Electronic Workshop 2 project
Analog Based Detection of Dip in Light Intensity

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1 AIM and Basic idea:

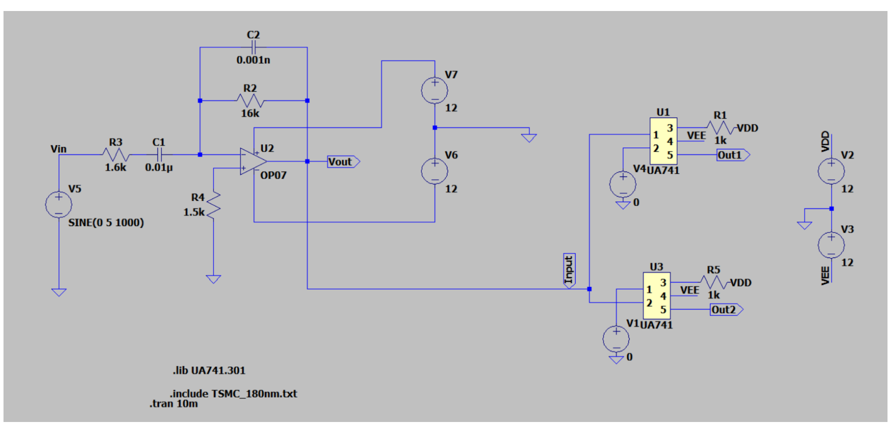
The objective of our project is to develop a robust system capable of effectively detecting fluctuations in light intensity. Our primary aim is to create a versatile solution that can reliably identify both increments and decrements in light intensity.

To achieve this, our approach revolves around the fundamental concept of differentiating and comparing incoming light intensity signals. Initially, we employ differentiation to extract the rate of change of the light intensity over time, commonly referred to as the slope. By doing so, we obtain valuable insights into the dynamic behavior of the light intensity variations.

Subsequently, we utilize these slopes in comparison with a predetermined reference voltage, established at zero. This comparison serves as the pivotal mechanism for discerning alterations in light intensity. When the slope surpasses the reference voltage positively, it signifies an upsurge in light intensity. Conversely, if the slope descends below the reference voltage, it indicates a decline in light intensity.

By integrating these differentiated signals and comparison mechanisms, our system ensures comprehensive detection coverage, enabling us to promptly respond to fluctuations in light intensity across various scenarios and environments

LTspice schematic of full circuit:



2 Components and their Description:

The following are the components required for our Circuit:

- Light dependent Resistor:

Light Dependent Resistor, also known as a photoresistor. It's a type of resistor whose resistance changes in response to the amount of light falling on it. This LDR sensor gives input to our circuit.

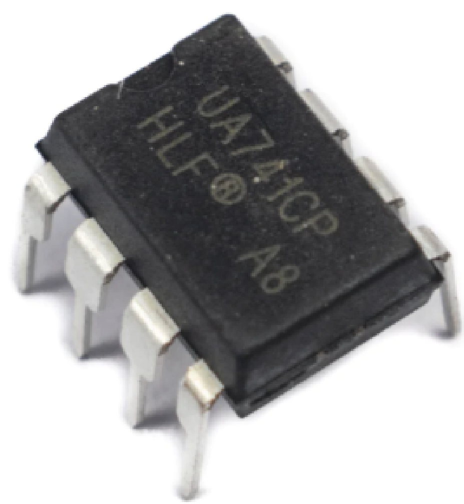
- Arduino UNO:

We upload a code to blink an LED in Arduino, and this output is utilized as input for an LDR with a specific intensity. The frequency of light is adjusted using the delay specified in the code.

