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Voltage and Current Waveform Monitoring

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Abstract

Voltage and current waveforms are good indicators of the quality of electricity supplied by the utility. Waveforms stored over a period of time can help us predict the health of an electrical circuit. This project report covers the implementation of a **Voltage and Current Waveform Monitoring Module**.

1 Introduction

The project involves monitoring the Voltage and Current waveforms. This is done by sampling each of the input voltage and current waveforms at a rate of about 10 kSa/s. The sampled values are read as a 12 bit value by the inbuilt unipolar ADC of the MSP430F147 micro-controller. The sampled values are expressed in Q15 notation (which requires that the bits be shifted to position 15). Now that we have the voltage and current values we transfer the data over the USB (Universal Serial Bus) to the Host PC. The USB is completely Host controlled. The Host PC plots the voltage, current and power waveforms. In addition it also calculates the P_{avg}.

2 Design Approach

Following is the modular breakup of the system.

- Generation of DC Voltages for Chip Operation
- Voltage Conditioning Circuit
- Current Conditioning Circuit
- Waveform Sampling and Storage

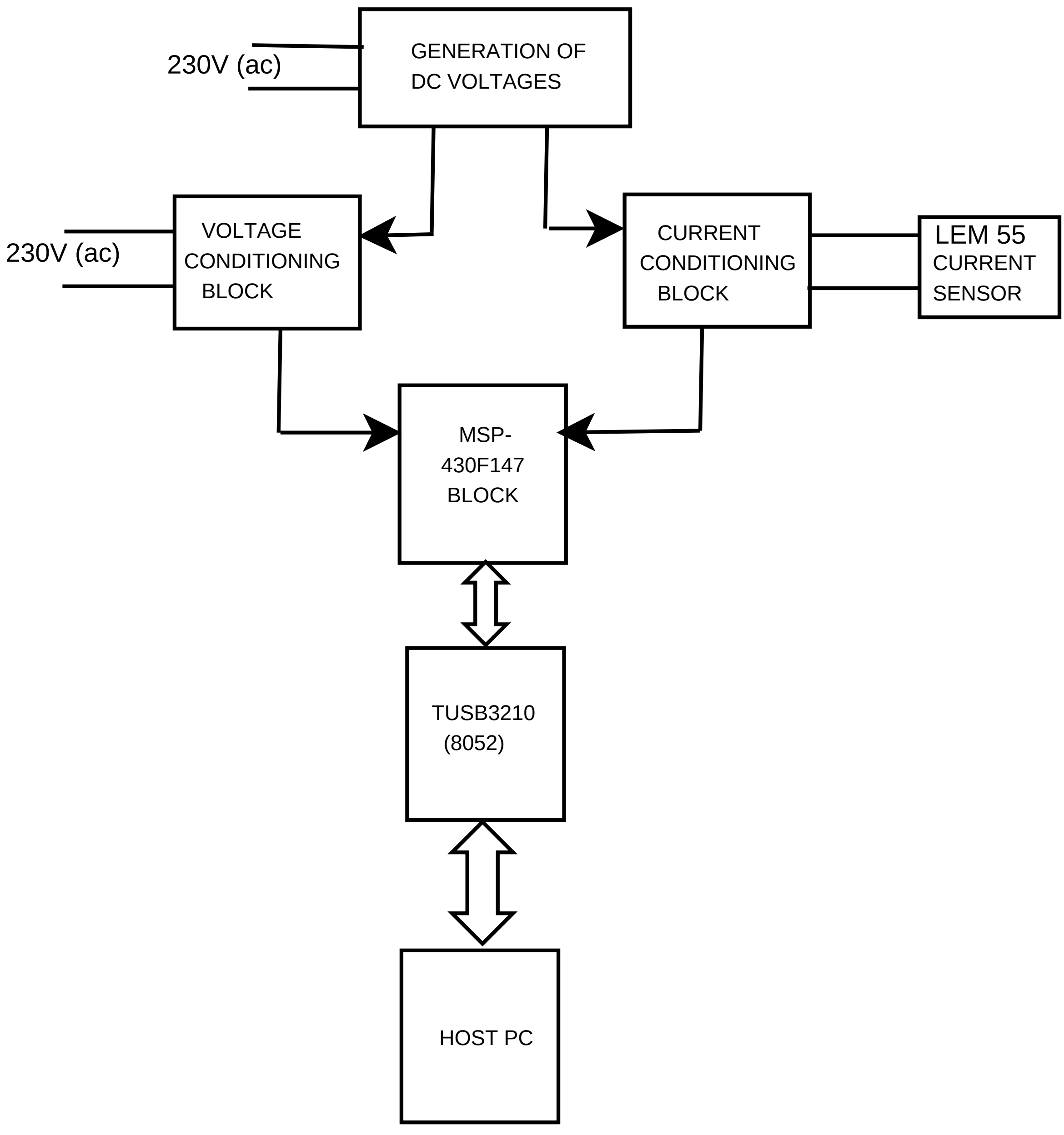

Figure 1: Block Diagram of System

- USB Interfacing

The block diagram is shown in Fig.1. Each module is discussed in detail in the following subsections.

2.1 Generation of DC Voltages for Chip Operation

2.1.1 Voltage Requirements

- $\pm$ 12 V for Current Sensor LEM55
- $\pm$ 12 V for Operational Amplifiers TL082
- 3.3 V for MSP430F147, MAX3243

2.1.2 Components Required

- 15-0-15 Transformer
- Diode Bridge
- Voltage Regulators: 7812, 7912, 7805, TPS 7333

2.1.3 Circuit Description

The only voltage source available to the module is the AC line voltage of approximately 230 Volts. All DC voltages required for the functioning of the various chips should be generated from this supply. A DC of ± 12 Volts is required for the operation of the Current Sensor and the Operational Amplifiers. A 3.3 Volt supply is required for MSP430 and MAX3243. It is important to note that the TUSB3210 also operates on 3.3 Volt but it derives it power from the USB. (Bus Powered Mode)

The 15-0-15 transformer followed by a diode bridge gives a DC voltage of approximately 17 Volts. Voltage Regulators 7812, 7912 and 7805 are used to generate $+12$, -12 and $+5$ Volts. TPS 7333 is used to obtain 3.3 V.

2.1.4 Circuit Diagram

Refer to Fig. 2. (I-pin1 denotes pin no.1 for 1st TL082 and likewise)

