AN5890

Application note

Inventorying nonmoving tag populations for ST25RU3993

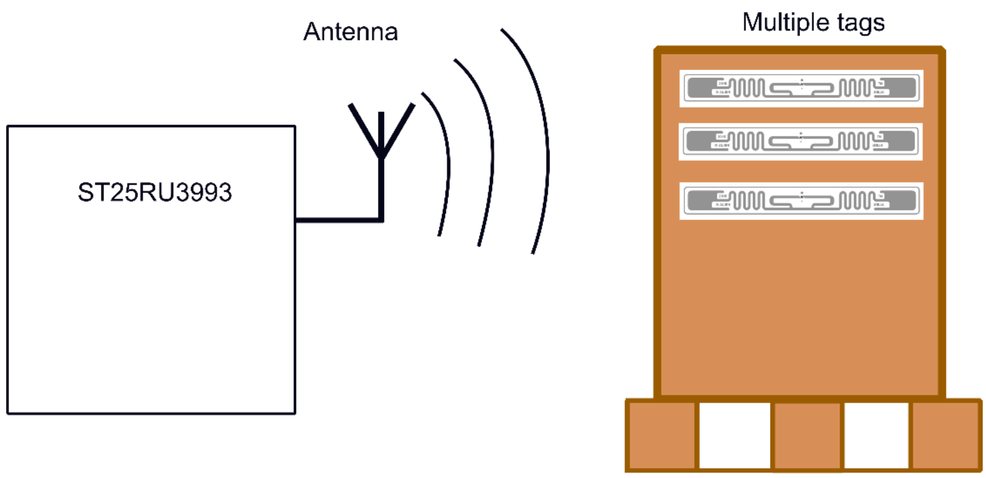
Introduction

This application note describes the use case of reliably inventorying a large, nonmoving tag population within a defined volume, for instance, a pallet, or a nonreflective enclosure, using the ST25RU3993-HPEV board. This board is a high-power RAIN® (UHF) RFID reader system based on the integrated reader IC ST25RU3993.

Dead spots within the volume are a result of tags being near each other. The problem of multipath fading and shadowing effects is addressed in this application note. The goal of this work is to find the optimum reader settings and an optimized hardware setup, to reduce the challenging effects and to read the static tag population in a short period of time.

As an example, the application of reading a pallet with tagged office supplies placed in boxes on a pallet, is applied. The process of inventorying the total tag population while optimizing the read rate, including measurement results, are described in the following sections.

Figure 1. **Reading large tag populations in a defined volume**



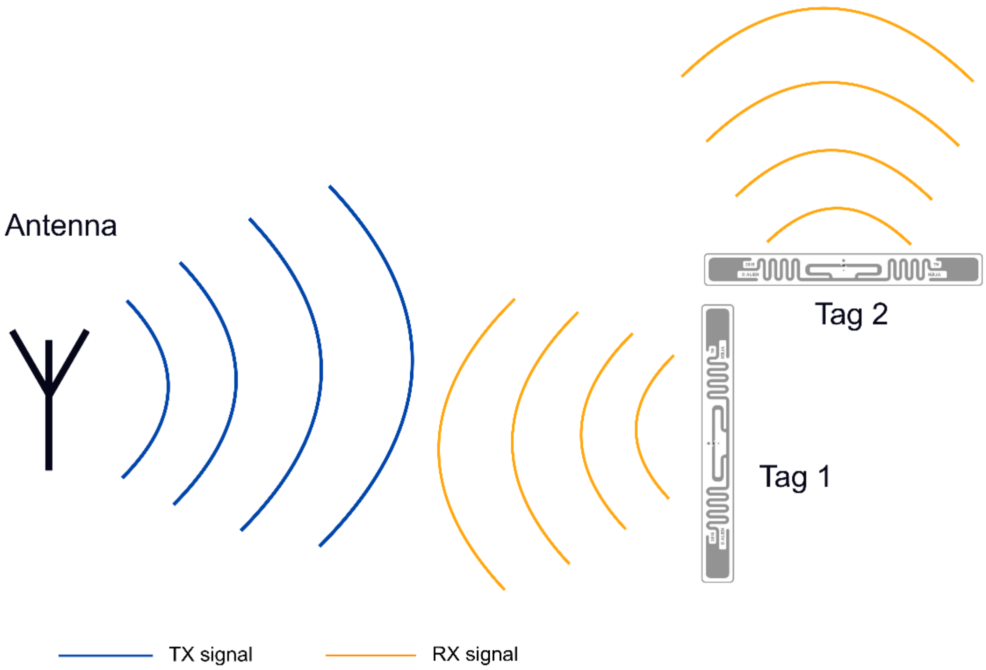
The figure above shows an example setup of inventorying a large tag population located on a pallet, which is the use case described in this application note.

1 Description

Reading a large, nonmoving tag population can be very challenging. Several circumstances, as reflecting objects, tightly spaced tags and field nulls within the volume, cause the inventory issue for the entire tag population.

In the case of a static setup, where neither the tag population, nor the reader antennas are moving, it can be difficult to capture all the tags of the population. One reason is the orientation of the tag antenna relative to the reader antenna, which has a major impact on the readability of the tag. If the tag position and orientation is in a way that the reader antenna cannot capture the response of the tag, it misses the information of this tag. This effect is shown in Figure 2.

