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Paradigm of AMS based SoC for Measurement of Physico-Chemical Parameters of the Water

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Abstract- Indeed, mixed signal (Analog + Digital) based VLSI design is an innovative technology, realizing commendable reconfigurability, which helps to emphasis wide spectrum of applicability, particularly in the field of precision measurements. Moreover, designing of precision instrumentation for measurements and controlling of various parameters such as pH, temperature, electrical conductivity, etc. depicts the meritorious application domain. Further, the deployment of mixed signal based Programmable System on Chip (PSoC) overcomes constraints in the configurability, which are otherwise exhibited by traditional VLSI. Mixed signal based PSoC device vendered by Cypress Semiconductor, USA has promising reconfigurabilty features. This paper presents the issues of the designing of an inexpensive and portable embedded system for precision measurement of electrical conductivity of solution under investigation. The PSoC, a CY8C55 family device, from Cypress has on-chip ARM7 cortex-M3 CPU core, which has operating at back end. Deploying standard conductivity electrode, the AC current, proportional to concentration of ions is extracted by programmable analog core of the PSoC5. Only conductivity electrode is off-chip. Rest of analog part of the hardware is designed on the chip. Analog as well as Digital signal processing is performed by configuring the system on-chip. The digitization of the signal is ensured by ΔΣADC, which is configured for 10-bit resolution. Moreover, hardware & software are co-developed. The results are displayed on smart LCD. Instead of traditional method of calibration, wherein three point calibration process is adopted, the system is uniformly calibrated for the range of investigation. The system is calibrated to the electrical conductivity, micro Siemen (µS). The system is standardized against standard electrical conductivity meter model HANNA HI991300. The electrical conductivity measured by the system under investigation is more precise and accurate and results closely matched with that of shown by standard meter.

Keyword: Mixed Signal, PGA, Electrical Conductivity, PSoC5, VLSI Technology.

I. INTRODUCTION

Now days, an innovative VLSI technology, the mixed signal (Analog + Digital) design, is becoming ubiquitous. This is playing a vital role in flourishing embedded technology. This mixed signal VLSI devices realizing commendable characteristics of reconfigurability and this reconfigurability helps to design a desired ubiquitous embedded system [1]. Therefore, mixed signal VLSI technology exhibits wide spectrum of applications in every domain, from simple toys to complex industrial applications. Further, designing of the instruments for precision measurement and control of various physical as well as chemical parameters such as dissolved oxygen, temperature, pH, electrical conductivity, etc. is the challenging job [2]. Presently, the investigators are employing the microcontroller of promising features for these parameters measurement. But in such embedded system the analog design is always off the chip, which realizes the concept of System-on-Board (SoB) design. Postolache et al have developed PIC 18F4520 based multi-sensor, temperature, electrical conductivity and turbidity, measurement system for water quality [3]. The 8031 microcontroller based embedded system for temperature dependent electrical conductivity has developed by Rajendran et al [4], wherein they measured conductivity by investigating ionic solution using a modified AC Wheatstone bridge network. SalehaBegum et al have employed a PIC microcontroller to develop an embedded system for measurement of electrical conductivity of the soil [5]. A new technique, Lorentz force sigmometry, for the contactless measurement of the specific electrical conductivity of a solid body and electrically conducting fluid are reported by Uhlig et al [6]. Helena et al have developed microcontroller based system for monitoring of water quality, which is suitable for indusial applications [7]. All these embedded systems discussed so far have SoB approach. Moreover, analog part of the system as well as microcontroller has limited configurability. Further, due to BJT based operational amplifiers, low input impedance, the chemical sensors could not interfaced.

Therefore, to overcome the constraints in the designing of the embedded system, the VLSI devices are opted by the investigators [8]. Further, CPLD and FPGA devices have constraints to the designing, wherein the reconfiguration is available only for digital design and analog part of the system is off the chip. To avoid this problem and to ensure better integrability an innovative technology called mixed signal VLSI technology is suitable. The Programmable System on Chip (PSoC) is one of the fields of the mixed signal technology. Presently, various vendors are vendoring their unique

features PSoCs in various variants. The PSoC are having highly promising analog as well as digital cores exhibiting commendable reconfigurability. Truly, the PSoC devices have better solution for an ubiquitous embedded system on chip design.

