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Analog Mixed Signal Based SoC for Measurement of AC Electrical Conductivity of Water

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Abstract- Designing with mixed signal (Analog + Digital) based SoC is an innovative field of VLSI technology, which features dynamic reconfigurability, that provides an opportunity to flourish wide domain of applications. For world of instrumentation, marching towards the great reliability and preciseness, this technology is becoming milestone. Deploying promising features of mixed signal based programmable system on chip, developed by Cypress Semiconductor USA, the PSoC5 (CY8C55), a system is designed for measurement of electrical conductivity of the water is designed and presented in this paper. The PSoC5 (CY8C55) operating at 80 MHz and 32 bit processing capacity with ARM7 Cortex-M3 as a computing core. The standard EC electrode (k=1.01) is employed off-chip, whereas remaining system is designed on-chip. The signal is extracted by configuring high input impedance PGA of PSoC5. To overcome the limitations of traditional three point method, system is calibrated over continuous domain of investigation. By standardizing with Hanna HI991300, it is implemented for measurement of EC of water and results shows good reliability.

Keyword- Mixed Signal, Electrical Conductivity, PSoC5, VLSI Technology.

1 INTRODUCTION

IN recent years, the analog and mixed signal design, an innovative VLSI technology, is capable to satisfy the prime requirement for ubiquitous embedded system, which is playing a dominant role in flourishing dedicated VLSI based embedded technology [1].The dynamic reconfigurability is the important feature of many mixed signal devices. Due to unique feature, reconfigurability, this innovative technology, mixed signal, has remarkable application in various field, from simple domestic appliances to critical space shuttle application. Therefore, many investigators shows their prominence on this reconfigurability to develop the ubiquitous embedded system [2], [3]. However, in the field of instrumentation especially precision measurement and controlling of various chemical as well as physical parameters, such as pH, dissolved oxygen, temperature, electrical conductivity (EC), etc. is the crucial task [4], [5]. The many investigators are opting suitable microprocessors and microcontrollers of renowned families, ARM, PIC, AVR ATmega etc., of commendable features to design an embedded system for such parameter measurement [6], [7]. But, all these embedded systems realise the concept of System-on-Board (SoB) design as analog design is always off-chip. An embedded system for measurement of electrical conductivity of the soil using PIC 18F4550 microcontroller is developed by SalehaBegum et al [8], where preamplifier, precision rectifier and level translator for PC via USB interface are off-chip. Rajendran et al have developed 8031 microcontroller based embedded system for temperature compensated electrical conductivity, wherein precision rectifier, ADC0808, PPI 8255 and RS232 transmitter/receiver interface are off-chip, to measure electrical conductivity they deployed the modified AC Wheatstone Bridge network [9]. Postolache et al have developed multi-sensing embedded system employing two PIC 18F4520 for water quality assessment [6]. They reported analog Data Acquisition System (DAS) for temperature dependent electrical conductivity measurement. Deploying Agilent 34401A Safarova et al measured the electrical conductivity of electrotextiles material [10]. Lorentz force sigmometry technique is employed by Uhlig et alfor the contactless measurement of the specific electrical conductivity of a solid body and fluid [11]. Jaimes-Ponce et al have implemented PIC 18F4550 based embedded system for hydroponic system of nutritious film to control flow and electrical conductivity of nutritious solution in growth channel [12], where DAS is developed around AD620. Pabiania et al have developed genetic algorithm in MATLAB prototype hydroponic system using PIC microcontroller to measure and monitor pH and electrical conductivity [13]. The four node neural network system using PIC18F452 for measurement of

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chlorides as well as temperature is developed by Kumaravel et al [14]. Helena et al has developed microcontroller based system for monitoring of water quality, which is suitable for indusial applications [15]. Khan et al, reported that the AVR series microcontroller, ATmega16, based embedded system is developed system for pH and electrical conductivity of soil [16]. Thus the embedded design realizes is SoB approach. The operational amplifiers based on BJT have low input impedance due to which interfacing of chemical sensors is not accomplished [17]. Also analog part of the DAS as well as microcontroller has limited configurability.

Therefore, it is clear that while designing an embedded system to interface with the real world analog circuits are indispensable although most of the functions in embedded system are implemented with digital signal processing. These limitations and constraints are minimised by many investigators by employing the VLSI devices. The VLSI devices, CPLD and FPGA, further have constraints to the designing, wherein only digital design reconfiguration available and analog design is off-chip. The recent advances in the state of the art for Computer-Aided Design (CAD) tools for analog and mixed-signal integrated circuits emerges Systems-on-Chip (SoC) designs[18], wherein digital design blocks as well as analog design blocks are available. Analog blocks typically constitute only a small fraction of the components on such SoC. Hence, an innovative technology, mixed signal VLSI technology, is suitable to overcome the designing constraints and to ensure better integrability [19]. Still this mixed signal SoC technology has limited features for configurability. The Programmable System on Chip (PSoC) is one of the fields of the mixed signal technology, which has an ability of dynamically reconfiguration of resources. Micro-semi, Texas, Actel and Cypress semiconductors are vendoring their unique features PSoCs in various variants. The mixed signals PSoC are having highly commendable analog as well as digital resources exhibiting dynamic reconfigurability. For an ubiquitous embedded system design PSoC devices have better solution.

