Development of Smart Fusion Technology Based Customizable System-on-Chip For Monitoring of Polyhouse Parameters

S. S. Shaikh, S. C. Pathan, P. V. Mane-Deshmukh, S. K. Tilekar and B. P. Ladgaonkar

Abstract- Indeed, the development of mixed signal (Analog+digital) based System-on-Chip (SoC) for dedicated application is an ubiquitous field. Moreover, in the field of VLSI design the Smart Fusion technology is emerged, which introduces the configurable analog cores along with customizable digital cores. Employing SmartFusion device from Microsemi USA, the A2F200M3F, the mixed signal based System-on-Chip is designed for monitoring of environmental parameters of polyhouse, where crops are cultivated in precisely controlled environment. Deploying dynamically reconfigurable resources of A2F200M3F, such as Analog Compute Engine (ACE), Signal Conditioning Block (SCB) etc, the Signal Conditioning stages for respective signals are designed. The analog front end (AFE), of the device provides ultra high input impedance, which helps to read the analog signals, very precisely. Moreover, on deployment of on-chip ADC and configuration of the same to 10 bit realizes the enhancement in the resolution. The device comprises ARM CortexM3 as a processing core, which ensure the 32 bit processing capacity. This results into increase in the processing speed with low power consumption. An IDE Libero SoC is used for design and customizing of hardware of System-on-Chip, whereas the firmware is co-designed by employing SoftConsole vendored by microsemi. To measure environmental parameters of polyhouse, the sensors such as SY-HS-220(Humidity), LM35 (Temperature) and BPW34 (Light intensity) are deployed. The system is calibrated and standardized to respective engineering unit. The results of implementation exhibit the high preciseness and reliability of the system.

Keyword- SmartFusion, System-on-Chip, Mixed signal based VLSI design, reconfigurability, agricultural parameters.

1 INTRODUCTION

Development of System-on-Chip for dedicated application is the revolutionary field of VLSI design. During early days, the reconfigurability was constrained for digital design, wherein the resources of programmable devices such as FPGA and CPLD etc are deployed [1, 2]. Azim-sadjadi et al [3] described the implementation of FPGA to design system to investigate sound signal in localized domain. They designed five analog paths that realize the off-chip design. For digitization of the signal they employed ARM SA1100 processor and Xilinx XC4000XLA FPGA to ensure digital design. Nguyan et al [4] have designed analog front end, comprising signal conditioning and data acquisition system, whose outputs are processed by FPGA. Thus, during early days, an electronic instrumentation ensures the System-on-Board (SoB) design, wherein required primitives are wired on a board [5-11]. However, due to advancements in the integration technology, the field of System-on-Chip (SoC) is evolved [12]. The System-on-Chip comprises reconfigurable soft as well as hard cores, on configuring which one can design highly sophisticated, reliable, low power and low cost electronic system for dedicated applications [13]. It is known that, the real world is full of analog signal and to undertake these analog signals the embedded designers deploy analog devices along with the digital device and processing cores [14]. Therefore, to cater this need, recently, analog and mixed signal (AMS) based Programmable System on Chip (PSoC) are launched by various vendors across the world. The mixed signal based PSoC comprises reconfigurable analog as well as digital primitives, processing cores of either 8-bit or 32-bit philosophy, memories and clock sources [15]. Availing the facilities of such PSoC devices, a smart embedded system with great reliability can be designed for dedicated application. It is found that, the Actel, USA has done pioneering job in the field of SoC. However, the PSoC devices, PSoC1, PSoC3, PSoC5 from Cypress Semiconductors, USA and Smart Fusion technology based customizable System-on-Chip (cSoC) of Microsemi, USA etc are becoming the milestones in the

