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Test Unit for Single Miniature Battery

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Abstract: ***In this paper we present a low cost electronic load which is suitable for measuring the discharge characteristic of a single miniature batteries in milli-ampere and sub milli-ampere. The discharge types include constant current, constant power, constant resistance and voltage-current relationship to see the voltage variation with discharging current. A charging circuit capable of charging at tickle charge to much higher capacity using constant current, constant voltage, CC-CV, pulse and brup charging is included in the circuit to observe effects charge-discharge cycles. The battery data acquisition system is assembled around 89S52 microcontroller with a 12-bit 4 channel differential input ADC, MCP 3304, and a DAC MCP 4921. The microcontroller based charging and discharging circuit is interfaced to a PC or a laptop using a USB to serial converter. The program for automation of electronic load is developed in Visual Basic. Measurement which includes open circuit voltage, load voltage and load current for different types of discharge and recharge are saved in excel format. Since the cost of the circuit is small and interfacing is through USB port, such circuits can be built in suitable number and can be used to test several batteries simultaneously.***

Keywords: Battery; Charge; Discharge, Electronic Load, Battery Discharge, Microcontroller, USB Interfacing, Charge Discharge Cycle

1. Introduction

In recent decades, development of battery technology has led to brighter future for green technology. Many researcher had use several methods to improvise battery reliability via studying charging-discharging profile and others parameter that will enhance the life cycle of the battery. Testing batteries implies to study the evolution of battery parameters like voltage (V), current (I), temperature (T) for hundreds and hundreds of charging-discharging processes. Different batteries must be tested in fully controlled environment to draw right conclusions.

Battery tests were traditionally performed manually which was both labor and expertise intensive. Manual observations inherently are subject to human errors which make results less conclusive and sometimes even flawed. In recent years with advent of programmable devices such as computer and microcontrollers the battery test procedures have been automated [1-7]. The main advantages of automated system over manual systems offer accurate collection and easier storage of accumulated data in system memory, accurate analysis and results. The instruments are compact and programmable for variety of measurements and for that not much skill is required for testing procedure (to operate it). The architecture of an automated battery test system for investigation of the behaviour of VRLA batteries in telecommunication standby application is presented by Pascoe and Anbuky [8]. It can be extended for several other batteries with few alterations and can be easily altered to suit different application such as uninterruptible power supply (UPS) applications or electric vehicle (cyclic) applications.

Researchers and engineers around the world have attempted to design system for testing batteries specific to their needs using conventional and unconventional test procedure. Jianhai et al have used a pulse width modulation (PWM) method along with PID control for constant current discharge providing a touch screen for setting the discharging parameters [9]. A new circuit for constant current discharge has been suggested by Govindaraja et al for testing their silver ion solid state batteries [10].Al-Refai et al have developed a charger with a real-time programmable approach to charge lithium-ion batteries with multiple cells using Mathwork's Simulink environment to control a current source [11]. Viera has developed a new system for testing the fast-charge process in medium or high capacity batteries [12].

Most of the systems designed although automated used for particular type of test on a battery of particular chemistry. While newer batteries are being developed they are made small and have low capacity. Ones they pass the capacity and other test they are tested for larger capacities. Automated test systems for batteries under developmental stage for low voltage and low current range are not available. Therefore, a dire need is felt to develop an automated programmable test system for such batteries.

This paper presents the architecture of an intelligent or automated battery test system based on the AT89S52 microcontroller which can perform various types and combination of charge, discharge (on primary batteries) and cyclic tests on secondary battery under developmental stage. In order to obtain accurate charging-discharging curves, all test results are sent to the PC by the serial communication through USB to serial convertor and are stored in computer memory. As the cost of development of the circuit is small and the interfacing of the circuit to the computer is through a USB port, thus, a required number of such units are prepared and further used for testing batteries.

2. System Design

Usually, operating voltage for cell varies from 1 V to 4 volts for various cell chemistries. For a resolution of 1 mV a 12-bit ADC is selected. Normally during charging or discharging the battery voltage do not vary much. The variation is high during change over from charging to discharging and vice versa and at the end of capacity of battery. Feedback control to correct the charging or discharging current for the set parameters also requires a higher sampling rate. All these are accommodated using a sampling rate of 5 per second. Date storage is done every second which automatically increases to 30 second or 5 minutes when the voltage variation is very small. During changeover from charging, discharging or rest period the data recording is again done every second so that minute details can be observed.

When the charging or discharging is at a low current, the battery temperature does not vary much and it is around ambient temperature hence it is not necessary to acquire temperature at a high rate. Acquisition rates in the order of a minute are acceptable. The temperature range of 10 to 60^{o}C suffices the proposed system.

