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HIGH SPEED APPLICATION (UP TO 200 KM/H) OF RFID SYSTEMS IN RAILROAD TRANSPORT

VYSOKORYCHLOSTNÍ APLIKACE RFID (DO 200KM/H) V ŽELEZNIČNÍ DOPRAVĚ

Marek Pola, Pavel Bezoušek[1]

Summary: In the paper a RFID automatic railway vehicle identification system is treated, consisted of readers, deployed along railroad tracks and tags clipped to the passing vehicles. The reader – tag setup including a reader wake-up sensor is described. The semiactive tags are assumed in this application to achieve a satisfactory long range operation and simultaneously a long tag lifetime. The communication between reader an tag is then analyzed, dimensions and further parameters of reader and tag antennas are discussed and a received power and Doppler shifts due to the tag motion are evaluated. It is shown, that the 2,45 GHz frequency band is a suitable choice for this application.

Key words: RFID, AVI, reader, tag, railroad car, Doppler effect

Anotace: V článku je zpracován RFID automatický identifikační systém železničních vozů, skládající se z čteček, rozmístěných podél železničních kolejí a tagů (značek) připevněných k projíždějícím železničním vozům. Je zde popsáno nastavení čtečky a tagu včetně senzoru probouzejícího čtečku. Pro tuto aplikaci jsou zvoleny semiaktivní tagy pro jejich schopnost operovat na dostatečně velké vzdálenosti a dostatečně dlouhou životnost. Poté je analyzována komunikace mezi čtečkou a tagem, jsou diskutovány rozměry a další parametry jejich antén a nakonec je určen přijímaný výkon a Dopplerův posuv vzniklý pohybem tagu. Je ukázáno, že frekvenční pásmo 2,45 GHz je vhodnou volbou pro tento typ aplikace.

Klíčová slova: RFID, AVI, čtečka, tag,železniční vůz, Dopplerův efekt

1. INTRODUCTION

The radiofrequency identification (RFID) technology is used widely in variety of applications [3], like individual product tracing in industrial processes, supply chain management, identification of persons, animals or vehicles or in various chip card and toll applications. Most recently also object positioning using RFID technology has been introduced. RFID systems consist of interrogators - readers (usually parts of the system infrastructure) and tags (fastened to monitored objects), communicating through radiofrequency waves. In most applications standard radiofrequency and communication HW

[1]prof. Ing. Pavel Bezoušek, CSc. Ing. Marek Pola, University of Pardubice, Faculty of Electrical Engineering and Informatics, Studentska 95, 532 10 Pardubice, Tel.: +420 466 036 035, fax 466 036 241,
E-mail: Pavel.Bezousek@upce.cz, Marek.Pola@upce.cz

are used and only system SW should be matched to the particular requirements. But in the case of a very high speed of the tracked object, the limited broadcast time interval and the Doppler frequency shift may lead to serious problems in communication between readers and tags. This is the case of automatic identification of vehicles including railroad cars, moving at a high speed.

2. PROBLEM DEFINITION AND THE USE OF THE 2.4 GHZ BAND REASONING

We assume systems operating from zero to high speed (up to 200 km/h). Target applications are characterized by basic situation, when moving vehicle with a tag enters the field of view of the reader which finds its identification number and eventually reads additional data stored in the tag memory. In the case of a R/W (Read/Write) tag and a sufficiently long contact of the tag and the reader, it could be possible even to write data like reader position etc. to the tag memory. From the operational point of view only the relative motion between the tag and the reader is important, not their location on the vehicle or in the fixed part of the transport infrastructure. For a satisfactory function of the system it is necessary to attain tag – reader communication in the range from 0.5 m to 7 m (or up to 10m) (see section 4). However, to achieve the needed sensitivity and to direct RF power, emitted by the reader to the chosen part of the vehicle, it is necessary to use an antenna with a limited beamwidth. Typical applications require a beamwidth of 10 ° to 40 ° (Section 4). The beamwidth is closely related to the antenna size D and the wavelength λ by an approximate formula:

$$\Phi_{3dB}[\deg] \cong \frac{60\lambda}{D} \qquad (1)$$

Because it is difficult in practice to use antennas with dimensions over 1 m, the maximum wavelength λ max ~ 0.17 m is only acceptable. It corresponds to the 2.4 GHz (λ = 0.125 m) or 5.6 GHz (λ = 0.053 m) microwave bands.

