EE389 Electronic Design Lab II (EDL II) Project Report, EE Dept, IIT Bombay
Submitted November 2006

Intravenous Drip Sensor Using a Capacitance Probe

Group No. D06
Rohan Sethi (03D07007) <rohan@ee.iitb.ac.in>
S. Vijay Kartik (03D07017) <vkartik@ee.iitb.ac.in>
Ankoor Das (03D07028) <ankoor@ee.iitb.ac.in>
Prashant Mishra (03D07029) <prashantm@ee.iitb.ac.in>

Supervisors: P. C. Pandey and L. R. Subramanyan

Abstract

The aim is to design an Intravenous Drip Sensor, using a capacitance probe to measure infusion rate, and display the number of drops passing through the drip chamber per minute i.e. the drip rate. The capacitance probe was made by strapping two copper plates across the drip chamber. When a drop passes through the drip chamber, the capacitance between the two plates changes due to the change in dielectric. The change in capacitance is reflected as a change in frequency of a square wave which is generated by using a 555 timer. A microcontroller is used to detect the frequency change for sensing the drop. Another microcontroller is used to measure the drip rate and display it using two 7-segment LED displays.

1. Introduction

Intravenous therapy is the administration of liquid substances (fluids) directly into the veins of the patient. The flow rate of the fluid to the body is calculated as number of drops falling through the chamber in a minute. Manually, the time taken for 15-20 drops to fall is observed and hence the rate as drops per minute is obtained. The required rate can be set by the nurse. But the contraction/dilation of the patient's veins might alter the drip rate. Moreover, the reduction in pressure as the fluid volume in the bag decreases also results in the decrease of drip rate.

An instrument for monitoring the drip rate has been previously designed using an optical sensor (infra-red light sensor assembly) to sense the passing drop [1]. There are some other instruments also reported on basically the same principle; a US patent on similar instrument has also been filed [2]. The problem with optical sensing is that when the orientation of the drip chamber is altered from being vertical, the drop may not intersect the light path and the sensing of the drop gets affected.

A capacitance sensor is likely to be more robust than the prevalent optical sensor because the capacitance between the parallel plates placed around the drip chamber does not change due to change in orientation of the chamber.

2. Design Approach

The following three approaches for detecting the change in capacitance were attempted. The first two were based on capacitance to voltage conversion, while the third is based on capacitance to frequency conversion.

a) The circuit is shown in Fig 1. Capacitance C_x represents the capacitance of the parallel plates across the drip chamber. The switches S_1 and S_2 are periodically switched ON/OFF. These switches have been realised using two CD4066 analog switches and the switching frequency is 16.6 kHz. The charge that gets stored in C_x and C_1 capacitor when S_1 is ON gets transferred to C_2 immediately after S_2 becomes ON. The capacitor C_2 now gets discharged through the resistor R_2. When the drop passes through the chamber the charge that gets transferred to C_2 increases and the change in the capacitance is observed as a change in the maximum value of voltage drop in the waveform obtained at the output i.e. V_y. Results obtained by pursuing this approach were not consistent and it also had problem of voltage saturation due to parasitic capacitance and dc errors. Also, the number of components used in this approach was large.

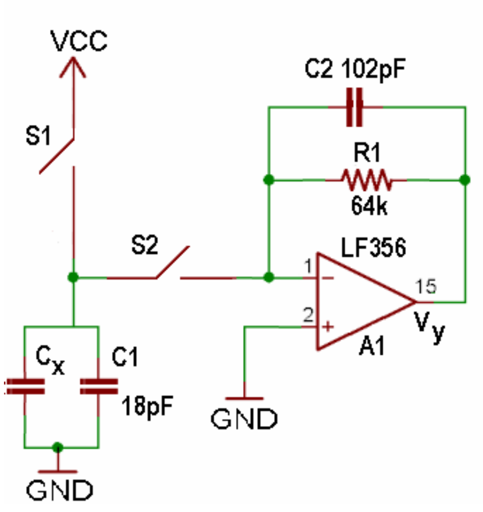


Fig 1: Circuit Diagram for capacitance to voltage converter

b) As shown in Fig 2, in this approach differential capacitance is used to measure the change in capacitance. Two capacitors C_1 and C_2 formed by two pairs of plates mounted on the drip chamber are used, one as a sensor and the other as a reference. A triangular wave V_x is generated using opamp A_1 and applied to two differentiators formed using C_1 and C_2, and opamps A_2 and A_3. The amplitudes of the square waves V_{y1} and V_{y2} thus produced depend on the capacitance values. Outputs V_{y1} and V_{y2} are applied to a difference amplifier which rejects common mode signal and amplifies the difference. The output (V_z) is a square wave with the same frequency as V_x but amplitude modulated by the drip rate.

The main problem with this approach was found to be related to parasitic capacitances. The output levels of V_{y1} and V_{y2} depend on parasitic and dc errors. Variations in parasitic capacitances can lead to output saturation and loss of drop detection.

