AIRCRAFT PRESSURE MEASUREMENT AND CALIBRATION SYSTEM

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Abstract: This project aims at developing a product which supports different types of pressure sensors, absolute, differential and gauge. The product is used shall be used as a ground servicing equipment calibrated in lab. This product shall be used to validate or cross verify the aircraft pressure system. The product will not be mounted on the aircraft.

Product being designed facilitates the display of pressure being applied currently and calibration. The hardware can be configured for three different applications as mentioned below

- PSTE (Pitot Static Test Equipment)
- FTLT (Fuel Tank Leak Tester)
- ASI (Air Speed Indicator)

The board can be configured to act as PSTE, FTLT or ASI by burning individual software on the IC for individual applications.

Calibration procedure for each of these applications differs a little bit based on what type of pressure sensor(s) is (are) connected. Primary data is pressure data in PSI and rest all derived data and pressure unit conversion. (Calibration of sensor is stored and displays the applied pressure). There will be mathematical air data calculation, air data unit conversion and pressure unit conversion.

The product has LCD display for user friendly messages for measurements/calibration etc. Four keys are provided for configuration/calibration.

I. System Reference

Aircraft constantly encounter atmosphere pressure changes as they climb, descend, accelerate or decelerate. The Pitot-static system is sensitive to airspeed, altitude and rate of altitude change. An Air Data Test set provide means to leak test an aircraft's Pitot-static system. It also simulates pressure and vacuum conditions required to calibrate the airspeed and altimeter, vertical speed, manifold pressure and engine pressure ratio (EPR) indicators.

A Pitot-static system is a system of pressure-sensitive instruments that is most often used in aviation to determine an aircraft's airspeed, Mach number, altitude and altitude trend. A Pitot-static system consists of a Pitot tube, a static port and the Pitot-static instruments.

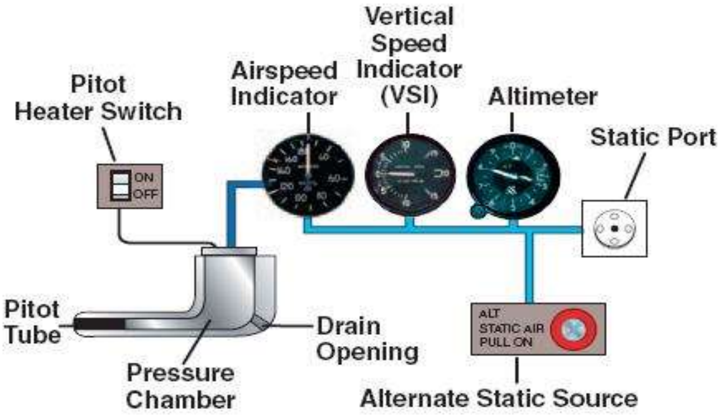

Figure 1

The Pitot-static system of instruments uses the principle of air pressure gradient. It works by measuring pressures or pressure differences and using these values to assess the speed and altitude. These pressures can be measured either from the static port (static pressure) or the Pitot tube (Pitot pressure). The static pressure is used in all measurements, while the Pitot pressure is only used to determine airspeed.

Pressure instruments operate by sensing changes in the pressure of air surrounding the aircraft. Altimeter shows static pressure as altitude. Air Speed Indicator indicates the difference between Pitot pressure and static pressure. Vertical speed indicator indicates the rate of static pressure change relating to rate of climb or descent.
The Air Data Unit (ADU) is a device, which measure static and differential pressures using pressure sensors and impact pressure (difference between the Pitot pressure and the static pressure). From these parameters various aerodynamic (Air Data) parameters: Mach-Number, Computer Air speed, Total Air speed, Standard Altitude, Altitude Rate etc. can be calculated. The ADU usually transmits these Air Data parameters via the standard ARINC digital lines.

Our project targets development of product which is used as a ground servicing equipment calibrated in a lab. This product is used to validate or cross-verify the aircraft pressure system. This product will not be mounted on the aircraft.

II. Product Description

Primary reference (pre-calibrated unit) is available in lab environment. Primary unit is not portable. Our project targets a product design which acts as a Secondary Unit for verification of the calibration at the site.

The product being designed is a single-board solution wherein different types of pressure sensors can be connected as inputs. Output of the pressure sensors is analog. Pressure sensors output serve as an input to the ADC inside the micro-controller. The product has LCD display for User-friendly messages during measurements/calibration.

