Lab 3.2: Putting opamps to 'gainful' use [POSITIVE Feedback]

Conceptual introduction

The prototype design for an opamp circuit using positive feedback is shown below in Fig 1

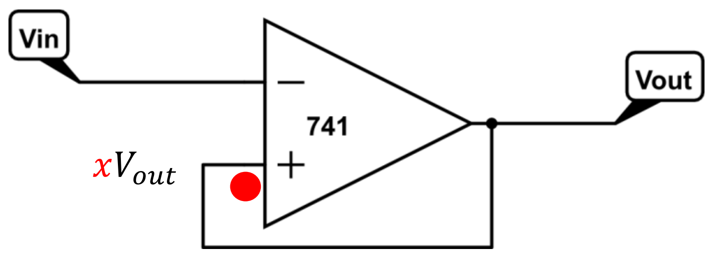


Fig 1: Prototype showing essential features of a positive feedback circuit. Fraction xV_{out} is send as feedback to the V_+ terminal

The two defining features of a positive feedback circuit are:

1) feedback signal is **always** applied to the V_+ terminal

2) V_{out} can have only two values - $+V_{sat}$ or $-V_{sat}$: these are the two states of the output – we will refer to the output 'switching' between these two states. V_{sat} is the maximum saturation voltage of the opamp output, usually a volt or so less than V_{CC}

The two Golden Rules of opamp design are obviously still applicable and all analysis is done on the basis of those two rules.

1) Circuit design

Problem statement:

What we DON'T want: Opamp running open-loop acts a comparator.

In Fig 1, consider what happens when the circuit in Fig 1 does not have the feedback loop in place. If $x = 0$ (i.e. V_+ is set to GND (and disconnected from V_{out}, breaking the feedback connection) then, V_{out} will switch states when V_{in} transitions from $V_{in} < 0$ to $V_{in} > 0$ and vice versa. However, as we know voltages are always noisy! So a small noise fluctuation in V_{in} around transition threshold will cause the output to switch multiple times.

With your kit's current battery state (maybe much less than 9V!) check the V_{sat} values you get with opamp open-loop comparator – most of the calculations below will depend on the numerimcal V_{sat}

WHAT WE WANT: Design a circuit that is called a **"Schmitt Trigger"**

The problem with noisy V_{in} and the desired solution for behavior of V_{out} is shown in Fig 2

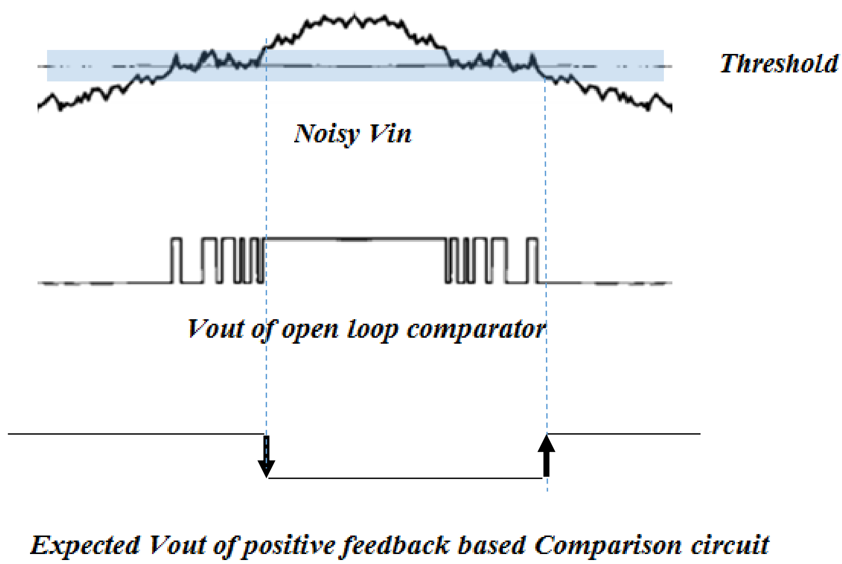


Fig 2: V_{out} of open loop comparator switches many times as noisy V_{in} crosses threshold.
OBJECTIVE: Should be able to set a specified value of threshold voltage V_T and have a specified safety 'noise' band around the threshold (marked as blue shaded box):
Required circuit: V_{out} must switch only when V_{in} exits that safety band.
Note: Timing & logic of the transitions highlighted above are caused by the intrinsic structure of our **inverting** Schmitt trigger.

