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Abstract **-** To monitor very low levels of hydrogen in cover gas plenum of fast breeder reactors, thin film sensors based on tin oxide doped with palladium are developed in IGCAR. The sensor patterns are integrated on a miniature alumina substrate and necessary electrical leads are incorporated in it. The conductivity of the sensor varies with H_2 concentration. The useful range of the sensor is 5 ppm to 80 ppm and the base line resistance of the sensor is around 2.5MΩ. This paper gives an outline of the PSoC based electronics developed to measure the H_2 concentration and associated signal processing. Low component count and feasibility of locating the sensor conditioning components remotely are emphasized in the design. The laboratory studies on the linearity performance of the various blocks of the system are discussed.

Keywords **-** *H_2 sensor, PSoC controller, PWM based DAC, pulse width measurement.*

I. INTRODUCTION

Sensors for on-line monitoring of hydrogen in cover gas plenum are needed to detect an event of steam leak at the steam generators of a fast reactor. A diffusion based hydrogen detection system [1] for monitoring hydrogen levels in argon cover gas has been presently in use. This system uses a thin walled nickel coil at 500 ^{o}C and a thermal conductivity detector (TCD) with a detection limit of ~ 30 ppm for sensing hydrogen. To extend the detection limit of this system down to 5 ppm, a surface conductivity based sensor, which makes use of a thin film of semi-conducting tin oxide, has been developed in our laboratory. Thin films of tin (IV) oxide were deposited using pulsed laser deposition (PLD) technique on a 0.5 mm thick alumina substrate. The details of the deposition conditions and parameters are described in reference [2]. This sensor is operated at 350^{o} C using a surface heater and the corresponding control circuit is discussed elsewhere [3]. The sensor resistance varies from 1 kΩ to 2.5 MΩ for the range of 80 ppm to background level. The sensor excitation signal is required to be around 300 mV. Measurement of sensor resistance to a very great degree of accuracy is very old and established technique. But considering the facts that the sensor is to be placed in the plant, the instrumentation system is designed with an emphasis on remote signal measurement with greater reliability and compactness. Also, the implementation scheme for measurement and application keep changing with the evolution of new sophisticated components incorporating advanced features like transmission methods, miniaturization, and integration solutions. These modern methods also emphasize on improved reliability, and endurance to environmental extremities with noise, temperature. The PSoC based instrumentation for resistive sensor and an application to measurement of H_2 concentration using thin film sensor take-in all these modern features; and thus becomes for ideal system for plant applications. The paper discusses in detail about the design/fabrication aspects of the development and also about the performance.

Based on these considerations the signal conditioning of the resistance is designed using a simple astable multivibrator with the sensor in the timing circuit so that the output signal is directly in the digital domain. Thus it is possible the signal can easily be transmitted by differential balanced line method and subsequent signal processing by customised PSoC.

II. OUTLINE OF THE DESIGN APPROACH

The block diagram of the instrumentation scheme is illustrated in the figure 1. The standard astable multivibrator circuit using RC time constant is adapted to convert the sensor resistance to proportional pulse width in the digital domain. Suitable potential divider is used to apply the recommended excitation voltage of ± 300 mV to the sensor. The output frequency with variable pulse width is converted into unipolar and into TTL appropriately. Then the signal is transmitted by a differential transmitter using differential balanced line to the (signal-processing unit) measurement unit. The corresponding differential receiver receives the signal and the resulting TTL signal is applied to PSoC module for measurement and subsequent processing.

