PROGRAMMABLE SYSTEM ON CHIP APPLIED TO LOW FREQUENCY RFID INTERROGATION

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ABSTRACT

Systems on chip, by definition, unite a number of functions and occasionally, sensors or actuators, into a unified, compact, lower-power solution to a signal processing problem. Recent efforts have seen the research, development, and commercialization of systems on chip that are sufficiently programmable and flexible to address a wider variety of applications and signal processing problems than their fixed configuration counterparts. In this paper, we present the application of a recently commercialized SoC effort to the problem of interrogating a low frequency radio frequency transponder, using an amplitude shift keyed encoding scheme. Within this representative application, the following reductions are realized compared to a discrete implementation: power 64%, cost 71%, component count 96%, and size 95%. In addition, the better matched components in the SoC provide a 25% improvement in read range over the discrete implementation of the radio frequency identification interrogator.

INTRODUCTION

Modular and user-defined design of electronic circuits is progressing rapidly in the integrated circuit industry. Reconfigurability and programmability of systems is most often associated with digital logic, such as in the popular Field Programmable Gate Array (FPGA). Modular, programmable, and mixed signal Systems on Chip (SoC), however, are gaining popularity in addressing a wide variety of user-defined applications, alongside their purely digital counterparts. The ability to dynamically configure analog circuit blocks, digital circuit blocks, and the interconnections between them on a single integrated die is key to facilitating rapid product development while maintaining the high level of precision and performance afforded by integrated circuits as compared to assemblies of discrete circuits. In addition to decreasing development time, programmable mixed signal SoC offer the potential to significantly reduce power, component count, size, and cost of a wider variety of systems than purely digital SoC can address.

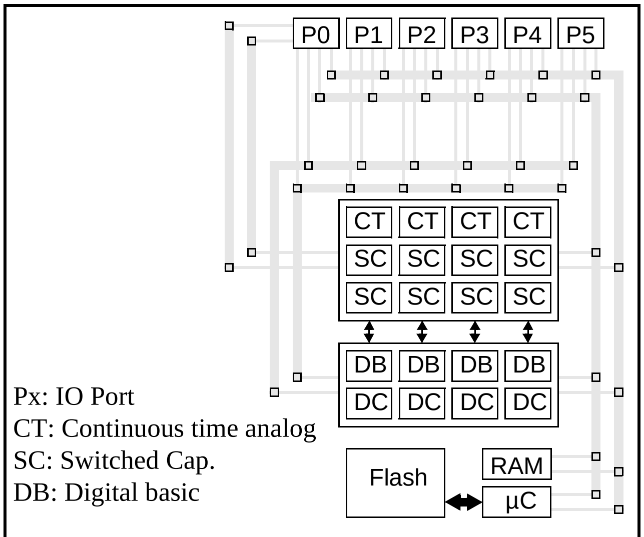

Figure 1: PSoC Microcontroller Block Diagram

Field programmable digital logic has been available commercially for almost two decades and has reached system-level configurability at the microprocessor level[1]. Field programmable analog arrays began to gain popularity in the late 80's and early 90's in the research community[2][3] as well as some representation in industry patents[4][5] and products[6][7]. Shortly thereafter, the advent of mixed signal programmability began with the ability to interface digital and analog signals (Actel patent[5] and AMD patents[9][10]) and progressed to the exchange of analog and digital signals on the chip itself [11] [12].

An important step forward in the programmable, mixed-signal SoC are the PSoC™ Microcontrollers from Cypress MicroSystems (CY8C2xxxx part family). These parts are the first to offer comfigurable analog and digital blocks in a