3. LEGISLATION AND STANDARDISATION

RFID systems are liable worldwide to special regulations regarding the permitted frequencies and the amount of radiated RF power or eventually of modulation type (for the short range devices the ERC Recommendation 70-30 Relating to the Use of Short Range Devices [1] holds).

Particularly for RFID applications in transportation equipment, Annex 11 of regulations [1] holds. The main requirements of this standard are as follows:

- Frequency band: 2446 - 2454 MHz
- Output power 0.5 W EIRP (product of the transmitted power and the antenna gain) at the duty ratio up to 100%

Regarding the standardization of RFID devices in the 2.4 GHz band, recommendations of ISO / IEC 18000-4: Parameters for Air Interface at 2.4 GHz was released [2] which defines reader – tag communication in the 2.4 GHz band to allow identification systems at high speeds between the reader and the tag. The reader under this standard sends a constant, unmodulated wave that is afterward modulated by the tag (system with semiactive tags) by an OOK or DE-BPSK modulation. For high relative speeds between the reader and the tag mainly the mode 2 of this standard is suitable. The principle of the operation at the high speed is as follows: once the tag enters the RF field of the reader and receives a sufficient energy, it wakes up and sends the first notification (i.e. the confirmation of its presence in the field of the reader) through the reflected wave modulation (the so called TTF mode - Tag Talks First). The notification contains the header (preamble), synchronization sequence including its identification number (32 bit –for the R/O tag it could be extended), inserted during the tag production process and a 16 bit CRC block. This represents the minimum system contact between the reader and the tag and applies particularly for R/O (Read Only) tags. In the case of tags, capable also to write information (R/W - Read Write tag) the link may continue by writing data to the tag and eventually by reading additional information from the tag or confirming the exchanged data validity. The selected parameters of the reader - tag communication according to this standard are listed in the Tab. 1

Tab. 1 - The selected parameters of the reader - tag communication (according to the 18000-4 standard, mode 2

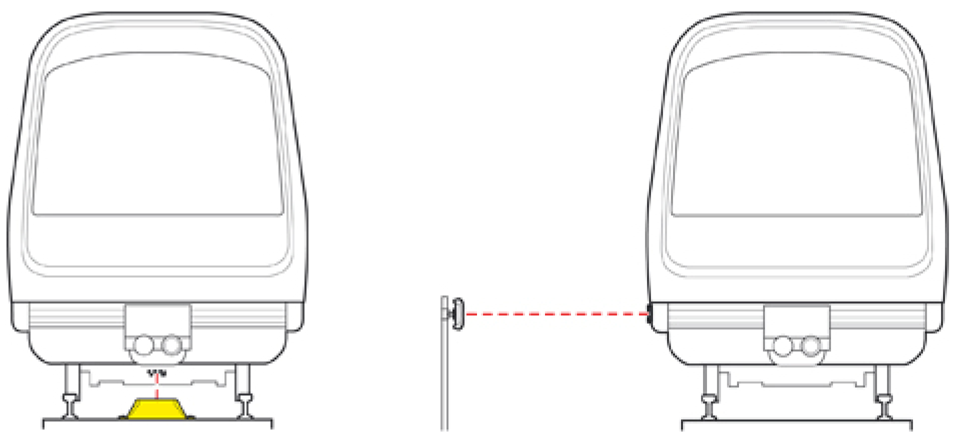
Parameter	**Parameter value**			**Note**
	min	**typical**	**max**	
Frequency	2 410,75 MHz		2 491,85 MHz	
Reference channels	f_n = (2 931 + n).819,2 [MHz] n = 0 to 99			The selection of n according to the local regulations. The communication channel is shifted by ±13x819.2 kHz
Communication channels	f_m= (2 931 + m).819,2 [MHz] m = n ± 13			
Intermediate frequency (IF) of the tag:	13x819,2 kHz = 10,6496 MHz			
Channel span	819,2 kHz			
Frequency accuracy			±200 ppm	
Channel width			1 MHz	(spectral mask defined by local regulations)
Subcarrier	notification: 153,6 kHz, communication: 384 kHz			tag→reader only
Subcarrier modulation	DBPSK or OOK			
Modulation reader→tag:	Communication carrier: GMSK, BT = 0,5 reference carrier: unmodulated (CW)			

Modulation depth	90%	99%	100%	Just OOK
Bit rate	notification: 76,8 kb/s; communication: 384 kb/s			
Modulation format	tag→reader: Differential reader → tag: Manchester			
Radiated RF power			0,5 W (EIRP)	Valid for transport applications in the CR
Switching time: transmission/ reception, and vice versa			< 0,5208 ms	
Reading range			108 Byte	
Writing range			144 Byte	
Information read time			R/W: 7,3 ms R/O: 15 ms	
Information write time			R/W: 7,3 ms	
Memory size	R/W: 2 kB R/O: 32 bit		R/W:256 kB R/O: 160 bit	
Number of simultaneously addressable tags	64			

Source: Authors

4. SOLVING THE PROBLEM OF THE LOCATION OF READER AND THE TAG ON A TRACK

Generally the transponders (tags) may be put to the vehicles bottom, and then readers are placed in the track on sleepers. Another option is to put tags on the side of the vehicle, and readers are then deployed on the sides of the track (Figure 1).



