High Speed RFID/NFC at the Frequency of 13.56 MHz

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Data-intensive applications based on NFC (Near Field Communication) or applications for healthcare/e-government will need an increase of the actual defined and standardised transmission rates of 848 kbit/s. It is topic of this work to point out physical layer parameters, limitations and concepts, allowing to enhance the transmission rate of passive 13.56 MHz RFID Systems. Additionally ongoing standardisation activities at ISO 14443 are pointed out, having the aim to standardise significantly enhanced datarates for passive RFID applications at 13.56 MHz. Finally an implementation of a lab scaled prototype with a transmission rate of 6.78 Mbit/s is demonstrated and discussed.

I. INTRODUCTION

Applications based on Radio Frequency Identification (RFID) first appeared in the 1980s and since then this technology started to influence our daily life significantly. While the original applications and intentions were mostly related to logistics or keyless entry, this technology is being used in a much wider range of applications nowadays and will be used in a significant broader area of applications in future. Here it is in particular the concept of NFC (Near Field Communication) which opens up a tremendous new variety of applications. Future applications related to NFC tend to have a stronger affinity to communications than to pure identification - in particular as the transmitted datavolume grows continually. Applications to be mentioned for NFC may be smart posters allowing to get informations (even videos) on the move on your mobile phone. Besides NFC based applications, there are especially licenses, health cards or electronic passports were datarate becomes an issue. Electronic passport is mentioned as an example of increasing datavolume because of saving fingerprints, irisscans etc. on it. As a result of this growing amount of data also the transmissionrate on the air interface becomes of significance, which was simply not the case for pure identification applications. The actual standards ISO 14443 and ECMA 352 (NFC IP2) define datarates up to 848 kbit/s, which is comparable low for data-intensive applications [1] [2]. Therefore standardisation activities for enhanced datarates were started.

Based on the requirement to transfer the higher amount of data in an according time it is topic of this paper to characterize possible concepts of how to enhance the transmission rate for passive 13.56 MHz RFID systems significantly. Chapter II summarizes the main functionality/principles of actual passive 13.56 MHz RFID systems based on load modulation as well as the main parameters. The following chapter discusses the standardisation activities for higher datarates. Based on that insights an already implemented lab scale prototype is depicted and described. Finally a short conclusion and outlook is given.

II. BASIC FUNCTIONALITY OF 13.56 MHZ RFID SYSTEMS

The function of a passive Radio Frequency Identification System can be described in its simplest form as that of an RFID reader identifying an RFID tag, reading data from the tag and writing data to the tag - without contact or line of sight. In the 13 MHz area we are (primarily) talking of inductively coupled systems where the necessary energy is provided by the magnetic field of the reader. Figure 1 depicts the very basic principle of an inductive coupled RFID system, which can be summarized as follows [3] [4]: For inductive coupled systems the underlying antennas are represented by coils of a defined size. It is well known that a coupling system of two coils can be replaced equivalently by a transformer. The connection between these two coils is given by the magnetic field (B) and the underlying value to describe this connection is the mutual inductance (M) and/or the coupling factor (k). The mentioned physical values are given by the following elementary laws/equations [3]:

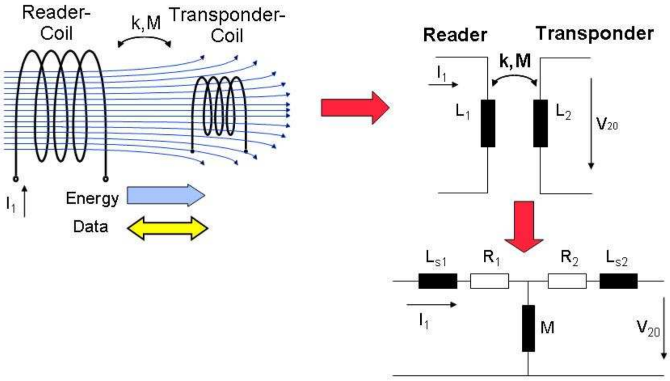


FIGURE 1 - RFID-PRINZIPLE FOR 13.56 MHZ

The law of Biot and Savart is given by

$$\vec{B} = \frac{\mu_0 \cdot i_1}{4\pi} \cdot \oint_S \frac{\vec{ds} \times \vec{x}}{|x|^3} \tag{1}$$

