# The Digital Altimeter

**Sariana binti Safian**
**Faculty of Electrical Engineering**
**Universiti Teknologi MARA**
**40450 Shah Alam**
**Selangor Darul Ehsan**
**Supervisor: Ir. Muhammad bin Ibrahim**

***Abstract*** - This paper presents the design and construction of an altimeter to indicate height which is used for trips, hiking, biking and other hobbies. It can also be used for determining the altitude of an aircraft, jet fighter and missile. This paper will also discuss on the theories related to altitude with respect to pressure as well as the architecture of the altimeter's circuit hardware. The hardware construction section of this paper will explain on the processes included to select the circuit hardware, characteristics of the circuit, as well as the processes involved in the design and construction of the circuit. Simulation software MPLAB C Compiler is used to compile the program while Protel DXP 2004 is used to design the PCB schematic in which are also discussed in this paper. The last part of this paper will discuss on the results of the simulation from MPLAB C Compiler.

***Keywords*** – Altimeter, altitude, pressure, MPLAB C Compiler, Protel DXP 2004.

## 1.0 INTRODUCTION

### 1.1 Introduction to Altimeter and Altitude

An altimeter is an active instrument used to measure the altitude of an object above a fixed level [1]. According to Cambridge Dictionary, an altimeter is an instrument indicating altitude that shows height above sea level, especially one mounted in an aircraft and incorporating an aneroid barometer that senses differences in pressure caused by changes in altitude [2]. In aviation, the term altitude can have several meanings. True altitude is the elevation above mean sea level, in other words, the vertical distance of a level, a point or an object considered as a point, measured from mean sea level while indicated altitude is defined as the reading on the altimeter when it is calibrated to the local barometric pressure, referred to as the "altimeter setting" [1].

### 1.2 Relationship between Pressure and Altitude.

Altitude is measured by using an air pressure sensor. Pressure sensors can be divided into two types; absolute pressure sensor which is a sensor that measures input pressure in relation to a zero pressure. This type of sensor is normally used to calculate altitude. The other type of sensor is the differential sensor which is designed to accept simultaneously two independent pressure sources [3]. Air pressure changes constantly due to varying weather conditions. Therefore, measured altitudes in the same position may vary. Pressure variations due to weather conditions, or indoor air-conditioning, may affect altitude readings [4]. As altitude increases, pressure decreases.

This paper is divided into three main sections. The first section introduces the concept of altitude, pressure and the definition of an altimeter. The second section of this paper describes the technical parameters of the altimeter as well as the basic components involved in the architecture of the altimeter. The third section explains the methods involved in the construction and development of the hardware and software of this project. Finally, the last section will discuss on the results obtained by the simulation by using MPLAB SIM.

## 2.0 METHODOLOGY

### 2.1 Hardware Construction

#### 2.1.1 <u>Circuit Description</u>.

The block diagram of the altimeter circuit is shown on the figure below

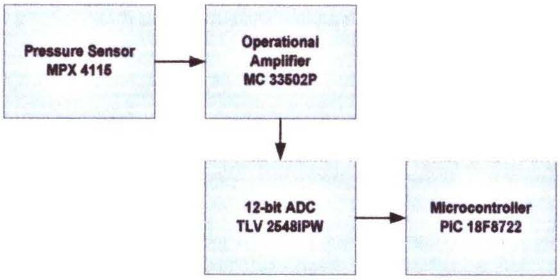


Figure 1 Block Diagram of Altimeter.

The resolution of this altimeter is approximately 1m. The maximum usable altitude of this altimeter is from 0m to 2000 meters. The altimeter's barometer range is from 700 to 1100 hPa. The altimeter uses a basic natural law that states atmospheric pressure decreases with increasing altitude. The basic formula of altitude is given by [5]:

$$D = -\ln(p/p_1) \times R \times T/g \qquad (1)$$

D = altitude in meter
Three variables have to be measured:
T = average temperature in degrees Kelvin
$p_1$ = atmospheric pressure at zero level
p = atmospheric pressure at current level

While the remaining values are fixed constants:
R = universal gas constant=286
g = gravitational acceleration

2.1.2 Basic Components.

(a) PIC 18F8722 (Microcontroller).