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progressive development in the field of mixed signal VLSI design [16]. Deploying a mixed signal based programmable System-on-Chip (PSoC), the Umbarkar et al have designed a System-on-Chip for investigation of localization of sound [17]. The features of programmable system on chip, the cost, the power, area, and performance etc are investigated by Bissi et al [18]. They investigated the effect of offset voltage exhibited by analog blocks of mixed signal based PSoC. They attributed their results to features associated with the respective analog blocks. In addition to analog blocks, the configurable data converter blocks are also playing vital role in mixed signal based System-on-Chip design. Most of the PSoC provides delta sigma modulater based ADC as well as DAC who provides the configurable resolution also [20]. Deploying Smart Fusion technology, the Microsemi has designed customizable System-on-Chip (cSoC), A2F200M3F, wherein along with analog competing engine and digital cores, the ARM CortexM3 processor core etc are introduced [19].

It is found that, in addition to, the industrial, research and development (R&D) and medical etc sectors, the agriculture sector is also leading towards modernization, which results into the field of precision agriculture. The precision agriculturists are demanding small, reliable and low cost electronics system to provide precisely controlled environment to the crops. An ubiquitous field of mixed signal development with SmartFusion technology can provide suitable solution for precision agriculturist.

Employing the smart fusion device A2F200M3F, a mixed signal based cSoC, an embedded system is designed to measure temperature, humidity and intensity of light of polyhouse environment and results of the implementation are interpreted in this paper.

2. Analog and mixed signal based embedded system for polyhouse application:

2.1 The System Architecture:

This paper emphasizes the designing of an embedded system, wherein the principle of mixed signal (analog + digital) based VLSI design is employed. According to the salient features, an embedded system comprises both hardware as well as firmware, which help to synchronize the operation of the system. Both hardware and software are designed and details regarding their design are illustrated through following two points.

- The Hardware
- The Software

2.2 Hardware:

Analog and mixed signal technology of VLSI design exhibits commendable growth, wherein analog as well as digital cores are reconfigured. For designing of such system a VLSI device of great reconfigurability is needed. Present system is developed about SmartFusion technology based customizable System-on-Chip (cSoC), A2F200M3F, from Microsemi, USA. The organization of the system is depicted by the block diagram shown in figure 1. As shown in figure 1 the system under design consists of

1. Sensors Array
2. Customizable System-on-Chip (cSoC) device
   - Programmable Analog devices
   - Microcontroller SubSystem (MSS)
3. Display unit

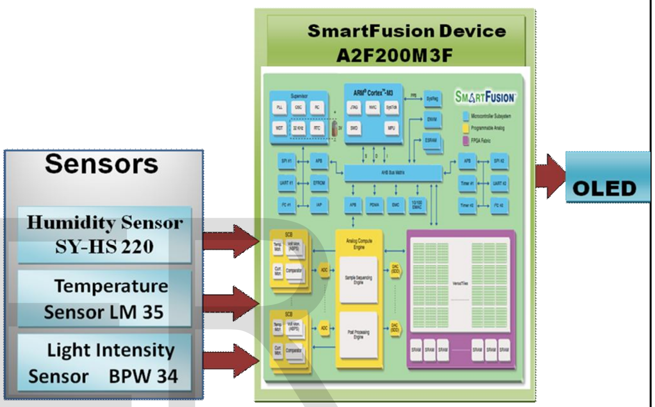

Figure1: Block Diagram of the System-on-Chip designed to monitor polyhouse parameters

2.2.1 Sensors Array:

For polyhouse, the environmental parameters such as humidity, temperature, intensity of light, gas concentration etc should be essentially monitored. To measure these parameters, the sensors of promising characteristics must be used. For this purpose an array of sensors, comprising the good quality sensor such as humidity sensor (SY-HS-220) module, Temperature sensor (LM35) and light intensity sensor (BPW34) is designed. These sensors are externally interfaced to cSoC device. The output of respective sensor is given to cSoC device for further processing. The design issues of each part of this sensor array are described.

a. Humidity Sensor (SY-HS-220):

