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Electrical Power
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ELECTRONIC ENGINEERING

Design of Altitude Measuring Unit for Guided Applications

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***Abstract*— This research paper focuses on the design of altitude measuring unit (Altimeter Unit) for infrared target seeking guided missile based on IGS (Inertial Guidance System). Moreover, the investigation highlights on IGU (Inertial Guidance Unit) that comprises accelerometers, pressure sensors and electromagnetic devices.**

The data acquisition, data storage, data computing facilities need to be extremely precise for this system. This paper also covered literature survey and source, collection of design for missile motion and the force vector derivations are also mentioned in the selection of control devices and equipments.

The software source code in each portion is developed for MPASM assembler and PIC C complier.

This research paper also endeavours to build a small model missile body to test our system on board. The design used data acquired from tests conducted by internationally known missile research laboratories the functional test results are explained and discussed for further extensions.

I. INTRODUCTION

This paper aims to construct a pressure sensor circuit to sense the absolute pressure and convert this pressure to give the altitude of the missile. This circuit includes the pressure sensor and microcontroller that store the data while in flight. It also includes the sensor amplifier that converts this output of pressure sensor to signal from 0.05 to 5V dc range the PIC16F877 is used for the ADC (analog to digital converter) because the output of sensor is an analog.

The altimeter determines altitude by sampling the surrounding air pressure during flight and comparing it with the air pressure at ground level. As the altitude increases, the air pressure is also decreased, and the altimeter unit converts the pressure difference to altitude.

The two main items used in altimeter unit are SCC15A pressure sensor and PIC 16F877. Specifically, the design provides the following features: saving the reference pressure, saving the pressure data in 2K EE-PROM, saving the take-off pressure.

II. OVERALL BLOCK DIAGRAM OF ALTIMETER UNIT

The altimeter is an electronic device that uses a pressure sensor to detect the air pressure difference between ground and in flight altitude. As the rocket rises up in the air space, the air pressure decreases. The altimeter records the maximum altitude attained by detecting the minimum air pressure measurement and also required time for reaching it's apogee.

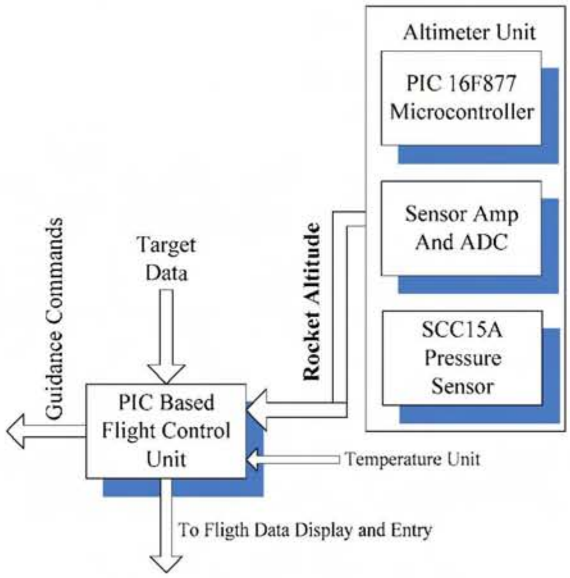

Fig. 1 Block diagram of Altimeter Unit

III. HARD WARE DESIGN FOR THE SYSTEM

In order to design an altimeter unit, it should be divided into several units or modules for its particular task and saved which first can be texted or implemented independently and than combine together. Firstly the separate lists for individual modules should be implemented.

There are some devices and components used in the design to implement the unit. There devices used in this system are: SCC15A pressure Sensor, 16F877 microcontroller, MAX 232, LM324, 4.0 MHz crystal oscillator, RS 232 cable.

A. SELECTION OF PRESSURE SENSOR

SCC15A Pressure Sensor

The SCC15A functions as a Wheatstone bridge. When the pressure is applied to the device, the resistors in the arms of the bridge, changes the resistance as shown in Fig. 2.

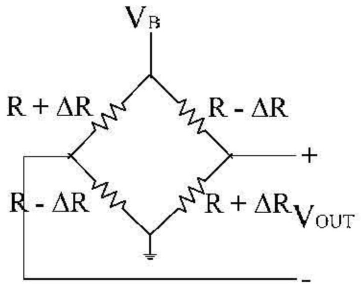

Fig. 2 Sensor Bridge Schematic
Source: Sensym.Inc

B. AMPLIFIER DESIGN

In order to optimize the SCC15A performance over temperature, a constant current source must be constructed. A current source of 1.5mA and an operating temperature range of -40 H C to +80 H C is recommended when using the SCC15A. There were two possible ways to construct a construct a constant current source. For this design, a resistor was connected to Vs to achieve a constant current source.

