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Laser Power Measurement Using Commercial MEMS Pressure Sensor along with PSoC Embedded Read-out

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Abstract: Solid-state, gas, semiconductor and other types of lasers are extensively employed in industry for producing laser beams used in such wide ranging fields as machining, medicine and communications. In such applications, it is necessary to be able to accurately measure the power of the laser beam that is emitted by the laser. This paper describes a novel design technique which uses the diaphragm of a commercial MEMS pressure sensor as a target surface on which laser beam impinge, transfer heat and causes change in piezo resistance. The measured change in resistance was proportional to the intensity of laser beam in the range of 0 to 300 mW. The ratio metric embedded read-out design using a single chip programmable system on chip (PSoC) has been used to acquire the resistance. *Copyright © 2011 IFSA.*

Keywords: Laser power measurement, MEMS pressure sensor, PSoC microcontroller.

1. Introduction

An accurate measurement of laser power is necessary to have a control over the laser beam emitted by the laser. The need to accurately measure laser power and energy has increased as more of these systems are used in medical procedures and industrial processes [1]. Although a fairly simple process, this measurement is not as straightforward as an electric power measurement. With lasers, more attention must be paid to the selection of the right sensor as since different sensors perform different measurements. Since lasers are good sources of concentrated heat, it was probably assumed that heat sensing methods would best be employed for measurement.

A measurement of the power output of a laser is required in almost every laser application. In photoelectric power meters, the light detector is a photocell which converts the laser light directly into

an electric signal. Light from a laser or other continuous light source is incident on the photosensitive surface of the light detector. The photosensitive surface usually is a silicon photocell, which converts a portion of the incident light energy into an electric current [2]. The electric current produced is proportional to the intensity of the incident light, but usually varies with the wavelength of the incident light. The variation with wavelength is referred to as the "spectral response" of the detector and must be considered when a measurement is made with an optical power meter. But the thermopile based laser power meters has a slow response and is usually bulky. In photo diode based measurement, even though a miniaturized system, its linearity is the question.

Micro-electromechanical systems (MEMS) are enabling technology for sensors like temperature, flow, position, acceleration, pressure etc. MEMS based sensor products provide an interface that can sense, process and/or control the surrounding environment. MEMS-based sensors are a class of devices that builds very small electrical and mechanical components on a single chip. MEMS-based sensors are a crucial component in automotive electronics, medical equipment, hard disk drives, computer peripherals, wireless devices and smart portable electronics such as cell phones. The major benefits of such tiny micro-structured sensors are its low cost, low power, miniaturization, high performance and its integration with the read-out electronics.

In the present work, a commercial MEMS pressure sensor has been reverse engineered and used for laser power measurement. In a commercial MEMS pressure sensor whose membrane piezo resistance change as a function of temperature is used to measure laser power. As a reverse engineering approach, a MEMS pressure sensor which is meant for measuring pressure is now used for laser power measurement.

2. Laser Power Measurement

The top casing of the pressure sensor chip has been chopped off to make use of the thin membrane coated with Piezoresistive Bridge for the measurement of laser power. Fig. 1a and Fig. 1b shows a typical piezo resistive membrane of a commercial MEMS pressure sensor and associated electronics for read-out mechanism of membrane deflection. Wheatstone bridge formed with piezoresistors R_1 , R_2 , R_3 and R_4 whose resistivity is dependent on the strain developed on a diaphragm, are formed on the top of the diaphragm.