To measure humidity, amount of water molecules dissolved in the air of polyhouse environment, a smart humidity sensor SY-HS-220 [20] is used for the designing of the present system. The humidity sensor SY-HS-220 is shown in the figure 2. On close inspection of figure 2, it is found that, the sensor module consists of humidity sensor along with signal conditioning stages. The humidity sensor module consists of sensor elements of capacitive type and comprising on chip signal conditioner as well. However, it is mounted on the PCB, which also consists of other stages employed to make sensor module rather smarter. 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 [20]. As shown in figure 2, it provides three pins for interfacing, blue (B), white(W) and red(R).

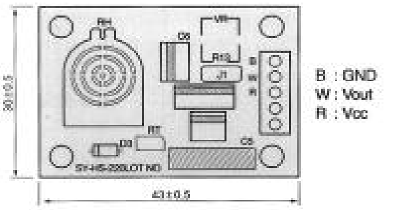

Figure 2: Schematic of Humidity Sensor module SY-HS-220

The W pin provide DC output, B is the ground. The module works with +5 Volt power supply given at pin R. The humidity dependent voltages are measured and send to SmartFusion device for further processing. To ensure the development of System-on-Chip, only the humidity sensor module is off-chip. Rest of the primitives of analog part are designed in the System-on-Chip by customizing the respective resources of the SmartFusion device.

b. Temperature Sensor (LM35):

Basically, monolithic temperature sensors exhibit promising characteristics. Therefore, they play vital role in enhancing the accuracy and preciseness of the system. Such temperature sensors provide the output voltage, which is directly proportional to respective temperature scales. The monolithic temperature sensors available are LM135, LM235, (10 mv/oK), LM34 (10 mv/oF) and LM35 (10 mv/oC). These devices are available in hermetic TO-46 transistor packages [21].

The temperature sensor LM35 is used for proposed system for sensing temperature. It is precision integrated-circuit temperature sensor whose output voltage linearly proportional to the degree Celsius temperature scale. Figure 3 shows the temperature sensor LM35, which has an advantage over the temperature sensors having temperature coefficient in mv/oK, because if temperature coefficient is mv/oC then the complexity of scale conversion is minimised. The LM35 does not require any external calibration for trimming [21]. It draws only 60μA current from its supply, it has very low self-heating, less than 0.1 oC in air. Therefore, it is suitable for environmental temperature measurement.

Figure 3: Temperature Sensor (LM 35)

In proposed system sensor used operates with single +5V power supply. However it can be used with dual plus and minus supply and it can operate on 4V to 30V. The 18Kohm resistor at load wired to provide typical accuracy over full -55 oC to +150 oC temperature range [21]. The temperature dependent voltage is measured and given to the ABPS3 pin of the SmartFusion device for further signal conditioning and processing. As discussed earlier, use of temperature sensor off the chip, realizes the design as well as customizing of System-on-Chip.

c. Light intensity Sensor (BPW34):

Figure 4 shows the light intensity sensor BPW 34. The sensor BPW34 is a PIN photodiode with high speed and high radiant sensitivity. It is sensitive to visible and near infrared radiation and the angle of half sensitivity is ± 65° [22]. Moreover, it is also found that this sensor is more sensitive to sunlight than other light sources. The present light sensor has direct type semiconductor material as sensing element. Therefore, the current in micro ampere flowing through this sensor is linearly dependent with intensity of light. Therefore, for proposed system 1K Ohm register in figure 7 is used at output of sensor to achieve output in voltage (mv) form. Light intensity dependent voltage is measured and given to ABPS7 pin of SmartFusion device for further process. The required analog part is design in System-on-Chip.

Figure 4: Light Intensity Sensor (PIN Diode BPW 34)

2.2.2 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 mixed signal FPGA is first introduced in fusion technology in which in addition to FPGA, the programmable analog blocks, configurable digital cores and soft processor cores are available. 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 fast system development time. It provides platform for both embedded and VLSI developers. For present system the SmartFusion A2F200M3F device from microsemi is used.

