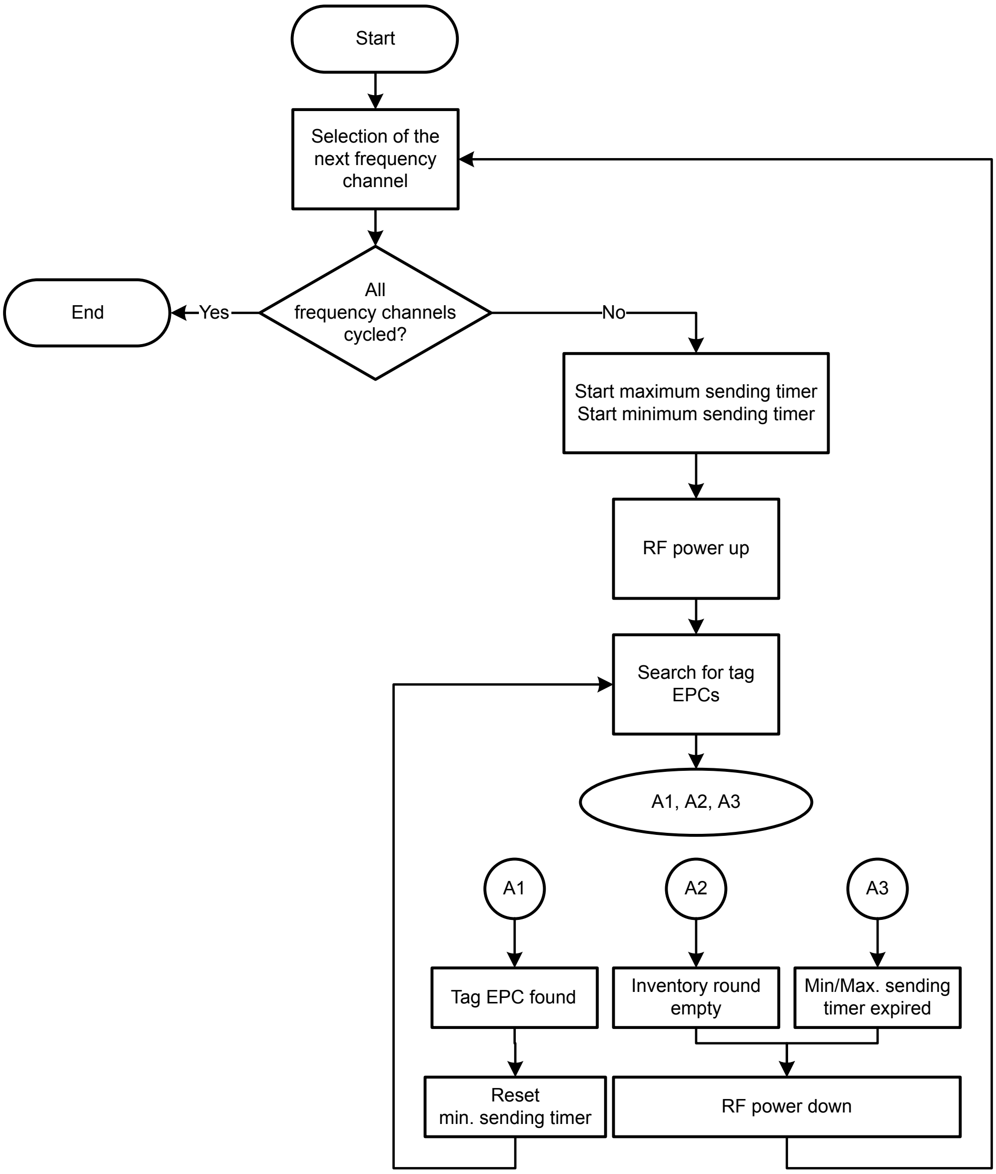


4.2 Fast mode

This hopping mode is handling the actual sending time for a frequency channel dynamically. Based on the outcome of a processed anti-collision slot during an inventory round or user defined min./max. sending time values, the reader continues to transmit on the frequency channel or decides to hop to the next one. The max. sending time value defines the transmit duration after which the reader must hop to the next frequency channel. If for the duration of the min. sending time, no tag EPC was received, the reader hops to the next frequency channel. The reader may hop to the next frequency even before the min sending time is reached if the last inventory round (starting with a Query or a Query Adjust command) is yielding no tag EPCs. The min. sending time is reset every time a tag was found.

The flow chart below shows the process flow for one cycle through all frequency channels for the fast frequency hopping mode. Once all frequency channels have been used for transmission the process is started over again cycling through the pseudo randomly generated frequency list.

Figure 4. **Flow Chart - Fast frequency hopping mode**

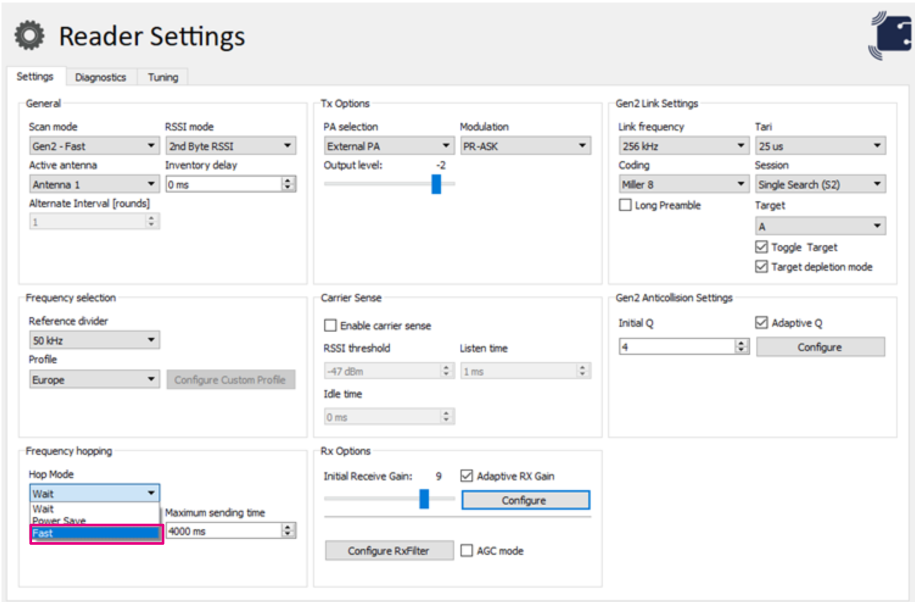


To summarize: The FAST frequency hopping mode is favoring frequency channels that yield tag EPCs by assigning more sending time to that frequency channel. Transmissions on frequency channels for which the reader is unable to find tags are ended early.

Note: Due to the implementation of this frequency hopping mode the usage for USA frequencies is not possible. This mode does not comply with FCC rulings as frequency channels can be re-used within 20 seconds. This rule applies for using 50 frequency channels. For ETSI frequencies on the other hand this hopping mode is applicable.

