

Design and Development of Mixed Signal Based SoC using SmartFusion Device for Wireless Sensor Network for Precision Agricultural (PA) Application

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Abstract: Farming has significant role in the progress of human development. Modern agricultural techniques are being used to multiply food production in order to increase food productivity. The agricultural sector is rapidly changing, with a focus on technological farming. Demanding labours are required for continuous monitoring and control of plants located in various locations. It is technically difficult to manage labour and financial profit. New technologies such as Wireless Sensor Network (WSN)

play an important role in modern agriculture in order to achieve this goal. Designing of Node using modern VLSI devices like PSoC and cSoC are low cost, low power and reliable. Based on ZigBee technology nodes in the agricultural field can communicate with the router or coordinator over a long range. The number of deployed sensor nodes and router will be increased to cover the entire field area under investigation.

Key Words: WSN, ZigBee, PSoC, cSoC etc.

1. Introduction:

Recent advancements in Wireless Sensor Network (WSN) technology demonstrate a broad range of applications in a variety of fields. WSN application scenarios include health monitoring, environmental monitoring, tracking, soil parameters monitoring, physical parameters monitoring and industrial parameter monitoring etc.. The present research work emphasizes the design and development of Wireless Sensor Network for monitoring of parameters of high tech agriculture. The WSN may provide suitable solutions to realize precision agriculture, wherein the crops are cultivated in precisely controlled environment [1]. According to the definition the WSN is systematic infrastructure of wirelessly linked Wireless Sensor Nodes [2]. The numbers of technologies have been reported by various researchers and many of them rely on embedded technology, in which the entire system reveals the system on board (SoB) design features [3]. However, recently, a technology, wherein the philosophies of System-on-Chip (SoC) design is emerging [4]. Therefore, to design hardware part of the Nodes the technology of System on Chip (SoC) design can be availed. Recently, Analog and Mixed Signal (AMS) based Programmable System of Chip design is becoming more pervasive [5]. PSoC and cSoC represents a whole new concept in system development. The integration of

microcontroller, Programmable analog blocks and configurable digital blocks allow realization of single chip solution for embedded system design [6].

2. Designing of Wireless Sensor Node:

Considering various features such as smartness of computing cores, static as well as dynamic configurability, analog and digital cores, configurability of communication interfaces, features of analog interfaces, input impedance of analog cores etc, the SmartFusion based customizable System on Chip (cSoC) device used for development of hardware. According to the salient features WSN and satisfying IEEE standards of wireless communication, the wireless sensor nodes have been developed about ZigBee device.

2.1 Block Diagram of Wireless Sensor Node:

The architectural view of the wireless sensor node is depicted in the block diagram shown in figure 1. Figure 1 is composed of three parts wired together to ensure the standards of IEEE 802.15.4 [7] These are

- A. Analog Sensing Unit
- B. SmartFusion A2F200M3F, the customizable System-on-Chip (cSoC) device.
- C. Radio Communication Interfaces (RF Section)

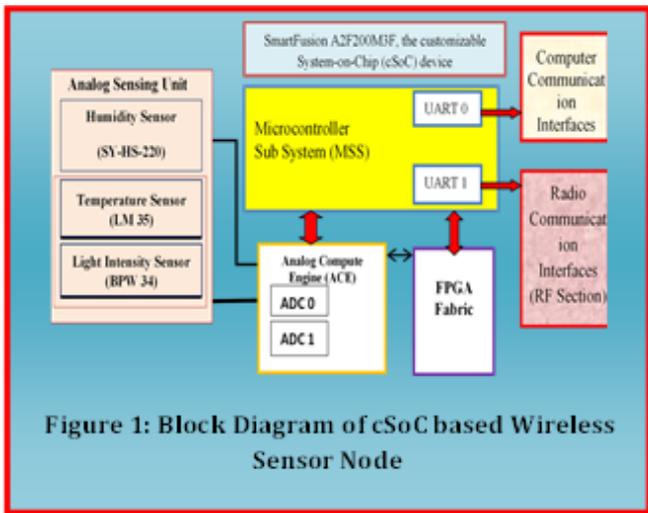


Figure 1: Block Diagram of cSoC based Wireless Sensor Node

To sense the information about physical world an analog sensing unit is developed. It comprises an array of the sensors to read the environmental parameters such as temperature, relative humidity, light intensity etc, within polyhouse. The second part plays the role of analog as well as digital computation. It is developed about Microsemi, USA based cSoC device SmartFusion A2F200M3F. The third part is realizes the themes of RF communication interfaces. This is wired about a smart RF module, the ZigBee, which operates in the region of 2.4GHz in ISM band [7]. The details regarding designing issues of each of above parts of the Nodes are discussed though subsequent points.