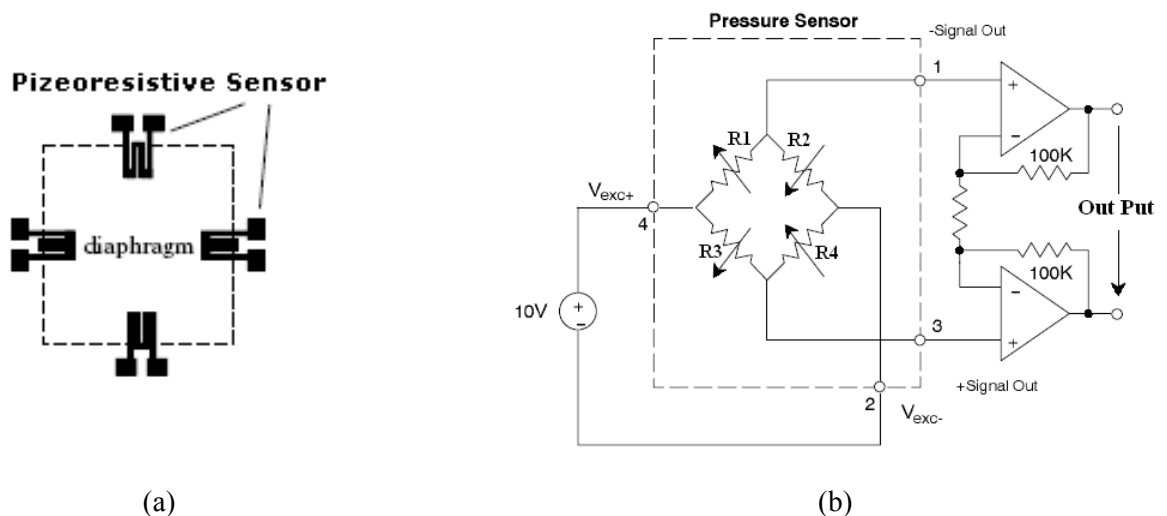


Fig. 1. (a) A piezo resistive membrane of a commercial pressure sensor; (b) Piezo resistors connected in Whetstones Bridge configuration.

The bridge configuration with current / voltage supply is the most popular interconnection of piezoresistors, formed by $R1$ and $R4$ (their resistance increases with pressure, say Rp^+), by $R2$ and $R3$ elements (their resistance decreases with pressure, say Rp^-). Two arms of piezoresistor with opposite resistance changes Rp^+ , Rp^- are used to sense the pressure variations. Interestingly piezo resistance depends on both applied pressure and temperature as given by $Rp(P, T) = R(T)[1 \pm S(T)P]$, where $R(T)$ is the nominal value of the piezoresistor at a reference pressure, $S(T)$ is the pressure sensitivity and P is the applied pressure on the floating membrane.

Present design exploits the temperature dependence of piezo resistor on membrane due to Laser heating. Fig. 2 shows the basic principle of laser power measurement by acquiring the change in resistance of the piezoresistance on the MEMS membrane. The pressure sensor (100 psi with temperature compensated till 60 °C) has full bridge configuration with four piezoresistors viz, $R1 - R4$. In our reverse engineering approach only one piezoresistor has been used by connecting a pair of thin leads across the piezoresistor of the full bridge adequately. It is necessary to measure the resistance across one arm of the bridge to avoid temperature compensation as per the designer of commercial sensor. Now the membrane was exposed to a variable power laser source ($\lambda = 488 \text{ nm}$) and calibrated to measure the laser power between 0 to 300 mW is shown in Fig. 3. It has been noted that the change in resistance due to laser exposure is dominated by piezo resistance than membrane deflection.

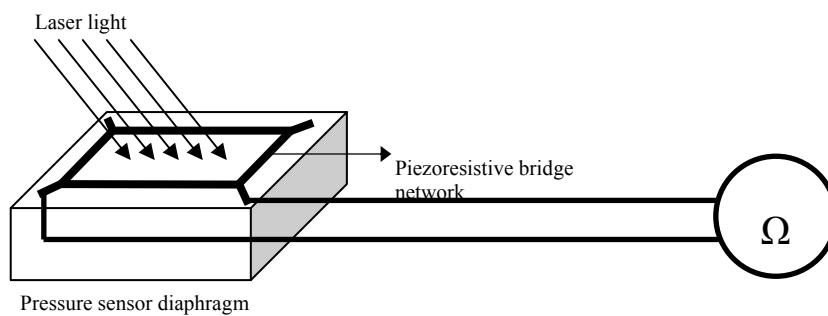


Fig. 2. Principle of Laser power measurement using MEMS piezoresistive pressure sensor.