To change the frequency hopping mode to the FAST mode, open the Reader Settings dialog in the ST25RU3993 Reader Suite and change the Hop Mode in the Frequency hopping section

Figure 5. Fast frequency hopping mode in the ST25RU3993 reader suite



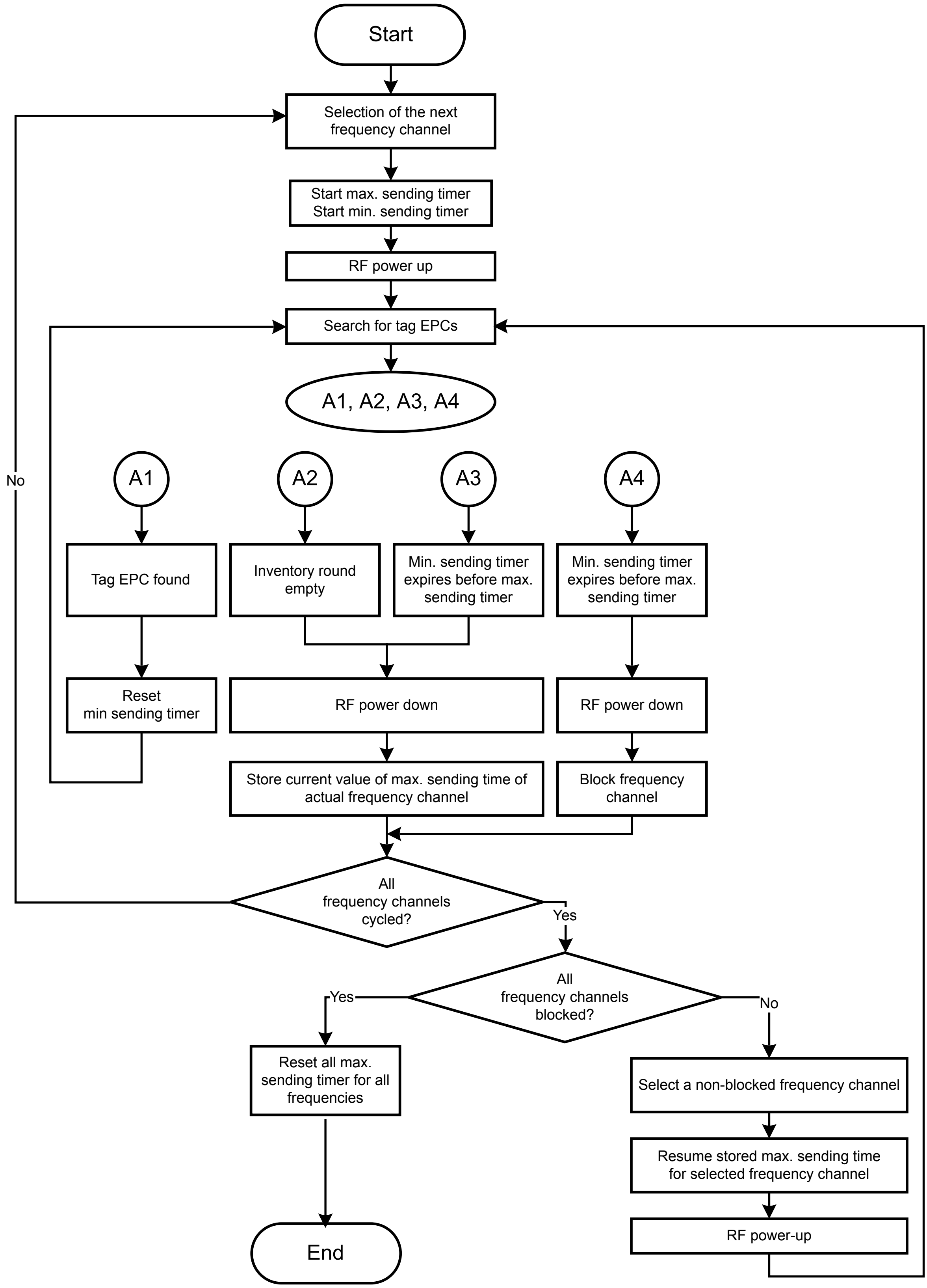
4.3 Fast FCC mode

The Fast FCC hopping mode is handling the actual sending time for a frequency channel dynamically. Based on the outcome of a processed anti-collision slot during an inventory round or user defined min. sending time values, the reader continues to transmit on the frequency channel or decides to hop to the next one. If for the duration of the min. sending time, no tag EPC was received, the reader hops to the next frequency channel. The reader may hop to the next frequency even before the min sending time is reached if the last inventory round (starting with a Query or a Query Adjust command) is yielding no tag EPCs. The min. sending time is reset every time a tag was found. After 400 ms the reader automatically hops to the next frequency channel.

Fast FCC keeps a record of the total transmission time of each frequency channel. If a frequency channel was used for 400 ms this frequency channel will be blocked for any further transmission. If all frequency channels are blocked (which happens after 20 seconds transmission time of the reader) the transmission time record for all frequency channels is reset and all channels can be used for transmission again.

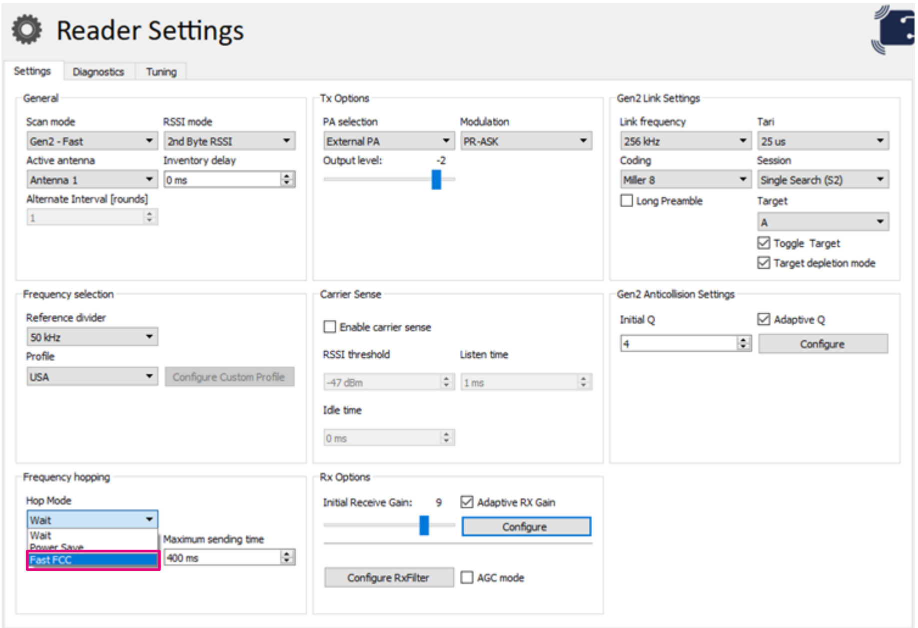
The flow chart below shows the process flow of the Fast FCC frequency hopping mode.