Calibration is to ensure that indicated reading is equal to the applied pressure. The calibration of the unit has to be done in order to ensure that the errors that creep into the indication due to individual sensor characteristics, electronics and ADC are minimized.

Calibration is done over 7 points, spaced equally/closely as physically as possible (based on availability of masses).

Four keys are provided for configuration/calibration. The board can be configured to act as PSTE, FTLT or ASI by burning individual software on the micro-controller for different applications.

Calibration procedure for each of the application differs a little bit based on what type of pressure sensor is connected, absolute, differential or gauge. Primary data is Pressure in PSI and rest all are derived data and pressure unit conversion. (Calibration of sensor is stored and displays the applied pressure). There will be mathematical air data calculation, air data unit conversion and pressure unit conversion.
The product design demands understanding of how the sensors would be made to interface with the ADC on-board, keypad, LCD interface to the board etc. Board design would demand choosing appropriate hardware components, keeping in mind the low-power, and low-cost design. Application SW design for configuration/calibration would require suitable development platform. Hardware-Software co-design model would be the basis in bringing up this product.

The error budget for main components is estimated for achieving net 0.1% accuracy on final display. The sources of errors are sensors, ADC, calculation, engineering unit conversion, rounding of LCD values etc.

III. Product Features

A single board solution facilitating configuration/calibration so that it can be used in 3 different applications i.e. PSTE, FTLT and ASI

Supports different types of pressure sensors such as absolute, differential or gauge

Meets the following functional requirements
- 7-point calibration as equally/closely as physically possible
- Configuration of the board to act as PSTE, FTLT and ASI
- Primary pressure data in PSI and rest all derived data and appropriate unit conversion for pressure values
- Net 0.1% accuracy on final display of the values

Meets the following non-functional requirements

- Low cost and low power design
- Power consumption target to be under 3W for the board

On-board LCD to display pressure values well within 0.1% of the precise value set during calibration

Keypad that allows configuration/calibration of the product

On-board power module (converter) produces different outputs for LCD, sensors, CPU etc.

Software/Firmware takes care of reset, ADC sampling, filter average, processing, result storage, engineering unit conversion, display format, display update, calibration etc.

Software/Firmware takes care of error corrections for achieving net 0.1% accuracy on final display (The sources of errors are Sensors, ADC, calculation, engineering unit conversion, rounding LCD values etc.).

External crystal 2 MHz can be provided in order to achieve processing/update timing requirements e.g. increasing the LCD update rate, engineering calculations etc.

Low power mode operation for the controller is achieved with a low frequency crystal (32 kHz). In this mode, ADC will not be operational.

IV. Block Diagram

The following block diagram gives an idea about how the overall system looks like