To provide the signal processing for pressure values, a microprocessor is needed. The heart of the altimeter is the PIC (Peripheral Interface Controller) Microcontroller which collects and processes data from all other devices. In this project, the Microcontroller PIC18F8722 was chosen due to its high-computational performance at an economical price, with an addition Enhanced Flash program memory of up to 128 Kbytes. Their program memory is used to store and execute the compiled C, or assembly code (machine language).

(b) MPX 4115AS (Motorola Absolute Pressure Sensor).

The absolute pressure sensor Motorola MPX 4115AS is used to sense absolute air pressure in an altimeter or barometer applications. Motorola sensor integrates on-chip, bipolar op-amp circuitry and thin-film resistor networks to provide a high level analog output signal and temperature compensation [7]. It has a range of 15 to 115 kPa and will produce a voltage output proportional to the pressure with a range of 0.204 to 4.794 V. The relationship between pressure and voltage are given by:

$$V_{out} = V_s \times (0.009P - 0.095) \qquad (2)$$

Where:

$V_s$ = supply voltage and
$P$ = pressure in kPa.

The sensitivity of this component is one of the main parameters that determine the resultant resolution of the altimeter [5]. The sensitivity of the absolute pressure sensor MPX4115 is about 46mV/kPa [7]. This fact indicates that 1 hPa decrease in pressure is equivalent to 8 meter increase in altitude. By using formula as in (1) and elementary mathematics it is found that 1 meter change in altitude causes about 0.6mV change in output voltage [5].

(c) MC33502P (One Volt SmartMOS Operational Amplifier).

The main goal of the signal conditioning circuit is to convert the MC33502P differential output to a single-ended, ground-referenced output. The MC33502 operational amplifier provides rail-to-rail operation on both the input and output. This rail-to-rail operation enables the user to make full use of the entire supply voltage range available [8]. Amplification is given by $R_1/R_3$. Since $R_1$=22kΩ and R2=10kΩ, it gave an amplification factor of 2.2.

(d) TLV2548 Serial Analog-to-Digital Converters).

The analog-to-digital converter used is the TLV2548 CMOS analog-to-digital converter (ADC). It is a 12-bit successive approximation converter used to convert an analog voltage from the pressure sensor to a 12 bit serial stream [9]. It is designed to interface and communicate with a microcontroller, and is therefore suitable for this application. The output of the operational amplifier is connected to the input of the AD converter. The AD converter uses a reference voltage equal to the level of the altimeter's power supply. The result of each conversion is sent upon request to the microcontroller through an SPI interface [9].

## 2.2 Software Development

### 2.2.1 MPLAB IDE v7.30.

MPLAB IDE (MPLAB Integrated Development Environment) is an integrated toolset for the development of embedded applications which employed Microchip's PIC microcontrollers [10]. This toolset enables the user to easily write an assembly code, in this case, a C language code, build the program and assemble the project with MPLAB wizards. It has built in simulator and debugger that allow the user to test the code. It is basically done by using the Stimulus Controller which is useful for debugging. This option substitutes the actual circuit with a virtual one [11].

The version used to compile and simulate the program is the MPLAB IDE v7.30. It is equipped with MPLAB SIM (simulator) as well as local variables window for many C compilers. Since the main program will be written in C language, the complier used to compile the program is the MPLAB C18, the highly optimized compiler for the PIC18series microcontrollers. This compiler integrates into MPLAB IDE to function transparently from MPLAB project manager, editor and debugger. MPLAB SIM is used as a high speed software simulator for PIC microcontrollers which are complete with peripheral simulation, complex stimulus injection and register logging [10].

(a) Flowchart of the program.

