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Smart Fusion Based cSoC for Wireless Sensor Network for Agricultural Applications

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ABSTRACT

Nowadays, the demand of cost effective, small size and reliable instruments for agricultural applications are increases. The need of hour is covered by growing technology like System on Chip as well as communication technology. Considering such facts, the Wireless Sensor Network is designed based on configurable System on Chip for monitoring of Temperature and Humidity. For this respective sensors are wired about configurable System on Chip and output is coupled to the communication technology for wireless data exchange. The developed Wireless Sensor Network is implemented for experimental authentication of the system and results are successfully interpreted.

Keywords: Smart Fusion, System-On-Chip, Re-Configurability, Wireless Sensor Network, Agricultural Applications

I. INTRODUCTION

The increasing demand industrial field is reliable and cost effective system with increase the Analogue content within single chip [1]. Recent rapid progress of integrated circuit technology has been going into integrate whole system on a chip. A concept of "System-on-Chip" (SoC) is just realized as an integrated product. The wide use of CMOS technology for analog circuits becomes vital for the mixed signal SoC. Mixed signal SoC has emerged recently and become main stream in VLSI industry. However some issues should be addressed in order to keep continuous growth in future.

The main goal of any design methodology is to facilitate an optimum design along with the correct use of computer aided design tool, to predict performances and verify that they meet the specification and last but not least, to reduce design risks [2]. The continued progress of semiconductor technology has enabled the System-on-chip (SoC) to become a reality. The platform based approach is one of the solutions and the hardware/software partition is an important issue for SoC system design [3].As the demand for smaller and low-power devices increases, state-of-art circuits are becoming more sensitive to the radiation effects and other environmental interaction. Another concern is the natural ageing of the integrate circuits, which impacts in the system performance, availability and reliability [4].

On Survey, it is found that modern embedded design engineers are facing a lot of different challenges cost reduction, low power consumption, high performance, short design cycle, reliability, flexibility etc. SmartFusion from Microsemi provides an ideal platform for engineers to achieve all those requirements. During early days the field of VLSI design was constrained in full custom design. Further due to advancement in integration technology, the semi-custom design field is emerged, like CPLD and FPGA. These devices are used for digital design. It is found that for electronic system design, in addition to digital design analog part is also equally important. Therefore, now days a new technology, wherein both analog as well as digital design is considered, is emerging. Such technology referred as mixed signal programmable system-on-chip. Therefore, use of such PSoC and cSoC devices helps to design a system with great significance. Recently, the field of Wireless Sensor Network is emerging and progressing towards the theme of IoT. Therefore, use of cSoC devices to facilitate the needs of WSN is an innovative concept. During recent days, the mixed signal VLSI design is becoming more pervasive due to its remarkable features. In the field of mixed signal

design Actel,Cypress, Microsemi playing vital role by providing PSC. Microsemi provides SmartFusion along with promising ARM Cortex-M3 core and analog computing engine. It is very useful for designing of customizable system-on-chip. The SmartFusion consist flash RAM, clock generator, nonvolatile memory, programmable I/O with some other peripheral resources. The SmartFusionA2F200M3F is having 32-bit ARM Cortex-M3core. It is high speed device working with 100MHz. The I/O pin exhibit great flexibility. Moreover, all blocks in microcontroller subsystem provide great re-configurability. In addition to hardware Microsemi provide LiberoSoC software to insure co-designing which is true IDE contains Simplify for synthesizing, Models for simulation, Soft Consol for developing application code. In short it can be said that an innovative technology of mixed signal cSoC having remarkable features by deploying which one can design sophisticated embedded system.

On literature survey it is found that, the field of industries, where in paper industries the controlling of humidity and temperature is very essential for controlling of quality of papers. Moreover, this find importance in the agricultural filed as well. Therefore there is a need of sophisticated instruments. By considering this fact present system is designed to measure environmental parameters particularly temperature and humidity for Agricultural Applications . The Wireless Sensor Network is developed, wherein the Wireless Sensor Node is developed around SmartFusion technology based customizable System-on-Chip (cSoC), A2F200M3F, from Microsemi, USA and Zigbee module. Also, base station is designed. Designing issues and results of the implementation are interpreted in this paper.

II. WIRELESS SENSOR NETWORK

A Wireless Sensor Network (WSN) consists of spatially distributed ***autonomous sensors*** to co-operatively monitor physical or environmental conditions, such as ***temperature, sound, vibration, pressure***, motion and pollutants etc and to co-operatively pass their data through the network to main location. A wireless sensor network is type of wireless network. It is small and infrastructure less. Basically, wireless sensor network consist a number of sensor node, called tiny device and these are working together to detect a region to take data about the environment.

