Deployment of SmartFusion Based SoC to Develop GSM Based Remote Monitoring System

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Abstract: Designing of system on chip, based on Smart Fusion technology, is the revolutionary field exhibiting wide spectrum of applications. Moreover, deploying GSM technology, the designing of remote monitoring systems can be realized. Emphasizing its inter disciplinary application, the data collection for precision agriculture, an embedded system is designed, wherein an innovative technology, "Smart Fusion Technology", is deployed. The architectural details of Smart Fusion technology A2F200M3F are explored and implemented to design temperature monitoring system. On interfacing the same to GSM module the remote monitoring is ensured. On reconfiguration of on chip resources of the devices the entire system is designed on single chip and integrated by deploying the dedicated IDE. The firmware required to ensure synchronization between on-chip and off-chip devices is designed in SoftConsole, wherein embedded C environment is used. The System is implemented for polyhouse and results are interpreted in this paper.

Key Words: GSM, Microcontroller Sub System, Mixed signal technology, SmartFusion device, Precision agriculture.

1 INTRODUCTION:

Recently, in the field of agriculture, an innovative technologies are deploying to enhance growth rate of crops and the yield as well. Cultivation of crops in controlled environment is becoming more and more pervasive across the world. To provide controlled environment to the crops the agriculturists are attempting to deploy modern techniques, wherein highly precise electronic instruments are employed. Basically, agricultural applications continue to demand the devices of increased flexibility, configurability, and good performance, along with reduced power demand and cost [1]. It is found that, the precision agriculturists are availing the polyhouse technology, wherein various environmental parameters should be precisely controlled. Moreover, these parameters exhibit spacial and temporal variability. For controlling of the parameters under study, highly sophisticated electronics instruments are needed. The suitable solution for these requirements is to develop an embedded system, wherein the smart devices, based an innovative technology such as mixed signal based VLSI design are employed. On survey, it is found that, the researchers are focusing on the novel technology, called Wireless Sensor Network (WSN), and are attempting to design WSN for polyhouse applications [2, 3, 4]. The reliability of WSN is solely depends upon the promising features of sensor nodes [5,6]. In fact, the sensor node realizes an embedded technology [7]. These sensor nodes should have the characteristics of reconfigurability. On literature survey, it is found that the reports on development of such sensor nodes, wherein microcontrollers of various families are deployed [8, 9, 10, 11, 12, 13] are available. Such sensor nodes, exhibits rather limited configurability in the hardware and software as well. Moreover, due to infrastructural constraints the wireless sensor network covers limited area. This is due to the fact that, the WSN realizes collaborative

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collection of data through wireless topology and demonstrates the same at base station. The nodes as well as base station are localized at particular position. Now days, everyone wants to be mobile by making use of cell phone. To ensure the deployment of this modern technology, the precision agriculturists are demanding sophisticated electronic system, which could establish communication with the cell phone device and monitor the data regarding environmental parameter of polyhouse on the cell phone device. Use of mobile phones to monitor the information may really help to overcome the limitations of traditional WSN system, wherein the base station is stationary.

Analog and mixed signal based System-on-Chip development is revolutionary area of VLSI technology, featured with static as well as dynamic configurability. Therefore, use of this technology to ensure modernization in agriculture, may really help to achieve the goals of precision agriculture. Recent advantages in mixed signal based technology results into the birth of novel devices called Programmable System-on-Chip (PSoC) and customizable System-on-Chip (cSoC). The PSoC are launched by Cypress semiconductor USA. However, cSoC technology is launched by Microsemi, USA. During early days, the microsemi incorporated Fusion technology for cSoC design. However, they launched SmartFusion technology with the use of ARM CortexM3 microcontroller based Subsystems. Thus, deploying mixed signal based cSoC from microsemi, the configurability in the WSN system can be enhanced. Therefore, it is proposed to deploy SmartFusion technology based cSoC to design the system to assist the precision agriculturists. In traditional WSN, the microwave with 2.4 GHz medium is employed to interact with the nodes [14]. Therefore, the range of communication will be constrained. Indeed, stationary messaging service, the deployment of mobile communication may significantly help to modernize the system. To enhance the range, the significant modification in the technology is expected. To ensure mobile networking the GSM technology can be availed. This paper presents confluence of two innovative technologies, the mixed signal based VLSI design and GSM, to develop wireless sensor network for polyhouse applications. A mixed signal based System-on-Chip is designed to monitor polyhouse parameters and results of implementation are interpreted.