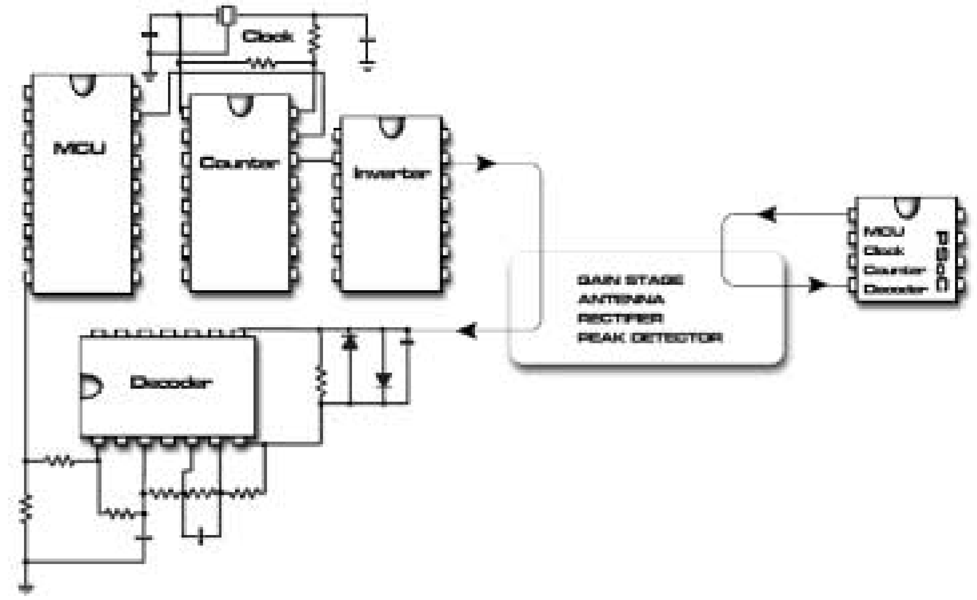

Figure 2: Discrete vs. SoC
This diagram illustrates the dramatic reduction in part count that the PSoC Microcontroller has on this application. The diagram also shows, at a high level, the basic building blocks of an RFID interrogator.

microcontroller. Programable analog configurations combined with a microcontroller offer tremendous advantages because most microcontroller applications are not completely digital, but require an analog interface to the external environment.

The usage model for the PSoC Microcontroller is one of adaptability (Figure 1). Each block, whether digital or analog, can be configured to perform a number of functions by writing to configuration registers. Block interconnect is also configurable, giving the system designer significant flexibility. The PSoC Microcontroller offers the following fully configurable blocks in an architecture that allows dynamic reconfiguration:

- 8 configurable digital blocks
- 4 continuous time
- 8 switched capacitor analog blocks
- 44 IO pins
- 44 digital IO, 4 analog outputs, 8 analog inputs
- 8-bit microcontroller
- 16K byte of Flash & 256 bytes of SRAM

The RFID application discussed here uses a small fraction of the internal resources of the PSoC Microcontroller, allowing the system to fit in an 8-pin part.

Cypress MicroSystems has collaborated with members of the University of Washington's Precision Forestry Cooperative to demonstrate the superior performance of the mixed signal PSoC Microcontroller for RFID transponder interrogation. Critical system improvements are realized for the highly portable field instruments required for insertion of these RFID devices into the forest products industry. Significant reductions in cost, power, space, and component count are presented here for the PSoC Microcontroller interrogator circuit along with improved performance of the RFID range capability.

SYSTEM DESCRIPTION

In an RFID system passive transponders are energized by magnetically coupling the interrogator circuit (Figure 2) to the passive transponder. Coupling occurs between the transponder circuit and the RLC resonator in the interrogator at a 125 kHz

The transponder sends data to the interrogator by shorting its winding momentarily thus causing a increase in the voltage within the interrogator's resonator. The changes in the resonator's voltage are conditioned by the receive portion of the interrogator to become the data stream into the microcontroller.

Once a digital stream has been created from the received signal, firmware in the microcontroller processes the bit stream to determine the transponder ID and the validity of the ID number (interrogation mode). Usually the validated ID data is then transferred to other hardware via a serial interface such as RS-232 (communication mode).PSoC Circuit Description

To build a RFID interrogator with the PSoC Microcontroller, all four of the chip's major resource categories will be used: digital blocks, analog blocks, general purpose IO, and the 8-bit microcontroller.