III. HARDWARE

In the area of embedded system there is a desired to create a system on chip, the implementation and multiple or entire system on the single chip. The present system is the reprogrammable. The hardware consist various stages of signal processing and ARM cortexM3 based subsystem is built within mixed signal based smart-fusion chip [5]. We design Hardware by configuring Microcontroller Subsystem (MSS) and Programmable Analog blocks of SmartFusion A2F200M3F device along with required peripherals. The MSS consists of number of peripherals like ARM CortexM3 core which is main part of the design, GPIO, UART, Timer, SPI etc.The designed system is reprogrammable, low cost, low power and reliable. The Wireless Sensor Node for Wireless Sensor Network for agricultural application is realization of the smart fusion based cSoC system.

In the block diagram the sensor node developed for environmental parameter monitoring for agricultural applications, is shown in figure1.a. As depicted in figure

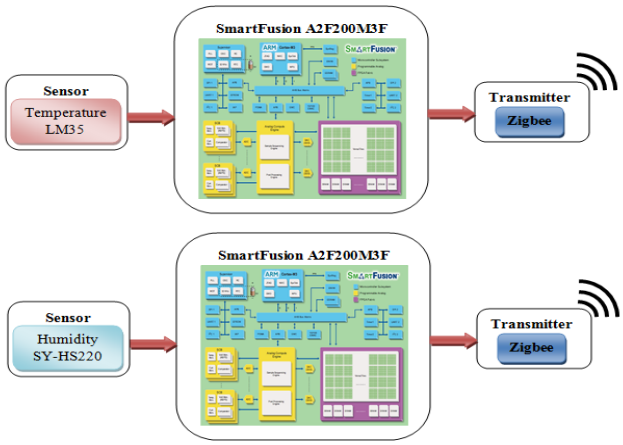

Figure 1 (a): Block diagram of wireless sensor node designed to measure temperature and humidity of agricultural applications

1.a sensor node is composed of temperature and humidity sensor. The figure 1.a shows one sensor interface to one SmartFusion device to make one node of wireless sensor network. Further, the figure 1.b shows the block diagram of base station (receiver) along with coordinator. The base station composed of coordinator to collect information and personal computer to demonstrate sensor node signal in real unite and display data on teraterm.