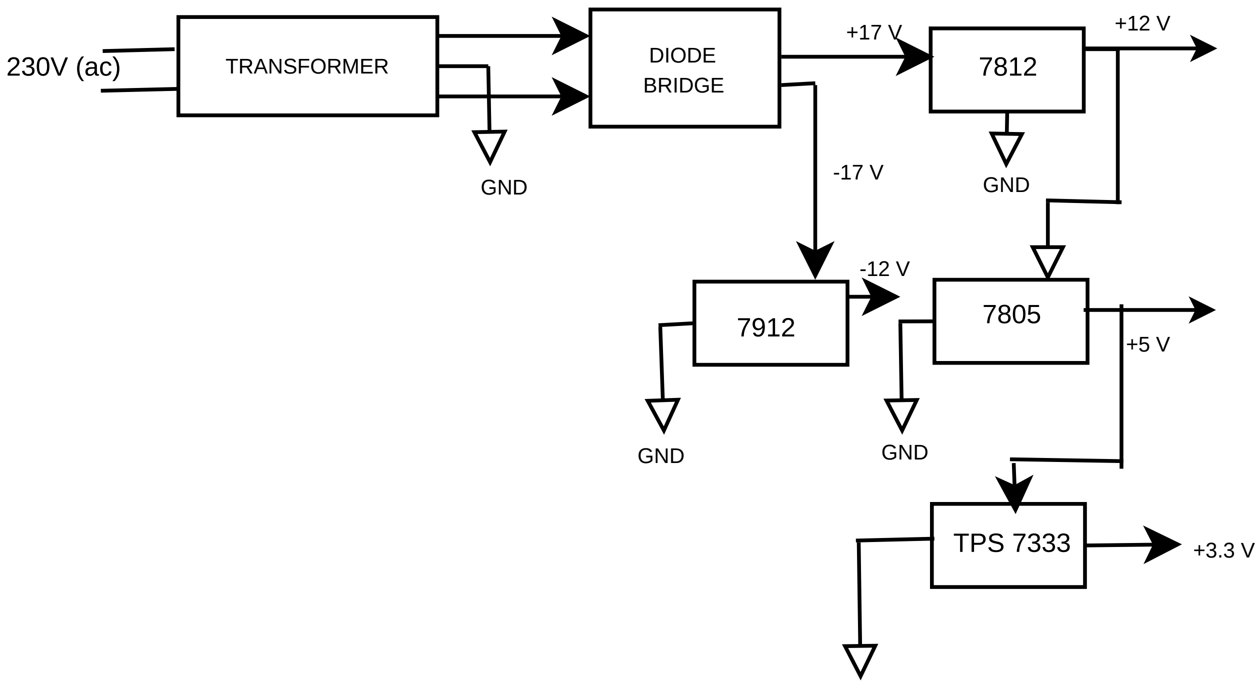

Figure 2: DC Voltage Generation Block

2.2 Voltage Conditioning Circuit

2.2.1 Design Issues

- The input voltage ranges from +325 V to -325 V (peak to peak).
- Our design should be able to handle voltage variations of the order of 10% which implies that design should be able to handle voltages from +360 V to -360 V.
- The inbuilt ADC module of MSP430 has a V_{ref+}= 2.5 V and V_{ref-}= 0 V. This implies a scaling factor of approximately 300 has to be introduced.
- Another important observation is that the input voltage variation is bipolar whereas the input voltage required by the ADC is unipolar which implies that the waveform has to be DC shifted.

2.2.2 Components

- Differential Amplifier
- Level Shifter using Operational Amplifier

2.2.3 Circuit Description

The AC line voltage is fed to a Differential Amplifier with a gain of 1/330. The resulting waveform has a swing from −1 to +1 volt. Since the ADC module of the MSP430 is unipolar the waveform is given a DC offset of 1.25 Volts.

A DC of −1.25 Volt is generated using another Operational Amplifier with a gain of −1/4 and input 5 Volts at the Inverting Input.

An Operational Amplifier with input −1.25 at the Inverting Terminal and downconverted AC waveform at the Non-Inverting Terminal is used to level shift the AC waveform.

2.2.4 Circuit Diagram

Refer to Fig. 3 and Fig. 4

2.3 Current Conditioning Circuit

2.3.1 Design Issues

- The circuit can accurately measure current upto 3.5 Amps (rms).
- The output of the Current Sensor is a current. This has to converted to a suitable voltage before being fed to the ADC of the MSP430.
- The conversion ratio of the sensor is 1000:1 which attenuates the current waveform heavily. We adopt two approaches to increase the output of the sensor.
  - We twist 4 turns of the current carrying wire around the sensor. The sensor detects 4 times the magnetic flux and so its output is increased by 4 times.
  - The output of the current sensor is passed through a I to V converter with a scaling ratio of 220.
- Another important observation is that the input current variation is bipolar whereas the input voltage required by the ADC is unipolar which implies that the waveform has to be DC shifted.