A) Analog Sensing Unit:

The system is designed for polyhose applications realizing high-tech agriculture, the environmental parameters such as humidity, temperature, intensity of light etc should be essentially monitored. Deploying the selected sensors, an array of sensors is designed, wherein humidity sensor (SY-HS-220) module, Temperature sensor (LM35) and light intensity sensor (BPW34) are united. These sensors are externally interfaced to cSoC device. The output of respective sensor is given to cSoC device for further processing.

a) Relative Humidity (RH%) Sensing circuit:

On extensive study of the available sensors, the humidity sensor SY-HS-220 [8] has been selected for the present system design. The circuit designed for relative humidity monitoring is shown in figure 2. This SY-HS-220 Sensor module provides DC voltage in proportion with relative humidity in %RH. Typically, the module exhibits current consumption less than 3 mA, operating humidity range is 30% RH to 95% RH, accuracy is ± 5% RH at 25°C. As shown in figure 2, the sensing unit provides three pins for interfacing, Blue (B), White (W) and Red(R). The W pin provide DC output, B is the ground and red (R) is VCC. The module works with +5 Volt power supply given at pin R. The humidity dependent voltages are extracted and send to SmartFusion device for further processing. Rest of the

primitives of analog part are designed in the System-on-Chip by customizing the respective resources of the SmartFusion device.

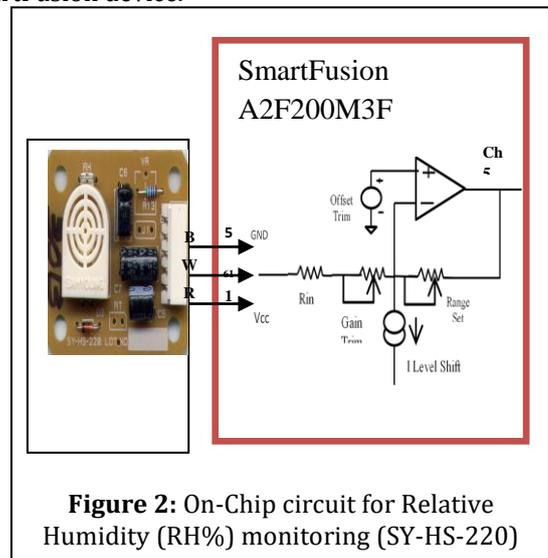


Figure 2: On-Chip circuit for Relative Humidity (RH%) monitoring (SY-HS-220)

b) Environmental Temperature (°C)

Sensing circuit:

One of the major parameter affecting crop growth is the temperature. The temperature sensors such as PT100, AD590, LM35, fiber optic temperature sensor etc. are studied. Emphasizing preciseness and cost effectiveness, the temperature sensor LM35 is selected for present design. Basically, monolithic temperature sensors exhibit promising characteristics [9]. It is precision integrated-circuit temperature sensor, whose output voltage linearly proportional to the temperature in degree Celsius. Figure 3 shows on chip circuit arrangement to interface the temperature sensor LM35. In present system the temperature dependent analog voltage generated from LM 35 is applied to the SoCABPS3 pin of the SmartFusion device for further signal conditioning and processing.

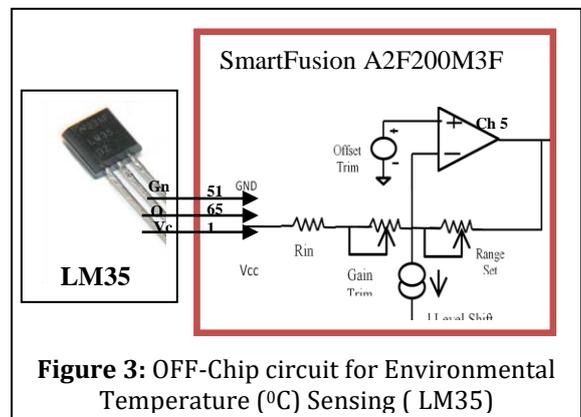


Figure 3: OFF-Chip circuit for Environmental Temperature (°C) Sensing (LM35)

c) Intensity of Light Sensing circuit:

Solar radiation (light and heat) are producing the largest impact on the growth of the crop. Therefore, it should be monitored. For present system, sensor BPW34 is deployed as a intensity of light sensor. The

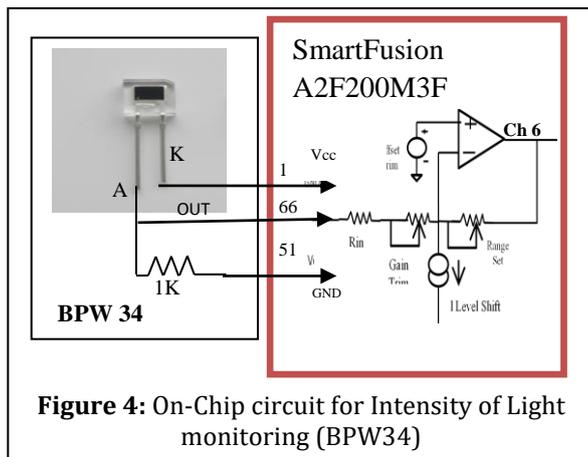


Figure 4: On-Chip circuit for Intensity of Light monitoring (BPW34)

BPW34 is a PIN photodiode based on very lightly doped n-silicon. Figure 4 shows the required on-chip circuit for light intensity sensor BPW 34. It is sensitive to visible and near infrared radiation and the angle of half sensitivity is $\pm 65^\circ$ [10]. Moreover, it is also found that, this sensor is more sensitive to sunlight than other light sources. As shown in figure 4, 1K Ohm register 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 configured on the System-on-Chip.

Thus, analog Sensing Unit, comprising an array of sensor, produces analog signal respectively for three parameters and these signal further given to cSoC device A2F200M3F for further processing of data and communication of the same to the base station as well.

B) SmartFusion A2F200M3F, the customizable System-on-Chip (cSoC) device:

Smart Fusion device mainly consist three parts

- Analog Compute Engine (ACE)
- Microcontroller Subsystem (MSS)
- FPGA Fabric

a) Analog Compute Engine (ACE)

Signal conditioning and offset compensation are carried out by this function. The reconfiguration of this block's various parameters results in a sophisticated system on chip design. Analog blocks play important role in the process of system calibration in the engineering unit. The cSoC based on SmartFusion technology includes an ADC with reconfigurable resolutions of 8, 10, and 12 bits, as well as two different clock sources and it can be configured in three modes for 500ksps, 550ksps and 600ksps with 2.56V internal reference voltage. The analog Signal Conditioning Block (SCB) is coupled to the analog to digital converter. The Analog Compute Engine ACE of analog block includes a Sample Sequence Engine (SSE) for configuring the parameters of the on-chip ADC

and DAC. The Post Processing Engine (PPE) is used for circuit-specific functions such as pass filtering and linear transformation.

b) Microcontroller SubSystem (MSS):

The SmartFusion device includes a processing subsystem known as the Microcontroller SubSystem (MSS). SmartFusion's Microcontroller SubSystem (MSS) is made up of a 32-bit, 100 MHz CortexM3 processor, internal memory blocks, clocking resources, and integrated peripherals that are linked together by a multilayer AHB bus matrix (ABM). It includes JTAG and serial wire debugging capabilities. 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 MSS also comprises embedded high-speed SRAM of 64 Kbytes and embedded flash memory of 256 Kbyte. In addition to that SmartFusion device having different sets of peripherals, which includes the components needed for communication, such as 10/100 Ethernet MAC, UARTs, SPI, GPIO, Timers, clock resources, two I2C peripherals etc. The UART module is used for serial communication. 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 allows for the customization of both analog and digital resources. The configurable platform is required to ensure customisation and routing. As a result, the SmartFusion device, A2F200M3F, is built on an FPGA platform to ensure the primitives' integrability. The FPGA fabric has great features like low power, flash based CMOS process, firm error immune.

d) Radio Communication Interfaces (RF Section)

A Wireless Sensor Network (WSN) is made up of spatially distributed autonomous sensors that work together and cooperatively pass their data through the network to a central location referred as base station. The primary goal of this work is to design a sensor node for a Wireless Sensor Network (WSN) that requires an RF module. Digi created the ZigBee wireless communication module in accordance with the 802.15.4/ZigBee standard shown in figure 5. It consumes very low power due to sleep mode and operates on low power supply typically 2.8V to 3.3V. Salient features of Zigbee modules are:

- 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



Figure 5: ZigBeeS2C Device

- Operates on DC +3.3 volt

The zigbee is configured into desired mode of operation before deploying respective WSNode. For configuration of ZigBee different IDE are used. The X-CTU is open source windows based software. The X-CTU supports inbuilt functions which help to easily configure the Xbee. ZigBee is configured in Three Modes End Device, Router and Coordinator.