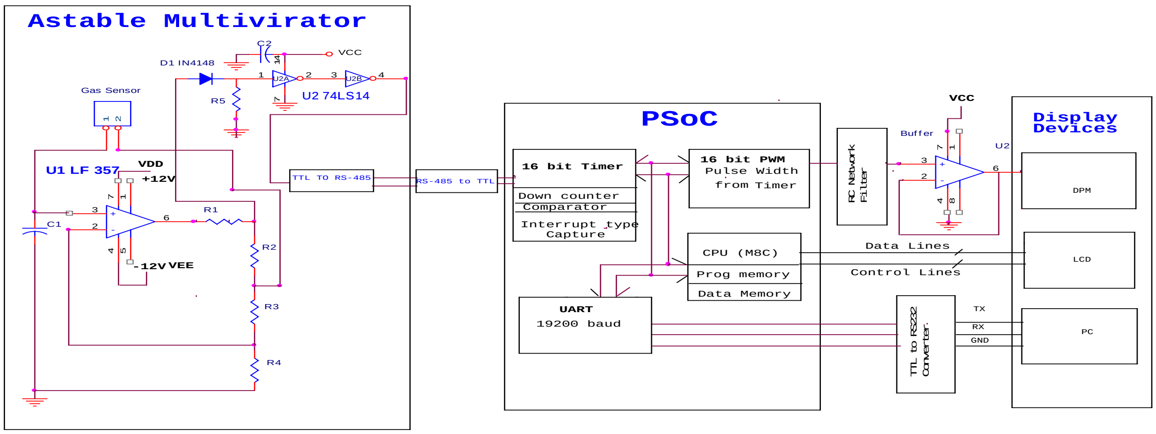

Fig. 1 : Block Diagram of Pulse Width Measurement for Hydrogen Sensor Using PSoC

As the resistance information is modulated in the width of the pulse, the pulse width is measured accurately by clocking the width by a 100 kHz reference clock pulses. The clock pulses for the period are counted using a 16 bit timer of the PSoC. The Counting is repeated every second. The value is further normalized with 12 bit PWM based DAC, another component of the PSoC. The analog output can be logged using standard commercial logger. The PSoC system also provides the data through its module UART, so that the data can be imported through hyper terminal of the PC [4]. The built in microcontroller coordinates the execution of the various sequential events. The program is developed using M8C C Compiler using PSoC Designer version 4.4 and screenshot of the implemented code is shown in figure 2.

III. DETALIED DESIGN ASPECTS OF THE PSoC MODULES

The variable pulse width generation, providing excitation signal and signal conditioning are done in a single opamp based astable multivibrator. For measurement, a PSoC CY8C29466 [5] from Cypress Semiconductor is used. The project uses PSoC designer 4.4 for configuring digital and analog modules along with the PSoC Programmer for burning the code in the PSoC Chip.

