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# An efficient Data Acquisition System for Launch Vehicle Telemetry

**Asha Vijayan[1], S.Suresh Babu [2]**

[1] M.Tech Scholar, Department of ECE, Sree Buddha College of Engineering, Alappuzha, Kerala, India

[2] Principal, Sree Buddha College of Engineering, Alappuzha, Kerala, India

**Abstract**: ***Data Acquisition and Telemetry are the key features of many demanding applications like industry and aerospace. In launch vehicle systems, it is essential to monitor and analyze the real time performance so that designs can be validated and tunable parameters could be adjusted to increase the performance and efficiency. Currently used DAQ systems are of increased size, weight and turn out to be costly and power hungry. In this work, a new mission-independent real time software programmable DAQ system using versatile MCU and sigma delta ADCs are proposed, taking into account size, weight, cost and performance without compromise on accuracy, resolution and drift performance. Additional digital filtering stages are also added to improve the system performance. This system is capable for direct connections with different pressure and temperature sensors which interfaces 32 low frequency channel and two high frequency channels. The system proposed operates in two modes; one is data acquisition mode and the other is program mode. Effective power reduction techniques and wireless interface protocol between different data acquisition modules are also touched upon as avenues for future work.***

**Keywords:** Data acquisition, Launch vehicle, Sigma delta ADC, Signal Conditioning, Telemetry system.

## 1. Introduction

Data AcQuisition (DAQ) is simply the process of bringing a real-world of physical parameters such as voltage, temperature, pressure etc., into a computer for processing, analysis, storage or other data manipulation. Data acquisition plays an important role in many fields and also in launch vehicle telemetry. The DAQ systems and telemetry systems have evolved substantially over the years and being used to gather real time data from sources in order to aid monitoring, analysis, and control facility [1]-[2]. For this purpose the flight transmitted telemetry data is received and stored in the ground station. The data of the previous mission forms a vital and significant source for the analysis and design in later missions.

Current data acquisition system considers only 16 low frequency channels and is controlled by an eight bit microcontroller of PIC18F6xxx family. Our requirement is to produce an efficient system with reduced size and weight which meet the signal conditioning and data acquisition requirements of launch vehicle telemetry, without compromising on accuracy and resolution. Modifying the current system with the existing microcontroller will increase the size and weight of the system and it posses peripheral and I/O (Input-Output) limitations too.

This work describes the design of a data acquisition system based on 16-bit PIC microcontroller of PIC24EPxxx family and sigma delta Analog to Digital Converter's (ADCs) of ADS1218 and ADS1255. The proposed system interfaces directly with sensors accepting their low frequency analog signal as input in case of ADS1218 and high frequency analog signal as input in case of ADS1255.ADCs associated with each channel performs the required signal conditioning .The gain and anti-alias filter cut-off frequency are set by the contents of control registers on the chip. The major parameters of signal conditioning such as gain ,input signal offset and anti-alias filter cut-off frequency are digitally controlled ,thereby rendering the system versatile and reconfigurable. There are two modes of operation. One is program mode and the other is data acquisition mode. The main program detects the mode of operation based on the voltage level on two digital I/O pins configured as input to the microcontroller. The program mode functions include writing to ADC's configuration registers and reading from these registers to verify the integrity of data. Other functions such as reset, self-calibration, system gain and system-offset calibration are also implemented in this mode. In data acquisition mode, the system acquires the digital data from the ADC and posts the appropriate data to Processing Unit. Use of one additional RS-485 link in the output for checkout purpose, is also considered as another major feature of this system [3]. Introduction of Digital filtering stages using moving average concepts also improves the efficiency of the system.

The block diagram representation of complete system with a brief explanation, and timing details are discussed in section II. The software organization including modes of operations and flow diagram are described in section III. Performance details and results are discussed in section IV .Section V concludes the work and brings out an overview for further enhancements in the system capabilities.

