

DIRECT SEQUENCE CDMA BASED WIRELESS INTERFACE FOR AN INTEGRATED SENSOR MICROSYSTEM

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Abstract-Utilization of wireless miniaturized electronic systems in medical diagnosis, environmental monitoring and other industrial applications has been made possible by emergence of system-on-chip technology. An important task in such a system is to convey information reliably on a multiple access based sensor networks are also characterized by their restricted power and area constraints. We describe a communication system based on direct sequence code division multiple access method.

Keywords - Communication, wireless, CDMA

I. INTRODUCTION

Utilization of wireless miniaturized electronic systems in medical diagnosis, environmental monitoring and other industrial applications is highly desirable. Wireless implantable sensors are also increasingly being used in medical field [1]. Recent developments in system-on-chip (SoC) technologies [2] accelerated these interests and made it feasible to shrink the size of such systems, while increasing their functionality. For example, an ingestible electronic capsule for monitoring some common physiological parameters of Gastro-intestinal tract such as temperature, pH, conductivity, and oxygen concentration has recently been described [3], [4]. It integrates several sensors, amplifiers, analog digital conversion, coding and transmitting circuitry.

One of the main problems of such a system is how to retrieve these information from the sensor system in real-time non-intrusively. The most feasible solution is to integrate a wireless communication circuit into the system which constitutes an important part of a SoC implementation. Some of the desirable properties of the communication system are capability of communicating with multiple sensor systems for the purpose of centrally monitoring or controlling more than one medium at the same time and interference rejection for reliable communication in critical applications such as medical diagnosis. A conceptual representation of a desirable system is shown in Fig. 1. Preliminary results of such a system design attempt have been reported in [5] and [6]. In this paper, we report the practical results of code division multiple access (CDMA) transmitter implementation, which was fabricated using AMS 0.6 μ CMOS technology.

II. METHODOLOGY

In a multiple access system, a large number of users share a common channel to transmit information to a receiver. The system has to manage resources appropriately in order to cover and support all the users that want to access the system. There are three common technologies used to create

an air interface; frequency-division multiple access (FDMA), time-division multiple access (TDMA), code-division multiple access (CDMA) [7].

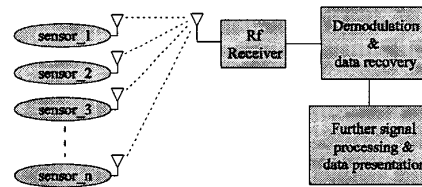


Fig. 1. Conceptual representation of typical multiple sensor system.

In FDMA, the available channel bandwidth is subdivided into a number of frequency nonoverlapping channels. These subchannels are assigned to each user upon request by the users. FDMA allocates a single channel to one user at a time. Although technically simple to implement, FDMA is wasteful of bandwidth. TDMA relies upon the fact that the signal has been digitized; that is, divided into a number of packets. It allocates a single frequency channel for a short time and then moves to another channel. The digital samples from a single transmitter occupy different time slots in several bands at the same time. The main drawback is that with narrower bandwidth there is greater distortion. In an environment where the transmission from the various users is bursty and low duty cycle, FDMA and TDMA tend to be inefficient because a certain percentage of the available frequency slots or time slots assigned to user do not carry information [8]. An alternative to FDMA and TDMA is to allow more than one user to share a channel by use of direct-sequence spread spectrum (DS-SS) signals [9], [10].

A. Direct Sequence Spread Spectrum

In a DS-SS system, each user is assigned a unique code sequence [11] that allows the user to spread the information signal across the assigned frequency band. Signals from the various users are separated at the receiver by cross-correlation of the received signal with each of the possible user code sequences. Possible narrow band interference is also suppressed in this process. By designing these code sequences to have relatively small cross-correlation, the cross-talk inherent in the demodulation of the signals received from multiple transmitters is minimized. This multiple access method is CDMA, which is a form of a DS-SS system [12], [13]. This modulation transforms an information-bearing signal into a transmission signal with a much larger bandwidth. This transformation is achieved by

encoding the information signal with a code signal that is independent of the data and has much larger spectral width than the data signal. This spreads the original signal power over a much broader bandwidth, resulting in a lower power density. The ratio of transmitted bandwidth to information bandwidth is called the processing gain G_p of the DS-SS system: $G_p = B_t/B_i$, where B_t is the transmission bandwidth and B_i is the bandwidth of the information bearing signal.