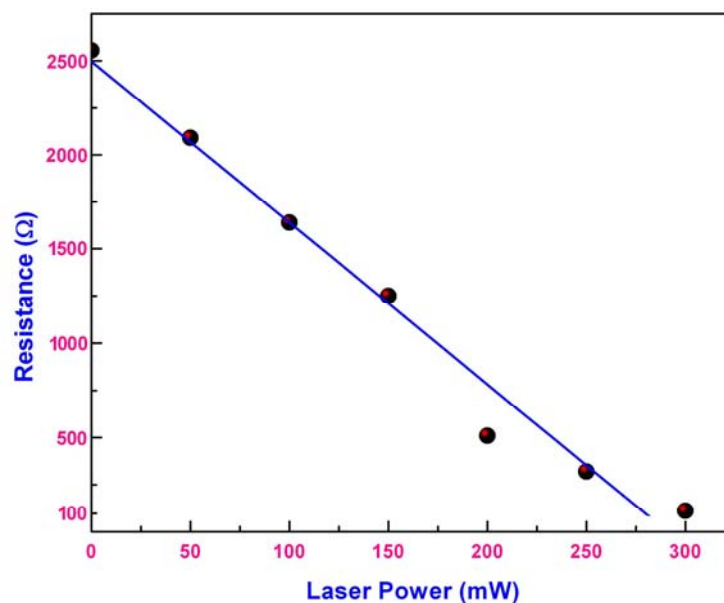


Fig. 3. Calibration of laser power measurement.

3. PSoC Implementation

Fig. 4 shows the Laser power measurement system using commercial MEMS piezo-resistive pressure sensor and embedded design with PSoC microcontroller chip (CY8C29466). Microcontroller was also programmed for a LCD port and was connected to a dot matrix LCD display. Microcontroller was powered by a rechargeable Ni-Cd battery.

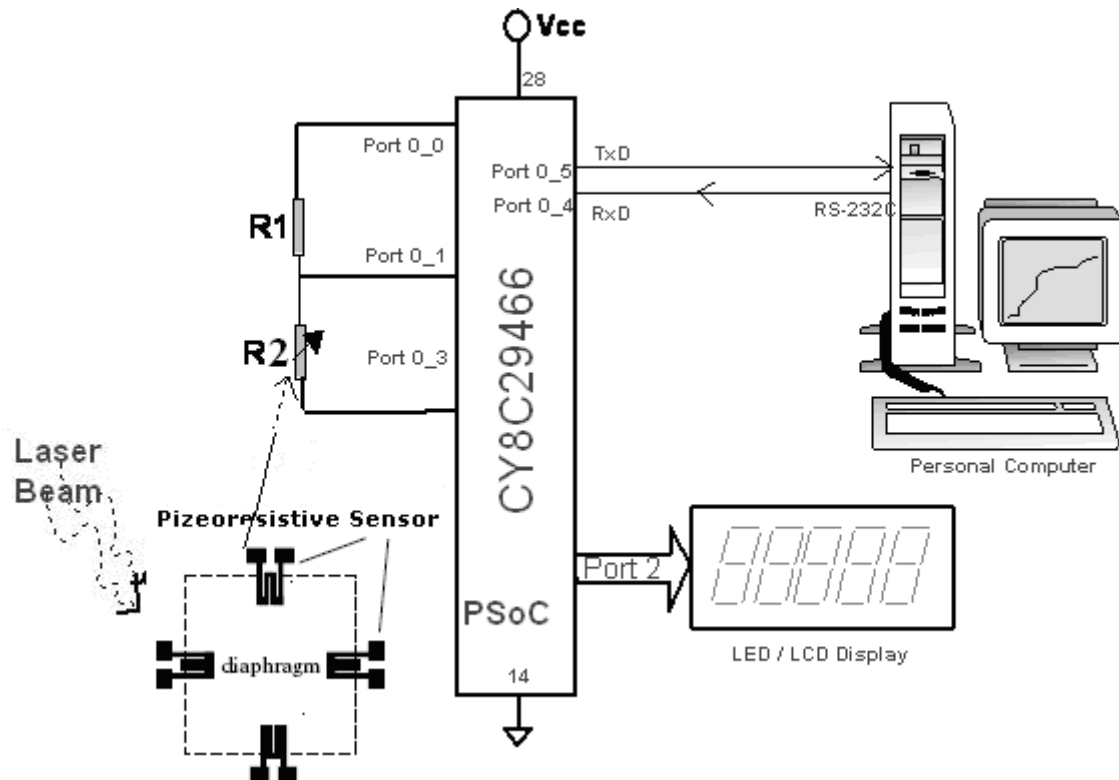


Fig. 4. MEMS Pressure Sensor and PSoC embedded design for Laser power measurement.