## 2. Design Details

### 2.1 Block Diagram Description

The hardware organization of the system is shown in Figure 1. The proposed_system interfaces 32 –low frequency channels and two high frequency channels .Each channel consists of 24-bit sigma delta ADC of ADS1218 in case of low frequency channels and ADS1255 for high frequency channels. Entire system is controlled by a single 16-bit microcontroller of PIC24EP512GU814 and these


Paper ID: SUB156759

microcontrollers feature built-in flash memory for program storage, Random Access Memory (RAM) for data buffering and support of a variety of standard interfaces such as Serial Peripheral Interface (SPI) and Universal Asynchronous Receiver Transmitter (UART). The output interface is electrically compatible to industry standard RS-485 and makes use of three MAX3443 devices for redundant monitoring. The ADCs are configured and read by the microcontroller through the SPI port and here the digital output from each channel is read and written on to the Data RAM inside the microcontroller. The data corresponding to each channel is then communicated to a downstream Processing Unit through RS485.Communication over RS-485 bus is handled through the UART port. Auxiliary circuits like Power-On- Reset (POR) and Voltage Reference Generators are also included to the hardware, to make it more efficient.

### 2.2 Timing Details

In normal operational mode the microcontroller polls the channels sequentially for data readiness. The order of polling can be as per a format stored in memory. The interface between microcontroller and ADC is by means of the standard SPI. The communications over the SPI port are synchronized by a Serial CLocK (SCLK) of 1MHz sourced by the microcontroller [4]-[5].The ADS1218 will cater to all low frequency measurements up to 60Hz bandwidth and have a master clock rate of minimum 1MHz and maximum 5MHz.

