Pseudorandom Noise based Channel Coding Scheme for Tag to Reader Communication in UHF-RFID Systems

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Abstract

This paper presents the capabilities of using Pseudorandom noise (PN) codes as a channel-coding scheme for the tag to reader communication. A comparative of the standardized coding scheme and the PN is presented. To take advantage of the PN code's orthogonality an example is shown using gold sequences of length 31 coding 16 symbols, which encodes the information that is backscattered by the tag. At the reader the corresponding correlation receiver is implemented to detect any of the 16 possible symbols. The decision is made using a maximum-likelihood method. This coding scheme will be compared to the EPCglobal GEN 2 standardized Miller codes in order to establish its advantages and disadvantages.

1 Introduction

The use of Ultra High Frequencies (UHF) for RFID Systems has grown considerately in the recent years. The implementation of the radio identification in the logistics and commercial applications, as well as the standardization by the EPCglobal [1], have opened the doors for a wide range of practical applications of the RFID technology. The channel characteristics, the frequency tolerances in the tags, and the requirements for multi-functionality for various frequencies/standards, increase the challenges for the RFID-readers. In the exploring of new ideas and system improvements, some results lead to changes that are not complies with the standards. Nevertheless important improvements can be archived even though it may lead to no standardized systems.

This paper is structured as follows: first a short introduction is given into the standardized coding schemes and the corresponding receivers. The new proposed PN coding scheme is presented and supplemented by a simulation. Additionally a hardware implementation based on a rapid prototyping platform is described and the measurements taken from this realization are presented. At last comparison results between the two coding schemes are given.

2 Channel Coding in UHF RFID

This paper is referred to the EPCglobal Gen 2 standard and the system description given in it. According to this standard the tag to the reader communication takes place using backscatting modulation techniques. In other words the tag uses the electromagnetic field, provided by the reader, to transmit the information back to the reader and to power it self. The information is encoded in 4 possible forms FM0, Miller 2, Miller 4 or Miller 8 see Figure 1.

The reader requests the information from the transponder and specifies the data rate as well as the coding scheme to be used. There are some characteristics referring to this coding scheme: the FM0 coding is the base for the other three types. The Miller 2 to Miller 8 can be seen as a combination of FM0 symbols. The FM0 symbols are orthogonal to each other, but the Miller 2 to Miller 8 symbols are not. Due to its non-orthogonality, the cross correlation of the Miller symbols does not result in a maximum euclidean distance. Nevertheless the length of the Miller codes can be used to decrease the bit-error-rate (BER). A symbol correlation receiver can take advantage of this and improve the signal-to-noise-ratio (SNR) of the signal, this would be shown in 4.

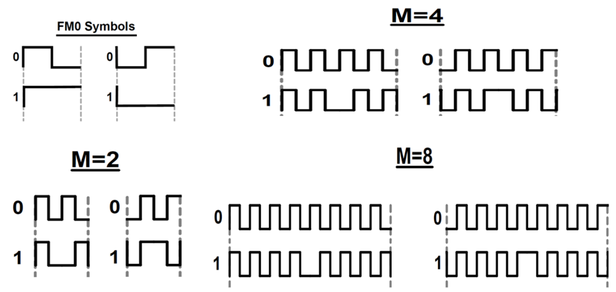

Figure 1 EPCglobal GEN 2 Channel Coding Scheme for Tag to Reader Communication

The concept of these long symbols representing a single one or zero is sub-optimal. Another coding scheme can be used that takes advantage of orthogonality and the correlation gain.

3 Pseudorandom Noise based Channel Coding in UHF RFID

A pseudorandom noise (PN) sequence is a signal with similar characteristics to noise, it satisfies one or more of the noise statistical randomness. PN coding is used in spread spectrum systems where the receiver correlates a locally generated signal with the received one. At the receiver side the local sequence has a very low correlation with any other sequence in the set, with the same sequence at a significantly different time offset, with a narrow band in-

terference or with thermal noise.
It was decided to use gold sequences for test and implementation purposes. Gold sequences are binary sequences of length $2^n - 1$ with a small cross correlation between sequences. This makes them convenient for digital signal transmissions. But other PN sequences can be used as well. Sequences of different lengths were tested and compared against the standardized coding scheme, the results would be shown in section 6.
The orthogonality of the gold sequences increases with rising length. There are $2^n - 1$ possible orthogonal sequences in a set, each one consisting of $2^n - 1$ chips. Short lengths present little or none orthogonality, therefore in order to demonstrate its feasibility for RFID systems, a set of sequences of 31 length was used. For a digital representation the next possible power of 2 is 16. Using 16 different sequences 4 information bits can be transmitted by one single symbol.