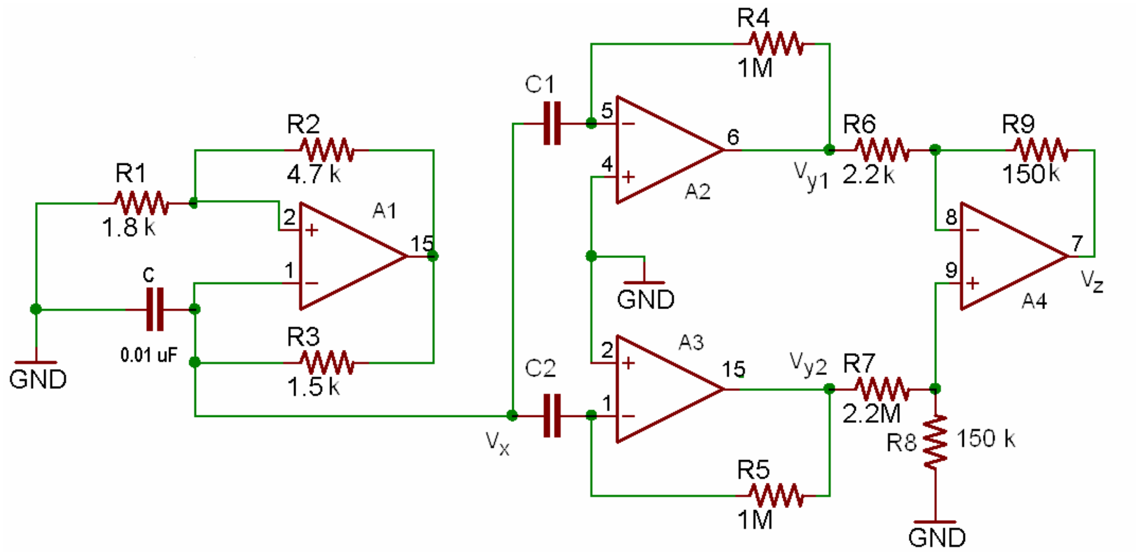


Fig 2: Circuit diagram for differential capacitance to voltage converter

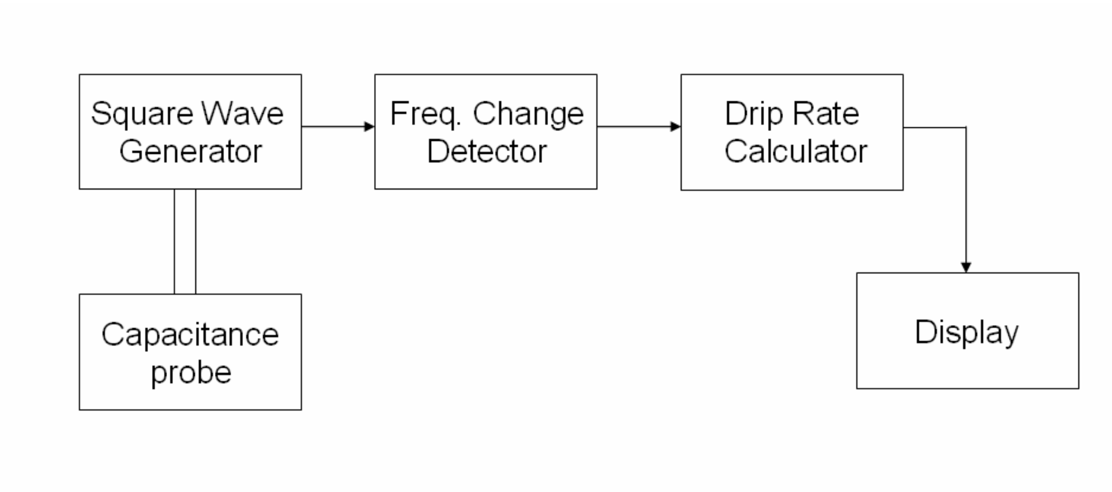


Fig 3: Block diagram of drip rate meter using capacitance to frequency converter

c) We then worked upon an approach which was based on converting the capacitance to be sensed into a frequency variation of a square wave generator. In this approach, the change in parasitic capacitances causes change in the base frequency, but a change in frequency can still be detected.

A parallel plate capacitor is fashioned out of two copper plates strapped around the drip chamber. On the event of a drop falling through the chamber, the capacitance of the capacitor increases due to the change in the dielectric between the plates. The capacitor is connected as the frequency controlling capacitance in the square wave generator circuit. An increase in capacitance results in corresponding decrease in frequency of the square wave output. Frequency detector detects decrease in frequency and if the decrease is beyond a certain threshold and lasts for more than a set time, it indicates a sensed drop. This scheme involving detection of change in frequency makes the sensor, to a large extent, insensitive to stray capacitances. The drip rate calculator calculates the drip rate and the value is given to the display section. We have employed a 555 timer based square wave generator. The frequency detection, drip rate counting and display operations can be implemented using a microcontroller. For the sake of modularity, our design employs two microcontrollers. One is used for frequency change detection and the other one for calculation and driving two 7-segment LED displays.

3. Circuit Design

3.1 Capacitance Sensor

As shown in Fig 4, two cuboidal wooden blocks of similar sizes having a cavity of similar dimension and shape in both have been made, where the copper plates are placed. The cavities are shaped to fit around the drip chamber when the blocks are placed across it. The setup is secured using Velcro tapes as straps and glue to fix the copper plates to the cavity. Wires are soldered to each plate and connected to the circuit using a connector.