Figure 6. Flow Chart - Fast FCC frequency hopping mode



To change the frequency hopping mode to the FAST FCC mode, open the reader settings dialog in the ST25RU3993 Reader suite and change the Hop mode in the frequency hopping section.

Figure 7. Fast FCC frequency hopping mode in the ST25RU3993 reader suite



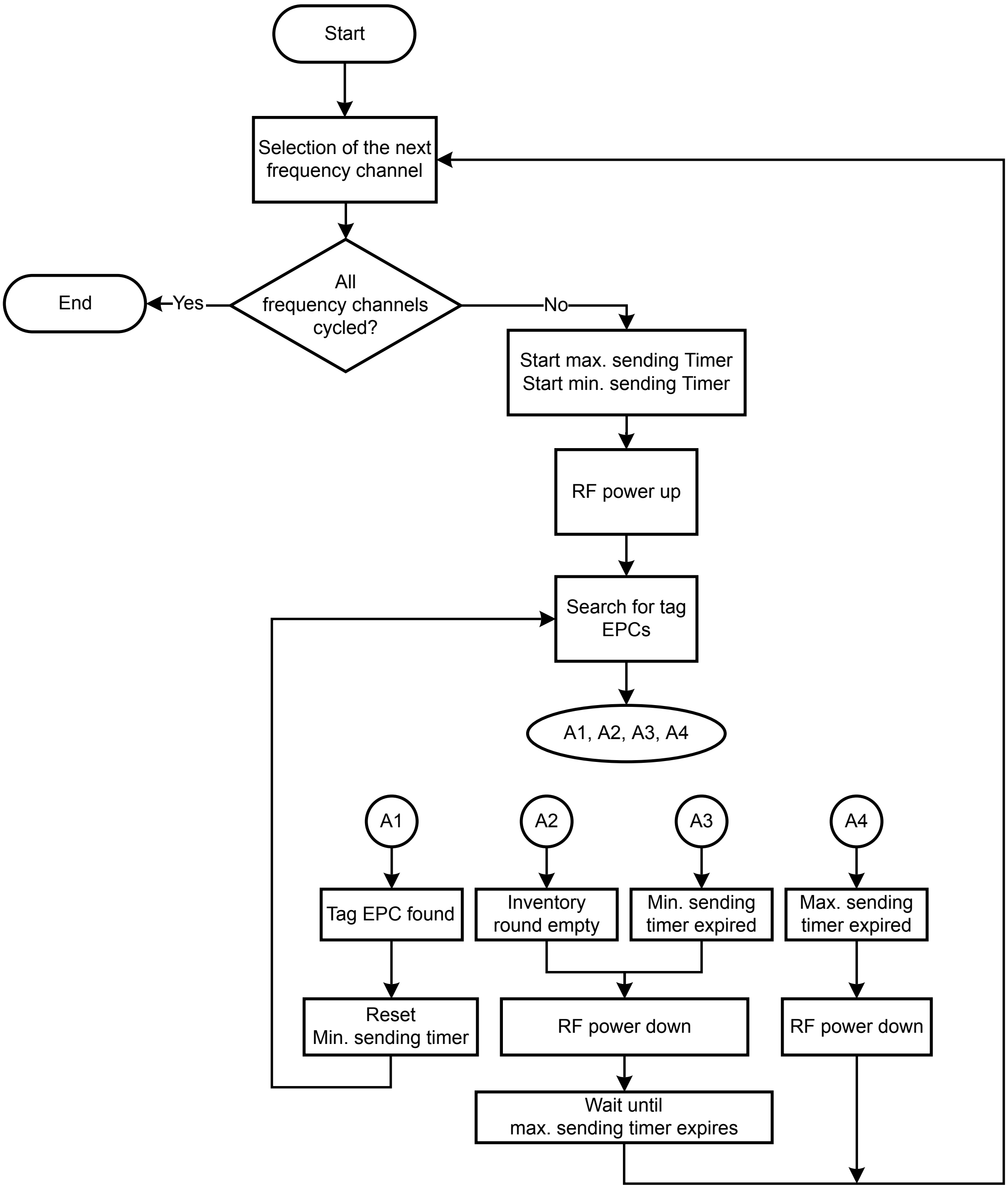
4.4 Power save mode

This hopping mode is handling the actual sending time for a frequency channel dynamically. Based on the result of a processed anti-collision slot during an inventory round, or user defined min./max. time values, the reader continues to transmit on the frequency channel or ceases the transmission until the maximum sending time is expired. When this happens, the reader continues the transmission on the next frequency channel.

Note: This hopping mode can be used for the ETSI and FCC frequencies.

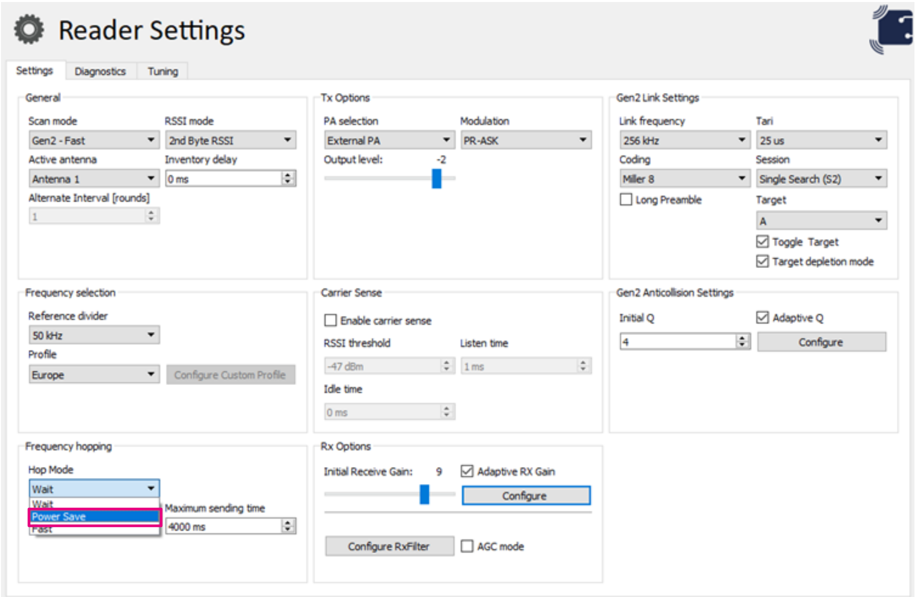
The flow chart below shows the process flow of the power save frequency hopping mode.

Figure 8. Flow chart - Power save frequency hopping mode



To change the frequency hopping mode to the power save mode, open the reader settings dialog in the ST25RU3993 reader suite and change the hop mode in the frequency hopping section.

Figure 9. Power save frequency hopping mode in the ST25RU3993 reader suite



5 Verification tests

To verify the benefits of the introduced frequency hopping modes, two reading scenarios were created for the test.

In the first scenario, the frequency hopping modes were tested in a multipath fading environment, which is an environment representing an office. For the remainder of this document, this scenario is referred to as setup A. The second scenario, used for the verification tests of a reader-to-reader interference with multipath fading condition, was created using a test fixture, which is referred to as setup B.