2.3.2 Components

- LEM55 Current Sensor
- Amplifier and Level Shifter using Operational Amplifier

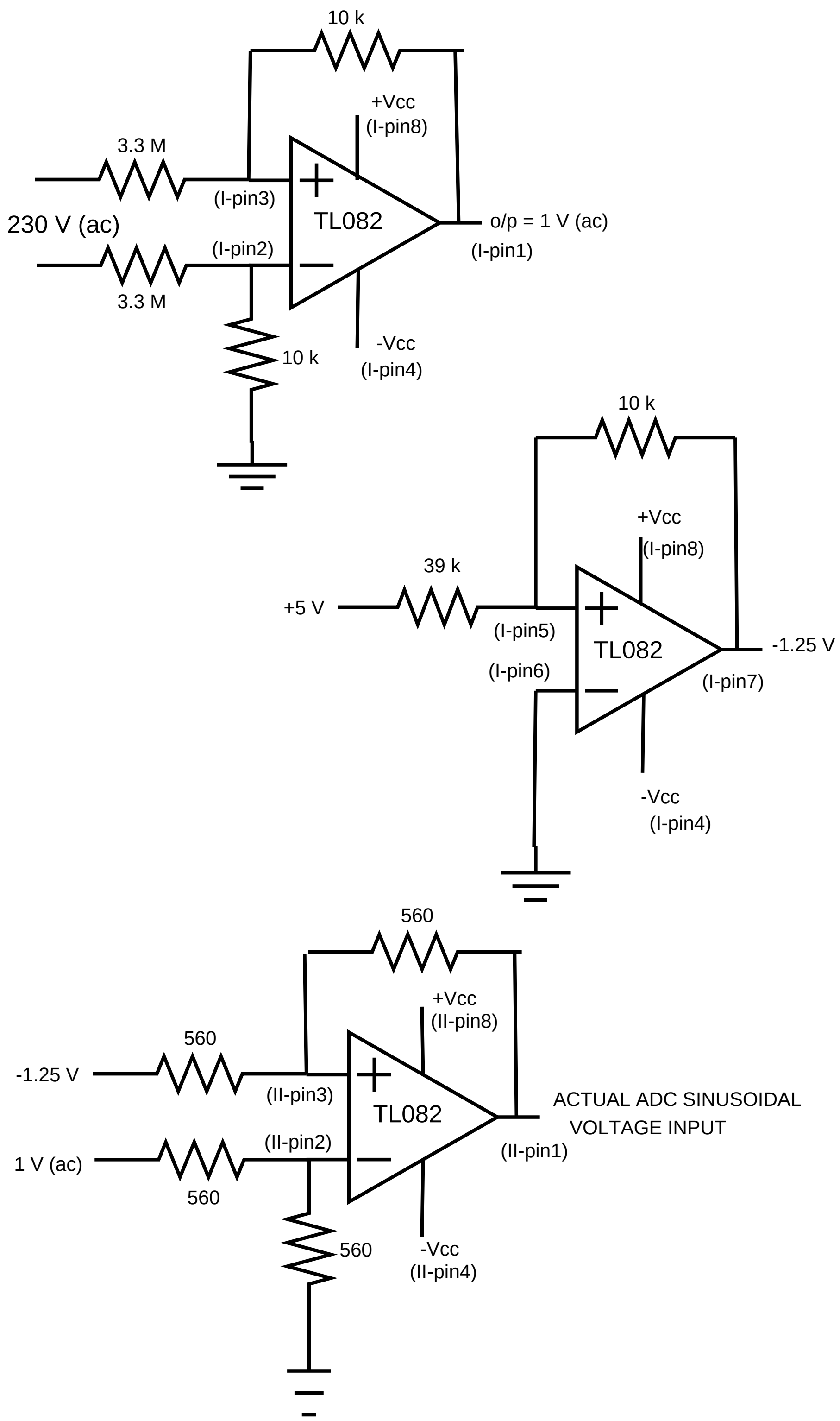

Figure 3: Voltage Conditioning Block

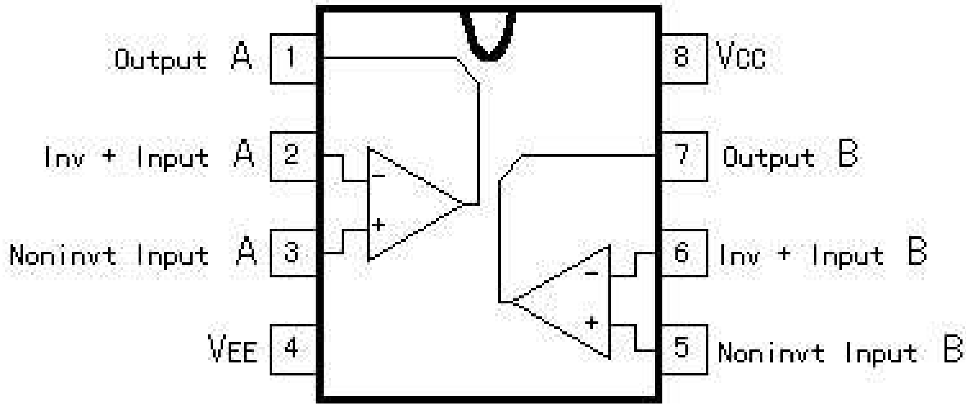

Figure 4: Pin Diagram of TL082

2.3.3 Circuit Description

The LEM55 Current Sensor works on the principle of reducing the magnetic flux through it to zero. It has a conversion ratio of 1000:1 and an offset current of approximately 0.2 mA. It requires DC $\pm$ 12 Volts for its operation. This is made available from the outputs of 7812 and 7912 respectively.

The datasheet of the current sensor requires that the current output should be terminated with a 50 Ω resistance. The voltage drop across the 50 Ω resistor is amplified by a factor of -220/50. The voltage waveform obtained has bipolar swing. To make it unipolar we again use an Operational amplifier with a gain of 1. A DC bias of 1.25 Volts at the Non-inverting terminal and the voltage waveform at the Inverting terminal of the Operational amplifier gives the desired waveform.