The internal block diagram of the PSoC microcontroller is shown in Fig. 5. The one arm of the built-in Piezoresistive *Wheatstone's* bridge in the commercial pressure sensor membrane top say R_2 is connected to port 0_2 of the PSoC pin, internally an output buffer B_2 is programmed to V_{ref-} , as well as connected to the internal analog multiplexer. The other end of R_2 and the reference piezo resistor R_1 junction connected to port 0_1 of the PSoC pin, internally connected to the analog input multiplexer as an another input. The reference R_1 's other end is connected to port 0_0 pin of PSoC, which is internally connected to positive reference voltage V_{ref+} through output buffer B_1 . The output of the analog multiplexer is amplified by programmable gain amplifier (PGA) block and then fed to a 12-bit analog-to-digital converter (ADCINC12) for digitization. The UART block transmits the digital image of the voltage drop across the piezoresistance R_1 and R_2 for further calculation, measurement and data transfer to personal computer.

Functionally, the output buffers B_1 and B_2 sets the reference voltage V_{ref+} and V_{ref-} to the built-in membrane piezoresistance R_1 and R_2 respectively as an excitation voltage to the resistive network literally to push a know current through a resistor and measure the voltage across the resistor. Simultaneous measurement of voltage across the piezo-resistance R_1 and R_2 were carried out through the input multiplexer (MUX) through the control program as per the measurement sequence.

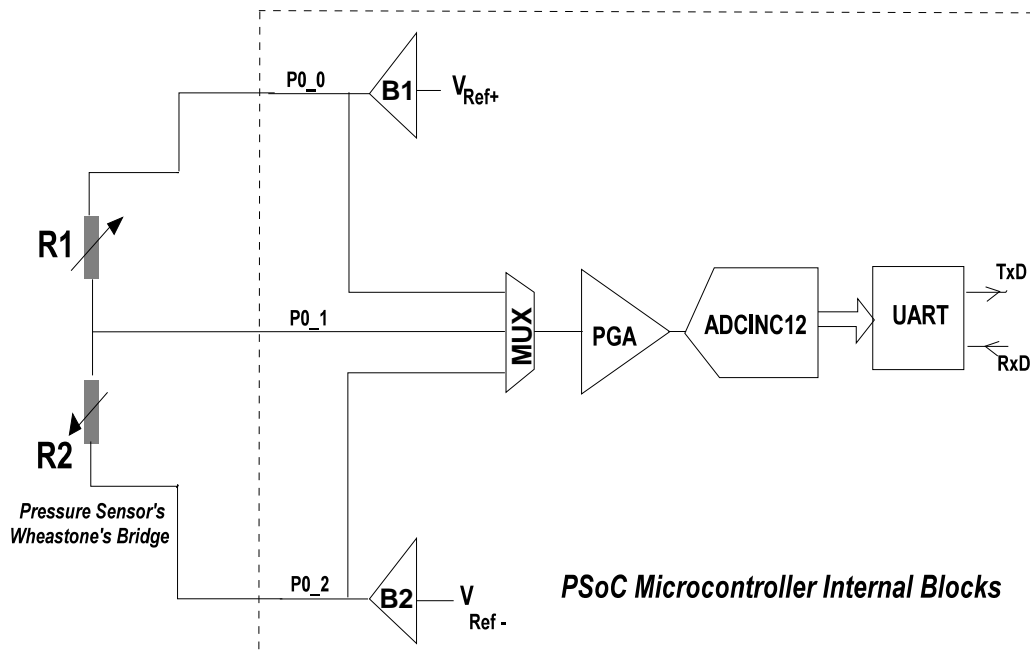


Fig. 5. Built-in Piezoresistance of a commercial pressure sensor connectivity to the PSoC internal (dotted box).