II. System Architecture:

The present work emphasizes the design of the GSM based temperature monitoring system, wherein the principle of mixed (Analog+Digital) signal based SoC design is employed. The system comprises configurability of both hardware and software. The hardware, using SmartFusion based cSoC and GSM module, is designed and software is also developed in SoftConsole. The details regarding the issue of design and development are illustrated through following two points.

1. The Hardware:
2. The Software:

Hardware:

Present system emphasizes the use of SmartFusion technology based customizable System-on-Chip (cSoC), A2F200M3F, from Microsemi, USA, to design embedded system. Moreover, the GSM module SIM 900 is employed to establish communication with given cell phone device. The organization of the system is depicted by the block diagram, shown in figure 1. The present work realizes the use of VLSI technologies, wherein entire system is designed in one chip.

As shown in figure 1, the system under design consists of following sections.

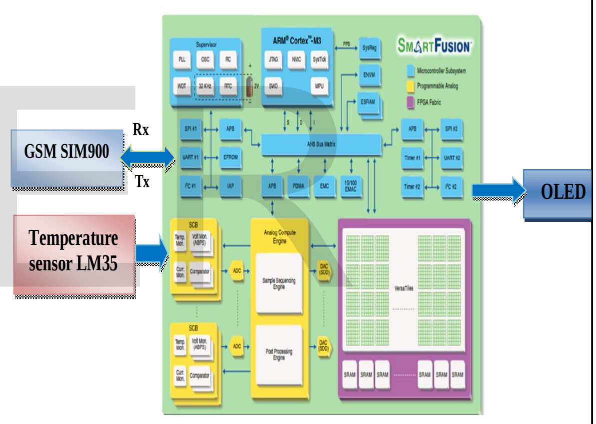

Figure 1 Block diagram of system, the sensor node, designed for monitoring of temperature of polyhouse environment.

1. Temperature Sensor unit
2. Customizable System-on-Chip (cSoC) device [A2F200M3F]
   - Programmable Analog devices
   - Microcontroller SubSystem (MSS)
3. GSM Communication

Details regarding designing issues are discussed in subsequent sections.

1. Sensor Unit:

The main objective of present work is to design, the system on chip to sense environmental parameter, the temperature, of polyhouse. For this purpose, the sensor unit is designed. Traditionally, to sense physical or environmental parameter, the sensor unit is required, which comprises, minimum

International Journal of Scientific & Engineering Research, Volume 5, Issue 11, November-2014
ISSN 2229-5518

blocks, such as sensor, signal conditioner and data acquisition block etc. Present work emphasizes the design of system on one chip, wherein all necessary cores are integrated on-chip. Only temperature sensor is connected externally, as Off-The-Self (OTS) component. Monolithic temperature sensor LM35 is employed to read thermal status of the domain of specific area of polyhouse. Basically, monolithic temperature sensors exhibit promising characteristics [15]. Therefore, they play vital role in enhancing the accuracy and preciseness of the system as well. Such temperature sensors provide the output in the voltage formats, which is directly proportional to respective temperature scales. The monolithic temperature sensors available in LM series are LM135, LM235, (10 mv/^{o}K), LM34 (10 mv/^{o}F) and LM35 (10 mv/^{o}C). These devices are available in hermetic TO-46 transistor packages [15].

The temperature sensor LM35 is used for proposed system for sensing temperature. This precision integrated-circuit temperature sensor, as discussed earlier, exhibit output voltage linearly proportional to the temperature in degree Celsius scale. Figure 2 shows the schematic of temperature sensor LM35, which has an advantage over the temperature sensors having temperature coefficient in mv/^{o}K [16], because if temperature coefficient is mv/^{o}C then the complexity of scale conversion is minimised. The LM35 does not require any external calibration for trimming [17]. It draws only 60µA current from its supply, it has very low self-heating, less than 0.1 ^{o}C in air. Therefore, it is suitable for environmental temperature measurement.

