Investigations to Achieve Very High Data Rates for RFID and NFC Applications

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***Abstract*—This paper deals with the increase of data rates for RFID and NFC systems. The paper gives an introduction to the basic functionalities of RFID systems and sums the required regulation and standard. Different modulation schemes are discussed to compare different approaches to achieve a data rate of 6.78 Mbit/s. The signals are compared based on their bandwidth, which is one of the main parameters for the communication in bandwidth limited channels. Measurements presented at the end of the paper show the feasibility of the modulation schemes and compare different concepts. It is shown that higher order PSK modulation performs 23% better in terms of required field strength than ASK and 3 times better in terms of voltage stability at the transponder.**

I. Introduction

The beginning of radio frequency identification (RFID), can be found in World War II. Radar was already then used to detect planes at large distances, employing radio frequency. Unfortunately at the beginning of Radar, there was no possibility to distinguish between a friendly or foe plane on the ground. German pilots realized that they can change the reflection at the base station by rolling their planes. Thus the change of reflection influenced the radar beam, and as a result planes appeared much brighter on the screen. As a consequence also the British army improved their identification (ID) system and mounted reflectors on their planes, which were tuned to the home frequency. The back scattering echo of their planes was much stronger, which finally appeared much brighter on the screen [1].

Many achievements later, the break through started in the 1980s with electronic article surveillance (EAS) systems. Those systems allow to detect products, which are removed unauthorized. In the 1980s new applications where installed and the interest grew in access control and transportation. In 1987 the first RFID based toll collection was used [2]. The emerging field of applications increased the need for unique standardized ways of communication. This led to strong standardization activities in the 1990s.

Since the introduction of the electronic Passports (ePassport) in Austria in 2006, RFID is commonly known. Personal data such as fingerprints and images are stored on the ePassport. With this additional biometrical data, the demand for security increased in parallel. The exchange of this information increased the traffic, due to the higher amount of data, and the secured transmission. This development led to the definition of higher data rates in [3]. Due to the continuous increase of the amount of data, the need for very high data rates (VHDR) is essential.

At the same time the amount of data is increasing, the transaction time should be kept constant, or even reduced [4]. In 2002 a new standard for near field communication (NFC) was defined. NFC allows both, the communication between mobile phones and RFID transponder, and between NFC devices. The number of possible applications grew rapidly, since the mobile phone allows the user to be an active partner in communication. Possible applications are e.g. downloading information from smart posters [5], buying tickets for public transportation on the phone, or contactless payment in shops. To summarize the increased date volume in identification applications and new applications for RFID are strong indicators for the need of VHDR. However, VHDR are not included in current standards. As basis for the introduction of VHDR this paper compares amplitude shift keying (ASK) and phase shift keying (PSK) modulation schemes to increase the data rate from current 848 kbit/s up to 6.78 Mbit/s [6].

The paper is organized as follows. First an introduction in general RFID systems will be given, leading to the regulation, which is mandatory for proximity coupling devices. A short introduction to the actual standard [3] introduces different reader to card communication modes, which will be compared accordingly. Measurement results at the end will prove the results described in this paper, and a brief summary concludes the paper.

II. Basic functionality of 13.56 MHz RFID Systems

Although 13.56 MHz RFID systems have a wide range of applications, its basic functional principle is the same. Figure 1 shows the basic principles of RFID communication.

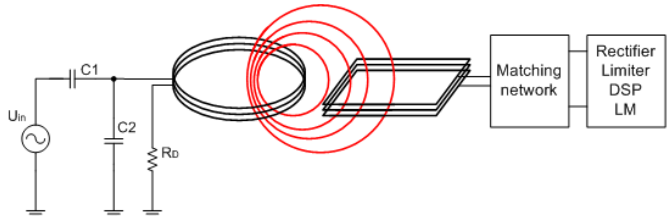


Fig. 1: Principle schematic of an RFID communication system

Since many transponders are passive, the reader has to provide a radio frequency (RF) field, which is used to power the transponder. Therefore a sine wave with a carrier frequency of $f_c = 13.56MHz$ is generated at the reader. In order to increase the power efficiency, a matching network combined with a resonance circuit is used. The antenna forms with the matching network a resonance circuit, which is used to increase the emitted field strength. The transponder is coupled to the reader inductively coupling. The use of a resonance circuit on both sides, the reader as well as the card, enables an efficient way to power the card. Additionally, the RF field of the reader is used for data exchange in both directions. For the communication from reader to card, the reader uses an active modulation, by changing the RF-field. Data transmission from transponder to reader uses the principle of load modulation (LM). Load modulation means that the transponder changes its impedance according to the transmitted data. The change of the impedance causes a change in the RF-field which can be detected by the reader.

