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Design of a digital modulator and demodulator for reader-less RFID Tag in 0.18 μm CMOS process

Syedul Amin*, Md Mamun, Jubayer Jalil and Labonnah Rahman

Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia, Bangi, 43600, Malaysia.
**Author for correspondence. E-mail: amin.syedul@gmail.com*

ABSTRACT. Both the Radio Frequency Identification (RFID) and Wireless Fidelity (WiFi) are popular and ubiquitous technologies. However, RFID is lagging behind due to vendor specific solutions and excessive reader cost. A WiFi compatible IEEE 802.11 RFID tag can eliminate the reader. A digital modulator and demodulator for the reader-less RFID tag in IEEE 802.11 protocol employing Direct Sequence Spread Spectrum (DSSS) and Barker code are proposed in this paper. To generate the 11-bit Barker code, MOD-11 synchronous counter and encoder are designed by utilizing only four D flip-flops instead of preloading the code sequence in multiple registers. For modulation, data are multiplied with this Barker code and for demodulation, the received data are multiplied with the same Barker code. Designed in 0.18 μm CMOS technology, the minimum, average and maximum power consumptions are 3.64 nA, 17.64 μA and 7.61 mA, respectively. The simulation results show the correct functionality of the modulator and demodulator where 1 bit is spread to 11 bits and 11 bits received data are de-spread to 1 bit, respectively. The design would help to implement the modulator and demodulator for the reader-less RFID tag with resistance to multi-path fading and interference and covering the highest distance with lower Bit Error Rate (BER).

Keywords: barker code, demodulator, IEEE 802.11, modulator, RFID.

Delineamento de um modulador e demodulador digital para RFID Tag sem leitor em processo CMOS 0,18-μm

RESUMO. A identificação de radiofrequência (RFID) e a fidelidade sem fio (WiFi) são tecnologias populares e onipresentes. Entretanto a RFID está atrasada devido a soluções específicas dos fornecedores e o preço excessivo dos leitores. Um WiFi compatível com IEEE 802.11 RFID tag pode eliminar o uso de leitores. Neste trabalho, propomos um modulador e demodulador digital para uma RFID tag em protocolo IEEE 802.11 empregando Seqüência Direta Espalha Espectro (DSSS) e código Barker. Para gerar o código Barker de 11 bits, um contador e codificador síncrono MOD-11 foram delineados utilizando somente quatro flip flops D, ao invés da pré-carga da sequência de código em registros múltiplos. Para a modulação, os dados foram multiplicados pelo código Barker, e para a demodulação, os dados recebidos foram multiplicados por esse mesmo código Barker. Projetado em tecnologia CMOS 0,18 μm, o consumo mínimo, médio e máximo de energia são 3,64 nA, 17,64 μA e 7,61 mA, respectivamente. Os resultados da simulação mostraram o funcionamento correto do modulador e do demodulador onde 1 bit é transmitido para 11 bits e 11 bits de dados recebidos são retransmitidos para 1 bit, respectivamente. O delineamento ajudaria a programar o modulador e demodulador para o RFID tag sem leitor com resistência para desvanecimento de multipercurso e interferência e cobrindo a maior distância com menor taxa de bits de erro (BER).

Palavras-chave: código barker, demodulador, IEEE 802.11, modulador, RFID.

Introduction

RFID is a popular technology. It offers realistic benefits nearly to everyone which includes supply chain management, access control to buildings, public transportation, airport baggage handling, express parcel logistics, etc. (JIANPING; KA, 2012). RFID is the utilization of radio waves to transfer data between a reader and a tag attached to an object for the purpose of identification and tracking. The tag uses an Electronic Product Code (EPC), which is a unique number attached inside for identification.

Like RFID, IEEE 802.11 (popularly known as Wi-Fi) also emerged as a ubiquitous and prevailing technology for wireless access. It uses Internet Protocol version 4 (IPv4). A new protocol, IPv6, will be used in coming days instead of IPv4 for objects-to-objects communications in global unique address structure (WEI-KUANG; JUNG CHIA, 2005). IEEE 802.11 based wireless communication has lower BER, higher range, resistant to interference and robust (JIANG; YAN, 2007). But RFID lacks in these aspects. It suffers from vendor specific solutions and excessive implementation cost. Specially, the reader is the most expensive part (NISSAR et al., 2010). An innovative RFID tagging system utilizing the built-in Wireless Network Interface Card (WNIC) as a reader was proposed by Rahman et al. (2012). According to the proposed system, there would not be any requirement of expensive reader. The EPC was proposed to be mapped in the IPv6 that is only 128 bits. The tag would transmit the 128 bit EPC address and also receive the request from the WNIC card. As such, the tag needs a modulator and demodulator for the receiver and the transmitter. However, the paper did not highlight the modulation and demodulation technique as IEEE 802.11 has different standards.

