Chapter 3
Hardware of Microcontroller
based Capacitance meter
3.1 Principle of Capacitance Measurement:

The capacitance value of a capacitor can be measured by utilizing one of its basic properties. The process is a bit complicated when compared to measuring of a resistance value because the capacitor is a reactive component and requires an AC source to pass current through a capacitor. In general people use to measure the capacitance value by comparing its value with the known value of another capacitor using complicated LCR bridge. In the present study, we adopted the basic principle of charging and discharging of the capacitor an arrangement similar to shown in figure3.1.

The basic circuit for measuring the capacitance is shown below. In this the capacitor C is charged through resistor R and during the process the voltage increases exponentially. Once the voltage reaches the maximum Capacity a comparator drives its output high, which is an indication of a fully charged capacitor. This signal is taken into the microcontroller which is the amount of time taken for charging depends on the capacitor, by substituting the values in the following formula the value of the capacitor can be determined.
C = \left( 1.442 \times \delta t \right) / R \quad \text{------ (3.1)}

Where:
- C = Capacitance of the Capacitor
- R = Resistance used for charging
- \delta t = difference in time between charging and discharging capacitor

Fig 3.1: Charging and discharging circuit of a circuit

3.2 Hardware

Electronic design basically consists of selecting a suitable set of hardware components that can perform a particular function and by arriving at the correct values of those components. The components and their values are chosen so as to have optimum performance and their efficiency at a reasonable cost. Combining these components result in task accomplishments with desired results.

The block diagram of the present low cost Microcontroller based capacitance meter is shown in the figure 3.2 and the schematic circuit diagram of the same is shown in figure 3.3. The capacitance meter consists of the following individual units:

- Constant Current Source
- Discharge Section
- Charging section
- Range Selection
- Comparator
- Counting Unit
FIG 3.2: BLOCK DIAGRAM OF MICROCONTROLLER BASED CAPACITANCE METER
FIG 3.3: THE CIRCUIT DIAGRAM OF MICROCONTROLLER BASED CAPACITANCE METER
Photograph 1: Hardware of Microcontroller based Capacitance Meter

Photograph 2: Capacitance Meter
Photograph 3: PC-MC Based Capacitance Meter
3.2.1 Constant Current Source

A constant current source functions as a regulated current source. It requires a change in thinking, to look at supply that puts out a constant current regardless of the voltage. A **constant source** is an electrical or electronic device that delivers or absorbs electric current. A theoretically perfect voltage generator would have zero internal impedance and a perfect current equivalent would have infinite internal impedance. If the source internal resistance is very low when compared to the load, then it is said to be “stiff” and approximates a pure voltage source. Voltage drop across the internal resistance ($R_g$) is negligible under load. If internal resistance is very large compared to the load resistance $R_l$, and the source voltage is increased, a changing load resistance
will have very little effect on load current. This is because the load current is mainly determined by the source voltage and the internal resistance and is independent of load resistance. Practically, the situation is valid for $R_l < R_g /10$, where $R_l$ is the load resistance in series with $R_g$. Achieving useful outputs with sources like batteries and resistors is not very practical, but does illustrate which parameters must be controlled in order to build true constant current (and constant voltage) supplies.

In the present study, the constant current source is designed using transistors (Q2N 2907). The pulse from pin P1.3 of microcontroller at the base of transistor Q8 switches on the transistor, thereby triggering Q4 and providing the source at Q5. When Q4 conducts the voltage at the collector of Q4 triggers the base of Q5 thereby providing the constant current to charge the unknown capacitor Cx. The ranges are dynamically selected and so there is no need to switch manually. This selection is a bit tricky and comes handy when it comes to range selection.

### 3.2.2 Discharge Section

The value of the capacitor depends on the time taken to charge the capacitor to a particular voltage on the other hand it is also important that we discharge the capacitor completely prior to the process of charging. So the capacitor discharges before counting the clock pulses of the microcontrollers. To do this task a pulse is applied from microcontrollers to the base of NPN transistor Q2N2222\(^2\) that is placed adjacent to the capacitor under test. This provides a low resistance path and will draw any voltage

![Discharge Circuit](image-url)
available across the capacitor, which acts as a voltage source in the circuit. As the Q2N222 has the fast switching times like turn-on time is 35ns, from 10% to 90%, rise time is 25ns and fall time is 60ns. This is best suited for the applications, which include very low switchover time.