Design specification:

As per Figures 1 and 2, design a positive feedback circuit using the LM741 such that:

1) Threshold Voltage $V_T = 2V$

2) Noise band allowed around V_T $is \pm 0.3V$

3) Use regular opamp power supply setup as earlier $\pm V_{CC} \sim \pm 8V$ don't forget the power supply bypass caps!

Hints for design:

a) As in negative feedback the fraction xV_{out} is set by a resistor divider. However, now our analysis is constrained by V_{out} being stuck to $\pm V_{sat}$ and having to set **two** bounds on the comparison :
both $2V + 0.3V$ and $2V - 0.3V$
For simplicity we have asked for a symmetrical noise band around V_T. In principle it is possible to set different lower and upper bounds around V_T
b) You will find THREE resistors are required instead of two as used in the negative feedback case.
c) Generally, such a circuit is called a 'Schmitt Trigger'

Solution to Question 1) **5**

Put a sketch of your Schmitt Trigger design here labelling the resistors and the design calculation equations that fulfill the required specifications.

(can be photo of hand-drawn sketch). Equations must be properly formatted

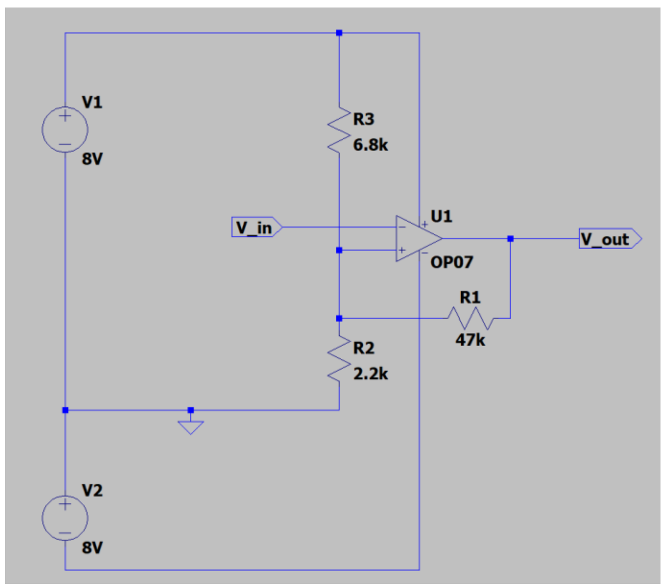
We have, $V_T = \frac{R}{R3}V_{CC} \pm \frac{R}{R1}V_{sat}$

Where R = R1||R2||R3 and Vcc = Vsat = 8V

We equate $\frac{R}{R3}V_{CC} = 2V \; and \; \frac{R}{R1}V_{sat} = 0.3V$

On solving these, we get $R_1 = \frac{20}{3}R_3 \; and \; R_2 = \frac{20}{57}R_3$