As per definition of wireless sensor network it consist only one coordinator and multiple sensor nodes to form a network. Coordinator is responsible for start the network, selecting the channel and PAN ID (both 64-bit and 16-bit). After starting a network coordinator can allow new devices to join the network. It can also route data packets and communicate with other devices on the

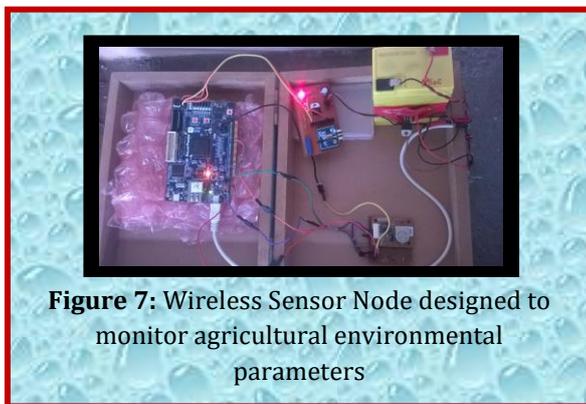


Figure 7: Wireless Sensor Node designed to monitor agricultural environmental parameters

network. The coordinator referred as a base station for the present design of wireless sensor network.

End device is also referred as node. End devices are capable to join the existing networks. It can send and receive information, but cannot act as messenger between any other devices.

Router joins in the network with PAN ID, for routing and exchange the data from end device to base station. Router allows other router and end device to participate in the network having same PAN ID. Network consist few number of router which is less than end devices.

The present Wireless Sensor Network includes one coordinator, three end devices and two routers.

3. Software:

The LiberoSoC is true IDE software. It includes a number of software applications such as synplify proAE for synthesising, modelsim for simulation, SoftConsole for application code development, and so on. Verilog and VHDL are the two HDL codes available for co-designing of hardware and software in the LiberoSoC software. Integrated circuit technology has advanced to allow for an increasing number of components on a single chip. The SoftConsole combines project management, make facilities, source code editing, program debugging, and complete simulation in one powerful environment. The SoftConsole editor and debugger are integrated in single application that provides a seamless embedded project development environment. Figure 6 depicts the algorithm employed for development of necessary firmware.

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 7 is the photograph of actual system. Such five nodes are designed.

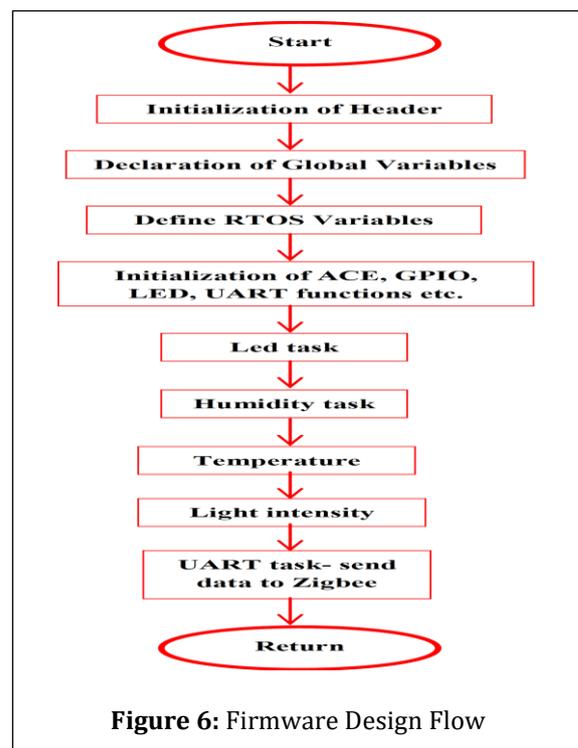


Figure 6: Firmware Design Flow

4. Calibration of the Wireless Sensor Nodes

(WSNodes) :