Figure 5 depicts the architecture of SmartFusion A2F200M3F device. It combines three main parts.

A. Programmable Analog block
B. Microcontroller SubSystem
C. FPGA fabric.

The architectural details of these parts are briefly discussed. An implementation of these parts is also described in this section.

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) and analog to digital converter (ADC), ∑∆ Digital to Analog Converter (DAC) and high performance analog Signal Conditioning Block (SCB) [24]. It is known that, to interface real analog signal to any sophisticated processing unit, one has to deploy the analog devices like operational amplifier and extract desired analog signal. The first part of analog devices work at front end to interface the signal [24]. Therefore, this block is referred as Analog Front End (AFE) device [24]. This AFE performs the task of signal conditioning. It also helps to ensure offset compensation. This signal conditioning block can also be configured to adjust the gain of amplifier. The reconfiguration of various parameters of this block results into enhancements in the sophistication of proposed system on chip design. This core of the 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 can be configured for 500ksps to 600ksps mode with 2.56V internal reference voltage [24]. The analog Signal Conditioning Block (SCB) is coupled to the analog to digital converter. The Analog Computing 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 [25].

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 cores along with the comparator core.

B. Microcontroller SubSystem (MSS):

In addition to customizable analog as well as digital cores, the SmartFusion device consists 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 debug. It includes Memory Protection Unit (MPU). It has single cycle multiplication instruction and exhibit multiply and accumulate operation as well. Moreover, the hardware component like barrel shifter ensures the deployment of hardware cores for fast mathematical functions. It provides debug facilities with JTAG and serial wire. The MSS also has single wire viewer, which facilitate the developers to look inside hardware for improving system performance and easy to trace error in system. 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 Microcontroller SubSystem (MSS) of SmartFusion also compose internal memory block, which includes embedded flash memory of 256 Kbyte and embedded high-speed SRAM of 64 Kbytes. It is implemented in two physical blocks to enable simultaneous access from two different masters. The SmartFusion device is composed of the on-chip clocking resources, 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.

In SmartFusion device based development board, vendored by Microsemi USA, the different sets of peripherals are also available, which includes the components such as 10/100 Ethernet MAC, UARTs, SPI, GPIO, Timers, clock resources, two I2C peripherals etc. As per need of system, out of two I2C one I2C peripheral is used for interfacing of Organic LED (OLED) based smart LCD 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 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.

2.2.3 Display Unit:

For electronic instrumentation, the design of display unit is the prime requirement. Traditionally, for alpha numeric display, the smart LCD of 16x2 lines is employed. However, it consumes rather more power sometimes the power consumption of LCD is significantly more than that of rest of hardware part. Recently, the organic materials of direct band gap have been investigated and deployed for synthesis of LED. These LED are therefore called as organic LED (OLED). In present system, instead of crystalline display the OLED display is employed. Figure 6 depicts the OLED based LCD. The OLED is thinner, lighter and more flexible than crystalline layer of LCD. It does not require backlight like LCD. A 9616-pixel low power OLED is made available on the development board for display. This low power device, BLUE OLED, requires 3.3 V power supply. The OLED is interfaced with the SmartFusion MSS using I2C port [26].

Fig 6: OLED based display

2.2.4: The schematic of the circuit:

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 schematic of the circuit synthesized in System-on-Chip is depicted in figure 7. As shown in figure 7, the necessary primitives are configured and integrated into one single chip.

