EMBEDDED SYSTEM DESIGN FOR A DIGITAL MULTIMETER USING MOTOROLA HCS12 MICROCONTROLLER

A Thesis Submitted in partial Fulfillment
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In

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Submitted by

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<u>CERTIFICATE</u>

This is to certify that this thesis entitled," Embedded System Design for Digital Multimeter using Motorola HCS12 microcontroller" submitted by Mr. Avinash Beck is a record of an original research work carried out by him under my supervision and guidance in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics & Instrumentation Engineering at the National Institute of Technology, Rourkela.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

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Next, I need to express my regards to my friends and my loving parents for showing me furthermore aiding me how to learn. They have been awesome wellsprings of motivation to me and I express my gratitude towards them.

Date Avinash Beck

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ABSTRACT

The goal of this project is to develop a digital multimeter using Motorola HCS12 microcontroller. This multimeter consists of a number of small modules such as a signal conditioning module for various types of input signal, an analog to digital converter (ADC) for signal conversion and a display. The signal conditioning circuit is made up of analog components whose parameters can be changed to measure across a large range. The signal is then passed to an ADC of the microcontroller. The microcontroller is programmed to analyse the values and display the result using a display device like LCD display.

CHAPTER 1

INTRODUCTION

HARDWARE AND SOFTWARE REQUIREMENTS

To develop this multimeter we required

- Analog components to develop the signal conditioning circuit.
- Motorola M68912DP256 microcontroller
- Freescale Codewarrior Development Studio for HCS12(x).
- LCD display

BASIC DESIGN OF DIGITAL MULTIMETER

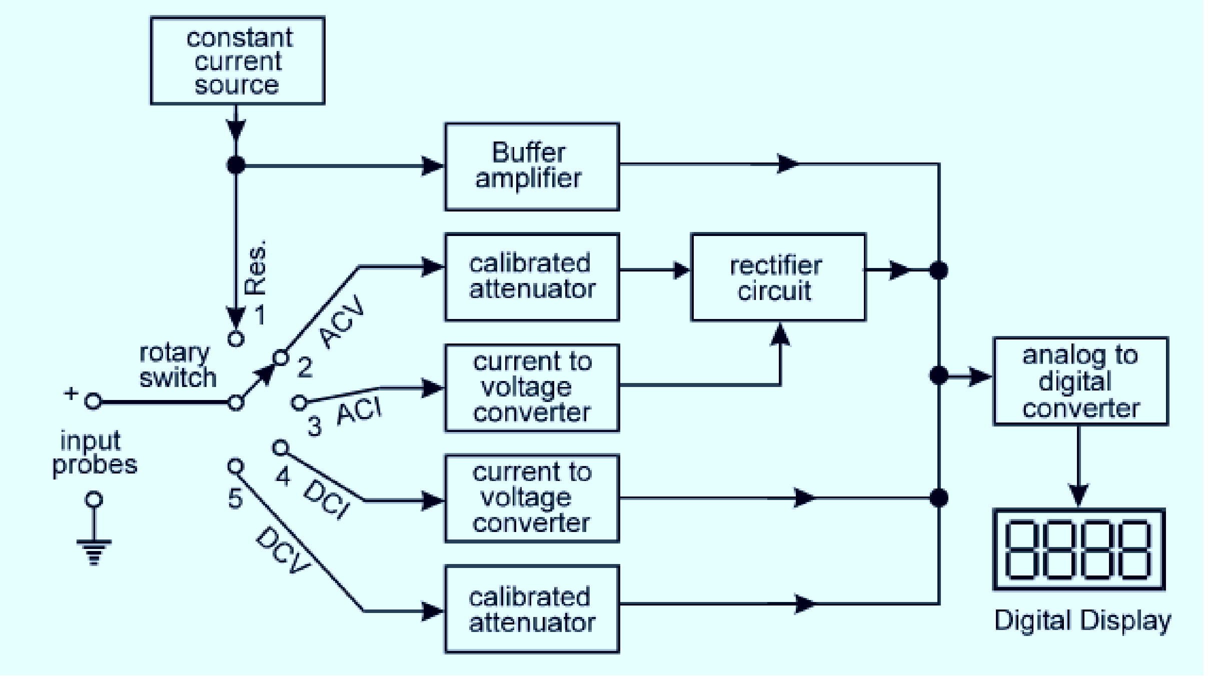

Fig 1. Block diagram

This block diagram displays how to measure resistance, dc voltage and current, and ac voltage and current.