Since the pressure sensor does not contain and on-board amplifier, an amplifier design was used to maximize the signal. The intent of the amplification design is to produce a circuit which does not load the bridge, involves minimal components and provides maximum performance at the lowest cost. A quad-amplifier chip was used in conjunction with the SCC15A pressure sensor to achieve this.

The resulting differential output voltage, V_{out}, is easily shown to be

$$V_{out} = V_b * \Delta R/R. \quad (1)$$

However, since the change in resistance is directly proportional to the pressure, V_{out}, can be written as

$$V_{out} = (S * P * V_{os}) * V_b \quad (2)$$

Where:

V_{out} = output voltage in mV
S = sensitivity in mV/psi
P = pressure in psi
V_{os} = offset error (the differential V_{out} when the applied pressure is zero)
V_b = bridge voltage in volts.

The offset and sensitivity calibrations should present little problem in most applications. They can easily be corrected for in the amplification circuitry, or connected digitally if a microprocessor is used in the system.

There are several significant performance features implemented into this system design. In order to allow for operation over a wide altitude range (0 - 15,000 ft.), the system is designed to display barometric pressures ranging from 30.5 in-Hg. to am minimum of 15.0 in-Hg. The display will read "low" if the pressure measured is below 30.5 in-Hg. These pressures allow for the system to operate with the desired resolution in the range from sea-level to approximately 15,000 ft. Because of the above reason we choose the SCC15A pressure sensor and its altimeter unit circuit.

Instrumentation Amplifier Design for Pressure Sensor

Design Requirement:

To design amplifier 0 to 5V dc output sending to input air pressure

Gain Requirement (Non Linear):

50x maximum with 20 kΩoutput impedance and 600Ω input impedance

Overall Gain = max output voltage/ max input voltage = 55.6

Max. I/P voltage = 90mV (from data sheet)

Gain = 1+ Rs/R6 + 2R5/RG

If R5 = R8 = 100kΩ
R6 = R7 = 100kΩ
RG = 3.7kΩ
Choose R9=1kΩ and set R10 =2.7kΩ

Note: R10 adjust until V_{out} = 5.0V when V_{in} = 90 mV

Table I
Comparison of Input Value and Output Values

V_{in}	0	45mV	70mV	90mV
V_{out}	0	0.05V	3.5V	5.0V

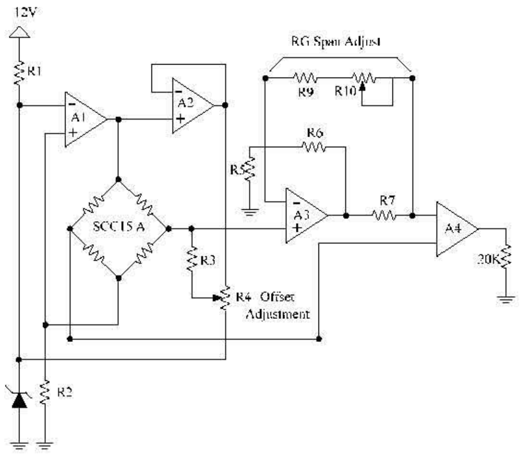

Fig. 3 Complete Instrumentation Amplifier

C. FEATURES OF 16F877 MICROCONTROLLER

- High performance RISC CPU
- 20MHz Clock Input-20ns instruction Cycle
- 8KX14 Work Flash Memory
- 368 X8 bytes RAM, 256 x 8 bytes of EEPROM data memory modules
- 3 independent timers
- Two capture / compare (CCP), PWM modules
- SPI and 12C Bus compatible
- 10 bit, up to 8 channel ADC

D. CONVERTING PRESSURE TO ALTITUDE

The altimeter works on the principle that the pressure within a column of air varies in a known way with height. The mathematical relationship that relates them is:

$$Z = (R\,T / g\,M)\ \ln (p_o / p) \qquad (3)$$

where Z is the height difference between the starting height and the measurement height, R is the gas constant (287.04 Jkg K for air), T is temperature of the air measured in Kelvin, g is the acceleration due to gravity ($9.80665 m/s^2$), M is the molar mass of the gas (in this case air), P_o is the atmospheric pressure at the starting height and p is the atmospheric pressure at the measurement high.