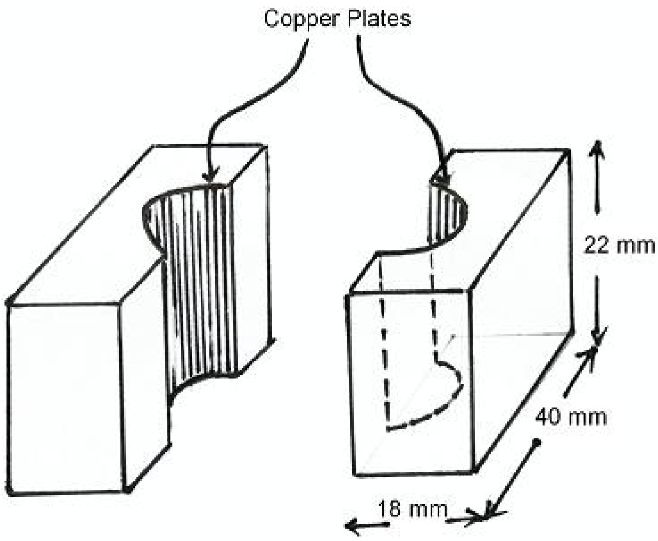
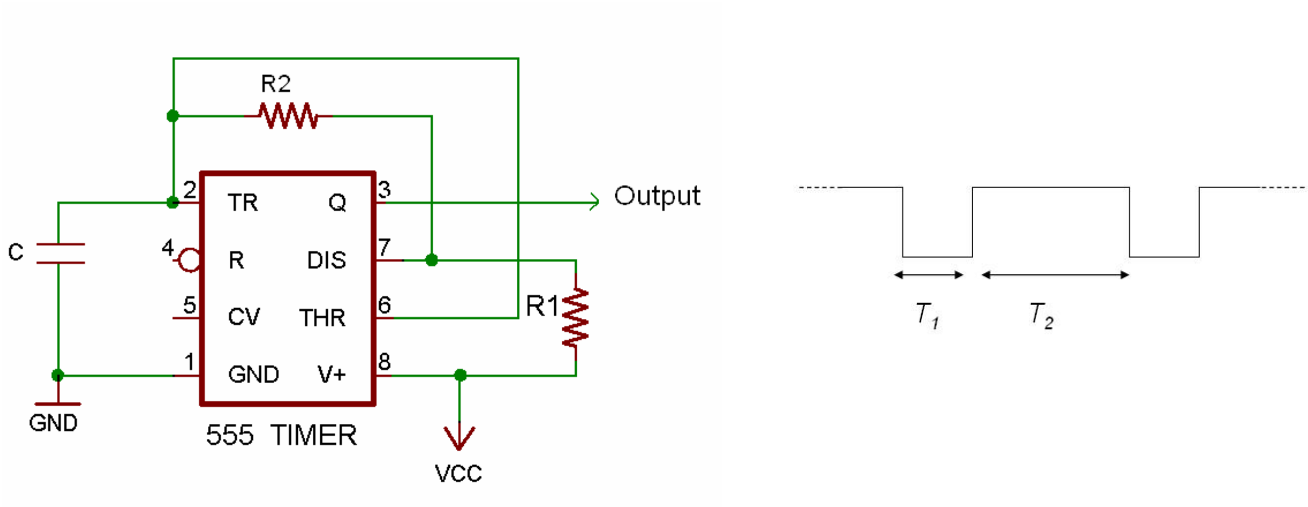


Fig 4: Wooden blocks for capacitance sensor

3.2 Square Wave Generator



(a) (b)

Fig 5: Square wave generator (a) Circuit diagram (b) Output

A 555 timer is used in the astable mode, as shown in Fig 5a, to generate a square wave whose frequency is a function of the capacitance used in the circuit.

The time intervals of the waveform are given as

$$T_1 = 0.7(R_1 + R_2) \qquad (1)$$

$$T_2 = 0.7R_2C \qquad (2)$$

Frequency f is given as

$$f = 1/(0.7(R_1+2R_2)C) \qquad (3)$$

The value of C in Fig 5a increases when a drop passes through the drip chamber and this results in a decrease in frequency f. The decrease in frequency Δf that occurs when the capacitance changes from C to $C+\Delta C$ is given by (4).

$$\Delta f = \Delta C/(0.7C^2(R_1+2R_2)) \quad (4)$$

To get large Δf, we have to operate the circuit the circuit at a high frequency. The actual circuit has parasitic capacitances and leakage resistances. In order to maximise Δf, we used different values of R_1 and R_2 and the observations are given in Table 1. Based on these observations we selected R_1 = 10 kΩ and R_2 = 1.5 MΩ to get f = 66 kHz and Δf = 4.4 kHz for our probe assembly.

Table1: Change in frequency corresponding to different values of R_1 and R_2

S.No	R_1 kΩ	R_2 MΩ	f_1 Frequency when drop not passing kHz	f_2 Frequency when drop is passing kHz	Δf Change in frequency kHz
1.	10	0.1	414	413	1
2.	10	1	101.4	98	3.4
3.	10	1.5	70.4	66.0	4.4
4.	100	0.47	80.5	78.3	2.2
5.	100	1.5	60.9	57.1	3.8
6.	1000	1	98.4	97.1	1.3
7.	3300	1.5	12.3	11.5	0.8

3.3 Frequency Change Detector

Various methods for detecting frequency change were considered [3], but we have used a simple approach which is discussed below.

An AT89C2051 microcontroller [4][5] has been used to detect the change in the frequency of the square wave. Whenever a change in frequency beyond a certain threshold is detected, a downward going pulse is generated by the microcontroller.