The PSoC Microcontroller has two types of 8-bit digital blocks: basic and communication. The digital basic blocks can be configured to be either a timer, counter, Pulse Width Modulator (PWM), dead band for PWM, Pseudo Random Sequencer (PRS), or Cyclical Redundancy Check (CRC). All of these functions, except for the dead band, are chainable, which allow the bit widths to grow from 8 to 64 in increments of 8. In addition to the functions provided by the basic blocks, each communication block can also be configured to be either an RS-232 receiver, RS-232 transmitter, SPI™ slave (Serial Peripheral Interface), or SPI master.

Analog functions provided by the PSoC Microcontroller are more difficult to list than digital functions due to the wide variety of configurations that are possible. However, the basic building blocks for the analog section of the PSoC Microcontroller are continuous time, op-amp based analog blocks, switched capacitor analog blocks, and a decimator. The following is a partial list of possible analog configurations: 12-bit incremental Analog to Digital Converter (ADC), 8-bit sigma delta ADC, inverting amplifier, programable threshold comparator, programable gain amplifier, 6-bit Digital to Analog Converter (DAC), 8-bit DAC, low pass filter, and band pass filter.

The PSoC Microcontroller also provides a number of choices at the pins of the device. The pins may be used as traditional inputs or outputs driven by the microcontroller or they may be used as direct digital IO to the digital blocks or analog IO to the analog blocks. The harvard architecture 8-bit microcontroller operates from 100Khz to 24 Mhz. The instruction set consists of 256 instructions with various addressing modes for RAM, ROM, and register access.

The RFID interrogator uses two digital blocks, one basic and one communication. While in "interrogation" mode, one block is used as a counter to produce the 125 KHz square wave that is the input to the external antenna power driver. The counter is driven by an internal oscillator that requires no external components. When the interrogator is in "communication" mode, the counter is reconfigured to be an RS-232 transmitter and a digital basic block is used to generate the BAUD rate for the RS-232 transmitter.

The receive portion of the RFID interrogator uses two continuous time analog blocks and two switched capacitor blocks. A port pin is configured as an analog input so that the external peak detector output can be fed to a Programable Gain Amplifier (PGA). The PGA's output is connected internally to two switched capacitor blocks which form a low pass filter. Next, the low pass filter output is routed internally to the final stage of the analog receive chain, a programable threshold comparator.

The comparator's output is read by the 8-bit microcontroller by polling the comparator output register. Firmware which runs on the 8-bit microcontroller analyzes the bit stream out of the comparator looking for and validating transponder IDs. Once the firmware determines the received ID is valid it converts the two digital blocks into an RS-232 transmitter and sends the data to the host system.

EXPERIMENTAL RESULTS

The oscillator, counter, microcontroller, filter, comparator and RS-232 device components of a typical ASK encoded RFID interrogation circuit have been integrated into the versatility of the PSoC Microcontroller. Results have been collected for both circuits in terms of proper functionality, read range, power consumption, space, component count and parts cost have been compared for the portion of the circuit consumed by the PSoC Microcontroller.

Conversion of the analog input to the PSoC Microcontroller to a digital bit stream is shown in Figure 3. This implementation of an ASK RFID interrogator consumes 25% of the digital blocks, 25% of the switched capacitor blocks, and 50% of the continuous time analog blocks within the PSoC Microcontroller. The implementation exceeds all of the performance metrics of the discreet implementation when tuned properly. The PSoC Microcontroller increases read range by 25% while reducing power consumption from 110 mW to 40 mW. Use of the PSoC Microcontroller also reduces part count from 47 to 2 which translates to a 95% decrease in printed circuit board area. Component cost is also reduced by 71%.

CONCLUSIONS

We have successfully demonstrated the use of the first commercially available mixed signal programable SoC for the task of low frequency RFID interrogation. The PSoC Microcontroller offers reduced component count, cost, space, and power consumption as well as improved performance compared to its discrete counterpart.

ACKNOWLEDGMENTS

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REFERENCES

[1] Steve Knapp and Danesh Tavana, "Field Configurable System-on-Chip Device Architecture," *IEEE Custom Integrated Circuits Conf*, 2000, pp. 155-158.