A. Hardware description:

The schematic circuit diagram of the proposed battery test system is shown in fig.1. It includes voltage and current measuring circuits, charging and discharging voltage and current control circuit and a temperature measuring circuit.

B. Discharging circuit

The two important devices which show constant current characteristics are the bipolar junction transistor and MOSFET. These devices in connection with an op-amp in feedback form a constant current load. MOSFET has very high gate resistance. The error due to circuit current adding to discharging current is absent and hence the discharge current is measured accurately.

Fig. 2 shows the schematic of the discharging circuit. It maintains a constant but adjustable load current. Operational amplifier U1 drives the MOSFET Q1. The discharge current flows only through resistor R1 and hence the voltage drop across R1 is proportional to it. R1 is a high precision, low temperature coefficient resistance to improve the detection accuracy. Large open loop gain and low bias current of op-amp used ensures the voltage drop across the resistor R1 is equal to the voltage applied at the non-inverting terminal input of the op-amp. Battery discharging current remains constant irrespective of the battery terminal voltage if the voltage at the non-inverting terminal of op-amp is maintained at a fixed value [13].

A small positive offset voltage cause the battery to discharge even when the control voltage is zero during resting period or when the instrument is not operating while power to the circuit is ON. A low offset voltage operational amplifier OP07 is used to keep the offset voltage minimum. In addition a small voltage is added so that the output is slightly negative to 1 – 2 mV. This will keep the discharging current to zero during non operation of the instrument.

Drain source leakage current is another important parameter to be taken care when the instrument is not operating. MOSFET BS170 which is used here has a low leakage current of 0.5 uA at 0 gate source voltage. Even this small value is a large percentage of the discharge current when the discharging rate is to be kept at lower range of few uA. A test circuit similar to shown in fig. 2 with slight negative voltage was used to test some of these types of MOSFET which will give very low drain source leakage current. Additional gain of 100 was given to the voltage across R1 = 10k so that measurements can be done using a 3-3/4 digit meter taking care of the offset voltage of op-amp. The leakage current was calculated from the voltage measured which varied from 400mV to 50mV for different MOSFETs corresponding to a leakage current of 400nA to 50nA. The MOSFETs with lowest leakage current were selected and connected in the circuit. The percentage of error at lowest range even with low drain source leakage current is higher but will reduce for higher range. The error will be caused only during the time when the battery is connected, power is ON and discharge operation is off. During the discharging process the feedback circuit will include the leakage current in its measurement and control the circuit according to set value of discharge current.

C. Charging circuit

The charging circuit consists of op-amp along with a MOSFET in closed loop with unity gain as shown in fig. 3. The voltage at the source of the MOSFET equals the voltage at the control input of op-amp. A resistor R2 is connected between the source of MOSFET and the test battery. The charging current is given by $V_{R2}/R2 = V_{Control}/R2$.

D. Microcontroller circuit

89S52 is a low power high performance high 8 bit microcontroller consisting of four 8-bit ports, 16-bit timers, a full duplex UART. Microcontroller control all the function of the test system which consists of ADC, DAC, charge-discharge circuit, the battery temperature measuring circuit and USB to serial interfacing circuit. The microcontroller receives commands from the computer and executes them. Microcontroller transmits the sampled data to the computer. The software in the computer analyzes the performance of test battery based on the received data.

Present day computer and laptop seldom have parallel port or even serial port. These ports have been completely replaced by the USB ports. Physical size USB is small and are hot pluggable. Several USB ports can be found on a computer laptop. While USB have several advantages they are not easy to program. General purpose commonly used microcontroller does not have USB port. On other hand serial port are in use since long time and are available in almost all the microcontrollers and are easy to program. Various computer languages have useful build in function to program serial ports. An USB to serial converter gives the user the advantages of USB port as well as serial port. It connects to computer USB ports and communicates between computer and microcontroller as if it is a serial port.

Fig. 4 depicts the connection of the system devices to microcontroller. Port 0 supply logic bits to control various operations like selecting the charging and discharging channel and range. ADC and DAC are connected to the microcontroller through port P1 and P3. The connection to computer is through the UART port of microcontroller.

Microcontroller transmits ADC binary data which is the measurement of battery voltage, and voltage proportional to discharging and charging current and temperature of battery. On the other hand it receives all the instruction regarding the control of the discharging and charging process. Microcontroller receives the start and stop commands of the process, OCV measurement command, range information and the binary equivalent of the charging or discharging magnitude of the current to be applied to the DAC. The main work of the microcontroller is to controls the peripheral devices depending on instruction given by computer and communication with computer. It does not perform any complex arithmetic calculations which are handled by computer. Hence assembly language program is preferred compared to higher language such as C for microcontroller programming.