The analog to digital converter used here belongs to the microcontroller unit.

The display is LCD.

Fig.2 Digital Multimeter

Specification of a general multimeter

Functioning

DCV	Range- 200mv to 1000V
ACV	Range- 200V to 750V
DCA	Range- 200uA to 10A
Resistor	Range- 200 to 2000k ohms

Such a large range of values are measured by using discrete analog components which break it down to smaller values which can be measured by the ADC of HCS12DP256 microcontroller.

THEORY

Measurement of resistance

An unknown resistor is connected across its input probes. The rotary switch is in the position 1. From constant current source, a proportional current flows through the resistor. Voltage is generated across due to the Ohm's Law. This voltage is directly proportional to its resistance. This voltage is buffered and fed to A-D converter and the result is displayed in Ohms.

Measurement of DC voltage

An unknown DC voltage is connected across input probes. The rotary switch is kept in position 5. If the voltage to be measured is larger than the ADC reference, it is attenuated by the signal processing circuit and fed into the ADC to get the digital reading in Volts.

Measurement of DC current

The DC current is measured indirectly. An unknown DC current is connected across input probes. The rotary switch is kept in position-4. The current is converted into voltage with the help of I-V converter in the signal conditioning components. Now this voltage is fed to A-D converter to get the digital display in Amperes.

Measurement of AC voltage

An unknown AC voltage is connected across the input probes. The rotary switch is kept in position 2. If the voltage is above the selected range and then it is attenuated and then rectified to convert it into proportional DC voltage. It is then fed to ADC to get the digital reading in Volts.

Measurement of AC current

Current is measured by converting it into proportional voltage. An unknown AC current is connected across input probes. The rotary switch is kept in position 3. The current is converted into proportional voltage with the help of I-V converter and then rectified by the signal conditioning circuitry. Now the voltage in terms of AC current is fed to ADC to get digital reading in Amperes.

So, in the above, we learnt how to measure five very important parameters of every circuit. This are the most basic functions of multimeters. Modern digital multimeters provide a vast range of measuring capabilities like

1. Capacitance
2. Temperature
3. Frequency
4. Transistor test
5. Continuity (buzzer)

There are many high end digital multimeter that provide better functions like auto-ranging. This DMM can sense from the input and choose the correct range for the value. Manual selection of the particular type of measurement to be made is still required.

Auto-polarity is another feature. This enables the Digital Multimeter to indicate the polarity of the reading with respect to its input connections without the need change the terminals.

CHAPTER 2

FREESCALE HCS12 MICROCONTROLLER SYSTEM

MICROCONTROLLER OVERVIEW

The MC9S12DP256 microcontroller unit (MCU) is a 16-bit microcontroller having multiple onboard peripherals with a 16-bit central processing unit (HCS12 CPU).
Its features are;

256K bytes of Flash EEPROM
12K bytes of RAM
4K bytes of EEPROM
two asynchronous serial communications interfaces (SCI)
three serial peripheral interfaces (SPI)
an 8-channel IC/OC enhanced capture timer
two 8-channel, 10-bit analog-to-digital converters (ADC)
an 8-channel pulse-width modulator (PWM)
a digital Byte Data Link Controller (BDLC)
29 discrete digital I/O channels
20 discrete digital I/O lines with interrupt and wakeup capability
five CAN 2.0 A, B software compatible modules (MSCAN12)
and an Inter-IC Bus.

The MC9S12DP256 has full 16-bit data paths. The external bus can also operate in an 8-bit narrow mode for lower cost or older systems with 8 bit memory.

It is manufactured by Freescale Semiconductors and are used in a wide range of application.

PORT SYSTEM

- Port A: General purpose I/O. Equipped with DDR to set I/O configuration to each pin.
- Port B: General purpose I/O. Equipped with DDR to set I/O configuration to each pin.
- Port E: Used for mode selection, bus control signal, initiate external interrupt.
- Port AD: Input for ADC system.
- Port T: Used as input capture and output compare pins for Timer System.
- Port S: Used for Serial Communication Interface & Serial Peripheral Interface.
- Port P: Used to interface with Pulse Width Modulation System.
- Port DLC: Interface to Byte Data Link Communication (BDLC) System.

