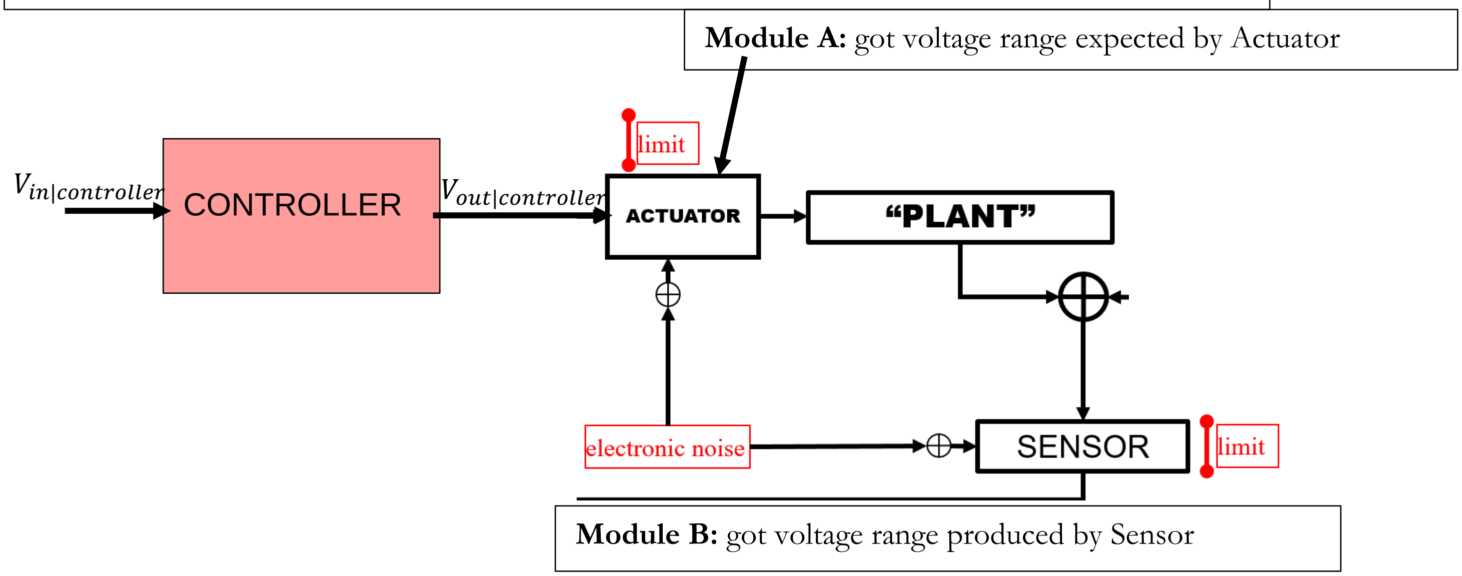
PH233 End-semester exam Module C: Controller

From Modules A and B we have a clear idea of the range of voltages coming from the sensor, and the range of voltages to be driven into the actuator as shown in Fig 1

Fig 1: Progress so far from Modules A + B: we have the plant, now we build the controller



In this module, we will build and test the highlighted controller module in Fig 1

Since $V_{out|sensor}$ and $V_{in|actuator}$ ranges are known, we are now ready to implement the mathematical feedback equation:

$$V_{out|controlller} = K_p e(t) + K_I \int_0^{\tau} e(\tau) d\tau + K_P \frac{de}{dt}$$

in terms of real voltage signals between opamp based blocks

For this assignment, we simplify the controller by dropping the latter 2 terms and implementing only the proportional term:

$$V_{out|controller} = K_p e(t) \ldots \ \ Equation\ (1)$$

Though very simple, controller based on equation 1 has major drawbacks for our breadboard feedback control system:

$V_{out|controller}$ can be positive or negative depending upon sign of $e(t)$. However, our actuator (LED) requires positive drive voltage (0 – 4V as tested in Module A). Hence $V_{out|controller} \rightarrow V_{in|actuator}$ needs to be positive definite

If we don't make provision for an offset voltage, consider the case when $e(t) \to 0$: $V_{out|controller} = 0$, thus turning-off the LED. No light incident on the sensor will increase $e(t)$ to maximum pushing $V_{out|controller}$ to max driving the LED back to full brightness! This cycle continues and the controller will oscillate

Hence, we need to modify the controller output equation by adding an offset

$$V_{out|controller} = K_p e(t) + V_{Offset} \ldots\ldots \textbf{ Equation (2)}$$

Where V_{Offset} is generally set to half the range of $V_{in|actuator}$.

