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Electrical Engineering Department, IIT Bombay

Intravenous Drip Sensor

Group No: D6

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Abstract

The aim is to design an Intravenous Drip Sensor, using a capacitive probe to measure infusion rate, and display the number of drops passing through the drip chamber per minute i.e. the drip rate. The capacitive 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. We measure the drip rate by sensing the change in capacitance.

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 calculated and hence the rate per minute is obtained. The rate can be set by the nurse depending on the requirement of the patient. But the rate set by the nurse might change due to various reasons. 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.

The drip sensor designed by us shall measure the instantaneous drip rate (number of drops per minute) by calculating the time taken between two drops only and displays the result through 7-segment LED display. The drip rate can hence again be changed by the nurse to the required value.

A similar apparatus for detecting the drip rate had been previously designed and it had used an optical sensor (infra-red light sensor assembly) to account for the passing drop. The problem with the earlier product was that there was considerable error in the drip rate calculated. This had occurred when the orientation of the drip chamber was altered from being straight and still and many a times the falling drop was not detected due to this.

A capacitive sensor is more robust than the currently 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 or due to movement of the same.

2. Design Approach

A block diagram depicting the overall working of the instrument is as follows:-

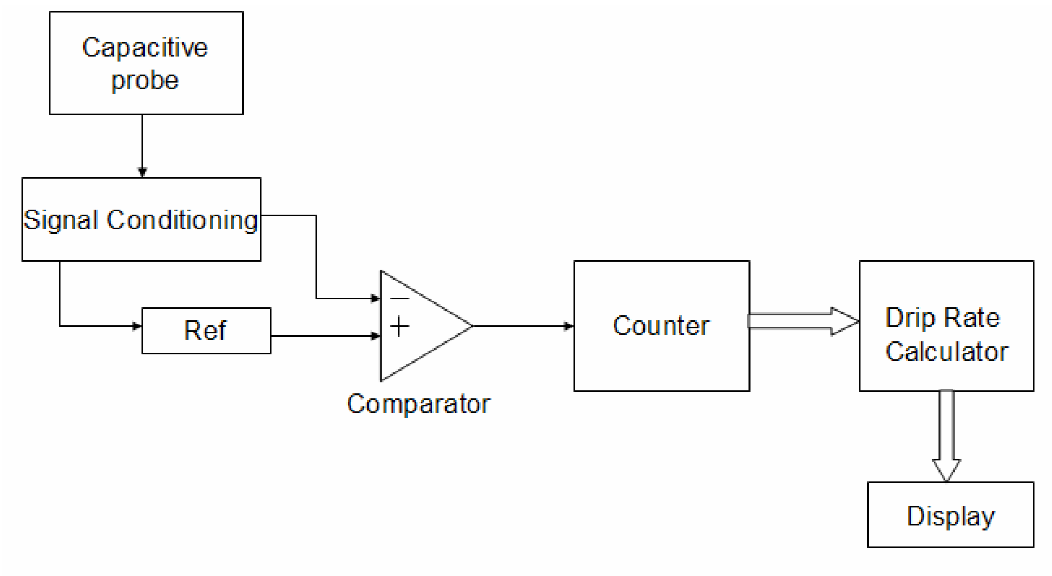


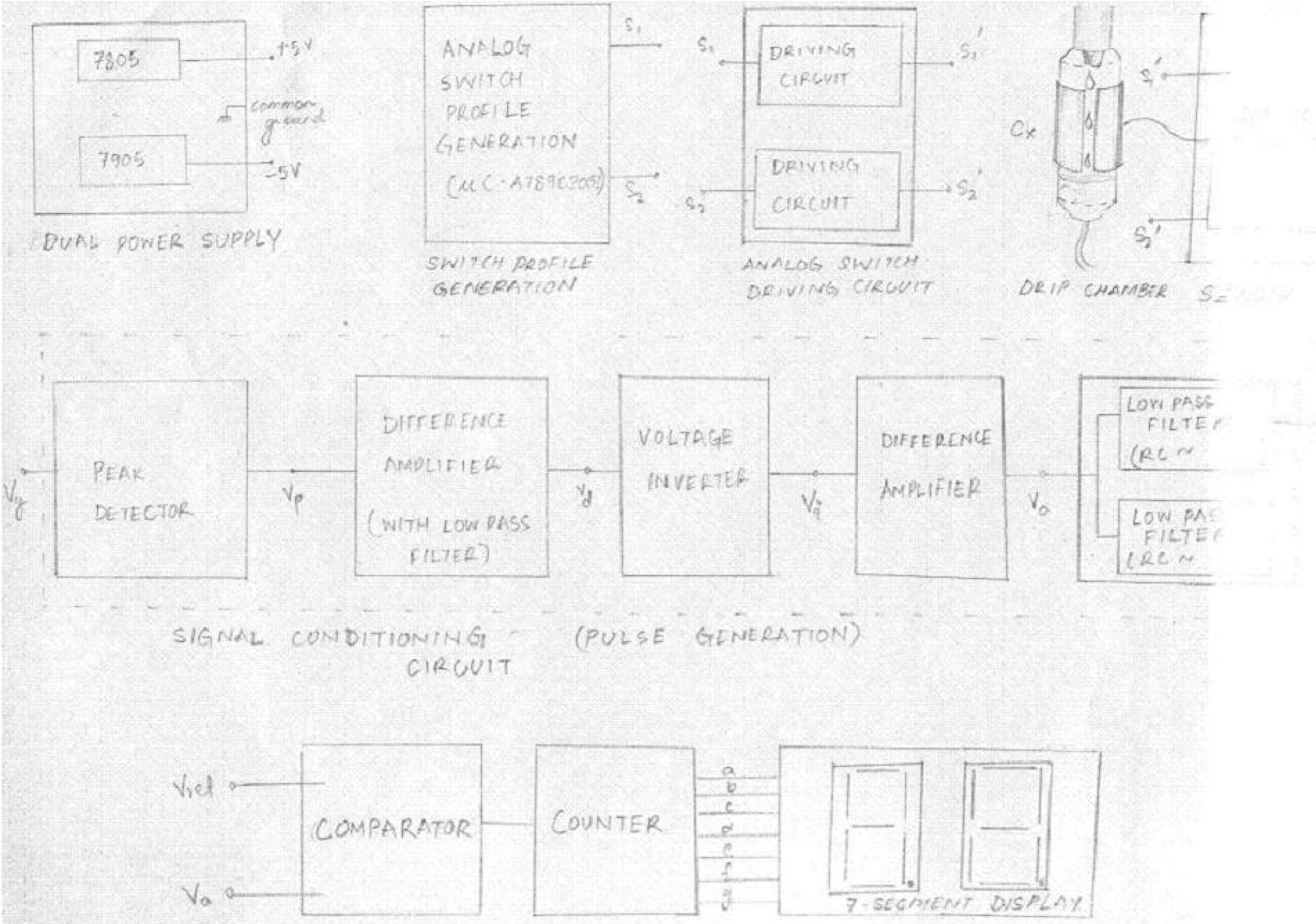
Fig. 1: Block diagram of drip rate meter using capacitive sensing

- A parallel plate capacitor has been fashioned out of two copper plates strapped around the drip chamber.

