

## Design and Implementation Considerations for an Advanced Wireless Interface in Miniaturized Integrated Sensor Microsystems

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**Abstract**—Developments in system-on-chip and wireless technologies have led to complex electronic systems to be miniaturized to size of ingestible capsule and implantable microsystems. Inevitably such miniaturized complex systems impose some constraints on the case of an ingestible diagnostic capsule. It is desirable that system be wireless, programmable, and reusable. In this paper, we describe a wireless interface link developed for such an ingestible microsystem. It is programmable and directly controlled by the on-chip microcontroller. It is also suitable for developing complex communication protocols for conveying the data to a remote basestation. At the heart of the system lie a direct sequence spread spectrum encoder.

**Keywords**—Wireless, system-on-chip, microsystem

### I. INTRODUCTION

Recent developments in system-on-chip (SoC) technologies made possible to shrink the size of some medical diagnostic systems to the size of an ingestible capsule [1][2]. These microsensor systems integrate several sensors measuring temperature, pH, conductivity, and oxygen concentration, amplifiers, analog/digital conversion, and include microsystem scheduling, coding and transmitting circuitry [3]. One of the main problems of such a system is reliable retrieval of these information from the sensor system in real-time. Our chosen solution is to integrate a wireless communication circuit into the system. This constitutes an important part of a SoC implementation. Some of the desirable properties of the communication system are ability to communicate with multiple sensor systems (for the purpose of centrally monitoring/controlling more than one medium at the same time), interference rejection for reliable communication in critical applications such as medical diagnosis, and programmability or reconfigurability to adapt to different conditions.

Recently, the first generation of an integrated sensor microsystem for industrial and biomedical applications with a simple off-chip transmitter based on on-off keying was reported [4]. A second generation system with a direct sequence spread-spectrum (DS-SS) based transmitter was designed and successfully fabricated [5][6]. Layout plot and associated explanatory diagram of this system is shown in Fig. 2. A limited programmability was provided through hardwiring. Here we report a fully programmable wireless interface for the third generation integrated sensor

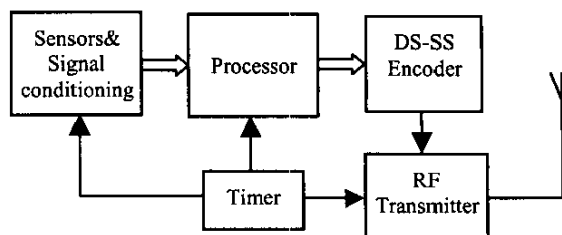


Fig. 1. Integrated sensor microsystem block diagram.

microsystem. The system block diagram is shown in Fig. 1. In this system, the DS-SS transmitter was integrated with an on-chip microcontroller for full programmability.

### II. METHODOLOGY

In designing transmitters for miniaturized integrated sensor microsystems for biomedical applications, several factors must be taken into consideration: power consumption, reliability, noise immunity, and multiple access capability for advanced applications. DS-SS transmitters are simple to implement, reject narrowband interference, and provide an efficient multiple access capability [9]. Therefore, a wireless interface based on the DS-SS technique was adapted for the integrated sensor microsystem. It comprises a memory block for storage of data, a programmable pseudo noise (PN) code generator block consisting of eight-stage LFSR and a multiplexer, a clock divider providing appropriate clock for the memory block and a PN code generator, a three-state buffer to interface to on-chip microcontroller, and a block of logic gates to perform the data coding and spreading.

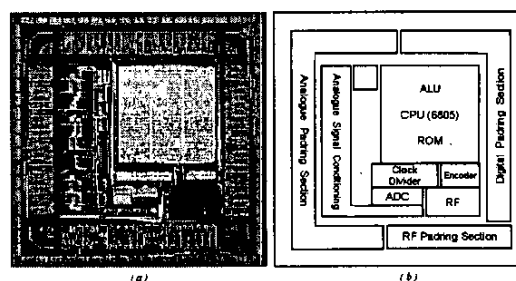


Fig. 2. Layout plot of the 2<sup>nd</sup> generation CMOS control chip (a) and associated explanatory diagram.