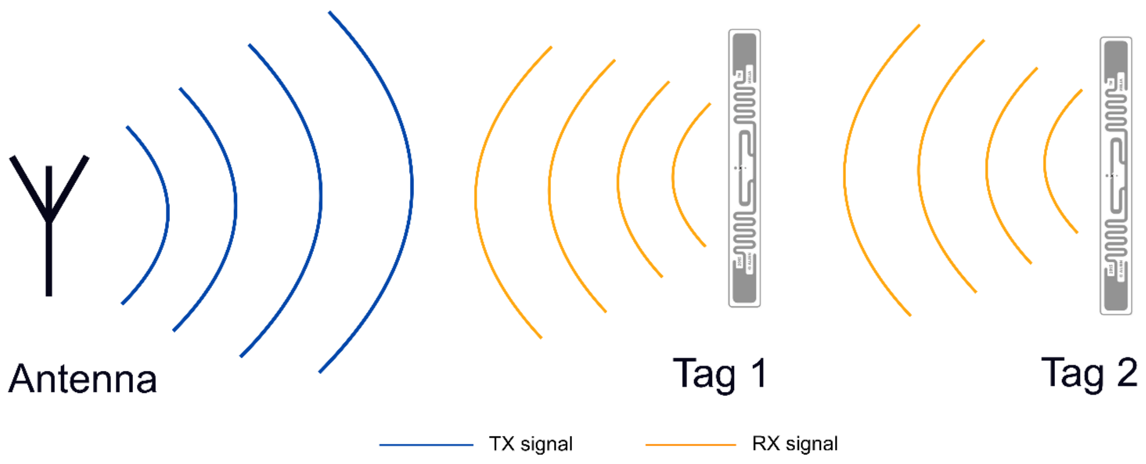
Figure 2. Different orientations of tags relative to a reader antenna



Tag 1 backscatters its response in the direction of the antenna, whereas due to the different orientation of tag 2, its response cannot be received by the reader.

In addition, if one tag is closer to the reader antenna than the others, as shown in Figure 3, the response of the nearby tag, captured by the reader's antenna, is stronger than the response of other tags further away, resulting in missing responses of the more distant tags.

Figure 3. Different distances from tag to reader antenna



The above two facts already reveal that antenna position with respect to tagged objects has an impact on the detection rate of the entire tag population.

Large tag populations also cause a lot of collisions in the tag responses. In case more than one tag responds to the reader request, the reader might not be capable of identifying any of the tags. Especially, when the responding tags are located at the same distance away from the reader antenna, similar signal strengths, make it difficult for the reader to decode the tag responses. Hence, one or even more tags are missed in the inventory round.

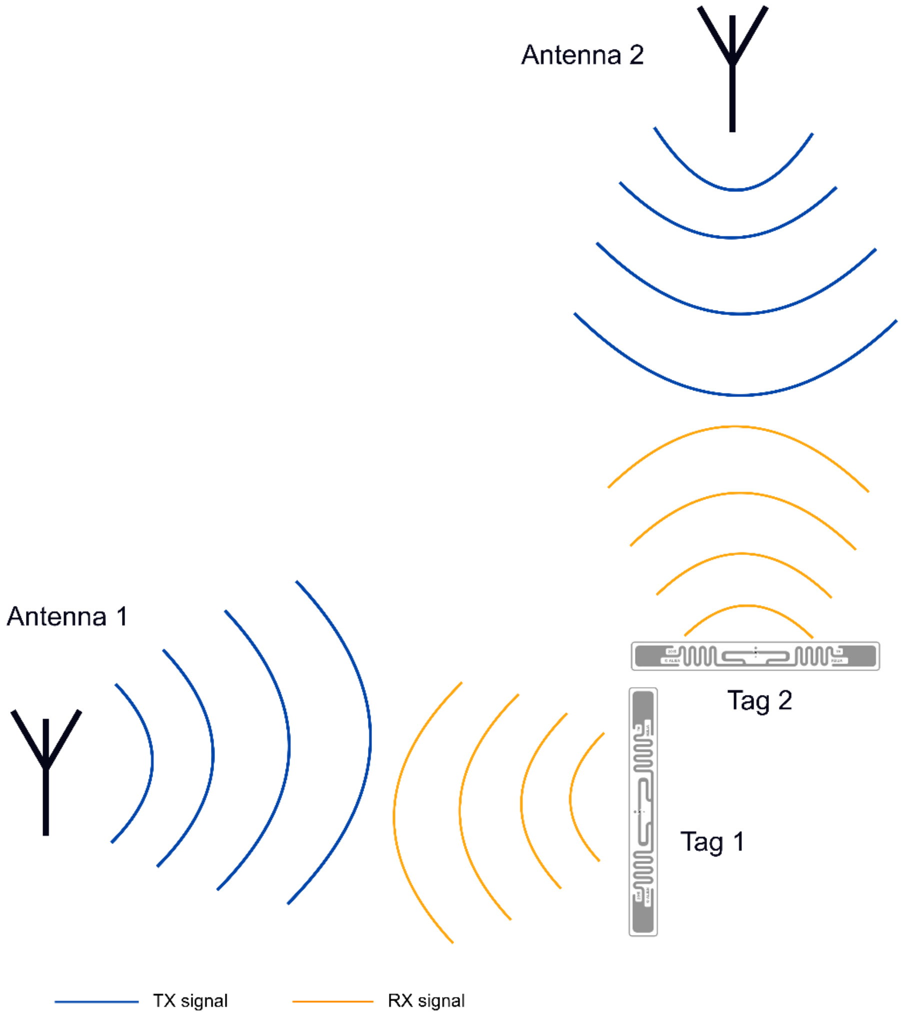
Other factor affecting the readability of a tag is the material to which it is mounted, and the material of the surrounding reflective objects nearby. For instance, metallic objects or liquids could detune the tag’s antenna making it unreadable for the reader.