In this project, we have to design a multimeter. So we need to be acquainted to the uses to different ports. The AD Port, is primarily used for ADC application. There are some other ports which will be used for LCD interfacing.

ANALOG TO DIGITAL CONVERSION SYSTEM

The special features of this HCS12 ADC system are

- Selectable 8 bit or 10 bit resolution
- Left or right justified and signed or unsigned result data
- External trigger control
- Flexible 1 to 8 conversion sequence length configuration
- Multiple ATD channels

Analog to Digital Conversion Technique

Successive-Approximation Converter is used by this microcontroller. It is an advanced version of Digital ramp type ADC which is designed to reduce the conversion and increase the speed of operation.

Given below is the block diagram of this technique.

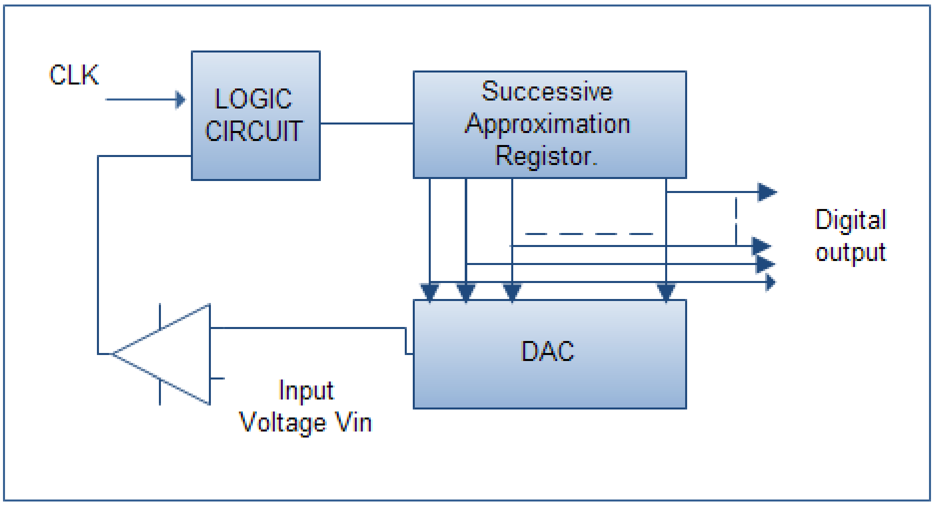

Fig.3. SAR Converter

Let us understand this process with an example.
Suppose the input voltage is 3.6 Volts (X) and is checked over a 10 bit ADC. Controller voltage is 0V (V_{min}) to 5V (V_{max}). The reference voltage is 5/2 = 2.5Volts. Now we compare our input to the reference voltage and see according to this table.

Condition	Value	Bit Status	Result
Is X >= 2.5	Yes	1	Retain 2.5
Is X >= 2.5+2.5/2 = 3.75	No	0	Discard 1.25
Is X >= 2.5+0.625 = 3.125	Yes	1	Retain 0.625
Is X >= 3.125 + 0.3125 = 3.4375	Yes	1	Retain 0.3125
Is X >= 3.4375 + 0.15625 = 3.59375	Yes	1	Retain 0.15625
Is X >= 3.59375 + 0.078125 = 3.671875	No	0	Discard 0.078125
Is X >= 3.59375 + 0.0390625 = 3.6328125	No	0	Discard 0.0390625
Is X >= 3.59375 + 0.01953125 = 3.61328125	No	0	Discard 0.01953125
Is X >= 3.59375 + 0.009765625 = 3.603515625	No	0	Discard 0.009765625
Is X >= 3.59375 + 0.0048828125 = 3.5986328125	Yes	1	Retain 3.5986328125

Table.1. SAR example

And so finally the reference voltage is equal to the input voltage. This explains the working.

Advantages: The conversion time is fixed and independent of the magnitude of the unknown signal.

Disadvantage: The hardware implementation is quite complex. The conversion technique is slower as compared to other methods.

HCS 12 Analog to Digital Conversion System

The steps to convert to ATD voltage are-

1. The ADPU bit in ATDCTL2 must be set to 1 to turn on the ADC.
2. Wait for 100us after setting ADPU to allow the ADC to settle.
3. Decide the type of ATD conversion by using the control registers.
4. Set the ATDCTL5 register and check if the SCF bit of ATDSTAT register is active.
5. Check the ATD result register.