Use **INVERTING** configuration opamps for both the following questions C.1 and C.2. To keep the two terms in Equation 2 independent, use one opamp to implement $K_p e(t)$ and a second opamp to add V_{offset}

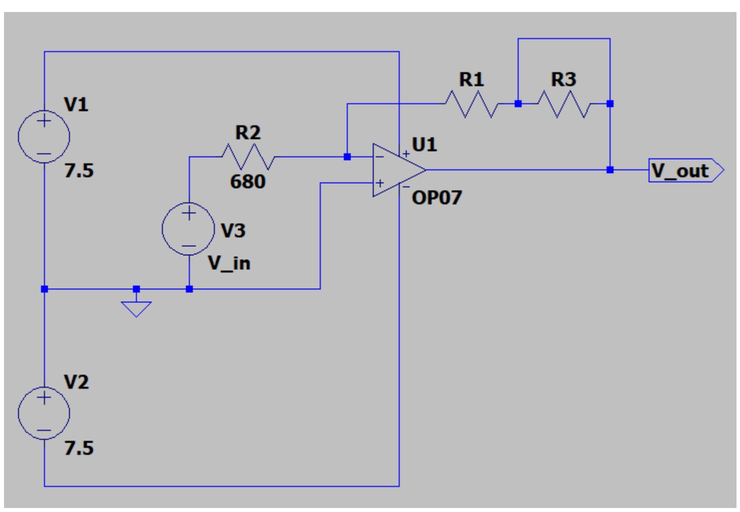
C.1) P controller $K_p e(t)$ 10

This is simply an inverting opamp gain configuration whose gain corresponds to the proportional constant K_P

Design and build an inverting gain opamp. Set the gain with a tunable resistor ratio (use a 10kΩ potentiometer in the feedback loop to set the gain)

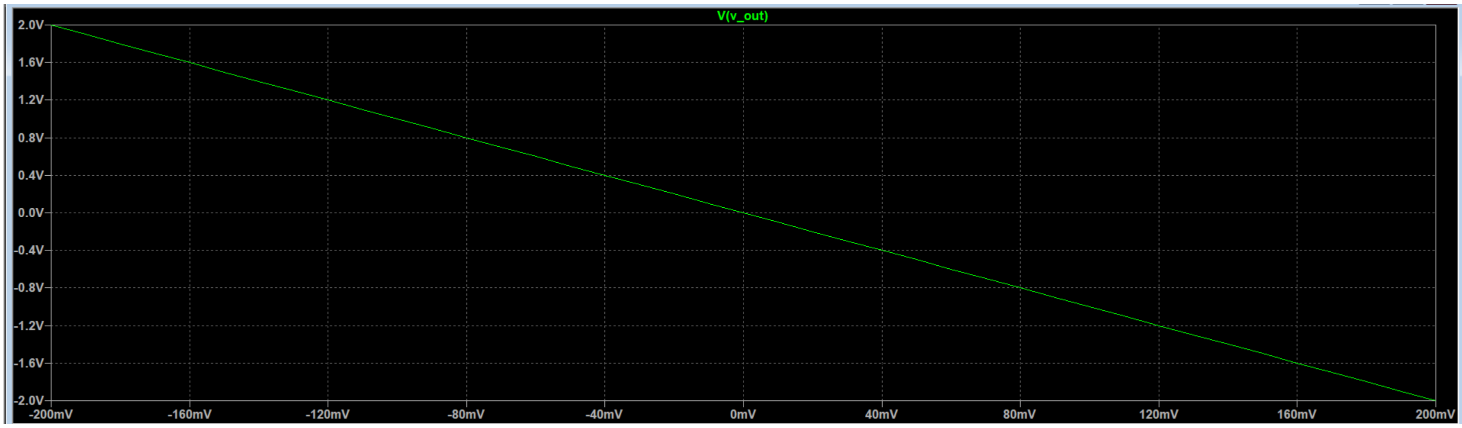
Test the functioning of your P block and tune its K_P gain by injecting various DC voltages $V_{in|controller} = -0.2V \text{ to } 0.2V$ to make sure it does not saturate the limits of $V_{out|controller}$. Assume that this is the worst case error imbalance you expect to see when you close the feedback loop.