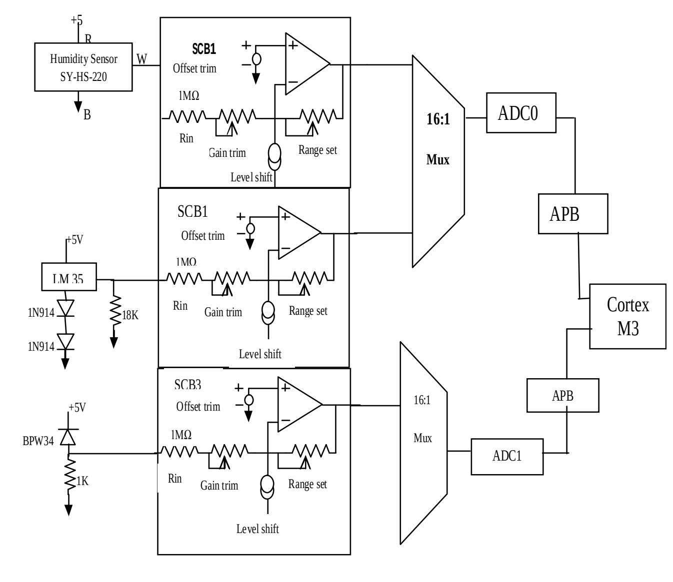

Figure 7: Schematic of the system-on-chip designed in LiberoSoC

Using on-chip signal conditioning features of SmartFusion device, mixed signal based System-on-Chip is designed, wherein the humidity sensor (SY-HS-220), temperature sensor (LM35) and light intensity sensor (BPW34) are directly interfaced to the SmartFusion device. The outputs of these sensors are in the voltage form. Therefore, these signals are given to the Active Bipolar Prescaler (ABPS) block, which is voltage monitoring block of the SCB of SmartFusion device. The output of humidity sensor and temperature sensor are given to the ABPS of SCB0. 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 [27]. 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 ADC0. 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 [27]. 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 [27]. For present system, the channel 5 and 6 (pin ABPS2 and pin ABPS3) are used for interfacing of humidity and temperature dependent signal. The output of this multiplexer is given to ADC0, which is based on the principle of Successive Approximation (SAR) technique. It gives the digitized output. An ADC1 is also having similar architecture. As the SmartFusion device consists of two ADCs, the ADC0 is used for digitization of humidity and temperature related signals. However, remaining voltage pins are used by the manufacturer, to monitor device parameters. Therefore, for measurement of third parameter, the intensity of light, the second ADC, the ADC1, is utilized. The light intensity sensor (BPW34) exhibits linear variation in the current with respect to the intensity of light. This current varying signal is converted into voltage and then interfaced. The output of this light intensity sensor given to ABPS7 pin of SCB3 and prescaler input range set to ±5.12V. Output of these ABPS is given to channel 6 of multiplexer and multiplexer output given to ADC1.

The output of both ADC, are 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 SubSystem (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.

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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 display unit and also sends to computer through UART. The firmware is developed for this dedicated application which configures and initializes the on-chip resources of the devices and computes the humidity, temperature and light intensity signal into %RH, oC and percentage respectively. The final system designed in Libero SoC shown in figure (9).