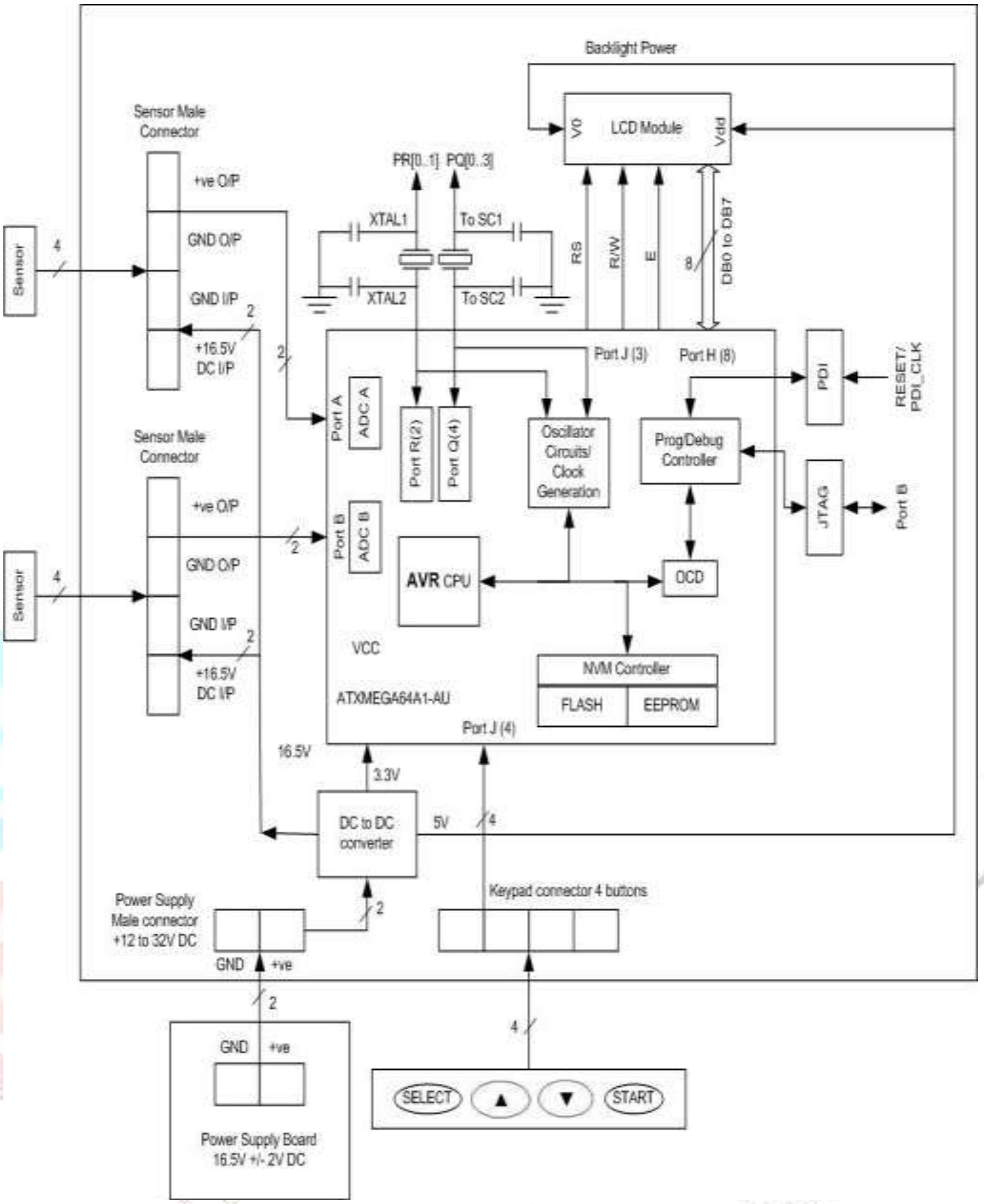

Figure 2

The system can be seen comprising of following major sub-modules

- Sensor interface
- On-board power module (converting voltages for inputs to CPU, LCD/Backlight, sensors)
- LCD module (with appropriate connections to the CPU)
- Oscillator/Clock (Software Controllable) for CPU
- ATXMEGA64A1-CU (Atmel® AVR® XMEGA™ A1 family), a low power, high performance, peripheral rich CMOS 8/16-bit micro-controller

V. HW Design & Interfaces

Electrical Interface

Power supply to the main board is 16.5 +/- 2V DC.

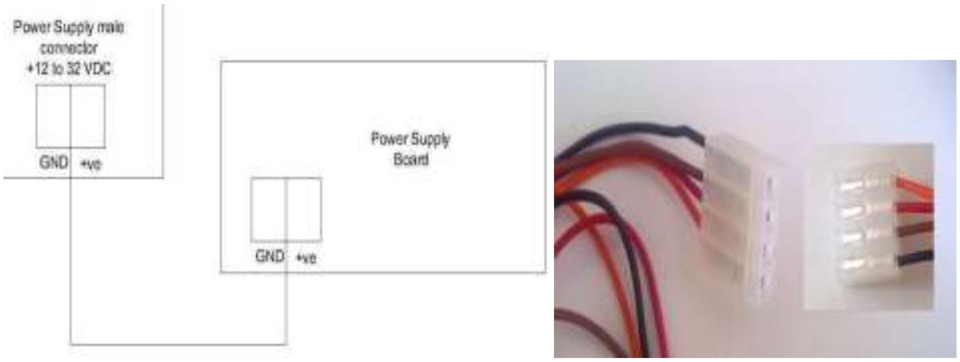

Figure 3

Sensor Interface

Power supply to the sensor i.e. 16.5 V DC is through the main board.

