Research on the influence of metal surroundings and reading method on the accuracy of UHF RFID tags tracking

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***Abstract*—In this paper we present the results of our research on the effectiveness of data exchange between the reader and the label in an RFID system in various environment configurations. Discussed technology is particularly useful in metal cabinets intended for storage and archiving of valuable items, such as documents or specialized equipment. Our results from this research are a solution in the realm of Internet of Things, responding to the needs of Industry 4.0 in the field of processing and exchange of data on resources used in enterprises. Our tests were carried out in four ambient configurations, i.e. 2 stations with metal cabinets and 2 in the open space. Research was carried out on RFID tags, used as document markers, placed in binders in five position variants. The influence of ambient conditions and the way of reading (stationary and dynamic reading in which the antenna is in motion) on the effectiveness of scanning was examined. It was found that the way of reading has less impact on its effectiveness than the surrounding conditions. As a result, it was determined that for the correct operation of systems intended for identification and control of objects stored in metal cabinets, the construction and material of the cabinet itself is important, as well as the way of reading RFID tags, the significance of which grows in more complex systems consisting of a larger number of tags, which can be more mutually shielded.**

Keywords—RFID UHF, tracking accuracy, metal cabinets, static readout, dynamic readout

I. INTRODUCTION

Recently, in automatic identification technologies, popular bar codes are being gradually replaced with Radio Frequency Identification (RFID) labels. This results from their significant advantages over bar codes, related to their high weather resistance, the detectability in non-line-of-sight conditions, and advanced encryption level. RFID technology transmits data from and provides power for electronic tags (RFID labels/tags) by using radio waves, emitted by a reader with an antenna. The beginnings of RFID date back to the first half of the last century, but its significant popularization is observed in the 21st century. RFID currently finds many applications in various industries, like logistics (e.g. inventory recording), production processes (e.g. identification of resources), security systems (e.g. anti-theft in stores), services related to workwear management (e.g. identification of clothes in laundries), sports (e.g. measurement of results achieved by runners while competing) or finances (e.g. contactless payments) [1].

The RFID tag consists of a substrate, a transmitting and receiving antenna, with a frequency-matched design and a chip attached to it. In addition, for applications on metal surfaces, the RFID tag has a ferrite layer that insulates the antenna from the metal. An important feature of RFID technology is the ability to identify objects marked with both active and passive tags. For economic applications, passive tags are most often used in practice [2].

From the power source perspective, RFID tags can be categorized into three groups:

- passive,
- active,
- hybrid (semi-passive).

Active RFID tags are equipped with autonomous power sources, unlike passive ones. On the other hand, the passive tags draw energy from the radio signal received by the antenna. Semi-passive tags are a hybrid of the active and passive tags [3][4].

With regard to writing data, RFID tags can be read-only (RO), write-once read-many (WORM) and unlimited read/write (R/W). Communication with the RFID tag occurs via radio waves, and its accuracy depends on the propagation of radio waves in a given medium and environment. Depending on the frequency range used, among others, effective reading distance and data transmission speed can vary [2][3].

In terms of utilized radio frequency, RFID tags can be grouped into:

- low frequency (LF), with the most often used frequency of 125 kHz,
- high frequency (HF), with the most often used frequency of 13.56 MHz,

- ultrahigh frequency (UHF), with frequency bandwidth of 868-956 MHz (865-868 MHz in Europe).

Recent technological advancements and cost reduction influence the growing popularity of HF and UHF frequencies. This article focuses on UHF technology and discusses the impact of the environment of metal enclosures, as well as reading methods, on the read accuracy of UHF passive RFID tags. This issue is important from the point of view of the possibility of using RFID technology in the identification and control of objects stored in metal cabinets. This category of furniture can be widely used both for storing and recording valuable items and resources, as well as important documents. The metal used in the cabinet housings shields electromagnetic waves. The use of a sealed construction, in turn, allows limiting the propagation of waves to the inside of the furniture, allows for reliable readings from the tags located inside the cabinet and thus correct verification of its content. In order for such solution to be practical, however, the most important is the accuracy and error-free reading of tags located inside the cabinet. Accuracy is understood as the number of correctly identified tags among all tags located in the metal cabinet. At the same time, metal is a significant challenge for UHF RFID technology and its implementation, as in such an environment there is more risk of unwanted radio wave interferences [2][3][5].