If other range is selected, the previously accumulated charge should be removed or it has to be discharged completely before the charging process begins again, otherwise the time calculated is completely wrong and will measure faulty capacitance value.

3.2.3 Charging Section

The basic advantage of the constant current source is to pump the constant current to the circuit following it, for providing consistent current over a period of time even if there are any voltage variations in the circuit preceding to it. This current is fed to the capacitor under test, the process of charging and discharging is done repeatedly so that we get much precision in our measurement.

A capacitor is made up of two conductors that store positive and negative charge. When the capacitor is connected to a battery current will flow and the charge on the capacitor will increase until the voltage across the capacitor, determined by the relationship \( C=Q/V \), is sufficient to stop current from flowing in the circuit.

Before the switches are closed, there is no charge on the capacitor. When switch \( S_1 \) is closed, current will flow in the circuit as the capacitor is charged. According to Ohm’s Law, the voltage across the resistor will be

\[
V = IR \quad \text{(3.2)}
\]
while the voltage across the capacitor will be given by

\[ V_c = \frac{Q}{C}. \quad \text{----- (3.3)} \]

By Kirchhoff's Rule the voltage changes around the circuit must add to zero so

\[ V_{\text{batt}} - V_R - V_C = V_{\text{batt}} - I R - Q/C = 0 \quad \text{----- (3.4)} \]

When the capacitor charges the charge, \( Q \), starts at zero and there is no voltage on the capacitor. This means that the current initially flows at its maximum rate \( I_{\text{Max}} = \frac{V_{\text{batt}}}{R} \) when \( Q=0 \). However as the flowing current charges the capacitor, the voltage on the capacitor increases. This voltage opposes the flow of more charge and the current begins to decrease. The rate at which the capacitor charges slows as the current decreases as more and more charge builds up the current becomes smaller and smaller. The current decreases exponentially as it asymptotically approaches zero for longer and longer times. Similarly the charge increases exponentially as it keeps growing but at a slower and slower rate and asymptotically approaches (but never actually reaches) its maximum value. It would take an infinite amount of time to actually reach the full value, since the rate of increase (current) becomes smaller and smaller as time goes by.
3.2.4 Range Selection

The section of the switches, as to which should be on and for how long, is based on the inputs received from the microcontroller\textsuperscript{21}. Capacitors with lower values of capacitance will charge very fast when the current supplied to them is high, on the other hand, Capacitors with high values of capacitance will charge very slow, so three different combinations of resistors in the constant current driving circuit are provided to get three different multiplying factors for charging the capacitor under test. This combination is said to be Range Selection, the microcontroller selects one at a time depending on the requirement in this Capacitance Meter automatically.

3.2.5 Comparator

The comparator designed using LM311. The LM311 series is a monolithic, low input current voltage comparator\textsuperscript{22}. Voltage comparators have input currents nearly a thousand times lower than devices like the LM106 or LM710. They are also designed to operate over a wider range of supply voltages from standard \( \pm 15\text{V} \) op amp Supplies down to the single \( 5\text{V} \) supply used for IC logic. The output is compatible with RTL, DTL and TTL as well.
as MOS circuits. Further, they can drive lamps or relays, switching voltages up to 50V at currents as high as 50 mA. In the present study it is designed with single power supply of +5V.

3.2.6 Counting Unit

The counting unit for the time difference is charging and discharging done by interfacing the analog unit with Microcontroller, which has very low error percentage. If starting and ending events are taken care, which are under software control then result arrived at is more precise value of the capacitance under test. The timer is set to mode 1 which is a sixteen bit counter which counts the internal clocks. If the timer sets overflow flag then through software increment counter which is internal to the code, after the counting is complete the counter is added to the timer. The formula used to detect the count is:

\[
\text{count} = \text{TL0} + \text{TH0} \times 256 + \text{ovr\_flow} \times 65536; \quad (3.5)
\]

where \text{count} is a variable to store the complete number of clocks which the controller counts

\text{TL0} & \text{TH0} are the hardware 8 bit registers, which are inside the microcontroller

\text{Over\_flow} is the software registers which are used to count number of times the timer over flows.

3.2.7 Microcontroller (AT89s52)

A microprocessor is a tool in the case of software design by writing a suitable program can be used to perform calculations and few memory operations. This tool
falls back when controlling a particular parameter directly without any additional hardware. To resolve this we have more advance featured processors they are called microcontrollers.

By introducing microcontrollers in the digital design one can reduce the space and expanding the functionality as this microcontrollers come with external and internal bus which can be externally interfaced with external memory, pins which react and control external environment.