Figure 2: Temperature Sensor (LM 35)

In proposed system, the sensor is biased with single +5V power supply. However, it can be used with dual power supply and it can operate on 4V to 30V. The 18KOhm resistor at load wired to provide typical accuracy over full -55 ^{o}C to +150 ^{o}C temperature range [17]. The temperature dependent voltage is extracted and given to the ABPS3 pin of the SmartFusion device for further signal conditioning and processing. As discussed earlier, use of only temperature sensor off the chip, realizes the design and customizing of System-on-Chip.

2. Customizable System-on-Chip (cSoC) Device (A2F200M3F):

A designing system-on-chip is novel area of research. During early days, the mixed signal technology depicts fusion technology. This technology is extended to SmartFusion on inclusion of ARM CortexM3 processor core on a flash semiconductor die. It provides more flexibility and configurability, highly reduced power consumption as well as less system development time. It provides platform for both embedded and VLSI developers. For present system the SmartFusion A2F200M3F device from microsemi is used. Figure 3 depicts the architecture of SmartFusion A2F200M3F device. It combines three main parts.

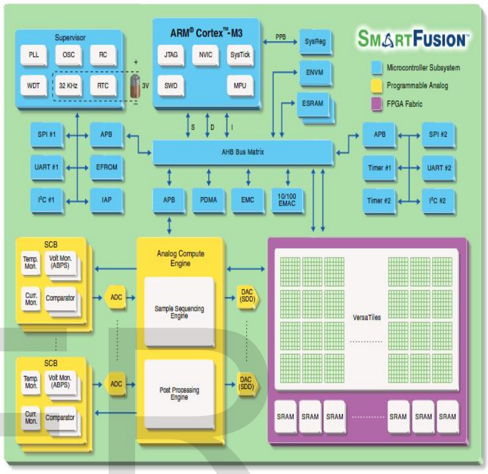

Figure 3 : Architecture of Smart Fusion device A2F200M3F

A. Programmable Analog blocks
- ➢ Mixed signal blocks
  - ❖ Analog Front End
  - ❖ Analog to Digital Conversion
  - ❖ Analog Compute Engine

B. Microcontroller SubSystem
- ➢ Communication interfaces
  - ❖ I^2C
  - ❖ UART
  - ❖ SPI

C. FPGA fabric.

A. Programmable Analog block:

The programmable analog block of the cSoC plays significant role to realize the mixed signal based VLSI design. On chip programmable analog block consists of Analog Front End (AFE) and Analog Compute Engine (ACE) [18]. The first part of analog devices work at front end to interface the analog signal. Therefore, this block is referred as Analog Front End (AFE) device. This AFE performs the signal conditioning and offset compensation. The reconfiguration of various parameters of this block results into sophisticated system on chip design. Analog block plays vital role in the process of calibration of the system in engineering unit as well. The SmartFusion technology based cSoC consist of ADC with reconfigurable 8, 10, and 12 bit resolution, two different clock sources and it can be configured in three modes for 500ksps, 550ksps and 600ksps with 2.56V internal reference voltage [18]. The analog Signal Conditioning Block (SCB) is coupled to the analog to digital converter. The Analog Compute Engine ACE of analog block consists of Sample Sequence Engine (SSE) for configuration of the parameters of on chip ADC and DAC as well. The Post Processing Engine (PPE) is deployed for functions such as pass filtering and linear transformation as per circuit requirements [19].

For proposed system the SmartFusion device, A2F200M3F, is used. It consists of two ADCs, ADC0 and ADC1, four SCBs two for ADC0 and two for ADC1. Each SCB consists of two voltage monitoring, one current monitoring and one temperature monitoring customizable cores along with the comparator. All on chip resources are featured with reconfigurability.

B. Microcontroller SubSystem (MSS):

In addition to programmable analog block the SmartFusion device consist of processing sub system called as Microcontroller SubSystem (MSS). The Microcontroller SubSystem (MSS) of SmartFusion is composed of 32-bit, 100 MHz CortexM3 processor, internal memory blocks, clocking resources and integrated peripherals, which are interconnected via a multilayer AHB bus matrix (ABM). The ARM CortexM3 microcontroller is low power consumption processor, which features low gate count, low predictable interrupt latency and low cost of debug. It includes Memory Protection Unit (MPU). It has single cycle multiplication instruction and exhibit multiply and accumulate operation as well. It provides debug facilities with JTAG and serial wire. In present system, the output of Analog Compute Engine (ACE) is given to ARM CortexM3 processor through Advanced Peripheral Bus (APB) interface for further processing of data.