4 Simulation

In order to analyze the characteristics of the coding schemes, a simulation of the entire system was done using Matlab [10]. Figure 2 shows the simulation model.

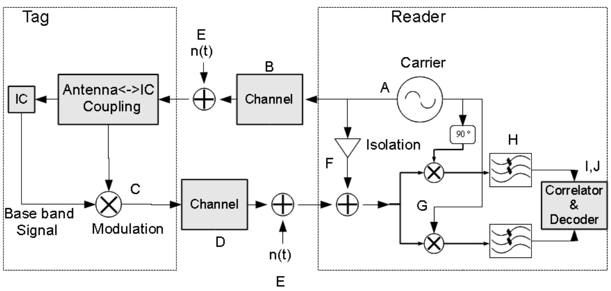

Figure 2 Simulation's Block Diagram

Last Figure shows the block diagram of the simulation. First the carrier is generated by the reader "A". The transmission channel is simulated as Rayleigh-distributed "B". The signal is modulated with a random 16-bit sequence encoded with both schemes "C". Passed throw the channel one more time for the up-link transmission "D". Some Gaussian noise is added to the signal "E". At the reader side a certain portion of the original carrier overlaps at the receiver "F". The signal is demodulated using a IQ demodulator "G". A low pass filter is used to remove the second harmonic of the carrier "H". After a DC removal the signal is correlated with the corresponding receiving filter "I". The output of the correlator is sampled at the symbol rate. The correlator output with the higher value decides which symbol was sent "J".

4.1 Bit-Error-Rate Test

The simulation was done for the EPCglobal Gen2 coding scheme and for the gold sequences. The length of the used Gold sequences were chosen as follow:

- gold sequence length 3 as a substitute for Miller 2
- gold sequence length 7 as a substitute for Miller 4
- gold sequence length 15 as a substitute for Miller 8

In this way the symbol lengths of the Gold sequences are comparable to the Miller symbols; considering the half of an FM0 code as a chip. Two Gold sequences for each substitute are used, one to represent a "1"and the other a "0".
To measure the bit-error-rate (BER) 100 000 bits were sent for each encoding scheme and at different SNR values. The SNR is set by simply increasing the added noise. The graphic in Figure 3 shows the resulting BER of the received signals according to its SNR. It is important to note that the chip length was normalized to one half of the time period of the FM0 symbol. Therefore the band width of all coding symbols is the same, only the symbol length changes. In this way the performance of each symbol form can be compared to the performance of the others.

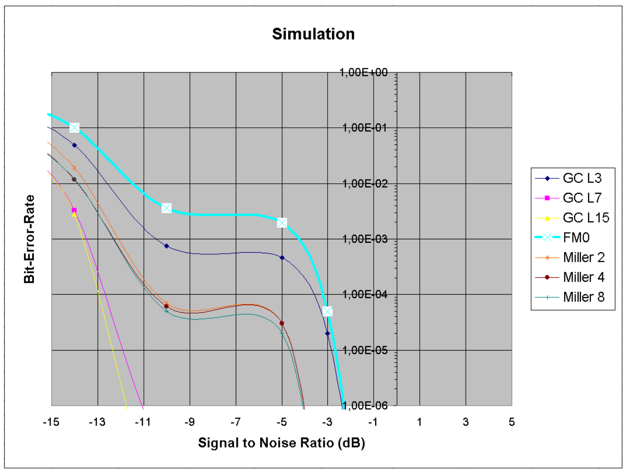

Figure 3 BER Results of the Simulation

The Figure shows the results of the simulation. It can be seen that the BER is reduced as the length of the miller codes increases. The correlation with a longer symbol increments the SNR of the signal reducing the BER [8]. The big difference between the Miller codes and the gold sequences of length 7 and 15 is also significant. The gold encoded signals present a quite better BER compared to their corresponding Miller symbols of the same length. It is important to remark that even though the gold sequences are one chip shorter than their corresponding Miller symbols, the BER is still lower.