Output from the 555 timer is fed into pin P3.4 (T0) of the microcontroller and a downward going pulse is generated as output at pin P3.7. The number of falling edges of the input square wave is counted [6] over an interval of 2.5 ms and the difference between the counts of two successive intervals is calculated. Whenever this difference exceeds a certain threshold, a drop is signaled by a downward going pulse. For the circuit wired on the bread-board the values of $f1$ and $f2$ are 70.4 kHz and 66.0 kHz respectively, and for the interval of 2.5 ms, we have $N1$ = 176 and $N2$ = 165 and thus ΔN is taken as 8. When the same circuit is built on the PCB values of $f1$ and $f2$ are 50.4 kHz and 48 kHz respectively, and for the interval of 4.5 ms, we have $N1$ = 226 and $N2$ = 216. Hence we have selected ΔN = 6 as a threshold for detecting the drop in the case of PCB. Interval in case of PCB was increased from 2.5 ms to 4.5 ms so that more number of pulses of the square wave can be counted and this reduces the error in detecting a drop. It was found that the drop takes 15 ms to pass through the capacitor and hence time interval of 4.5 ms is appropriate.

The algorithm implemented for the above procedure is given below.

Algorithm:

1. *Start:*
   Initialize all registers and counter register to zero.
2. *Set:*
   Set timer T1 in auto reload mode for 2.5 ms and T0 as counter
3. *Begin:*
   SETB P3.7
   Start T1 and T0
4. If(timer T1 overflows)
   stop counter T0
   move previous value of count(from r3) to r5
   store counter value in register r3 as current value
5. If (current value> previous value)
   JMP Begin
   Else
   If ((previous value – current value)<threshold)
   JMP begin
   Else
   CLR P3.7
   CALL Delay of 12 ms
   JMP Begin
6. *End*

The sensor circuit is kept close to the capacitance probe. In order to keep the sensor circuit small, the drip rate measurement and display block is kept separate from the sensor circuit.

3.4 Drip Rate Measurement and Display

This part has been made using an AT89C2051 microcontroller. The downward going pulse generated by the previous part is given as an input V_a (refer Fig 6) to the inbuilt comparator of this microcontroller. V_{ref} is set at 2.25 volts. Whenever V_a falls below V_{ref}, the microcontroller generates a hardwired internal interrupt (on port 3.6, which does not have an external pin). The interrupt signals the commencement of a counting process which leads to the measurement of the time until the next interrupt is generated. This obtained value of time is used to calculate the drip rate thus.

Time between two interrupts = Time between two drops = t s
Drip rate = $60/t$ drops per minute

The integer part of the number hence obtained is taken and displayed as a 2-digit number on two 7-segment displays. The passing of a drop is indicated by the blinking of both decimal points on the 7-segment displays.

Displaying the number is done efficiently using only seven pins for both the 7-segment displays. The same pins are alternately used by each 7-segment display to read values from the microcontroller (time multiplexing). The switching between the two is done every 6 ms. Because of persistence of vision, the display appears continuous.

An additional feature in this part of the circuit is the 'stop-watch' mode. The stop-watch can be started and stopped by a push button which is connected to a single pin of the microcontroller. This can be useful for the nurse while measuring the patient's pulse and/or temperature. Although only two digits have been used for the stopwatch mode, the decimal points have also been included to increase the range to 0-399 seconds, with a resolution of 1 s.

Algorithm Description

The structure of the drip rate calculation and display program is as follows:

1. *Start*

Initialize timer/counter T0 for periodic interrupts every 6ms for display
Initialize one register (R1) with 0 count for counting multiples of 50ms between two drops.
Initialize register (R2) with address location reserved for storing the value of R1.
Store anode pattern of 0 in rate-display buffer for displaying rate as 00.
Start timer T0 for display.

2. *Mode Check*

If (mode input = low)
clear status flag & JMP Stop Watch Mode
Else
set status flag & JMP Drip Rate Mode

3. *Stop Watch Mode*

Check status flag. If high go to "Start" else check for P1.3 (start / stop pulse)
If (P1.3 low)
complement status of timer T1
If (timer is "OFF")
hold display static "00"
If (timer is "ON")
reset timing register, start timer T1 and store time in s in "stop watch display buffer"
Poll for pin P1.3 (start / stop pulse)
If (P1.3 is low)
JMP Stop Watch Mode
Else
JMP Mode Check

4. *Drip Rate Mode*

Initialize timer/counter T1 for periodic interrupts every 50ms for time interval measurement between consecutive drops.
Start T1.
Poll for comparator output low.
If (P3.6 is high)
continue polling
Else
check if the output is low for 60 µs
Store the period value in the old location.
Store the interval count as the new period value.
Calculate the average of old period count and new period count
Calculate drip rate, rounded to integer in 0-99 range
Store result in "rate display buffer.
Wait for 200ms. Poll for comparator output = high for > 60 us
Check status flag
If (Status Flag is high)
JMP Drip Rate Mode
Else
JMP Mode Check

5. *Display Routine*

Initialize T0 with 6ms for display.
Alternately move anode pattern of the digit at unit's place and digit at ten's place to port 3.

Start T0 again.
Return from interrupt.