- LEDs:

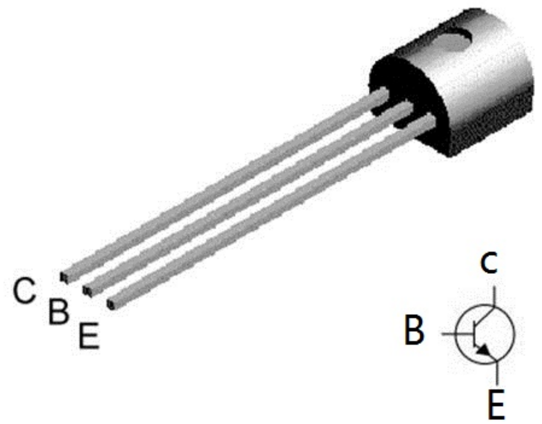
LEDs are used to represent the rise and fall of intensity: one LED glows for the increase, while the other glows for the decrease. Additionally, we provide LED light intensity as input to better understand our circuit.

- Op Amp:UA741 :



The UA741 is the heart of our circuit, as we use it to create a differentiator and a comparator.

- BJT:547BC :



The BJT (Bipolar Junction Transistor) is connected to the LDR (Light Dependent Resistor) in a light sensing circuit because the LDR's resistance changes with the intensity of light. The BJT is used to amplify this change in resistance and control the flow of current.

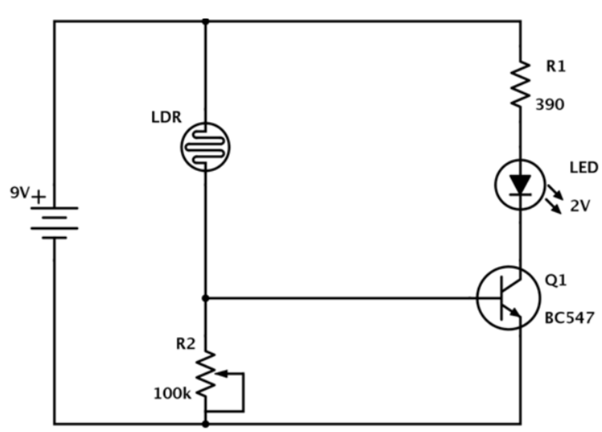
3 Stages of the projects:

Basically our circuit is divided into 4 stages:

1. Giving input to ldr through arduino
2. Differentiator
3. Comparator for rise detection
4. Comparator for fall detection

3.1 Giving input to ldr through arduino:

The LDR changes its resistance according to the intensity of light it receives. Utilizing this property of the LDR, we are using an LED as input. Now, this LED blinks with a specific frequency, programmed by the Arduino. This part of the circuit is enclosed because the LDR is sensitive to light from the surroundings. In order to obtain the LED's light intensity as input, we cover it.



The LDR (Light Dependent Resistor) is connected to a BJT (Bipolar Junction Transistor) in a light sensing circuit because the LDR's resistance changes with the intensity of light. The BJT can be used to amplify this change in resistance and control the flow of current. In the diagram above our circuit goes in the place of LED. To bias a BJT (Bipolar Junction Transistor) with proper resistor values for light sensing using an LDR (Light Dependent Resistor), you can use a voltage divider bias circuit. The LDR and a fixed resistor form a voltage divider, which is connected to the base of the NPN transistor. The voltage divider should be designed so that when the LDR is at the operating point (in the middle of its resistance range), the voltage at the base of the transistor is around 0.6V to 0.7V, which is the threshold for the transistor to start conducting.

The fixed resistor value depends on the LDR's resistance range, the supply voltage, and the desired base current. A common approach is to use a fixed resistor value that, when combined with the LDR's resistance at the operating point, forms a voltage divider that produces the desired base voltage.

For example, if the LDR has a resistance range of $4\,\mathrm{k\Omega}$ to $7\,\mathrm{k\Omega}$, and the supply voltage is $3.3\,\mathrm{V}$, you can choose a fixed resistor value that, when combined with an LDR resistance of approximately $5.5\,\mathrm{k\Omega}$ (the average of $4\,\mathrm{k\Omega}$ and $7\,\mathrm{k\Omega}$), produces a voltage of around $0.65\,\mathrm{V}$ at the base of the transistor. This can be calculated using the voltage divider formula:

$$V_{\text{out}} = V_{\text{cc}} \cdot \frac{R_2}{R_1 + R_2}$$

Where V_{out} is the voltage at the base of the transistor, V_{cc} is the supply voltage, R_1 is the LDR resistance, and R_2 is the fixed resistor value. Solving for R_2, we get:

$$\begin{aligned}
R_2 &= \left(\frac{V_{\text{out}}}{V_{\text{cc}}}\right) \cdot (R_1 + R_2) \\
&= \left(\frac{0.65\,\mathrm{V}}{3.3\,\mathrm{V}}\right) \cdot (5.5\,\mathrm{k\Omega} + R_2) \\
&= \frac{0.65}{3.3} \cdot (5.5 \times 10^3 + R_2) \\
&= 0.0197 \cdot (5.5 \times 10^3 + R_2) \\
&= 0.0197 \cdot 5.5 \times 10^3 + 0.0197 \cdot R_2 \\
&= 108.35 + 0.0197 \cdot R_2 \\
0.9803 \cdot R_2 &= 108.35 \\
R_2 &\approx 110.3\,\mathrm{k\Omega}
\end{aligned}$$

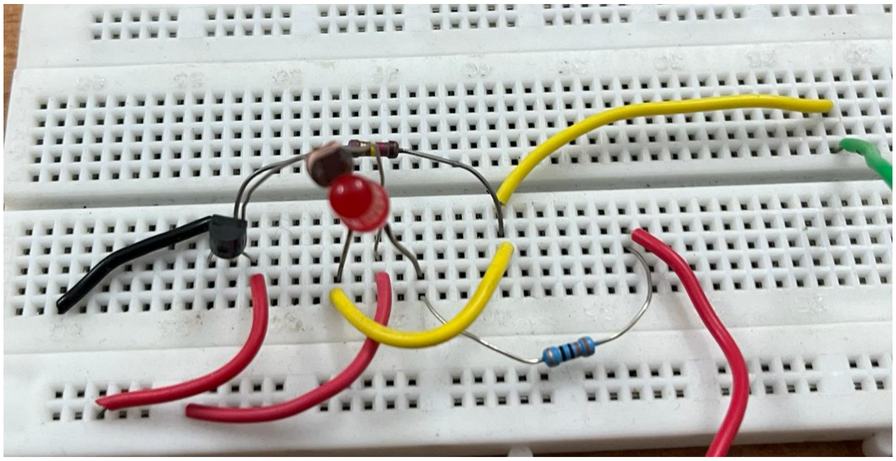
So, a $110\,\mathrm{k\Omega}$ resistor can be used as the fixed resistor in this example.

It is important to note that the LDR's resistance range and the supply voltage may vary, so the fixed resistor value should be calculated accordingly. Additionally, the base current should be considered to ensure that the transistor operates in the active region. A small base current (typically in the micro-ampere range) is sufficient to turn the transistor on and allow it to conduct the required collector current.

also the Arduino code goes here:

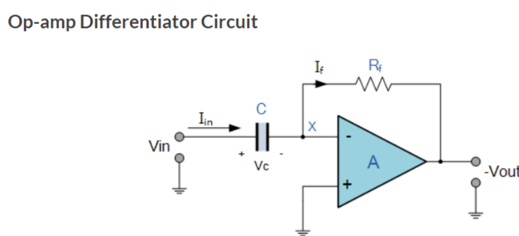
```
const int ledPin = 9;    // LED connected to digital pin 9

void setup() {
  pinMode(ledPin, OUTPUT); // Set the LED pin as an output
}

void loop() {
  // Generate a sinusoidal waveform using PWM
  for (int i = 0; i < 360; i++) {
    int brightness = 128 + 127 * sin(i * 3.14 / 180); // Scale the sine wave to PWM range (0-255)
    analogWrite(ledPin, brightness); // Write the PWM value to the LED pin
    delay(10); // Adjust the delay for the desired frequency (in milliseconds)
  }
}
```

Hardware circuit:



3.2 Differentiator:

We use an op-amp as a differentiator circuit. This differentiator circuit provides us with the slopes, producing a voltage output that is directly proportional to the input voltage's rate of change with respect to time. Hence, we can utilize both the increasing and decreasing slopes