E. ADC and DAC unit

MCP3302 is an 8 multiplexed channel 13 bit SPI SAR ADC from Microchip and has a sampling rate of 100kps. The 8 channels of the ADC can be used either separate 8 single ended channel or 4 differential channel. 12 bits gives the magnitude of the voltage and the 13th bit gives the polarity of the signal voltage during differential mode. 3 channels of the ADC are utilized to measure the battery voltage, discharging current and the charging voltage. Serial ADC requires a smaller area on PCB and just 4 port pins of the microcontroller for its connection at a cost of programming overhead which is slightly higher than the parallel ADC. Measurement of the battery voltage, discharge current or the charging voltage is taken sequentially 16 times and then averaged to get final value. The reference voltage of 4.092 volts gives a resolution of 1mV. ADC interfaces to microcontroller using port P3.4 – P3.7.

MCP4921 is a 12-bit buffered voltage output Digital-to-Analog Converter (DAC). The device operates from a single 2.7V to 5.5V supply with an SPI compatible Serial Peripheral Interface. The device utilizes resistive string architecture, with its inherent advantages of low differential non-linearity (DNL) error and fast settling time. The reference voltage to this IC is set at 4.092 volts which gives the resolution of 1mV. Interfacing to microcontroller is through Port pin P1.0 to 1.3. DAC data is calculated in the computer and passed to microcontroller. The microcontroller then serially output the digital data to the DAC. The analog output of DAC is given to both, the charging circuit and the discharging circuit, through the analog switch.

F. Range switching circuit

Fig. 5 shows schematic diagram of the charging and discharging system along with range selector circuit. The range of the discharging current is from 40uA to 400mA and that for the charging current is from 40uA to 400mA.

The charging range circuit consists of 4 MOSFET transistors switches Q2 to Q5 in series with the corresponding charge range resistor RC1 to RC4. The charge range resistors are high precision 5000, 500, 50 and 5 ohms resistor corresponding to charging current range of 40-400uA, 0.40-4mA, 4-40mA, 40-400mA and respectively for a battery of 1.5V. The maximum current depends on battery voltage and is not specific to the above values. For battery the lead acid or lithium battery which have higher voltage maximum charging current will decrease correspondingly. The de-multiplexer selects one of the 4 MOSFETs and switches it ON. Feedback loop consisting of op-amp, charging MOSFET and switching MOSFET has unity gain and hence its output will be equal to the voltage at the non-inverting terminal of the op-amp U1. Charge range resistor is connected between the output and positive terminal of battery. Hence charging current is given by

$$I_{charge} = (V_{DAC} – \text{Battery voltage})/ \text{Charge range resistor}$$

Voltage across the charge range resistor can vary up to 2.5 volts for a 1.5 volts battery to give the above mentioned charging current. The resistors are automatically selected by switching ON the corresponding MOSFET by the software depending on the magnitude of the charging current set initially or during the process when charging current increases or decreases beyond the range.

The discharging circuit consists of another unity gain closed loop similar to that is used for charging. The loop consists of op-amp U2 and U3, discharging MOSFET Q6, switching MOSFET (Q7-Q10) and an analog multiplexer. Input to op-amp U2 is applied from DAC whose voltage ranges up to 4.092 volts. For feedback loop to give a unity gain the voltage at the inverting input of U2 must be equal to applied voltage at its non-inverting input. Usable battery gives voltage above 1 volt and if battery is discharged up to 50% of the open circuit voltage than the battery voltage will drop to 0.5 volts. Assuming some voltage drops across the two MOSFET within the loop a maximum voltage drop of 0.4092 volts across the discharging range resistor is selected. A gain of 10 is given by U3 and then the amplified voltage is applied as feedback to U1 to complete the loop with unity gain. ADC measures the output from op-amp U3 which is the measurement of discharging current.

An analog multiplexer is used here to select a discharging range resistor RD1 – RD4 selected by switching ON the corresponding MOSFET (Q7 to Q10). Another analog multiplexer simultaneously connects the voltage across that discharge range resistor to the input of the op-amp U2 to complete the feedback loop. Discharging current is given by

$$I_{discharge} = V_{DAC}/ (10 * \text{Discharging range resistor})$$

Discharging current range of 40-400uA, 400-4000uA, 4-40mA, 40-400mA is achieved using high precision low temperature coefficient resistance of 1000, 100, 10 and 1 ohms respectively.