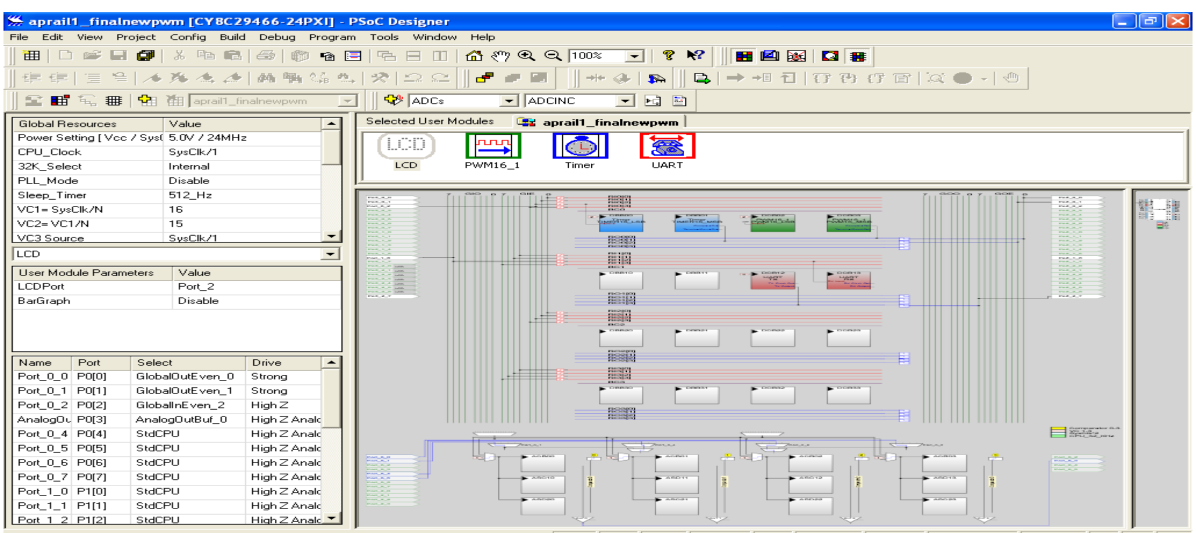

Fig. 2 : Screen shot of design implementation using PSoC Designer ver. 4.4

Major modules of the project are the 16-bit timer for the measurement of pulse width in terms of counts, 12 – bit Digital to Analog Converter along with a low pass filter to get a proportional analog DC voltage. The pulse width measurement is done using ‘timer capture’ and the 8-bit Microcontroller unit within PSoC chip with suitable ‘C’ coding. The final DC voltage signal is varying from 0-5 Volts thereby giving a linear one to one correspondence with concentration of hydrogen in ppm. The ppm value is also displayed in an LCD. The DC voltage is given for recorder input or for DPM.

IV. DESIGN IMPLEMENTATION

The Overall block diagram of the implementation is shown in the figure.3. The basic idea involves the pulse width measurement and DAC implementation.

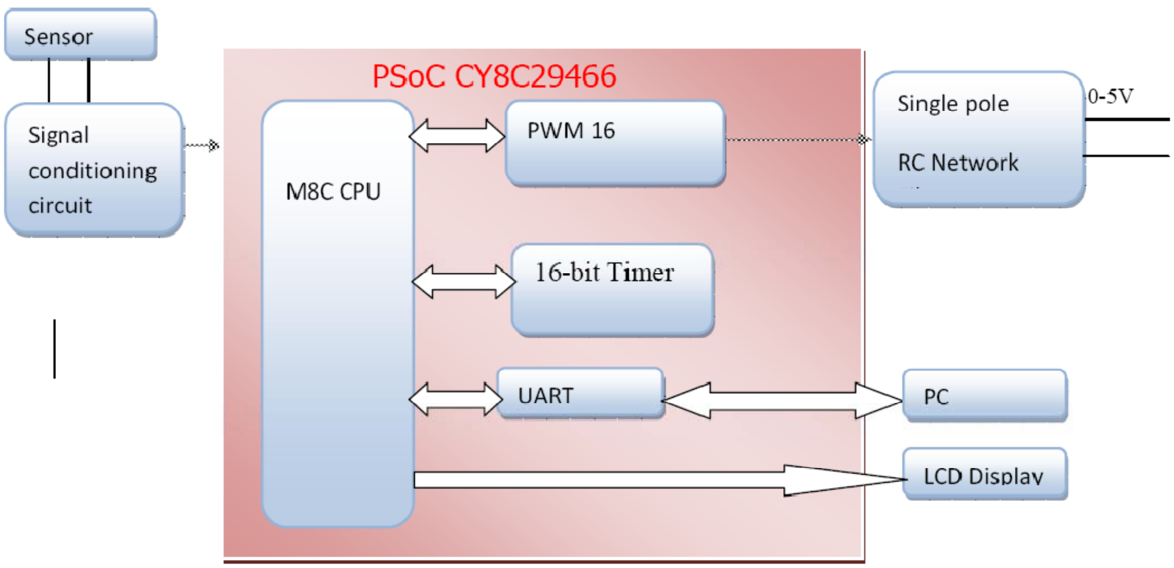

Fig. 3 : Block Diagram of Pulse Width Measurement for Gas Sensor Using PSoC

A. *Pulse Width Measurement Using 16 Bit Timer[4]*

Clock (100 kHz)

16-bit Timer

To PWM16

Input pulse width

Fig. 4 : Timer Configuration

With reference to above figure,

- CLK frequency = 100 kHz (10 µs)
- 16 bits corresponds to 65535 counts
- It can measure a maximum of 655350 µs
- So, the Range of pulse width measured – 0 to 655 ms (calibrated up to 2.4 MΩ resistance). This range can be changed by changing clock frequency.
- DACPW=TIMER COUNT * 4096 / 65535.