In present study an effort has been made by the author to develop a capacitance-measuring unit using a microcontroller (AT89s52).

The AT89s52 is a low power, high performance CMOS 8-bit microcontroller with 4Kbytes of flash programmable memory. The device is manufactured using Atmel’s high-density non-volatile memory technology. The on-chip flash allows the program memory to be reprogrammed in-system or by a conventional non-volatile memory programmer.

The circuit diagram of Microcontroller based Capacitance measurement system with 89s52 is shown in fig 3.2. The control lines and data lines of the LCD (LM16200)²³ are connected to the port 1 and the data lines are connected through port 0. The EPROM is also added in the circuit incase of any analytical program has to be added as online or offline purpose in a process measurement situation or online analysis, measurement and control situation, because the program may not fit in 4Kbytes of flash which is in the 89s52. Also there is 256K bits of ram connected to the microcontroller for reading and writing of any data which is stored in the field, as this unit is perfectly adaptable for a demanding situation for any long time data
acquisition system. For serial communication between microcontroller and Personal
Computer, RXD line P3.0 is connected to the Rout of the RS232 and TXD line P3.1 is
connected to the Tin of the RS232 and GND is connected to GND line.

3.2.8 Memory unit

The 89s52 has 8KB of flash (program) memory and 256B of data memory
which is sufficient for most of the applications which the use wish to develop for any
specific needs if in case this program exceeds 8KB of memory then the user may be in
trouble. To overcome this, the author has introduced memory unit IC AM27C512,
which is 64KB CMOS EEPROM. It operates from a single +5 V supply, has a static
standby mode, and features fast single address location programming. AMD’s CMOS
process technology provides high speed, low power, and high noise immunity.
Typical power consumption is only 80 mW in active mode, and 100 μW in standby
mode.

If it is required to store data for longer durations the data memory available in
89s52 is not enough so the design has additional 32KB of data memory externally.
This comes handy when there is requirement to store large amounts of data.

3.2.9 Liquid Crystal Display Module

In the present study the LCD display LM16200 used for displaying
measured Capacitance of a capacitor. The display module is a dot matrix liquid crystal
display that display alphanumeric, characters and special symbols. The built-in-
controller & driver provide convenient connectivity between a dot matrix LCD 4 or 8
bit microprocessors or microcontroller.
All functions required for dot matrix liquid crystal display are provided internally. Internal refresh is provided by the LAMPEX. The CMOS technology makes the devices ideal for applications in hand held portable and other low powered instruments.

**FEATURES**

- Easy interface with a 4-bit or 8-bit MPU
- Built-in Dot Matrix LCD controller with font 5x7 or 5x10 dots
- Display Data Ram for 80 characters (80x8 bits)
- Characters generator ROM, which provides 16 characters with font 5x7 dots and 32 characters with font 5x10 dots
- Both display data and character generator RAMs can be read from the MPU.
- Internal automatic reset circuit at power ON.
- Built-in Oscillator circuits (No external clock required).
- Wide range of instruction functions: Clear Display, Cursor Home, Display ON/OFF, and cursor shift, Display shift.

In present system LM16200 LCD module is used with 8 data and 3 control lines. The LCD interface is used as follows:

- P1.0 for Enable (EN)
- P1.1 for Read Write (RW)
- P1.2 for Register Select (RS)
- P0.0 - P0.7 for data (AD0:AD7)
3.2.10 Serial Communication (RS-232)

Microcontroller transfer the data in two ways as parallel and serial. In parallel data transfers, often 8 or more lines (wire conductors) are used to transfer data to a device that is only a few meters away. Example of parallel transfers is printers. Each uses cable with many wire strips. Although in such cases a lot of data can be transferred in a short amount of time by using many wires in parallel, the distance should be short. To transfer to a device located many meters away, the serial method is used.

![Circuit for Serial Communication between Microcontrollers & PC](image)

Fig 3.8: Circuit for Serial Communication between Microcontrollers & PC

To allow compatibility among data communication equipment made by various manufacturers, an interfacing standard called RS232 was set by the Electronics Industries Association (EIA) in 1960. In 1963 it was modified and called RS232A. In this we use RS232. RS232 is the most widely used serial I/O interfacing standard. This standard is used in PCs and numerous types of equipment. Its input and output voltage levels are not TTL compatible. In RS232, a 1 is represented by -3 to -
25V, while a 0 bit is +3V to +25V. For this reason, to connect any RS232 to Microcontrollers system we must use voltage converters such as MAX232\textsuperscript{27} to convert the TTL logic levels to the RS232 voltage level, and vice versa. Max 232 IC chips are commonly referred to as line drivers.