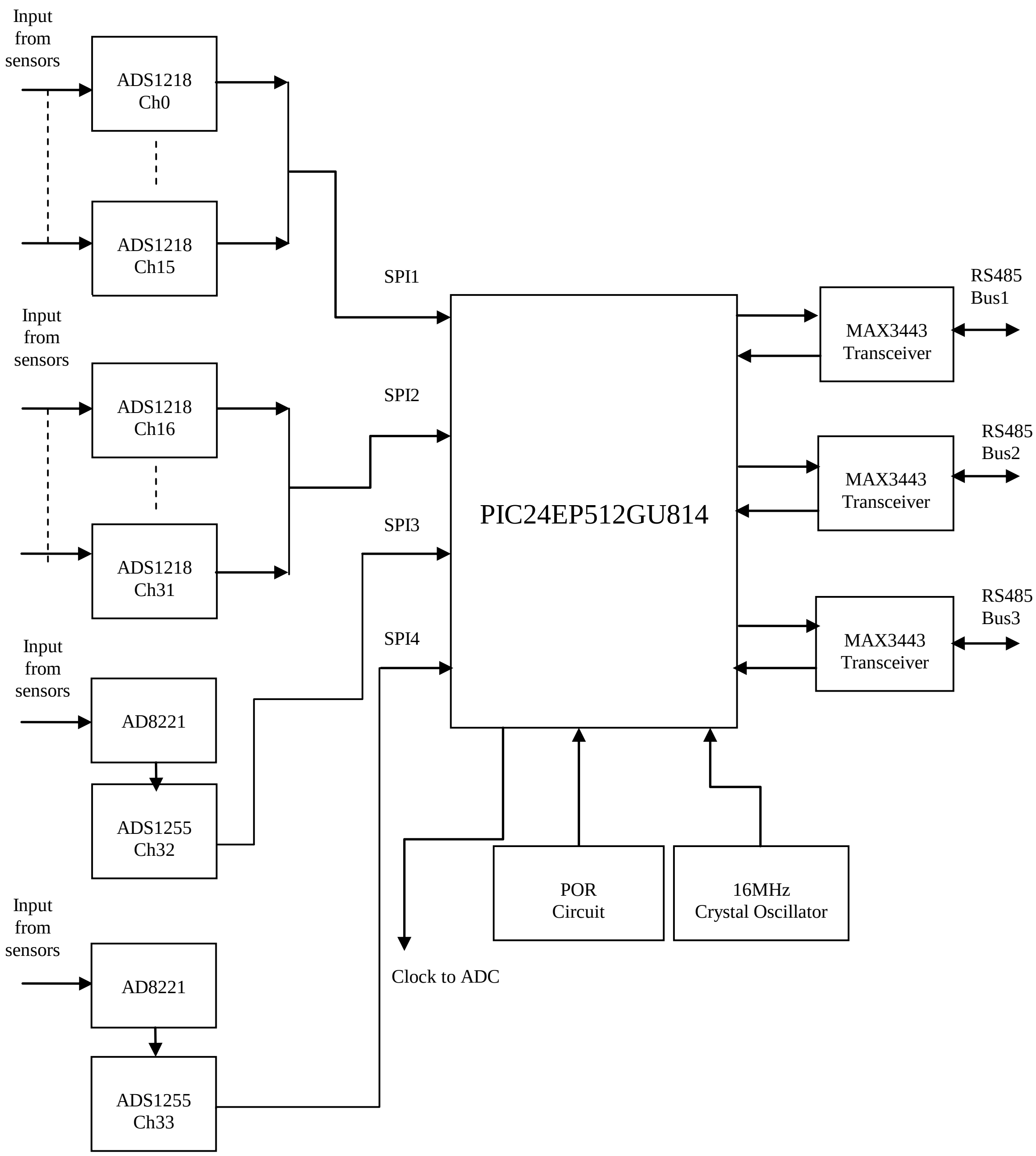


**Figure 1:** Block diagram of a 34-channel data acquisition system




Paper ID: SUB156759

ADS1255 channels are used for high frequency measurements up to 1.06 KHz bandwidth and have a master clock rate of minimum 0.1MHz and maximum 8MHz. The communication over the RS-485 bus follows the standard asynchronous communication protocol .When command from Processing Unit arrives, the command is send to the DAQ unit through RS-485 bus, which is configured in half duplex multi drop bus format. Then each unit decodes the address and the one whose base address matches the command word sends back a reply word to the Processing Unit. The communication over RS485 output interfaces are based on the priority, interrupt driven mode controlled by the microcontroller unit (MCU). The MCU is configured in external crystal oscillator mode with an operating frequency of 16MHz so that corresponding instruction rate of 8MIPS (Million Instructions Per Second).The UART supports a baud rate of 2MBPS .The UART commands are of 11 bits which requires 0.5µs for each bit transmission. The signaling rate of 2MBPS supported by the transceiver will ensures that the output port can sustain a combined throughput of 1 data samples in every 32 microseconds [6].

## 3. Software details

The Integrated Development Environment (IDE) is an environment which integrates different simulation tools and compilers to provide a single window solution to development and debugging. MPLABV8.92 is an IDE provided by the microchip, used as the simulation platform. It is a software program that runs on PC to develop applications for Microchip Microcontrollers.

### 3.1 Program Mode

Functions such as reset, self-calibration, system- offset and system-gain calibration are implemented in this mode based on the commands FE, F0, F3 and F4 respectively, shown in Table 1.Data flow sequence from check out PC should be in an order of header (AA, 55), command byte identification bit (1 for single byte command and 18 for multi byte command), Channel Address (CA), and finally the command for required function. Figure 2 shows the flowchart for program mode operation. The RS-485 interface itself can be used to load the

**Table 1:** Different commands used to program ADC

| Serial No. | Description | Command byte | | Type of command | Data flow sequence from checkout pc |
|---|---|---|---|---|---|
| | | ADS1218 | ADS1255 | | |
| 1 | RESET | FE | FE | One byte Write command | AA,55,1,Channel Address, FE |
| 2 | SELF CAL | F0 | F0 | One byte Write command | AA,55,1,Channel Address,F0 |
| 3 | SYS OFFSET CAL | F3 | F3 | One byte Write command | AA,55,1,Channel Address,F3 |
| 4 | SYS GAIN CAL | F4 | F4 | One byte Write command | AA,55,1,Channel Address,F4 |
| 5 | Write to ADC registers starting from location ‘0’ | 50,0F,16 register values | 50,0A,11 register values | Many bytes Write command | AA,55,18,CA,50,0F,16 register values<br>AA,55,18.CA,50,0A,11 register values |

configuration data for each channel [7]-[8]. The Programming of ADC chip is an off-line operation and it is configured in such a manner as to load this data automatically in power-up onto its configuration registers. These ADCs have different gain values and is based on the internal reference voltage and differential input voltage of the ADC [9]. Different gain settings of ADC are shown in Table 2.