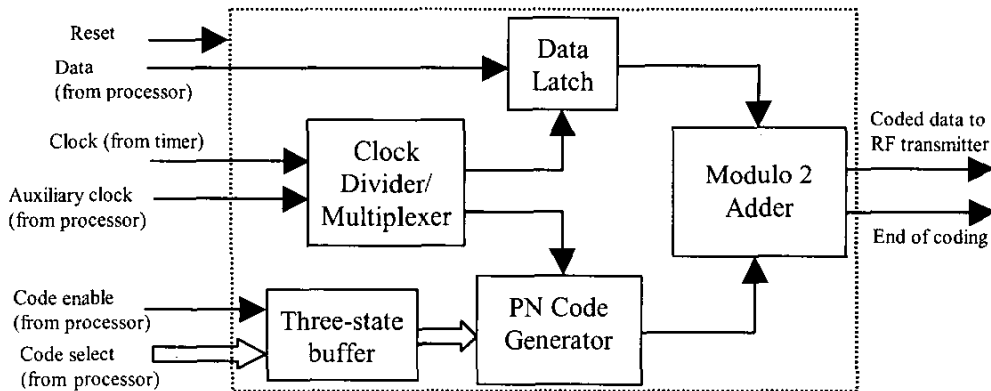


Fig. 3. The functional block diagram of the programmable DS-SS transmitter.

The PN code generator is based on Linear Feedback Shift Registers [9][10]. A PN code 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. The data is spread by multiplying with the PN code. The PN code length is programmable to provide appropriate spreading of the data for a particular application. Available code lengths are 32, 64, 128, and 256. Three different PN codes for each code length are available depending on the code select inputs. The required feed-back combination for a particular PN code is selected by a multiplexer.

The DS-SS transmitter code control inputs (4 bits) are connected to microcontroller's I/O port through a three-state latch. The clock for the circuit is derived from an on-chip timer unit. An *auxiliary clock* input and an *end of coding* output are also provided for controlled data transmission, enabling the utilization of more advanced transmission protocols in the future. A functional block diagram of the DS-SS transmitter is illustrated in Fig. 3.

TABLE I  
ESTIMATED POWER CONSUMPTIONS FOR DS-SS ENCODER

| PN Code length | Power Consumption ( $\mu$ W) |
|----------------|------------------------------|
| 32             | 1.22                         |
| 64             | 1.49                         |
| 128            | 2.02                         |
| 256            | 2.99                         |

### III. RESULTS

The transmitter was synthesized using Synopsys Design Compiler and Austria Micro Systeme (AMS) 0.6 $\mu$  CMOS technology. Netlist simulations were performed using Cadence's Verilog-XL simulator assuming a 100 kHz

operating frequency and a 3 Volts power supply. Test data recorded from an intravascular pressure sensor were used. The switching activity information obtained from the netlist simulations was fed into the Synopsys Design Power and total power consumptions were estimated. Estimated power consumptions for the programmable transmitter is given in Table 1. Area for the DS-SS encoder unit was approximately 72000 square micron.

Fig. 4 illustrates a screen shot of a post-layout simulation instance. Transmission is allowed when the *reset* input (`tx_ideas_tbs.transmit.RESET`) is active high. The desired PN code and the clock is selected by setting 4 bits *code select* inputs (`tx_ideas_tbs.transmit.Cs`) to appropriate value and then applying a pulse to the *code enable* input (`tx_ideas_tbs.transmit.Cen`). In this example the chosen code is 0001. The three-state latch operation is necessary because the DS-SS encoder unit shares the same I/O pins of microcontroller with some other units. The *input data* (`tx_ideas_tbs.transmit.data`) is captured at the rising edge of the *data clock* (`tx_ideas_tbs.transmit.clk_dat`). Clock rate of the PN generator clock (`tx_ideas_tbs.transmit.clk_png`) is code-length times (32 in this example) higher than the data clock rate (`tx_ideas_tbs.transmit.clk_dat`). Inspection of the output (`tx_ideas_tbs.transmit.out`) reveals that logic 0 is encoded by the PN code (`tx_ideas_tbs.transmit.pn_in`) and logic 1 is encoded by the inverse of the PN code. Ending of the encoding can be seen on the *end of coding* output (`tx_ideas_tbs.transmit.end_of_coding`).