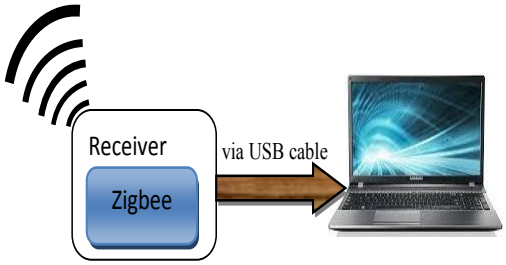

Figure 1(b): Block diagram of Receiver

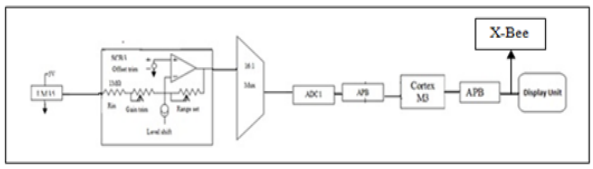

Figure.2 (a) schematic of the system on chip designed in Libero for temperature

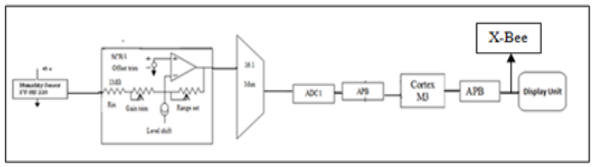

Figure.2 (b) schematic of the system on chip designed in Libero for humidity

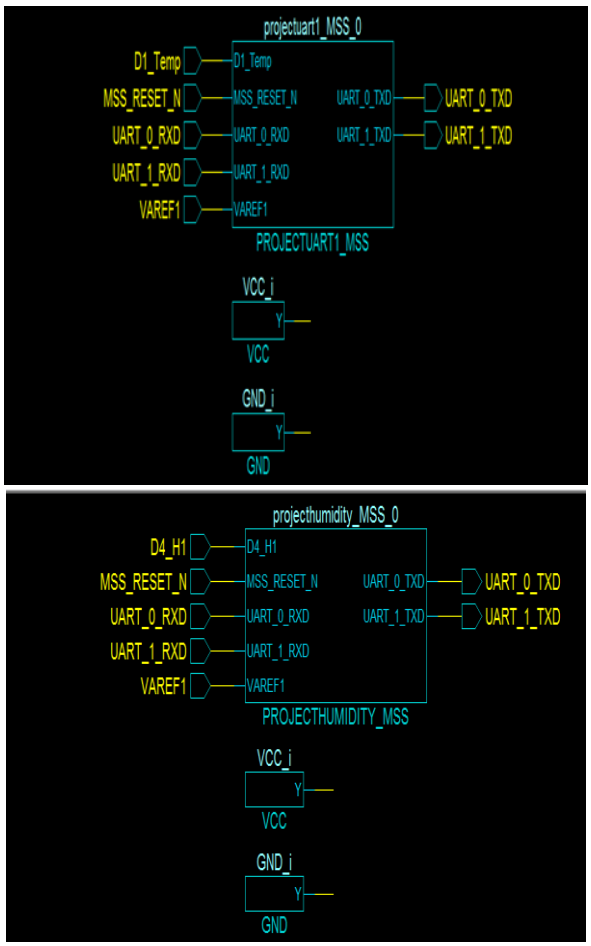

Figure 3: Netlist Viewer

A) Circuit Schematic of sensor node

As the present system realizes the design of mixed signal based programmable System-on-Chip, the analog as well as digital part of the system is designed on-chip. However, the circuit schematic of the sensor node synthesized in System on-Chip is depicted in figure. As shown in figure 2 , the necessary primitives are configured and integrated into one single chip.Further, the details about the each components are described in detail through following points:

As shown in figure 2.a and figure 2.b, the necessary primitives are configured and integrated into one single chip.Using on-chip signal conditioning features of SmartFusion device, mixed signal based System-on-Chip is designed, wherein temperature sensor (LM35) and humidity sensor (SY-HS 220) are directly interfaced to the SmartFusion device. The outputs of these sensors are in the voltage form [6]. Therefore, these signals are given to the Active Bipolar Prescaler (ABPS) block, which is voltage monitoring block of the SCB of SmartFusion device. The outputs of sensors are given to the ABPS of SCB1. The ABPS is an analog block, which is composed of continuous time Op-Amp in an inverting configuration. The operational amplifier can be configured for one of the full scale voltages ranges ±2.56V, ±5.12V, ±10.24V and ±15.36V [7]. Accordingly the gain of this prescaler can be configured. For proposed system, the gain is set to prescaler input range ±5.12V. This supports to realize the deployment of ADC of 10 bit resolution. The output of prescaler is given to the analog multiplexer, exhibiting 16-channels, of ADC1. Out of 16 channels the Channel 1 and 2 are used for ABPS input of SCB0. The channel 3 and 4 can be used for current and temperature monitoring [6]. Channels 5 and 6 are availed for ABPS output of SCB1 and channels 7 and 8 are for current and temperature monitoring of SCB1, respectively. The channels 9,10,11,12 are used for direct ADC inputs. The channel 13 and 14 are having no connection and channel 15 is used for Sigma Delta DAC (SDD). It is found that, the Channel 1 and 2 are used by manufacturer for die voltage monitoring [8]. For present system, the channel 6 (pin ABPS7) is used for interfacing of temperature dependent signal. The output of this multiplexer is given to ADC1, which is based on the principle of Successive Approximation (SAR) technique. It gives the digitized output.

The output of ADC, is given to Analog Compute Engine (ACE), wherein sampling, sequencing, post processing etc. are done. Here the role of ACE is to offload Cortex-M3–Based Microcontroller Sub System (MSS) from Analog part of the system. Through, Advanced Peripheral Bus (APB), the digital output of ACE is given to cortexM3 based microcontroller subsystem for processing the data.

The Analog Front End (AFE) of programmable analog block reads the analog signal coming from sensors. Deploying on-chip ADC in ACE, it digitizes the signal to 10-bit resolution. The microcontroller, which is processes otherwise working at backend processes the data and send to UART through that will further transmit to TX pin of RF module Xbee that transmit the data to base station through wireless communication. The firmware is developed for this dedicated application which configures and initializes the on-chip resources of the devices and computes the temperature and humidity signal into ºC and % RH respectively. The same circuit is deployed for fabrication of number of nodes. The final system designed in Libero SoC shown in figure 3.