The resistance measurement has been carried out by sequentially measuring voltages V_0 corresponding to the reference voltage V_{ref+} , V_1 towards the voltage drop across the resistance R_2 , which provides measurement on change in resistance due to incident laser beam and V_2 corresponding to the reference voltage V_{ref-} . The PSoC microcontroller, with its Analog Output Buffers and input multiplexer, makes it an ideal choice for measuring resistance. The PSoC designer program developed for the interconnectivity of the component placed for the total functionality to measure and display on the PC screen is given in the Annexure-A. The following equation shows how the change in piezoresistance R_2 quoted on the thin membrane is determined, when the laser beam incident on the membrane:

$$R_2 = R_1 * [(V_1 - V_2) / (V_0 - V_1)].$$

As shown in the above equation, any offset errors in the measurement system are removed by the subtraction of two measured voltages. The ratio of these two difference values removes any measurement path gain error. This leaves the measurement error to be determined by: R_1 . This is valid as long as the measured signal is never outside the range of the ADC. Fig. 6 shows the implementation of internal blocks of PSoC for MEMS pressure sensor piezoresistive connectivity for Laser power measurement application.

The mixed array of analog and digital blocks in a single chip is an added advantage of using PSoC microcontrollers. Virtual instrument (VI) based graphical language control program written in LabVIEW acquires the wireless transmitted RF sensor signal, provides on-line plotting, saving data and analyzing the data as per the user requirement. The front panel *virtual instrument* menu driven graphical control program user screen for the laser power measurement is shown in Fig. 7. The on-line plot of an acquired data for the incremental laser power of 0 mW up to 300 mW, decimal display as well as the slider for visual indication of laser power is displayed in the user screen.