Table 2 provides the pins and their labels for the RS232 cable the commonly referred to as DB9. IBM introduced the DB9 version of the serial I/O standard, which uses 9 pins.

<table>
<thead>
<tr>
<th>PIN</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data carrier detect (DCD)</td>
</tr>
<tr>
<td>2</td>
<td>Received data (RXD)</td>
</tr>
<tr>
<td>3</td>
<td>Transmitted data (TXD)</td>
</tr>
<tr>
<td>4</td>
<td>Data Terminal ready (DTR)</td>
</tr>
<tr>
<td>5</td>
<td>Signal Ground (GND)</td>
</tr>
<tr>
<td>6</td>
<td>Data set ready (DSR)</td>
</tr>
<tr>
<td>7</td>
<td>Request to send (RTS)</td>
</tr>
<tr>
<td>8</td>
<td>Clear to send (CTS)</td>
</tr>
<tr>
<td>9</td>
<td>Ring indicator (RI)</td>
</tr>
</tbody>
</table>

The connection between a PC and microcontroller requires a minimum of three pins. TXD, RXD, and ground as shown in figure 3.5. Notice in that figure that the RXD and TXD pins are interchanged.

The 89s52 have two pins that are used specifically for transferring receiving data serially. These two pins are called TXD and RXD and are part of the port3 group (P3.0 and P3.1). Pin 11 of the 89s52 (P3.1) is assigned to TXD and pin 10 (P3.0) is designated as RXD. And used for the present study for the analysis made with Personal Computer.
The RS232 has two sets of line drivers for transferring and receiving data as shown in figure. The line drivers used for TXD are called T1 and T2, while the line drivers for RXD are designated as R1 and R2. In many applications only one of each is used. For example T1 and R1 are used together for TXD and RXD of the 89s52, and the second set is left unused. RS 232 requires four capacitors ranging from 1 to 22uF. In this project we used these capacitors of 10 uF shown in figure 3.5.

Further there are four programmable modes for serial data communication that are chosen by setting the SMX bits in SCON. The baud rate in 'the 89s52 is programmable. Baud rates are determined by the mode chosen. This is done with the help of timer1. The serial port can operate in 4 modes.

Mode1 has a variable baud rate. The baud rate is generated by timer1. for this purpose, timer 1 is used in mode2 (Auto – Reload).

\[
\text{Baud rate} = \frac{\text{K} \times \text{Osc Freq}}{32 \times 12 \times \text{[256-TH1]}} \quad (3.6)
\]

If SMOD =0 then K=1

If SMOD=1 then K=2 (SMOD is in the CON register).

Most of the time the user knows the baud rate and needs to know the reload value for TH1.

\[
\text{TH1} = 256 - \frac{\text{K} \times \text{Osc Freq}}{32 \times 12 \times \text{Baud rate}} \quad (3.7)
\]

With XTAL=11.0592MHz and TH1=9600

\[
\text{TH1} = 256 - \frac{\text{K} \times 11.0592 \times 10^6}{32 \times 12 \times 9600} \quad (3.8)
\]

\[
\text{TH1} = \text{FDh}
\]
TH1 must be an integer value. Rounding off TH1 to the nearest integer may not produce the desired baud rate. When timer 1 is used to set the baud rate it must be programmed in mode 2, that is 8-bit auto reload.

Since the PCON register is not bit addressable, one way to set the bit is logical ORing the PCON register (i.e., ORLPCON, #80h). The address of PCON is 87H.

In programming the 89s52 to transfer character bytes serially, the following steps must be taken.

- The TMOD register is loaded with the value 20h, indicating the use of timer 1 in mode 2 (8-bit auto reload) to set the baud rate.
- The TH1 is loaded with FDh to set baud rate =9600kbs for serial data transfer
- (XTAL=11.0592MHZ)
- The SCON register is loaded with t value 50H, indicating serial mode 1.
- TR1 is set to 1 to start timer1.
- TI is cleared.
- The character byte to be transferred serially is written into the SBUF register.
- The TI flag big is monitored, to see if the character has been transferred completely.

In programming the 89s52 to receive character bytes serially, the following steps must be taken.