The output of the DS-SS encoder is connected to an on-chip RF transmitter operating at 40 MHz chosen to minimize RF absorption by the human body.

### IV. DISCUSSION AND CONCLUSION

We have designed and implemented a programmable/reconfigurable DS-SS based communication system integrated with an on-chip microcontroller as part of

an ingestible integrated sensor microsystem. The simulation results indicate that the system functions as intended. The SoC of the system described here has been submitted for fabrication. The described communication system provides a reliable data transmission in a noisy environment by rejecting narrow band interference and multiple access capability. The functionality of the communication system was also extended to enable to utilize more complex transmitting protocols by introducing extra control terminals and interfacing to an on-chip microcontroller.

#### ACKNOWLEDGMENT

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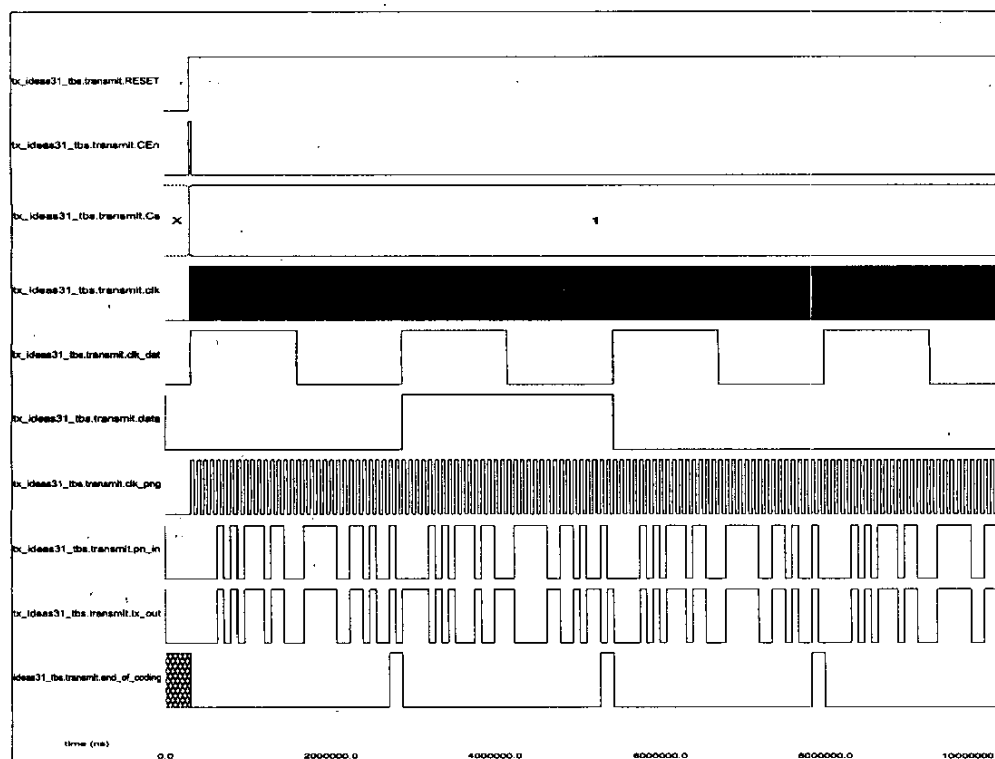


Fig. 4. Simulation results of the DS-SS transmitter for the input data '0100'.