and allows the calculation of the magnetic field at every point as function of the current i_1, as well as of geometry. In equation (1) μ_0 describes the permeability, x stands for the distance and s describes the integration-path along the coil.

Besides this the mutual inductance and the coupling factor, which is in general easier to handle, are given by

$$M = \int_{A_2} \frac{B(i_1)}{i_1} \cdot dA_2, \tag{2}$$

$$k = \frac{M}{\sqrt{L_1 \cdot L_2}} \tag{3}$$

Here A_2 describes the area of the second coil, while L_1 and L_2 describe the inductance of the two coils. The distance between reader-coil and transponder-coil also determines the coupling factor.

Figure 1 depicts additionally that due the connection between first and second coil a change of the impedance on transponder side leads to an unequivocal change on the reader side (change of the seen impedance). This variation of the impedance on the secondary side, which is realized on the primary side is called load modulation - simply by loading the field more or less, information is transferred.

The actual functionality of 13.56 MHz RFID systems is based on resonant circuits (tuned to 13.56 MHz) on reader and card side to generate sufficient voltage and power. An exemplary circuit of an RFID-system based on a passive transponder is illustrated in figure 2. The capacitances C_{rs} and C_{rp} and the resistance R_{ser} build a resonant circuit with the receiver-coil. On the transponder side the resonant circuit consists of R_2 and C_2 and the transponder-coil. To protect the RFID-chip against high voltages caused by this approach a limiter is used in case of high coupling factors. In figure 2 the limiter is depicted by a Z-diode after the rectifier (G). The resistance R_L stands for the resistive load of the RFID Chip and the capacitance C_6 stands for the capacitive load of the IC. All these elements influence more or less the data transfer between reader and transponder.

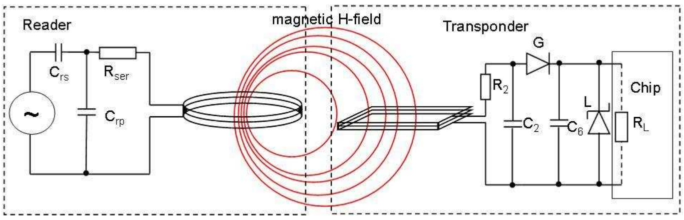


FIGURE 2 - PRINZIPLE CIRCUIT OF AN RFID-SYSTEM

Several aspects in the context of higher datarates for RFID are to be pointed out, having a severe influence on the possible implementation, functionality and performance - parameters as quality factor, energy transmission, modulation/coding concept, corresponding transceiver structure and others. The most significant statement in that context is that none of the above aspects can be taken into account solely, as showing significant addictions between each other. One of the most significant parameters for these resonant circuits is the quality factor - given by

$$Q = \frac{\omega_r \cdot L}{R_{ser}} = \frac{R_p}{\omega_r \cdot L} \tag{4}$$

In equation 4 R_p describes the equivalent parallel resistance of the circuit, R_{ser} describes the equivalent serial resistance, L stands for the inductance and ω_r describes the angular frequency at resonance. The resonant behavior with its corresponding quality factor defines the superelevation of voltage and therefore also the energy transmitted. Based on that, it is obvious that a high quality factor would be of advantage to ensure to power the card. At the same time it is obvious that a high quality factor leads to a slow decaying of the envelope. The envelope and the decaying time are defined as:

$$\begin{aligned} envelope &= \hat{I} \cdot \left((1-x) + x \cdot e^{-\frac{t}{\tau}}\right) \quad with \\ \tau &= \frac{Q}{\pi \cdot f_0} \end{aligned} \tag{5}$$