2 Problem solution

To eliminate the detuning effects of metallic or liquid containing objects, a tag type optimized for the tagged object must be chosen. The market offers several tag ICs and tag antenna designs that are optimized for various materials.

As the tags inside the read-zone may differ in their orientation, a reader antenna setup that captures all the tag's responses should be used. Using a second reader antenna with a different orientation, can be helpful, see Figure 4.

Figure 4. Setup with two reader antennas at different location and with different orientation.



To further reduce the impact of the difficulties described above, the communication protocol parameters can be adapted. The aim is to inventory the total tag population with optimized reader settings. Various protocol parameters have an impact on the read speed and the tag detection rate. Q-value adaption, toggling the target, and using proper session flags can improve the reader performance. Therefore, optimizing the reader for this application helps to successfully inventory all tags in the field.

2.1 Test setup description

Various office supplies, such as printing paper, envelopes, pens, file binders, tapes, paper blocks and separator sheets are labeled with RAIN RFID tags. Each set of the office supplies is tagged separately and placed inside a cardboard box. All boxes containing the various office articles are put on a wooden pallet. In total there are 170 RAIN RFID tags on the pallet. Each cardboard box contains between 10 and 25 tags that are attached to the objects.

The ST25RU3993-HPEV kit is connected to one or two antennas facing the pallet from different angles. Antenna positions are varied throughout the test to investigate the impact of the different locations.

As reader antenna the T-7 circular polarized UHF antenna, SlimLine–A5020 for the adequate frequency range is used. This antenna is 150 mm square-sized and has a far-field gain of 5.5 dBiC.

To verify the impact of antenna gain on the readability of the tags, the antennas are replaced for one measurement by a circular polarized poynting patch antenna with an antenna gain between 7.5 and 8 dBi in the frequency ranges of ETSI and FCC band.

The total volume of the pallet holding the boxes containing all articles is 870 x 650 x 1200 mm (L x W x H). Figure 5 shows the dimensions for the measurement setup.

Figure 5. Measurement setup with measured dimensions

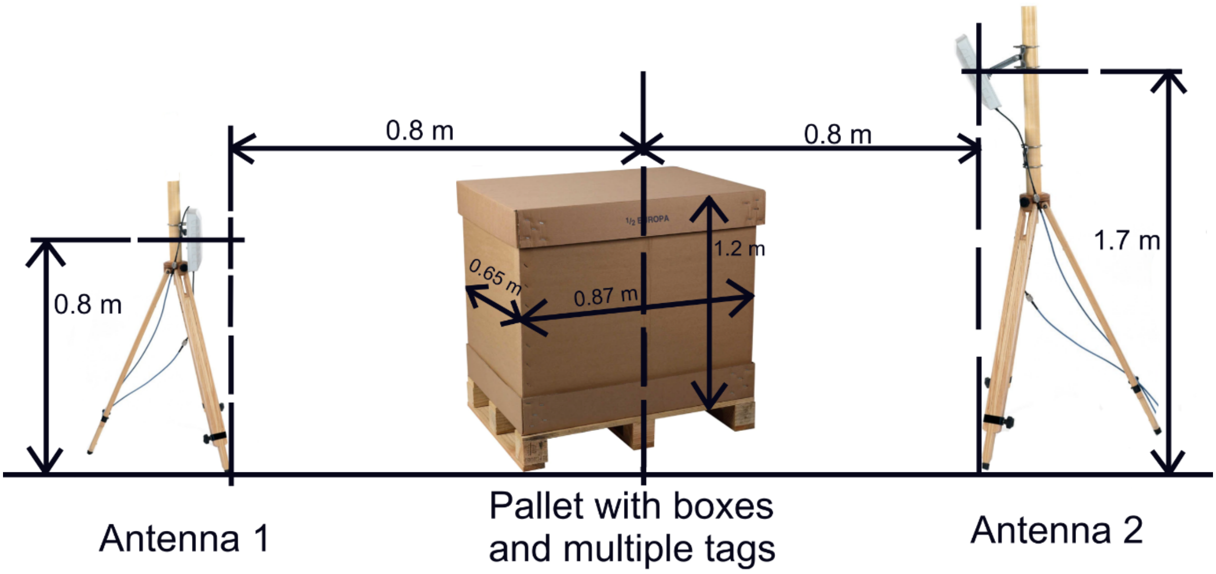


Figure 6 shows the measurement setup of the boxes placed on a pallet, and the antennas from side and top position, mounted on antenna holders.

Figure 6. Measurement setup

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There are four setups of antennas with respect to the pallet position used for the measurements.

- Setup 1: One antenna is placed on the front side of the boxes.
- Setup 2: One antenna is placed on the front side of the boxes on the pallet, at 0.8 m away from the closest tag. The second antenna is pointing downwards with a tilt of 45° on the pallet and at a distance of 0.8 m from the closest tag.
- Setup 3: The first antenna is at the same position as in setup 1. The second antenna is placed directly underneath the pallet, at the distance of 0.1 m from the first box.
- Setup 4: Both antennas are placed below the pallet.

2.2 Test procedure description

To point out the impact on the tag detection rate and the read speed, the following measurements are performed:

- Single antenna versus dual antenna (setup 1 versus setup 2 - 4)
- Default reader settings versus optimized reader settings
- Shifting position of antennas (setup 2 - 4)

Initially, the impact of the tag orientation is shown by comparing the unique tag count and read speed for single and dual reader antenna usage. For this measurement, the default settings are used.

In the next step, the optimum reader settings are investigated. As the default GUI software settings are set for no specific application, but for a general purpose, the settings must be tuned for the application at hand. Therefore, the reader settings are tuned in a way to reach high read speed and detection rate.