Rathode has reported pulse oximeter by employing PSoC1 based on spectrophonic measurements [20]. Based on PSoC5 of Cypress semiconductors, the precise measurement of temperature compensated pH measurement embedded system was developed by Tilekar et al [21]. The Ni-Zn Ferrite Based Smart Humidity Sensor Module using PSoC was reported by Ladgaonkar et al [22]. Srihari et al incorporated the MEMS in robotics using PSoC5, wherein robot was controlled using RF remote by PSoC based accelerometer device [5]. The accuracy analysis of dissolved oxygen measurement embedded system was developed using mixed signal array PSoC1 was reported by Hrgetic et al [23], where Clark's type polarographic oxygen sensor and thermistor have interfaced to the CY8C26233 and CY8C27433 chips. Still this design instrumentation amplifier TLC271 and Operational amplifier LF411 are off-chip, so embedded system falls in SoB. However, the precision chemical parameter measurements of the liquid using PSoC5 mixed signal technology are rather rare. Therefore, employing mixed signal VLSI technology based embedded system is synthesized for measurement of AC electrical conductivity of the water under investigation. The developed embedded system is truly SoC and results of the implementation are interpreted in this paper.

2 SYNTHESIS OF PSOC FOR AC ELECTRICAL CONDUCTIVITY

Actually, emphasis is given to the PSoC's as its various configurable modules and application programming interface routines furnishes faster synthesis and programming of the system. Definitely all the steps from signal acquisition, conditioning to transmission of formatted data, which includes analog to digital conversion, data processing and digital to analog conversion all are within a single chip that ensures the SoC, which makes the functionality and portability of the system at low cost. Cypress Semiconductors, USA, are pioneers of mixed signal based PSoC chips of their own features of different variants. In which single chip accomplished with a wide range of integrated analog as well as digital peripherals of high dynamic reconfigurability along with the cores of dominant computing devices is present. Hence, the designed embedded system leads to increase the efficiency as well as portability. Moreover, PSoCs are the low cost functionality is increased The PSoC1, PSoC3 and PSoC5 are the three generations of the PSoCs devices launched by Cypress Semiconductor. However, PSoC5 is opted for this system. The architecture of the CY8C55 family PSoC5 is depicted in the figure 1. This family introduces ultra-low power, flash Programmable System-on-Chip (PSoC) devices, part of a scalable 8-bit PSoC3 and 32-bit PSoC5 platform. The CY8C55 family provides high degree of both static as well as

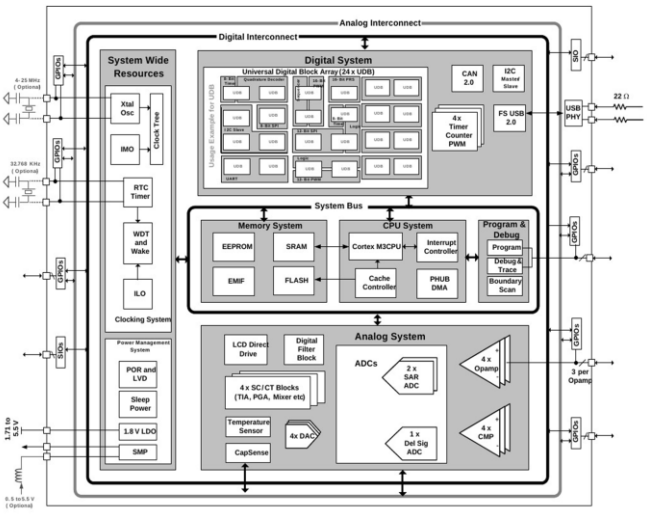

Figure 1. The architecture of CY8C55 family PSoC.

dynamic reconfigurable analog as well as digital cores and interconnect circuitry around a CPU subsystem [24]. The CPU subsystem has a powerful 32-bit ARM Cortex-M3 processor

with a flexible analog subsystem, digital subsystem, routing and I/O enables a high level of integration for wide variety of complex applications. Further, non-volatile subsystem, programming, debug and test subsystem, Inputs and outputs, Clocking, Power, PSoC's digital subsystem provides half of its unique reconfigurability. The digital signal from any peripheral to any pin through the digital system interconnect (DSI) is also available. The functional flexibility as well as reconfigurability is made available through an array of small, fast, low power universal databases (UDBs).