Since the node voltage of the operational amplifier at its inverting input terminal is zero, the current, i , flowing through the capacitor will be given as:

$$I_{in} = I_F \quad \text{and} \quad I_F = -\frac{V_{in}}{R_F}$$

The charge on the capacitor equals Capacitance times Voltage across the capacitor:

$$Q = C \cdot V_{\text{in}}$$

Thus, the rate of change of this charge is:

$$\frac{dQ}{dt} = \frac{d}{dt}(C \cdot V_{\text{in}}) = C \cdot \frac{dV_{\text{in}}}{dt}$$

but

$$\frac{dQ}{dt} \text{ is the capacitor current, } i :$$

$$i = C \cdot \frac{dV_{\text{in}}}{dt}$$

from which we have an ideal voltage output for the op-amp differentiator is given as:

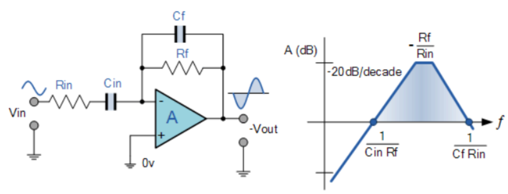
$$V_{\text{out}} = -R_f \cdot C \cdot \frac{dV_{\text{in}}}{dt}$$

Therefore, the output voltage V_{out} is a constant $-R_f{\cdot}C$ times the derivative of the input voltage V_{in}

with respect to time. The minus sign (–) indicates a 180 degree phase shift because the input signal is connected to the inverting input terminal of the operational amplifier.

Improved Op-amp Differentiator Amplifier:

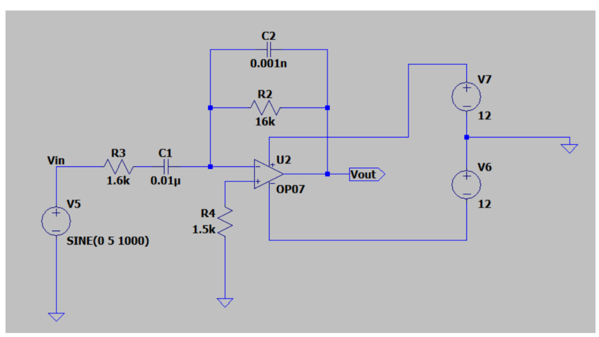
The basic single resistor and single capacitor op-amp differentiator circuit is not widely used to reform the mathematical function of Differentiation because of the two inherent faults mentioned above, “Instability” and “Noise”. So in order to reduce the overall closed-loop gain of the circuit at high frequencies, an extra resistor, Rin is added to the input as shown below.



Adding the input resistor RIN limits the differentiators increase in gain at a ratio of Rf/RIN The circuit now acts like a differentiator amplifier at low frequencies and an amplifier with resistive feedback at high frequencies giving much better noise rejection.

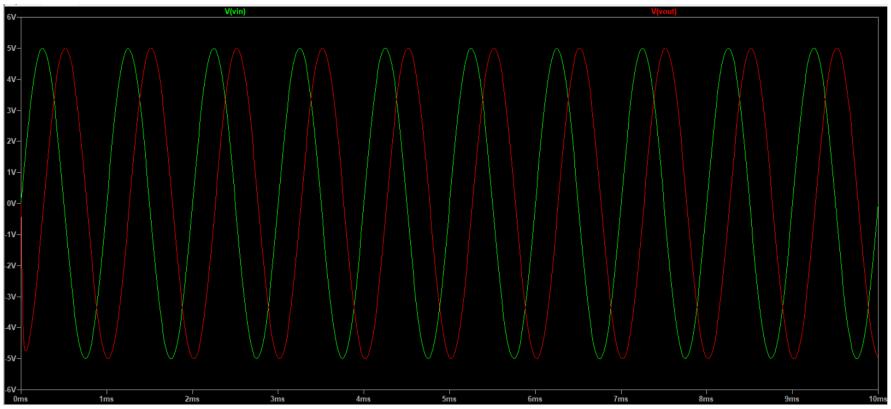
Additional attenuation of higher frequencies is accomplished by connecting a capacitor Cf in parallel with the differentiator feedback resistor, Rf. This then forms the basis of a Active High Pass Filter.