As the alignment of boxes on a pallet is rather random and the positions and orientations of the boxes also have an impact on the readability of the tags, the reader antennas are shifted in multiple times to investigate any improvement in detection rate.

For all the measurements performed the unique tag plot, provided in the reader GUI software is used. This result plot shows the number of unique tag reads over time.

Measurements are done for both, European frequency band and US frequency band. As the results of read speed and tag detection rate are similar for both frequency bands, the following sections describe the results for the European frequency band only. Although the US frequency band covers a broader frequency band, no improvements in detection rate and speed are observed. This results from lower reader power in the FCC band than in the ETSI band and shorter hop cycles (400 ms in one channel compared to 4000 ms in one channel). Therefore, the unique tag plot using the FCC band is flatter, but more continuous than the curves in the ETSI band.

3 Software configuration

With the default GUI software settings, all tags are hard to capture. Responses to tag with weak backscatter power, might potentially get missed in most of the inventory rounds. Therefore, the session parameter S1 or S2 can be used to render a tag silent for a certain time when already inventoried.

Another important fact is the target parameter used by the reader. Tags powers-up with target state A responds in case the reader sets the target to A in the query command. After the tag responds its EPC and receives the next valid reader command, it inverts its target parameter to B. This has the effect that once the tag switched to target B, it does not respond to the reader commands.

In case the reader searches for both target states (A and B), the tags respond multiple times to the effect that weak tag responses might get missed. Hence, it might be useful to disable Target toggling to quickly inventory all tags that have not yet been inventoried. This virtually reduces the tag population size while the inventory is running until the last tag was read.

However, under certain circumstances it might be possible that the reader misses a tag EPC. The tag would change its state and would never respond to the reader anymore. In that case, it might be useful to use the toggling of the target. For this purpose, the reader offers the target depletion mode setting in combination with the toggling of the target. In case both are active the reader scans on one target and changes the target in case no new tag information is arriving.

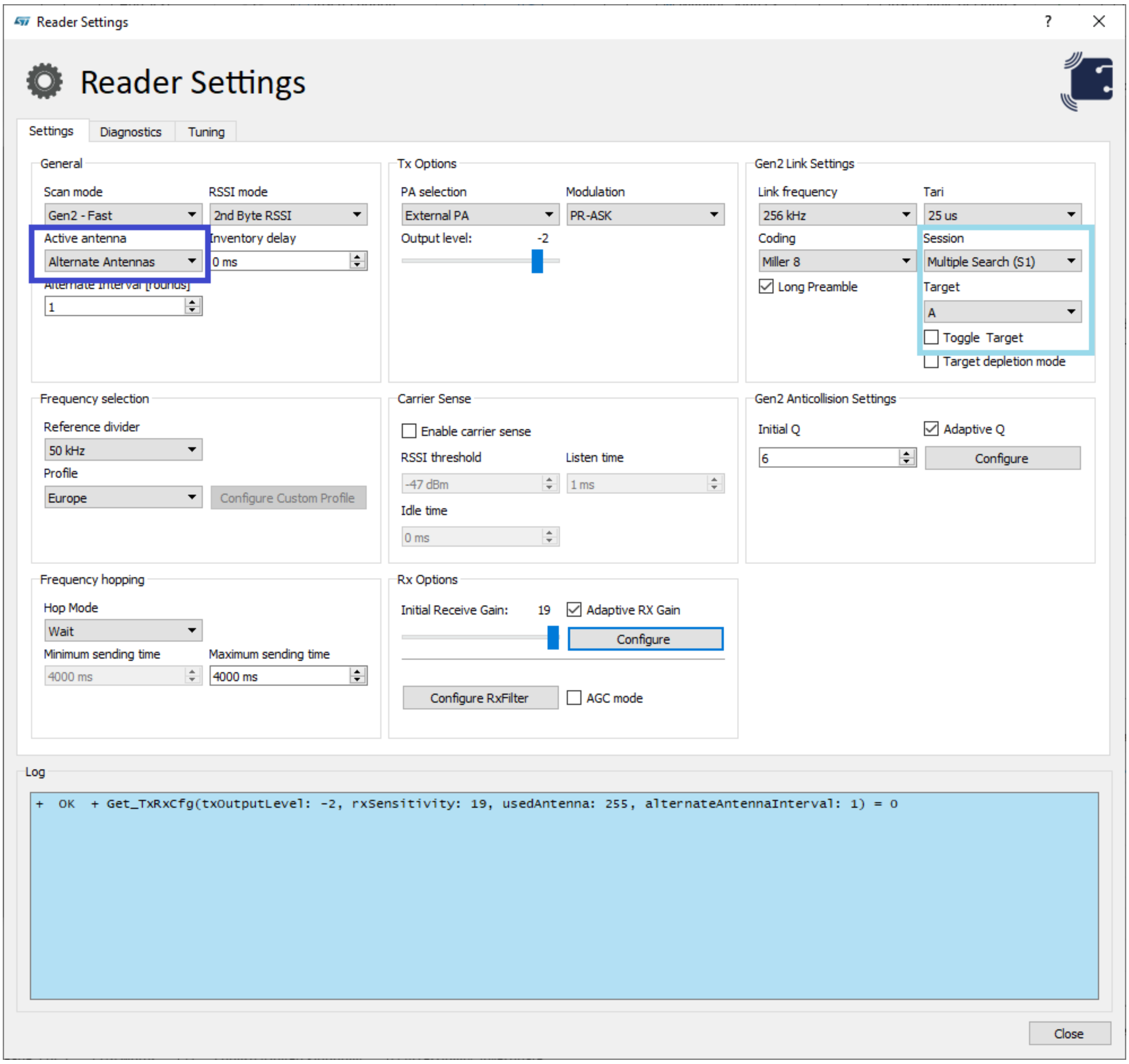
Using session S1 or S2 and target A causes the tags to respond only once until their target gets reset or until they are not powered for a time greater than their persistence time (500 ms to 5 seconds for S1 and at least 2 seconds for S2). In case the tags are inventoried again, before the persistence time elapses, the Target parameter must be switched to Target B.