II. Description of The Issue

RFID systems operating in the UHF range use communication based on backscatter radio waves propagation. This is widely described in the specialist literature. To obtain effective reading of passive tags, it is required to provide the right amount of energy to power the tag and generate a response. Reading performance is influenced by, among others, frequency and signal strength, as well as the type of tags themselves, including the type of the substrate, shape, the type and the size of the antenna. From the point of view of performance, the phenomena of electromagnetic reflection and collisions are very important. When there is more than one RFID tag in the reader field at the time, many reflected signals reach the reader. It may happen that they cannot be processed simultaneously and collisions occur. The metal environment in which the waves propagate affects the number of collisions caused by wave reflections. The solution to this problem is the use of anticollision algorithms. These include the following procedures: ALOHA and a binary search algorithm that have been described in the literature. RFID readers offer more and more effective algorithms, which, combined with fast processors, significantly improve reading results [6].

This research was performed during research and development phase of the project implemented by TECHMARK L.OGŁOZA S.ZDZIECHOWSKI SPÓŁKA JAWNA (co-financing agreement POIR.01.01.01-00-0241/17), hereinafter referred to as the project. During research, it was established that the type of the equipment used has a very significant impact on the reading efficiency, and the difference in results may reach up to several tens of percent. Measurements made for 80 tags using several types of readers, allowed obtaining results at a level from 50% correct reading to 100%. This article focuses on discussing the research and its results, carried out for one of several possible optimized configurations of RFID system. This configuration consisted of:

- Zebra FX 7500 RFID reader (transmit power output from 10 dBm to +31.5 dBm; maximum receive sensitivity: -82 dBm) [7],
- antenna with linear polarization (gain 8 dBi; beam width: 60°/60°),
- universal tags, dedicated for document marking – Spine 451_1 (antenna length 95 mm; width 4 mm) [8].

The research was carried out with the use of Zebra SessionOne software.

The RFID equipment was selected based on the evaluation of its parameters and the verification thereof. It was required that the equipment ensures 100% effectiveness for approximately 10 tags placed within the range of the antenna at a distance of 58-68 cm, for example the ambient described as Test Rig A (described in the next part of this article). The effectiveness of other devices was also verified, and another highly effective configuration was selected, based on the Impini Speedway Reader R420 with no replacement of any other components. In this configuration, for all the tested rigs, in open environment – stationary reading, the results were identical and specified in Table I. For further research, one configuration, based on the Zebra reader, was chosen. During further research, no changes of the equipment for the tags, neither for the RFID antenna were introduced, since this would significantly influence the ambience of the tests in the area of mutual shielding of tags, which has a significant impact on the problem discussed in this article. For example, the use of tags of a different shape and a different size of the antenna would influence the level of mutual shielding. In the described experiment, the focus was laid on the reduction of the variables that constituted the main field of research. Additionally, the character of the research was targeted at launching the production of furniture with the implemented RFID technology, and consequently they were carried out using the equipment that was both available and meeting the economic criteria [9].

An important issue for the proper assessment of reading accuracy is to maintain similar, most preferably unchanged, conditions in terms of: distribution of tags, location of the antenna, RFID equipment operating parameters. This is a very important and complex problem in experiments carried out for UHF RFID technology, because even the smallest changes, e.g. in tag placement, their position in relation to the antenna, the medium on which the tags are placed, affect wave propagation and correct reading. In order to eliminate this phenomenon, 40 samples were used and test rigs were prepared in a way that ensures repeatability of results, i.e. unchanged reader operating parameters were used, unchanged distance in the test system, i.e. the distance and position of the antenna relative to test rigs, as well as the placement of tags that were permanently affixed in research stands (detailed preparation of test rigs is described below). The conditions of the tests were also selected to reflect the actual use of RFID technology for the purpose of identifying objects stored in metal cabinets [2][10][11].

III. Study of The Impact of Metal Environment and Reading Method on Performance

As part of the project, at the initial stage of the research, the scenarios of reading tags in an open environment and in a metal enclosure were analysed. In the next step a study was performed on the impact of antenna movement during reading on reading efficiency. As part of development work, a metal cabinet prototype was created, enabling testing in a metal environment that was electromagnetically sealed from the outside. The Focus of the research was on tests in laboratory and real conditions, without formulating mathematical models or simulations. The research was rejected due to the lack of availability of ready models that could simulate the examined phenomena, the complexity of the matter of their construction and the final requirement to verify them in real conditions. Formulating mathematical models and their effectiveness in reflecting the real conditions is an interesting issue, the development of which may optimize the designing of highly complex projects based on RFID UHD. In the targeted research described in this article, the focus was laid on another area, connected with the verification of the problem in real conditions.