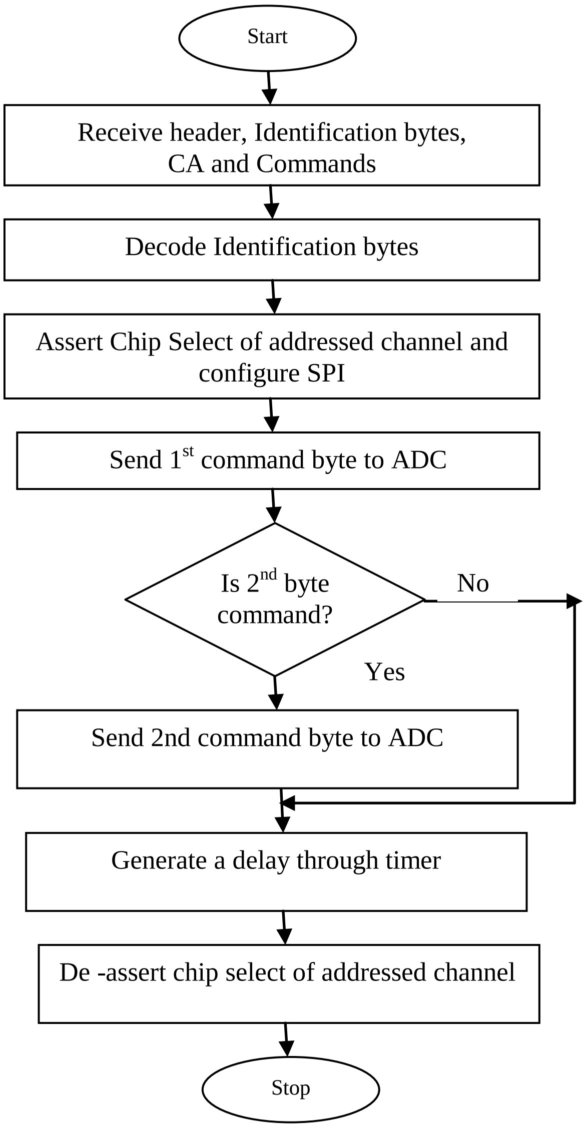


**Figure 2:** Flowchart for program mode operation

## 3.2 Data Acquisition Mode

In this mode, the A DCs are polled continuously. The 16-bit data is read from ADC and stored in the data memory of microcontroller .It is possible through SPI routine and this process continuous until the microcontroller receives a command from Processing Unit. This command request is handled using interrupts and the interrupt service routine handles the posting of reply to Processing Unit. It is possible through UART routine. After sending the reply, the microcontroller returns to ADC polling [10].

**Table 2:** Gain settings of ADC

| V ref | Differential input Voltage range | Gain |
|---|---|---|
| 2.5V | 0-2.5V | 1 |
| 2.5V | 0-1.25V | 2 |
| 2.5V | 0-0.625V | 4 |
| 2.5V | 0-312.5mV | 8 |
| 2.5V | 0-156.25mV | 16 |
| 2.5V | 0-78.125mV | 32 |
| 2.5V | 0-39.0625mV | 64 |
| 2.5V | 0-19.53mV | 128 |
| 1.25V | 0-10mV | 128 |

### 3.2.1 SPI routine

The communication between MCU and ADC is possible through SPI by means of five hand shaking signals ,the Chip Select(CS),Data Ready(DRDY),SCLK(Serial Clock),Data Input(DI) and Data Output(DO)lines. Figure 3 shows the flow diagram for SPI routine. The individual ReaDY (DRDY) signal corresponding to each chip is used to check the data validity before reading the corresponding channel. The CS lines are individually supplied to each chip when corresponding channel is to be accessed. The data transfer is synchronised with a SCLK of 1MHz.The microcontroller polls channel sequentially, selects the ADC if data is ready, issues a Read Data (RDATA) command and reads the data over the SPI port.