Only one of the two processes, either charging or discharging, operates at any time. Hence one DAC is used to generate charging or discharging voltage. A two channel analog multiplexer controlled by microcontroller connects the DAC voltage either to U1 for charging or U2 for discharging. So, one of the op-amps receive the DAC voltage while the other op-amp is at 0 volts. A feedback resistor of 1M-ohms, bypassing all the range switching circuit, both in charging or discharging part of circuit keeps the respective op-amp gain to unity and does not go into saturation.

G. Temperature measurement:

During charging or discharging of the test battery if the current is limited then the battery maintains temperature around ambient temperature. Only when the charging is done at much faster rate the battery temperature rises. Higher temperature results in degradation of the battery life time. The main purpose of the temperature measurement unit here is to measure the battery temperature during charging and discharging so that suitable action can be taken if necessary. IC LM35 which has a sensitivity of 10mV/^{o}C is used here to measure the temperature of the battery. The flat surface of LM35 contacts the side surface of the button size battery in the test assembly.

H. Software

The flexibility of the test system depends on the control and data acquisition software. Test process is simplified if a specific program for programming the tests, controlling the equipment, and data storing and processing is developed [14]. There are a lot of programming languages that allows us controlling equipment remotely. Visual Basic programming environment eases program construction and modification and also provides good user interface support. Therefore the test system software is written in the Visual Basic (VB) programming language. Provision is made for real time graphing of battery data for current, voltage and power vs. time and also voltage vs. current characteristics. Fig 6 shows the test software front panel screen. Once the software is executed it searches for the USB to serial port and configures it for transfer of data between the test system and the computer. Open circuit voltage based on zero discharging current and approximate short circuit current based on very low load resistance is measured and displayed when the respective buttons are pressed. The types of charge and discharge and other setting such as end limit of charge and discharge are entered. The details of the different types of charging and discharging performed are listed below. The data is recorded in computer in excel format which is later used to analyze the behavior or plot the characteristics of the test battery.

3. Tests

a) Constant current discharge

It is the most important test performed on any battery to test the capacity of the battery. The battery is discharged at constant current till its fall to some percent of the open circuit voltage. The test instrument constant current discharge range is from 40uA to 400mA. The characteristics show a linear fall in the terminal voltage until the cell is nearly discharged, beyond which the terminal voltage drops exponentially.

b) Constant power discharge:

The battery is discharged at a constant power. So as the terminal voltage of battery falls, the current tends to increase keeping the discharge power constant. Software monitors the battery voltage and adjusts the discharge current so that the discharging power remains constant. Batteries show a steep fall in voltage during the final stage of discharging as discharge current increases rapidly to maintain constant discharge causing further fall of voltage.

Constant load discharge:

The load current falls as the terminal voltage falls due to discharge. The software monitors the battery voltage and continuously reduces the discharging current proportional to the fall in voltage to achieve the purpose of constant resistance.

c) Voltage-Current characteristics:

The battery is discharged with continuously rising current from 0 to some high value and the voltage is observed. This test can be performed in a short duration of few minutes in an automated system. This test also helps in determining the current at which the constant current, load or power discharge may be performed for further testing. In newly developed battery when no data is available about it then this might become the first data from where the further work may be carried on.

d) Constant current charging:

Constant current chargers vary the voltage they apply to the battery to maintain a constant current flow, switching off when the voltage reaches the level of a full charge. This design is usually used for NiCd and NiMH batteries.

e) Constant voltage:

Battery is charged from a constant voltage, so as the battery gets charged its voltage increases and charging current decreases. Charging is stopped when the charging current falls below some percentage of the initial value. Constant current in combination to constant voltage method is used to charge lithium batteries.

f) Pulsed charging:

Pulsed chargers feed the charge current to the battery in pulses. The charging rate can be precisely controlled by varying the width of the pulses. Pulse charging leads to improve the performance of various secondary electrochemical cells [15, 16].

g) Burp charging:

It applies a very short discharge pulse during pulse charging, typically 2 to 3 times the charging current for very small time, limited to maximum discharging current range of instrument during the charging rest period to depolarize the cell. These pulses dislodge any gas bubbles which have built up on the electrodes during fast charging, speeding up the stabilization process and hence the overall charging process [17, 18].

4. Result

A prototype circuit was developed on the basis of the system designed to test the small batteries being developed in the lab. Singh et al have developed and tested performance in proton conducting solid state batteries [19-22]. The test batteries have diameter of around 10 mm, height of 2-3mm and weighs less than one gram. These batteries have a short circuit few tens of mA and tested for a discharge and charge current of few hundred uA. Charge discharge cyclic tests were conducted on cell made with Zn + $ZnSO_4$ as composite anode, $P_2O_5.5H_2O$: ($92SiO_2$:$08Al_2O_3$) composite electrolyte and γ-MnO_2 + Graphite as cathode material for 30 cycles at a constant current of 100uA. Fig. 7a shows the voltage variation of cell as the cell discharge. Fig 7b shows the charge discharge cycle constructed from the data recorded in the excel sheet by the prototype system.