LTspice schematics:

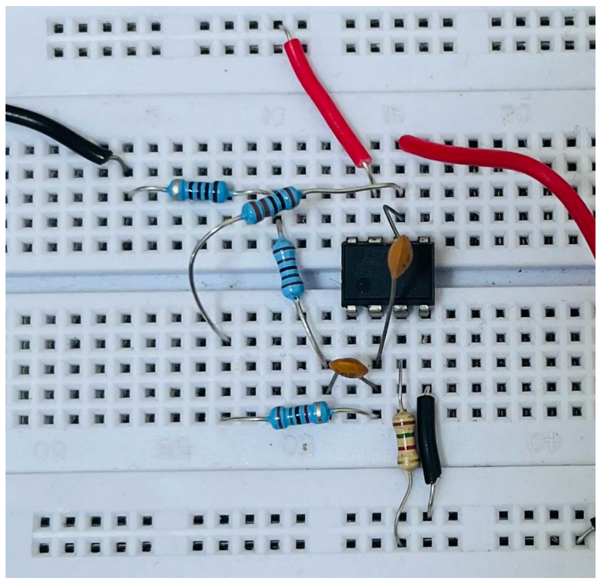


Here input is sine wave and we get a negative cosine wave as the output from the diffrentiator circuit.

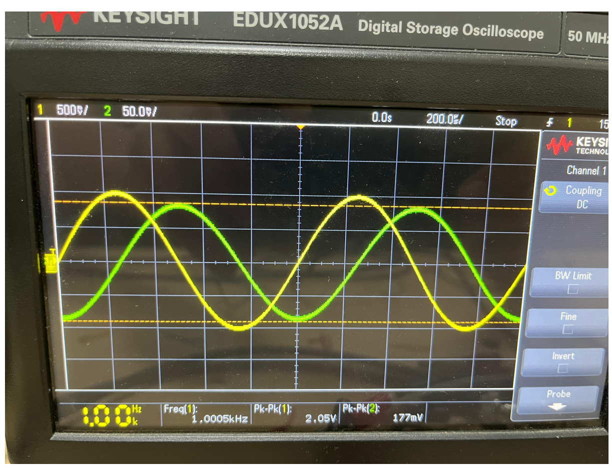
Output on LTspice:



Hardware circuit:

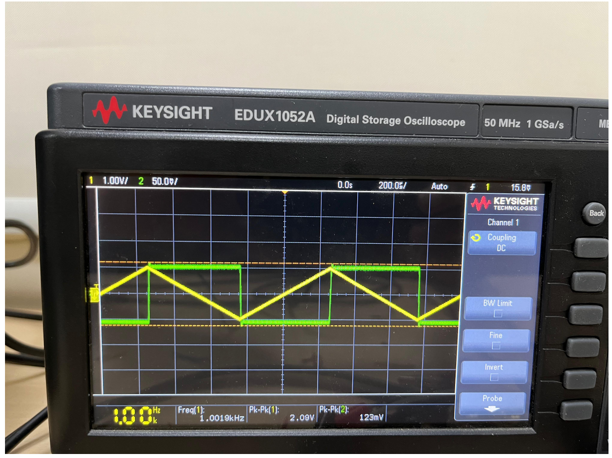


Output on DSO:



Here input is sine wave and we get a negative cosine wave as the output from the diffrentiator circuit.

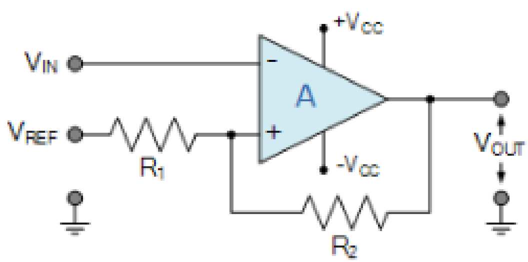
Output on DSO:



Here input is triangle wave and we get the slope as the output from the diffrentiator circuit.