Table II
Pressure at Varying Altitudes

Altitude (feet)	Pressure (psi)
0	14.70
500	14.43
1000	14.18
2000	13.67
3000	13.19
4000	12.70
5000	12.23
10,000	10.10
80,000	0.403

E. COMPLETE SYSTEM OF ALTIMETER UNIT

Altimeter Circuit Using PIC16F877

The complete system of altimeter unit is as shown in Fig. 1.This circuit, uses the SCC15A pressure sensor, PIC16f877 and LM324.

Providing features:

1. displays the current air-pressure
2. saving of the pressure data in built-in memory of PIC16F877
3. saved data can be transferred to a PC after flight
4. PIC Source in C (PCM PIC C Compiler by CCS)

Operational Principles

1. Sensed the atmospheric pressure by SCC15A pressure sensor
2. SCC15A gives the 40-95 mV output voltage according to input pressure
3. amplifier stage amplifies the voltage from sensor to 0.05-5 V output voltage and applied to the PIC

Design for Pressure Sensor Unit

The complete schematic diagram for pressure sensor unit is as shown Fig. 5.

Design Requirement: To sense the atmospheric pressure of maximum 15psi and to develop the signal conditioning circuit for sensor. After achieving the sensor signal the processor operates for the conversion, storage, calculating and then reading again.

I/O pin Assignment: AN0 is set as the analog input and PORTB as the output port. But only RB0, RB1 and RB2 are used and other unused pins are set as output port to consume the low power. Pins CLKIN and CLKOUT are connected to a 4MHz crystal oscillator.

A/D Sample time calculation

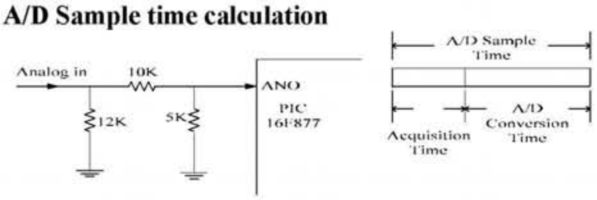

Fig. 4 A/D Conversion

Rs = (12k + 10k) // 5k = 4.1 kΩ

Acquisition Time,

T_{ACQ} = Amplifier Setting time + Holding Capacitor charging Time + Temperature Coefficient

$= T_{AMP} + T_C + T_{COFF}$

$= 2\mu s + T_C + [(\text{Temp}-25\ HC)(0.05\mu s/\ HC)]$

$T_C = -C_{HOLD}(R_{IC}+R_{SS}+R_S)\ \ln (1/2047)$

$= 11.1\ \mu s$

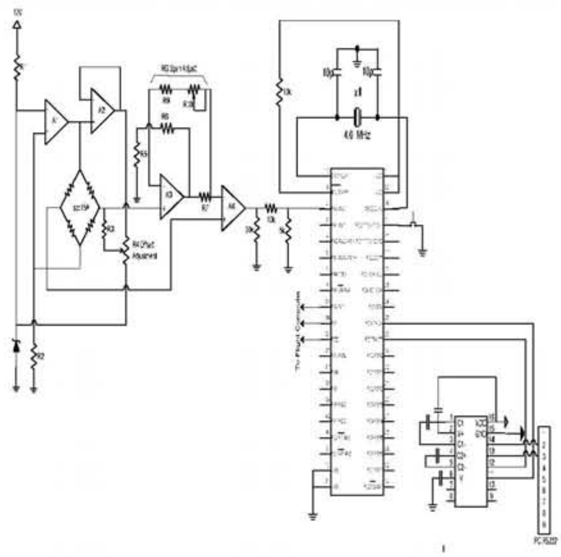

Fig. 5 Complete Schematic Diagram of Pressure Sensor Unit

Therefore, T_{ACQ} = 14.35 µs.

This calculation is based on the following application system assumptions from datasheet.

C_{HOLD} = 120 pF
Conversion Error = 1/2 LSB
VDD = 5V
Rss = 7kΩ (from graph in Fig. 6)
Temperature = 50 HC (system max)
V_{HOLD} = 0V @ time = 0

Analog L/P Model

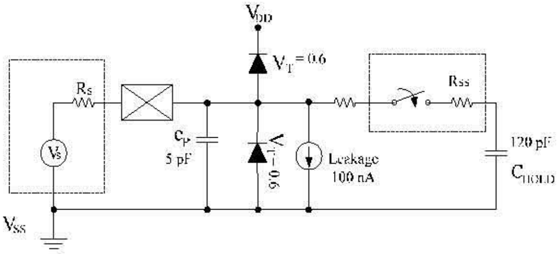

Fig. 6 A/D Conversion Graph
Source: http://www.microchip.com/

A/D Conversion Time

Table III
T_{AD} vs. Maximum Device Operating Frequency

A/D Clock	Source	T_{AD}	MaximumDevice Frequency
Operation	ADCS1:ADCS0	1.6µs	Max.
2TOSC	00	1.6µs	1.25 MHz
8TOSC	01	1.6µs	5 MHz
32TOSC	10	1.6µs	20 MHz
RC	11	2-6µs	