R3 can be chosen to be 6.8kΩ. Therefore, R1 = 47kΩ and R2 = 2.2kΩ



2) Simulation **5**

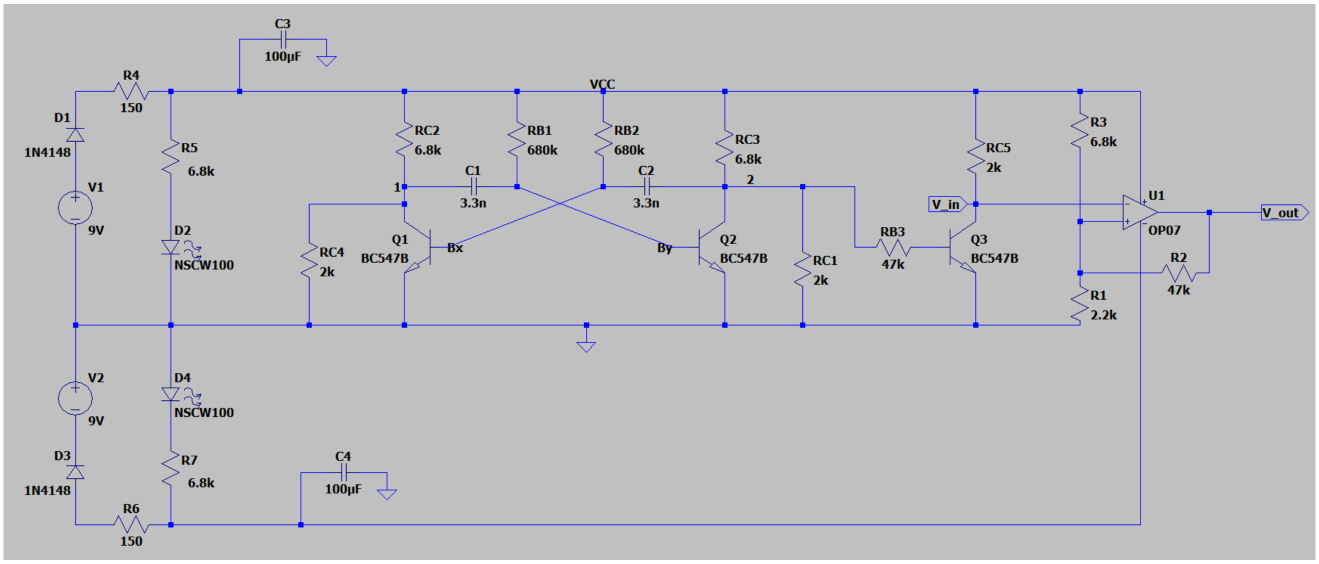
Simulate the circuit in LTSpice. For V_{in} Use the full-scale output of your standard square waveform from FG's collector of transistor Q3. Normally, the square wave output of the FG swings 0V to slightly less than V_{CC}.
Simulation will give a very fast transition across the threshold voltage. But note that in the next question, when you do the circuit test the actual V_{CC} may be much lesser, and V_{in} will be quite a bit noisier!

Circuit diagram **2 marks**

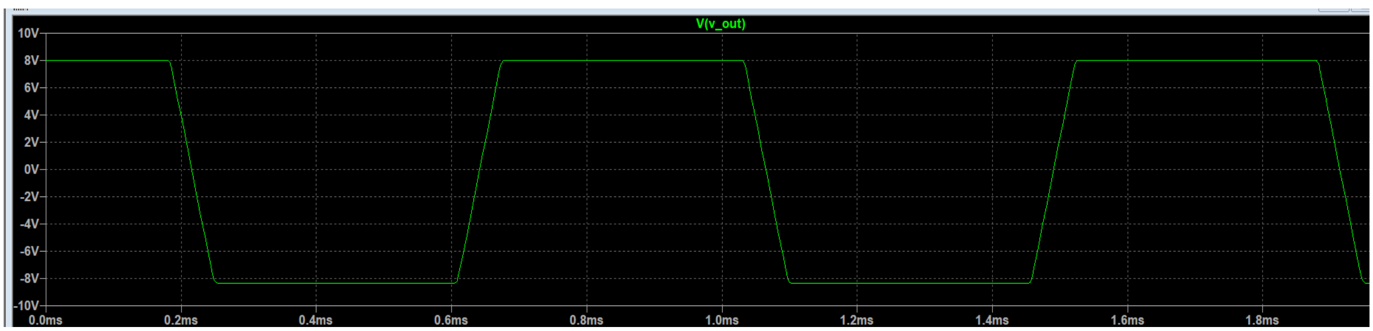
Plot of V_{out} & V_+ (time domain) **1 mark**