In equation 5 x stands for the modulation depth in percent and f_0 describes the carrier frequency of 13.56 MHz. A decaying and rising envelope for a 13.56 MHz signal and a quality factor of 30 is shown in figure 3. It becomes obvious that with a shorter symbol duration (higher transmission rate) intersymbol interference will occur. This intersymbol interference makes detection complex and limits the transmission rate. It is essential to point out that for the actual datarate of 848 kbit/s this effect is of minor relevance. The following diagram 4 points out the behavior between quality factor, datarate and intersymbol interference (number of influenced bits) very clearly. In this diagram a symbol is counted as influenced if the amplitude of the previous bit/bits is still higher than 10%. Although some interference will not prevent a detection, it is obvious that with a rising quality factor and rising datarate the detection becomes more and more difficult.

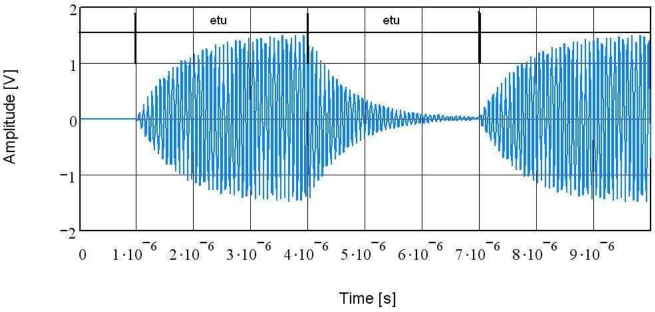


FIGURE 3 - ENVELOPE OF A 13.56 MHZ SIGNAL AND Q=30

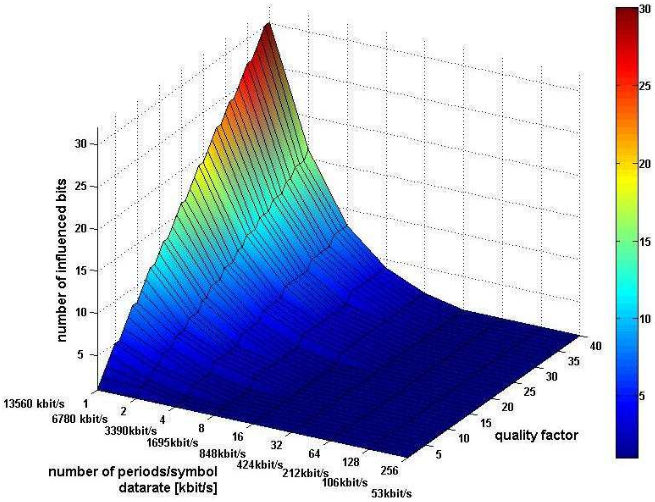


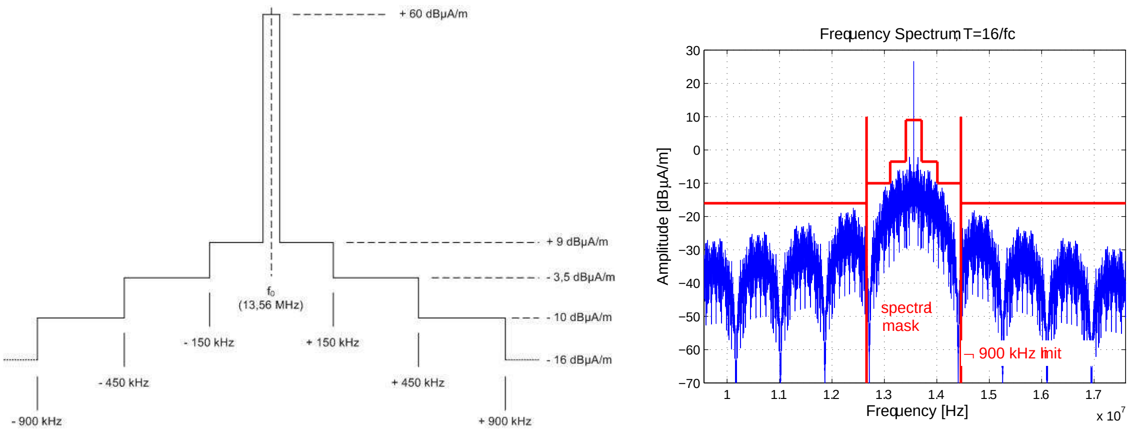
FIGURE 4 - ON THE EFFECT OF QUALITY FACTOR [7]