3.3 Comparator as fall detector:

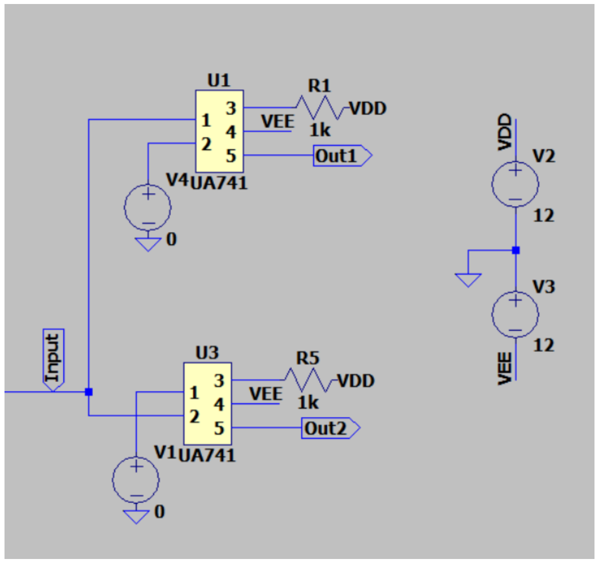
The output from the differentiator is an inverting output. Here, we select a reference voltage of zero for the non-inverting comparator. Therefore, when the slope is negative, the output from this comparator becomes positive, which is later connected to an LED. Consequently, we can recognize a decrease in light intensity provided.



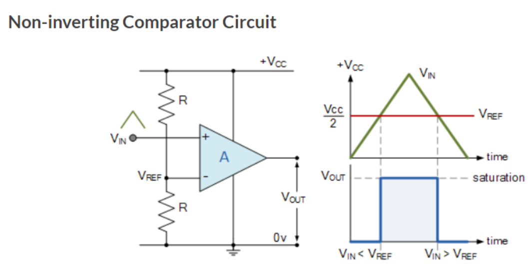
OP AMP AS COMPARATOR:
The op-amp voltage comparator is an analog circuit that compares two input voltages, typically using open-loop configuration or positive feedback. Unlike op-amps with negative feedback, which operate in the linear region, comparators switch their output between saturated states based on the voltage comparison.

In open-loop mode, the comparator's high open-loop gain causes its output to swing fully to either the positive or negative supply rail when the input signal exceeds a preset threshold. This behavior resembles that of a digital bistable device, with two possible output states: +Vcc or -Vcc.

LTspice schematics:



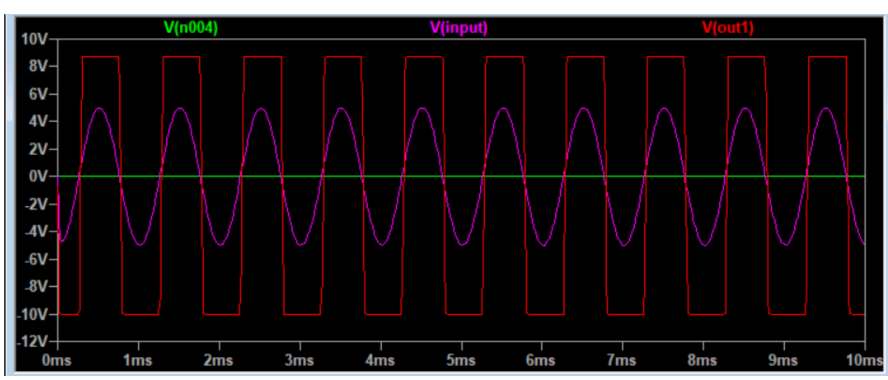
NON INVERTING COMPARATOR:



The non-inverting op-amp comparator circuit compares an input voltage (VIN) with a reference voltage (VREF). When VIN ¡ VREF, the output is low (-Vcc), and when VIN ¿ VREF, the output is high (+Vcc). It acts as a threshold detector, transitioning between saturation states based on VIN's relationship with VREF. The output depends solely on this comparison, limited by the op-amp's supply rails. Various methods can set the reference voltage, such as resistive dividers or zener diodes.

Essentially, the voltage comparator acts as a 1-bit analog-to-digital converter, where the input signal is analog but the output behaves digitally, indicating which input voltage is higher.