This paper discusses the different IEEE 802.11 standards and proposes 1 Mbps data rate in DSSS technique employing Barker code for the digital modulator and demodulator of the RFID tag to be used in the transmitter and receiver section. Higher range, anti interference, anti multi-path fading and lower BER were considered while selecting modulation and demodulation techniques. The modulation and demodulation techniques will not only be applicable for IEEE 802.11 protocol compatible tag, but also can be used in other systems as it can overcome the drawbacks of the conventional tag problems like multi-path, interference, security, short distance, BER etc. The proposed modulator and demodulator are designed using the 0.18 μm CMOS technology.

The rest of the paper is organized as follows. The material and methods section discusses the various standards of IEEE 802.11 with the advantages of 1Mbps data rate in DSSS, the details of the Barker code generation and the modulator and demodulator design by using the Barker code. Simulation results and discussion section covers the simulation result and related discussion and finally the paper is concluded.

Material and methods

Institute of Electrical and Electronics Engineers, Inc (IEEE) released the 802.11 standards in 2.4 GHz band in 1997 for wireless LANs, defining 1 and 2 Mbps data rate (ADRIAN, 2008). It was ratified in September 1999 for higher rate to 5.5 and 11 Mbps as IEEE 802.11b. The hunt for higher speed brought the 802.11 g in 2003 for 54 Mbps. IEEE 802.11n reached the speed of 300 Mbps recently. To attain the higher data rate, changes were basically made only to the physical layer (HUANG et al., 2011). The higher data rate needs complex circuitry at the physical layer which increases cost as well as power consumption. BER also increases at the higher data rate. Whenever the BER increases due to speed, distance, noise or interference; all the IEEE 802.11 standards fall to the lower data rate gradually to reduce the BER. It even falls back to the basic data rate of 802.11 which are 1 and 2 Mbps. As such, all the 802.11 standards have the backward compatibility with the basic 802.11 standard (HUANG et al., 2011).

IEEE 802.11 utilizes the spread spectrum communication technique. Spread spectrum was developed by the military to reduce jamming and eavesdropping. It is an RF communication system where the base band signal bandwidth is intentionally spread over a larger bandwidth by injecting a higher frequency signal. So, the energy used in transmitting the signal is spread over a wider bandwidth and appears as a noise. There are mainly two types of spread spectrum techniques: Frequency Hopping Spread Spectrum (FHSS) and DSSS.

In FHSS, the carrier frequency hops from channel to channel in a pre-arranged sequence. The receiver is programmed to hop in the same sequence with the transmitter. The major drawbacks of the FHSS are the limited data rate, poor range resolution and interference to other systems, requirement of positive SNR and lesser efficiency in non-coherent modulation (FREITAG et al., 2001).

On the contrary, in DSSS, a pseudorandom code known as chipping code is directly applied to the data for spreading before the carrier modulation (WANG; WU, 2011). It is accomplished by phase shift keying the RF carrier with the pseudorandom digital code sequence consisting of M chips, which is independent of the data symbol. As the chip rate is larger than the symbol rate, the resulting bandwidth is larger than the information signal bandwidth. It produces transmitted signals with low spectral densities and provides tolerances to multi-path interference. Thus, DSSS signal has the characteristics of pseudo-randomness and correlation processing, which leads to many advantages, such as anti-noise, anti-interference, anti-multi-path fading, low power spectrum density, high secrecy, multi-access flexibility and high precision measurements (ZHAN et al. 2005). Considering these properties, DSSS is more suitable to implement in RFID.