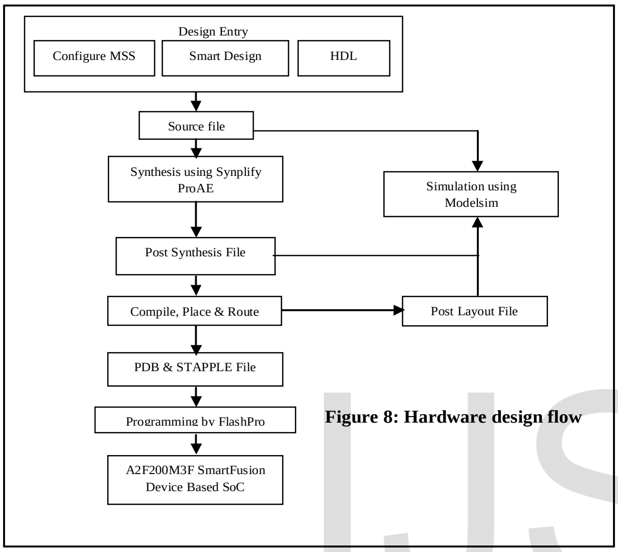

Figure 8: Hardware design flow

The configurable sophisticated electronic system comprises two prime components the hardware and firmware. 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, analog as well as digital cores, and the software, wherein the tools provided by microsemi are subsequently deployed. The IDE, Libero SoC from microsemi are used to configure the on-chip hardware cores. The LiberoSoC is true IDE, which 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. The flow used in present System-on-Chip design is depicted in figure 8. As presented in figure 1, in the beginning, the hardware part for present system is designed and configured as per the need.

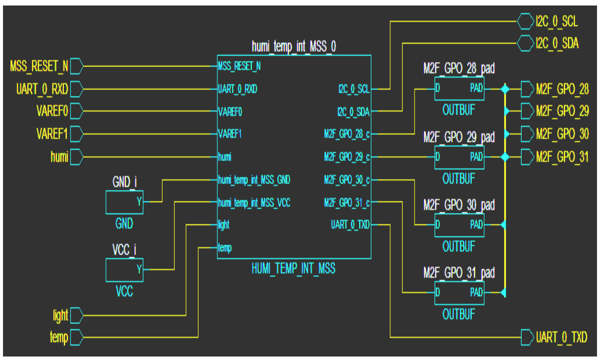

Figure 9: View of the circuit synthesized by adopting LiberoSoC on the chip A2F200M3F

Following the design flow of the IDE, Libero SoC, the System-on-Chip is designed for this dedicated applications. Figure 9 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 target device.

2.3 The Firmware:

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. Figure 10 depicts the algorithm employed for development of necessary firmware.

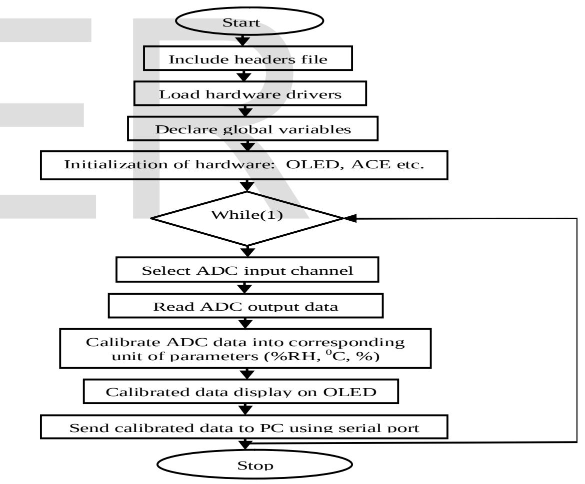

Figure 10: Firmware Design Flow

Deploying FlashPro programmer the device is programmed with .Hex file. Thus, the system-on-Chip is co-developed to monitor various environment parameters. Thus based on SmartFusion technology, deploying the development board vendored by microsemi USA, the cSoC is developed for polyhouse applications. Figure 11 is the photograph of actual system.

3. Results and Discussion:

Based on SmartFusion technology, a system is developed to monitor the environmental parameters of the polyhouse. figure 11 depicts system designed to monitor humidity, temperature and light intensity of polyhouse. The results of implementation of this system are discussed through three points.

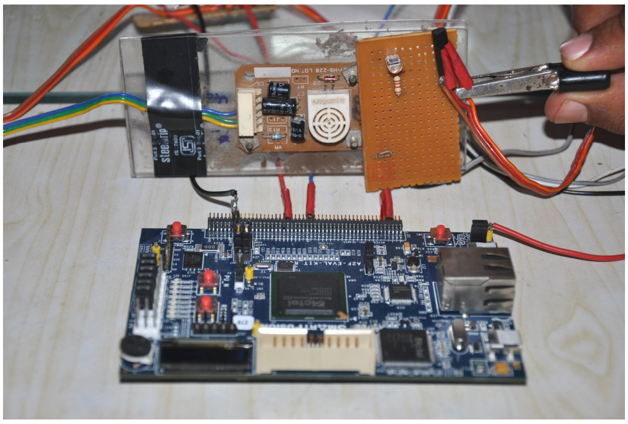

Figure 11 Photograph of actual system.