B) Sensor Array:

Sensor Array of the present sensor node consists of two sensors such as temperature sensor(LM35) and Humidity sensor(SY-HS220).

1. Temperature sensor: The LM35 shown in figure 4 is precision integrated-circuit temperature sensors, whose output voltage linearly proportional to the Celsius (Centigrade) temperature. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55°C to 150°C temperature range [9]. Lower cost is assured by trimming and calibration at the wafer level. The low-output impedance, linear output, and precise inherent calibration of the LM35 makes interfacing to readout or control circuitry supplies. LM35 draws only 60 μA from the supply. it has very low self-heating of less than 0.1°C in still air.

Figure 4. Temperature sensor

2. Humidity sensor (SY-HS-220): Humidity is the presence of water in air. The presence of water vapor also influences various physical, chemical, and biological processes. Humidity measurement in industries is critical because it may affect the business cost of the product and the health and safety of the personnel. Hence, humidity sensing is very important, especially in the control systems for industrial processes and human comfort. The (SY-HS-220)shown in figure 5. The humidity sensor moduleconsists of sensor elements of capacitive type and comprising on chip signal conditioner as well. Sensor module provides DC voltage depending upon humidity of the surrounding in %RH. Typically, the module exhibits current consumption less than 3 mA. The operating humidity range is 30% RH to 95% RH. The standard DC output voltage provided at 250C is 1980 mV. The accuracy is ± 5% RH at 250C.

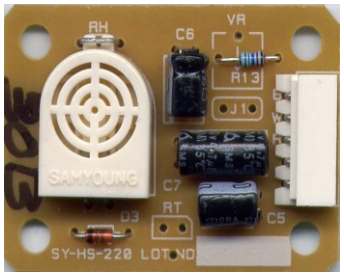

Figure 5. Humidity sensor

C) Customizable System-on-Chip (cSoC) Device (A2F200M3F):

The main aim is to ensure programmability of on-chip both analog as well as digital core of SmartFusion technology based cSoC and implementation of the same for development of sophisticated system for dedicated application. Therefore, structural details of these ubiquitous devices are explored and discussed.

The SmartFusion technology combines analog capability, Flash memory, and FPGA fabric along with microcontroller subsystem in PSoC. Microsemi is company that manufactures FPGA chips. It use a low power CMOS technology and company proprietary interconnection fusing technique called programmable Low impedance circuit element (PLICE) to produce their version of a FPGA. Microsemi provides software's for system co-designing and Complete FPGA development software Libero SoC v10.1. Libero SoCv10.1 is true IDE (integrated design environment) it integrate number of software's in one software. This software suits for designing with all FPGAs, including the new Smartfusion2 intelligent FPGA and managing the entire design flow from design entry, synthesis and

simulation, through place-and-route, timing and power analysis. Smartfusion A2F200M3F divides in three main parts.

A. Microcontroller subsystem (MSS)
B. Programmable Analog block
C. ProASIC3 FPGA Fabric

1. Microcontroller Subsystem (MSS): The MSS is composed of a 100 MHz Cortex-M3 processor and integrated peripherals, which are interconnected via a multi-layer AHB bus matrix (ABM). This matrix allows the Cortex-M3 processor, FPGA fabric master, Ethernet message authentication controller (MAC), when available, and peripheral DMA (PDMA) controller to act as masters to the integrated peripherals, FPGA fabric, embedded nonvolatile memory (eNVM), embedded synchronous RAM (eSRAM), external memory controller (EMC), and analog compute engine (ACE) blocks. SmartFusioncSoCs of different densities offer various sets of integrated peripherals. Available peripherals include SPI, I2C, and UART serial ports, embedded FlashROM (EFROM), 10/100 Ethernet MAC, timers, phase-locked loops (PLLs), oscillators, real-time counters (RTC), and peripheral DMA controller (PDMA).
2. Programmable Analog block: The analog section is a little harder to catch quickly. We are familiar with earlier an Actel Fusion chip, that's way this analog section familiar to us. It includes 8, 10 and 12-bit, 600 Ksample/s successive-approximation ADCs and 12-bit sigma-delta DACs (up to three of each), up to ten, 50ns comparators, and a variety of current, voltage, and temperature monitors. All together the chips offer up to 32 analog inputs and three outputs. One of the benefits of the Flash process, Microsemi points out, is that it gives us the high-voltage transistors as need for simple analog design.
3. ProASIC3 FPGA Fabric: The **Microsemi's Smart Fusion FPGA** is based on **Microsemi**´s flash technology and offers full IP protection, and ease-of-use. The **SmartFusion FPGA** is ideal for hardware and embedded designers who need a true system-on-chip solution that gives more flexibility than traditional fixed-function microcontrollers and without the excessive cost of soft processor cores on traditional **FPGAs**. The **Microsemi SmartFusion** is an innovative solution for the industrial, medical, energy, communications, and military markets in diverse applications, including system management, power management, motor control, industrial networking, and display. The FlashPro4 programmer can be used as an easy in-system programming method for **SmartFusion FPGAs**.