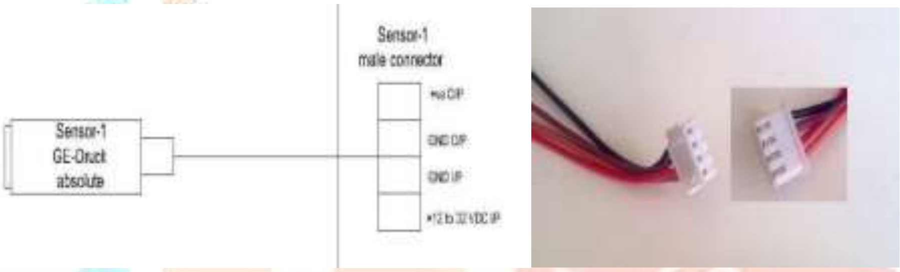

Figure 4

Keypad Interface

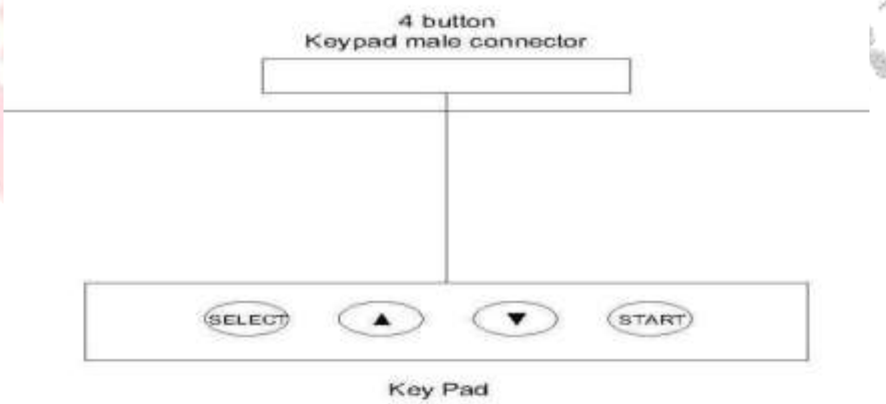

Figure 5

LCD Display Interface

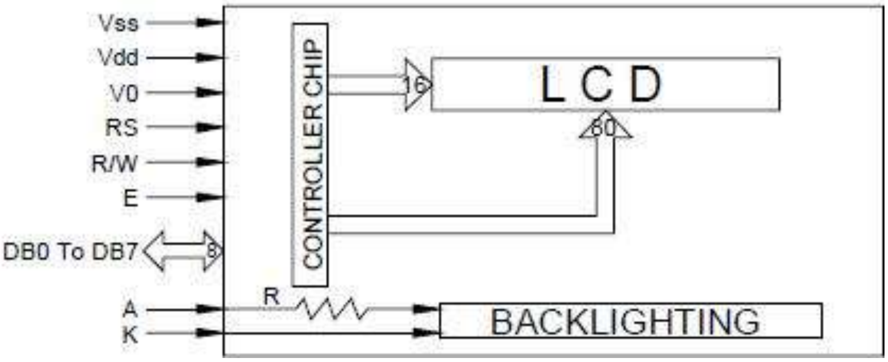

Figure 6

VI. Schematic Diagram

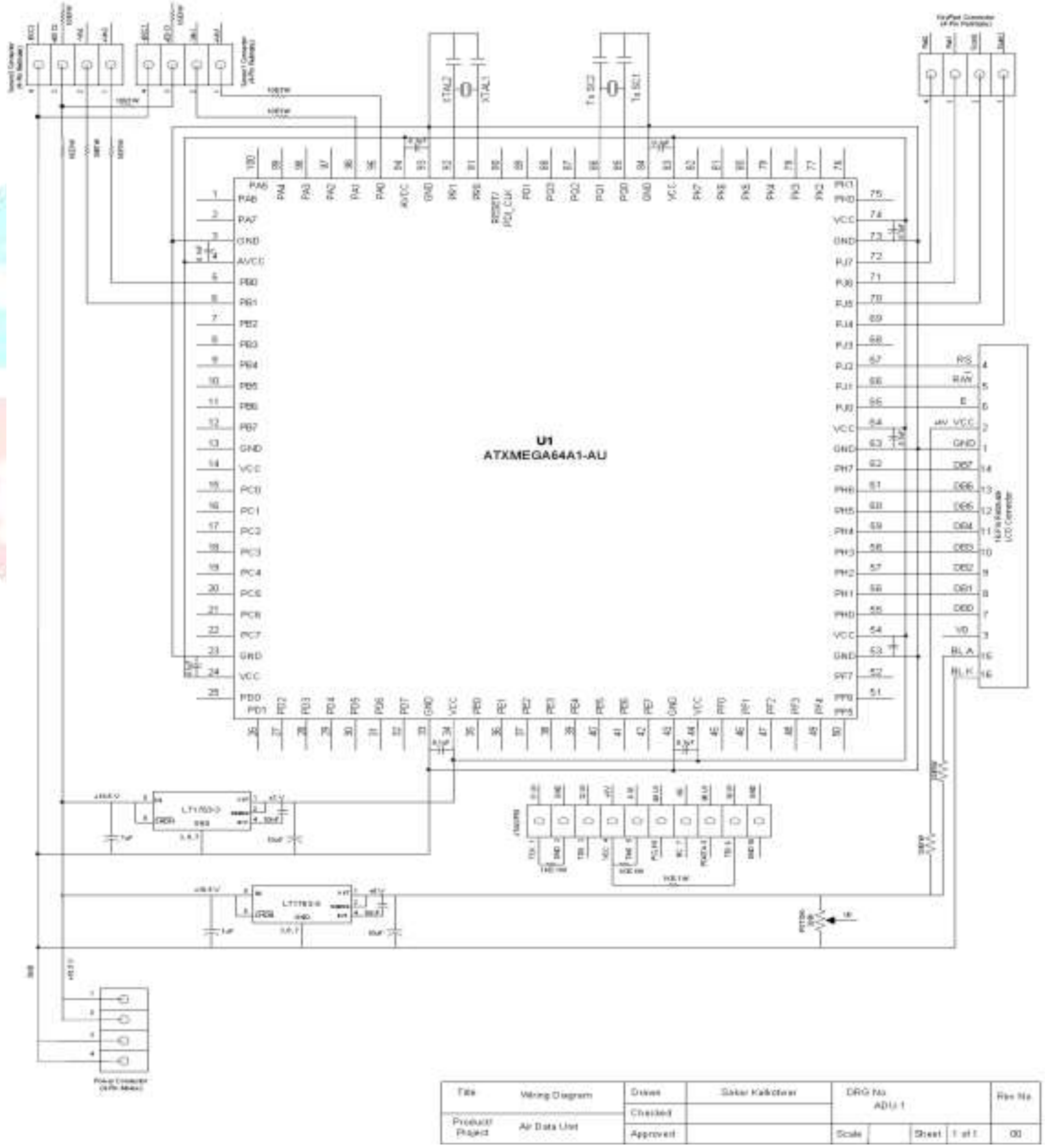

Figure 7

VII. HW Design Limitations

Micro-controller selection is primarily based on low cost and low power requirements for the product as a whole.

The XMEGA is an 8-bit AVR. It uses the AVR CPU and the architecture, but with improved (re-designed) peripheral modules.

XMEGA is operating on supply voltages from 1.6V to 3.6V. This is partly due to manufacturing process, which is selected from a power consumption point of view. The manufacturing process that XMEGA is produced in offers unmatched low power operation, but is limited to 3.6V operation. 5V operation is thus not possible for the first XMEGA families.

The conversion from the board supply of 16.5V DC to 5V and 3.3V for operation is done with the help of suitable regulators IC's on board.

XMEGA has two eight-channel 12-bit, 2 Msps Analog to Digital Converters. We have selected a micro-controller with 12 bit ADC for the following reason

1 LSB error → means 1/4096 * 100% = 0.025%

Instead if we had gone with a micro-controller with 8-bit ADC, we would have ended up

1 LSB error → 1/256 * 100% = 0.390625% which doesn't fit into our requirement of achieving 0.1% accuracy on the final display.

VIII. Power Consumption Overview

Power consumption is targeted to be under 3W for the product

Component	Voltage	Current	Power
Sensors (SPT-4V series) (2Nos)	16.5V	5 mA	0.0825W
Sensors (Druck PMP 4000 series) (2Nos)	16.5V	6 mA(Assumption)	0.099W
Sensors (UNIK 5000 series) (1Nos)	16.5V	3 mA	0.0495W
Micro-controller (ATXMEGA64A1)	3.3V	200 mA	0.66W
LCD	4.5V	2 mA	0.009W
LED Backlight	5V	60 mA	0.3W
Miscellaneous (20%)	-	-	0.2763W
Total	-	-	1.6578W