The SmartFusion device is composed of the on-chip resources, the clocking, which includes main oscillator, battery-backed 32 KHz low-power oscillator with real-time counter (RTC), 100 MHz embedded RC oscillator and embedded analog PLL with four output phases. For present system, the on-chip RC oscillator, with 1% accuracy is used and configured to derive the clock of 80 MHz. The Microcontroller SubSystem (MSS) of SmartFusion also comprises internal memory block, which includes embedded high-speed SRAM of 64 Kbytes and embedded flash memory of 256 Kbyte. It is implemented in two physical blocks to enable simultaneous access from two different masters.

Communication interfaces:

In SmartFusion device based development board, vendored by Microsemi USA, the different sets of peripherals are also available, which includes the components needed for communication, such as 10/100 Ethernet MAC, UARTs, SPI, GPIO, Timers, clock resources, two I^2C peripherals etc. As per need of system, out of two I^2C one I^2C peripheral is used for interfacing of Organic LED (OLED) to display the processed data. The UART module is used for sending data to the computer through UART to USB bridge converter. Out of 32 GPIO available on SmartFusion evolution board the four GPIO are used for LED interfacing as well.

C. FPGA Fabric:

The present SmartFusion technology based cSoC realizes the customizing of the analog as well as digital resources. To ensure customising and routing, the configurable platform is essential. Therefore, the SmartFusion device, A2F200M3F, consists of FPGA platform to ensure integrability of the primitives. The FPGA fabric has great features like low power, firm error immune, flash based CMOS process, embedded SRAM and FIFOs. It also combines ISP with 128-bit AES via JTAG and flash lock to esquire FPGA contents.

3. GSM Communication:

The Global System for Mobile (GSM) Communication network has the advantages of wide covering area, long distance communication, and reliable communication effect etc. The GSM communication is standard, globally accepted digital cellular communication technology wherein the TDMA technology is used. The communication is established with identification and authentication of the subscriber. Therefore, it ensures great security for messaging of either text or graphical. It operates in the 900 MHz band [890MHz-960MHz] and 1900MHz band. The GSM network depicts the communication through server and not direct cell phone to cell phone, which otherwise happen in case of traditional Wireless Sensor Network (WSN). Traditional WSN utilizes, the Zigbee for RF communication at it operates on 2.4 GHz ISM band. Therefore, the GSM technique reveals wide area of coverage with minimal infrastructure. Hence, deployment of GSM technology to ensure designing of wireless sensor node, may emerge new technology for polyhouse application.

It is found that, about 83% of the total cell phone avail this GSM facilities. The GSM can be deployed to establish PC based communication. Confluence of GSM with embedded technology results into great revolution in communication technology. Moreover, the interfacing of GSM with mixed signal based PSoC, helps to develop new area of research, in wireless mobile telecommunication. To ensure GSM based communication, the short message service (SMS) facility is deployed. Through the SMS service the data regarding environmental parameters are given to cell phone device. To establish this communication the GSM module (SIM900) is interfaced to the SmartFusion cSoC A2F200M3F.

The GSM modem (SIM900) is interfaced to serial port of the cSoC device. Figure 4 shows the SIM 900 GSM module. The SIM900 is a complete

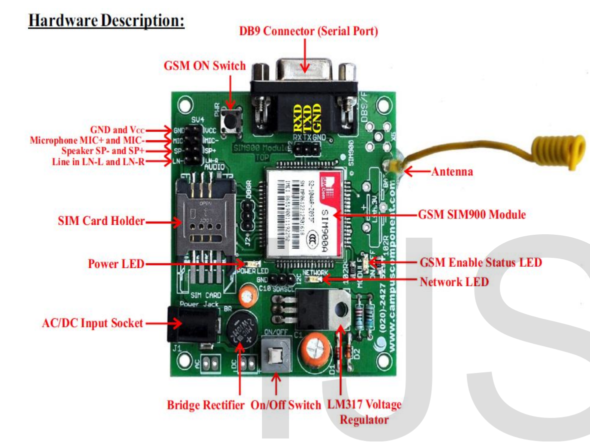

Figure 4: SIM 900 interfacing board

quid-band GSM/GPRS solution [20]. Featuring an industry standard interface, the SIM900 delivers GSM/GPRS 850/900/1800/1900 MHz performance for voice, sms, data and fax in a small form factor and with low power consumption. SIM900 is designed with a very powerful single chip processor, integrating AMR926EJS core [20].