Based on PSoC5 of Cypress semiconductors, the precise measurement of temperature compensated pH measurement embedded system was developed by Tilekar et al [9]. Ladgaonkar et al have reported Ni-Zn Ferrite Based Smart Humidity Sensor Module using PSoC [10]. However, the precision electrical conductivity measurements of the liquid using this mixed signal technology are rather rare. Therefore, employing an innovative VLSI technology, mixed signal, an embedded system is designed for measurement of electrical conductivity of the water under investigation and results of the implementation are interpreted in this paper.

II. DESIGNING OF MIXED SIGNAL SOC FOR ELECTRICAL CONDUCTIVITY

Presently, different vendors such as Cypress Semiconductors, Altera, Actel, etc. are providing mixed signal based PSoC chips of their own features, in which single chip both analog as well as digital cores of high reconfigurability along with the cores of computing devices is present. The Cypress Semiconductor launched three generations of the PSoCs (PSoC1, PSoC3 and PSoC5), but PSoC5 is opted for this system. The general architecture of the PSoC is depicted in figure 1.

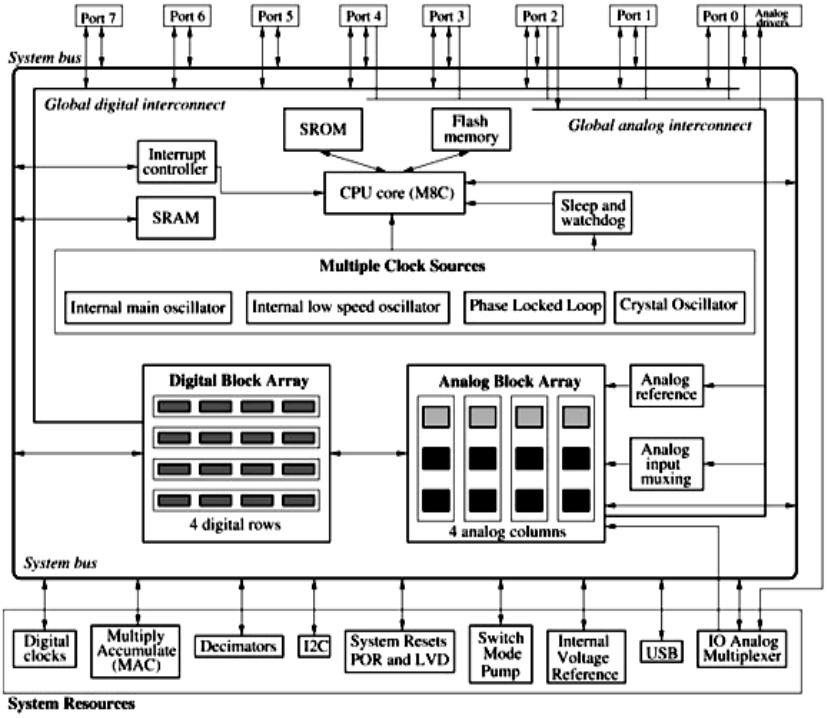

Figure 1. The general architecture of Programmable System on Chip.

The PSoC5 architecture has a powerful 32-bit ARM Cortex-M3 processor along with high degree of both static as well as dynamic reconfigurable analog and digital cores. In analog cores the principle of Switching Capacitor (SC) [11] is employed for configuration needed for analog design. Moreover, PSoC5 architecture is supported by the PSoC Creator, an Integrated Development Environment (IDE).