At the beginning of the program, the pin configuration on the microcontroller is defined. The chip select and enable pins are used to enable the PIC microcontroller to select the altimeter and to indicate that information data transfer will take place between the PIC microcontroller and the Analog-to-Digital converter. The ports on the microcontroller are also configured on this stage.

After the initialization phase is done the data is stored to the memory. The next step is to turn ON the pressure sensor MPX4115AS by applying bias voltage to the channel transistor T1 (P-MOSFET). This allows the pressure sensor to take measurement of pressure which in turn will be converted to output voltage.

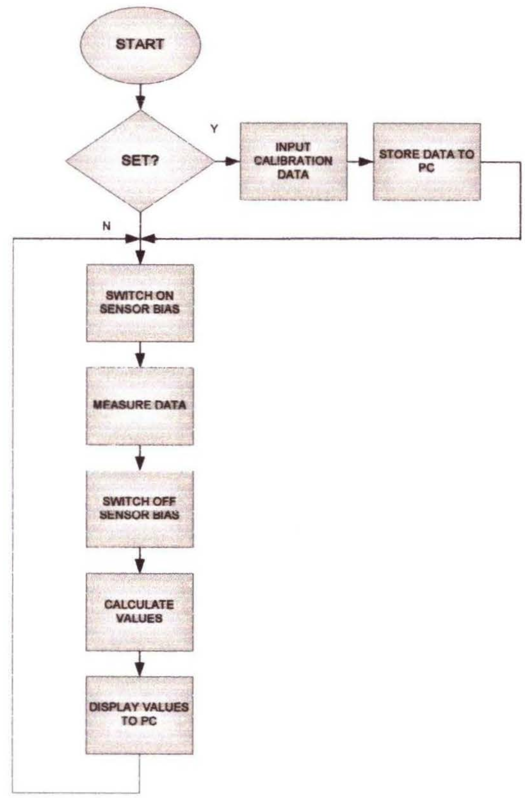


Figure 2 Flowchart of the program.

After measurement has been taken, the T1 (P-MOSFET) channel transistor is turned OFF to save the usage of power. This is done as the sensor and operational amplifier takes a big portion of the total energy. It allows the operational amplifier and the pressure sensor to be powered only during measurement.

The AD converter will convert analog voltage output from the operational amplifier to serial data to be transmitted to the microcontroller. The AD converter is a 12-bit approximation converter which produces a stream of 12-bit serial data within the required voltage span of the AD converter.

The obtained bit count will be transmitted serially to the PIC microcontroller and the PIC will calculate the altitude of the altimeter. The final values will be displayed on the monitor.

(b) Programming steps.

Programming a microcontroller normally involves the following steps [11]:

- Coding/Debugging – This step is done using a high level language such as C or assembler language and is written on the *Text Editor* of the compiler. Certain configurations are done before compiling the program. After all the configurations are done, the project is built and is checked for errors.
- Compiling the code into machine language - After all errors checked, the next step is to compile the program into machine language file (.hex). This file contains the original program code converted into a hexadecimal format.
- Simulating by using MPLAB SIM – MPLAB SIM is a simulator that runs as a software program on the computer. To test the application on the simulator, stimulus signal can be applied to pins and registers. For more complex stimulus control, actions are entered in the SCL Workbook. Once the events are described in the SCL Workbook, they are compiled into an SCL file that can be loaded into the Stimulus Controller.

### 2.2.2 Protel DXP 2004.

For the construction of the Printed Circuit Board (PCB) of the altimeter, Protel DXP 2004 was used. This construction of the PCB involves designing the circuit board by using Protel DXP 2004 software. For this altimeter project, all the components for this circuit are Surface Mounted Devices (SMD). The designed PCB have a dimensions of W=29.40mm and L=49.02mm.

(a) Component Selection.

Selecting the components for the altimeter involves the following steps:

- Refer to manufacturer's catalog and surf the internet to survey for price and availability.
- Check for technical parameters such as current characteristics and size of case or packaging.
- Select the best components that match all requirements. List out order code.
- Contact the manufacturer to place order. Determine shipping period.
- Collect components.