D) RF module Zigbee:

The main aim of the present work is to design the sensor node for Wireless Sensor Network (WSN), which needs RF module. The ZigBee is a wireless communication module that Digi built to the 802.15.4/ZigBee standard. The beauty of the 802.15.4/ZigBee wireless standard is that it can form self-healing mesh networks. These are great for making a wireless control network that spans from one corner of your house to the other. Zigbee module designed for extremely low cost then other RF models and it is easy to diploy. It consumes very low power due to sleep mode and operates on low power supply typically 2.8V to 3.3V,chrgeable batteries. Salient features of Zigbee modules are:

Figure 6. The ZigBee RF module

- Power output: 1 mW (+0 dBm)
- Indoor/Urban range: Up to 100 ft (30 m)
- Outdoor/RF line-of-sight range: Up to 300 ft (90 m)
- RF data rate: 250 Kbps
- Operating frequency: 2.4 GHz
- Operates on DC +3.3 volt

IV. SOFTWARE

The LiberoSoC is true IDE software. It consists number of software's like synplify proAE for synthesizing, modelsim for simulation, SoftConsole for application code development etc. In Libero IDE software there are two HDL codes are available for programming which is verilog and VHDL. Integrated circuit technology has improved to allow more and more components on chip; digital systems have continued to grow in complexity. As digital systems have become more complex, detailed design of the system at the gate and flip-flop level has become very tedious and time consuming. For this reason, use of hardware description language allows a digital system to be designed and debugged at a higher level before conversion to the gate and flip-flop level. Use of synthesis computer-aided design tools to do this conversion is becoming more widespread. This is

analogues to writing software programs in a high level language such as C and then using a compiler to convert the program to machine language. One of the important characteristics of an embedded system is the firmware required to embed into the flash memory of the target device.

The SoftConsole combines project management, make facilities, source code editing, program debugging, and complete simulation in one powerful environment. The µvision development platform is easy to use and helping quickly creates embedded programs that work. The SoftConsole editor and debugger are integrated in single application that provides a seamless embedded project development environment. In addition to this the Tera term IDE is utilsed for the base station to demonstrate data on PC.

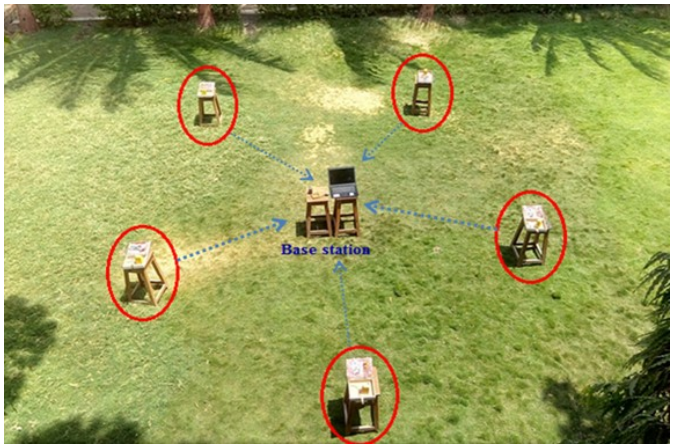

Figure 7: Experimental arrangement of sensor nodes and base station

IV. IMPLEMENTATION WIRELESS SENSOR NETWORK

The wireless sensor node is designed to monitor the agricultural parameters of Polly house environment. The computer of the laboratory is used as the based station on which received the data could be displayed. The Zigbee RF modules are connected to sensor node under investigation, whereas other zigbee RF module is interfaced to the computer which acts as coordinator. Sensor node was kept at middle part of the garden, covered with the green net, located at about 80 meter away from the base station. The temperature and humidity of this environment is recorded at the base station continuously. Figure 7 shows experimental arrangement of senser nodes and base station.