The sensor array, as discussed earlier, interfaced to cSoC, produces analog emf proportional to the variations in the respective physical parameters. Therefore, the parameters are extracted in the terms of either current or voltage. Hence, to represent the values of the parameters in actual units one should calibrate the system more precisely, so that the exact values could be outputted from the system under investigation. Each Node is designed for monitoring of relative humidity in RH%, temperature in °C and light intensity in Lux of polyhouse environment. These parameters have their own characteristics and therefore, the Nodes are separately calibrated for these parameters. To achieve major goal of the farmer to increase the yield, the internal temperature, humidity and intensity of light must be controlled to the desired value. For present system, the temperature sensor LM 35 is used for temperature monitoring. Humidity is one of the most

The applied temperature (t °C) is measured by using standard digital thermometer DM 97. By employing least square fitting method the data is fitted to straight line.

Expression shown in figure could be transformed as,

$$\text{Temperature (t)} = (v_t - 22.021)/9.4752 \dots(1)$$

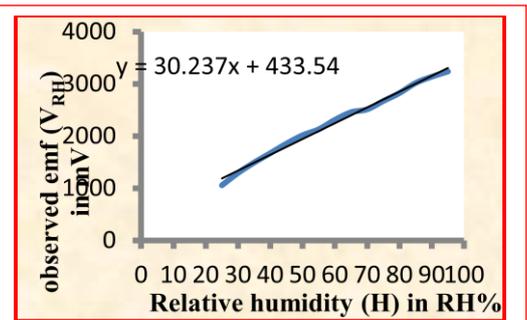


Figure 10: Graph of observed emf (V_{RH}) in mV against relative humidity (H) in RH%

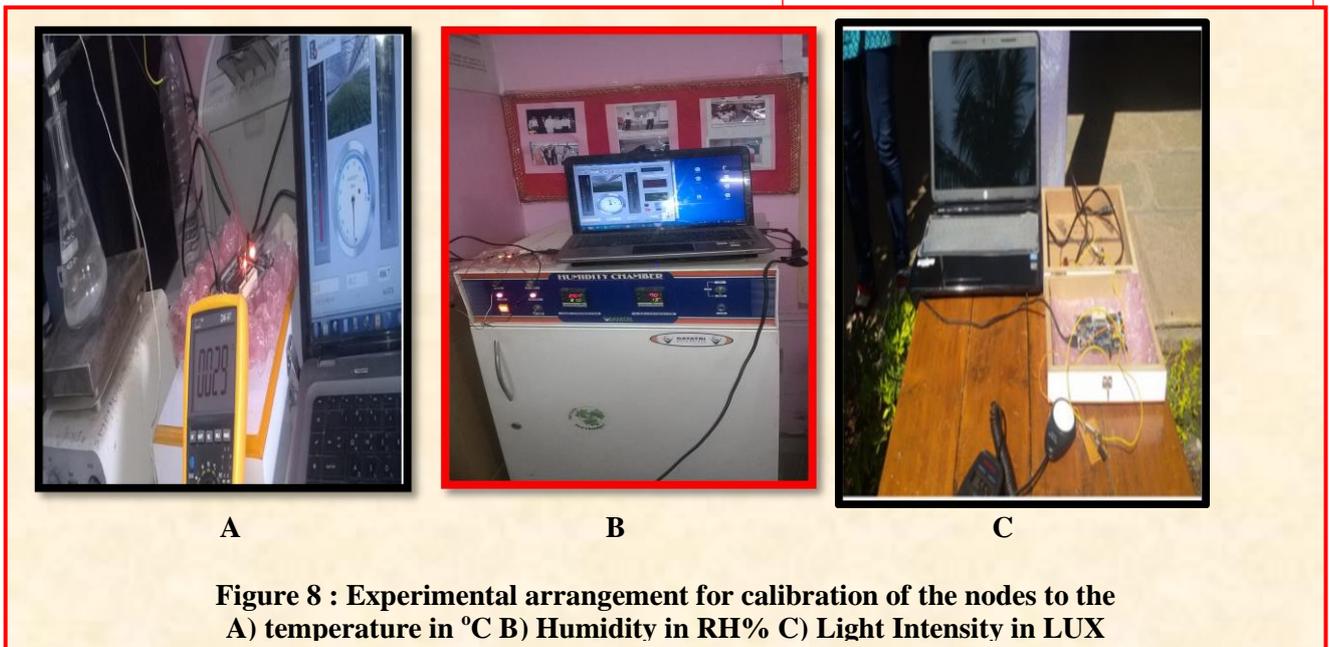


Figure 8 : Experimental arrangement for calibration of the nodes to the
 A) temperature in °C B) Humidity in RH% C) Light Intensity in LUX

important environmental parameter. For measurement of humidity SY-HS-220 humidity sensor is employed. The calibration of the Node for temperature in °C for humidity in RH% and for light intensity in LUX is essential. Therefore, deploying sophisticated methodology the Nodes calibrated. To monitor intensity of the Sun light, detection of light energy is needed. To sense the light energy, the light intensity sensor BPW 34 is employed. Experimental arrangement for calibration is depicted in figure 8.