III. STANDARDISATION ACTIVITIES

Standardisation activities for enhanced datarates were started within ISO (for the corresponding proposals see ISO/IEC JTC1/SC17/WG8 N 865, ISO/IEC JTC1/SC17/WG8/TF2 N 377, ISO/IEC JTC1/SC17/WG8 N 1296, ISO/IEC JTC1/SC17/WG8 N 1236). Actually there are aspects like higher order modulation schemes, multiamplitude versus multiphase modulation, direct carrier - versus subcarrier modulation, new protocol structures etc. under discussion. Some aspects to be mentioned.

a) Communication from reader to transponder:

To increase the actual datarate for the communication from reader to transponder a reduction of the symbol duration seems to be the obvious first step. Of course thereby the bandwidth of the modulated and radiated signal is increased. But this bandwidth is limited by European regulations for an active device like the reader. The spectral mask of the actual valid regulation is pointed out in figure 5(a) [6]. Exemplary the spectra of an amplitude modulated signal (ASK) for a



(a) Spectral mask

(b) Spectrum 256-ASK etu=16/fc

FIGURE 5 - THE SPECTRAL MASK AND THE SPECTRUM OF AN ASK

symbol duration of $etu = 16/fc$ is shown in figure 5(b). It can be noticed that the spectrum not extends the mask. For symbol durations lower than $16/fc$ the spectrum extends the defined mask, due to that no further increase of the datarate can be realised based on the lowering of the symbol duration in Europe. Different appars the situation in the USA where restrictions are different, allowing also lover symbolrates.

Another way to further increase the datarate using a symbol duration of $16/fc$ are higher oder modulation schemes. The most promising modulation methods are multiamplitude shift keying (M-ASK) and multiphase shift keying (M-PSK). The advantage of ASK versus PSK are the smaller bandwidth, the easier realisation and detection. On the other side the main problem for an ASK is the dynamic behavior of RFID systems. The movement of the transponder from and to the reader causes this dynamic behavior. Due to this movement the amplitude of the magnetic field that reaches the transponder coil is changing significantly and that influences the modulated amplitude shifts making a detection more complex. Due to this dynamic behavior the limiter on the transponder is needed to limit the supply voltage. This limiter generates another problem for the ASK demodulation. When the limiter gets active he limits the amplitude of the voltage on the transponder to a defined level and therefore eliminates the modulated amplitude shifts. These two problems can hardly be resolved and therefore the best solution it is, to use an M-PSK for higher datarates from our point of view. As is described before, a reduction of the symbolrate is limited to $etu = 16/fc$ due to that only an increase of the oder (M) of the modulation can further increase the datarate. The relation between the transferable datarate and the order of the modulation (M) and the symbol rate (etu) is demonstrated in table 1. The blue line shows the limit of being compliant with respect to the actual regulation.

etu/d	180°	90°	45°	22,5°	11,25°	5,62°	2,81°	1,4 °
128/fc	106	212	318	424	530	636	742	848
64/fc	212	424	636	848	1059	1271	1483	1695
32/fc	424	848	1271	1695	2119	2543	2966	3390
16/fc	848	1695	2543	3390	4238	5085	5933	6780
8/fc	1695	3390	5085	6780	8475	10170	11865	13560
4/fc	3390	6780	10170	13560	16950	20340	23730	27120