In mixed signal technology applications, switched-capacitor (SC) principle [25] circuits are pervasive in highly integrated circuit design. For analog core design, SC circuits play a vital role in mixed-signal that is analog to digital interfaces. The SC incorporates a large class of functions, such as sampling, filtering, and digitization. Furthermore, implementation of these functions makes SC circuits more suitable for high integrated complex design along with digital signal processing blocks in a compatible.

Moreover, PSoC5 architecture is powered by the PSoC Creator, an Integrated Development Environment (IDE), which provides a library of pre-built and tested standard digital peripherals.

The present PSoC is developed by employing the Cypress Semiconductors, PSoC5 development board, wherein device CY8C5568AXI-060 is installed. This is ensuring hardware as well as software co-designing. The system on chip designed and depicted in the figure 2.

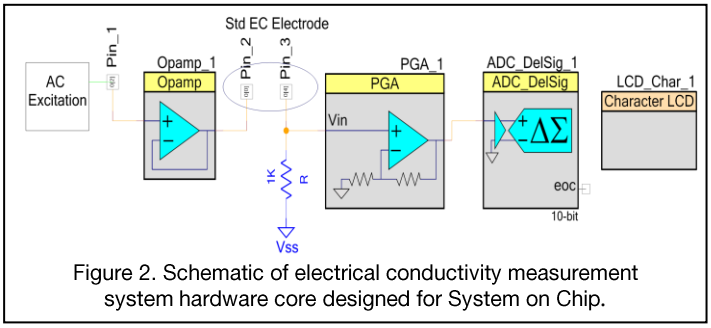

Figure 2. Schematic of electrical conductivity measurement system hardware core designed for System on Chip.

The electrical conductivity is a measure of concentration of positive as well as negative charge carries to contribute electrical conduction. The concentration inorganic dissolved solids of the negative charge carriers is due to chloride, nitrate, sulphate etc. and phosphate anions and positive charge carriers due to sodium, magnesium, calcium, iron, aluminium etc. cations.

The present prototype emphasises the synthesis of PSOC for measurements of AC electrical conductivity of the water. The standard electrical conductivity electrode having different cell constants are available in the market. However, for the present system standard electrode (K= 1.01), Equip-Tronix make, is opted. Because by applying a DC electric field between the two electrodes, ions will migrate and deposit on the electrodes to develop a thin layer of oxides which electrically isolates the positive electrode. If the applied DC voltage is larger than 1.3 V [26] then the electrolysis phenomena appeared and measured electrical conductivity will be erroneous. Therefore, many investigators emphases AC sources or pulsating sources than a continuous level of voltage as a excitation having frequency in the range 200 Hz to 10 KHz and amplitude of not more than 1.3 V to avoid the damage of electrode due to deposition [6], [9]. Deploying MCP606, precision CMOS Operational amplifier, is wired as phase shift oscillator to generate AC excitation signal of 541 Hz and 1.2 V. The excitation source is powered with highly stable power supply of PSoC5 development board as +5V and extracted through Pin_1 of on-chip buffer of PSoC5 by configuring Opamp_1. At Pin_2 of on chip buffer and Pin_3 of on chip Programmable Gain Amplifier (PGA), PGA_1 the conductivity electrode is externally connected. The Pin_1, Pin_2 and Pin_3 are configured as Analog Pin at P0(2) *opamp+*, P0(0) *opamp:out* and P0(4) *opamp+* respectively. The on-chip PGA has input impedance more than 100 M⊙⊙ hence, PGA_1 is configured as buffer. The various methods are implemented for electrical conductivity measurements [27] as Wenner array, Wheatstone bridge, simple voltage drop etc., but simple voltage drop technique is used for this embedded system. Thus, conductivity dependent emf which is developed across the external 1 K⊙ resistor is read using the on-chip PGA_1 and conductivity electrode is truly isolated between two buffers. The on chip ΔΣADC configured, 10-bit resolution and 10 KHz conversion rate, as single input with continuous mode (ADC_DelSig_1) to digitized the emf developed across the PGA_1. The ΔΣADC follows the Nyquist criteria therefore there is no need of precision rectifier that is AC emf is directly applied to the ΔΣADC. The PSoC5 facilitate the on-chip16X2 lines smart LCD block to designer and configured as ASCII to number conversion routine, where LCD_Char_1 is placed can be directly routed to the off-chip smart LCD module via P2(6:0). The initialization and accessing of all these on-chip analog as well as digital configured cores are made in firmware. Consequently, the necessary systems firmware, hardware as well as software, is co-designed in embedded C by using PSoC creator 2.1 IDE. On successfully building the project, 'devich.h' file is generated and burned into the target device CY8C5568AXI-060 ensuring the synthesised SoC for electrical conductivity measurement.

3 EXPERIMENTAL

The mixed signal based embedded PSoC system for measurement of electrical conductivity of water under the investigation is developed employing Cypress PSoC5 device and presented in figure 3.