DSSS resolves the multi-path components and attenuates those paths with delays in excess of one chip duration from the in-phase autocorrelation peak (O'FARREL, 2008). The attenuation depends on the sidelobes values of the aperiodic autocorrelation function as these sidelobes manifest inter-symbol interference in a dispersive channel. An autocorrelation function with zero sidelobes values is desirable, but it does not exist in the binary spreading sequences' families (O'FARREL, 2008). Barker sequence is close to this property which possesses good aperiodic correlation. Let $\{a_n\}$ denote a real-valued binary sequences of length N, where the sequence elements $a_n \in \{-1,+1 : n = 0,1,\ldots, N-1\}$ are referred to as sequence chips. Then, the aperiodic autocorrelation function $\{a_n\}$, denoted $C_a(\tau)$ for an integer chip delay τ is given by (1).

$$C_a(\tau) = \sum_{n=0}^{N-\tau-1} a_n a_{n+\tau} \quad (1)$$

Ronald H. Barker considered the problem of synthesizing real-valued binary sequences with aperiodic autocorrelation function sidelobes bounded by $|C_a(\tau)| \leq 1$. Binary sequences that satisfy these bounds are known as Barker sequences. Only Barker codes of lengths 2, 3, 4, 5, 7, 11 and 13 exist (BARKER, 1953). It is conjectured that no longer Barker codes exist. The list of known Barker codes is given in Table 1.

Table 1. List of known Barker codes.

Length	Code
2	1 0, 1 1
3	1 1 0
4	1 1 0 1, 1 1 1 0
5	1 1 1 0 1
7	1 1 1 0 0 1 0
11	1 1 1 0 0 0 1 0 0 1 0
13	1 1 1 1 1 0 0 1 1 0 1 0 1

Barker code produces a single peak and uniformly low sidelobes when correlated against time shifted versions of itself and thereby it rejects multi-path (MAU-LIN et al., 2001). This simply means that due to the non-repetitive behavior of the code, a matched filter correlator can easily identify the location of a Barker code in a sequence of bits (LECHANG et al., 2011). If one or more chips in the bit are lost during transmission, statistical techniques embedded in the receiver can recover the original data without retransmission. IEEE 802.11 utilizes the 11-bit Barker Code. The value of the autocorrelation function for the 11-bit Barker code is 1, -1, or 0 at all offsets except zero, where it is 11. The autocorrelation function of 11-bit Barker code is shown in Figure 1.

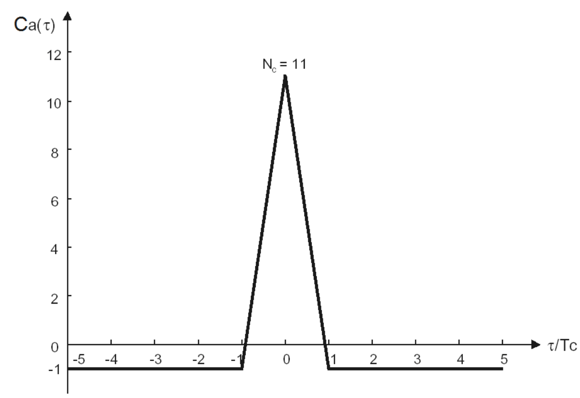

Figure 1. Autocorrelation function of 11-bit Barker code.

In IEEE 802.11, the data to be transmitted are modulated with the 11-bit Barker code and thereby the data are spread over a wide bandwidth. On the other hand, data to be demodulated are again multiplied with the same 11-bit Barker code which de-spreads the data and the data are recovered. The block diagram of the proposed modulator and demodulator utilizing Barker code is shown at Figure 2.

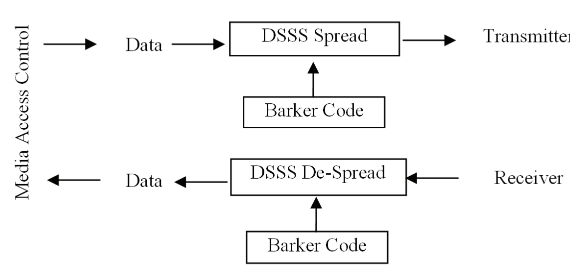

Figure 2. Proposed Modulator and Demodulator for RFID Tag.

Barker code, modulator and demodulator design

The heart of the modulator and demodulator is the 11-bit Barker code that is a sequence of 11100010010. The leftmost bit will be output first in time and thereby the sequence will be 10110111000. A code generator can be designed from different approaches. A very simple and systematic approach is followed for designing the

Barker code. At first, an MOD-11 synchronous counter is designed which counts from 0 to 10. This counter is fed in the 11-bit encoder and the output of the encoder is the 11-bit Barker code. The block diagram for the Barker code is shown in Figure 3.