The prototype was used to test a standard AA size Duracell to check for the integrity and performance of the system. The cell was discharged at a constant current of 30mA. Fig 8 shows the variation of voltage during discharge process. It also shows that the discharge current remains within a very small limit of 29.98 to 30.02mA.

Fig 9 a, b and Fig. 10 a, b shows the response of same type of battery at a constant power discharge of 30mW and constant load discharge at 40 ohms.

5. Conclusion

An automated battery test system has been developed which is useful in testing the batteries that are in developmental stage which are small in size and have low current charging and discharging capacity. All known possible charging and discharging methods have been accommodated so that standard test procedure can be applied to test any kind of battery. The system is programmable and can be used for various combinations of charge and discharge methods and cycles. The data is stored in the excel format in the computer so that later data processing is possible and is also displayed graphically on-line.

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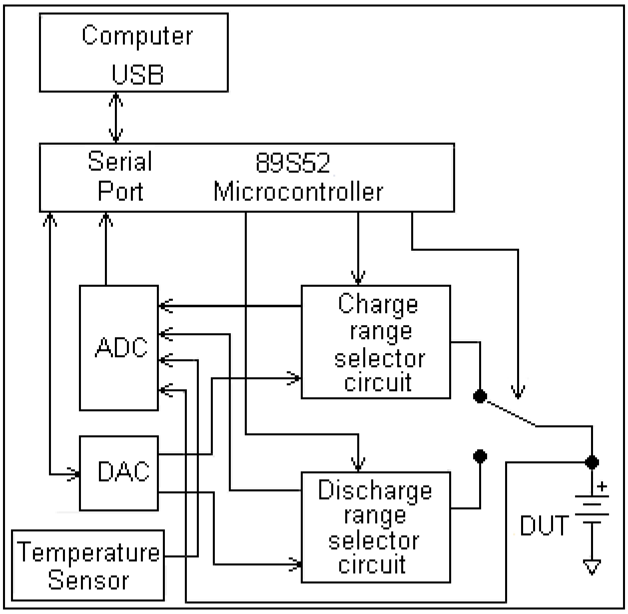