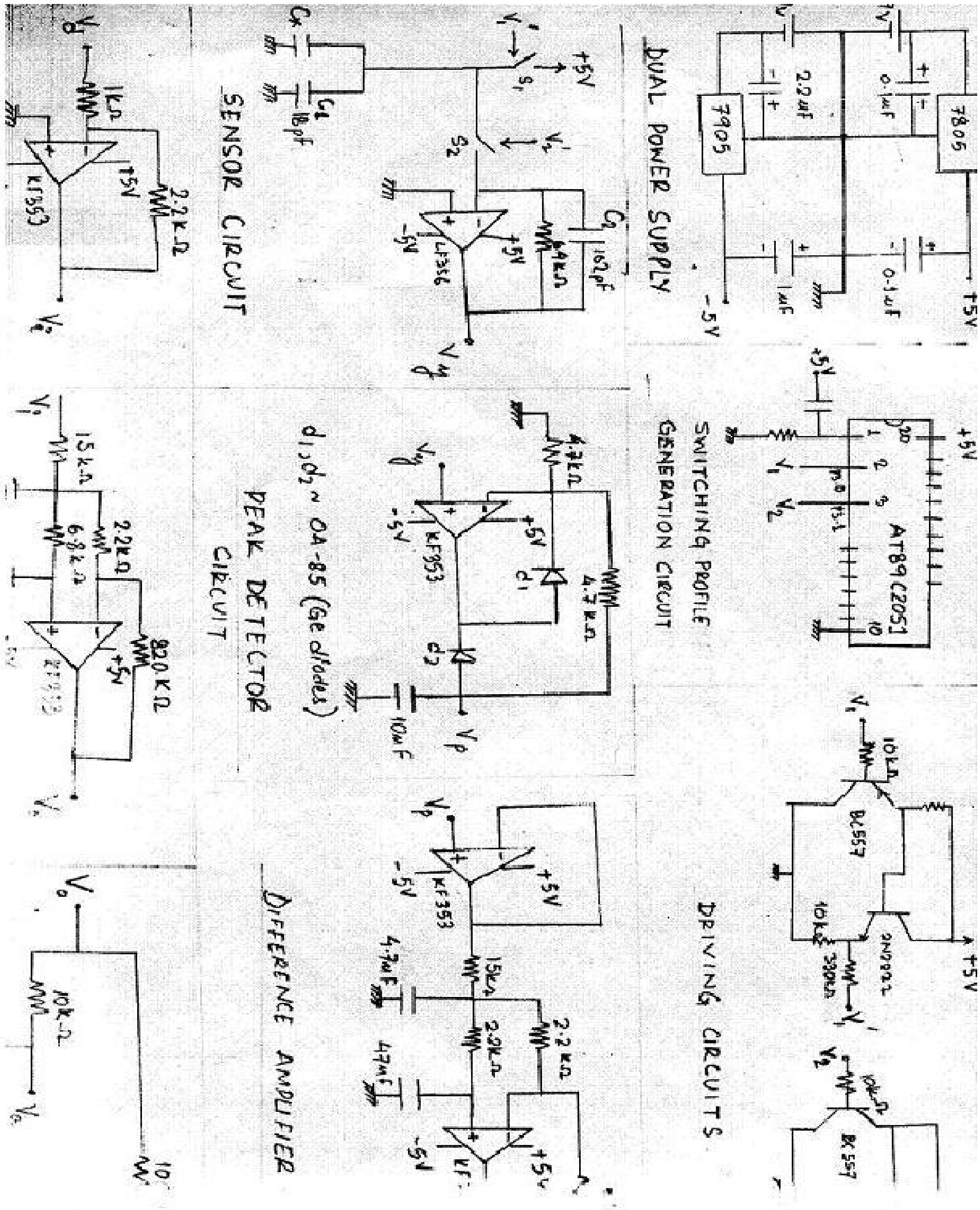
- On the event of a drop falling through the chamber, the capacitance of the capacitor increases due to the change in the dielectric between the plates. The change in capacitance is measured in terms of a corresponding change in the output voltage of an indigenously designed circuit (ref. ckt1) whose design and working are described later.

- The voltage change is conditioned into an upward pulse suitable for counting through a microcontroller based counting circuit (ref. ckt2).

- The microcontroller counting circuit counts the number of drops falling per minute and displays the same by using two 7-segment displays.