Source: Authors

Fig. 1 - Location of readers on sleepers or on the sides of the track.

In our case we prefer the latter option. According to the cited regulation [1] it is necessary in the rail transport to ensure that reader is turned on only during the train passage. It requires that the system contains a sensor, which turns on the reader, when the train is approaching and turns it off after the train passes away.

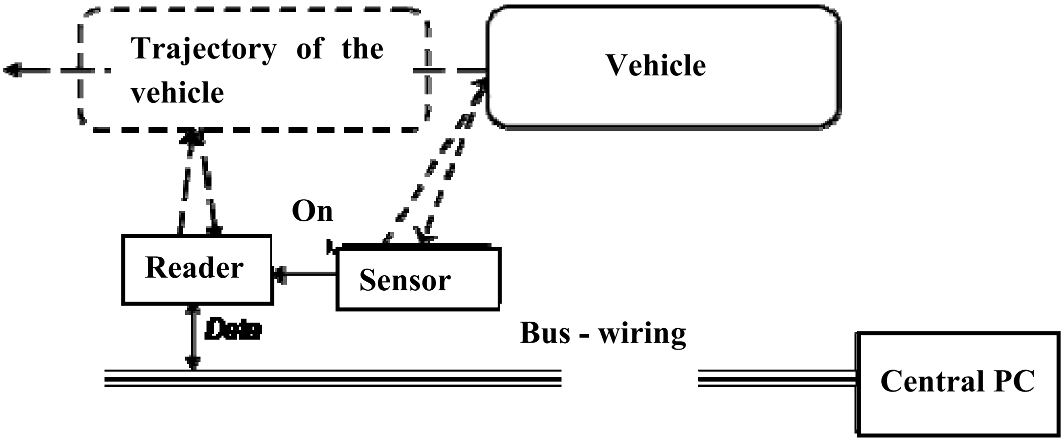


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Fig. 2 - Structure of the system at one point of reading

At a standard railways in the Czech Republic the free profile width should be of 4 m and the tracks spacing used to be about 4.2 m. Therefore, the reader could also be situated between tracks. The minimum distance of any object at the track sides should be of 2.5 m (4 m from the track axis recommended).

Although a large number of trucks types are used on the Czech railways, there are still some common features of them. Figure 3 shows a drawing of a goods wagon. It is possible to place a tag either at the side of the base of the cargo area (point A) or below the base (point B) where the tag would be better protected against damage during loading and unloading wagons. In the case of the tag location at the place B its off - axis distance could be selectable, for instance 1.2 m (which means outside the wheels from the front view). Then the tag could be mounted on most vehicles at the same distance of the axis and thus also of the reader. Then the distance between tag and reader would be approximately: 0.8 m for the reader installed between the parallel tracks or 2.8 m if installed along the side lines, or 7 m in the case of reading tags on vehicles passing on the adjacent track.