(b) Steps to design a PCB.

Steps to design a multilayer PCB [12].

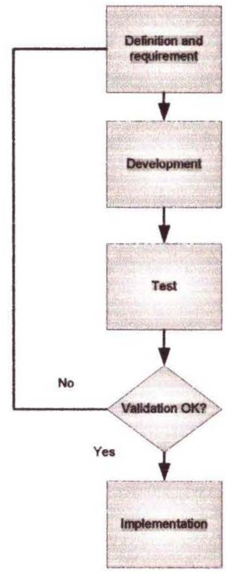


Figure 3 PCB Design.

To design a PCB, the first thing to be considered is to define scope and requirement of the board. Parameters such as types of component, board dimension and component's size have to be defined. Once all the parameters defined, the development stage requires designing the board by using the schematic editor. To test the designed PCB, the board must go through routing process. The next step is to verify that the routed circuit board conforms to the design rules by running Design rule Check. If the entire test passed, the PCB is fabricated by generating manufacturing files which include the output Gerber files which is used to fabricate the PCB.

## 3.0 RESULT AND DISCUSSION

In this section, we will discuss on the results obtained from the simulation using MPLAB SIM. During simulation, the program being simulated by the simulator may require stimuli from the outside. The stimulus could be a pulse to an I/O pin of a port or it could be a change to the values in an SFR (Special Function Register). By using MPLAB SIM, stimulus input could be injected to the pre-defined input pins or registers by using the Stimulus Controller. The type of stimulus sources applied is the sequential data which can be in the form of dialog or a file and are applied to pins, registers, or bits.

### 3.1 Stimulus Controller

The Stimulus Controller is used to send signals to pins or registers in the simulator. Figure 4 shows the stimulus that is applied to the registers. The first line shows a register stimulus RCREG1 is injected and the resulting output that will be displayed on the SIM Uart1 window is the value of the current pressure which is "1010". The next asynchronous stimulus is the RCREG1 input 0x0D that is used to let the program to proceed to the next line. The last RCREG1 input stimulus register "x" is used to force the program to exit the program loop.


Figure 4 Stimulus Controller Window.

After the stimulus signal is applied to the registers, the resulting altitude of the altimeter can be shown on the Output window, via the SIM Uart1 tab. The initial output will appear as in the Figure 5. The current pressure 1010 hPa is the result of firing the first asynchronous stimulus input on the Stimulus Controller window.

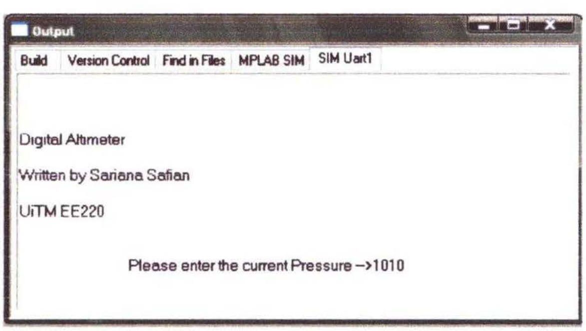


Figure 5 Asynchronous Stimulus 1 Fired.

### 3.2 Watch

The Watch window enables the user to update the contents of the register so that it can be used as a trigger. After the asynchronous stimulus is applied, the next step is to update Special Function Register (SFR) value of the SSP2STAT register on the Watch window. The SFR value could be used as a trigger if it is updated by the user, which is by setting specific value to the SFR. On Figure 6, we can see that the SFR register SSP2STAT value is changed from 0xC0 to 0xC1. By doing this, the contents of the SSP2STAT register could be read. This is done to set the BF bit (buffer) status as "Full".

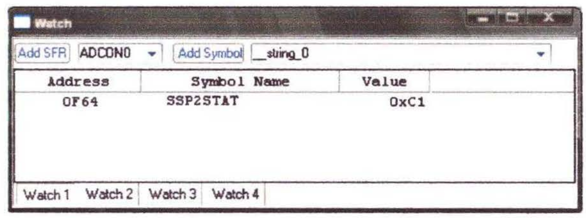


Figure 6 Watch Window.