Figure 1: System design of proposed battery test unit

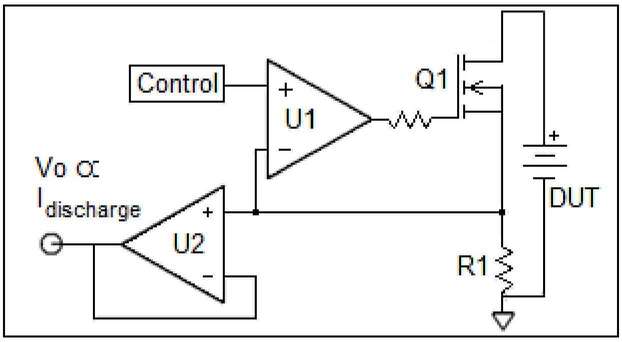


Figure 2: Schematic diagram of discharging circuit

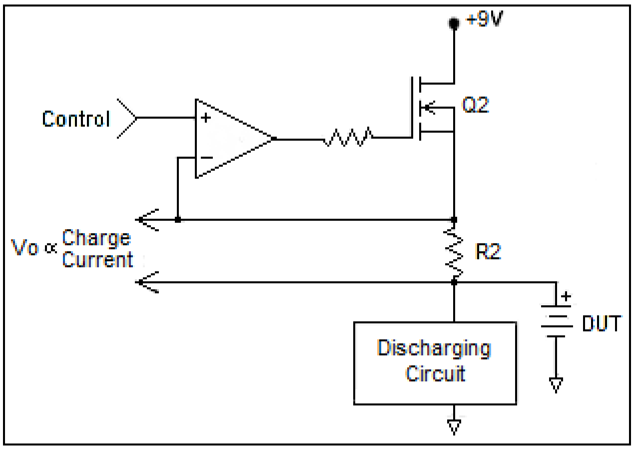


Figure 3: Schematic diagram of charging circuit

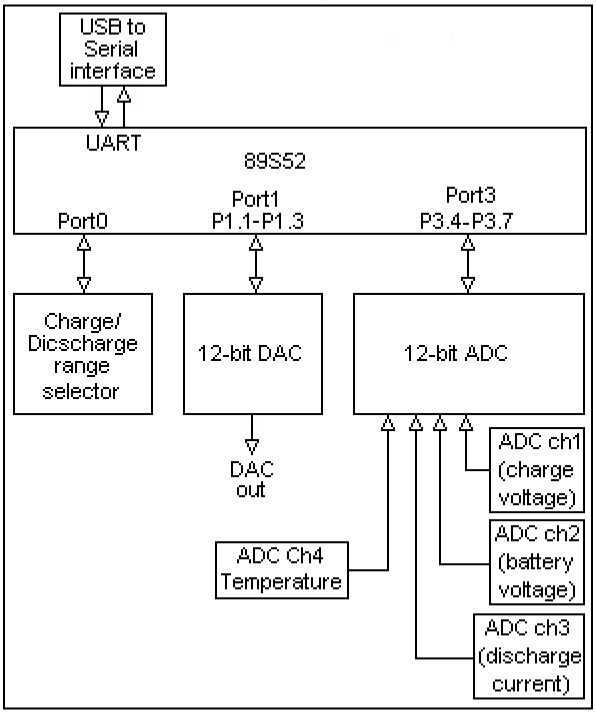


Figure 4: Connection of system devices to microcontroller 89S52

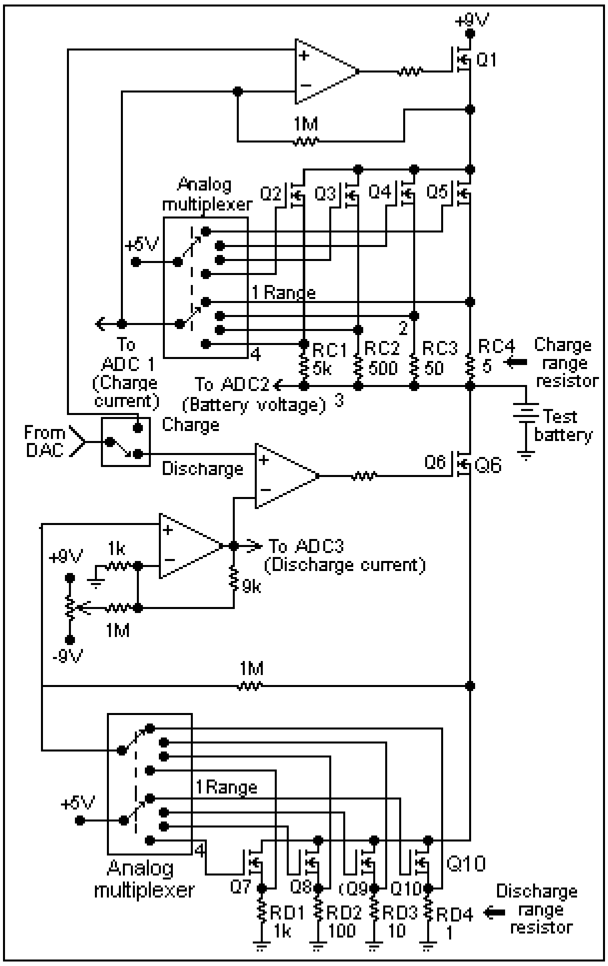


Figure 5: Schematic diagram of the range switching circuit

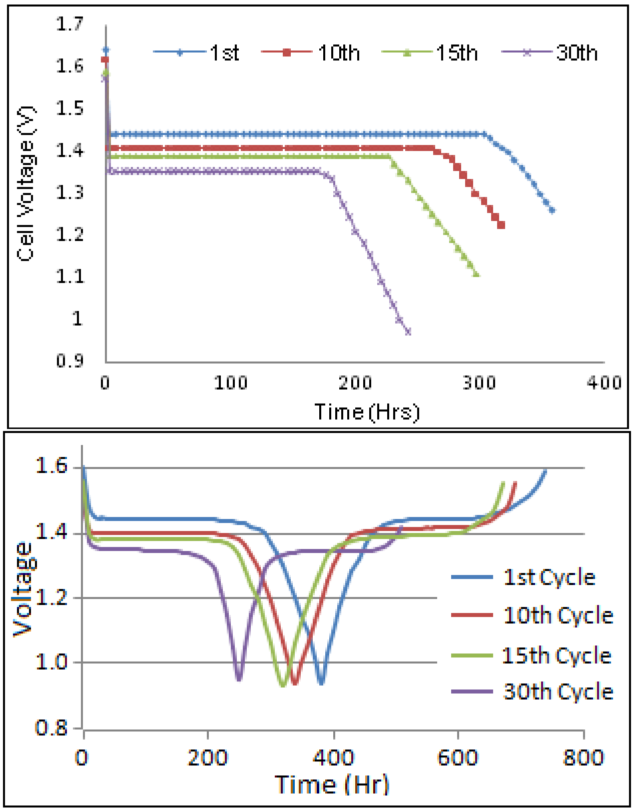


Figure 7: a Discharge characteristics of cells made using Zn+ZnSO$_4$/P$_2$O$_5$.5H$_2$O:(92SiO$_2$:08Al$_2$O$_3$)/γ-MnO$_2$ + Gr at constant current. b) charge-discharge cycle of the battery