The power which can be transmitted as RF field by the reader strongly depends on the quality factor of the resonance circuit. The quality factor (Q) of a parallel and serial resonance circuit [7] is defined as:

$$Q = \frac{2 \cdot \pi \cdot f_r \cdot L}{R_{ser}} = \frac{R_p}{2 \cdot \pi \cdot f_r \cdot L}, \tag{1}$$

where f_r is the resonance frequency and L is the inductance of the antenna. A serial resistor R_{ser} is defined in case of a serial resonance circuit and a parallel resistor R_p in case of a parallel resonance circuit. It can be seen that the quality factor is dependent on the frequency and values of the electronic components.

Thus, a higher quality factor on the one hand decreases the power consumption of the reader but on the other hand influences the effective spectral bandwidth of the system. The lower spectral bandwidth is a negative impact on the signal shaping. The bandwidth (BW) can be calculated as:

$$BW = \frac{f_r}{Q}. \tag{2}$$

Beside the bandwidth limitation of the system itself, frequency regulation limits the usage of the bandwidth as well.

A. Regulation

Each country has its own regulations, for physical parameters, such as allowed field strength, frequency or bandwidth. This guarantees that systems do not influence each other. For 13.56 MHz proximity coupling devices the regulation is defined in [8]. Figure 2 shows the allowed spectral mask for 13.56 MHz operating frequency and the bandwidth for proximity coupling RFID systems. Each product has to pass this frequency mask before market entry. It can be seen that the energy of the carrier frequency, with a bandwidth of $\pm 7\ kHz$ is 51 $dB\mu A/m$ above the next allowed bandwidth limitation of $\pm 150\ kHz$. By decreasing the allowed power, the possible bandwidth is increased. In the standard the energy radiated by the reader is measured at a distance of 10 meters.

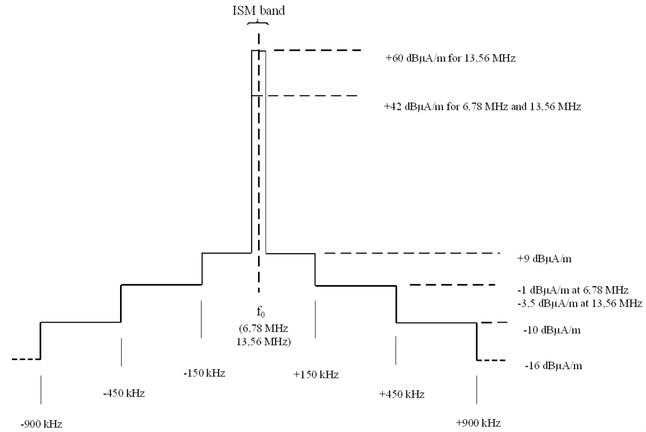


Fig. 2: Spectral mask for 13.56 MHz RFID systems (taken from [8])

The challenge is to find a modulation, which allows the system to stay within the defined ranges of the regulation and fulfills the spectral mask. The same time it has to be ensured, that enough power is transmitted to supply the transponder. In the following chapters, various modulation schemes are investigated with respect to bandwidth requirements.

B. Standardized reader to card modulation modes

The ISO/IEC 14443 Part-2 standard [3] defines two different methods of communication from reader to card. The first is called Type A, and performs an 100% ASK modulation which is Manchester coded. The second is called Type B and uses 10% ASK modulation with non return to zero bit coding. The