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

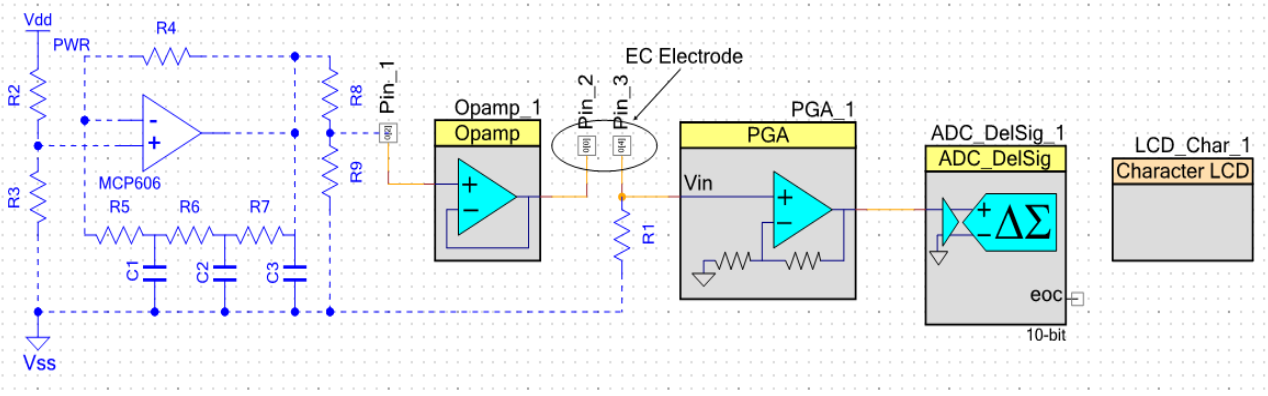

Figure 2. Schematic of System on Chip under the investigation.

The electrical conductivity is a measure of concentration of charge carries, which contribute electrical conduction. Present investigation emphasises the development of system on chip for measurement of electrical conductivity of the water. The various vendors are providing the standard electrical conductivity electrode having different cell constants. However, for the present system standard electrode (Equiptronix Cell constant K=1) is employed. The electrode is excited externally by deploying CMOS Op-Amp MCP606 wired for sinusoidal oscillator. The generated signal is extracted through on-chip buffer of PSoC5. The MCP606 is wired as a phase shift oscillator and powered with highly stable power supply (+5Volt) of PSoC5 development board. This AC excitation signal of 541 Hz and 1.2 V is applied to the Pin_1 of on chip buffer by configuring Opamp_1 [Figure 2]. The AC excitation is employed to avoid the damage of electrode due to deposition [3, 4]. The conductivity electrode is externally connected at Pin_2 of on chip buffer and Pin_3 of on chip Programmable Gain Amplifier (PGA), PGA_1. This PGA_1 is also configured as buffer having input impedance more than 100 MΩ. Thus, electrical conductivity dependent emf is read using the on-chip PGA and conductivity electrode is operating in between two buffers. This emf read by the PGA is digitized by employing the on chip ΔΣADC configured for 10 bit resolution with continuous mode (ADC_DelSig_1). The PSoC5 furnishes the 16X2 lines LCD block facility to designer, where LCD_Char_1 is placed can be directly routed to the off chip smart LCD module. The initialization and accessing of all these configured IP cores are done through firmware. Consequently, the systems necessary firmware is co-designed in embedded C by using PSoC creator 2.1 IDE.

On successfully building of the project, the 'devich.h' file is created and burned into the target device CY8C5568AXI-060 to ensure the development of SoC for electrical conductivity measurement.

III. CALIBRATION

The mixed signal based embedded PSoC system for measurement of electrical conductivity of water is developed employing promising features of Cypress PSoC5, CY8C5568AXI-060, device and presented in figure 3.