In DS-SS transmitter the data is spread by multiplying with a pseudo-random noise (PN) sequence. A PN sequence is a binary sequence that exhibits randomness properties but has a finite length and is therefore deterministic. They are used to implement synchronization and uniquely code individual user signals across the transmission interface. PN generators are based on Linear Feedback Shift Registers (LFSR) [14].

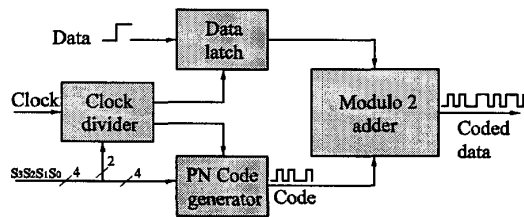


Fig. 2. The block diagram of the DS-SS transmitter

A DS-SS receiver is based on a correlator, which utilizes correlation properties of the PN codes [14]. The correlators attempt to match the incoming received signal with each of the candidate prototype waveforms (PN sequences) known *a priori* to the receiver. Since we deal with the discrete signals in practice, the discrete form of the correlation of two discrete signals is given as

$$r_{xy}(k) = \sum_{n=0}^{N-1} x(n)y(k+n) \quad (1)$$

Equation (1) is the fundamental equation implemented in software and hardware. The hardware implication is that the implementation of a correlator is based on a multiplier-accumulator circuit (MAC). At the receiver, the same PN sequence used in the transmitter is correlated with incoming signal. Block diagram of the receiver is shown in Fig. 3.

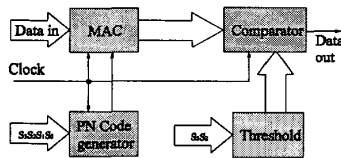


Fig. 3. The block diagram of the DS-SS receiver.

B. Design and implementation

Block diagram of the transmitter is illustrated in Fig. 2. It comprises a programmable PN sequence generator, a memory block for storage of data, a clock divider providing appropriate clock for the memory block and the PN generator, and a block of logic gates to perform the data coding and spreading. The PN generator consists of 8 stages LFSR and a multiplexer. The PN code length was programmable to provide appropriate amount of data spreading for a particular application. One of the 12 different codes (3 for each length) is available depending on code select inputs ($s_3s_2s_1s_0$), as described in Table I. Upper two bits of code select input determine the PN code length and active LFSR stages, and multiplex the appropriate PN code to the output pin. The required feed-back combination is selected by setting the remaining bits of code select input to the appropriate logic levels as given in Table I.

TABLE I
CODE SELECTION FOR PROGRAMMABLE DS-SS TRANSMITTER

$s_3s_2s_1s_0$	LFSR Feed-back	PN Code length
0 0 0 0	Coding bypassed	-
0 0 0 1	[5,2]	32
0 0 1 0	[5,4,3,2]	32
0 0 1 1	[5,4,2,1]	32
0 1 0 0	Reserved	-
0 1 0 1	[6,1]	64
0 1 1 0	[6,5,2,1]	64
0 1 1 1	[6,5,3,2]	64
1 0 0 0	Reserved	-
1 0 0 1	[7,1]	128
1 0 1 0	[7,3]	128
1 0 1 1	[7,3,2,1]	128
1 1 0 0	Reserved	-
1 1 0 1	[8,4,3,2]	256
1 1 1 0	[8,6,5,3]	256
1 1 1 1	[8,6,5,2]	256

III. RESULTS

A. Simulations

The transmitters and the receivers were synthesized using Synopsys Design Compiler and AMS 0.6 μ technology. In order to evaluate the performance of the designed cores, several netlist simulations were performed using Cadence's Verilog-XL simulator. In order to demonstrate the functionality of the design, a normalized pressure waveform obtained by an intra vascular pressure sensor was used. This waveform data, which is shown in Fig 3(a), was used in the netlist transmitter simulation. The normalized reconstructed pressure waveform at the receiver with 8 bit input resolution is shown in Fig. 3(b)}. Fig. 7(c) illustrates the difference between the original pressure waveform and the reconstructed waveform. This difference is mainly caused by the quantization.