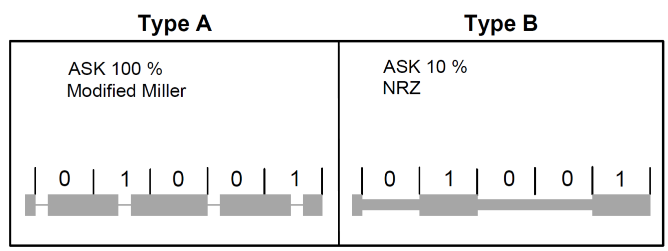
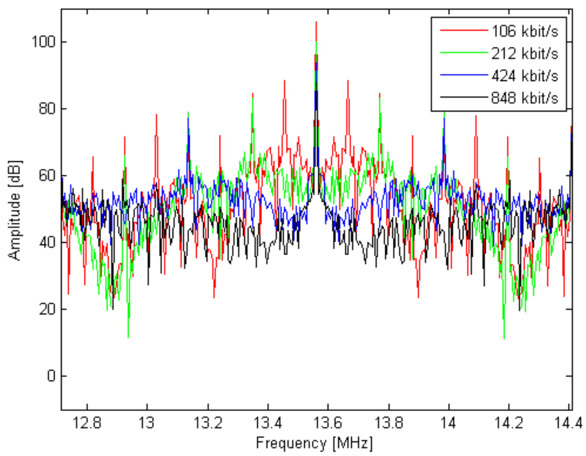
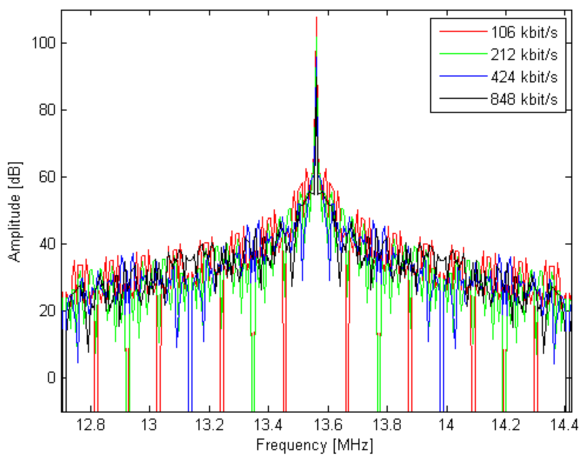


Fig. 3: Reader to card modulation and bit coding definition (taken from [3])

wave shapes of the signal are clearly defined in the standard, in order to guarantee that different systems can communicate with each other. The wave shapes are shown in Figure 3 The ISO standard [3] defines the bit rates of 212, 424 and 848 kbit/s as higher data rates. For higher data rates the signal shaping definition differs due to the fact that a certain quality factor limits the bandwidth and influences the signal. Figure 4 shows the spectrum of the basis data rate and all higher data rates for both methods, Type A and Type B. Note, we assumed an ideal transmission system and channel for these investigations. Increasing the data rate, also means increasing the bandwidth, which can be seen in the plots.



(a) Type A



(b) Type B

Fig. 4: Spectrum of the communication from reader to card

III. Reader to card modulation modes

For a further increase of the data rate, different possibilities are feasible. In the following part, the increase of the data rate with an ASK modulation is shown, and as comparison a PSK modulation. The different modulation methods will be compared with respect to their bandwidth and in measurements according to their energy transmission behavior with the ISO test assembly as defined in [9].
The difference between ASK and PSK is that the information is once stored in the amplitude, and once in the phase. In case of ASK the amplitude will be varied dependent on the data, which results in a time variable amplitude A(t) [6]. The modulated signal is defined as:

$$y_{ASK}(t) = A(t) \cdot cos(\omega t) \tag{3}$$

where A(t) is the modulated amplitude, $\omega = 2\pi f_c$ is the carrier frequency in radian and t is the time index. For the phase modulation the amplitude is constant, and the encoded information in phase:

$$y_{PSK}(t) = A \cdot cos(\omega t + \varphi(t)) \tag{4}$$

Here, $\varphi(t)$ is the information carrying variable. Independent of the modulation method, the reader has to transmit enough energy in order to power the transponder.

A. Amplitude Shift Keying

To increase the data rate up to 6.78 Mbit/s, a possibility would be to use the ASK modulation as in the actual standard and reduce the symbol time, in order to increase the data rate. If the actual standard should be enlarged, the two different transmission protocols have to be considered separately. For Type A this would mean that the pause time is reduced again. At the basis data rate, the pause time is 3 μs. This means in a symbol, which lasts for 128 carrier periods, the carrier will be turned off for 40 periods. A carrier period equates $1/f_c$ $sec.$ Thus a modulation of 40 periods correspond to a duty cycle of 33 %. Increasing the data rate and keeping the duty cycle constant, the pause time is reduced to 0.37 μs at 848 kbit/s. This is equivalent to 5 carrier periods of pause within a symbol of 16 carrier periods length. Going up to 6.78 Mbit/s, a symbol would last for 2 carrier periods and a duty cycle of 33% can not be achieved any more. According to this duty cycle and short symbol time, the wanted data rate can not be achieved and Type A can not be extended.
Type B uses a different bit coding where a change in the amplitude lasts for the whole symbol time. That way it is easier to enhance the data rate up to 6.78 Mbit/s. However decreasing the symbol time results in increasing the bandwidth as shown in Figure 5. it can be seen that the bandwidth of 1.67 Mbit/s is 3.39 MHz, while the bandwidth increases to 13.56 MHz at a data rate of 6.78 Mbit/s. Another way to increase the data rate at ASK modulation would be to add more amplitude levels, to transmit more information within the same symbol length. Till now only one bit is transmitted within one symbol. Increasing the amplitude levels would allow to