SPI operating frequency is calculated using equation 1.

$$FSCK = \frac{FCY}{\mathrm{Pr}\,imaryprescale * Secondaryprescale} \quad (1)$$

- FCY=Device system frequency
- FSCK= SPI clock frequency

### 3.2.2 UART routine

In the output, the microcontroller is interfaced to the Processing unit through UART. The UART uses the standard Non-Return –to-Zero (NRZ) format with one start bit, 8 data bits, 1 mode bit and one stop bit. The mode bit is used to differentiate between command and reply. The command sequence from Processing Unit and the reply sequence from DAU (Data Acquisition Unit) in the RS-485 protocol are shown in Figure 4 and Figure 5 respectively.

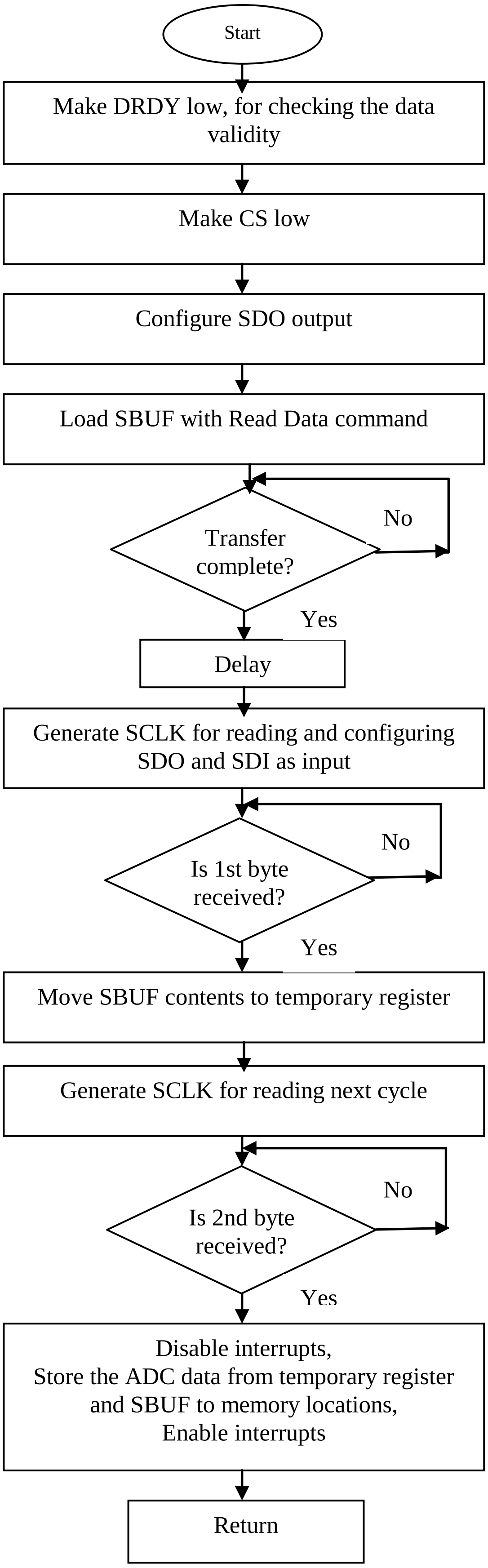


**Figure 3:** The flow diagram for SPI routine

The UART module consists of a dedicated 16-bit Baud Rate Generator. The UxBRG register controls the period of a free-running, 16-bit timer.

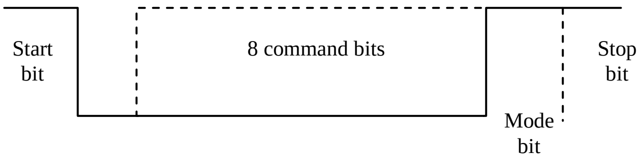


**Figure 4:** Command sequence from Processing Unit

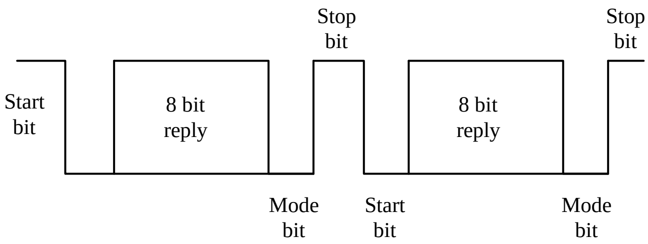


**Figure 5:** Reply sequence from DAU

UART Baud Rate calculation for BRGH = 1 is shown in equation 2.

$$Baudrate = \frac{FP}{4(UxBRG + 1)} \qquad (2)$$

FP = (FOSC/2)

- FP = The instruction cycle clock frequency
- FOSC=Oscillator frequency

The maximum baud rate (BRGH = 1) possible is FP/4 (for UxBRG = 0) and the minimum baud rate possible is FP/ (4 * 65536).