Circuit design and simulation (LTSpice) 5



(NOTE: V1 = V2 = 7.5V due to draining of my battery after prolonged use. Hence, used the same value in the simulation)

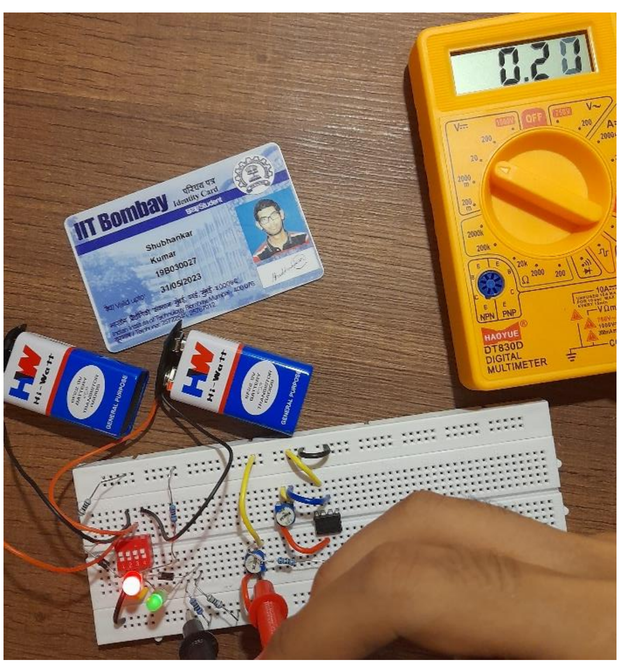
In the above circuit, R1 and R3 correspond to the potentiometer, and Vin ranges from -0.2V to +0.2V.

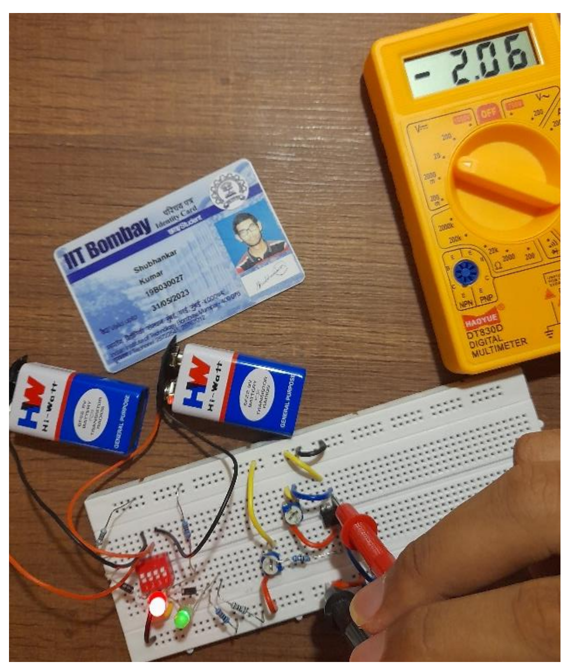


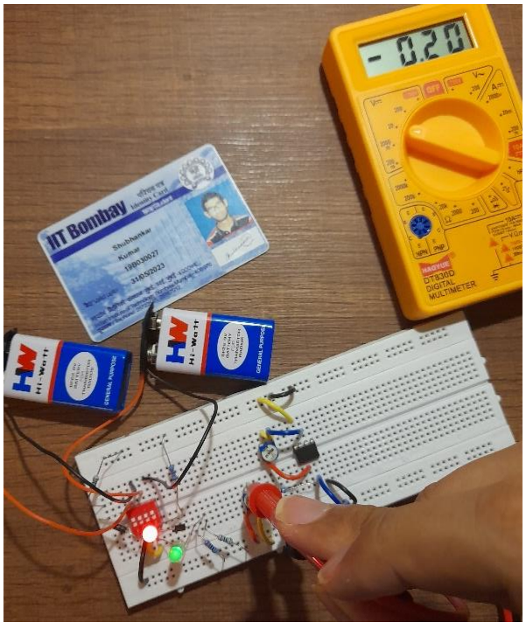
For obtaining the plot above with gain = 10, R2 = 6.8k**Ω** and R3 = 3.2k**Ω**. A DC sweep analysis on V3 with range -0.2V to +0.2V generates the above plot.

Photos of built-up circuit tested with worst case DC input voltages of –0.2V and +0.2V and corresponding output voltages at $K_P = 10$ (measure with DMM) **5**