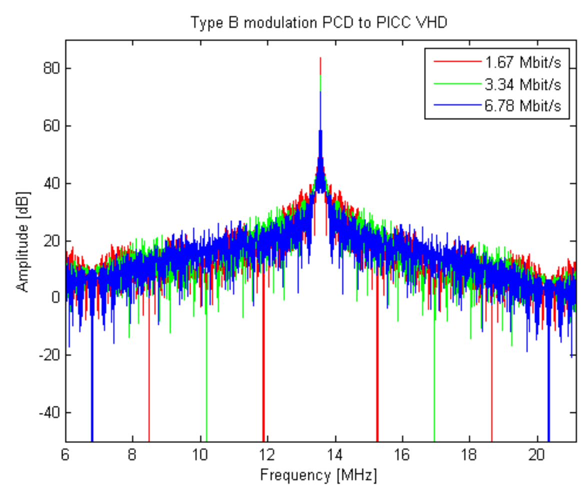


Fig. 5: Frequency spectrum of Type B method at VHDR

transmit more bits within one symbol. That way the bandwidth would not be doubled, if the data rate is increased by the factor of 2. However, this possibility causes the problem that the card has a limiter structure which is used to regulate the voltage to power the transponder, but also protects it from too high voltages, if too much energy is transmitted. By regulating the voltage to a certain level, the limiter works against the amplitude modulation, which makes it difficult to use more amplitude levels.

B. Phase Shift Keying

Another way would be to use a PSK modulation instead of ASK modulation in RFID systems. Since RFID systems distort the phase information less than the amplitude, more bits can be coded per symbol. This enables to use more than 2 phase states per symbol for transmission. Note, coding more bits per symbol allows higher data rates without increasing the spectral bandwidth. This can be seen in Figure 7 for a PSK of the full circle. The advantage in this case is that the bandwidth restriction can be avoided by using more phase states.
Another advantage is that the limiter is harmful to the amplitude variations, but not critical for phase changes, why the limiter does not affect the modulation at all.
To reach the wanted data rate of 6.78 Mbit/s different scenarios are possible, which can be seen in Table I. One way would

symbol time	2PSK	4PSK	8 PSK	16 PSK
8/fc	1.67	3.34	5.09	6.78
4/fc	3.34	6.78		
2/fc	6.78			

TABLE I: Possible data rates

be to reduce the symbol time and keep the same PSK order (along one column), or to keep the symbol duration constant but increase the order of PSK (stay in a row). In both ways the wanted data rate is reached with different modulations. Reaching the data rate by the same order of PSK, the bandwidth would increase at every step, as can be seen in Figure 6. By changing the order of PSK instead of the symbol time, the data rate can be increased as well, but the bandwidth remains constant. This can be observed in Figure 7. By increasing the order of PSK, the required bandwidth is lower compared to ASK with only one bit per symbol at the same data rate. Increasing the order of PSK on the other hand also means that the required signal to noise ratio (SNR) has to be increased, since the distance between the possible symbols is decreasing. Comparing Figure 5 with Figure 7 no peak at f_c is contained in the PSK spectrum. However the energy carried by f_c is needed to power the passive transponder. The energy contained at f_c can be enlarged by reducing the modulation angle (φ) of the phase modulation. That means that the symbols are not mapped to the whole circle any more but rather to a segment. Figure 8 shows the spectrum of the 16-PSK at 6.78 Mbit/s, for three different modulation angles. It can be seen that the carrier is not present at all, when the signals are mapped to the whole circle (2π), but as soon, as the modulation angle is reduced,