Output on LTspice:

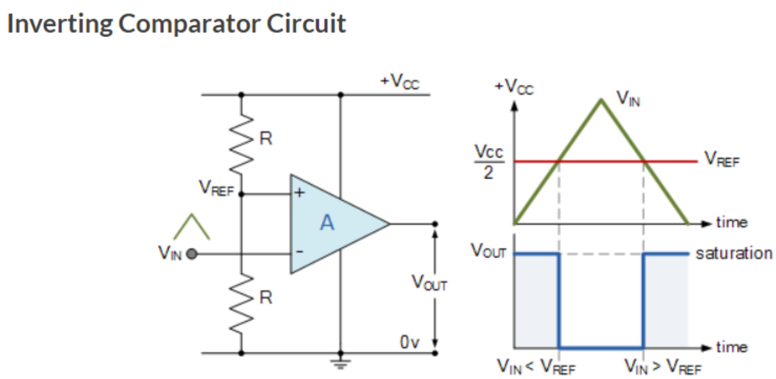


Here input is a sine wave, and we get a square wave which is positive when $\mathrm{V_{in}} > V_{\mathrm{ref}}$ (Here, $V_{\mathrm{ref}} = 0$) and negative when $V_{\mathrm{in}} < V_{\mathrm{ref}}$ as the output from the comparator circuit.

3.4 Comparator as rise detector:

Here, opposite of previous stage is done where we replace the non inverting comparator with inverting comparator and the reference voltage is the same. the LED connected at the output now detects the rise in input.

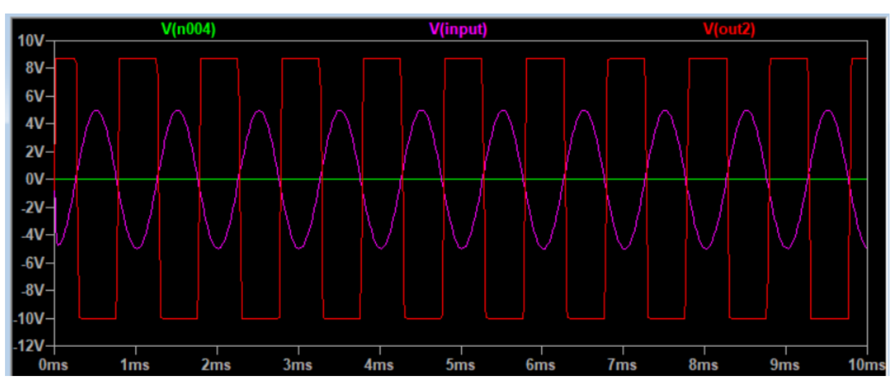
INVERTING COMPARATOR:



The inverting op-amp comparator configuration flips the roles of input signal and reference voltage compared to the non-inverting setup. Here's a concise paragraph summarizing its functionality:

In the inverting configuration, the reference voltage (VREF) connects to the non-inverting input of the operational amplifier, while the input signal (VIN) attaches to the inverting input. When VIN is less than VREF, the comparator output saturates towards the positive supply rail (+Vcc), and when VIN exceeds VREF, the output saturates towards the negative supply rail (0V). Depending on the relative magnitudes of VIN and VREF, the output switches between positive and negative saturation states. This setup enables the creation of both inverting and non-inverting outputs depending on the chosen input configuration. Additionally, combining both inverting and non-inverting op-amp comparator circuits allows the creation of a window comparator, facilitating detection of whether the input signal falls within a specific voltage range defined by two reference voltages, enabling more complex signal monitoring and control.