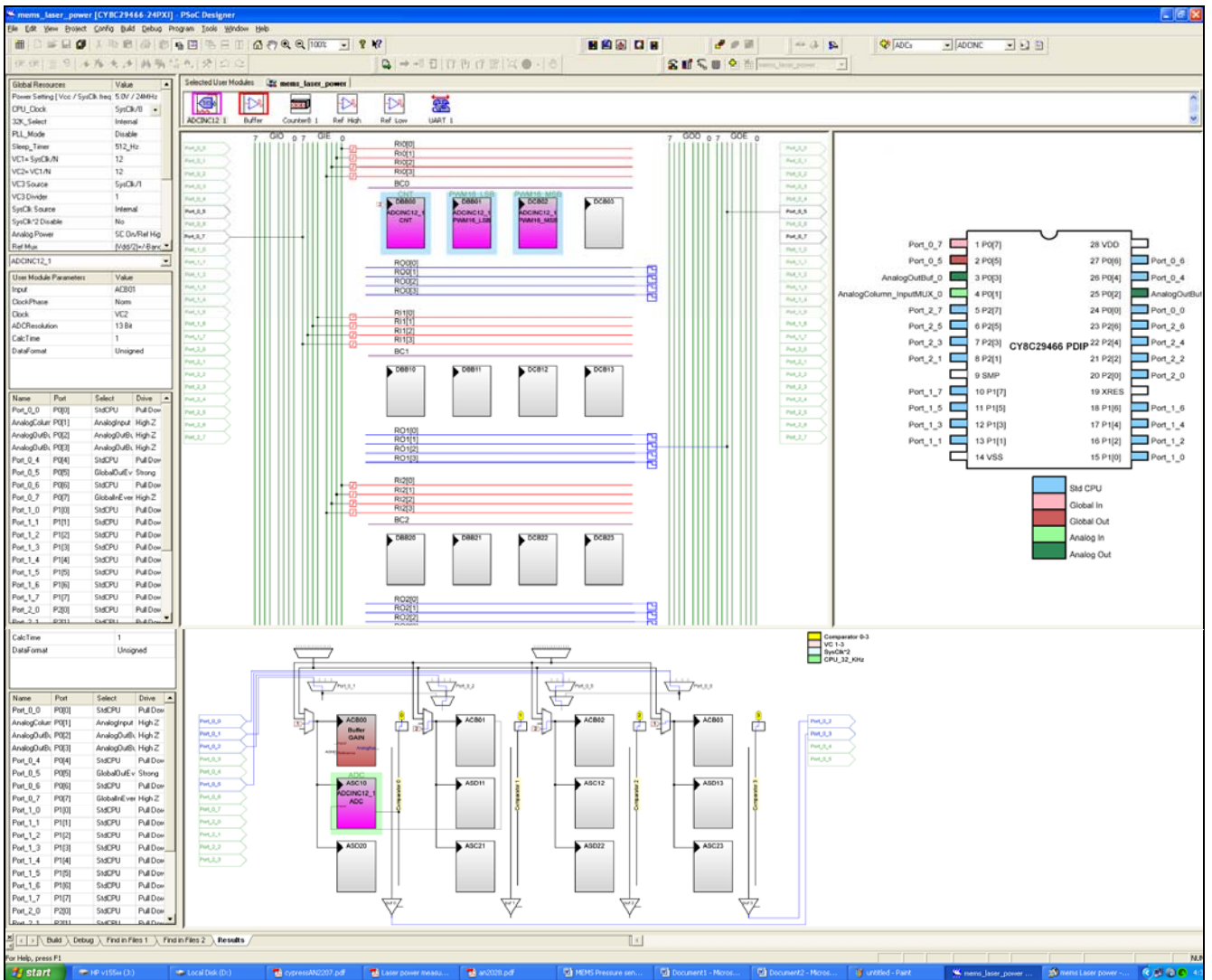


Fig. 6. PSoc microcontroller designer internal block diagram and pin diagram.

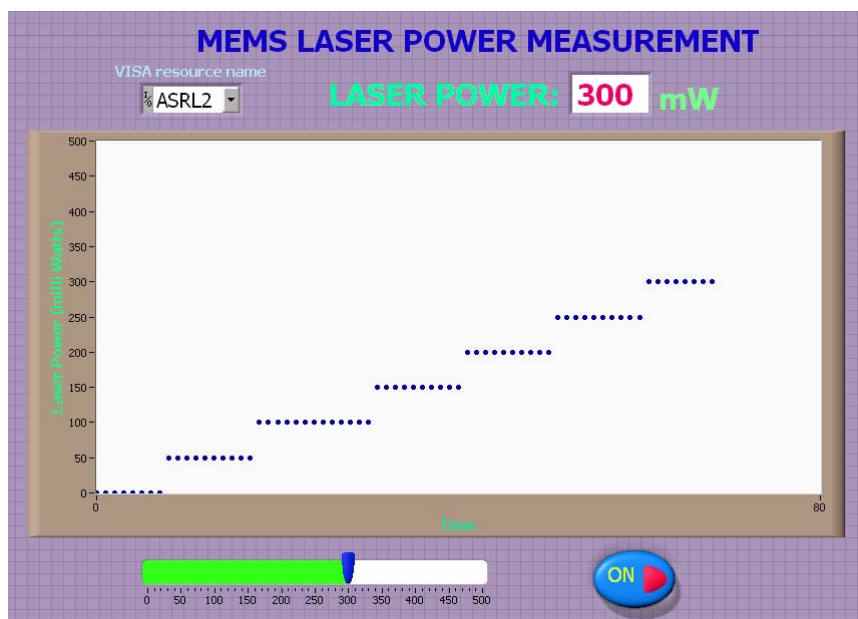


Fig. 7. Front Panel Graphical User Interface LabVIEW Program: Screen for MEMS Laser Power Measurement System.

4. Conclusions

A novel prototype sensor making use of commercial MEMS pressure sensor in a reverse engineering approach can measure the laser power up to 300 mW with a good resolution. By using the suitable membrane wide range and better resolution can be achieved. This design enables a new design approach to use a microstructured piezo resistance pattern on a thin membrane for laser power measurement.

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References

- [1]. Introduction to Lasers and Their Applications, *Addison-Wesley Publishing Co.*, Reading, MA, 1978.
- [2]. Jayapandian J., Embedded Design and Virtual Instrument Programming Simplify Laboratory Automation, *Current Science*, 90, 6, 2006, pp. 765 – 770.