### 3.3 Filtering Stage

A digital filter at the output of ADC using moving average concepts increases the efficiency of the system. The Effective number of bits (ENOB) in an ADC can be calculated using equation 3.Before filtering, 500 data samples from a channel with a Vref of 2.5 results in an ENOB of 14.05. A simple low pass filter produces an ADC with improved resolution and thus the system becomes more efficient [11]-[12].The ENOB values for different number data samples after filtering is shown in Table 3.

$$ENOB = Log2\left(\frac{Vref}{3 * S\tan dardDeviation}\right) \qquad (3)$$

- ENOB=Effective Number of Bits

**Table 3** The ENOB values after filtering

| Number of Samples taken for average | Standard Deviation | ENOB |
|---|---|---|
| 5 | 0.045357 | 14.16528 |
| 15 | 0.036069 | 14.49584 |
| 20 | 0.018575 | 15.45322 |

## 4. Results

In Data Acquisition mode, the ADCs channels are polled continuously and the available data is read and stored in the memory of microcontroller. This process continuous until it receives a command from Processing Unit. The command request is handled using interrupts and interrupt service routine handles the posting of reply to Processing Unit .The simulation results for SPI and UART routine in data acquisition mode are shown in Figure 6 and Figure 7 respectively.

The program is tested in the demo board of PIC24E series. The board provides a low-cost, modular development system for Microchip's enhanced 16-bit Digital Signal Controllers (DSCs) or High-Performance Microcontrollers (MCUs). It also consists of a crystal oscillators, Green power indicator LED, USB connectivity for on-board debugger communications, Three push button switches (SW1, SW2, SW3) for user-defined inputs, Three user-defined indicator LEDs (LED1, LED2, LED3), USB Type A connectivity for PIC24E USB host-based applications, Host mode power jumper and a Regulated +3.3V power supply for powering the starter kit via USB or an expansion board.