This normalised value is given to ‘16 bit PWM’ as the digital input count.

B. *12 bit Digital to Analog Converter using 16 bit Pulse Width Modulator and the low pass filter*

In the PWM-based technique the digital input sets the pulse width of the output PWM signal. This output signal is fed to a low-pass filter. The output of the low-pass filter is proportional to the width of the ON pulse of the PWM signal, which is in turn proportional to the digital input [6],[7]. For superior performance, the two-pole low-pass filter can be used, providing an attenuation of 40db/decade past its cut-off frequency. There are several design considerations involved in the selection of the cut-off frequency of the low-pass filter. Primarily, the filter cut-off frequency must be much lower than the PWM frequency to reduce the noise generated by PWM switching. However, a very low cut-off frequency imposes a corresponding limitation on the DAC data input rate, because the time constant associated with the filter increases.

Considering these constraints, the PWM DAC is designed with the following specifications:

The maximum number of data conversions per second is 1 (sampling frequency of 1 Hz). A cut-off frequency is chosen as around 10 Hz (10 times the input rate) to ensure that the fastest DAC output signal is not attenuated.

The measurement of H_2 concentration is required with an accuracy of 0.1 ppm over the range of 100 ppm, the resolution of DAC is chosen to be better than 10 bit (100 /0.1 =1000 & 2^10 =1024) that is 12 bit. The 12 bit DAC is not a standard module in PSoC, so using the 16 bit PWM and suitable low pass filter the 12 bit DAC is realized. The details are shown in the figure 5. The input CLK frequency, 4 MHz is applied to the PWM and the period parameter is set to be 4096 (2^12) to obtain PWM frequency of 977 Hz.

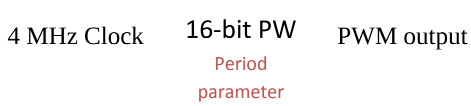

Fig. 5 : PWM Configuration

The low pass cut off frequency is much lower than 977 Hz that ensures the PWM frequency is eliminated in the output.

- Pulse Width parameter counts from 0 to PERIOD-1 i.e. 0 to 4095.
- Duty cycle is varied from 0 - 100% by varying the Pulse width parameter from 0 – 4095. Duty cycle = Pulse Width / (PERIOD-1)

C. Communication method [7]

The Pulse width data is transmitted to UART Serial Port by configuring UART module of PSoC Chip. UART is 8-bit Asynchronous Receiver Transmitter that supports standard duplex RS-232 compliant, data format serial communications over two wires. High level API is used to send and receive the data.

D. LCD display

The data is also displayed on LCD by configuring LCD module. Industry standard LCD Display driver chip protocol is used. Suitable data and control lines are used to interface LCD. High level API is used to write the data to LCD.

V. PERFORMANCE STUDIES

In order to ascertain the linearity between the sensor resistance and the output counts an experimental run was conducted. In the first experiment, a set of standard resistance in the range up to 2.5 MΩ was connected in the input circuit and the output pulse width was measured by the counter. The counter values are plotted against the input resistance values (figure.6) The plot shows there exists a linear relation between them. Subsequently, the corresponding DAC analog output also was measured and plotted against the resistance (figure.7). This shows that linear performance of the DAC. The total system was connected to the hydrogen sensor and trial runs were conducted by injecting known amount of hydrogen 80 ppm and 40 ppm and the response is shown in figure.8. The DAC output is logged in the PC and the same is plotted in the figure. The graphs show the H_2 response is in good linearity with DAC output and the H_2 concentration. The plot also exhibits the base line stability of the signal over a period of 8 hours.