Furthermore, the Q-value used for the inventory anti-collision plays an important role. If the Q-value is too small for the tag population, the number of tag response collisions increases. If the Q-value is too large, the number of empty slots would be too high. The automatic adaption of the Q-value for a nonmoving tag population is necessary to adapt to the decreasing number of tags participating in the inventory round, due to the internal state change of the tags when inventoried.

As a result of the measurements conducted, the optimum reader settings, displayed in Figure 7, use antenna alteration, session S1, target A with toggle target unchecked. It could be observed, that in case the toggle target and target depletion mode are active, similar results could be achieved. Furthermore, adaptive Q parameter must be checked, which is already the case by default, to let the reader adapt to the changing number of tags participating in the inventory rounds. The default initial Q-value of 6 is adequate for a tag population of 170 tags. It might be necessary to increase or decrease the value in the case of different tag population sizes.

Additionally, the reader output level is specified to be -2. This setting account for a reader output power of 28.4 dBm in the ETSI band and ranges from 27.5 to 27.9 dBm in the FCC band. High reader output power is necessary to power all tags in the field. Decreasing output level might be necessary for higher gain antennas, to follow local radio regulations. An output level of -4 in the reader settings accounts for 26.8 dBm in ETSI and around 25.8 dBm less in the FCC frequency band.

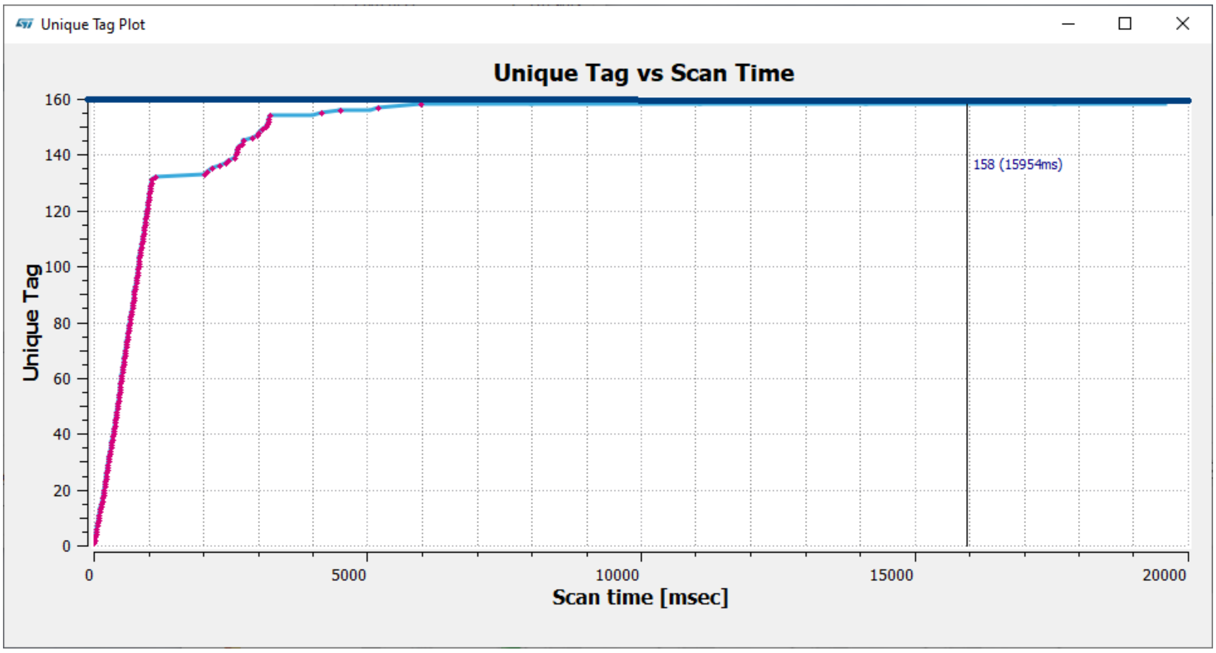
Figure 7. **Optimized reader settings**



4 Test results

Using the reader default settings, it is very difficult to identify the entire tag population. For the first measurement, a single antenna setup is used [Setup 1], which causes additional challenges of capturing all tags, due to the unknown orientation of tags inside the boxes. For the setup 1, 158 out of 170 tags could be read within 20 seconds (see Figure 8). Using only a one antenna has the effect that the entire tag population cannot be read, even if the read time is increased.