Table 1

IX. Error Budget/Accuracy Target

Error budget is assumed to be as follows

Sensors	=> 0.04%
ADC - +/-1 LSB	=> 0.025%
Noise (1mV)	=> 0.02%
Engineering Calculations	=> 0.015%

Net accuracy of 0.1% on the final display is targeted

X. SW Design & Development

AVR Studio

AVR Studio is an Integrated Development Environment (IDE) for writing and debugging AVR applications in Windows XP/Windows VISTA/Windows 7 environments. AVR Studio provides a project management tool, source file editor, simulator, assembler and front-end for C/C++, programming, emulation and on-chip debugging.

The following image is a snapshot of the AVR studio IDE

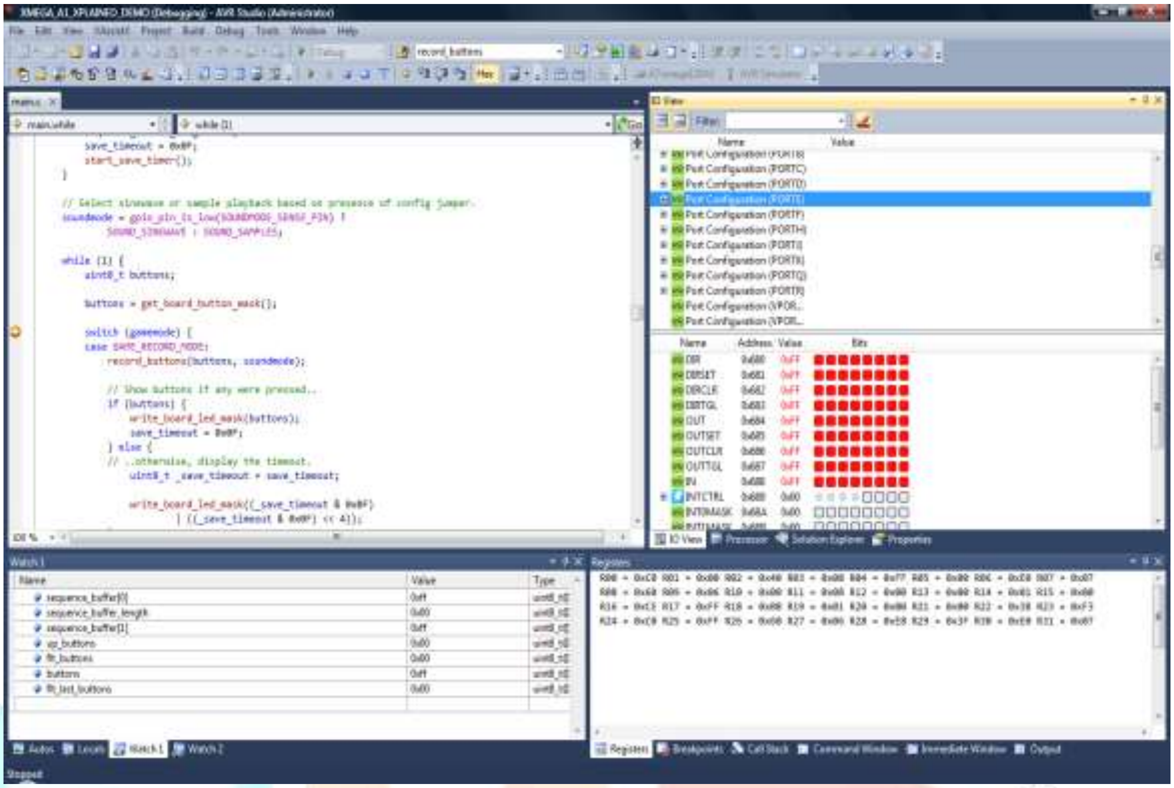

Figure 8

AVR GNU toolchain includes all the necessary tools, such as C/C++ complier, assembler and linker, for AVR application development. The tool chain integrates with the Atmel AVR Studio 4 or later through AVR GCC plug-in.

JTAG mkII programming hardware is used for programming a blank chip (XMEGA).

Figure 9

FLIP

Programming can also be performed by using the command line tool (BatchISP) from the FLIP installation

BatchISP is an In-System Programming application which can perform the same operations as FLIP but is designed to be launched from the DOS command window. The main purpose of batchisp is to automate ISP operations on lot of parts. It may also be launched from an IDE like Keil’s µVision2; you can compile and link your embedded program, generate the HEX file and download it to the target hardware.