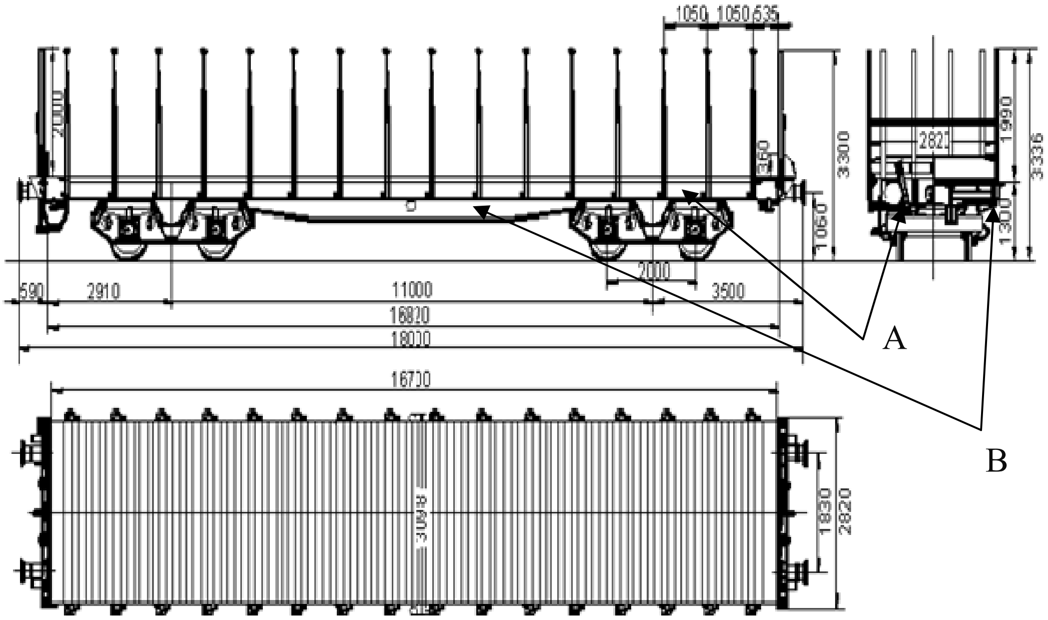

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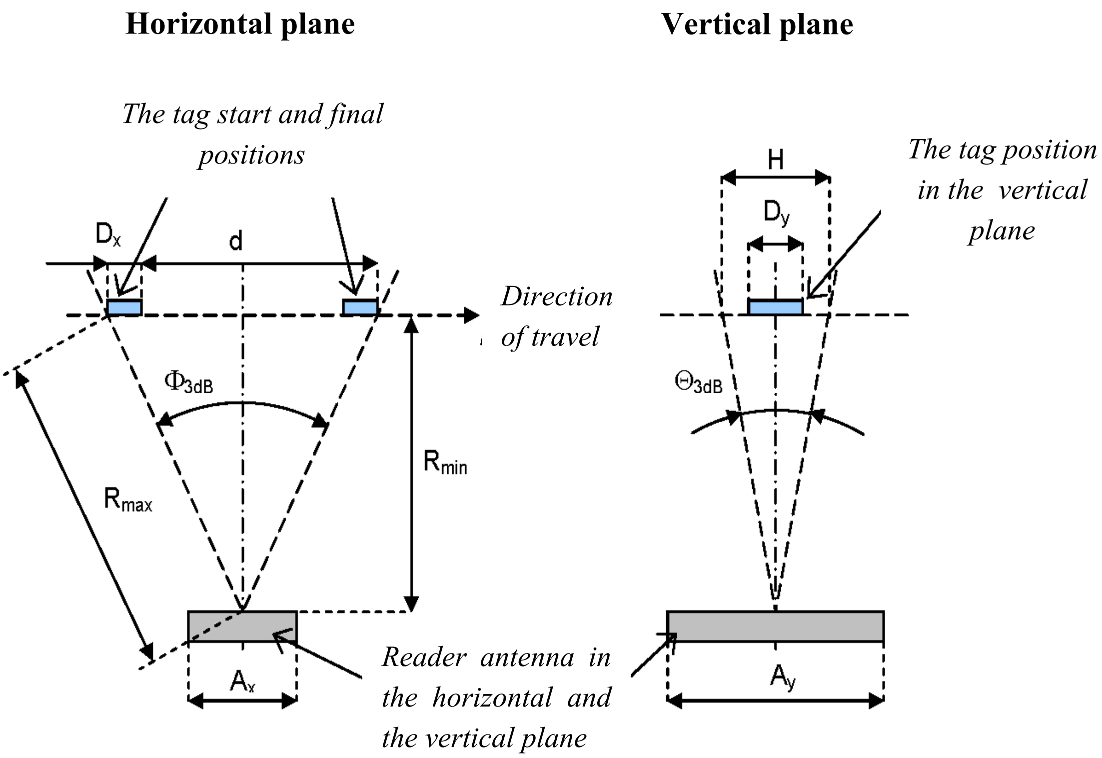
Fig. 3 - Diagram of the truck flatbed type ob. Position A represents the location of the tag on the side of the platform, B the location under the platform