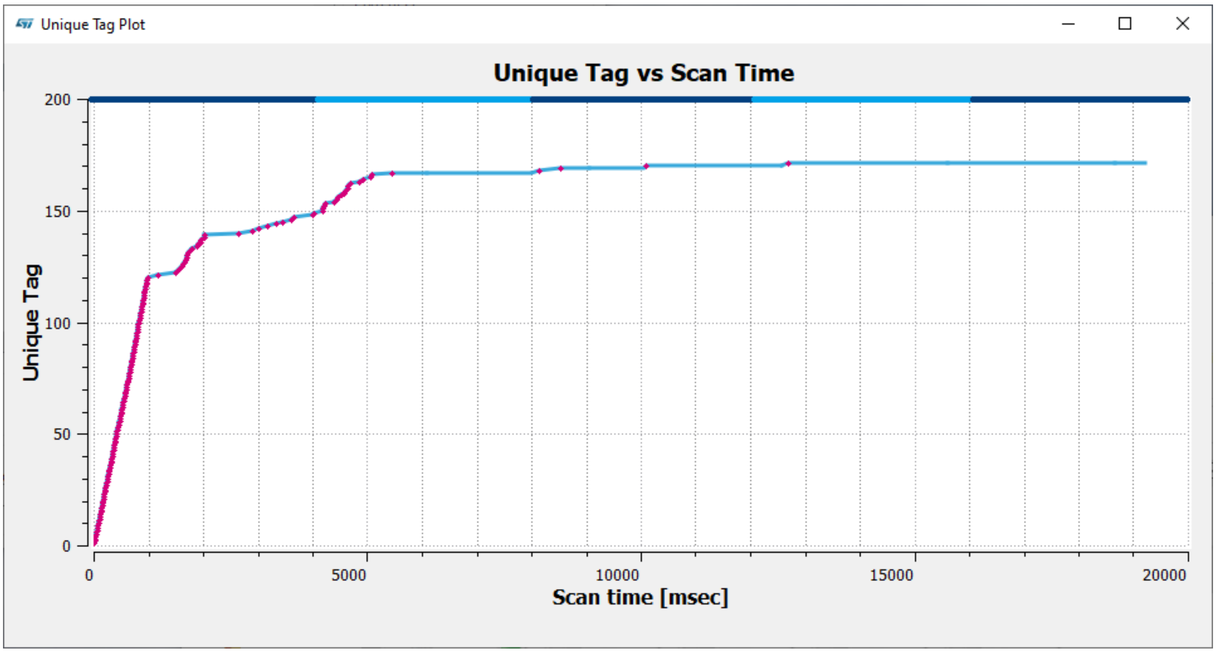
Figure 8. Unique tag read for default settings with single antenna



Using a second antenna with a different orientation, shows that 169 unique tags are read within 20 seconds (see Figure 9).

Antenna 1 faces the front of the pallet, while antenna 2 faces the pallet from the top, with a 45° tilt [Setup 2]. This result indicates, that the tags inside the boxes are oriented randomly. Therefore, adding a second antenna makes it is easier to capture tags. The dark blue line in the graph indicates that the reader is transmitting via antenna 1, whereas the light blue indicates transmission via antenna 2. The reader antenna is switched every 4 seconds.

Figure 9. Unique tag plot for two antennas using default settings



Placing one antenna at the bottom of the pallet, instead of at the top with a tilt [Setup 3], shows a slightly reduced read rate of 160 tags read within 20 seconds. Placing two antennas at the bottom of the pallet [Setup 4] even further decreases the read rate, due to the same orientation of the antennas in respect to the pallet.

This shows that also the positions of the two antennas have a major impact, which is dependent on how the tags inside the boxes on the pallet are aligned. For that use case, the tags inside the boxes mostly point in vertical and horizontal direction. Hence, the usage of one antenna placed on the front side of the pallet, and another one placed on top of the pallet [Setup 2], shows that the best success rate and all 170 tags can be inventoried.

In addition to the antenna position, optimizing the Gen2 parameter (session and target) help to reliably read all tags in the read zone. Setting session S1 and toggle target enabled all tags can be inventoried within 10 seconds. To increase the speed, the usage of session S1 with toggle target disabled, shows that 170 out of 170 tags could be read within 6 seconds (see Figure 10). Dark blue line in the figure shows transmission via antenna 1 and light blue line shows transmission via antenna 2.

Figure 10. **Unique tag plot for session S1 and toggle target disabled–all tags read in less than 6 seconds**