For all tests using the FAST or the FAST FCC frequency hopping mode, the goal was to inventory as many unique tags EPCs as possible, as fast as possible.

For the SAVE frequency hopping mode, on the other hand, the goal was to achieve a similar inventory performance measured in number of unique tags as with the conventional frequency hopping mode but with less RF ON time, to save energy.

Test setup A – Multipath fading (simulated office environment)

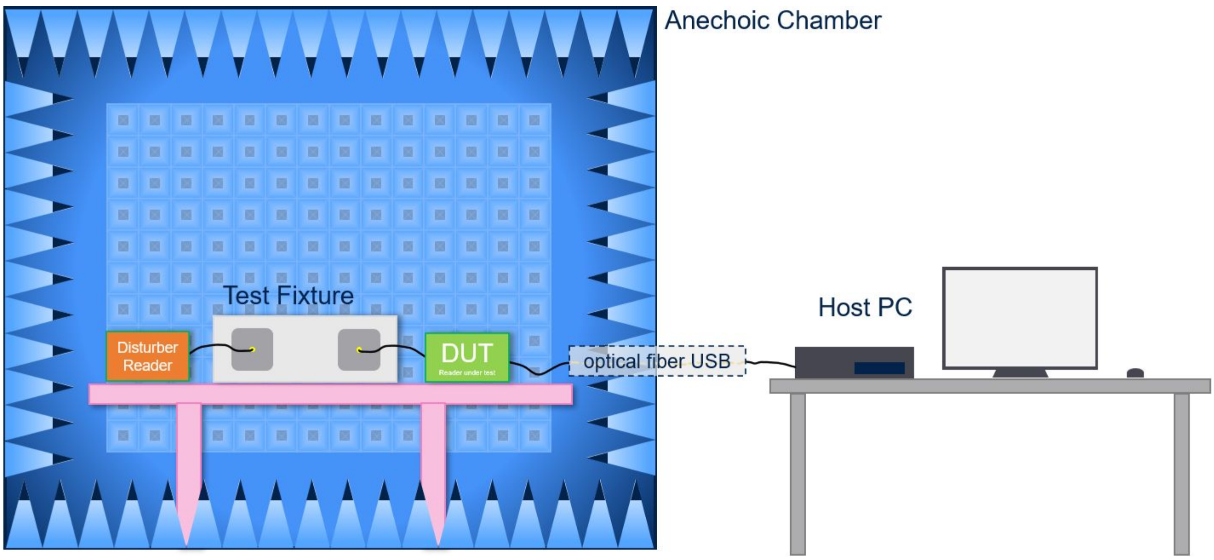
Test setup A includes the test reader (DUT) and tags (> 160) laid out in a simulated office environment. The test setup A was used to test the introduced frequency hopping modes in a multipath fading scenario. The tags were deliberately laid out in an area that was much larger than the assumed read-zone of the reader. Therefore, it was expected that some tags might not be discovered by the reader.

Test setup B – Reader-to-reader interference / Multipath fading

Test setup B comprised of a test fixture that enclosed a larger number of tags (> 300) and two reader antennas in a reflective environment. Test setup B was primarily used to test the reader-to-reader interference but due to the interior design of the test fixture multipath fading effects were assumed to be present as well. Adding the dense tag layout inside the test fixture it created a challenging environment for the reader under test. The test fixture should simulate a worst-case scenario to ensure a performance margin over real-world scenarios.

The test fixture was placed inside an anechoic chamber to avoid disturbances from exterior sources. The reader was controlled from the outside using an optical USB connection to the host PC. The test reader (DUT) was connected to antenna 2 while a second reader was connected to antenna 1. The second reader was constantly inventorying tags and therefore was acting as a disturber for the test reader.