A. *Test rigs preparation*

In prepared test rigs, the tags were glued onto a plastic document sleeves, which, thanks to their transparency, enabled their proper positioning. Sleeves were put in workbooks, which limited the possibility of accidental change of their position during testing. The workbooks had been attached to a binder for easy setup. Four sheets were inserted into each plastic sleeve, which reflected conditions similar to actual use, illustrating the designation of a document consisting of 4 sheets (depending on the font size and type of printout, it is a document containing about 8000 characters for one-sided printing). These sheets provided a gap between the tags (the thickness of the sleeve with 4 sheets was about 0.5 mm (Fig. 3), which was the minimum possible distance for the tags stacked on top of each other). The advantage of such a design of the test rig is the accurate representation of the actual conditions for document storage. At the same time, such conditions, in which the tags are located close to each other, which causes their mutual shielding, are disadvantageous, but very likely to occur in practice [12][13].

Test rigs description:

- Rig A – 10 tags placed in a distance from each other, as to avoid mutual shielding.
- Rig B – 12 tags, each pair stacked together, so that the tag on top shields the tag on the bottom. By stacking we define a placement such that at least half of the surface of the bottom tag is covered by the tag on top. In this rig there are 6 stacks (each with two tags in it), placed in a distance from each other, as presented in Fig. 1.
- Rig C – 9 tags, where each 3 are stacked together, so that tag on the top is shielding two tags underneath. By stacking we define a placement such that at least half of the surface of the bottom tag is covered by the tag on top. In this rig there are 3 stacks (each with 3 tags in it), placed in distance from each other. This rig is constructed similarly to rig B, presented in Fig. 1, Fig. 2, Fig. 3.

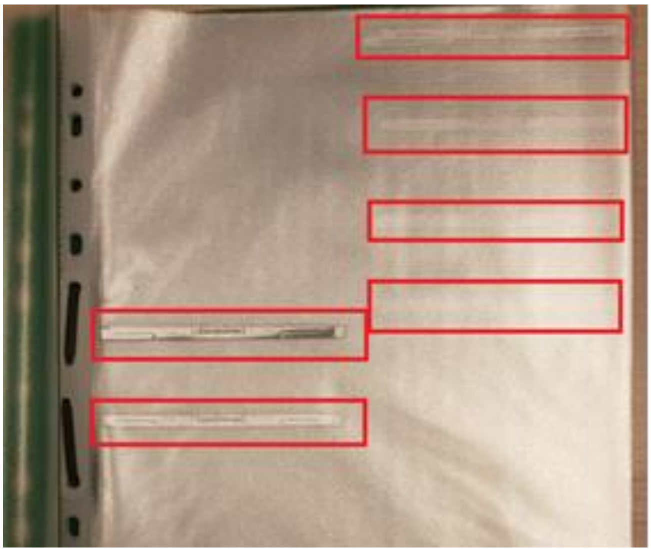

Fig. 1. Test rig B with marked stacks of tags, each with 2 tags – photo taken before inserting paper in the sleeves.

Fig. 2. Test rig B with paper in document sleeves.

Fig. 3. Thickness measurement of paper in a sleeve, which determines the distance between each pair of tags.

- Rig D – 20 tags, where each 4 are stacked together, so that tag on the top is shielding three tags underneath. By stacking we define a placement such that at least half of the surface of the bottom tag is covered by the tag on top. In this rig there are 5 stacks (each with 4 tags in it), placed in distance from each other. This rig is constructed similarly to rig B, presented in Fig. 1, Fig. 2, Fig. 3.
- Rig E – 10 tags, where each 5 are stacked together, so that the tag on the top is shielding four tags underneath. By stacking we define a placement such that at least half of the surface of the bottom tag is covered by the tag on top. In this rig there are 2 stacks (each with 5 tags in it), placed in distance from each other. This rig is constructed similarly to rig B, presented in Fig. 1, Fig. 2, Fig. 3.

B. *Study on the influence of metal environment on the reading accuracy.*

As part of the project, an analysis of the influence of the metal environment on the reading accuracy was carried out in this research. For this purpose, with identical parameters regarding tags placement and reader work parameters, 40 control measurements were made for each test rig, in different measurement conditions, including open and metal environments. In both environments, a measurement was carried out with the antenna stationary during reading (stationary reading method). The rigs were located 58-68 cm away from the antenna.