[2] M. Sivlotti, "A Dynamically Configurable Architecture for Prototyping Analog Circuits," *MIT VLSI Conf*, 1988, pp. 237-258.

[3] E. Lee and G. Gulak, A CMOS Field_Programmable Analog Array," *Intl Solid State Circuits Conf*, Feb 1991, pp. 186-188.

[4] K. Austin, "Integrated Circuit for Analogue System," *U.S. Patent* 5,196,740, Pilkington Micro-Electronics, March 23, 1993.

[5] N. Sako, "Integrated Circuit and Gate Array," *U.S. Patent* 5,298,806, Kawasaki Steep Corp., March 29, 1994.

[6] Xicor, "Nonvolatile Digital Potentiometer," datasheet available at:
http://www.xicor.com/folders/X9C102.php,
http://www.xicor.com/folders/X9C103.php,
http://www.xicor.com/folders/X9C104php.

[7] Texas Instruments, TLC32046X, "Analog Interface Circuit," datasheet available at http://focus.ti.com/docs/prod/productfolder.jhtml?genericPartNumber=TLC32046&pfsection=features.

[8] K.A. El-Ayat, "Mixed Mode Analog/Digital Programmable Interconnect Architecture," *U.S. Patent* 5,107,146, Actel Corporation, April 21, 1992.

[9] O. Agrawal and M. Wright, "Programmable Logic Device Incorporating Digital-to-Analog Converter," *U.S. Patent* 5,191,242, Advanced Micro Devices, March 2, 1993.

[10] O. Agrawal, M. Wright, and S. Sidman, "Programmable Logic Device Incorporating Voltage Comparator," *U.S. Patent* 5,153,462, Advanced Micro Devices, Oct. 6, 1992.

[11] Julio Faura, Chris Horton, Bernd Krah, Joan Cabestany, Miguel Angel Aguirre, and Josep Maria Insenser, "A New Field Programmable System-on-a-chip for Mixed Signal Integration," *Proc of the European Design and Test Conf*: Paris, France, Mar 17-20, 1997, p. 610.

[12] J. Madrenas, J.M. Moreno, E. Canto, J. Cabestany, J. Faura, I. Lacadena, and J.M. Insenser, "Rapid Prototyping of Electronic Systems Using FIPSOC," *IEEE Intl Conf on Emerging Technologies and Factory Automation*: Barcelona, Spain, 1999, pp. 287-295.

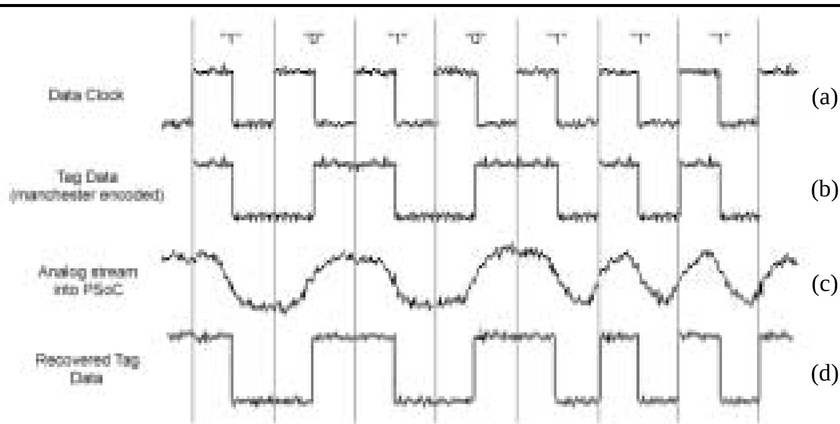

Figure 3: Signal Conversion

The figure shows the extraction of the tag information in Manchester encoded format. (d) Transitions of the tag signal, in relation to the (a) clock signal, are interpreted as digital 1's and 0's to arrive at the final tag ID. By using more stringent comparator thresholds and reducing noise through enhanced filtering, the PSoC Microcontroller is able to achieve improvements in read range of the tag ID through the conversion of the (c) analog signal received from the tag to the (d) digital signal that represents the tag ID.