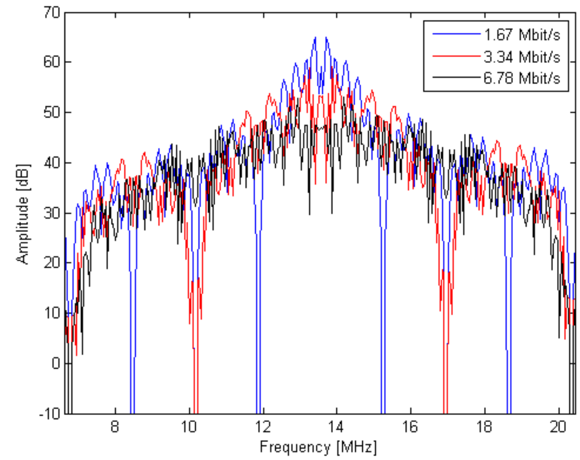


Fig. 6: Spectrum of 2PSK at different data rates up to 6.78 Mbit/s

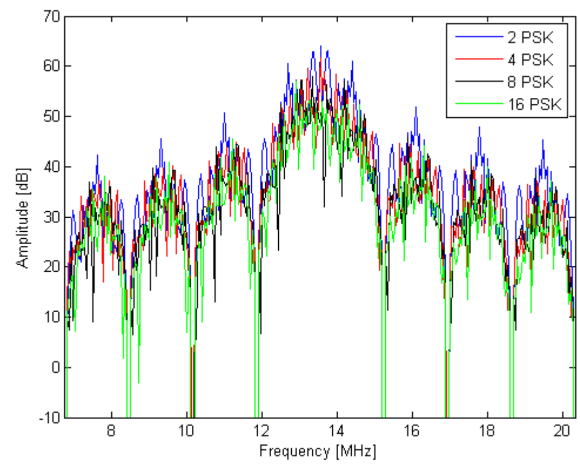


Fig. 7: Spectrum of different PSK orders at data rates up to 6.78 Mbit/s

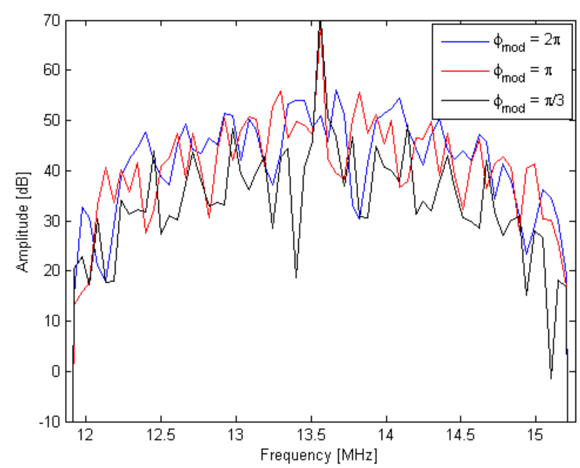


Fig. 8: Spectrum of the 16-PSK at different phase modulation angles at 6.78 Mbit/s

the carrier gets a dominant part in the spectrum. This peak at the carrier frequency is used to transmit the power, without violating the spectral mask. With this solution, the energy transmission of the PSK can be guaranteed, and the required bandwidth is reduced, compared to a lower PSK order. The drawback of this scenario is that the SNR has to be increased again, since the constellation points are very close together and phase noise could cause errors in the communication.

C. Comparing ASK and PSK

To compare the different modulation schemes with each other, one parameter is the required bandwidth. It is also possible to transmit the signal at lower bandwidth, but then inter symbol interference (ISI) [6] can cause errors in the communication. As shown in Table II, the bandwidth of the 2 PSK is increasing at higher data rate. The same can be seen for ASK, while the required bandwidth for higher order PSK stays the same. According to this table, a higher order PSK has a lower bandwidth than ASK or 2-PSK. This means that the ISI and the errors in the communication will be lower in this case.