The Universal Asynchronous Receiver Transmitter (UART), on-chip resource of the smart fusion device A2F200M3F is configured and deployed to interface the GSM module. For initialization of GSM modules, the standard AT commands are required which are executed through the cSoC device under development.

The schematic of the circuit:

The schematic of system, designed to ensure GSM based communication and VLSI based design for sensor node is depicted in figure 5. The necessary primitives are configured and integrated into one single chip.

Using on-chip signal conditioning features of SmartFusion device, the mixed signal based System-on-Chip is designed, wherein the temperature sensor (LM35) are directly interfaced to the SmartFusion device. As depicted in figure 5, the sensor is powered with +5V supply. The output of the sensor is in the voltage form. Therefore, this signal is given to the Active Bipolar Prescaler (ABPS) block, which is voltage monitoring block of the SCB of SmartFusion device. The output of temperature sensor is given to the ABPS of SCB1. The ABPS is an analog block, which is composed

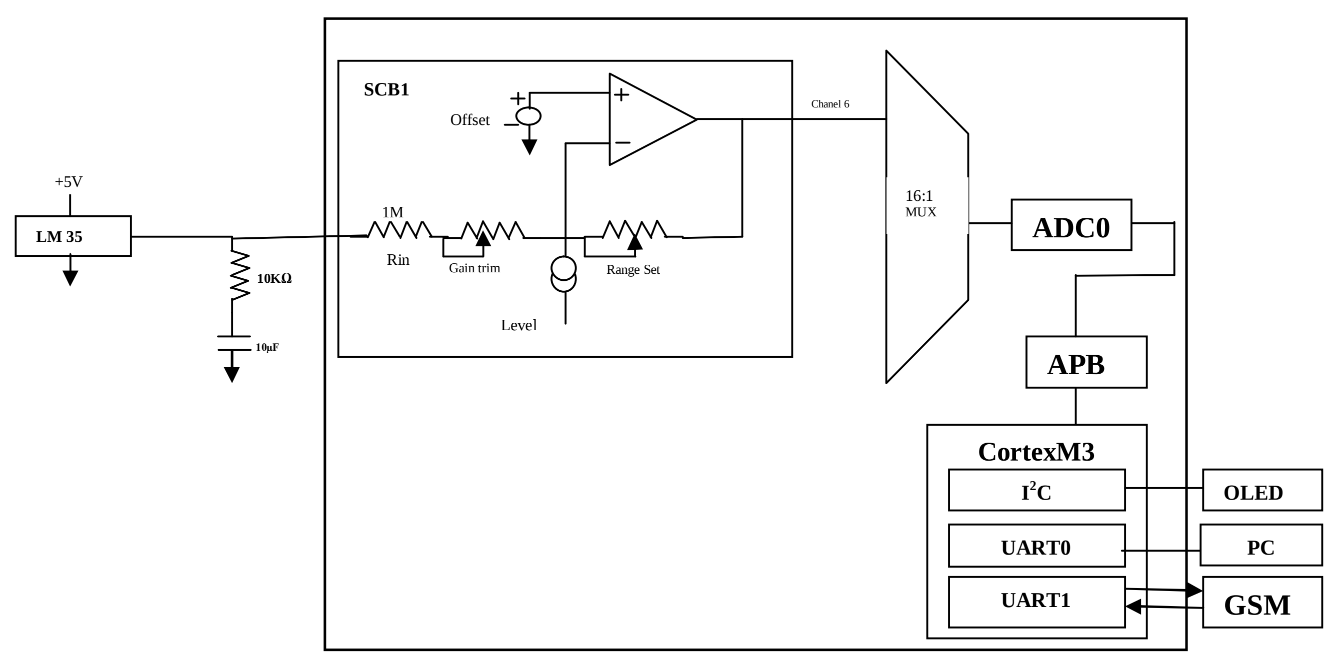

Figure 5: Schematic of the circuit designed for remote temperature monitoring.