V. CALIBRATION OF SENSOR NODES

The smart fusion based cSoC for wireless sensor network under investigation is designed for agricultural application. Before implementation, sensor nodes are calibrated for temperature in degree Celsius and Humidity in % unit. The sensor node is calibrated to the maximum temperature and humidity. For present work we use temperature sensor LM 35, it shows the temperature coefficient as 10mV/0C. The output in 0C is adopted by dividing output voltage by 10.

Temperature in 0C = Output voltage/10.

Table1 shows Temperature of controlled ferns and Temperature measured by system the system extracts the signal in millivolt.

The humidity must be measured in % RH. Therefore, the calibration of the device is essential and therefore, the system is further subjected to the process of calibration. Table2 shows, Humidity of controlled humidity chamber to humidity dependent emf produced by system. In this way the range of voltage is available. These limits, upper and lower limits of observed emf are considered for further electronics design. The analog part of the circuit is designed so that the output for high humidity should not be saturated. The reference constraint the voltage is ±5.12 V. Therefore the circuit is designed to upper limit to ±5.12 V. This confirms that the system never gets saturated for high humidity level.

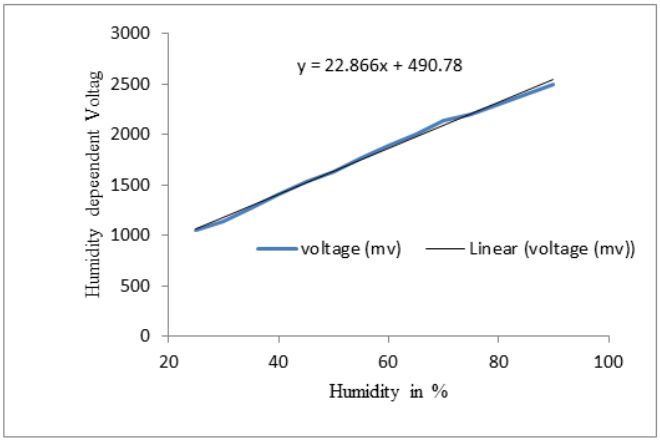

Figure 7: Humidity Vs Voltage

Further, the system is subjected for process of calibration. For calibration, the standard humidity hygrometer is used. The keeping environment variable, the humidity applied to sensor is varied. The data regarding humidity is collected. The observed emf is

plotted against humidity(x) in % RH as shown in figure 7.

Using least square fitting process of data analysis the coefficients are obtained for straight line expression. The expression resulted from curve fitting procedure is, same to give humidity in % RH. The system is precisely calibrated.

$y = 22.86x + 490.7$ Therefore,

Relative Humidity (% RH) = $(y - 490.7) / 22.86$

This expression is used for further calculation. The expression is solved during firmware execution. It takes produced by system (as illustrated in software) and process the same to give humidity in % RH. The system is precisely calibrated.

VI. RESULT AND DISCUSSION

After successful calibration of the sensor nodes, the wireless sensor network is implemented at the college garden as shown in figure 7. The five sensor nodes are systematically located by fragmenting the area under investigation in hypothetical cells. These nodes are powered from rechargeable battery. The sensor nodes sense the agricultural parameters, temperature and humidity surrounding to the localized area and processes data according to the developed firmware of respective nodes and transmit the same data towered the base station. On other hand, base station collects the data from distributed sensor nodes and stored at the database in real time of the base station. On observation of the database it is found that the 34 0C temperature and 52 % Humidity is present in the environment of area under investigation.

Table 1: Temperature of controlled ferns and Temperature measured by system

Temperature in environment (^{0}C)	Temperature measured by system (^{0}C)
34	34.24
35	35.02
36	36.89
37	37.50
38	38.02
39	39.45
40	40.52
41	41.18
42	42.22
43	43.34
44	44.06

Table 2: Calibration of Humidity

Humidity	voltage (mv)
25	1049
30	1141
35	1271
40	1410
45	1531
50	1639
55	1769
60	1890
65	2011
70	2144
75	2208
80	2308
85	2402
90	2505

VII. CONCLUSION

Emphasizing the revolutionary technology, smart fusion based system-on chip design; the system is designed for temperature and relative humidity measurement. Realizing reconfigurability, both hardware and software are co-developed. The system is calibrated to °C. The results obtained from the system under investigation show close match with that of given by the standard instruments. This supports the accuracy in designing of both hardware and software. Based on Zigbee technology, the WSN is established in star topology. It is the realization of on-site deployment of site specific data collection. It can be concluded, that the mixed signal based system-on-chip based WSN is designed successfully for measurement of temperature and relative humidity. On inspection of result it can be said that present system work satisfactorily and precisely.

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