The registers used in the HCS12 ADC system are

1. Control register- Registers that are used to tailor an ATD conversion sequence to user specification.
2. Status register- Register containing a series of flags that indicate the status of ATD system.
3. Result register- Eight identical 8 bit register that store the value generated by the ADC.
4. Test register- 2-byte ATD test register that can only be read from or written to in special modes.

Now, we are going to write the code for ADC of the signal generated from the signal conditioning circuit. This digital output is now represented by any display device like LCD.

LCD INTERFACING

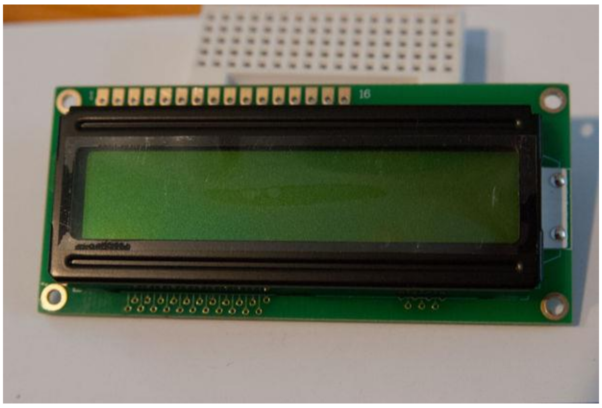

FIG 4. Liquid Crystal Display

It is very important to check the status of any automated and semi-automated devices. This can be done by displaying their status on a display module such as an LCD (Liquid Crystal Display). 16x2 LCD module is one of the most common device on the market.

The liquid crystal display has been replacing many other displays like 7 segment and others. This is because of the multiple benefits of LCDs i.e that they are economical. It can be programmed easily and doesn't have any limitations of displaying special and even custom characters. LCD can easily be interfaced with a microcontroller to display a message or status of a device.

In this topic we need to use a Hitachi HD44780. We will interface it with HCS12 microcontroller in 4 bit mode and check the result generated by the ADC.

Pin Configuration of LCD-

Pin	Symbol	Description	
1	V_{SS}	Ground	0 V
2	V_{CC}	Main power supply	+5 V
3	V_{EE}	Power supply to control contrast	Contrast adjustment by providing a variable resistor through V_{CC}
4	RS	Register Select	RS=0 to select Command Register RS=1 to select Data Register
5	R/W	Read/write	R/W=0 to write to the register R/W=1 to read from the Register
6	EN	Enable	A high to low pulse (minimum 450ns wide) is given when data is sent to data pins
7	DB0	To display letters or numbers, their ASCII codes are sent to data pins (with RS=1). Also instruction command codes are sent to these pins.	8-bit data pins
8	DB1		
9	DB2		
10	DB3		
11	DB4		
12	DB5		
13	DB6		
14	DB7		
15	Led+	Backlight V_{CC}	+5 V
16	Led-	Backlight Ground	0 V

Table.2. Pin details

LCD Initialisation

For displaying anything in LCD, it has to be initialised by sending set of commands to initialize the LCD or the internal reset circuit. It is upto the choice of the user to use which method. We are going to use the commands to initialize LCD.

Initialisation by internal reset sequence

When the LCD is turned on, an internal reset circuit initializes automatically. During this time the following instructions are executed. Until the initialization ends the BF(Busy Flag) is kept in busy state. It lasts for about 10ms after the VCC rises to 4.5V.

- Clear Display
- Function set:
  DL = 1; 8-bit interface data
  N = 0; 1-line display
  F = 0; 5 x 8 dot character font
- Display on/off control:
  D = 0; Display off
  C = 0; Cursor off
  B = 0; Blinking off
- Entry mode set:
  I/D = 1; Increment by 1
  S = 0; No shift

Normal LCD initialisation

1. Send 0x30 command - Using 8-bit interface
2. Delay 20ms
3. Send 0x30 command - 8-bit interface
4. Delay 20ms
5. Send Function set - see Table 3 for more information
6. Display Clear command
7. Set entry mode command

Instructions used for LCD interfacing-

Hex Code	Command to LCD Instruction Register
1	Clear display
2	Return home
4	Decrement cursor
6	Increment cursor
C	Display ON, Cursor OFF
E	Display ON, Cursor ON
80	Force the cursor to the beginning of the 1st line
C0	Force cursor to the beginning of the 2nd line
30	Use 1 line and 5x7 Dots
38	Use 2 lines and 5x7 Dots

Table.3. List of LCD commands

To successfully process the command or data, a delay is needed. Such a delay can be created by a delay loop of the required time which is greater than the time required to process the command or by reading the busy flag. The latter method is usually recommended.
The reason to use busy flag is that delay produced is the exact amount of time for which LCD need to process the time. So is best suited for every application.