Plot of V_{out} v/s V_{in} **2 marks (notice the hysteresis behavior!)**

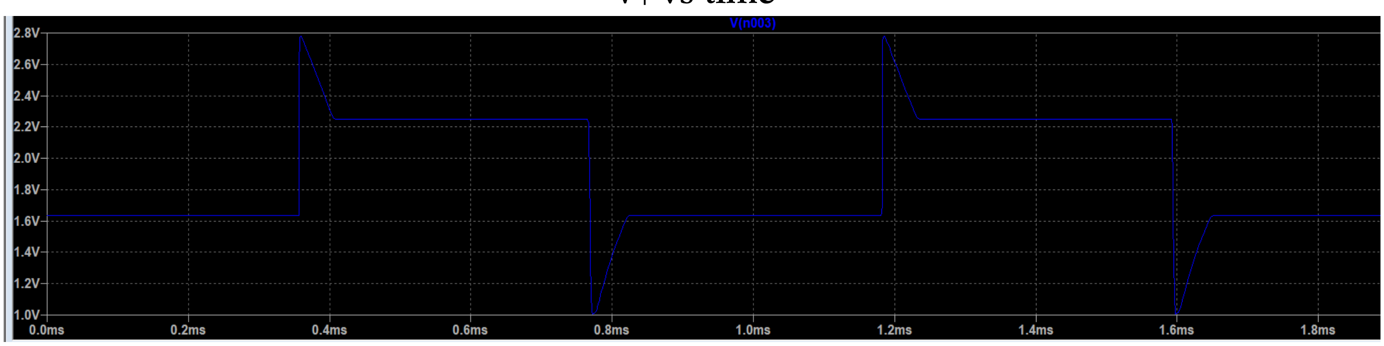
Circuit Diagram



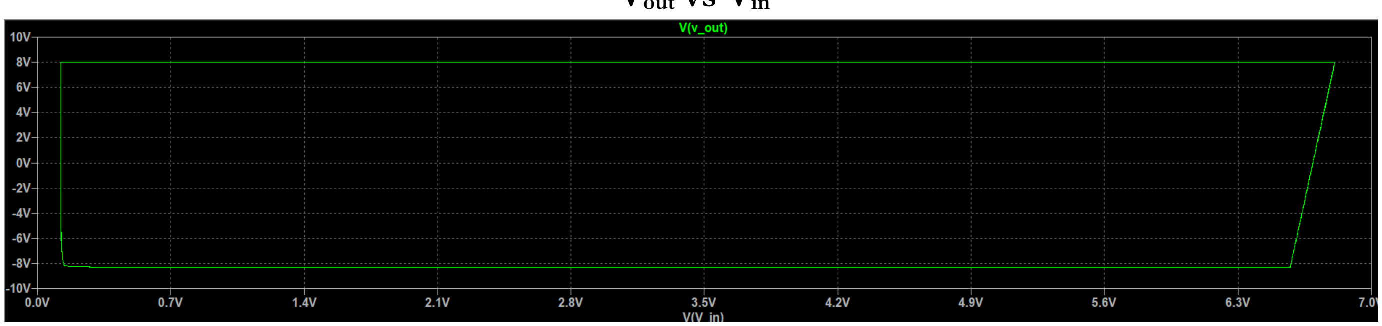
V_{out} vs time



V_+ vs time



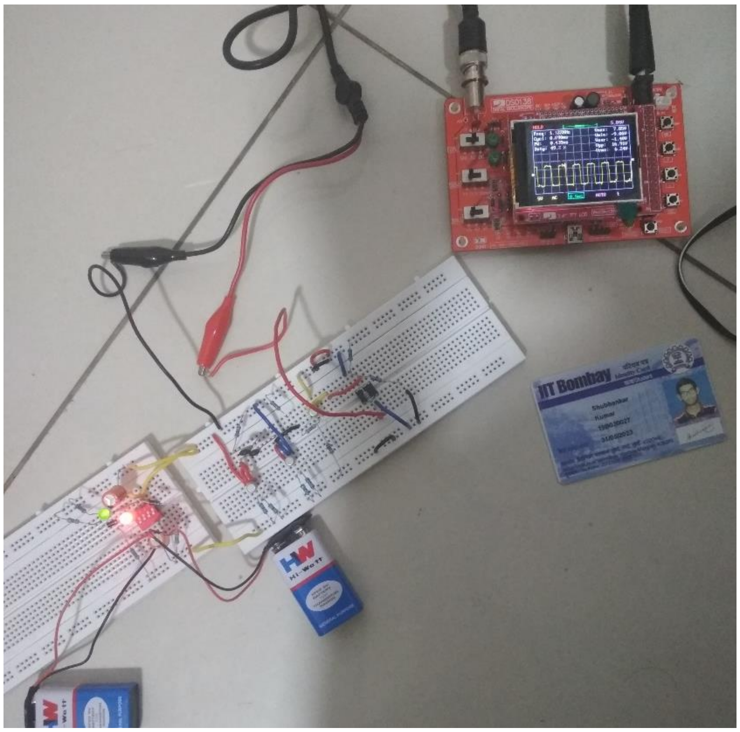
V_{out} vs V_{in}

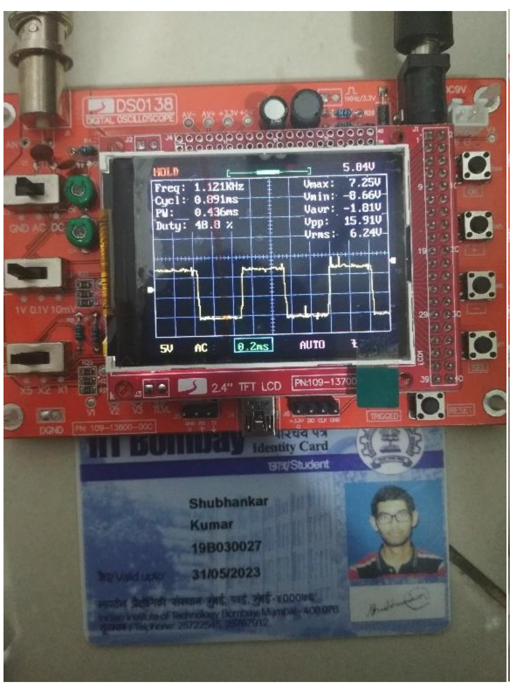


3) Circuit test – electrical voltages 5

Build the Schmitt trigger circuit designed and simulated on your breadboard.