TABLE 1 - BITRATE IN KBIT/S FOR THE PSK

b) Communication from transponder to reader:

For the communication from a passive transponder to the reader a loadmodulation based on subcarriers and higher order modulation schemes has been proposed. Due to the fact that the transponder is a passive device the limitation through the spectral mask is no longer valid. Examplary the bitrate for a loadmodulation with a subcarrier frequency of 6780 kHz $(fc/2)$ is shown in table 2. In this table a minimum of $1/2$ period resolution of the 13.56 MHz carrier is proposed, witch seems to be a good trade of between detection effort and achievable datarate. Based on the above table it becomes obvious that the data rate is always doubled by reducing the symbol duration by two while the data rate grows with the logarithmus dualis (ld) when doubling the number of states. Therefore it is obvious that lower symbol duration leads faster to higher data rates.

Symbol(S)	1bit/S	2bit/S	3bit/S	4bit/S	5bit/S	6bit/S	7bit/S	8bit/S
etu								
$128/f_c$	106	212	318	424	530	636	742	848
$64/f_c$	212	424	636	848	1069	1272	1484	
$32/f_c$	424	848	1272	1696	2120	2544		
$16/f_c$	848	1696	2544	3392	4240			
$8/f_c$	1695	3390	5085	6780				
$4/f_c$	3390	6780	10170					
$2/f_c$	6780	13560						

TABLE 2 - BITRATE IN KBIT/S FOR THE LOAD MODULATION WITH SUBCARRIER $fc/2$

IV. IMPLEMENTATION OF A COMMUNICATION FROM TRANSPONDER TO READER

The entire assembly of the lab scaled prototype is shown in picture 6 and consists of a transponder (a) and a reader (b) coil according to ISO 10373-6 [8]. The 13.56 MHz carrier signal is generated by an FPGA board (d). To provide an appropriate field strength the carrier signal is amplified first (c).

A bit stream for the loadmodulation is saved on a CPLD (complex programmable logic device) of the type coolrunner on the transponder (a). Immediately after the CPLD is powered by the magnetic field of the reader he begins to modulate continuously. The received signal is sampled directly on the ISO-coil board (b) and filtered by an band-stop filter (f). The received signal is digitised by an 12 bit A/D-converter (e) and loaded in the FPGA which quantizes the digital signal and regenerates the bit stream. The transponder circuit of the lab scaled prototype consists of an ID1 coil, a resonance capacity, a rectifier structure, a limiter, a clock signal generator, a CPLD as well as two resistances which are switched by two high speed dual-MOSFET transistors. Two resistances were used to get a more symmetric behavior of the circuit. The control signal for the two transistors is generated by the CPLD which simulates a conventional RFID chip, with simi-

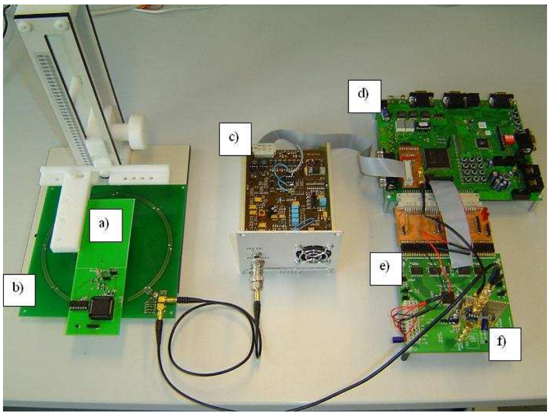


Figure 6 - The development of the lab scaled prototype with datarate 6,78Mbit/s

lar supply voltage and load. An inverter is used to extract the clock signal for the CPLD out of the magnetic field. The circuit that is implemented on the transponder lab prototype is illustrated in figure 7. The used loadmodulation consists of two different amplitudes and can be compared with a 2-ASK. The modulation frequency generated by the CPLD is 6.78 MHz ($fc/2$). The highest difficulty to demodulate the loadmodulated signal on reader side is the low modulation depth. When the transponder is far away from the reader the coupling factor is low and that means that the transponder has a low impact on the reader. Therefore also the change of impedance on transponder side is hardly be seen by the reader. The closer the transponder comes to the reader the more the magnetic field is influenced.