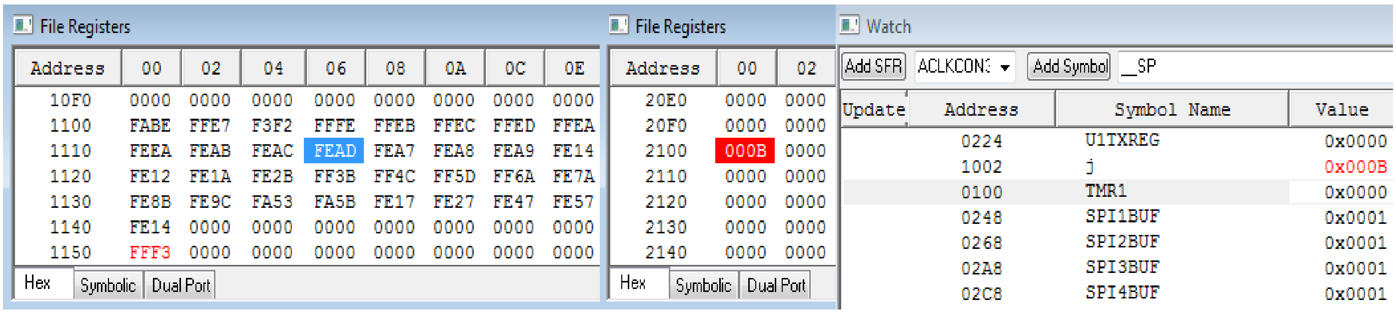


**Figure 6:** Polling process and reception of command by the microcontroller

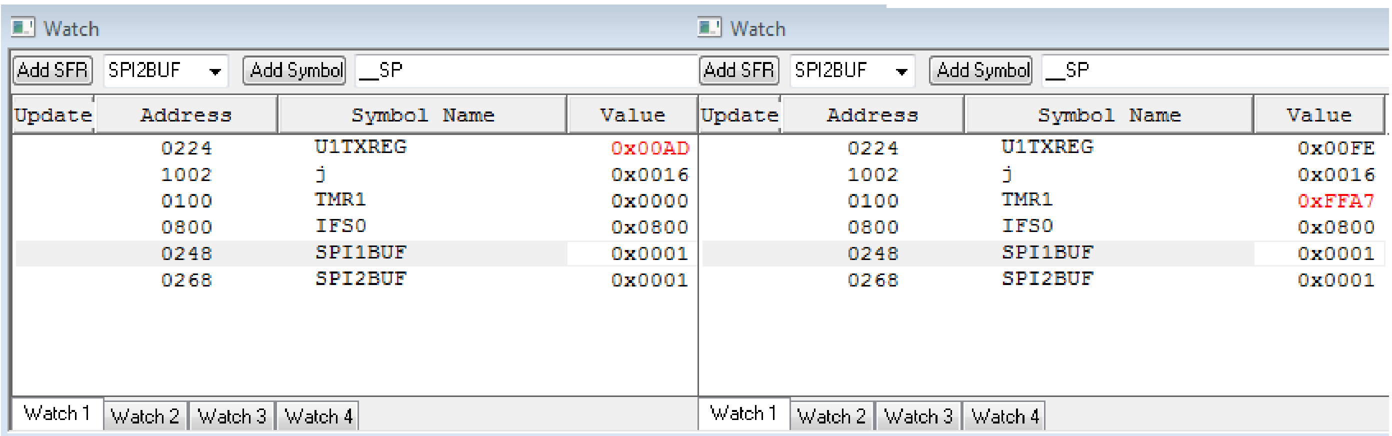


**Figure 7:** Transmission of required data requested by the Processing Unit

## 5. Conclusion and Future works

Data acquisition and telemetry are part of winning formula of many fields including industry and aerospace. The implementation of an efficient software programmable real time data acquisition system with reduced size and weight is discussed in this work. It results in an efficient system in terms of sigma-delta ADCs, that can offer higher input signal bandwidth and the digital filter placed at the output of ADCs, which produces improved resolution. The versatility of the system in terms of software reconfiguration, calibration and sensor interface extends its application.

Work is on track of improving the system performance by considering power reduction concepts. Introduction of a wireless protocol between different data acquisition module will also improve the performance [13].

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## Author Profile

**Asha Vijayan** pursuing her Master of Technology in Embedded System from Sree Buddha College of Engineering, Alappuzha, affiliated to Kerala University. She received her B.Tech degree in Electronics and Communication Engineering from University of Kerala in 2013. Her areas of interest include Embedded System design, Communication Engineering and VLSI.

**Dr. S Suresh Babu** received his B.Tech degree in Electronics & Communication Engineering from University of Kerala in 1982, M Tech in Computer Science & Technology from IIT Roorkee in 1988 and PhD in IT enabled services from PSG College of Technology in 1997. He has served as Principal to College of Engineering, Chengannur, College of Engineering, Munnar, T K M Institute of Technology, Kollam and T K M College of Engineering, Kollam. His research interests are in IT Enabled Services, Image Processing, and Mobile & Ad-hoc Networks. He is a reviewer and Editorial Board member of many international journals/conferences. He has got a number of publications in various peer reviewed journals of international repute. Dr.S Suresh Babu was a member of Board of Studies (PG) & Faculty of Engineering at Cochin University of Science & Technology (CUSAT). He is also a member of PG Board of Studies in Engineering at University of Kerala and M G University. He acted as Chairman, M Tech Board of Examinations of University of Kerala, CUSAT and University of Calicut. He was a member of the Standing Appellate Committee (SAC) of the All India Council of Technical Education (AICTE), New Delhi. Dr S Suresh Babu is a member of Indian Society of Technical Education (ISTE), Computer Society of India (CSI), Quilon Management Association (QMA), Institute of Electrical Electronics Engineers (IEEE), Solar Energy Society of India and Melvin Jose Fellow (MJF) of the Lions Club International. He is also a Director of IT Company at Technopark, Thiruvananthapuram; Cadmium Technologies (P) Limited and a Research Supervisor to Noorul Islam University & Karpagam University, Tamil Nadu.