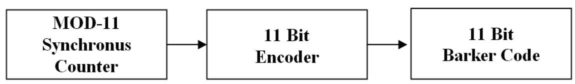

Figure 3. Block diagram of 11-bit barker code generator.

MOD-11 synchronous counter

A MOD-11 synchronous counter is required as the Baker sequence is 11-bits. As such, the counter needs to have 11 distinct states. The number of flip-flops is found four by using the equation $N < 2^n$ where n is the number of flip-flops required and N is the number of states present in the counter (SAHA; MANNA, 2007). D flip-flop of the CEDEC standard library of Mentor Graphics is considered for the counter. An excitation table for the D flip-flop is simplified and minimized by Karnaugh Map.

11-Bit encoder

For the 11-bit encoder, the Barker code 10110111000 is considered as the left most bit would be output first in time. The sequence is written sequentially with a count from binary 0 to 10 (0000 to 1010). The code sequence is then simplified and minimized by Karnaugh Map.

11-Bit barker code

The 11-bit encoder needs the signals from the 11-bit counter. The connections are drawn according to minimized Karnaugh Map of the 11-bit Barker encoder. When the counter is activated by clocking, the 11-bit encoder outputs the Barker code as per the sequence which is 10110111000 and then repeats.

Modulator and demodulator

According to the principle of DSSS, for modulation, the data need to be multiplied with the 11-bit Barker code. An XOR gate is used to multiply the data with the 11-bit Barker code. In one input of the XOR gate, the data to be transmitted are connected and at the other input the Barker code output are connected. As per the principle of XOR gate, for data representing 1bit, the Barker code will have reverse phase, but for 0 bit it will remain same. For demodulation, the received data are again multiplied with the same Barker code. An XOR gate is used for the demodulation. At one input of the XOR gate, the received data are connected and at the other input the Barker code output is connected. When these data are multiplied with the Barker code, the data are recovered. As such, the output of the XOR gate provides the demodulated data. The schematic diagram of the modulator and demodulator with the 11-bit Barker code in 0.18 μm CMOS process technology using CEDEC standard library is shown in Figure 4. The complete layout including the input and output pins are shown in Figure 5.

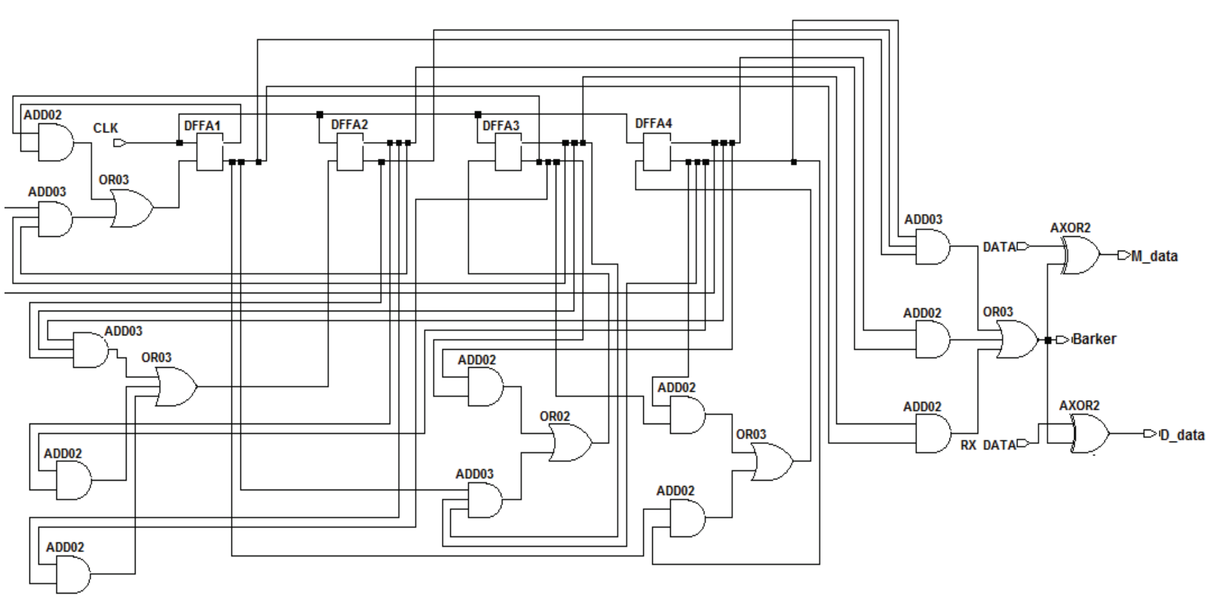

Figure 4. Schematic diagram of proposed modulator and demodulator.