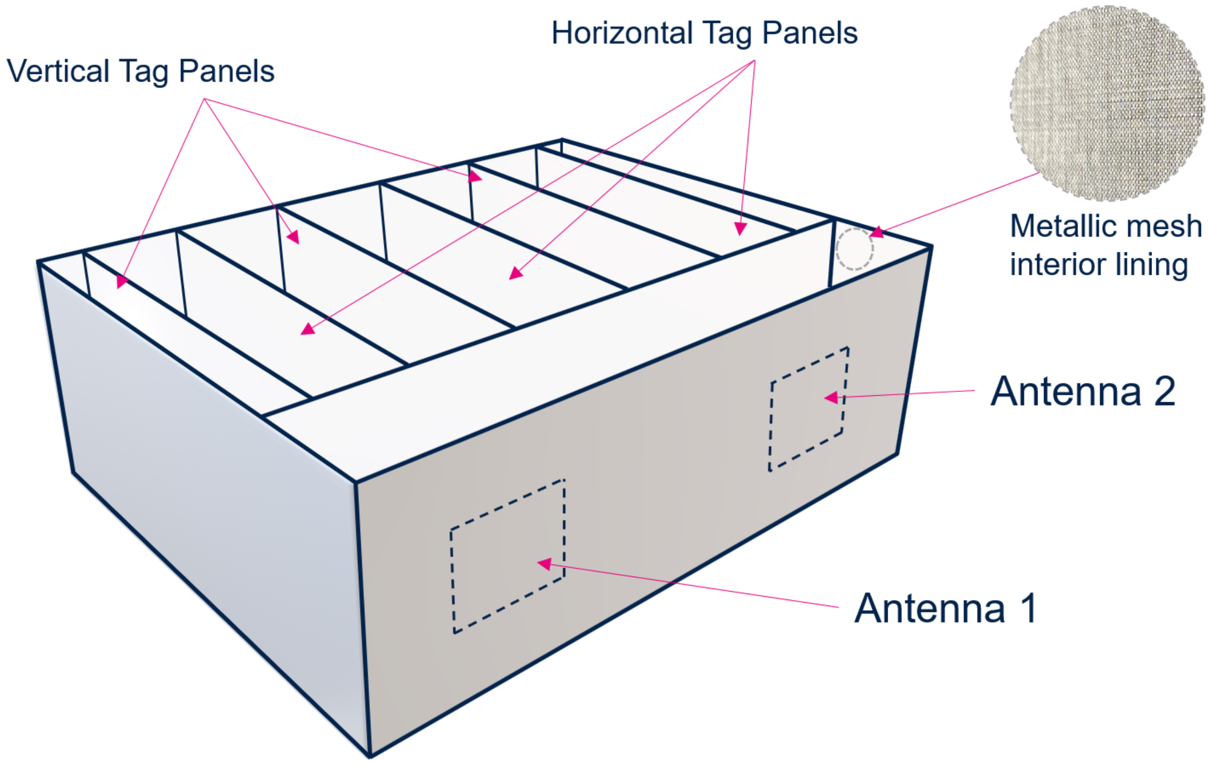
Figure 10. Test setup B



5.1 Test fixture

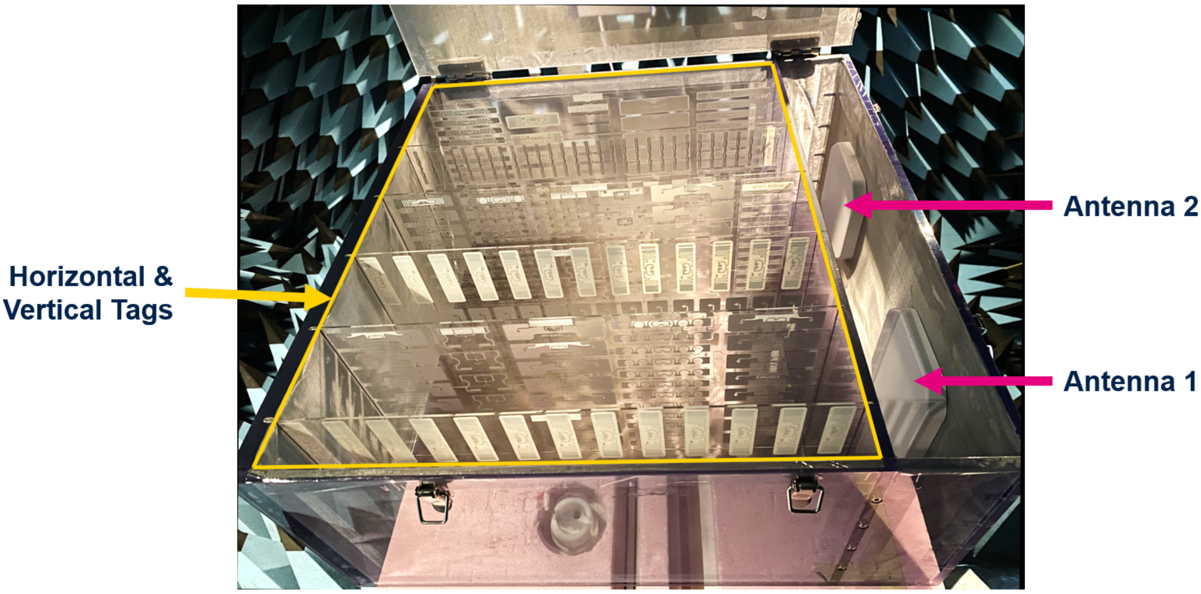
The test fixture was an enclosure, which contained > 300 tags as well as two reader antennas. The interior walls of the enclosure were fitted with a metallic mesh lining. The metallic mesh causes reflections for the RF radiation, which challenges the reader and tags as a multipath fading environment is created. In addition, the narrow-spaced setup of the tags inside causes RF shadowing effects, which pronounced dead spots inside. The tags of various types from various vendors were aligned horizontally and vertically.

Figure 11. Test fixture for test setup B



The image below shows a picture of the test fixture with the lid opened providing a look inside at the tags and the reader antennas.

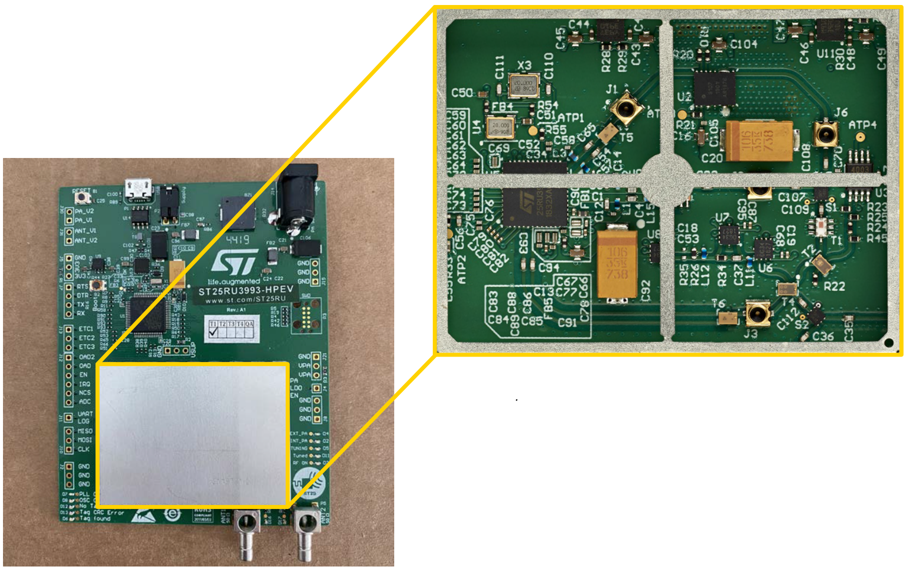
Figure 12. Test setup impression



5.2 Test reader

All tests were performed using a ST25RU3993-HPEV reader.

Figure 13. ST25RU3993-HPEV reader



6 Test results

Each test result plot shows the first read event of a tag-EPC over the inventory time of the test reader (blue line). Tag EPCs that were inventoried a second time, or more, are not displayed. Therefore, the plot essentially shows the number of unique tag-EPCs that the test reader was able to discover.

All the tests were conducted with the test reader inventorying tags in Session 2. The test reader was using a proprietary Target switching mode (Target Depletion Mode) to select the tags inventoried flags. For more information regarding the Session 2 and Targets, please refer to the current version of the Gen2/ISO18000-63 standards.

Additional information about the Target depletion mode can be found in the current version of the user manual of the ST25RU3993-EVAL board software (UM2268).

The plots also show a reference trace (gold line) to provide a visual comparison of the corresponding frequency hopping mode with the conventional frequency hopping mode (WAIT).

Results are presented for FCC and ETSI frequency profiles.

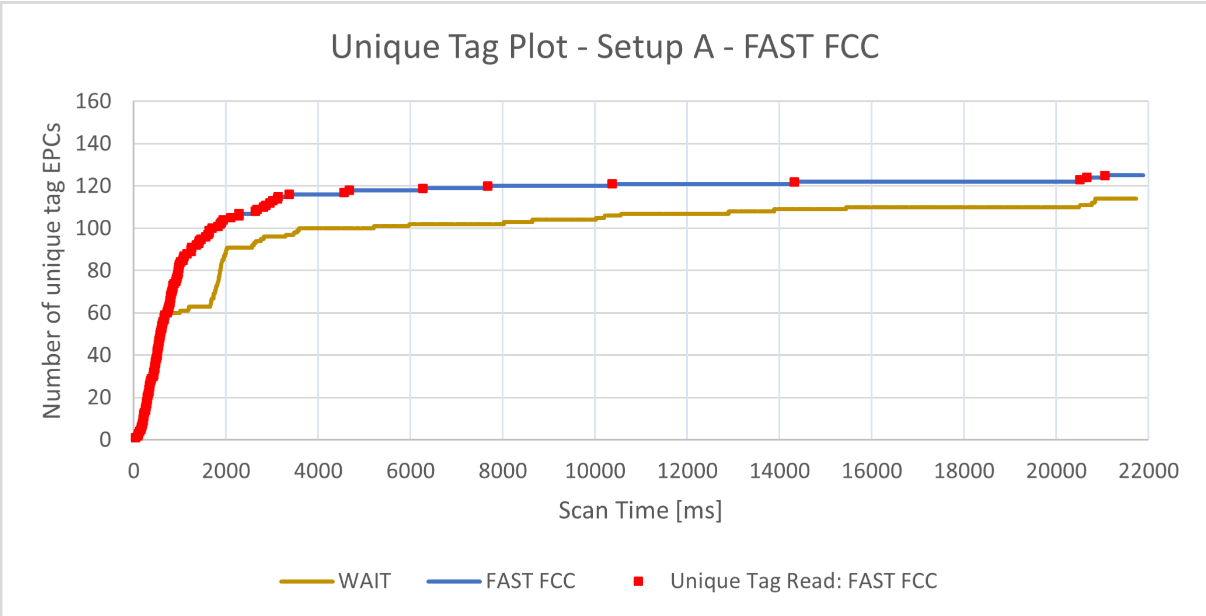
6.1 Multipath fading – Simulated office environment (test setup A)