Do a photogenic demo of your V_+ and the V_{out} of your Schmitt trigger. Label each photo to distinguish which is which.
Use the full scale square wave output from FG as V_{in}





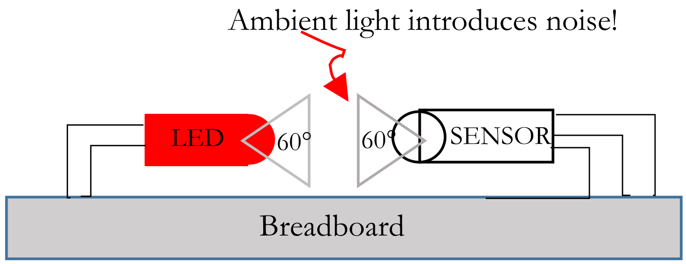
V_{out} **V_+**

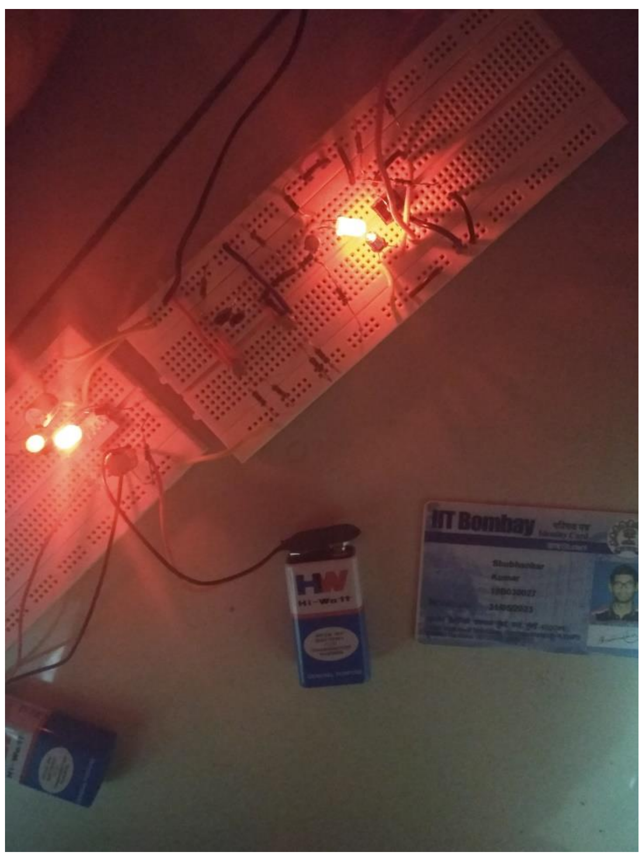
4) Circuit test – noisy light intensity measurement 10

Now we would like to test the Schmitt trigger with a realistic, noisy sensor voltage input.