7805
+5V
common ground
7905
-5V
DUAL POWER SUPPLY
ANALOG SWITCH PROFILE GENERATION
(μC-AT89C2051)
S1
S2
SWITCH PROFILE GENERATION
DRIVING CIRCUIT
DRIVING CIRCUIT
S1'
S2'
ANALOG SWITCH DRIVING CIRCUIT
Cx
DRIP CHAMBER
PEAK DETECTOR
Vp
DIFFERENCE AMPLIFIER
(WITH LOW PASS FILTER)
Vd
VOLTAGE INVERTER
Vq
DIFFERENCE AMPLIFIER
Vo
LOW PASS FILTER
LOW PASS FILTER
SIGNAL CONDITIONING CIRCUIT
(PULSE GENERATION)
Vref
Vo
COMPARATOR
COUNTER
a
b
c
d
e
f
g
7-SEGMENT DISPLAY


DUAL POWER SUPPLY
7805
7905
SENSOR CIRCUIT
SWITCHING PROFILE GENERATION CIRCUIT
AT89C2051
PEAK DETECTOR CIRCUIT
d1, d2 ~ OA-85 (Ge diodes)
DRIVING CIRCUITS
DIFFERENCE AMPLIFIER

3. Circuit Design

3.1 Capacitor sensor:

Two cuboidal wooden blocks of similar sizes having a cavity of similar dimension and shape in both, where the copper plates are to be 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 out from each plate and placed on the circuit (ref Fig2.).

3.2 Sensor Circuit:

An indigenously designed circuit, ref. ckt1, is used with C_x being the capacitance of the parallel plates across the drip chamber. The switches S_1 and S_2 are periodically switched ON/OFF. The charge that gets stored in C_x and 18pf 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. $V_{y,}$ ref. Fig 3. The change in voltage level on passing of a drop was observed to be <10 mV.

The two switches S_1 and S_2, obtained from CD4066 (Analog switches), have switching profiles as shown in Fig3.

These switching profiles are generated by an AT89C2051 microcontroller. The frequency of switching was 16.6 KHz. Two separate driving circuits are placed as an interface between AT80C2951 (microcontroller) and CD4066 (analog switch). An important feature to note is that the profiles are non-overlapping. This is to ensure that both switches are never ON at the same time. This to prevent discharge of C_x through S_2 instantaneously before S_1 is turned off.

3.3 Signal Conditioning (Pulse generation):

The voltage waveform obtained from the previous circuit, i.e. V_y, needs to be conditioned into an upward square pulse which is to be fed into the microcontroller for counting. The same objective has been achieved by using a Peak Detector circuit, followed by two Difference Amplifiers and a Voltage Inverter, ref. ckt1.

The output from the previous circuit is sent as an input to the peak detector circuit. This circuit detects the minimum voltage peaks obtained in V_y (ref. fig2), and hence the envelope for the peak varies with the presence of a drop in the drip chamber, due to an increase in capacitance. The change in the voltage is very low (<10 mV) and hence the envelope obtained after the peak detector has a very small drop in voltage.

This waveform V_p is fed into a voltage follower, which acts as a buffer, followed by a Low-Pass Filter (RC ~ 70ms), which suppresses the high frequency noise. The signal obtained after the LPF is sent to the inverting terminal of the opamp, and the same is also passed to the non-inverting terminal through another Low-Pass Filter (RC ~ 32 ms).
So with the occurrence of a downward pulse, the circuit acts as a difference amplifier and amplifies the drop in voltage.

The waveform obtained (V_d) is passed through a voltage inverter circuit as the micro-controller circuit works for positive square pulses only. Another difference amplifier is used now in order to increase the voltage change so as to make it detectable by microcontroller's inbuilt comparator.

3.4 Drip Rate Measurement and Display:

This part has been made using an AT89C2051 microcontroller. The positive square wave and the reference voltage waveforms obtained from the previous circuit are fed to the microcontroller. AT89C2051 has an inbuilt comparator which compares V_a and $V_{ref.}$. Whenever V_a rises above V_{ref}, the microcontroller generates a hardwired internal interrupt (on port 3.6, which doesn't 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.