These are steps to read a busy flag

1. Select command register
2. Select read operation
3. Send enable signal
4. Read the flag

Move data to LCD port

1. select command register
2. select write operation
3. send enable signal
4. wait for LCD to process the command

Sending Data to LCD

To send data we simply need to select the data register. Following are the steps:

1. Move data to LCD port
2. select data register
3. select write operation
4. send enable signal
5. wait for LCD to process the data

4 Bit LCD Interfacing

There are many reasons why sometime we prefer to use LCD in 4-bit mode instead of 8-bit. One basic reason is lesser number of pins are needed to interface.

Only 6 pins are needed in this process to interface an LCD. The unwanted data pins of LCD i.e. D0-D3 are connected to ground. D4-D7 are the pins used for data transfer in nibble. Enable and register select are the LCD control pins and are also connected to the controller. The Read/Write (RW) Pin of the LCD are not used, as we are only writing on the LCD. So this pin is grounded. In case you want to read from LCD, this pin is also connected. In this process an extra pin is also required which is not needed in this project. Potentiometer RV1 is used to control the LCD contrast.

After the connections are made, now the data has to be send. In this mode the data is sent in nibbles. In the beginning a higher nibble is send followed by a lower nibble. A special sequence of initialization is followed to used to enable 4 bit mode. Now the LCD controller knows that user has selected 4-bit mode of operation. This special sequence is called as resetting the LCD.

Following is the reset sequence of LCD.

1. Wait 20mS
2. Send instruction value (0x30)
3. Wait 10mS
4. Send instruction value (0x30)
5. Wait 1mS
6. Send instruction value (0x30)
7. Wait 1mS
8. Select bus width (0x30 - for 8-bit and 0x20 for 4-bit)
9. Wait 1mS

CHAPTER 3
IMPLEMENTATION

PROGRAMMING LANGUAGE

CodeWarrior Development Studios

This is the software used to program the freescale HCS12 microcontroller.

Freescale's Codewarrior Development Studios provide the tools to enable the design with Freescale microcontrollers. It contains a standalone C cross-compiler, pre-processor, assembler, linker, simulator, and debugger for use with freescale microcontroller boards. Such tools are highly essential for engineers in the development of products. Any team can reuse the features of a common project and work on the project already completed by the previous team.