4.2 Orthogonality Test

As already mentioned, the orthogonality of the gold sequences could be used to increment the data rate by sending more than one bit per symbol. Gold sequences of 31 chips length can be used to encode 16 different symbols, each representing 4 bits.
Figure 4 shows the cross correlation of one of the sequences with the other 30, and the auto correlation as well.

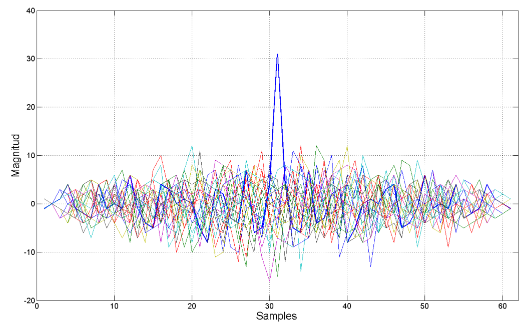

Figure 4 Cross Correlation of one Gold Sequence of Length 31 with the other 30 sequences and Itself

From the Figure 4 it can be seen that at the sample time only one signal arises (blue line).

5 Hardware Implementation

5.1 Hardware Platform

Software Defined Radio facilitates the development and fast implementation of new algorithms. The application of this technology in RFID readers has been explored in [6] [5] [3] [4], and is used to implement the coding scheme presented in this paper. This reprogrammable platform allows to test receiver architectures and the encoding schemes in a short period of time.
The first part of the platform is an analog front end for signal conditioning. The analog signal is digitized by an ADC which provides the digital signal to an FPGA where the signal processing takes place. Figure 5 shows a block diagram of the hardware platform, refer [6] for more details of the system.

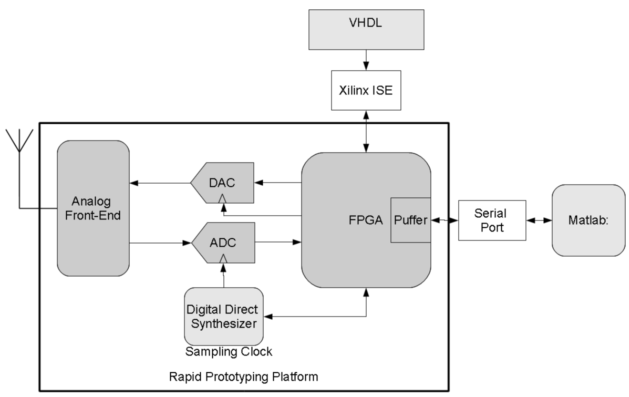

Figure 5 Block Diagram of the Rapid Prototyping Platform

5.2 Bit-Error-Rate Test

After showing the possible advantages of the gold sequences as a coding scheme in UHF RFID systems, the results were corroborated by implementing the system in our rapid prototyping platform. The bit-error-rate test was repeated under the same conditions as for the simulation. 8 random bits are generated in matlab, these ones are transferred to the FPGA where they are encoded. The encoded signal is used by a test transponder to switch the matching circuit of the antenna. This creates a backscatting signal that is received back by the hardware platform. Figure 6.

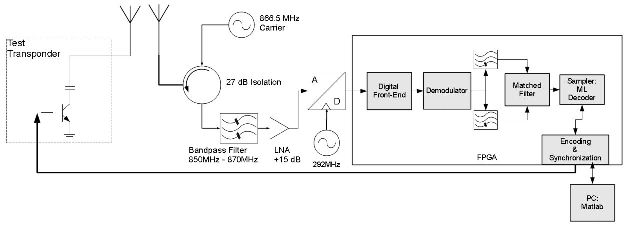

Figure 6 BER Test Block Diagram

In order to decode and recognized the symbols sent by the transponder, the base band signal is correlated with the possible symbol forms. The signal is sampled at the symbol rate. The correlation that provides the maximum output value determines which symbol was sent. The received binary data is transferred back to Matlab where it is compared to the sent data in order to find possible errors in the transmission. This procedure is repeated for all the codes and at different SNR values. The SNR setting was done by changing the distance between the tag and the reader antenna. Figure 7 shows the resulting BER using different coding schemes.