V_{IN} = +0.2V **V_{OUT} = -2.06V**







V_{IN} = -0.2V **V_{OUT} = 2.14V**

C.2) Offset to be added to P control $+V_{adjust}$ 10

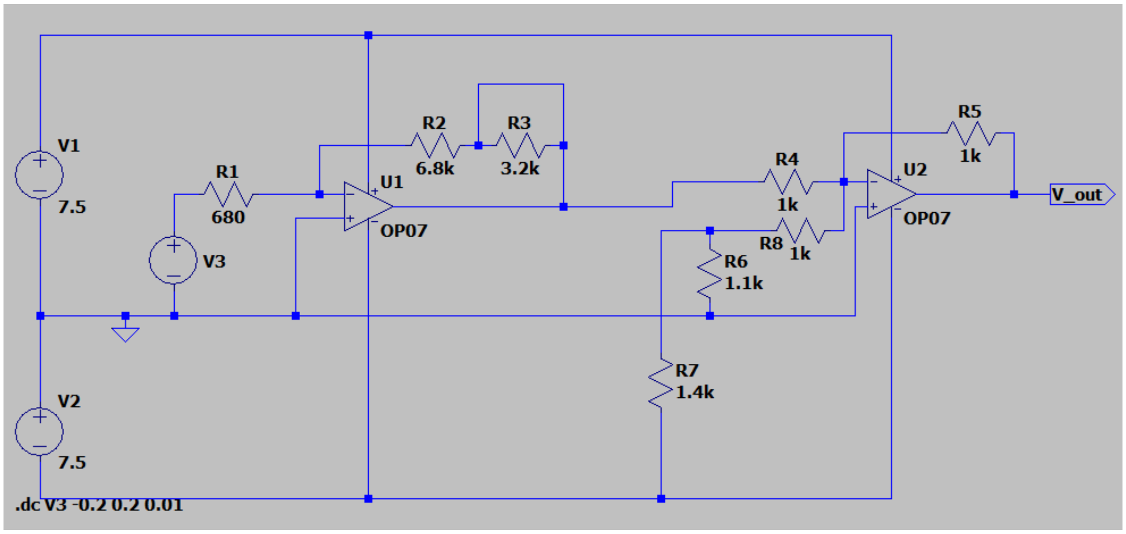
The keyword here is that you need a **summing** amplifier. $K_P e(t)$ is summed with an adjustable DC voltage.

$$V_{out|controller} = K_P e(t) + V_{adjust} \quad \ldots Equation\ (2)$$

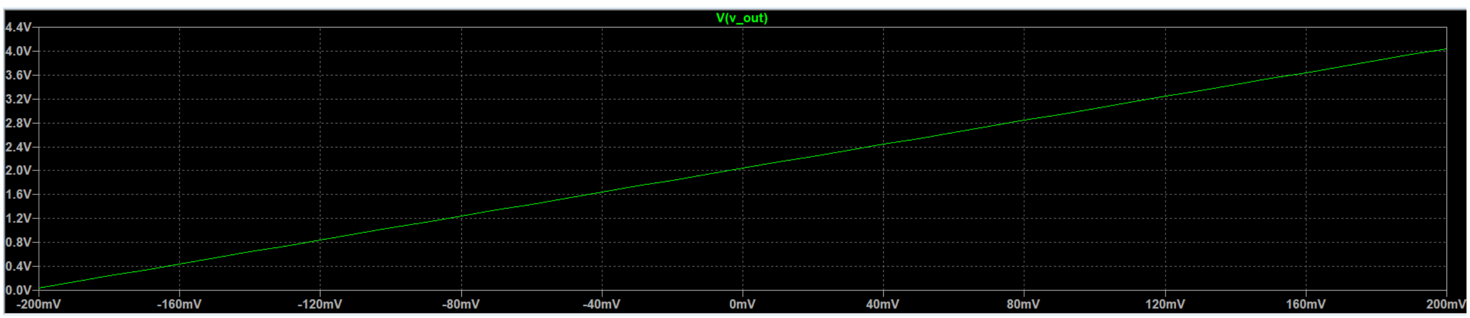
Notice that the gain K_P in the feedback controller (Equation 1) is positive by definition.

Due to the TWO inverting stages used in the above questions C.1 and C.2, the net gain of your P controller will be positive Each opamp is setup up for inverting operation. So (-1)×(-1) the net gain of the controller comes out positive.
The advantage of using two opamps is that it allows you to keep the two terms in Eqn 2 independent

LTSpice Circuit design and simulation adding two DC voltage levels **5**



In the above circuit, R6 and R7 are chosen such that $V_{junction}$ = -2V



We see that for V_{IN} = -0.2V, the output from the first op amp will be +2V. This is added with V_{adjust} = -2V, giving 0V as the output from the second op amp. In a similar way, we get +4V as the final output when V_{IN} = +0.2V

Circuit demo: Connect the summing amplifier on your breadboard. Measure with DMM a DC voltage +2V being summed to each of the $K_P \times (\pm 0.2V)$ cases checked in question C.1