The open environment was setup on the floor, with a nearest obstacle located at a distance of over 6 m from the antenna in its line of sight (see Fig. 4). The metal environment was, in turn, a space constructed of a metal structure with a volume of more than 0.75 m3, in which the antenna was located at a distance of about 1 m from the opposite metal wall. The tags were placed on of two shelves spaced vertically from each other by approx. 40 cm (see Fig. 5).

In Table I, Table II and graphs Fig. 6 and Fig. 7, the measurement results are presented, including minimum, maximum and average values. The reading time was set for 9 seconds.

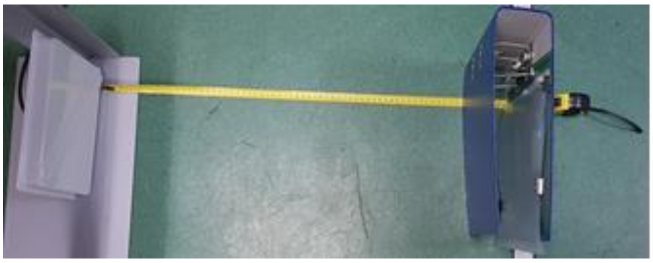

Fig. 4. Open environment, in which the tests were performed.

Fig. 5. Metal environment, in which the tests were performed.

TABLE I. RESULTS OF TAG SCANNING (OPEN ENVIRONMENT – STATIONARY READING)

Rig	Number of tags	Open Environment – Stationary Reading			
		Average number of correct reads	*Min*	*Max*	*Accuracy*
A	10	10	10	10	100%
B	12	10	10	10	83%
C	9	7	7	7	78%
D	20	7	7	7	35%
E	10	5	5	5	50%
Overall	61	39			64%

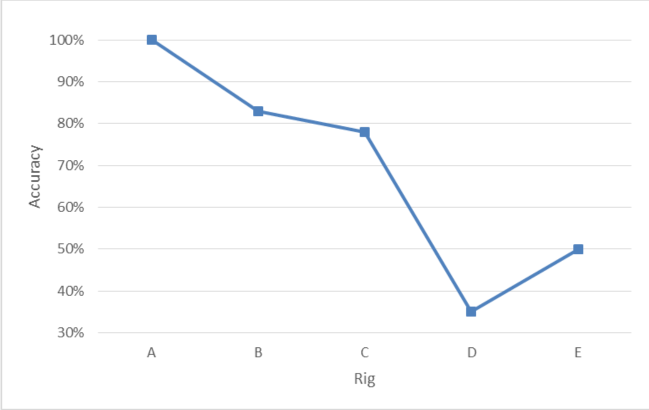

Fig. 6. Results of tag scanning (open environment – stationary reading).

TABLE II. RESULTS OF TAG SCANNING (METAL ENVIRONMENT – STATIONARY READING)

Rig	Number of tags	Metal Environment – Stationary Reading			
		Average number of correct reads	*Min*	*Max*	*Accuracy*
A	10	10	10	10	100%
B	12	10	10	11	84%
C	9	9	9	9	100%
D	20	18	17	18	88%
E	10	9.8	9	10	98%
Overall	61	57			93%

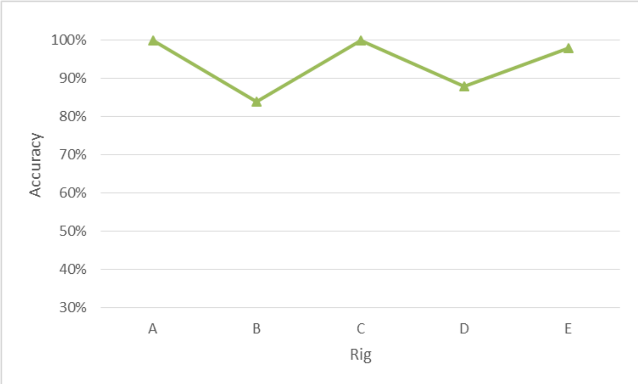

Fig. 7. Results of tag scanning (metal environment – stationary reading).