In our further analysis of this system, we assume that the process of mutual exchange of data between the reader and the tag takes place within the main lobe of the reader antenna having beamwidths of Φ_{3dB} and Θ_{3dB} in the horizontal and vertical planes respectively. In order to maximize the use of radiated power and to limit radiation in the unwanted directions we have to choose the antenna beamwidth as small as possible, taking into account the device function. The beamwidth should then be adapted to a particular geometry (i.e. reader antennas will depend on the reader locations). The situation is shown schematically in the Figure 4. Estimating the distance d traveled by wagon during communication interval, we assume that the system should work at speeds up to 200 km/h at least. The time required to transfer a single session, i.e. to read the tag identification number, including the preamble and the CRC is τ = 15 ms (notification) in RFID systems compliant with [2]. Suppose that in order to improve the transmission reliability, at least two such sessions of 15 ms are required. From the signal processing point of view, the tag dimensions should be as large as possible but the horizontal tag dimension should not exceed half of the horizontal dimension of the reader antenna, otherwise it would significantly limit the reflected power in the extreme positions of the tag. The vertical tag dimension should be less than the height H of the illuminated area to ensure the full tag exposition.



Source: Authors

Fig 4 - Tag in the main beam of the reader antenna. Dx, Dy are the horizontal and vertical dimensions of the tag, d is the distance traveled by car during the session, Φ_{3dB}, Θ_{3dB} are beamwidths of the reader antenna in the horizontal and vertical planes, Ax, Ay are the horizontal and vertical dimensions of the antenna, Rmax, Rmin are the maximum and minimum distances from the tag to the reader, H is the vertical dimension of the illuminated parts of the car.

The minimum horizontal antenna beamwidth Φ_{3dB} for a given configuration (i.e., for minimum distance R_{min} between the tag and the reader), the horizontal dimension of the antenna A_x, the horizontal dimension of the tag and the ratio of maximum and minimum distances of tags and readers in their communication will therefore be:

$$\begin{aligned} \Phi_{3dB} &= 2\arctan\left(\frac{d + D_x}{2R_{\min}}\right) \\ \frac{R_{\max}}{R_{\min}} &= \cos^{-1}\left(\frac{\Phi_{3dB}}{2}\right) \\ A_x &\cong \frac{60\lambda}{\Phi_{3dB}[\deg]} \\ D_x &\leq 0{,}5A_x \end{aligned} \qquad (2)$$

, where λ is a wavelength.

For the vertical beamwidth we choose the size of the illuminated area H = 0.5 m. Then we have:

$$\Theta_{3dB} = 2\arctan\left(\frac{H}{2R_{\min}}\right)$$
$$A_y \cong \frac{60\lambda}{\Theta_{3dB}[\deg]} \qquad (3)$$
$$D_y \le 0{,}5H$$
$$G = \frac{52\,524}{\Phi_{3dB}[\deg]\cdot\Theta_{3dB}[\deg]\cdot L_n}$$

Where G is the gain of the reader antenna and Ln is a reader antenna loss due to radiation to the sidelobes (for a high quality antenna with a narrow beam it used to be around 2 dB, for antennas with wide beam it is even lower).

To calculate the signal power, received by the reader and reflected (and modulated) by the tag radar equation applies ([4]). With expression for the power P_T, received by the tag and an approximate relation for estimating the effective area of the tag antenna we get the following relations:

$$P_P = P_V G^2 \frac{\lambda^2\sigma}{(4\pi)^3 R^4}\cdot\frac{1}{L} = EIRP\cdot G\frac{\lambda^2\sigma}{(4\pi)^3 R^4}\cdot\frac{1}{L}$$
$$P_T = P_V G\frac{\sigma}{(4\pi R)^2}\frac{1}{L} = EIRP\frac{\sigma}{(4\pi R)^2}\frac{1}{L} \qquad (4)$$
$$\sigma \cong \eta_A \frac{S}{L_n}$$

Where:

P_P, P_V are received and transmitted by the reader signal powers,

P_T is the power received by tag,

σ is the effective area of the tag antenna,

L is the total loss between the tag and reader including depolarization (in our case it can be neglected, i.e. $L \cong 1$),

R is the instantaneous distance of the reader and tag,

$EIRP = P_V.G$ is the effective isotropic radiated power of the reader, limited by the standard [1],