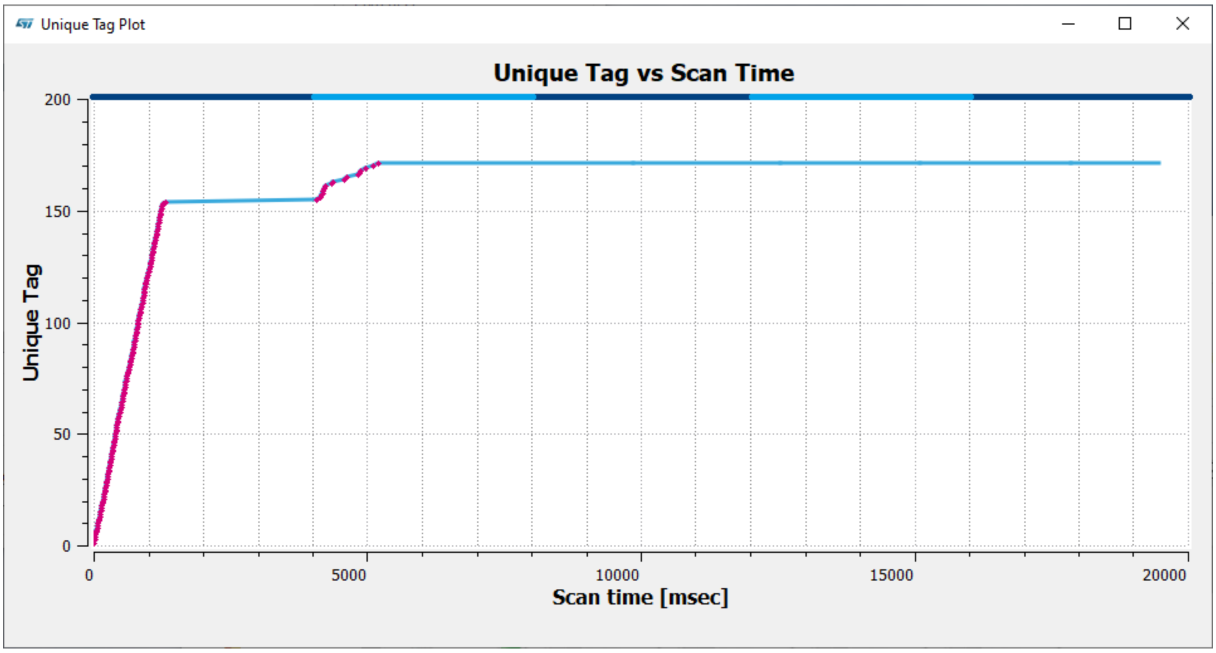
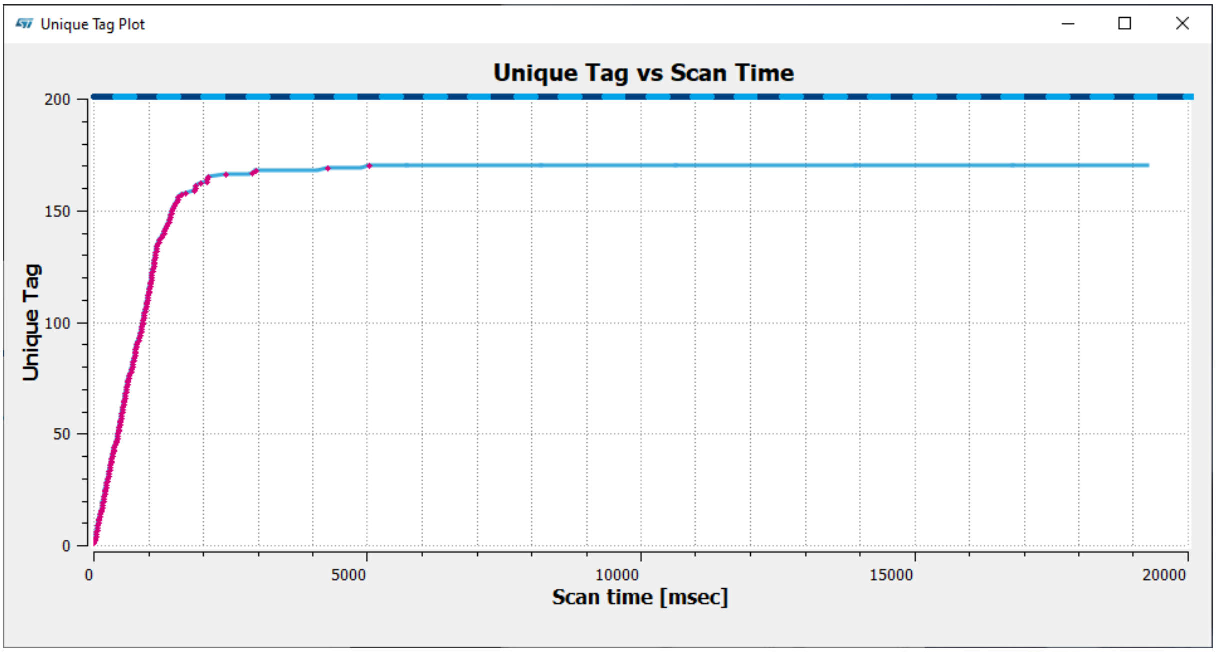


Figure 11 shows the unique tag plot when operating the reader in FCC band. The dark blue and light blue lines in the graph indicate the transmission via antenna 1 and antenna 2, respectively. Antennas are switched every 400 ms. The settings used for this measurement are the same as above, using session S1 and toggle target disabled. Also, in this case all tags can be inventoried within 6 seconds.

Figure 11. **Unique tag plot for optimized settings in FCC band**



Until now, the read speed could be improved and for this setup the session S1 and disabling toggle target, delivered the fastest read speeds. However, from time to time one or two tags might get missed. To further improve the reliability in reading all tags in a certain period of time, the slim antennas are replaced by the patch antennas, which have a higher gain and hence more directivity.

Using the circular patch antennas with higher gain of 7.5 to 8 dBi, placed in a way to align optimally with the labels inside the boxes all 170 tags in the read zone can be reliably read. With the optimized settings of using session S1 and disabling the “Toggle Target” parameter and using the optimized antenna setup, inventorying the total tag population can be done in less than 5 seconds (see Figure 12).

Figure 12. Unique tag plot for optimized Gen2 settings and antenna with higher gain