As per Least Squares fitting methodology, the data regarding emf generated by the system with respect to applied temperature is collected. Calibration of the nodes to the temperature scale is depicted in figure 9.

The temperature sensor LM 35 is exposed to different temperatures by employing electric heater.

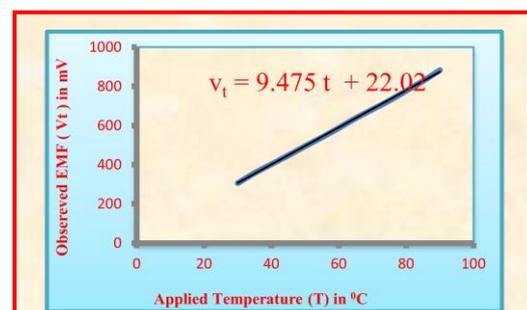


Figure 9: The graph of observed emf (v_t) in mV against applied temperature (t)in °C

or precise calibration, the humidity of different values

are applied to the sensor, SY-HS-220. For production of required environment, wherein humidity concentration is precisely controlled, a highly sophisticated humidity chamber, model Gayatri Scientific Ltd. Mumbai, is employed. The humidity (H) from 30 RH% to 95 RH% with accuracy of 1 RH% is applied. Calibration of the nodes to the humidity is depicted in figure 10.

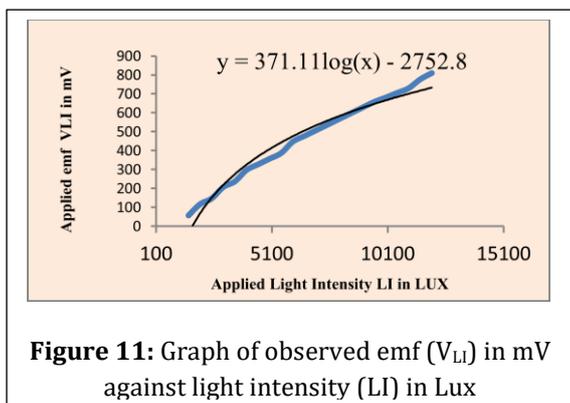


Figure 11: Graph of observed emf (V_{LI}) in mV against light intensity (LI) in Lux

By employing least square fitting method the data is fitted to straight line. Expression shown in figure could be transformed as,

$$\text{Humidity (H)} = (V_{RH} - 433.54)/30.237 \quad \dots(2)$$

The scientific unit used to express the light intensity is the LUX. For this purpose, the system is calibrated in the LUX unit. To measure intensity of light the standard LUX meter model Mastech make MS6610 is deployed. The sensor BPW34 is exposed to the light of different intensities. Using this LUX meter, intensity of incident light is measured. The instantaneous emf (V_{LI}), in mV, produced for various light intensities (LI), in the LUX, are recorded and shown in figure 11. As shown in figure 11 the trend of increase in the observed emf with increase in light intensity suggests logarithmic relation.

$$\text{Light Intensity (LI)} = 371.11\log(V_{LI}) - 1752.8 \quad \dots(3)$$

The expression 1, 2 and 3 employed in firmware to measure parameters in its engineering unit.

After successful calibration of the Nodes, it is essential to verify and validate the results given by the system under investigation. To ensure validation of system designed, it is subjected to the process of standardization. The parameters under investigation presented in table 1.