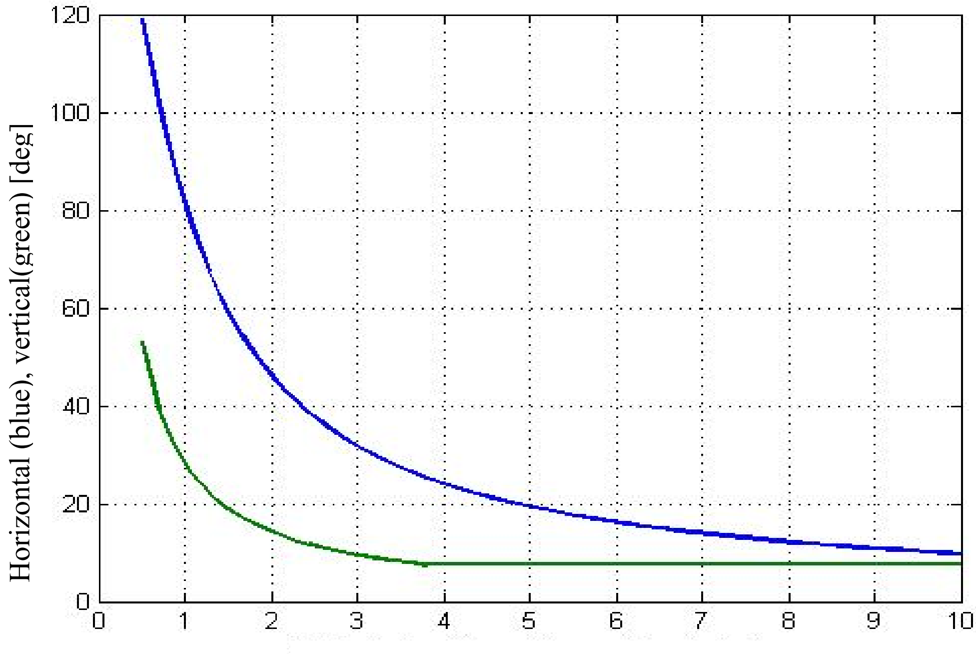
η_A is the reader antenna efficiency (at small printed antennas it can be expected around $\eta_A = 0.9$),

S is a physical area of the front of the tag.

The formula for the effective area of the tag antenna σ is only a rough estimate of this quantity. The power P_T, transmitted by the reader and received by the tag is important for the function of the system, because it must ensure tag waking-up process when the tag enters the readers RF field. On the Fig 5 to 8 there are plotted dependencies of the individual reader antenna characteristics and of the received power on the range R_{min}, calculated using relations

(2) and (4) provided: τ = 15 ms (interval length of communication), *EIRP* = 0.5 W, D_x = 40 mm, D_y = 80 mm, *H* = 0.5 m. However, since the vertical dimension of the reader antenna and its gain computed by relations (3) at a high range R_{min} appear too high, which is not realistic in practice, we limited the vertical dimension of the reader antenna in these calculations to 1 m.

THE READER ANTENNA BEAMWIDTHS



Source: Authors

Fig. 5 - The reader antenna beamwidth optimized for a given distance of the reader - tag trajectory distance. Vertical beamwidth is limited by the maximum vertical dimension of the antenna 1 m