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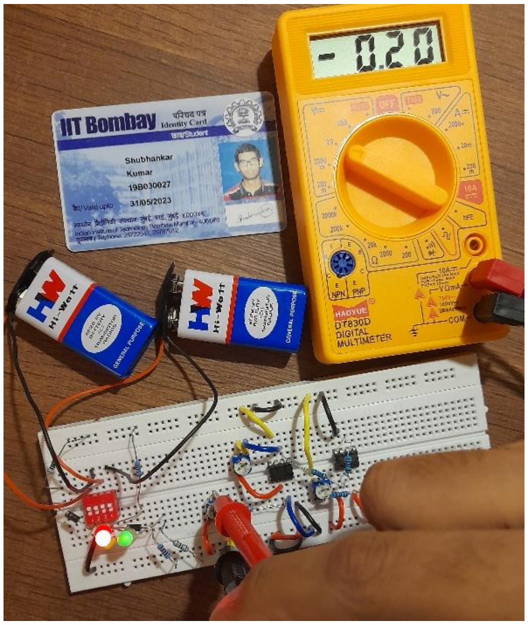
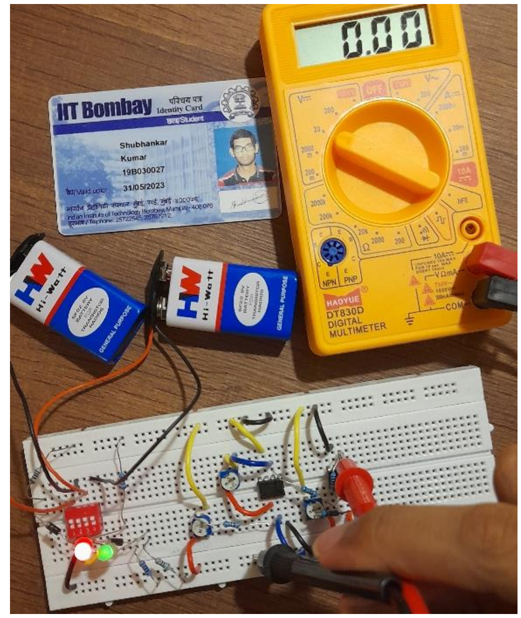
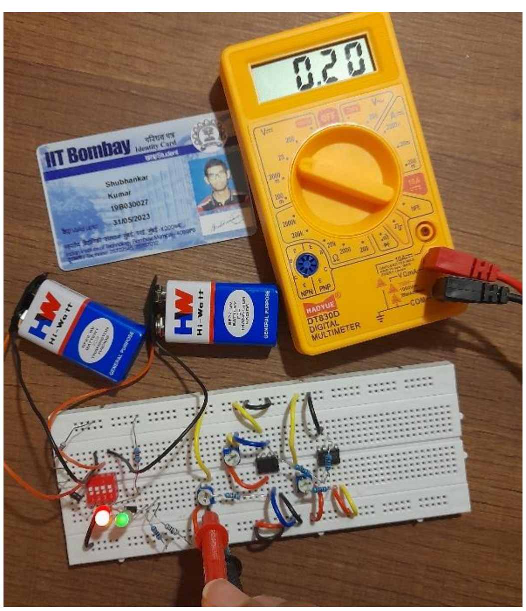


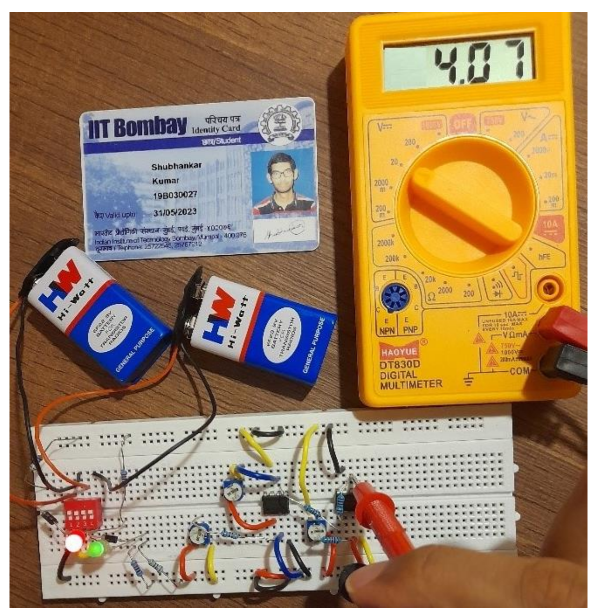
V_{IN} = -0.2V



V_{OUT} = 0V



V_{IN} = +0.2V



V_{OUT} = 4.07V