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 [21]. Accordingly, the gain of this prescaler can be automatically configured. For present system, the gain is set to prescaler input range ±5.12V. This supports to realize the deployment of ADC of 8 bit resolution. The output of prescaler is given to the analog multiplexer, exhibiting 16-channels, of ADC0. Out of 16 channels the Channel 1 and 2 are used for ABPS input of SCB1. The channel 3 and 4 can be used for current and core temperature monitoring [21]. Channels 5 and 6 are availed for ABPS output of SCB1 and channels 7 and 8 are for current and core 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 [22]. For present system, the channel 6 (pin ABPS3) is used for interfacing of temperature dependent signal. The output of this multiplexer is given to ADC0, which is based on the principle of Successive Approximation (SA) technique. ADC0 gives the digitized output. As the SmartFusion device consists of two ADCs, out of which the ADC0 is used for digitization of temperature related signals.

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 isolate Cortex-M3–based Microcontroller Subsystem (MSS) from Analog part of the system. Through, Advanced Peripheral Bus (APB), the digital output of ACE is given to microcontroller subsystem for processing the data.

The present system emphasizes, the development of mixed signal based System-on-Chip by employing SmartFusion Technology. It ensures the philosophy of co-design of both the hardware and software, wherein the tools provided by microsemi are subsequently deployed. The IDE, Libero SoC from microsemi is used to configure the on-chip resources. The LiberoSoC integrates Sinplify ProAE for synthesis, Modelsim for simulation and SoftConsole for application code development. Moreover, following SinplifyProAE the system is designed on chip. This realizes the RTL level design of the system under investigation. In the beginning, the hardware part for present system is designed and configured as per the need. Figure 6 depicts the actual system designed on the chip A2F200M3F.

To identify the correctness of the design the tool, Modelsim is deployed for simulation of the operation. The generated PDB and STAPPLE files are programmed into targeted device.

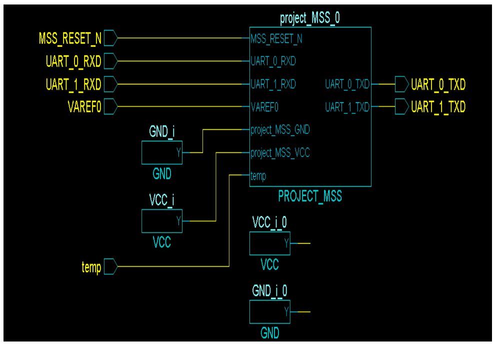

Figure 6: View of the circuit synthesized by adopting LiberoSoC on the chip A2F200M3F

The Software:

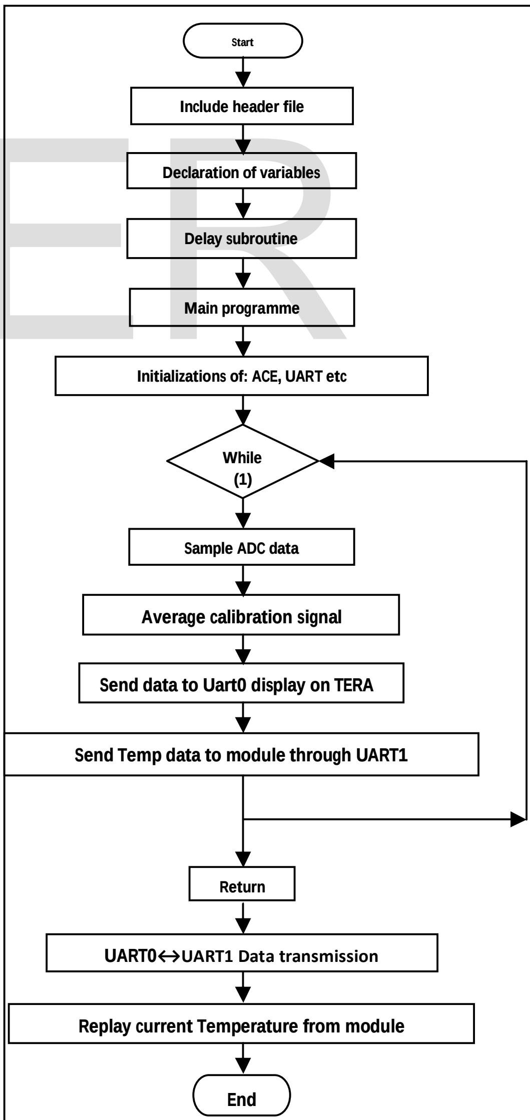

Figure 7: Flow chart

On successfully design of the hardware part on the system, the application code is developed for which the IDE SoftConsole is deployed. The firmware required for synchronization of hardware and for data processing to real unit is developed in embedded C environment using SoftConsole and required Attention (AT) commands for communication between GSM module and cSoC device, are used in software. Figure 7 depicts the algorithm of the firmware.

Deploying FlashPro programmer the device is programmed with .Hex file. Thus, the system-on-Chip is co-developed for remote monitoring of temperature. Thus, based on SmartFusion technology, the development board vendored by microsemi USA is deployed for present embedded design.

III. Result and Discussion:

To realize analog and mixed signal (AMS) VLSI based system on chip designing for agricultural applications, the hard as well as soft cores of the SmartFusion device A2F200M3F are reconfigured by employing the respective IDE. Moreover, the firmware is also developed in softconsole, wherein embedded C is employed. Thus, emphasizing philosophy of embedded technology, the system is designed to monitor the temperature of the polyhouse environment. As discussed earlier, the present embedded system depicts typical node of WSN designed for dedicated applications. The results of calibration of the node and implementation of the same are also discussed.

a) Calibration for Temperature:

Calibration is the key point of the instrumentation. Therefore, one must look for the precise and accurate calibration to the engineering units. That means, the temperature must be observed in °C. For calibration of the system to temperature, scale following procedure is adopted.

The present system under investigation produces the signal in mV. Therefore, in the beginning temperature dependent voltage (V_t) is measured in mV for various temperatures from room temperature to 90 ^{O}C. The temperature of the heater is measured by standard digital thermometer. At room temperature, the output voltage observed is 29.80 mV and 82.80 mV at 89 ^{O}C. The temperature dependent emf (V_t) are plotted against temperature (t) and depicted in figure 8. Following the process of regression, the empirical relation obtained is

$V_t = 0.938\, t_{obs} - 1.604$ ---------------------------- 1

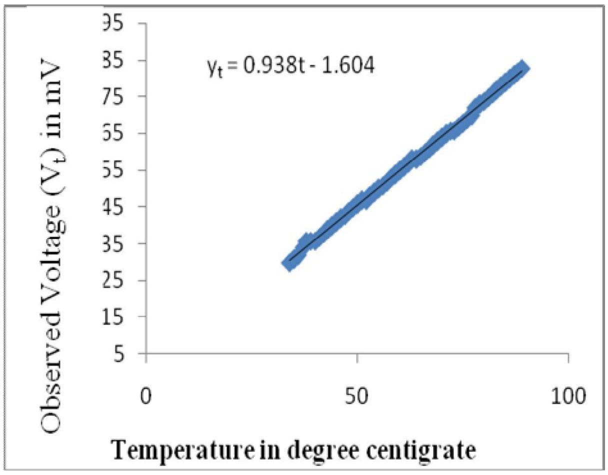

Figure.8 Graph of observed emf (Vt) against applied temperature (t).

Figure 8, reveals the linearity of the system. The offset of 1.604 mV may be due to analog part of the design. However, it is compensated through software. The slope of graph can be attributed to the temperature coefficiant (α) (1 mV)/ ^{O}C of the LM 35. However, the α value estimated for present system is 0.938, which found closely match with the standard α value Therefore, observed temperature ` $t_{obs}$ ` is given by

$t_{obs} = (Vt+1.604) /0.938$ ------------------------ 2

This expresion is employed in the software for processing. On programming of the device by porting the firmware into target device, the system is designed. Thus, designed system is implemented in the laboratory for measurement of temperature from 30^{o}C to 90^{o}C. The temperature is also measured by standard digital thermometer.

b) Implementation of system:

For performance validation, the system is implemented in the beginning for measurement of temperature of the internal environment of the chamber. The data regarding the temperature shown by the system under investigation and that of given by the standard digital thermometer are recorded. The temperature is varied from room temperature to 90 ^{O}C and data is presented in table 1.