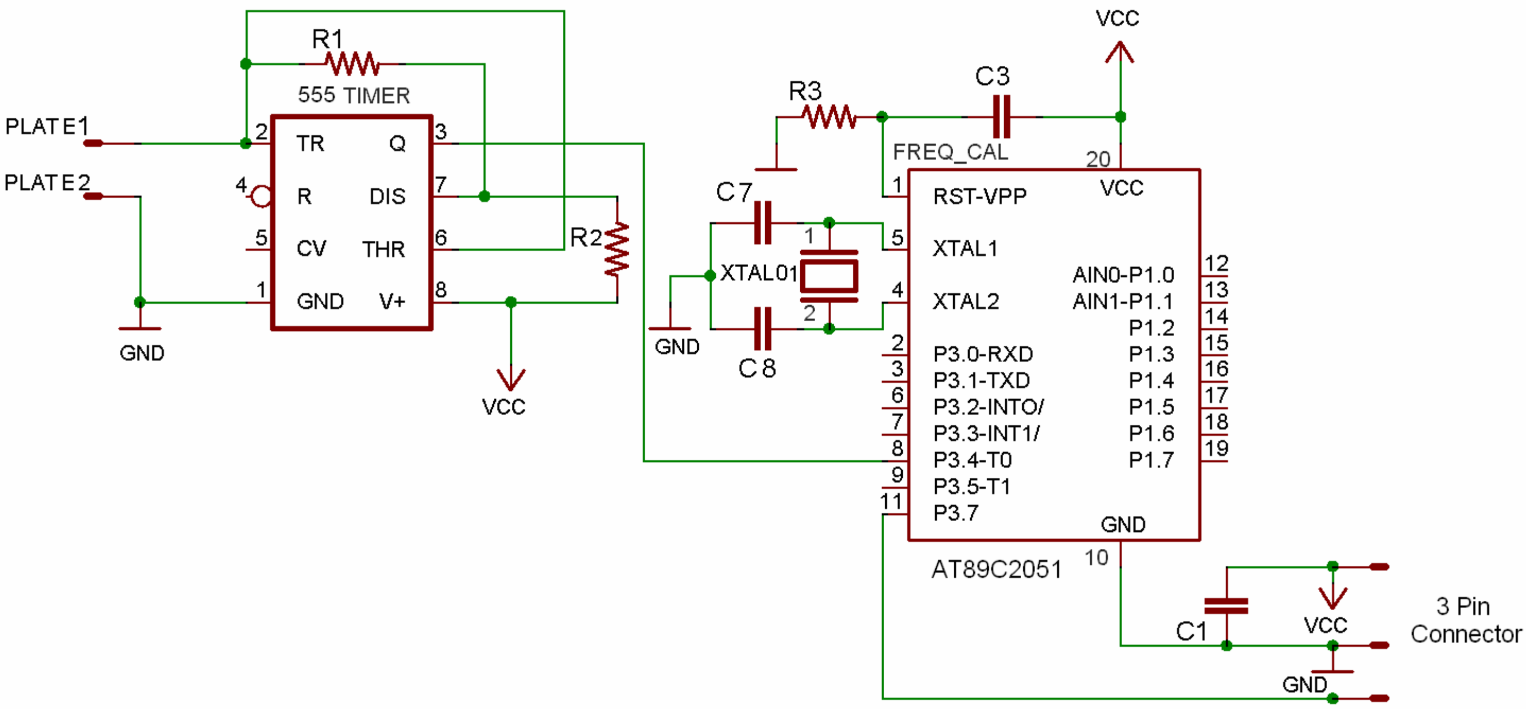
6. *Interval Measurement Routine*

Initialize T1 with 50ms for measuring time interval.
Check for mode control pin P1.2.
If (pin P1.2 is high)
JMP Drip Rate Mode
If (pin P1.2 is low,
update the “stop watch display” buffer

7. *End*

4. Complete Circuit Diagrams

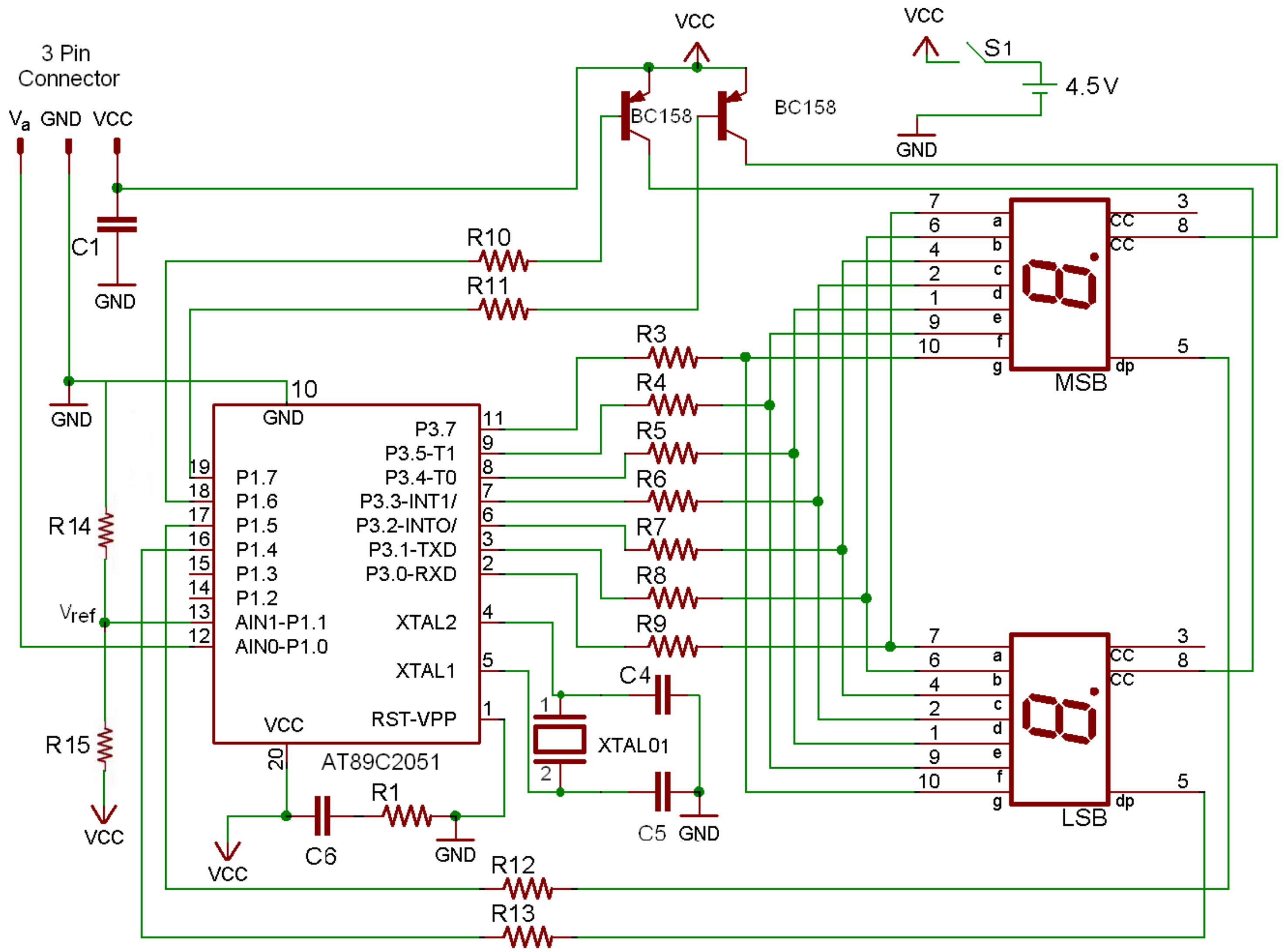
The circuit diagram of the sensing part is shown in Fig 6 and that of the rate measurement and display part is shown in Fig 7.