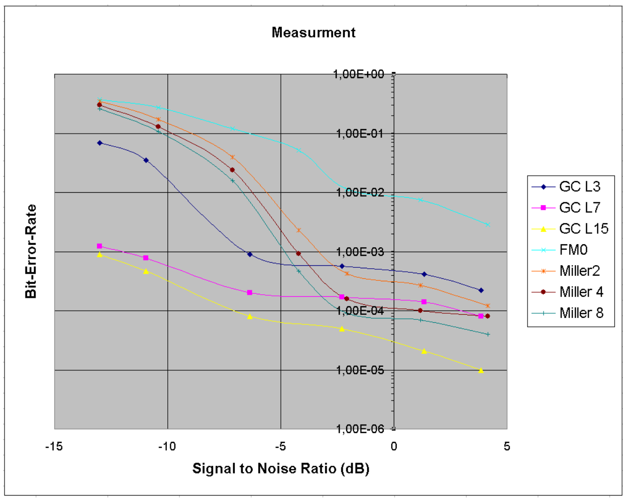

Figure 7 BER Results of the Measurement

From Figure 7 it can be seen that the performance of the Miller coding scheme is worse than it was shown at the simulation. By the PN coding scheme the BER does not converge to zero as fast as by the simulation. Important is the notorious difference between Miller and PN codes, the real system even shows a bigger difference than the simulation. The unexpected straightening of the curves at

higher SNR values could be caused by bit errors that are introduced by the hardware and the imperfections in the implementation.
Even though the simulation was made as close as possible to the implementation, there are some differences between the measured and simulated results. Important is the demonstration of the advantages of using gold sequences to encode information over the usage of RFID standardized codes.

5.3 Orthogonality Test

The same hardware platform was used to test the advantages of orthogonality. A random binary message was encoded with 16 possible symbol forms and sent to the test transponder. In order to decode and recognize the symbols sent by the transponder. The reader needs to correlate the received signal with all possible symbol forms. In other words there are 16 correlation filters at the receiver each one loaded with one of the 16 symbol forms. The 16 outputs are sampled at the symbol rate and the values compared to each other in order to decide which symbol was sent. To test the coding scheme a message of 64 bits was sent, i.e. 16 symbols.

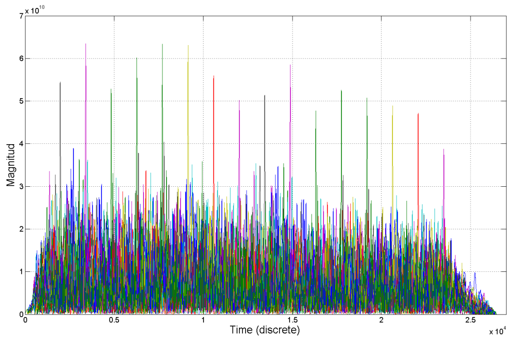

Figure 8 Correlation Bank Output

Figure 8 shows the output of the 16 correlation filters each one plotted in a different color to facilitate the recognition of each symbol. Each peak represents the detection of a respective symbol. Only one peak is seen at the sample time.

6 Comparison

It is important to point out that the comparative is relative, it only compares the performances of the coding schemes to one another. All possible system influences are equal to all tests, which leaves only the SNR of the signal and the BER. This applies for both the simulation and the implementation.
It was shown that the gold encoded messages were received with less errors than the Miller-coded ones. This is due to the orthogonality of the symbols as well as the characteristics of the PN codes, that make them less susceptible to environment influences.

The code form itself presents direct advantages, the symbols are orthogonal to one another which decreases the bit-error-rate. If one half of the FM0 symbol is considered as a chip in the Miller coding, the two codes can be compared according to their chips-per-bit rate. At miller 8 one bit is sent using 16 chips. At its comparable gold sequence 3 bits are sent using 15 chips, that is 5 chips per bit instead of 16 chips per bit of the Miller 8 coding scheme.
The implementation of the coding logic at the tag is relatively easy. Nevertheless one disadvantage of this procedure is the increase of complexity at the reader. Each sequence requires a corresponding correlator at the reader, and by extending the length of the sequence the resources required by the correlator increase as well.

7 Conclusion and Outlook

This paper presents the feasibility and advantages of PN sequences as a coding scheme for the tag to reader communication in RFID systems. This procedure can be added or be the base of new standards that could improve UHF RFID systems. The application of this concept is useful specially in high-noise environments where the distortions are considerable. The main changes to be considered are: the encoding of the digital data in the tag and the receiver architecture of the reader.

8 References

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