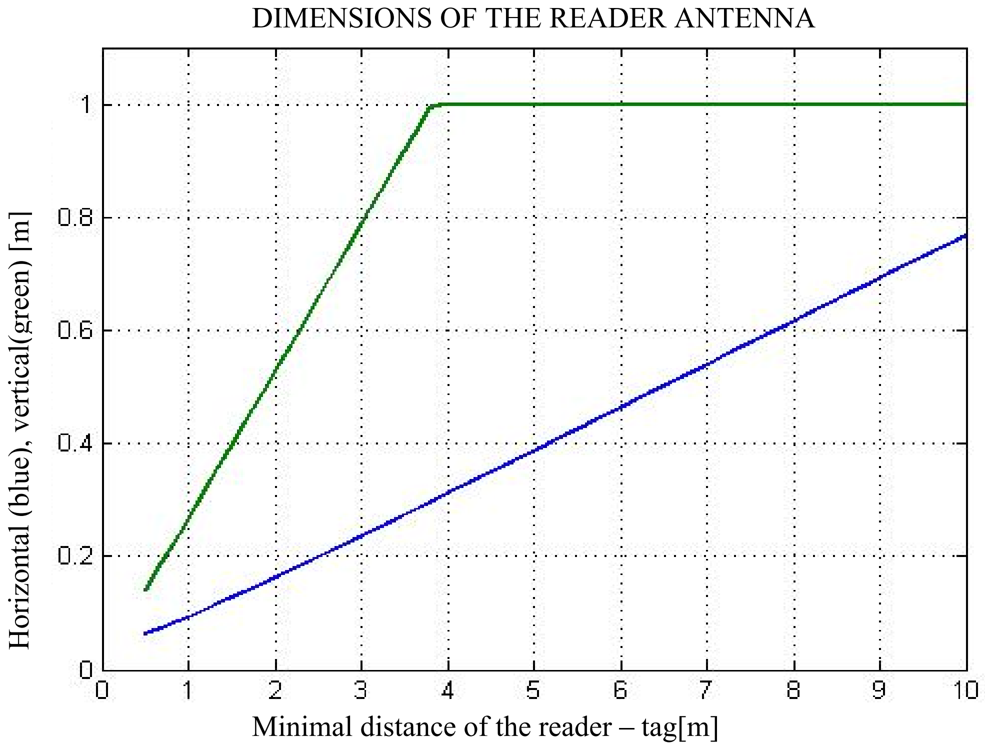


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Fig. 6 - Dimensions of the reader antenna, depending on the reader – tag trajectory distance. The horizontal dimension is optimized for a given distance, the vertical is optimized up to the size 1 m

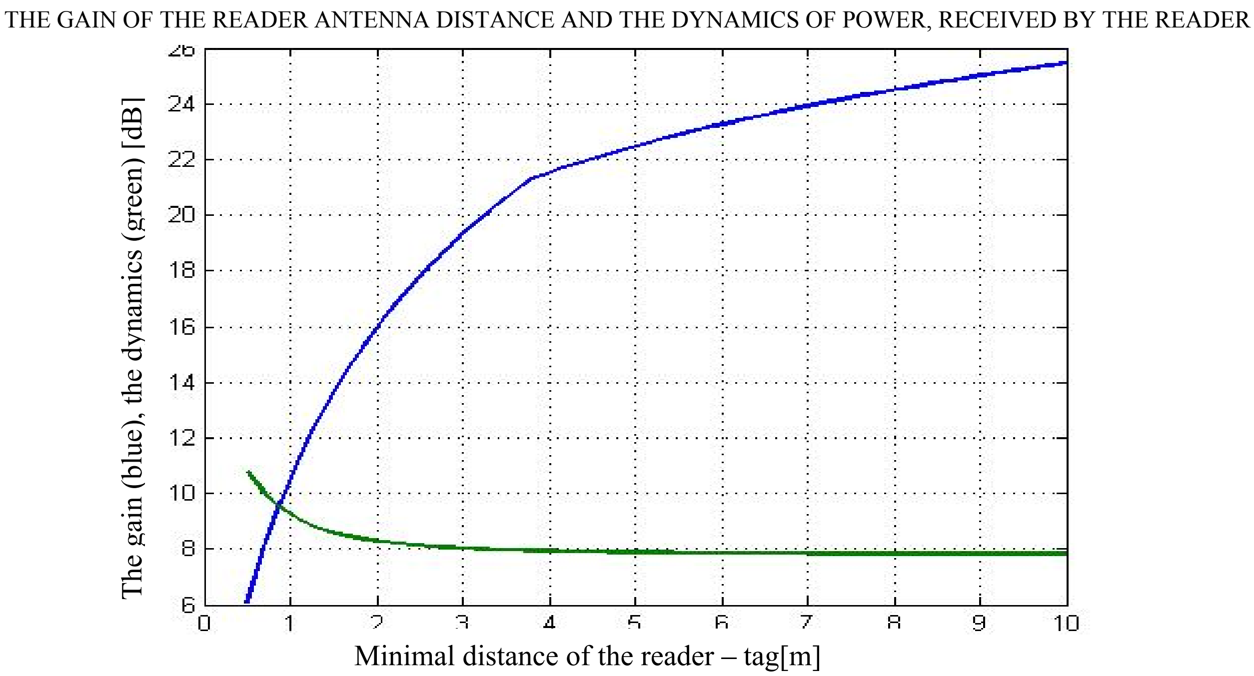

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Fig. 7 - The gain of the reader antenna, depending on the reader - tag trajectory distance and the dynamics of power, received by the reader. Beamwidth and the reader antenna dimensions are optimized for the respective distance up to the antenna sizes of 1 m