The test reader was inventorying tags laid out in a simulated office environment.

6.1.1 Frequency profile: FCC

Frequency hopping mode: Fast FCC

Figure 14. **Unique tag plot - Setup A - Fast FCC**



The FAST FCC frequency hopping mode exhibits in test setup A an advantageous inventory performance compared to the conventional frequency hopping mode. With the FAST FCC frequency hopping mode, the test reader was able to inventory tags more quickly and for the given scan time it was able to discover more unique tags.

Test reader configuration:

- Frequency profile: FCC
- Frequency hopping mode: FAST FCC
- Minimum sending time 100 ms
- Maximum sending time 400 ms
- BLF: 256 kHz

- Coding: M8
- S2

Frequency hopping mode: SAVE

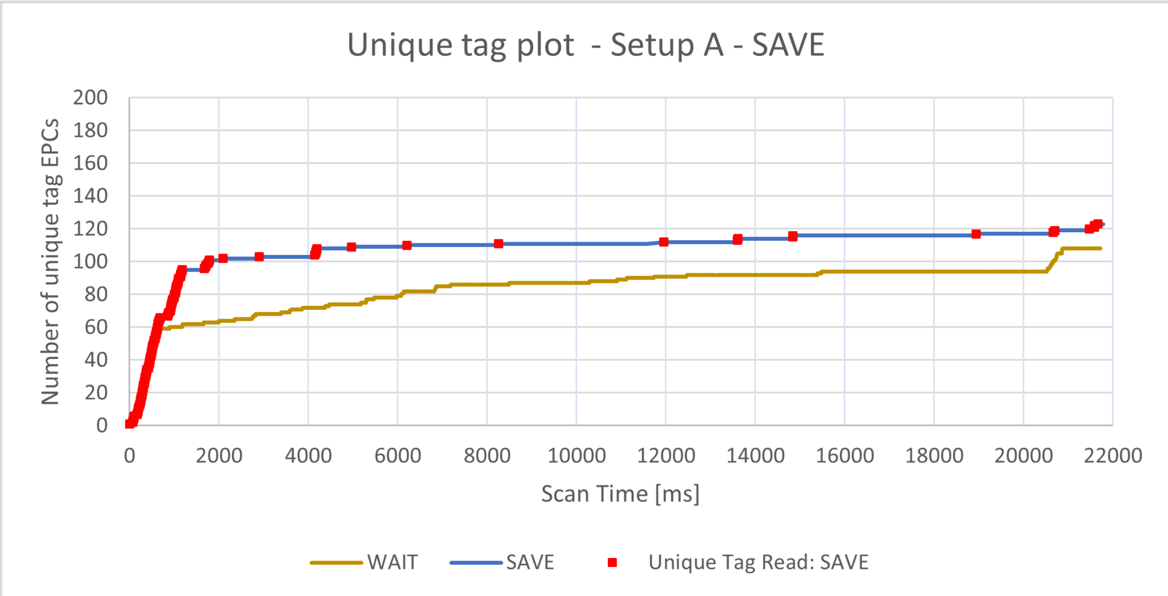


Figure 15. **Unique tag plot - Setup A – SAVE**

The SAVE frequency hopping mode can identify more unique tags as with the wait frequency hopping mode. In the first seconds of the inventory scan the SAVE mode is even discovering tags at a faster rate. When comparing the RF ON time, the SAVE mode had the RF power switched ON approximately 2.68 sec. which is about 12 % of the total inventory time of 22 sec. Therefore, the SAVE frequency hopping mode used less power compared to the WAIT frequency hopping mode while outperforming the conventional frequency hopping mode.

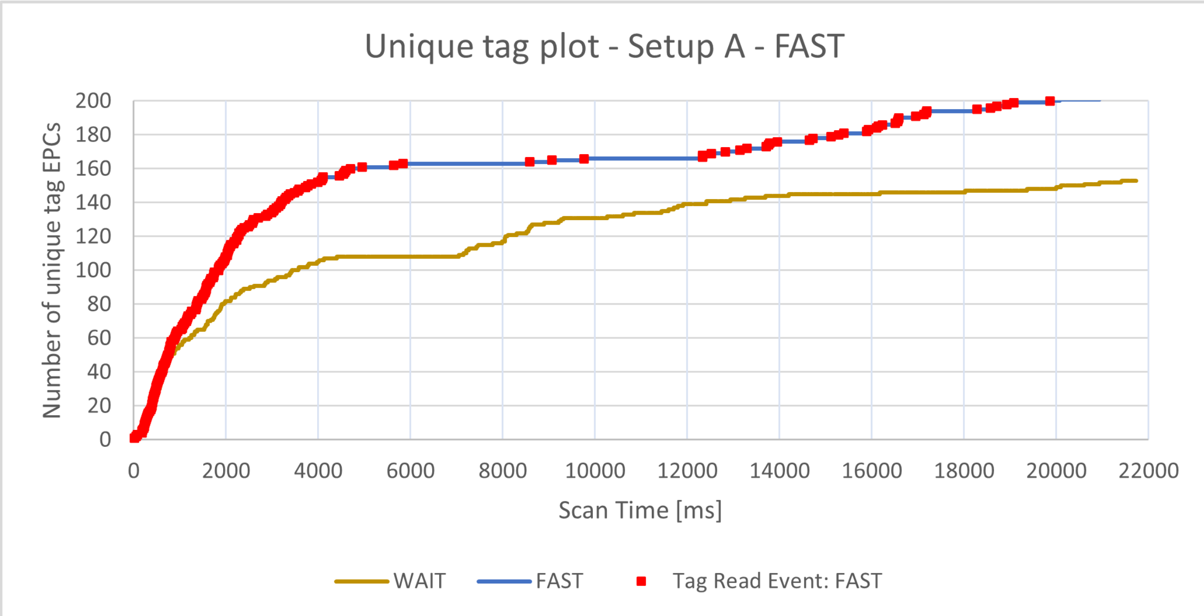
Test reader configuration:

- Frequency profile: FCC
- Frequency hopping mode: SAVE
- Minimum sending time 100 ms
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S2
- Starting Q: 8

6.1.2 Frequency profile: ETSI

Frequency hopping mode: FAST

Figure 16. Unique tag plot - Setup A - FAST - ETSI



The FAST frequency hopping mode in test setup A shows an advantageous inventory performance compared to the conventional frequency hopping mode. With the FAST frequency hopping mode, the test reader was able to inventory tags more quickly and for the given scan time it was able to discover more unique tags.