Appendix – A

//PSoC Designer Program for the MEMS Laser Power Measurement system//

```
#include <m8c.h> // part specific constants and macros
#include "PSoC_API.h" // PSoC API definitions for all User Modules
#include "ADCINC12_1.h"
#include "Buffer.h"
#include "Ref_Low.h"
#include "Ref_High.h"
#include "Counter8_1.h"
#include "UART_1.h"
#include "stdlib.h"
#include "math.h"
#define CR 0x0D
#define LF 0x0A
#define Rref 0.1 //100 ohms
int iV0, iV1, iV2, index1, index2, dec, dec2, index3, index4;
float rAnswer;
float rR, remainder;
char res1[10], res2[10];
// //SteinHart-Hart Constants
float rA = 0.001130151;
float rB = 0.000234011;
float rC = 0.000000088;
void main(){
    Ref_Low_Start(Ref_Low_HIGHPOWER);
    Ref_High_Start(Ref_High_HIGHPOWER);
    Buffer_Start(Buffer_HIGHPOWER);
    ADCINC12_1_Start(ADCINC12_1_HIGHPOWER);
    UART_1_CmdReset(); // Initialize receiver/cmd buffer
    //UART_1_IntCntl(UART_ENABLE_RX_INT); // Enable RX interrupts
```

```

UART_1_Start(UART_PARITY_NONE);
ACA00CR2 |= 0x1c; //set testmux to ref+
ACA03CR2 |= 0x18; //set testmux to ref-
M8C_EnableGInt;
while(1){
//Reading V0 (Vref+)
  ABF_CR = (ABF_CR & 0x70) | 0x8d; //Selecting Column 0 Input mux
  AMX_IN =(AMX_IN & 0xfc) | 0x01; //P0.3
  ADCINC12_1_ClearFlag();
  ADCINC12_1_GetSamples(1);
  while(!ADCINC12_1_fIsData());
  iV0 = ADCINC12_1_iGetData();
//Reading V1 (Signal)
  AMX_IN =(AMX_IN & 0xfc) | 0x00; //P0.1
  ADCINC12_1_ClearFlag();
  ADCINC12_1_GetSamples(1);
  while(!ADCINC12_1_fIsData());
  iV1 = ADCINC12_1_iGetData();
//Reading V2 (Vref-)
  ABF_CR = (ABF_CR & 0x70) | 0x0d; //Selecting Column 1 Input mux
  AMX_IN =(AMX_IN & 0xf3) | 0x04; //P0.2
  ADCINC12_1_ClearFlag();
  ADCINC12_1_GetSamples(1);
  while(!ADCINC12_1_fIsData());
  iV2 = ADCINC12_1_iGetData();
  rAnswer =((float)(iV0-iV1))/((float)(iV1-iV2));
  rR=rAnswer * Rref;
// Setting the Baud rate to 115200
  Counter8_1_WritePeriod(155);      /* set period to 51 clocks */
  Counter8_1_WriteCompareValue(78); /* generate a 50% duty cycle */
  Counter8_1_EnableInt();           /* ensure interrupt is enabled */
  M8C_EnableGInt;                   /* enable global interrupts */
  Counter8_1_Start();               /* start the counter */
//Transmitting via UART
  UART_1_CPutString("\n\nThe Pizeoresistance value is ");
  res1[0]=0;
  res2[0]=0;
  dec= (int)rR;
  remainder=(rR-dec)*1000;
  itoa(res1, dec ,10);
  itoa(res2, (int)remainder,10);
  index1=0;
  index2=0;
  index3=0;
  index4=0;
  while (res1[index1]){
    while (!(bUART_1_ReadTxStatus() & UART_TX_BUFFER_EMPTY) ) {}
    UART_1_SendData( res1[index1]);
    index1++;
  }
  UART_1_CPutString(".");
  while (res2[index2])
  {while (!(bUART_1_ReadTxStatus() & UART_TX_BUFFER_EMPTY) ) {}
    UART_1_SendData( res2[index2]);
    index2++;
  }
  if ( res2[0]!= 0)

```

```
{while (!(bUART_1_ReadTxStatus() & UART_TX_BUFFER_EMPTY)) {}  
    UART_1_SendData( LF);  
while (!(bUART_1_ReadTxStatus() & UART_TX_BUFFER_EMPTY)) {}  
    UART_1_SendData( CR);  
    res2[0] = 0;  
    index2 = 0;  
    index1=0;  
  
    }  
}  
iV0=0;  
iV1=0;  
iV2=0;  
}
```

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