POWERS RECEIVED

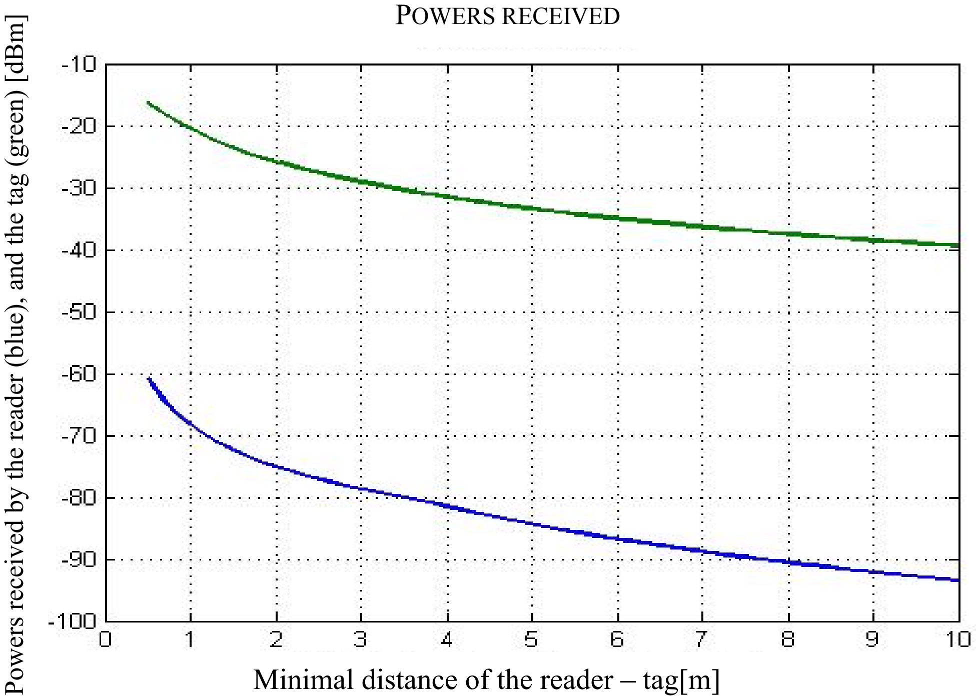

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Fig. 8 - Powers received by the reader and the tag, depending on the reader to the tag trajectory distance. Beamwidth, reader antenna size and gain are optimized for the respective distances up to 1 m. EIRP = 0.5 W, tag size: 40 x 80 mm

When tag is moving over the beam the power received by the reader changes in range shown in the Figure 7. Hence we can see that the maximum changes are at a short reader - tag trajectory distance. At a distance of 3 meters or more, the dynamics is close to 6 dB, caused by the decrease in sensitivity at the edges of the reader antenna beam.

Now we consider the tag speed effect on frequency due to the Doppler effect. Maximum Doppler frequency shift Δf_T of a signal received by the tag and the maximum shift Δf_R of the reflected signal and received by the reader are given by:

$$\Delta f_T = f_0 \frac{v_{\max} \cdot \sin\left(\frac{\Phi_{3dB}}{2}\right)}{c} \qquad (5)$$

$$\Delta f_R = 2\Delta f_T$$

where: f0 is a central frequency of the transmitted wave, v_{max} is the maximum speed of the vehicle in the direction shown in Figure 4 and c is the speed of the light. Substituting v = 55.55 m/s (200 km/h), f0 = 2.4 GHz and Φ3dB = 80° (R_{min} = 1 m) we get the following values for the Doppler shifts:

- Δf_{T01} = 285,65 Hz ,
- Δf_{R1} = 571,3 Hz

  and for R_{min} = 3 m:
- Δf_{T3} = 133,63 Hz ,
- Δf_{R3} = 267,26 Hz.

The values of Doppler shifts do not affect system performance, because the tag operates in the modulation of the incident wave with a bandwidth of several MHz. Shift Δf_R causes frequency shift of demodulated subcarrier by 153.6 kHz or 384 kHz, which represents 0.37% respectively 0.149% of the subcarrier frequency. Because of the standard 18000-4 ([2]) requirements a sub-carrier frequency deviation should be less than 0.35% the computed Doppler shifts are found on the boundary of parameters guaranteed by the standard. In any case an automatic synchronization of the demodulator on the received subcarrier should be used (for example by a Costas loop). When tag is moving over the beam the signal time delay is also changed. The total delay of the signal at a minimum distance of the tag and reader R_{min} = 10 m is only 66.7 ns. Changes in the distance about 1 m will therefore correspond to the changes in the time delay of only 6.67 ns, which is negligible in respect to the subcarrier period of 2,6 μs.

5. CONCLUSION

This analysis leads to a definite choice of 2.45 GHz frequency band for the intended application. The article discusses the available received power and the antenna size of the tag and the reader. The tag motion in the assumed geometry leads to the received signal amplitude variation in the range of 6-13 dB and to a variable Doppler shift of 133-570 Hz, which should be compensated by automatic synchronization of the demodulator oscillator to the instantaneous frequency of the received signal. Time shifts, due to displacement of the tag are not important for synchronization.

6. ACKNOWLEDGEMENTS

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