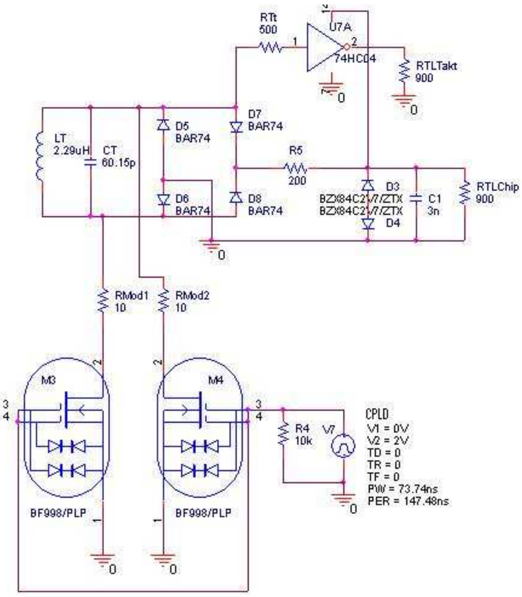


Figure 7 - Prototype VHD-transponder circuit

Without any further countermeasures the extraction of the low amplitude changes due to the high amplitude of the carrier signal can hardly be realised for the underlying datarate. The 6.78 Mbit/s can not be detected accurate on reader side. A way out of this problem can be a realisation of a carrier suppression. This carrier suppression is realised on the prototype by a narrowband band-stop filter. With this band-stop filter the carrier of 13.56 MHz is suppressed and the loadmodulated signal with the lower frequency of 6.78 MHz remains. Another feature of this band-stop filter is the reduction of the slope caused by the quality factor of the resonant circuits of transponder and reader. Due to the improvement achieved by the band-stop filter an accurate detection of the transfered data from the transponder is possible. A bit error rate (BER) curve related to the distance between the transponder and the reader-coil is depicted in figure 8. Up to a distance of 20 mm an error free data transmission was accomplished. Above this distance the BER increases slightly. For an integrated version of tis prototype a better BER is expected due to less tolerances of the single devices, error correction etc.

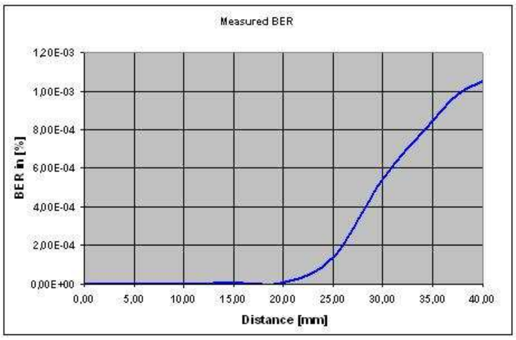


Figure 8 - BER related to the distance between transponder and reader

V. Summary and outlook

It is topic of this paper to point out aspects for future high speed interfaces of passive RFID applications at 13.56 MHz. Therefore typical applications have been discussed, which will result from the possibility to enhance the transmission rate significantly. The main topic of the underlying investigation is it to characterize limiting factors on physical layer level. In particular the quality factor has been pointed out as one of these dominating factors. Finally a first lab-scale prototype has been presented, depicting an achieved datarate from transponder to reader of 6.78 Mbit/s. This lab scaled prototype is also used for investigations for data transmission from reader to transponder with very high datarates. Further an integrated version of this prototype will be developed.

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