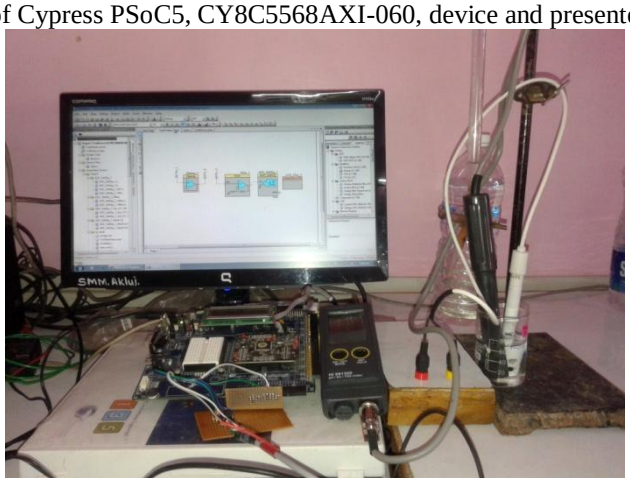

Figure 3. Implementation of the designed mixed signal PSoC system under investigation.

It is known that the unit of the electrical conductivity is the µs/cm. Therefore, present electronics system must be calibrated to this unit. Following the process described the system is calibrated. The water samples of different conductivity from 70 µs/cm to 1187 µs/cm are used for calibration [3, 5]. The conductivity is measured by standard meter HI 991300, HANNA Instruments, USA. The system is exposed to these samples and corresponding emf values are (V_{obs}) against conductivity of the samples (EC) are recorded. The plot of V_{obs} against EC is shown in figure 4. This data is then subject to the process of regression. On regression, it is found that the emf observed (V_{obs}) found best fit for the polynomial of the order two. The resulting expression from this fitting process is

$$EC = a(V_{obs})^2 + b\,(V_{obs}) + c \qquad ...(1)$$

Where, a, b, and c are the coefficients to be optimized. The values of these coefficient found are a= 0.0202, b= 1.7976 and c= 72.887.

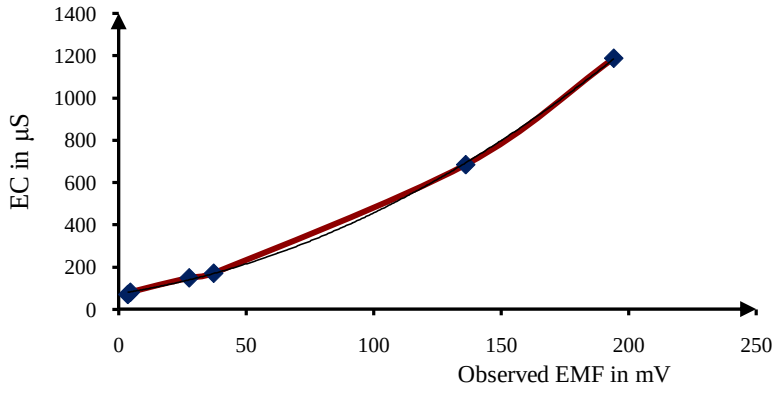

Figure 4. The graph of emf observed against electrical conductivity on Hanna Conductivity meter HI991300.

This polynomial relation is utilized in firmware for calibration and system is standardized to µs/cm.

IV. IMPLEMENTATION

Thus, designed system on chip is implemented for measurement of conductivity of the water samples. The water sample, tube well, distilled water, water purifier model AQUA FRESH Super Grand and rain water are used to measure electrical conductivity. Experiment is carried out at 27 ^{0}C. 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 meter HI991300 meter are closely matched.

Table I. The graph of emf observed against electrical conductivity on Hanna Conductivity meter HI991300.

Water samples	EC shown by the system under investigation (µS/cm)	EC shown the standard EC meter HI991300 (µS/cm)
Tube Well	1068	1085
Distilled Water	759	734
AQUA FRESH Super Grand	114	107
Rain Water	65	59

V. CONCLUSION

Deploying the feature of Cypress PSoC5, the Programmable System-on-Chip is designed to measure electrical conductivity of the solution. The present system ensures the mixed signal based VLSI design. The system is calibrated to the engineering units. The data of electrical conductivity shown by the system under investigation show close agreement with that of obtained from HI991300 meter. This supports the reliability and accuracy in the hardware and software co-design for dedicated system on chip.

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