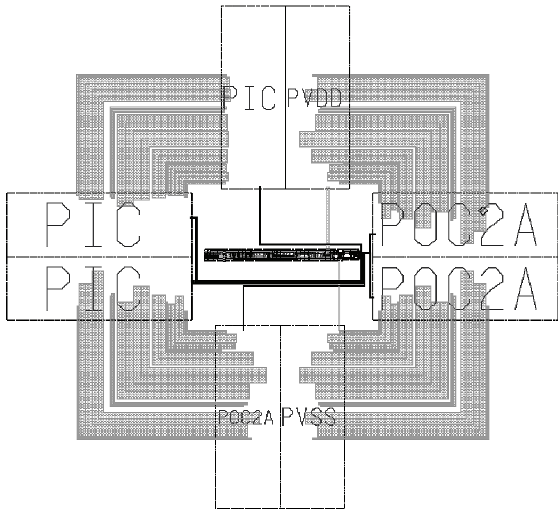

Figure 5. Layout of the proposed modulator and demodulator including input output pin.

Results and discussion

The simulation of the designed RFID tag modulator and demodulator are carried out utilizing ELDONET simulator. DC 1.8 V is used as power supply. The data rate of the modulator and demodulator is 1 Mbps which means the period of 1 bit is 1 μs. These data are modulated with the 11-bit Barker code. As such, the period of 1bit of Barker code is 1/11 of a μs which is 90.909090 ns. Thereby, the clock pulse period is 90.909090 ns and the width is 45.454545 ns. The initial value of the clock is set to *0* and 1.8 v pulse is used. The rise time and fall time for the clock are used as 0.1 ns. The simulation result in Figure 6 shows that the counter can count from 0 to 11 and correct 11-bit Barker code is generated from the encoder which is a sequence of 10110111000. For the data to be modulated, a pattern of 101 is used with 1 μs period. The data 101 are modulated with the Barker code. For the 1 bit, the Barker code is inverted and for the 0 bit the Barker code remains unchanged. As such, the modulated output data for 101 become 101101110000100100011110110111000. These results show the correct functionality of the modulator.