On inspection of the table 1 it is found that, Temperature, Humidity and Light intensity recorded by Wireless Sensor Node under investigation and measured by standard standard meters are closely matched. This

Table 1: parameters shown by Nodes under investigation

Temperature shown by standard digital thermometer °C	Temperature shown by Node under investigation °C	Humidity shown by Humidity meter in %RH	Humidity shown by Node in %RH	Light intensity Shown by standard meter in LUX	Light intensity given by Node under investigation in LUX
30.00	30.02	40.00	38.08	2000	1687
35.00	35.02	45.00	42.05	3000	2994
40.00	40.02	50.00	47.00	4000	4300.5
45.00	45.00	55.00	54.04	5000	5171.1
50.00	49.77	60.00	60.02	6000	6041.9
54.50	54.50	65.00	63.06	7000	6912.8
59.40	59.50	70.00	68.03	8000	8049.2
65.00	65.00	75.00	73.00	9000	9089.8
70.00	70.03	80.00	80.02	10000	9960.6
75.00	75.10	85.00	85.50	11000	10831.5
80.00	80.00	90.00	90.20	12000	11984.7
85.00	85.10				
90.10	90.30				

supports to the reliability and accuracy of On-Chip and OFF chip hardware design.

5. Implementation of Wireless Sensor Network in Polyhouse:

The Wireless Sensor Network (WSN), comprising Wireless Sensor Nodes (WSNodes) and Base Station (BS) is established by deploying star topology

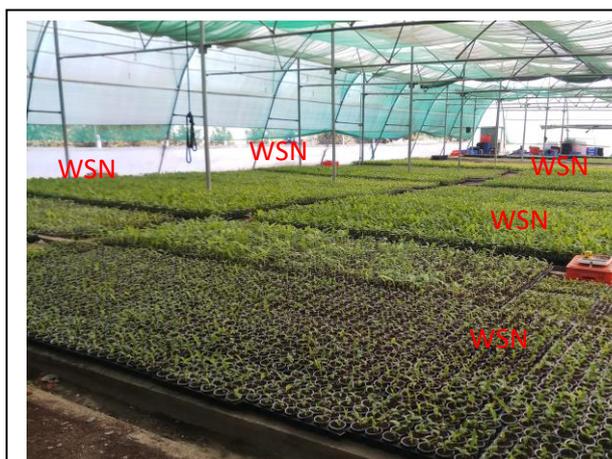


Figure 12: The experimental arrangement of WSNodes for monitoring environmental parameters.

and implemented to monitor the environmental parameters of the high tech polyhouse. The present WSN implemented at polyhouse of Shri Gansh Nursery, Located at A/P-Ganeshgaon and result of implementation are interpreted. The arrangement of Wireless Sensor Nodes (WSNodes), to realize the site

specific variability of the environmental parameter, is depicted in photograph shown in figure 12.

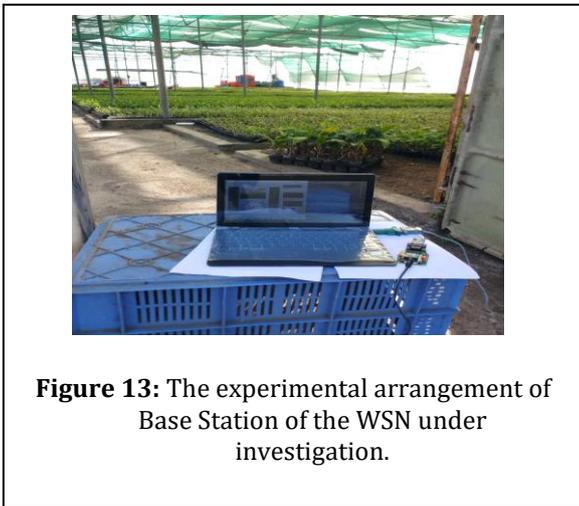


Figure 13: The experimental arrangement of Base Station of the WSN under investigation.

All nodes are battery operated. Therefore, fully charged batteries are installed in each WSNode. The

On close inspection of table 2, it is found that, data depicts site specific variability. The nodes are spread over entire area. Therefore, depending upon location of the nodes, the parameter values are observed. On investigation of table 2, it is found that, the relative humidity (RH%) is almost same throughout the area of investigation. The values of parameters, environmental temperature and intensity of light, shown by the WSNodes can be attributed to location of placement of the nodes. The results reveal that, the WSN collects site specific data.