Figure 12: Photograph of the system under investigation exposed for calibration.

a) Measurement of the Humidity
b) Measurement of the Temperature
c) Measurement of Intensity of the light

3.a) Measurement of Humidity:

To measure humidity within polyhouse environment the smart sensor SY-HS-220 is employed. While designing of the hardware of the system, it is considered that the sensor produces the humidity dependent emf. Therefore, system must be calibrated to real unit, the RH%. At the beginning, the range of observed emf is decided, by measuring the same from normal room condition to the state of condensation of water. The analog part of the circuit is designed accordingly. Then the process of calibration and standardization is carried out.

Calibration:

For calibration, the humidity chamber, Gayatri Scintific Ltd. (India) is employed. Experimental arrangement is shown in figure 12.The humidity from 30 RH% to 95 RH% is applied for temperature range between 250C to 550C. By keeping temperature constant, the humidity in between 30 RH% to 95 RH% is applied to the sensor. The voltage (VRH) observed is plotted against humidity (H) in RH% and shown in figure 13. On inspection of figure 13, the calibration curve, it is found that, the observed emf exhibit good linearity with applied humidity within the range of investigation. Using least square fitting process, the standard regression process, the data is analyzed and fitted to straight line. The this regression process results into the expression

$$\text{Humidity (H) (RH\%)} = (VRH + 115.4)/32.56 \qquad 1$$

Where, VRH is the humidity dependent emf produced by the analog part of the system under investigation.

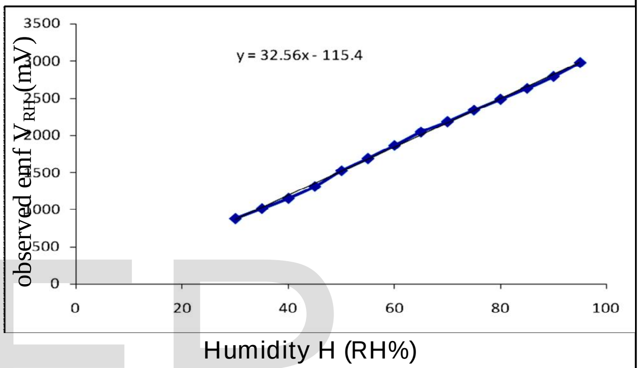

Figure 13: The graph of observed emf V_{RH} (mV) against humidity H (RH%)

Table 1: Humidity data shown by system under investigation and that of by standard meter

Humidity shown by the standard humidity chamber RH%	Humidity shown by the System under investigation in RH%
30.00	29.4
35.00	33.4
40.00	37.9
45.00	43.5
50.00	48.7
55.00	54.1
60.00	59.0
65.00	63.7
70.00	68.3
75.00	73.1
80.00	77.7
85.00	82.2
90.00	87.1
95.00	93.8

B) Measurement of Temprature:

As the temperature is significant parameter, which plays vital role on growth of the plants, its online monitoring is the need of hour. Therefore, ensuring mixed signal based design by fusion technology, the system is designed for measurement of the temperature. For calibration of the system to real unit, the degree celcius, the temperature dependent emf (VT) is measured and plotted against temperature from 25oC to 95oC. The calibration curve is depicted in figure 14. On inspection of figure 14, it is found that the system exhibits good linearity for temperature. By adopting process of regression, the empirical relation obtained is