The following image is a snapshot of the FLIP Graphical User Interface

☑ Erase
☑ Blank Check
☑ Program
☑ Verify

Size: 32 Kbytes
Blank: FF
Range: 0000 - 0066
Checksum: 00403B
Offset: 0000
No Reset Before Loading

HEX File: FAE_DEMO.hex
103 bytes

T89C51CC01
Signature Bytes: FFFFFFFF
Device Boot Ids FFFF
Hardware Byte FF
Bootloader Ver. 1.F.F
☐ BLJB ☐ X2
BSB / EB / SBV FF FF FF
Device SSB FF
● Level 0 ○ Level 1 ○ Level 2
☐ Reset

Memory verify pass
COM1 / 38400

Figure 10

XI. SW Modules

Application SW Flow

The following block diagram represents the overall application SW flow

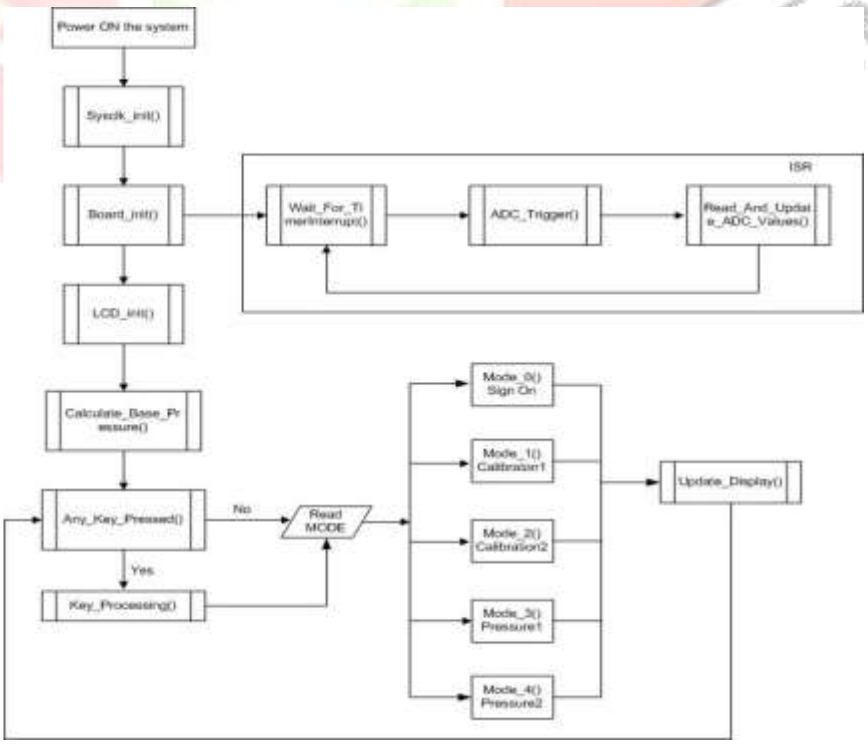

Figure 11

Sysclk_init():

- This function will initialize the system clock and its source
- Mask all synchronous clocks except for any clocks which are essential for normal operation (for example internal memory clock)
- Set up the system clock pre-scalers as specified by the application's configuration file.
- Enable the clock source specified by the application's configuration file (oscillator or PLL) and wait for it to become stable.
- Set the main system clock source to the clock specified by the application's configuration file.

Board_init():

- This function can be framed to contain code which does board-specific initialization
- Configure general purpose I/O pins
- Configure the ports connected to LCD
- Parallel to this board specific initialization, recording of instantaneous ADC values are done and stored as shown

LCD_Init():

- This function does the job of initializing the LCD connected to corresponding ports
- Initialize the LCD module.
- Display the Welcome Message as required.
- Display the Message for "Wait for few seconds"
- During these few seconds, the controller records the base pressure. After that the controller is ready for viewing the pressure.

Any_Key_Pressed():

- This function waits for Key presses, records the key press as an event and passes control to Key Processing module.

Key_Processing():

- Key processing module, based on the configuration and the key press, sets certain flags/variables and sets the operating mode.

Mode_0():

- Mode 0 is the Sign On mode where Welcome Message is displayed.