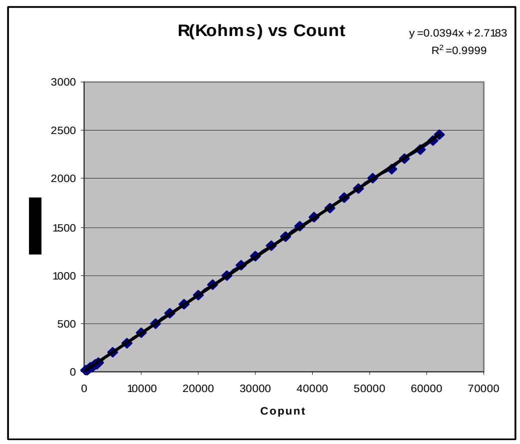

Fig. 6 : Graph showing the resistance vs. count

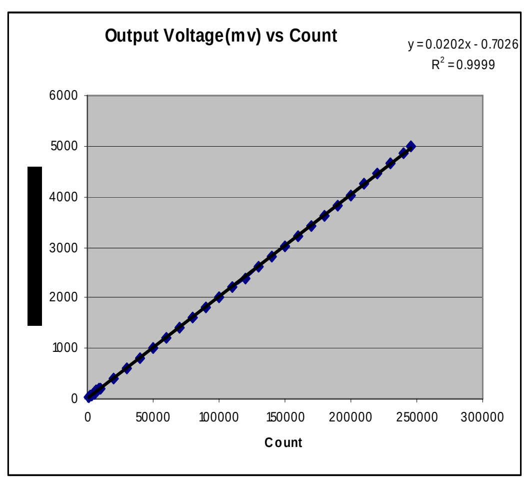

Fig. 7 : Graph showing the DAC output vs. count

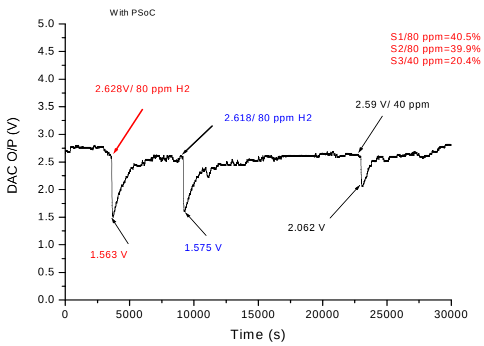

Fig. 8 : Graph showing measured output from Hydrogen sensor

VI. CONCLUSION

The C code for measuring the pulse width is bug free and has been compiled and checked. The code is compliant with the MISRA C (Motor Industry Software Reliability Association) Standard.

The processing module is a compact standalone unit and does not need any user control or optimization. The data can be imported by the plant computer and used for further analysis. A reliable PSoC based on line H_2 gas monitoring instrumentation has been developed suitable for plant application.

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REFERENCES:

[1] S.Premalatha,K.H.Mahendran , R.Parthasarathy, “Instrumentation for Hydrogen Detection in argon cover gas for Fast Breeder Reactors” International Conference on sensors and related networks (SENNET-09) at VIT University, Vellore December 07-10,2009

[2] E. Prabhu, V. Jayaraman, K.I. Gnanasekaran, T. Gnanasekaran and G. Periaswami, “Pulsed Laser Deposition made thin film sensor for monitoring hydrogen in gas streams” Asian Journal of Physics, 14, 33-40 (2005).

[3] S.Premalatha, R.Parthasarathy “ A voltage regulator based temperature controller and sensor electronics for tin oxide based hydrogen sensor” International Conference on sensors and related networks (SENNET-09) at VIT University, Vellore December 07-10,2009.

[4] Steve Gerber, Sensing – Measuring an input PWM - Application Notes - Cypress Semiconductor Corporation, 2003

[5] CY 8C29466 PSoC Mixed Signal Array data sheet, Cypress Semiconductor

[6] Application Note: Digital-to-Analog Conversion Using PWM in Z8 Encore! XP® Microcontrollers AN015004-1207

[7] J.Jayapandian, AN2335 “Data Acquisition and Control System” the PSoC way - Cypress Semiconductor Corporation, 2006.