CIRCUIT DESIGNS FOR SIGNAL CONDITIONING

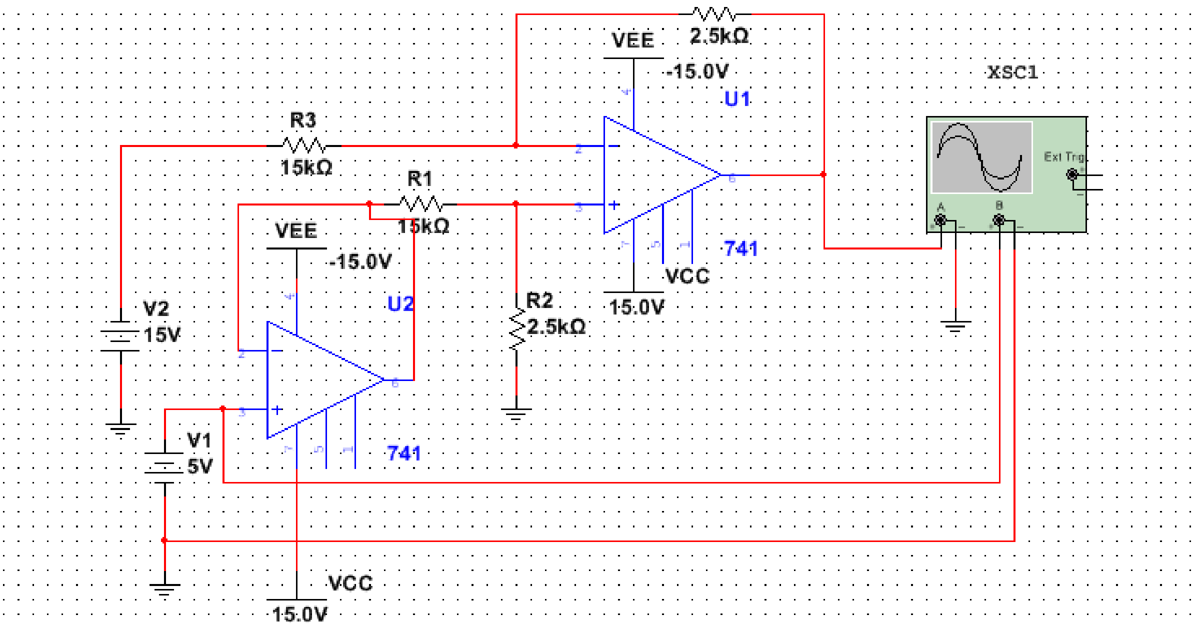

Fig 5. Differential Amplifier Signal Conditioning Circuit for DC voltage

Input Value (in Volts)	Output Value (in Volts)	Calculated Value(in Volts)
-15	0.148	0
-10	0.834	0.833
-5	1.668	1.667
0	2.5	2.5
5	3.333	3.333
10	4.168	4.167
15	4.854	5