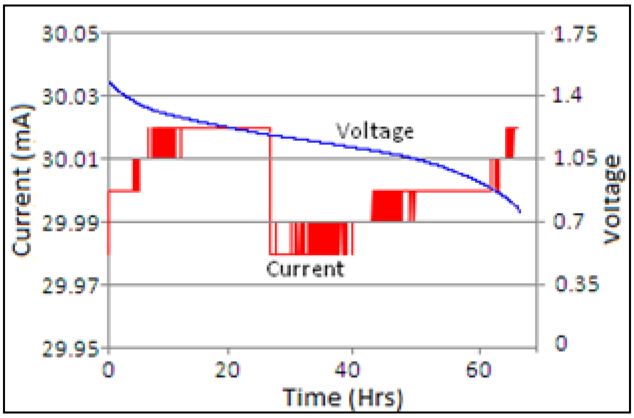


Figure 8: Discharge of Duracell AA size battery at 30mA

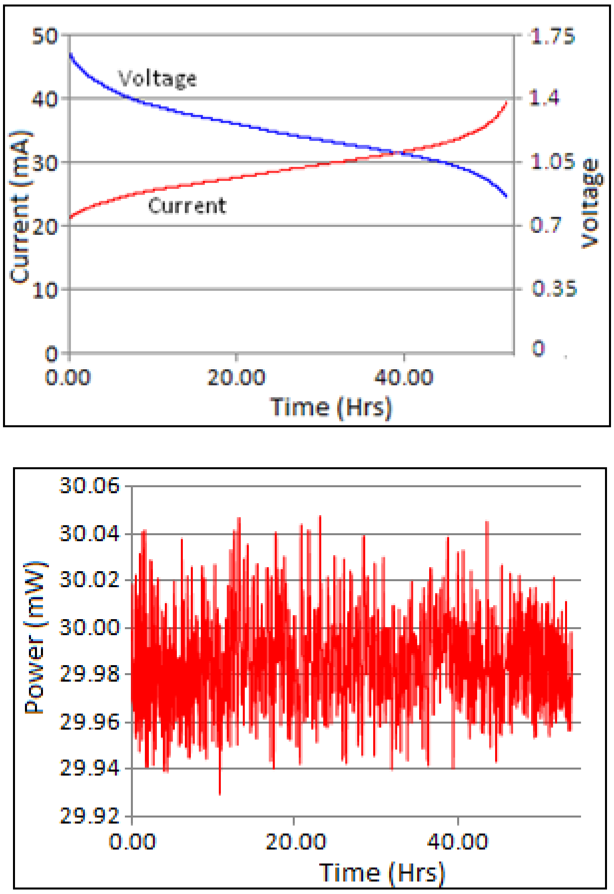


Figure 9: a , b Discharge of Duracell AA size battery at constant power of 30 mW

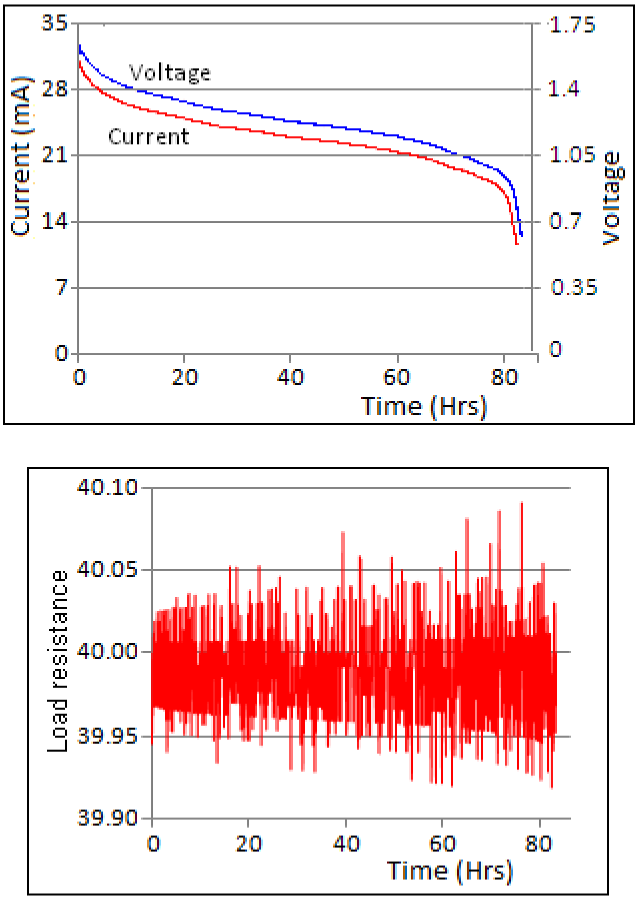
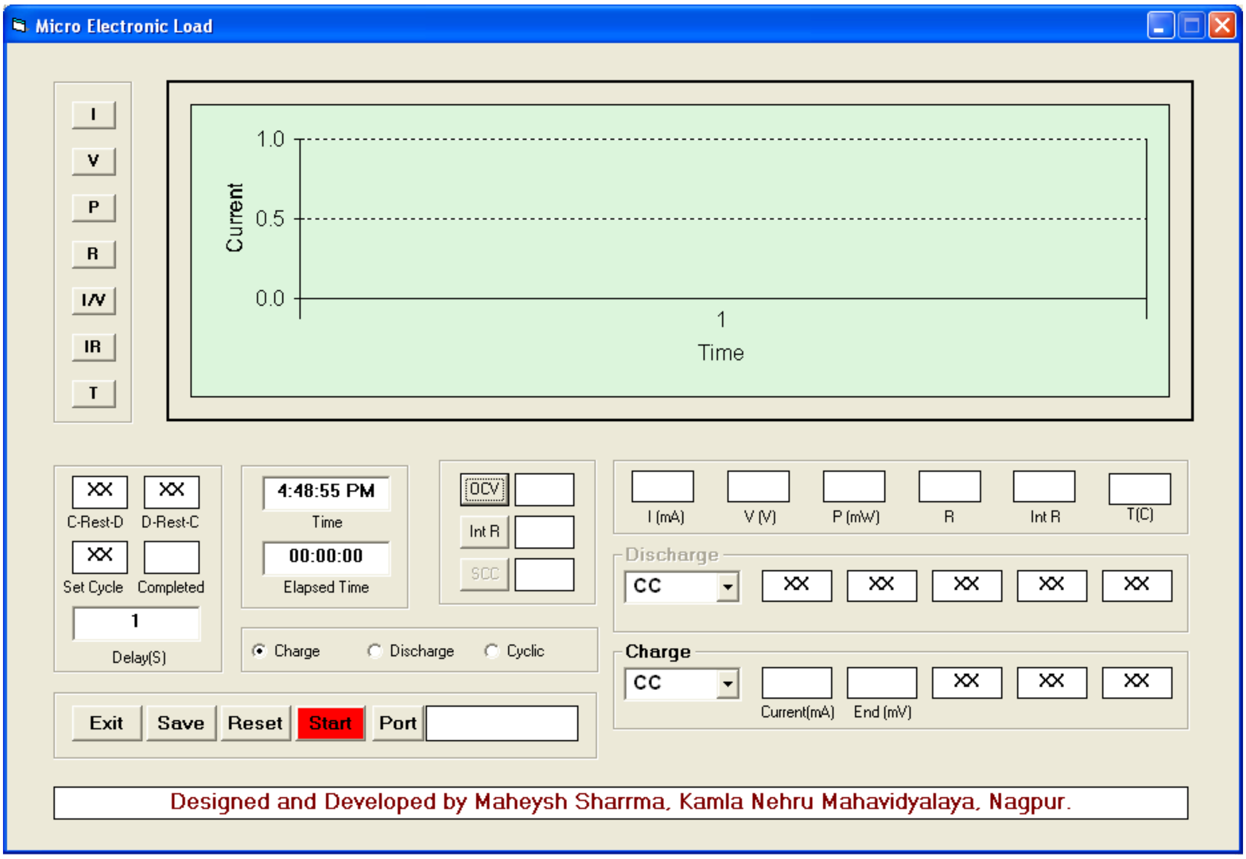


Figure 10: a, b Discharge of Duracell AA size battery at constant resistance of 40 ohms



4:48:55 PM
Time

00:00:00
Elapsed Time

1
Delay(S)

● Charge ○ Discharge ○ Cyclic

Discharge: CC

Charge: CC

Designed and Developed by Maheysh Sharrma, Kamla Nehru Mahavidyalaya, Nagpur.

Figure 6: Front panel of the proposed electronic load