On inspection of above table 1, it is observed that, the temperature observations shown by the present system reveal good agreement with that of the given by standard digital thermometer. It supports the validation of the design. The system on chip (SoC) designed and integrated on chip depicts good performance and reliability.

Table.1: Temperature shown by system under investigation and that of by standard digital thermometer

Temperature shown by digital Thermometer in ^{0}C	Temperature shown by System under investigation in ^{0}C
31.00	31.35
35.00	35.61
40.00	40.01
45.00	45.21
50.00	50.54
55.00	54.80
60.00	59.07
65.00	65.46
70.00	69.73
75.00	75.00
80.00	80.32

On confirmation of validation of the design, the system under investigation is implemented for monitoring of the temperature of the polyhouse environment. For experimentation, the system is kept at typical location wise. Experimental arrangement is shown in figure 9a. The system operates in hand shaking modes. It is known that, the GSM module interfaced to the PSoC works to establish the communication with the registered mobile phone.

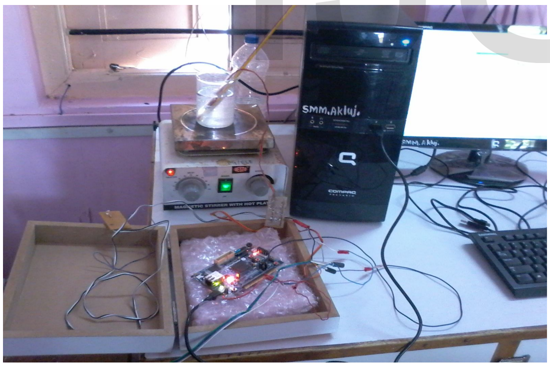

Figure 9a: Experimental setup to design SoC under investigation.

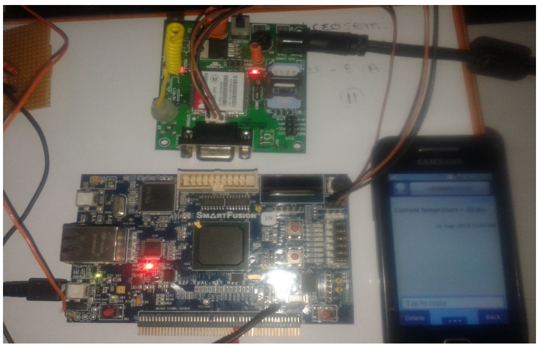

Figure 9b: Implementation for monitoring of Temperature

The temperature of the polyhouse is continuously monitored. However, to obtain the same on mobile phone, the request message is to be send through mobile. In response to the message the information related to current temperature, present in polyhouse, is send through return message shown in figure 9b. The present system is configured in event driven mode instead of continuous polling mode. Therefore, it helps to save power, reduce the expenditure of messaging and bandwidth of mobile network as well. The data is communicated only to the registered mobile device. Therefore, it helps to ensure the proper security in the data communication. The present system helps the farmers to obtain data of polyhouse from distant location as well. Moreover, such nodes, if interfaced with the Zigbee devices, realizes the establishment of the wireless sensor Network and collects the data of entire polyhouse at the base station, where smart co-ordinator is interfaced to the PC. The Co-ordinator collects the data transmitted by end device. This co-ordinator may work as cluster head and communicating the data to mobile phone. Therefore, the farmers can obtain data regarding environment of the entire polyhouse on the registered mobile phones. Thus, the present system reveals good application potential in agriculture sector.

IV. Conclusion:

The mixed signal technology based wireless sensor node, to ensure mobile monitoring of the WSN is successfully designed by deploying Smart Fusion device A2F200M3F and the GSM module for polyhouse application. The use of smart sensor LM 35 enhances the reliability and accuracy. Realizing reconfigurability, both hardware and software are co-developed for present system on chip. The GSM module SIM900 is used to ensure long distance communication and secure data transmission. The system is calibrated with respective its engineering unit ^{O}C. The results of implementation of the system under investigation show close match with that of given by the standard digital thermometer. This confirms the validation of the design of both hardware and software for dedicated application.

V. Acknowledgement:

One of the author S. C. Pathan wish to thanks, Tim McCarthy, Worldwide Training Manager, Microsemi SoC Products Group for support to the research work.

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