- The TMOD register is loaded with the value 20h, indicating the use of timer 1 in mode 2 (8-bit auto reload) to set the baud rate.
- The TH1 is loaded with FDh to set baud rate =9600kbs for serial data transfer
• (XTAL=11.0592MHZ)
• The SCON register is loaded with t value 50H, indicating serial mode 1.
• TR1 is set to 1 to start timer1.
• RI is cleared.
• The RI flag bit is monitored, to see if an entire character has been received.
• When RI is set, SBUF has the byte. Its contents are moved into a safe place.

3.2.11 Power supply

Most of the devices in electronic equipments require essentially a constant d.c voltage for their operation. Therefore, almost all electronic equipments include a circuit that converts a.c voltage of mains supply into D.C voltage, which is independent of changes in a.c line voltage. The circuit diagram of +5v power supply required for the present study

![Circuit diagram of Power Supply](image)

**Fig 3.9: Circuit diagram of Power Supply**

Fig 3.9 shows a complete solid-state +5v power supply required for the present study using power transformer, a full wave rectifier with two P-N junction diodes, a filter section, a transistor series voltage regulator and a voltage divider.

The A.C. voltage to be rectified is applied to the primary of power transformer T. two p-n junction diodes for full wave rectification. It is then followed by a filter,
which filters the unidirectional pulsating voltage of the rectifier output. A transistor series voltage regulator 7805 regulates it. At Output of regulator we get 5V regulated power supply.

3.2.12 Personal Computer

In the present study a Personal Computer with the following features is analysis the capacitor under test

- Pentium –III Intel Microprocessor (upward compatible)
- 256MB RAM
- 10GB Hard disk drives
- 1.44MB Floppy disk drives
- One Serial port
- One Parallel Port

Normally PC has one COM port with RS232-type connectors and is designated as COM1. We can connect the 89s52 serial ports to the COM1. A program to identify the incoming data can be written in any language. The data can be of two types one online data that is calculating at present or offline that is stored in the memory location in the hardware itself.

3.3 Operation of the Circuit

The capacitor under test is placed at Cx. The program is written in such a way that as soon as the system is started that is as soon as the unit is switched ON it first discharges the capacitor by switching high to low and then low to high in short duration there by giving a pulse to the discharge section. This triggers Q3 transistor to provide low resistance path to any charge, which is accumulated in Cx.
Then a pulse to the base resistor of Q8 transistor triggers constant current source to start its function, thereby providing constant current source till the voltage in capacitor reaches its maximum value. This voltage is continuously fed to inverting input of an op-amp, which acts as a comparator. This comparator LM311 transfers its level from high to low and once the input voltage crosses the voltage at non-inverting input, which is a reference voltage.

In microcontroller the program is written in such a way that the time difference between the output pulse from microcontroller (pin 1.6) to discharge section and the input pulse from comparator (pin 1.7) is counted. This process is repeated to get more precise value of count, which in turn gives more precise value of capacitor under test. The counted time is directly proportional to the capacitance and it is calculated by using the formula

\[ C = \frac{1.442 \, t}{R} \quad (3.9) \]

Depending on the value it can be shown directly as nano, pico or micro farads on LCD display module and same can also be stored in memory. There is also serial port from which the user can exchange information from the unit to personal computer for further processing.

3.4 Limitations and tradeoff

Any hardware design has its own limitations. The design criterion may vary depending on various factors. Though the theoretical design may be good, the desired result depends on the accuracy and the reliability of the components used. The other
factors that affect the hardware design are the speed with which they operate on the life of the components.

The accuracy of the design will depend purely on the tolerance level of the hardware components used in the circuit design. If the tolerance level is to uniform, the circuit may function erroneously without giving the desired output.

Some of the components may change with the surroundings. The heat generated in a circuit will change the value of the components, which definitely affect the desired output. The hardware included in a design can rectify some of the problems introduced by hardware design. Including a software in the design greatly supports in reducing the errors introduced in the hardware design by the environment like temperature, humidity, and other factors also the recurring cost of maintenance each component can be reduced.

The main advantage of the software design included is that the parameters in the design or the final output can be regularly monitored and corrected if necessary even from the remote location.

It is not possible to have only software design or if cannot use only hardware with errors so we have to compromise the hardware to the software or software for the hardware. Sometimes writing a program may be too complicated instead of replacing with hardware.

This requirement clearly shows that if one need to have proper plan for trade off between hardware and software to make a design much more acceptable and durable.