$$VT = 10\, tobs + 41 \quad 2$$

Therefore, observed temperature ` tobs ` is given by

$$tobs = (VT - 41)/10 \quad 3$$

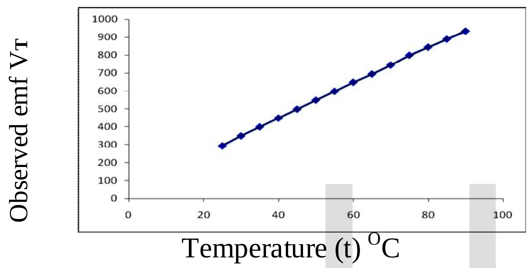

Figure 14: Observed emf (V_T) in mV against Temperature t in °C

Table 2: Temperature shown by system under investigation and that of by standard digital thermometer

Temperature shown by the standard digital thermometer in °C	Temperature shown by the System under investigation in °C
25.00	24.70
30.00	30.20
35.00	35. 20
40.00	40. 30
45.00	44. 20
50.00	50. 40
55.00	55. 30
60.00	60. 20
65.00	65. 20
70.00	70. 30
75.00	75. 20
80.00	80. 30
85.00	85. 40
90.00	90. 20
95.00	95. 20

his expression 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 for measurement of temperature of the closed environment from 25^{0}C to 95^{0}C the range of investigation. The temperature is also measured by standard digital thermometer.

The temperature shown by standard digital thermometer and that of shown by the system under investigation are presented in table 2. From table 2, it can be said that the temperature values depicted by the system under investigation show close agreement with standard data.

C) Measurement of Light Intensity:

The light intensity, amount of light energy falling on the crops plays vital role on crop growth. The photosynthesis process is always taking place in presence of sun light. Therefore, measurement of sunlight intensity is important. In present system the Sun light intensity is measured for different time domains in open environment and data regarding intensity of light is recorded. In fact, the light intensity is measured in unit of Lux. However, at present the system is calibrated to relative unit, the percentage. The emf (Vd) shown by the system for full dark is recorded. Deploying voltage compensation techniques, the Vd is compensated to zero volt. Further, the emf (Vb) for full bright sun is recorded. It is supposed to be maximum. These, emf values are used for calibration. The intensity of light, percentage, is given by

$$L\,(\%) = (Vi/Vb) \times 100 \quad 4$$

Where, Vi is the instantaneous emf observed for light intensity of polyhouse environment.

Thus the present System-on-Chip is calibrated to standard units and the designed system is implemented to ensure polyhouse application.

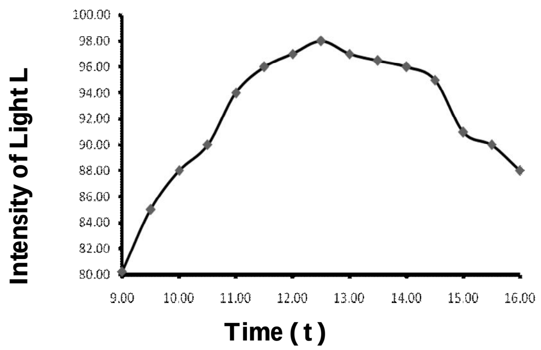

Figure 15: Intensity of light L (%) against time (t)

The system under investigation is implemented to measure intensity of sun light entered into polyhouse. Light intensity of internal environment of polyhouse is measured in percentage unit during day time from 9.00 am to 4.00 pm The graph of light intensity, L, (%) against time (t) is depicted in figure 15. On inspection of the figure 15, it is found that, mixed signal based system on chip designed for measurement of light intensity of polyhouse environment, provides the data with great precision.

CONCLUSION

Emphasizing the revolutionary technology, smart fusion based system-on-chip design, the system is designed for precision agriculture and implemented for measurement of environmental parameters of polyhouse. Realizing reconfigurability, both hardware and software are co-developed. The system is calibrated to respective units. The present system designed for measurement of relative humidity, temperature and light intensity of polyhouse environment. 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. Results obtained from on line implementation reveal the reliability of the system.

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