Test reader configuration:

- Frequency profile: EU (ETSI)
- Frequency hopping ode: FAST
- Minimum sending time 50 ms
- Maximum sending time 1000 ms
- BLF: 256 kHz
- Coding: M8
- S2

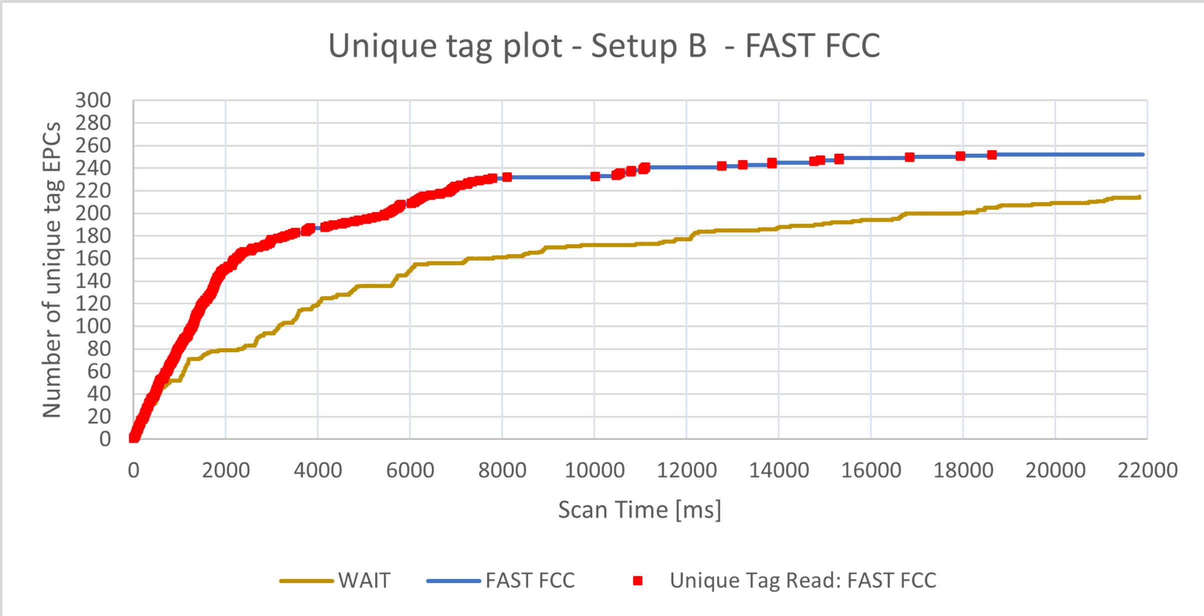
6.2 Reader-to-reader interference / Multipath fading - Test result (test setup B)

The test reader was inventorying tags inside the test fixture while at the same time a second reader was acting as a disturber by inventorying the same tag population.

6.2.1 Frequency profile: FCC

Frequency hopping mode: Fast FCC

Figure 17. **Unique tag plot - Setup B - Fast FCC**



The FAST FCC frequency hopping mode exhibits a clear advantage compared against the conventional frequency hopping mode while a second reader is active. With the FAST FCC frequency hopping mode, the test reader is able to inventory tags more quickly and for the given scan time it is able to discover more unique tags.

Test reader configuration:

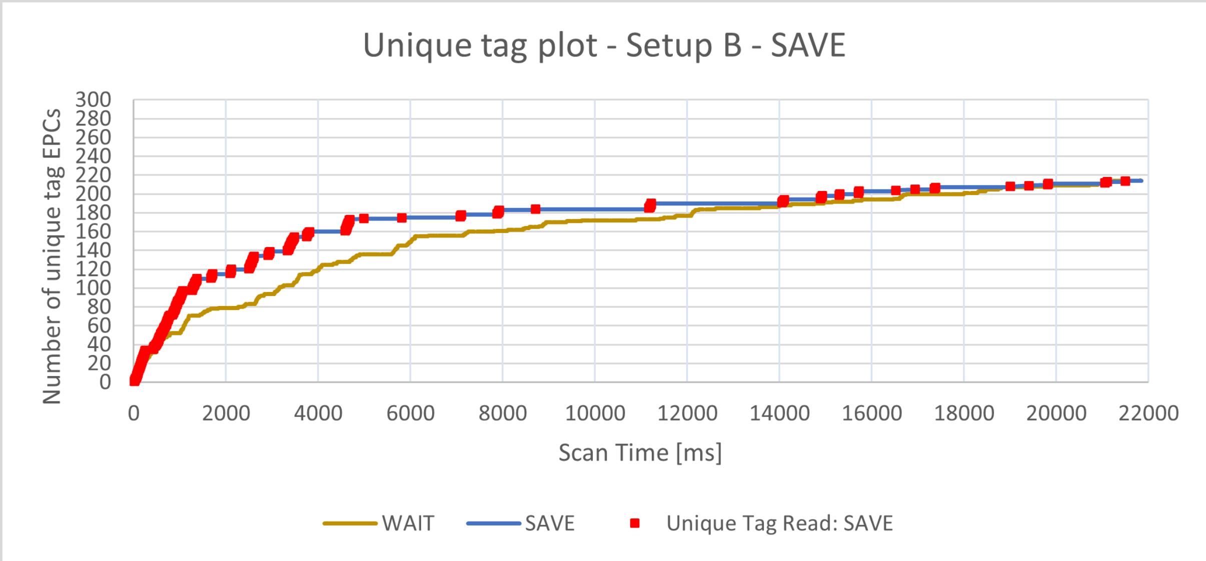
- Frequency profile: FCC
- Frequency hopping mode: FAST FCC
- Minimum sending time 100 ms
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S2

Disturber reader configuration:

- Frequency profile: FCC
- Frequency hopping mode: WAIT
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S3

Frequency hopping mode: Save

Figure 18. **Unique tag plot - Setup B - Save - FCC**



The SAVE frequency hopping mode shows the same number of unique tags as with the WAIT frequency hopping mode while a disturber reader is active. In the first few seconds of the inventory scan, the SAVE mode is even discovering tags at a faster rate. When comparing the RF ON time, the SAVE mode had the RF power switched ON approximately 3.58 s, which is nearly 16% of the total inventory time of 22 sec. Therefore, the SAVE frequency hopping mode used less power compared to the WAIT frequency hopping mode while reaching a similar inventory performance.