Table 4. Results of the Signal Conditioning Circuit for DC voltage

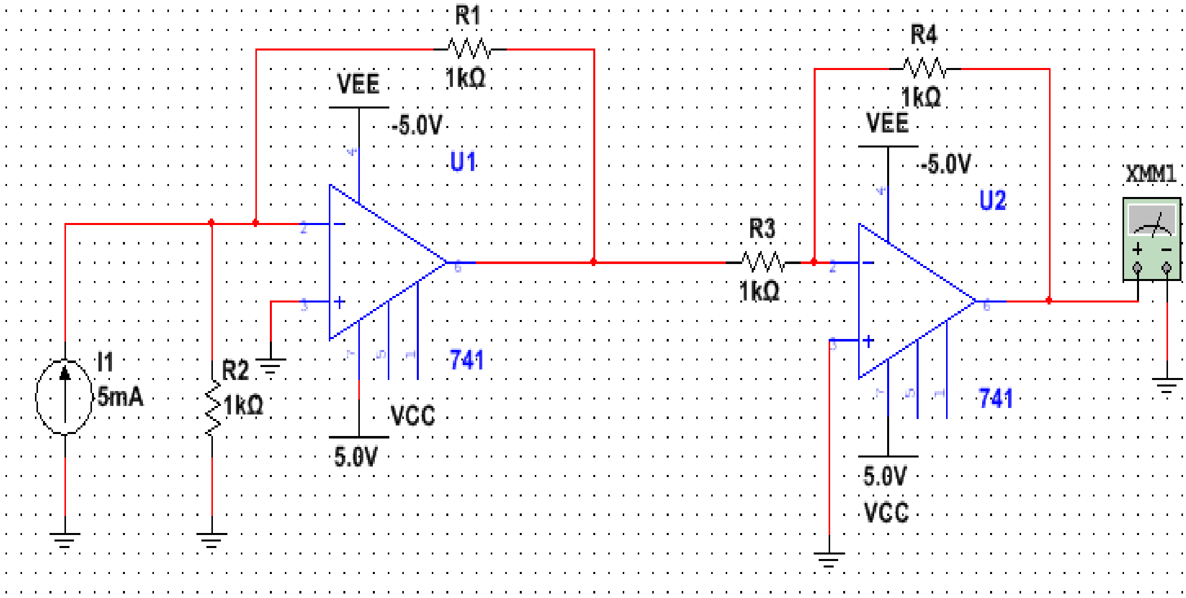

Fig 6.Circuit Design for DC current measurement

Input Value in mA	Output value in Mv	Actual Value in mV
5	5	5
7	6.9	7

Table 5. Results of the Signal Conditioning Circuit for DC current

IMAGES OF THE FUNCTIONING KIT

FIG 7.a. Image of the setup

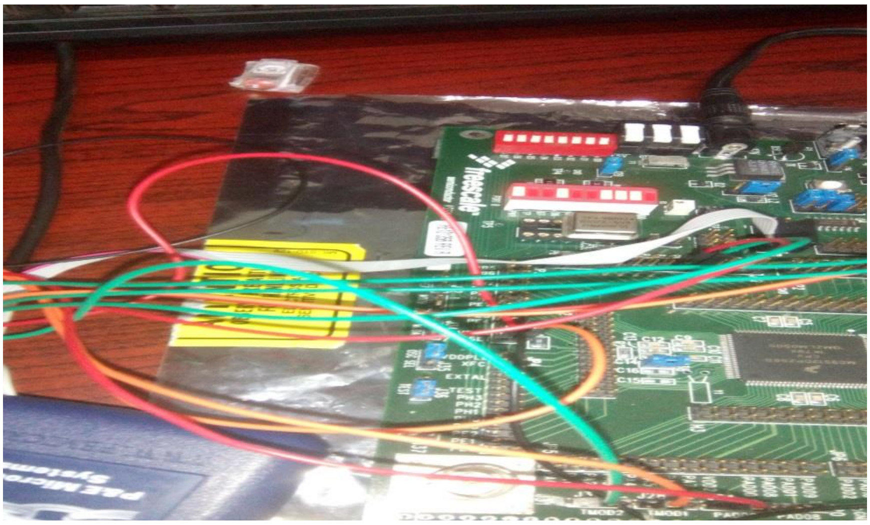

Fig 7.b. Output observed through LEDS

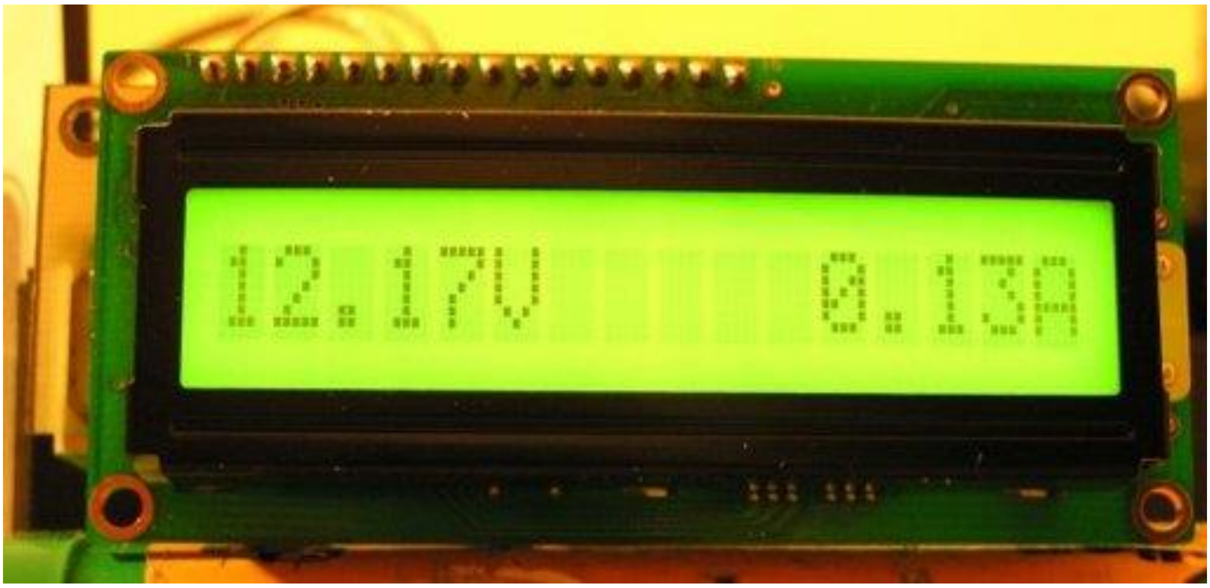

FIG.7c. Images of result

Another way is to directly read from the LED ports. But it is not required since we have LCD

Result Calculation from LED ports

The results obtained in the above diagram are still in digital. To covert it, we use the following procedure.

1. Convert it in decimal format
2. (Decimal value/resolution)* ADC reference voltage level

eg. 00001100= 12

Resolution = 8 bit = 256

Reference voltage = 5V

Calculated output= (12/256) *5= 0.23

CONCLUSION

A simple multimeter was successfully designed. The proposed digital multimeter can work in a large range as required by changing the signal conditioning circuit. It has a very high resolution because of 10 bit ADC. However, since it is designed on a HCS12DP256 microcontroller board, the cost is very high. The aim of this project was to learn about this new microcontroller which is new in the market and whose proper documentation is not available. With proper reduction of board size and PCB design there can be a significant reduction of price.

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