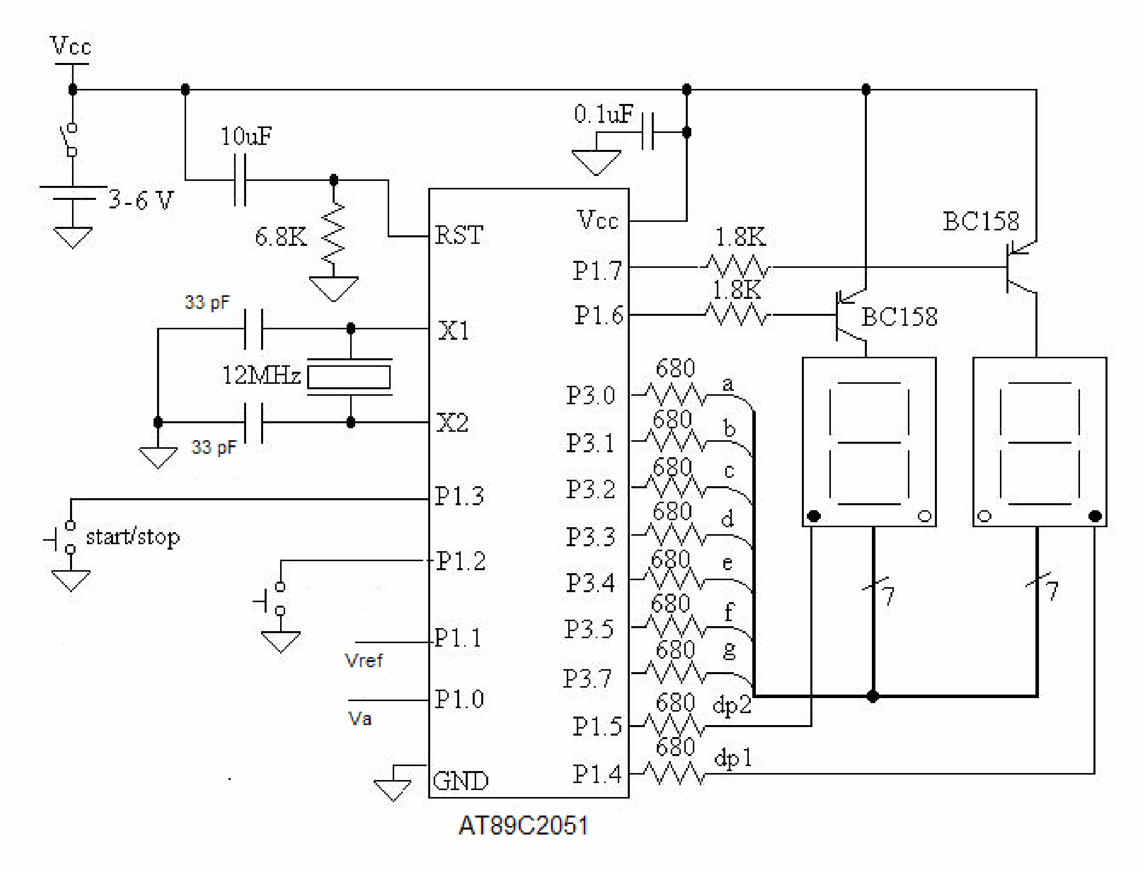


Fig. 4: Circuit Diagram for microcontroller interface

Time between two interrupts = Time between two drops = t seconds
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 being done efficiently using only seven pins for both the 7-segment displays. The same pins are being alternately used by each 7-segment display to read values from the microcontroller (time multiplexing). The switching between the two is being done every 6 ms. This time duration is small enough to escape detection by the human eye. Thus the display seems steady and 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 point have also been included to increase the range of the to 0-399 seconds. Clearly, the resolution of the stopwatch is one second.

4. Algorithm Description

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

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.

Mode Check:

- If mode input = high, clear status flag & go to “Stop Watch Mode”.
- If mode input = low, set status flag & go to “Drip Rate Mode”

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 low go to “Stop Watch Mode” else go to “Mode Check”.

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 for 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 locations.
- 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 high go to “Drip Rate Mode” else go to “Mode Check”.

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.

Interval Measurement Routine:

- Initialize T1 with 50ms for measuring time interval.
- Check for mode control pin P1.2.
- If pin P1.2 is “high”, go to “Rate”.
- If pin P1.2 is “low”, update the “stop watch display” buffer.

5. Observations

No detection of change in capacitance when 741 opamp was used in sensor circuit.