$R_1 = 1.5\ M\Omega$, $R_2 = 10\ k\Omega$, $R_3 = 6.8\ k\Omega$

$C_1 = 0.1\ \mu F$, $C_3 = 10\ \mu F$, $C_7 = 33\ pF$, $C_8 = 33pF$, XTAL01: 12 MHz

Fig 6: Circuit Diagram for drop sensing part



$R_1 = 6.8$ kΩ, R_3 ,R_4 ,R_5 ,R_6 ,R_7,R_8 ,R_9 , R_{12} ,R_{13} = 470 Ω, R_{10} = 1.8 kΩ, R_{11} = 1.8 kΩ, R_{14} = 1 kΩ, R_{15} = 1 kΩ, C_1 = 0.1 μF, C_4 = 10.0 pF, C_5 = 33 pF, C_6 = 10.0 μF
XTAL01: 12 MHz

Fig7. Circuit used for displaying the drop rates using 7-segment LED displays

5. Problems Faced and Solutions

In the approach using differential capacitance we faced a problem of voltage saturation due to parasitic capacitance which was solved when we switched to the present approach involving capacitance to frequency conversion. We used Digital Storage Oscilloscope (Tektronix TDS210: 60MHz, 1 G Sa/s, record length = 2500 sample points per channel) to detect change in frequency on passing of a drop, but the instrument was unable to capture the waveform for both cases (that is absence as well as presence of a drop) at the same time. Also, when the waveform obtained on the screen for large durations was expanded, the results were interpolated which did not represent the true waveform. Consequently, we could not ascertain the validity of the frequency change. Hence, we switched to another DSO (Agilent 54621D: 60 MHz, 200 M Sa/s, record length = 2 Mega sample points). With this DSO, we could observe and measure the change in frequency because of the drop. The complete circuit was large in size and also heavy because of the weight of batteries. Therefore the whole circuit could not be mounted on the chamber. To counter this we have split the circuit into two parts: sensor circuit (Fig 6) and measurement and display circuit (Fig 7). These are connected through 3 wires (V_{cc}, Ground and Sensor Output). Both the circuits use one microcontroller each.

6. Conclusion

The intravenous drip sensor measures the drip rate with a fair amount of consistency and has been observed to give stable readings during operation. The normal drip-rate varies from 25-60 drop/sec. The instrument uses a capacitance sensor to sense the drop and after detection, feeds a suitable wave to the microcontroller which calculates the drip-rate and displays it as a 2 digit number on a 7-segment display.

The working of the instrument is not affected by alignment of the drip chamber, ambient light etc. It works on three 1.5 volts battery and is designed as two separate parts. As the circuit can work over $V_{cc} = 4.5 – 6.0$ V, no regulation is used. The total current drawn is 40 mA. Still the instrument has the following limitations:

1. The maximum range for drip rate we took as 99 drops/minute, above this we show “OL” that signifies over limit. We need a different display for monitoring of higher drip rate.
2. Our probe has dimensions for a specific IV (intravenous) drip chamber available in market. Different probes shall be needed for different chamber dimension, or a probe should be redesigned to automatically fit all the commonly used chambers.

The design can be extended to include an alarm system which can go off whenever the drip rate goes above or below critical levels. This alarm system can also be implemented through a wireless connection. Right now we have two separate Printed Circuit Boards for display and sensor circuits. Using SMD chips one can miniaturize the circuit so that it can be implemented on a single PCB which can be mounted on the drip chamber.