Obtained results clearly indicated a significant, beneficial effect of the environment made of iron based alloys, namely DC01 low carbon steel, on the accuracy of RFID reading. In the open environment only in the case of rig A accuracy of 100% was obtained (reading of all tags in all 40 samples). The average accuracy for all reading in open environment was 64%, and for the rig D with the highest number of tags it was only 35%. In the case of metal environment, the average efficiency for all rigs was 93%. On average, more than 80% of correctly read tags were obtained for all measurements performed inside metal enclosure. Reading accuracy was defined as the percentage of correctly received information stored in the tag and confirmed by checking the checksum, relative to the total number of read attempts [14].

In the case of an open environment, one can also observe no fluctuations in the number and position of correctly read tags. Each of the 40 measurements gave the same result (the minimum and maximum values were the same). In the case of metal surroundings, the level of fluctuations was insignificant and limited to the difference in the reading of 1 tag.

These experiments showed the beneficial influence of the metal environment on the RFID reading accuracy. This is due to the density of the radio signal due to wave reflections from the walls of the metal cabinet. At the same time, the density of radio waves and the number of collisions did not affect the amount of interference that would worsen the results or prevent reading at all. This shows that the metal enclosure was designed in the right size and shape for this purpose.

In addition, these studies confirmed that with the increase in the number of tags, in particular those located in close proximity to each other, including those stacked, there was a decrease in the number of correctly read tags. This was due to mutual shielding of the tags. In the case of rig A, where the tags were arranged in such a way that they do not shield each other, 100% efficiency was obtained for all measurements. The results obtained for the remaining positions indicate that the distribution of tags in stacks affects the effectiveness of their identification.

C. *Study on the influence of reading method on the reading accuracy.*

During subsequent trials and tests carried out as part of the development work, the effect of antenna movement during reading on the reading accuracy was examined. In order to test such method, measurements were carried out for similar conditions in terms of environments and tags locations, as well as reading parameters, as described in previous part (see III.B). The only modification was the antenna movement during the reading process. The speed of movement of the antenna was 0.25 m/s. The distance between the rig and the antenna (55-65 cm) and the reading time (9 seconds) remained unchanged compared to the tests carried out in the stationary reading method. The parameters of RFID equipment were also kept the same.

TABLE III. RESULTS OF TAG SCANNING (OPEN ENVIRONMENT – DYNAMIC READING)

Rig	Number of tags	Open environment – dynamic reading			
		Average number of correct reads	***Min***	***Max***	***Accuracy***
A	10	10	10	10	100%
B	12	10.2	10	11	85%
C	9	9	9	9	100%
D	20	12.4	11	14	62%
E	10	7	7	7	70%
Overall	61	48.6			80%

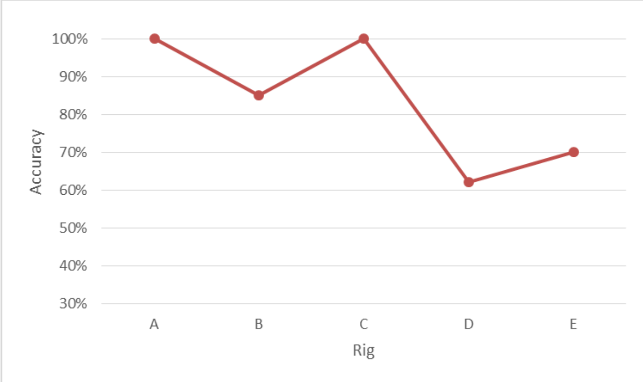

Fig. 8. Results of tag scanning (open environment – dynamic reading).

TABLE IV. RESULTS OF TAG SCANNING (METAL ENVIRONMENT – DYNAMIC READING)

Rig	Number of tags	Metal environment – dynamic reading			
		Average number of correct reads	***Min***	***Max***	***Accuracy***
A	10	10	10	10	100%
B	12	12	12	12	100%
C	9	9	9	9	100%
D	20	20	20	20	100%
E	10	10	10	10	100%
Overall	61	61			100%

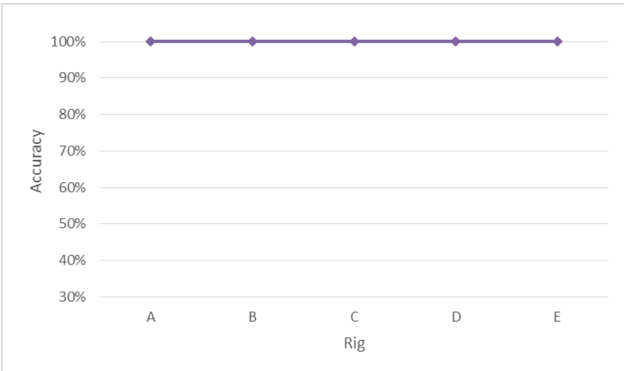

Fig. 9. Results of tag scanning (metal environment – dynamic reading).