Sensor: Setup the photo-transistor in your kit as a light detector. With the base left unconnected, the voltage obtained at the emitter is proportional to the light incident on the device

Light source: Use an LED connected to the FG output with a suitable series resistor to provide a variable light intensity to your sensor photo-transistor. Note that the LED and photo-transistor must be mounted facing each other on the breadboard as close to each other as possible. The LED has ≈ 60° cone of light emission and the phototransistor also has maximum sensitivity within a 60° cone as shown below.





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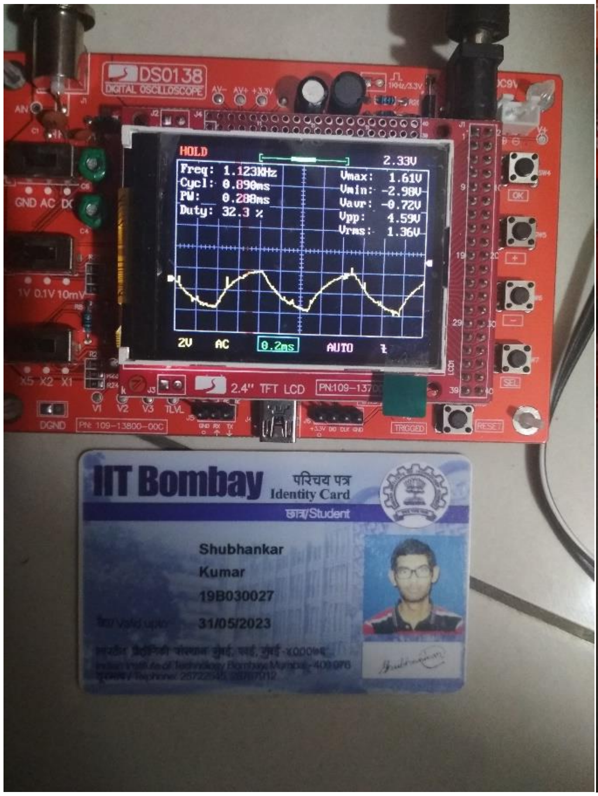

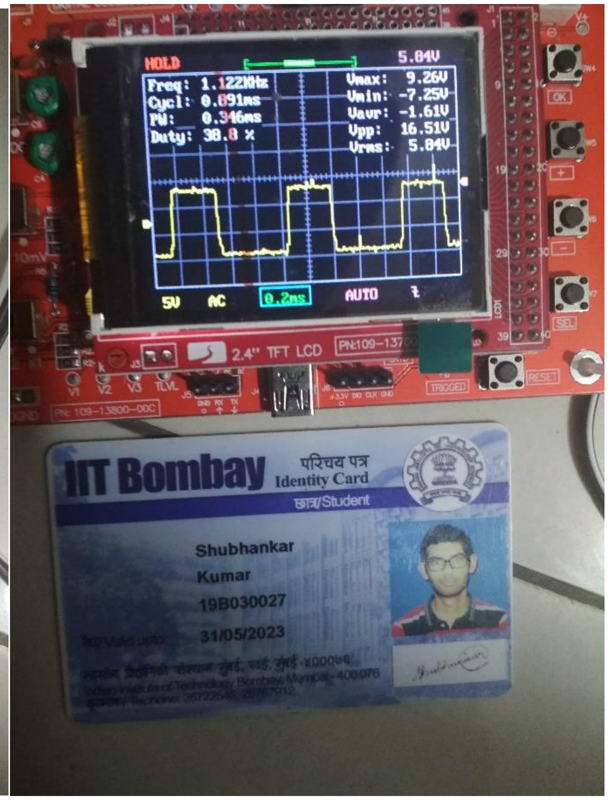

$\mathbf{V_{in}}$ $\mathbf{V_{out}}$

We observe that the voltage waveform from the phototransistor happens to be a sawtooth wave. The output waveform from the op amp due to the Schmitt trigger will be a square wave (as shown in the right figure).