8. References

1. V. V. Kamble, P. C. Pandey, C. P. Gadgil and D. S. Choudhary, " Monitoring of Intravenous Drip Rate", in *Proc. ICBME 2001*, Dec. 2001

2. G. Gallagher, *Method and Apparatus for Monitoring Intravenous Drips*, Patent No.: US 6736801 B1, May 18, 2004

3. T. S. Rathore, *Digital Measurements Techniques.* New Delhi: Narosa Publishing House, 1996

4. Atmel Corporation, *AT89C2051 Datasheet, Revision G.* http://www.atmel.com/atmel/acrobat/doc0368.pdf , last accessed June 2005

5. Vault Information Services, *8052 Resources*. http://www.8052.com last accessed Sep. 2006

6. K. J. Ayala, *The 8051 Microcontroller Architecture, Programming and Applications.* Mumbai: Penram, 1996

Appendix

PCB Designs

1. Frequency Change Detection Circuit PCB

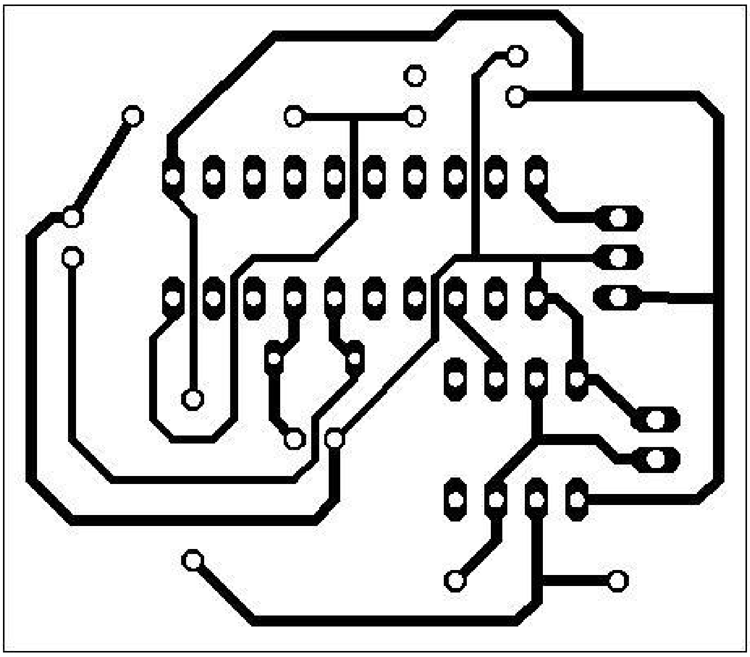


Fig 8: Frequency Change Detection Circuit PCB – Bottom

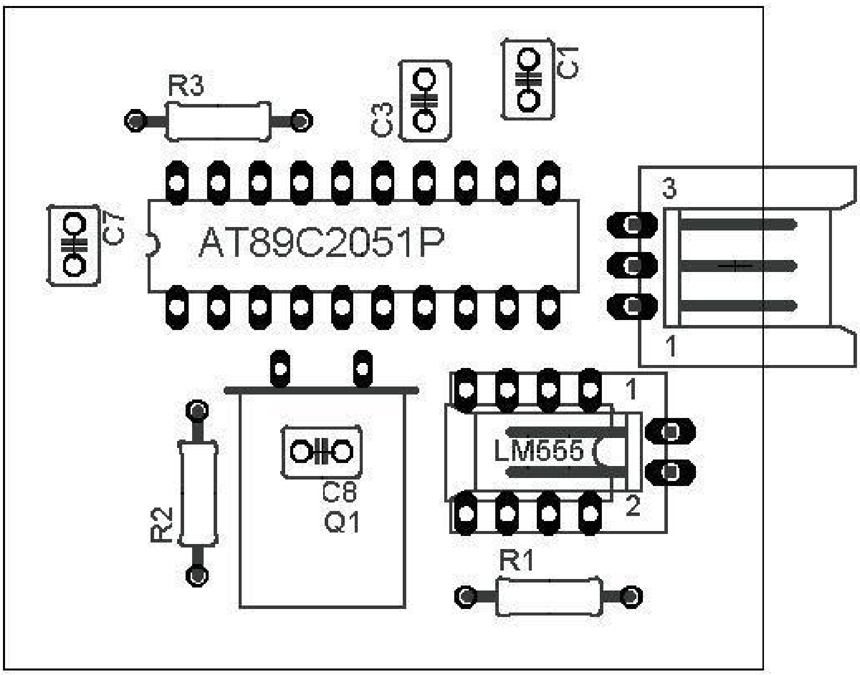


Fig 9: Frequency Change Detection Circuit PCB - Components Placement

2. Display Circuit PCB

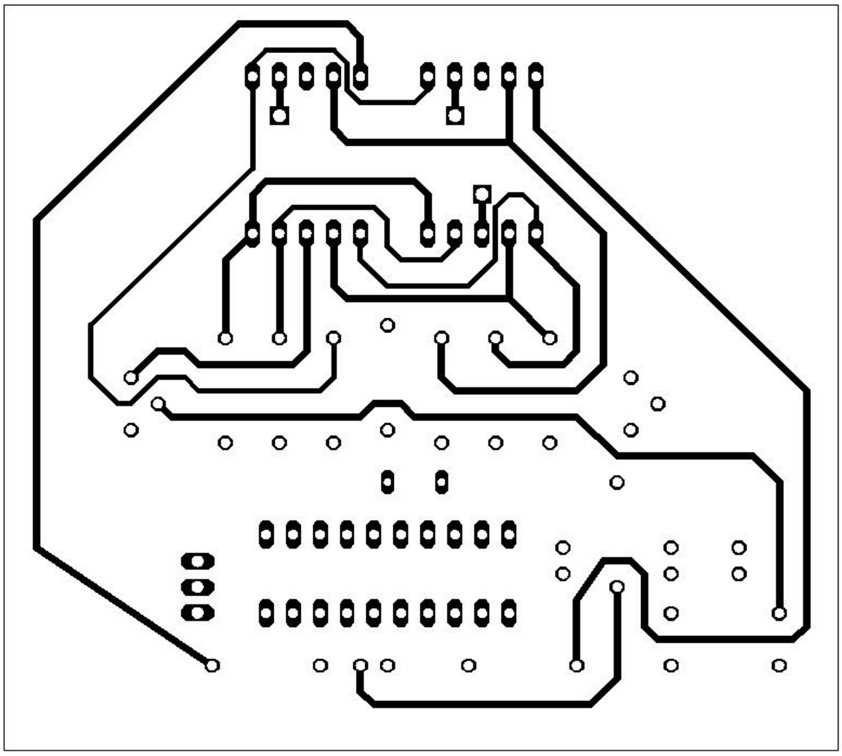


Fig 10: Display Circuit PCB- Top

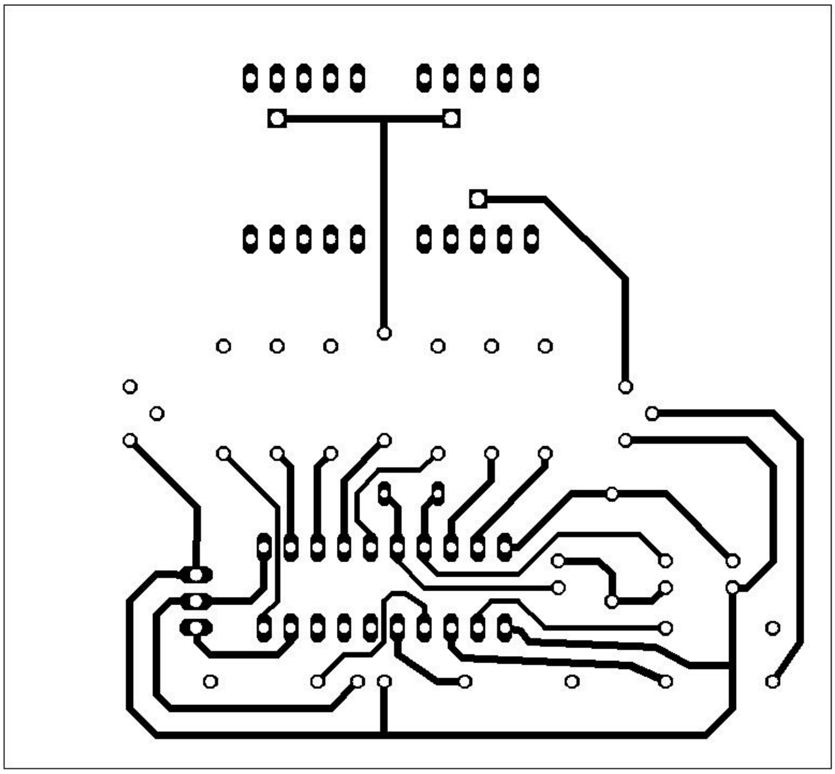


Fig 11: Display Circuit PCB - Bottom

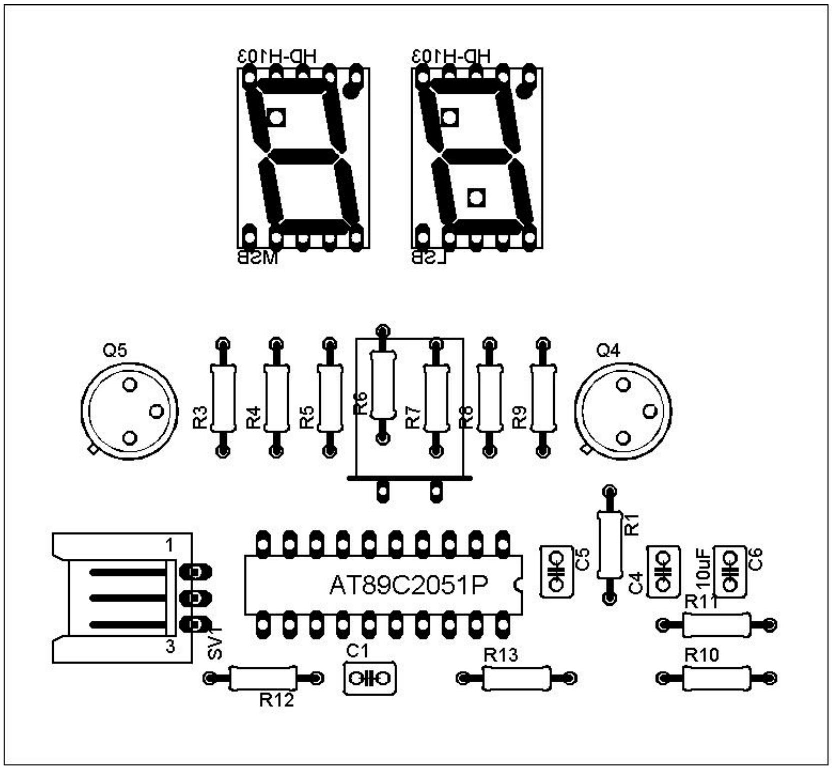


Fig 12: Display Circuit PCB – Components Placement

Fig 13: A working model of our instrument