B. Implementation

The DS-CDMA transmitter circuit was implemented and fabricated as part of an integrated microsensor system and tested for functionality. Early results indicate that the system functions as intended. Fig. 4 illustrates the transmitter outputs recorded by a digital scope for the PN code length of 256, 128, 64, and 32. Autocorrelation results of the signals given in Fig. 4 are illustrated in Fig. 5. This verifies that the circuit functions as intended.

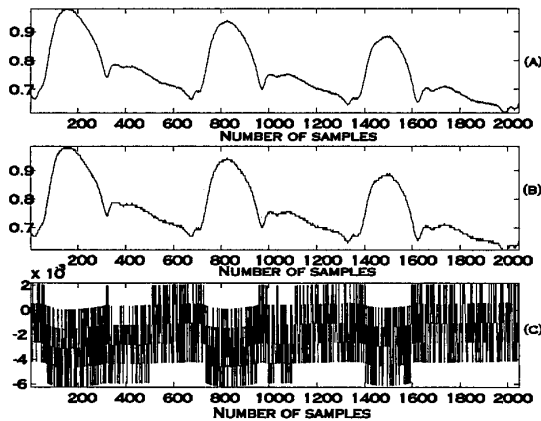


Fig. 3. (a) Normalized original signal from an intra vascular pressure sensor, (b) normalized reconstructed signal at the receiver, and (c) the difference between the original signal and the reconstructed signal.

IV. DISCUSSION AND CONCLUSION

We have designed and implemented a DS-SS based communication system incorporating a certain degree of programmability to be used in an integrated sensor microsystem. The SoC of the system described here has been fabricated and tested for functionality. The system functions as intended. The design reported here require very low power (approximately 3 μ W at 100 kHz operating frequency) enabling its utilization in advanced communication system where area and power budgets are severely limited. The described communication system provides a reliable data transmission in a noisy environment by rejecting narrow band interference. It also provides a simple multiple access capability. Since the receiver is based on a correlator, the synchronization requirement is also significantly reduced.

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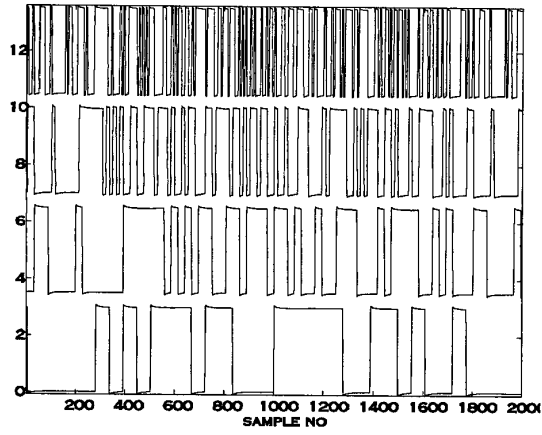


Fig. 4. Transmitter outputs recorded by a digital scope for the PN code length of (a) 256, (b) 128, (c) 64, and (d) 32.

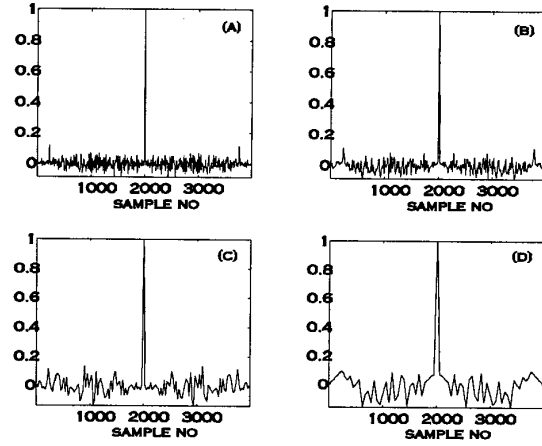


Fig. 5. Normalized autocorrelation functions of the signals given in Fig. 4.