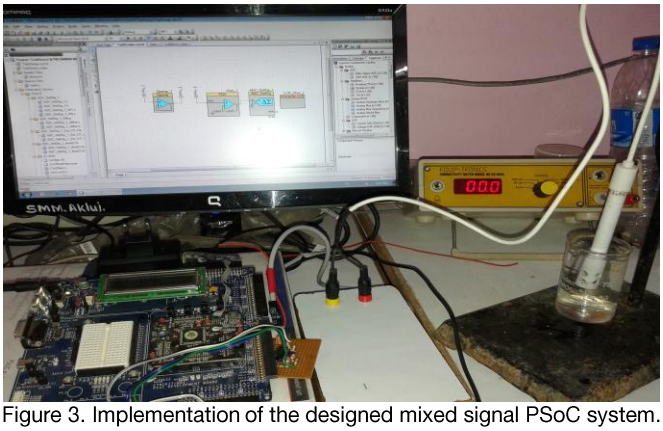

Figure 3. Implementation of the designed mixed signal PSoC system.

From the literature survey, the unit of the electrical conductivity is the μs/cm. Therefore, it is must to calibrate the developed system to μs/cm. Many investigator employed a KCl or NaCl solutions of wide range of electrical conductivity [6], [8], [26] for calibration of the developed system. The LR grade KCl solution of electrical conductivity ranging 81 μs/cm to 51700 μs/cm is used for calibration. The conductivity is measured by standard meter Equip-Tronix make model EQ-660A. The present system is exposed to these samples and corresponding emf values are (Vobs) against conductivity of the samples (EC) are recorded. The plot of Vobs against EC is shown in figure 4. The same nature of the plot is reported by investigators [6], [8]. This recorded data is subjected to the statistical process of regression. On regression, it is found that

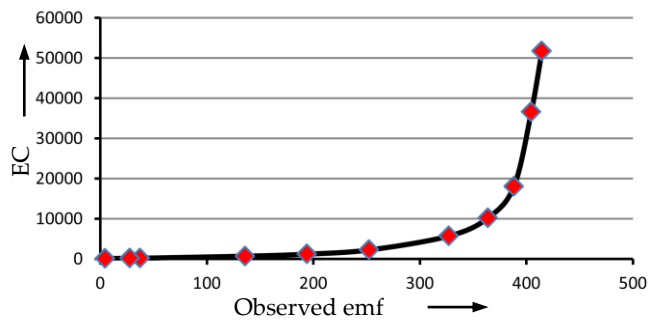

Figure 4. The graph of emf observed in mV against electrical conductivity (EC) in μs/cm on Equip-Tronix Conductivity meter EQ-660A.

the emf observed (Vobs) found best fit for three empirical solutions in different region of the curve. The first section of the curve is up to 194.00 mV and a polynomial solution of the order two is found best fitted, equation 1.

$$EC = 0.0202\ (Vobs)^2 + 1.7976\ (Vobs) + 72.887 \quad .....(1)$$

The second section of the curve is from 194.01 mV to 363.95 mV and an exponential solution is found best fitted, equation 2.

$$EC = 98.49\ e^{(0.012\ Vobs)} \quad .....(2)$$

The last section of the curve is above 363.96 mV and an exponential solution is found best fitted, equation 3.

$$EC = 0.068\ e^{(0.032\ Vobs)} \quad .....(3)$$

TABLE 1
The observed conductivity on developed system, Hanna HI991300 and Equip-Tronix EQ-660A meter.

Water sample	Observed EC in μs/cm on		
	PSoC system under investigation	Hanna HI991300 meter	Equip-Tronix EQ-660A meter
Aqua Sure Hard water outlet	2306	2420	2445
Tube Well	1694	1768	1792
Distilled Water	759	734	750
Water Supply Akluj	244	248	252
Aqua Sure purified water outlet	114	107	116
Rain Water	65	59	60

These three solutions are employed in the firmware for calibration and system is standardized to μs/cm.

Finally, developed mixed signal based embedded system is implemented for measurement of EC of the various water samples viz. hard water, tube well, distilled water, Akluj village water supply, water purified by Aqua Sure (RO) and rain water are used to measure electrical conductivity. The observation are tabularized and presented in table 1. On inspection of these data it is found that the conductivity shown by the system and that of shown by standard EC meters Equip-Tronix EQ-660A and HI991300 meter are closely matched.

4 CONCLUSION

Emphasizing mixed signal based SoC technology, a system is designed about Cypress PSoC5 to measure electrical conductivity of water. Deploying empirical relations, obtained three identified ranges, the system is calibrated to EC in ◎s/cm. The results shown by the system under investigation and that of obtained from standard EC meter show close match. The results of the implementation reveal the preciseness in the design.

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