#### 3.2.1 Figures of Current Height of the Altimeter.

Figure 7 to 11 show the current height of the altimeter when the SFR register SSP2STAT is triggered by a value of 0xC1 on the Watch window. The resulting altitude readings will be in unit meter and it will be recorded continuously until the program is forced to a "Halt".

(a) Current Height at 10 meters.

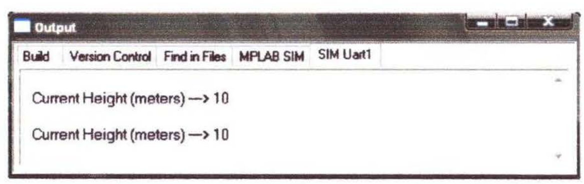


Figure 7 Current Height at 10 meters.

(b) Current Height at 26 meters.

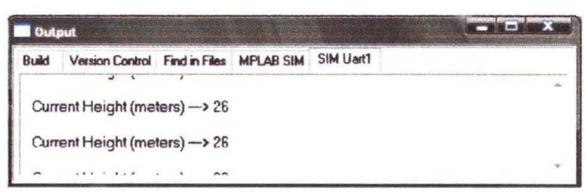


Figure 8 Current Height at 26 meters.

(c) Current Height at 192 meters.

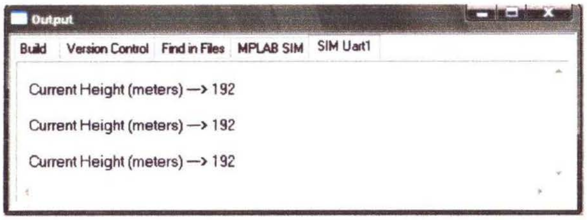


Figure 9 Current Height at 192 meters.

(d) Current Height at 224 meters.

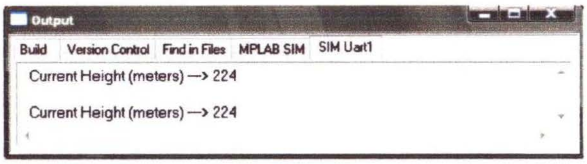


Figure 10 Current Height at 224 meters.

(e) Current Height at 255 meters.

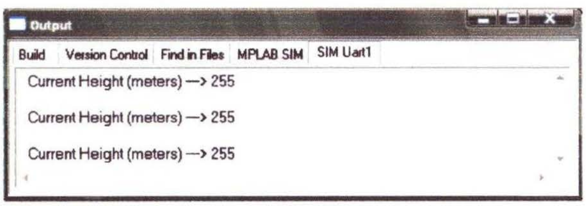


Figure 11 Current Height at 255 meters.

## 4.0 CONCLUSION

Air pressure is caused by the weight of air pressing down on the earth. Since the pressure depends on the amount of air above the point of measurement, the pressure falls as we go higher. Atmospheric pressure is inversely proportional to altitude. As altitude increases pressure decreases. The air pressure also changes with weather. For a given location during the course of the day the air pressure may change considerably depending on the weather. An altimeter that measures altitude by measuring pressure will therefore need to be calibrated in regular intervals. The objective of developing and constructing an altimeter to indicate height is successfully achieved in this paper.

## 5.0 DEVELOPMENT AND FUTURE WORK

For the development and future work of this altimeter, the author thinks that to increase the accuracy of the altimeter, a higher-bit Analog-to-Digital converter can be used in replace of the current 12-bit ADC. A 14-bit or 16-bit ADC is considerably good to increase the resolution but these devices are rather expensive. The performance of the altimeter could be increased by adding a temperature sensor as an input to be applied to the Analog-to-Digital converter. This temperature sensor will record the actual temperature while it records the pressure of the altimeter.

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