Output of final circuit when LF356 is used in sensor circuit:

Input power supply (+9.0 V Ground -9.0 V)
Output of 7805= +5V with respect to common ground
Output of 7905 = -5V with respect to common ground
Output of Switching profile= 0 to 4V at f=16.6 KHz

Output of Sensor Circuit (V_y) 0 to -1.6V
Output at 2nd Difference amplifier when no drop passes through is 3V and 1V change when drop passes through.

6. Problems faced and their solution

1. Dynamic voltage reference

The value of reference voltage needed for the comparator has to be set dynamically as the capacitance of the drip chamber might vary because of the liquid droplets that might collect on the walls of the chamber during operation. If a constant voltage reference is used then drip rate calculation will have errors.

2. Capacitance of bread-board

Initially we were working on bread-board and we were able to sense capacitance changes in the nF range only. As suggested by Prof L.R. Subramaniam we made the sensor part on the all purpose board and hence we were able to detect the change in pF range.

3. Length of wires and their capacitance

Initially wires that were used to connect capacitive sensor to bread-board were long 20cm-30cm). But as capacitance of our capacitive sensor assembly was very small (about 3 pf), capacitance of wires (30 pf) were dominant and we could not measure any change. By reducing wire length to 3-4 cm we were finally able to detect the change as the drop passes through the assembly.

4. Clock used for switching

First we tried to produce clock pulses by shift registers but it was very difficult to adjust the frequency. Then we used microcontroller for the purpose.

Initially the clocks provided to the analog switches overlapped (due to delay) which caused the discharge of C_x through S_2 instantaneously, before S_1 was turned off. On Prof P.C. Pandey's suggestion this was rectified by using non overlapping clock.

5. Leakage of charge through analog switches

Initially we were operating at low frequencies (~100 Hz) which caused the leakage of charge on capacitance C_x through the analog switches.

The frequency of operation of switches has been kept 16.67 KHz; such a high value has been used to ensure that the charge on capacitor does not leak through OFF resistance of switch which is around 400 Mega ohms.

6. Simulation of capacitance change

Repeated checking of the sensor circuit by using drip chamber assembly was inconvenient. Therefore we simulated the falling of a drop by switching a 2pf capacitance in parallel with C1.

7. Peak Detection

Initially the width of the downward going pulse V_y (ref Fig2) was around 2 microseconds which was not detectable by the peak detector circuit. To increase the width of the pulses we had to increase the value of resistance R_1 (through which C_2 was discharging). We could not increase the value of R_1 because of high Bas currents of 741 opamp which we were then using for our sensor circuit. To counter this problem we used LF356 which had very low bias currents.

8. Buffer Circuit

The peak detector circuit was being loaded by the difference amplifier circuit as a result of which the capacitor in the peak detector circuit was getting discharged through the difference amplifier circuit's resistance. This was avoided by using a voltage follower between peak detector and difference amplifier circuit.

7. Conclusion

The intravenous drip sensor has been designed to measure 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 capacitive sensor to sense the drop and after suitable analog signal conditioning, feeds it to a 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 two 9 volts battery and can be designed to be made portable if made on a PCB.

8. Limitations

1. The maximum range for drip rate we took as 99 drops/minute, above this we show "OL" that signifies over limit. This is a reasonable good assumption for general case but in some case monitoring of higher drip rate may also be needed.
2. Our instrument has been developed for the standard IV (intravenous) drip chamber available in market. If a specialized IV apparatus is used, our instrument may not fit the chamber due to variation in size.
3. The circuit has been tested for stray capacitance of as large as 30pf. If stray capacitance increases beyond this because of length of wires, the peak detector circuit might go into saturation and no drip level would be measured.
4. The instrument takes approximately five seconds to reach stable voltage levels and the readings obtained during this period would be incorrect, and thus should be ignored.

9. Future Scope

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 technology. Also a feedback control system could be devised which would increase/decrease the drip rate as and when the drip rate deviates significantly from preset standard values. Clearly this would also involve devising a mechanism to control the flow of fluid.

10. References.

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