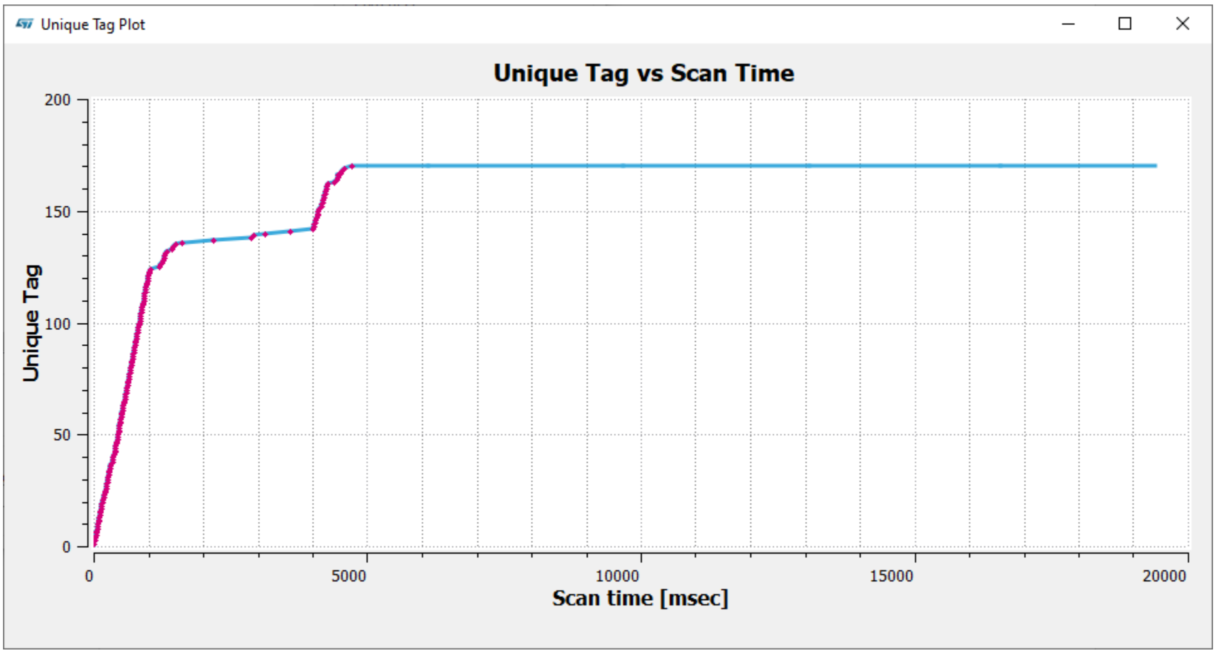


Table 1 summarizes the number of unique detected tags and the read duration for the different antenna setups and GUI software settings.

Table 1. Measurement results summary

Hardware setup	Reader settings	Number of unique tags detected (out of 170)	Read duration
Setup 1 - Slim antenna	Default	< 160	20 seconds
Setup 2 - Slim antenna	Default	165-170	20 seconds
Setup 2 - Slim antenna	S1, Toggle Target enabled	168-170	< 10 seconds
Setup 2 - Slim antenna	Optimized (S1, toggle Target disabled)	168-170	< 6 seconds
Setup 3 - Slim antenna	Optimized (S1, toggle Target disabled)	< 160	20 seconds
Setup 4 - Slim antenna	Optimized (S1, toggle Target disabled)	< 150	20 seconds
Setup 2 - Patch antenna	Optimized (S1, toggle Target	170	< 5 seconds

5 Conclusion

Inventorying large tag populations in a nonmoving setup can be very challenging. There are several impacts on reliably reading the total tag population in an adequate amount of time.

The measurements described in this application note, proved that the number of antennas, the placement of the antennas as well as the antenna type used, have an impact on the read rate.

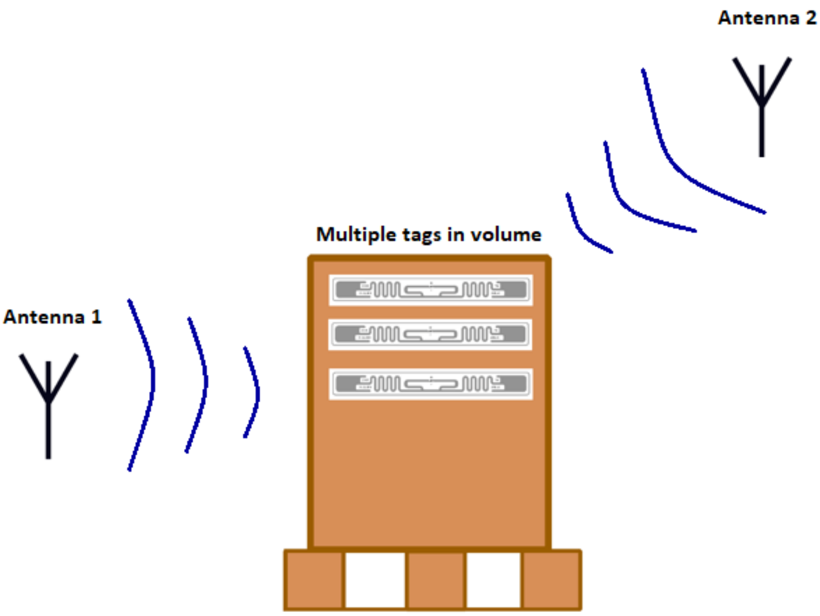
By using a single antenna, it is difficult to cover the whole volume and it shows lots of dead spots. For this setup, a maximum of 160 tags were readable with a single antenna only. Using two antennas can minimize the dead spots inside the volume, however, also the direction of which the antennas are pointing at the pallet is of major importance. In case the orientation of the tags inside the volume is rather random, the antennas should not face in the same direction but point at the pallet from different directions. If the orientation of the tags is known, the antennas can be placed to face most of the tags. Having a tilt of one antenna compared to the other is helpful to cover random placement of the tags in the total volume.

Further impact on the success rate and on the read speed comes from the reader settings used. The default reader settings are not optimized for the application of reading a large number of tags in a static environment. Changing the session parameter from S0 to S1 improves the readability of the tags, as the inventoried tags do not reset their internal state immediately after the reader is not powering the tag. Also disabling the toggling of the Target parameter further improves the speed of inventorying the total tag population.

The orientation and position of the antenna only have an impact on the reliability of detecting the total tag population, whereas the reader settings also impact the read speed.

The combination of using two antennas at proper position in respect to the antennas and using optimum reader settings shows that large tag populations in a defined volume, can be reliably read in a short period of time. For this special setup of random tag placement, measurement setup 2, depicted in Figure 13, shows the most reliable results, especially when using antennas with higher Rx gain.

Figure 13. Optimum hardware setup



Revision history

Table 2. Document revision history

Date	Version	Changes
29-Nov-2022	1	Initial release.

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