Note 1: The RC source has a typical T_{AD} time of 4 µs.
Selecting the A/D conversion time
T_{AD} = A/D conversion time per bit
A/D conversion = 11.5 T_{AD} per 10bit conversion

Since the device frequency is 4MHz, the device must be in SLEEP mode. (According to data sheet). So the internal RC oscillator is selected as the source of A/D conversion clock. Therefore,

T_{AD} = 4µs. (Typing time of RC source According to data sheet)
A/D conversion = 11.5 x 4
= 46µs. for 10 bit
A/D sample time = T_{ACQ} + T_{AD}
= 14.35 + 46
= 60.35 µs.

From data sheet, minimum delay time before acquisition again = 2 TAD = 8 µs. So, A/D sample time = 60.35 + 8 = 68.35 µs.

Selecting Oscillator

PIC16F877 provides the feature of on-chip RC oscillator (IntRC mode) running approximately at 4 MHz. This mode is the least expensive oscillator available. IntRC mode is used for timing insensitive applications. RS-232 is not recommended due to the inherent inaccuracies of an RC oscillator.

Hence, other four different oscillator modes are considered to choose. These four modes are: LP Low Power Crystal, XT Crystal/ Resonator, HS High Speed Crystal/ Resonator, RC Resistor/ Capacitor.

Choice:

4MHZ crystal oscillator is chosen.

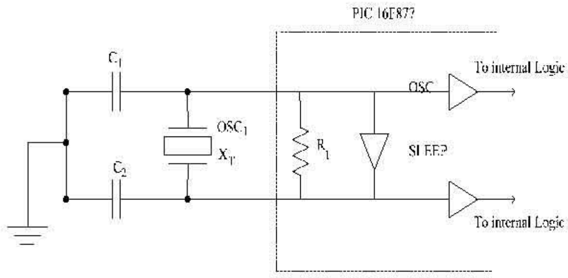

Fig. 7 Crystal operation
Source: http://www.microchip.com/

Choose C_1 = C_2 = 20pF (According to data sheet)

Communication Protocol

PIC16F877 has a standard serial (FS232) interface built in, which permits use of standard protocols to transfer data at 9600 bits/sec. To set the baud rate in SPBRG (Baud rate generator) register:

Baud = F_{osc} / (16X+1)
where,
Baud Rate = 9600 ps
Fosc = 4MHz
X = value in OPBRG
Then,
X =
= 25.04
X = 25

IV. HARDWARE IMPLEMENTATION

The pressure sensor was tested to know whether the pressure sensor works properly or not. Then the adjustment was made with the amplifier as the following procedures:

1. At reference pressure (0 psi for diff, and gage adjust R4 until the output reads 0.050V.
2. With full pressure applied adjust R10 (span adjust) until V_{out} reads 5.0V.
3. Repeats steps 1 and 2.

After the testing process, the PCB layout design was developed and the PCB board was implemented. The experiment test was conducted.

Fig. 8 Top View of Pressure Sensor Circuit

Fig. 9 Bottom View of Pressure Sensor Circuit

V. SOFTWARE IMPLEMENTATION

The software implementation procedure is not outlined due to the limited size of the paper.

VI. CONCLUSION

The pressure sensor and temperature measurement module devices are used for rocket and missile applications and their endurance, dependability and efficiency have already been tested. This paper has presented some portions of the tests for reliability of components and they were found appropriate. The integration of sensor data into embedded controllers prior to flight computing is a very latter day concept. Previous designs are based on flight computer data input directly from sensors. The new concept of using embedded system was tested and found more adaptable than previous system. The reason being that complexity of programming and processor run time are greatly reduced since separate processors are working simultaneously. The conversion of analog data to digital data is done separately in contrast to combined operation in a single processor. Thus embedded technology is most appropriate for guidance technology applications.

VII. VII. FURTHER DEVELOPMENT

In out altimeter unit, we used SCC15A pressure sensor. It can operate only for 0 to 15 psi pressure range. We can enhance the altimeter unit for dynamic pressure sensing and banding time pressure sensing for rocked by using the pressure sensor, such as MSP400, which can operate for higher-pressure range.

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