Mode_1():

- This is a mode for calibrating pressure 1.
- Upon selection of this mode, user can make use of "Up/Down" keys in order to move up or down through the increment steps.
- Each step in this procedure corresponds to a pre-defined pressure value which needs to be calibrated.
- User can come out of this mode by selecting SELECT key.
- After calibration is complete, calibrated pressure will be displayed.

Mode_2():

- This is a mode for calibrating pressure 2.
- Upon selection of this mode, user can make use of "Up/Down" keys in order to move up or down through the increment steps.
- Each step in this procedure corresponds to a pre-defined pressure value which needs to be calibrated.
- User can come out of this mode by selecting SELECT key.
- After calibration is complete, calibrated pressure will be displayed.

Mode_3():

- This is a mode for viewing pressure 1.
- Upon selection of this mode, user can make use of "START" key in order to view the pressure 1.

- Use of “Up” key allows taring of pressure. Taring can be done only when corresponding pressure is being displayed.
- Once Taring is completed, pressure becomes zero.

Mode_4():

- This is a mode for viewing pressure 2.
- Upon selection of this mode, user can make use of “START” key in order to view the pressure 2.
- Use of “Up” key allows taring of pressure. Taring can be done only when corresponding pressure is being displayed.
- Once Taring is completed, pressure becomes zero.

Update_Display():

- This module is responsible for updating the LCD display with relevant messages during different modes
- LCD display displays pressure values in Pressure View mode and user messages in Calibration mode
- Pressure values could be a result of engineering calculations done on ADC values representing the pressure applied as an input either in Pressure View or Calibration mode
- Engineering calculations takes care of conversion of pressure units to different parameters as demanded in a specific application (PSTE, FTLT or ASI) e.g. ASI in knots, Rate of Climb etc.
- After this, control goes back to Key_Processing() module, here key press would be considered as an event and corresponding mode would be activated OR switch from one mode to another mode can be achieved

XII. Achieving net 0.1% accuracy

The values displayed on LCD should be well within +/- 0.1 % of the precise value set during calibration.

For example, for 0 to 3 psi with 7-point calibration
Applied pressure will be 0.0000, 0.5000, 1.0000, 1.5000, 2.0000, 2.5000, and 3.0000 in that order

The sensor will convert the pressure to corresponding DC voltage, say 0.010V, 0.490V, 1.020V, 1.495V, 2.100V, 2.500V, and 3.010V

We can see that the values are not linearly proportional. Even the ADC will make it more non-linear.

So, non-linearity constants are calculated assuming piece-wise linearity

That is

In the range, 0.0000-0.5000 PSI, $p = m1 \times ADC + c1$
in the range, 0.5000-1.0000 PSI, $p = m2 \times ADC + c2$
in the range, 1.0000-1.5000 PSI, $p = m3 \times ADC + c3$
in the range, 1.5000-2.0000 PSI, $p = m4 \times ADC + c4$
in the range, 2.0000-2.5000 PSI, $p = m5 \times ADC + c5$
in the range, 2.5000-3.0000 PSI, $p = m6 \times ADC + c6$
in the range, 3.0000-3.5000 PSI, $p = m7 \times ADC + c7$

The constants, m1, m2, m3, m4, m5, m6, m7, c1, c2, c3, c4, c5, c6 & c7 during calibration since the inputs are known precisely.

Then when a random precise pressure say 1.2345 psi is applied from the same source, LCD display should be well within +/- 0.1% (i.e. 0.0030 psi for 3.0000 psi full scale) i.e. between 1.2315 & 1.2375 psi.

XIII. Conclusion & Scope for future work

With the proposed design (appropriate HW components and SW design), it is possible to achieve 0.1% accuracy on final display which is the first and foremost requirements. As of today, board is designed to support 2 sensors connections and 2 modes of operation i.e. Calibration and Pressure view mode.

In future, the board design can be re-visited to consider better accuracy than 0.1% on final display. This can be achieved with appropriate modifications (HW as well as SW) in order to support external ADC usage. Also, the SW design can be re-factored in order to support multiple table (calibration table) look-ups and also to support complex engineering calculations in response to increased number of derived parameters.

These possibilities of design improvements drive the possibility of extending the possible configurations (other than PSTE, FTLT and ASI) in which the unit can be operated.

The design can also be extended in order to support external communication interfaces (typically inside the aircraft e.g. ARINC bus) and the information be transmitted for reference.