Test reader configuration:

- Frequency profile: FCC
- Frequency hopping mode: SAVE
- Minimum sending time 20 ms
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S2

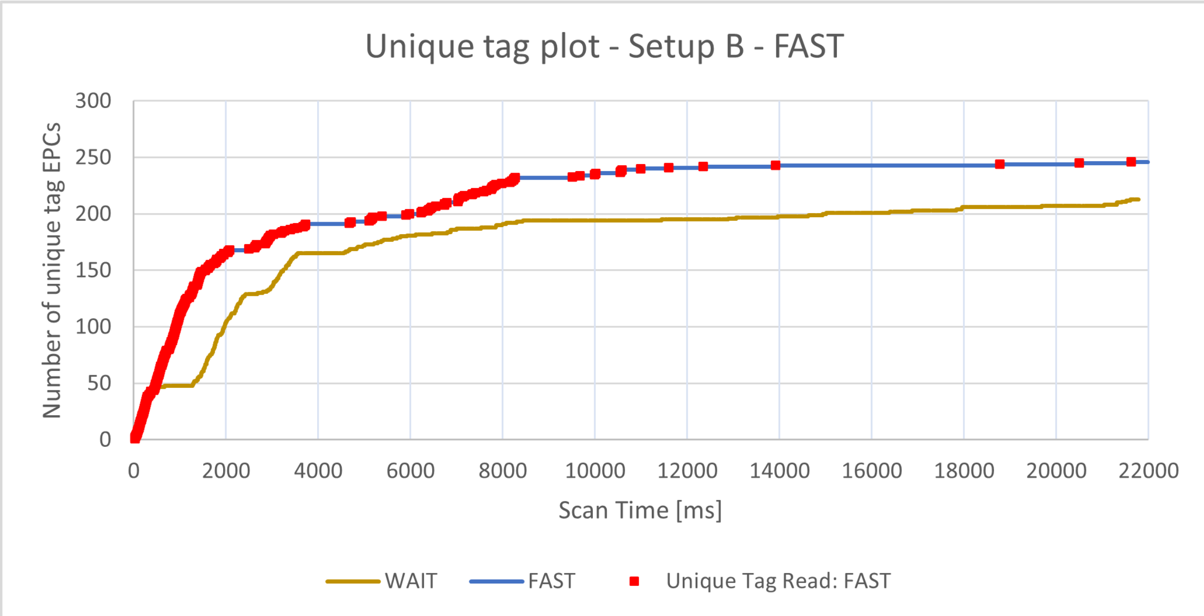
Disturber reader configuration:

- Frequency profile: FCC
- Frequency hopping mode: WAIT
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S3

6.2.2 Frequency profile: ETSI

Frequency hopping mode: FAST

Figure 19. **Unique tag plot - Setup B - Fast - ETSI**



The FAST frequency hopping mode once again shows a clear advantage compared to the conventional frequency hopping mode while a disturber reader is active. With the FAST frequency hopping mode, the test reader was able to inventory tags more quickly and for the given scan time it was able to discover more unique tags.

Test reader configuration:

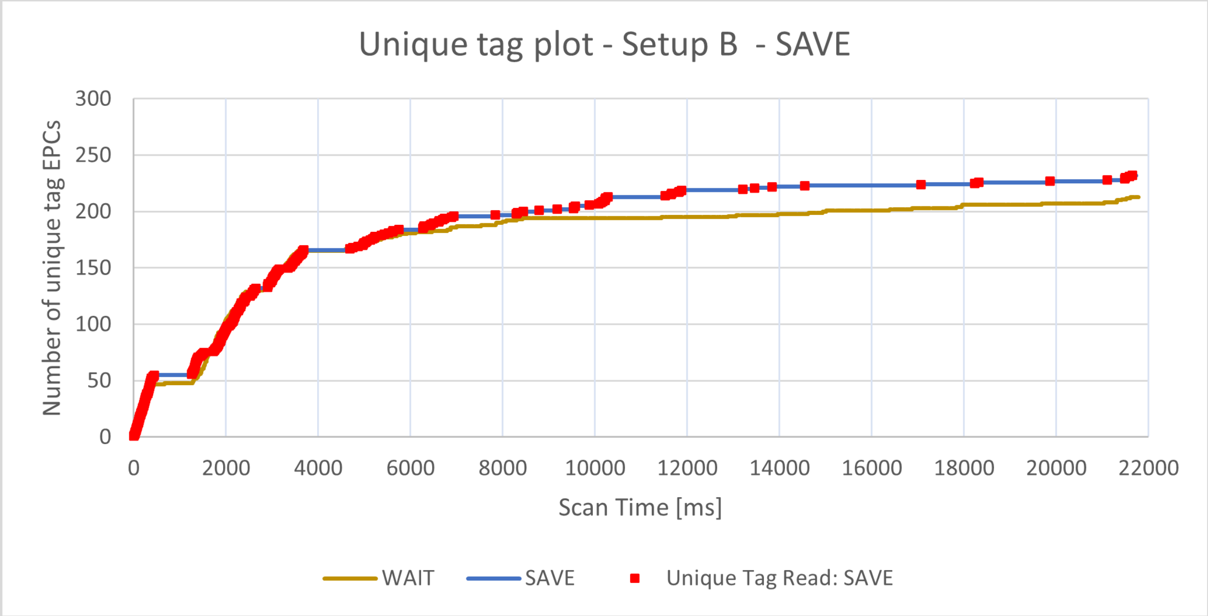
- Frequency profile: EU
- Frequency hopping mode: FAST
- Minimum sending time 100 ms
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S2

Disturber reader configuration:

- Frequency profile: EU
- Frequency hopping mode: WAIT
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S3

Frequency hopping mode: SAVE

Figure 20. **Unique tag plot - Setup B - Save ETSI**



The SAVE frequency hopping mode shows about the same number of unique tags discovered as with the WAIT frequency hopping mode while a disturber reader is active. When comparing the RF ON time, the SAVE mode had the RF power switched ON ~15 sec., which is approximately 69% of the total inventory time of 22 sec. Therefore, the SAVE frequency hopping mode used less power compared to the WAIT frequency hopping mode.

Test reader configuration:

- Frequency profile: EU
- Frequency hopping mode: SAVE
- Minimum sending time 100 ms
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S2

Disturber reader configuration:

- Frequency profile: EU
- Frequency hopping mode: WAIT
- Maximum sending time 400 ms
- BLF: 256 kHz
- Coding: M8
- S3

7 Conclusion

The introduced FAST frequency hopping modes show a better inventory in terms of how fast the reader can inventory tags after starting to search for tags. This improvement is exhibited even if the reader is competing with another reader that is interfering on the frequency channels. The POWER SAVE frequency hopping mode shows a similar inventory performance while using only a fraction of the RF ON time compared to the conventional frequency hopping mode (WAIT). This performance improvement can be observed if the reader is inventorying the tag population in the session 2 of 3 in combination with target switching using the Target depletion mode.

Revision history

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09-Jun-2022	1	Initial release.

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