The DC of 1.25 Volt is generated using another Operational Amplifier with a gain of -1 and using -1.25 Volt as the input which was generated in the Voltage Conditioning Circuit. The -1.25 V is fed to the -ve terminal of a difference amplifier and hence the circuit results in a +ve dc offset of +1.25 V.

2.3.4 Circuit Diagram

Refer to Fig. 5 and Fig. 4

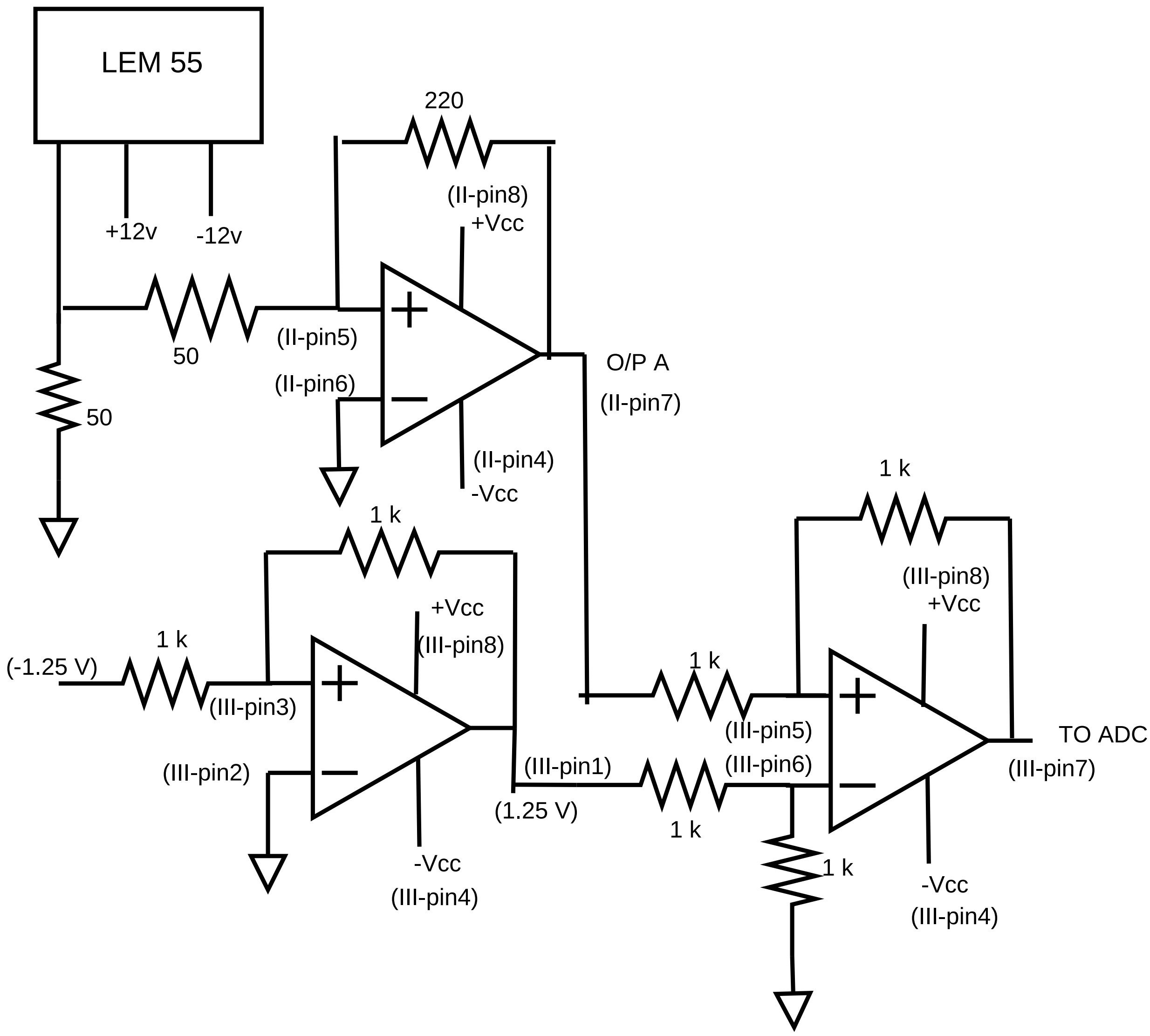

Figure 5: Current Conditioning Block

2.4 Waveform Sampling and Storage

2.4.1 Sampling Rate Considerations

- The line frequency is $\sim$ 50 Hz.
- Waveform contains many orders of harmonics.
- The ADC module of MSP430F147 supports a maximum of 200 k Sa/sec.
- Operating Clock Frequency of MSP430F147 is $\sim$ 8 MHz.