Obtained results are presented in Table III, Table IV and graphs Fig. 8 and Fig. 9. They clearly indicate significant differences in the achieved efficiency in favour of dynamic reading in the metal enclosure for which 100% accuracy was obtained (full reading for all measurements). In the case of an open environment, the accuracy was at 80%. Similar to the reading in the static antenna system, this is due to the signal density due to wave reflections. This allows for a fully effective reading for all tag placements, even with mutual shielding of tags. However, it should be expected that as the number of tags increases, the accuracy for a dynamic reading method in metal environment will decrease.

The metal environment also has other risks associated with interference levels. In our experiments, the size of the metal environment was relatively large (over 0.75 m3), however, for smaller spaces, the density of waves may be too high and the reading efficiency may decrease or even be completely disrupted.

D. *Summary analysis*

A summary of the average values of the reading accuracy obtained during our research on all test rigs is presented in Table V and in graph Fig. 10. In a summary conclusion from this research, the results presented in Table V indicate that:

- There was a significant influence of mutual tag shielding on reading efficiency. For rig A, where 10 tags were placed in such a way as to exclude mutual shielding, regardless of the method of measurement, 100% accuracy was obtained. For other rigs, including those in which the number of tags was also 10 (rig E) or smaller (rig C with 9 tags), it was not possible to obtain the correct reading of all tags in an open environment with stationary reading method.
- The influence of the metal environment on the reading efficiency is greater than that of the reading method (however dynamic method has an advantage over stationary method). This can be seen in both partial and cumulative results, where for the open environment and dynamic reading method, the obtained accuracy was at the level of 80%, and for the metal environment and static reading method, obtained accuracy was at 93%.

TABLE V. SUMMARY OF THE RESULTS ON THE ACCURACY OF TAG READING

Configuration	**Rig**					**Overall**
	A	***B***	***C***	***D***	***E***	
Open environment – stationary reading	100%	83%	78%	35%	50%	64%
Open environment – dynamic reading	100%	85%	100%	62%	70%	80%
Metal environment – stationary reading	100%	84%	100%	88%	98%	93%
Metal environment – dynamic reading	100%	100%	100%	100%	100%	100%

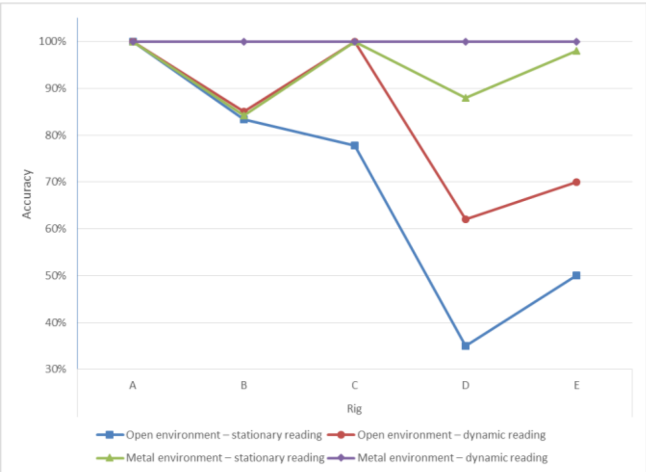

Fig. 10. Summary of the results on the accuracy of tag reading

IV. SUMMARY

The effectiveness of data exchange between the reader and the RFID tag depends on many factors. In the conducted research, reading was tested in four ambient configurations, two in an open space and two inside a metal cabinet.

RFID tags were used as document markers, placed in binders in five position variants. The influence of environmental conditions and the method of reading (stationary and dynamic) on the reading accuracy was examined.

Optimal amounts and location of tags were determined, for which 100% of readings are correct.

It was determined that the method of reading has less influence on the accuracy than the environmental conditions.

It follows that for the correct operation of systems for documentation and other objects collected in metal cabinets, first of all the construction and material of the cabinet are important, and then the method of reading. In the situation where it is necessary to read more tags and their mutual shielding, obtaining an effective reading depends on all relevant system components, i.e. the structure and material of the cabinet, as well as the way of reading.

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