7. Conclusion:

Wireless Sensor Nodes (WSNode) have been designed and developed, wherein an innovative technology, Analog and Mixed Signal Based Customizable System-on-Chip is realized. Both hardware and software are successfully co-developed. It is developed about Microsemi, USA based cSoC device, SmartFusion A2F200M3F. Hardware for WSNode, the SoC, is developed on the chip by employing dedicated IDE

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Humidity given by the WSNodes of WSN in RH%					Temperature given by the WSNodes of WSN in °C					Intensity of light given by the WSNodes of WSN in LUX				
1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
47.7	46.4	45.3	44.2	43.9	24.7	24.8	28.5	27.8	27.5	1830.9	1781.1	1507.5	1545.7	1897.7
47.9	46.6	45.6	44.5	43.3	24.4	24.6	28.2	27.9	27.6	1845.9	1787.0	1517.5	1535.7	1827.4
47.9	46.4	45.9	44.3	43.7	24.5	24.4	28.3	28.4	27.2	1836.3	1778.4	1483.8	1447.8	1797.1
48.1	46.8	45.7	44.5	43.4	24.3	24.5	27.9	28.5	27.2	1832.8	1770.9	1445.3	1431.7	1789.4
48.2	46.9	46.1	44.2	43.7	24.6	24.5	27.8	28.2	26.9	1827.3	1745.4	1442.1	1420.4	1776.8
48.2	47.2	46.3	44.9	43.8	24.7	24.7	27.7	27.9	26.9	1818.4	1734.7	1389.7	1387.3	1768.9
48.5	47.2	46.4	45.2	43.9	24.4	24.6	27.4	27.6	26.7	1780.2	1726.6	1431.4	1380.5	1754.7
48.7	47.3	46.6	45.2	43.9	24.5	24.4	27.5	27.6	26.6	1789.5	1719.3	1420.3	1367.2	1732.6
48.9	47.5	46.7	45.2	44.1	24.3	24.1	27.5	27.8	26.4	1786.0	1695.7	1418.9	1354.8	1702.8
48.9	47.5	46.7	45.5	44.4	23.6	24.0	27.2	27.7	26.3	1764.7	1689.6	1410.5	1340.2	1678.4
49.2	47.5	46.8	45.3	44.6	23.8	23.9	27.1	27.5	26.1	1754.7	1680.5	1398.7	1321.6	1663.6
49.4	47.8	47.0	45.7	44.6	23.7	23.6	26.9	27.3	25.8	1754.4	1637.3	1393.4	1278.5	1637.2
49.5	47.9	47.3	45.8	44.6	23.7	23.6	26.7	27.1	25.7	1745.9	1631.4	1320.1	1250.9	1621.5
49.8	48.3	47.5	45.6	44.9	23.6	23.9	26.7	26.9	25.5	1740.3	1624.9	1267.4	1217.8	1614.4
49.9	48.4	47.5	45.9	44.8	23.4	23.7	26.6	26.8	25.5	1731.8	1580.6	1254.8	1086.9	1596.3
50.3	48.3	47.5	46.3	44.9	23.5	23.5	26.5	26.6	25.4	1729.2	1572.9	1256.2	989.6	1589.3
50.3	48.5	47.7	46.8	45.2	23.2	23.7	26.1	26.5	25.3	1718.5	1562.7	1247.8	976.5	1574.3
50.5	48.6	47.6	46.9	45.3	23.4	23.6	25.8	26.5	24.7	1690.3	1498.4	1233.4	976.2	1561.7
50.6	48.9	47.8	47.1	45.6	23.1	23.6	25.6	26.2	24.7	1690.3	1489.2	1229.2	965.4	1553.7
50.8	48.9	49.0	47.5	45.8	22.8	23.9	25.5	26.1	24.7	1687.7	1456.6	1218.9	954.9	1545.9

Table 2: Environmental parameters under investigation

arrangement depicting the establishment of Base Station is shown in figure 13

All WSNodes collect the environmental data and after processing send it toward base station. The base station is supposed to be centralized control room shown in figure 13. The WSNodes are battery operated and after powering, the WSNodes starts transmitting data towards base station. The base station continuously receives the data and demonstrated on computer or laptop.

6. Results and Discussion:

Environmental parameters shown by Wireless Sensor Nodes (WSNodes) at base station are listed in table 2.

smart RF module, the Zigbee, which operates in the region of 2.4GHz in ISM band. The Wireless Sensor Network under investigation is deployed to monitor the environmental parameters of polyhouse. The three environmental parameters, Relative humidity (RH%), Environmental Temperature (°C) and Intensity of light (LUX), are considered during this on-site deployment. Employing five WSNodes developed by using Smart fusion technology and Zigbee technology, the WSN is established in above polyhouse. Thus, from results of investigation, it can be said that, present wireless sensor network is successfully established and functions with great reliability.

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