A sampling rate of 10 kSa/sec was finally chosen because it allowed

- Considerable time between two interrupts.
- Optimum utilization of the available resources.

The inbuilt ADC of the MSP430 returns a value in a word (2 Bytes). However, the value is a 12 bit value. The 4 MSBs are set to zero. We adopt a Q15 notation to store the bits. The obtained value is left shifted by 3 so that the MSB is zero and the reading of the MSP occupies the next 12 bits. The benefit of using such a notation is that when this word is transferred to the Host PC, it can be directly read as a signed integer thus facilitating computation.

2.5 USB Interfacing

The **Voltage and Current Waveform Monitoring Module** is completely under the control of Host PC. The Host PC can

- Start Sampling
- Procure 200 Voltage and Current Samples, which correspond to one cycle of line frequency ($\sim$50 Hz) when the sampling rate is 10 kSa/sec.
- Stop Sampling
- Refer to Fig. 6

On obtaining the voltage and current readings the Host PC performs the following functions

- Normalize, Save & Plot Voltage Waveform
- Normalize, Save & Plot Current Waveform
- Calculate, Save & Plot Power Waveform
- Calculate P_{avg}

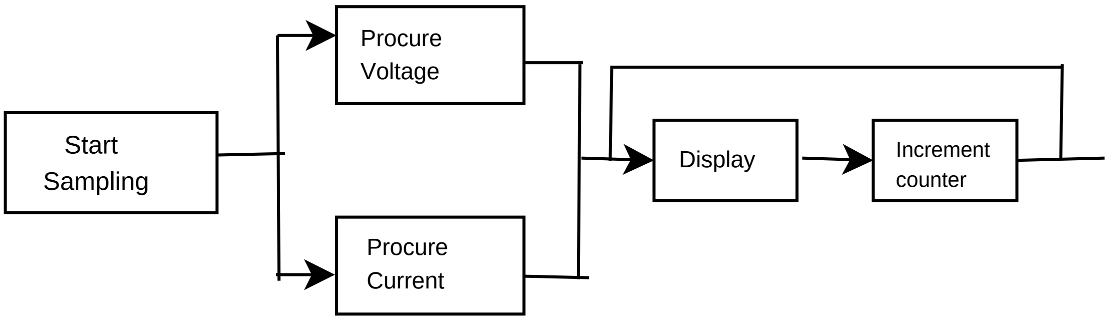

Figure 6: USB Interfacing and Sampling

2.5.1 Design Issues

The Universal Serial Bus is always Host Controlled. The Host PC issues commands to initiate various activities on the module. The TUSB 3210 is used to interface the MSP430 to the Host PC. All data flow between the Host PC and the MSP430 occurs through the TUSB 3210. A rudimentary protocol (with Acknowledgment) was developed to reliably transfer data/commands between the MSP430 and the Host PC. Subroutines catering to each command issued by the PC were written in the MSP. Though a number of commands were implemented in the protocol they are issued only in a predefined sequence.

This section has been written to highlight the importance of **Gray Codes** while implementing a protocol. As mentioned above the commands are issued in a specific sequence i.e. specific subroutines are invoked in a predetermined manner. The MSP430 continuously polls for a command on its input ports.

After obtaining the data on the computer we normalize each of the waveforms according the scaling factors introduced in the hardware. The data is stored in a file for later use and simultaneously plotted without any user intervention.

3 Conclusion

We have successfully integrated The MSP430 microcontroller and TUSB3210 to get voltage and current data from the main supply to a specific load. these data are then transfered to a host PC using USB communication. On a single key stroke, using our system, a user can monitor

- Voltage waveform of one cycle.
- V_{rms} of the cycle.

- Current waveform of the same cycle.
- I_{rms} of the cycle.
- Power waveform of the same cycle.
- P_{avg} across the cycle.

4 Acknowledgment

We extend gratitude to our guide, Prof. Mukul Chandorkar, for giving us such an interesting project to work on. We thank him for introducing us to field of low power microcontrollers and USB protocols. We are also thankful to our EDL course instructors, Prof. P. C. Pandey and Prof. L. R. Subramanyam, for their constant support and guidance to achieve our task. Many faculty members have been inspirational and the interaction which we had with them have certainly made a difference to us. The EDL will remain one of the most cherished learning experience of our life.

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