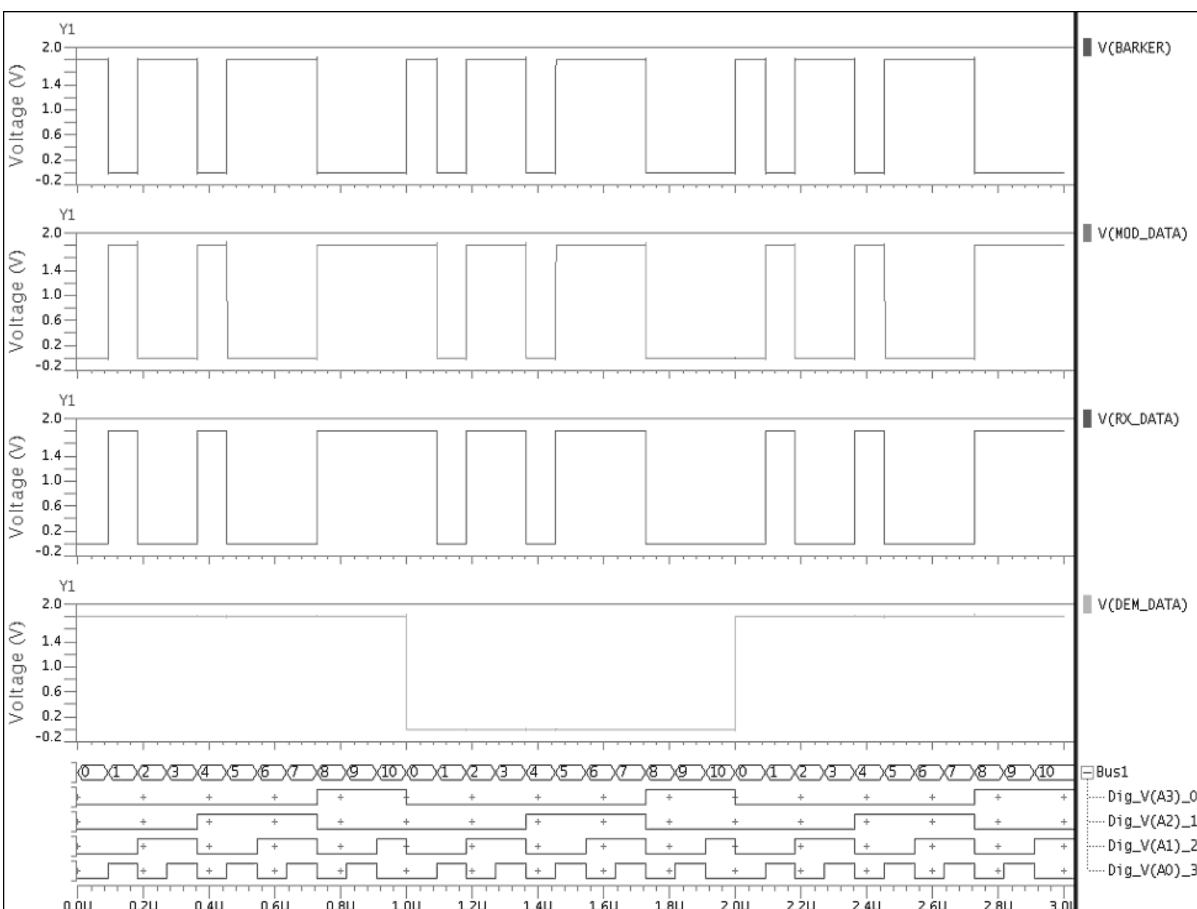

Figure 6. Simulation result of the proposed modulator and demodulator.

For the simulation of the demodulator, a pattern of 101101110000100100011110110111000 is used as the received data. The period of the data pattern is considered 90.909090 ns as the data are a multiplication of 11-bit Barker code. These data are multiplied again with the 11-bit Barker code. As such, the data are recovered to a pattern of 101 by canceling out the Barker code. Thereby, the simulation result in Figure 6 shows the correct functionality of the demodulator. Figure 7 shows the power consumption of the proposed modulator and demodulator. The minimum, average and maximum power consumptions are found 3.64 nA, 17.64 μA and 7.61 mA, respectively.

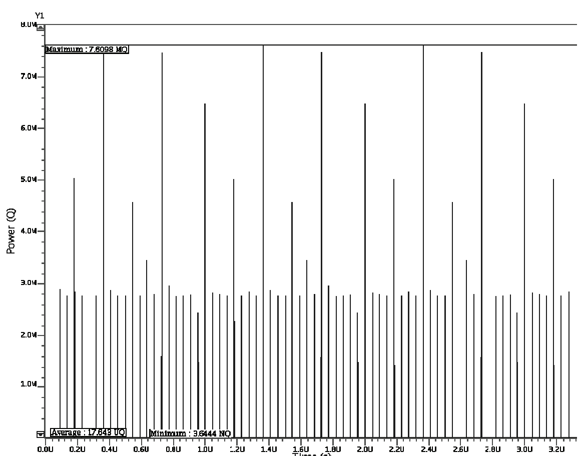

Figure 7. Power consumption of the proposed modulator and demodulator.

Conclusion

Both RFID and WLAN are popular and widely used technologies. RFID suffers from vendor specifications and huge implementation cost. It is also susceptible to noise, interference and multi-path fading. On the other hand, IEEE 802.11 has a standard with different variations for achieving higher data rate with a backward compatibility to 1Mbps. The proposed RFID tag only needs to transfer 128 bits EPC mapped IPv6 address. As such, the designed digital modulator and demodulator using 11-bit Barker code can easily pass the 128 bits data of the tag address. The design works towards the readerless RFID system by implementing a simple modulator and demodulator using Barker code. Besides using in IEEE 802.11 compatible protocol, the proposed modulator and demodulator can also be used in other RFID system to get rid of the fading, multi-path, interference etc.

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