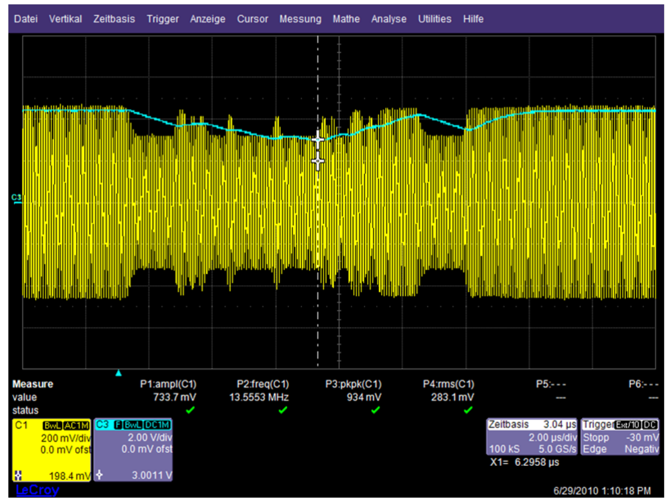
datarate [Mbit/s]	2 PSK [MHz]	ASK [MHz]	M-PSK [MHz]
1.68	3.39	3.39	2: 3.39
3.34	6.78	6.78	4: 3.39
5.09	-	-	8: 3.39
6.78	13.56	13.56	16: 3.39

TABLE II: Required bandwidth of different modulation schemes

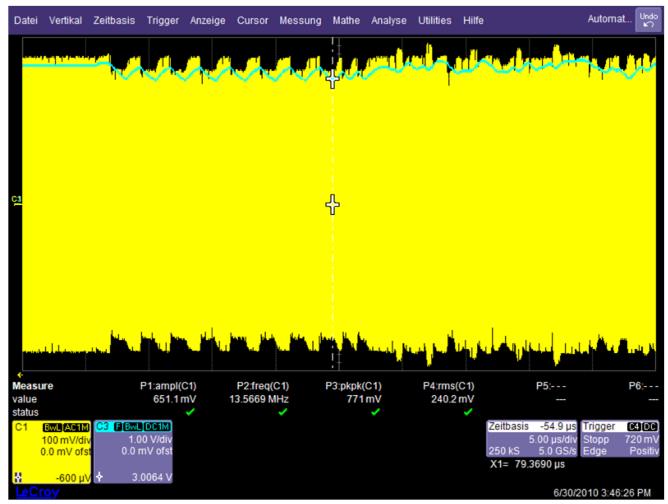
IV. Measurements

To compare the performance of ASK and PSK in a real environment, measurements were done at 6.78 Mbit/s according to the ISO setup. The ISO setup has a system quality factor of 4.2, to be able to show the fast changes of the signal. The reference card, described in [9], was used to measure the energy transmission to the transponder. The resonance frequency of the transponder was tuned to 15.5 MHz, and the load of the card was fixed at 3 $k\Omega$. The reference transponder does not have a limiter, therefore a resistor is used to simulate a certain current consumption. The setup is the same for ASK and PSK modulation. The test condition of the measurement guarantees that the voltage at the transponder is $\geq 3\ VDC$ during the whole communication.

Figure 9 shows the oscilloscope screen of the measured results. In both figures the field is shown in yellow, while the voltage at the transponder is plotted in blue. Figure 9(a) shows the measurement of the ASK modulation. It can be seen that the voltage level decreases during the communication. Figure 9(b) shows the same measurement with a 16-PSK modulation, and it can be seen, that the voltage level decreases less, than in the ASK case. Table III summarizes the measurement results. It is shown that the required field strength for the ASK modulation is higher than for PSK modulation, if the voltage level at the transponder has to stay $\geq 3VDC$. At the same time



(a) ASK (request B)



(b) PSK (start of frame)

Fig. 9: Voltage measurements of the communication from reader to card

the voltage drop is smaller in the PSK version, which shows, that the PSK modulation has a better performance than the ASK modulation.

modulation	required field [A/m]	voltage drop [%]
ASK	1.027	32
PSK	0.79	10

TABLE III: Measurement results for ASK vs. PSK at 6.78 Mbit/s

V. Conclusion

This paper started with a discussion on the basic principle and the limitation of 13.56 MHz RFID systems. Additionally we investigated emitted and frequency limitation due to regulation with respect to VHD. In a first analysis we showed that only Type B transmission method of the ISO standard can be extended to VHDR. However the extension would result in a frequency bandwidth occupation which exceeds the regulation limits by orders. Introducing PSK modulation would mean a higher complexity in the beginning, since there are less concepts for PSK demodulation in RFID applications. A drawback would be to guarantee the backwards compatibility since the modulation differs, which would result in two demodulators in parallel. Even with this drawback the introduction of PSK modulation has benefits in terms of efficient energy transmission and bandwidth requirement, which is also proved with measurements. In future considerations should show the advantages of PSK modulation for the use in VHDR RFID systems.

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