Output on LTspice:



Here input is a sine wave, and we get a square wave which is negative when

$$V_{\text{in}} > V_{\text{ref}} \text{ (Here, } V_{\text{ref}} = 0)$$

and positive when

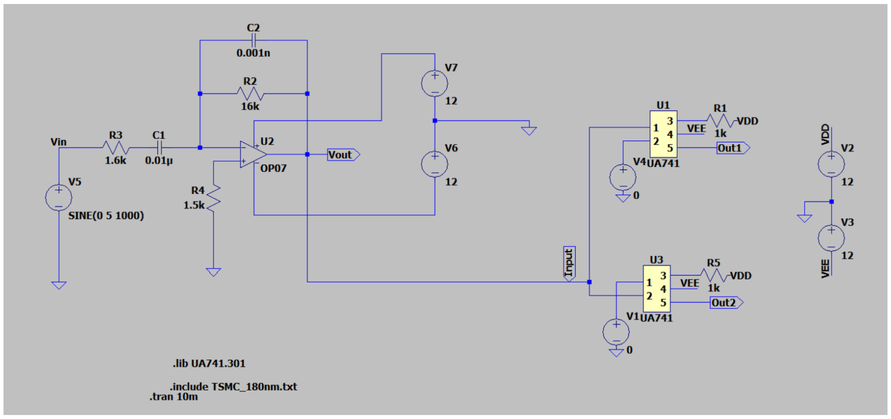
$$V_{\text{in}} < V_{\text{ref}}$$

as the output from the comparator circuit.

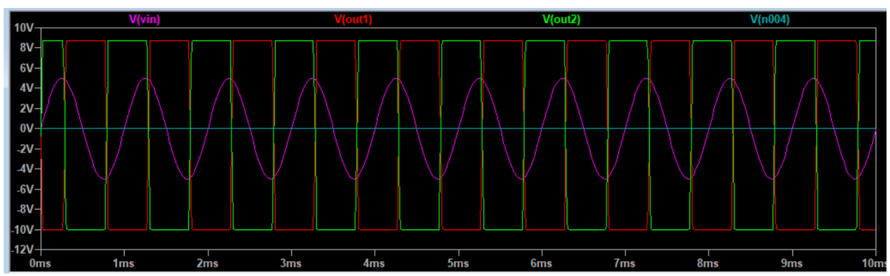
4 Results:

Connecting all the building blocks – LDR circuit, Differentiator and comparators, the final circuit is implemented. The final circuit will produce two waves as the output from the two comparators which is connected with 2 LEDs which detects the rise and dip in light intensity

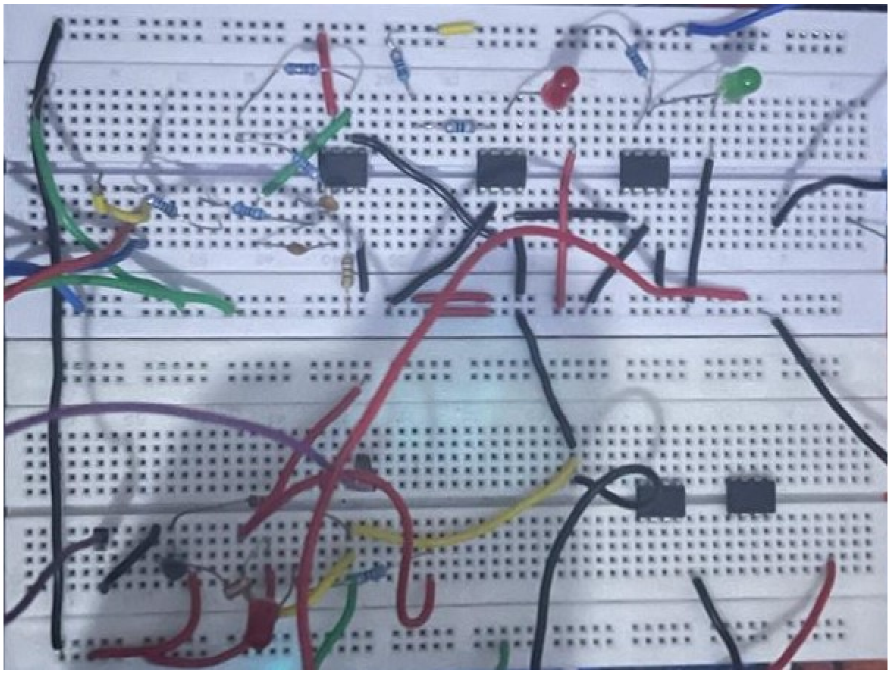
LTspice schematic of full circuit:



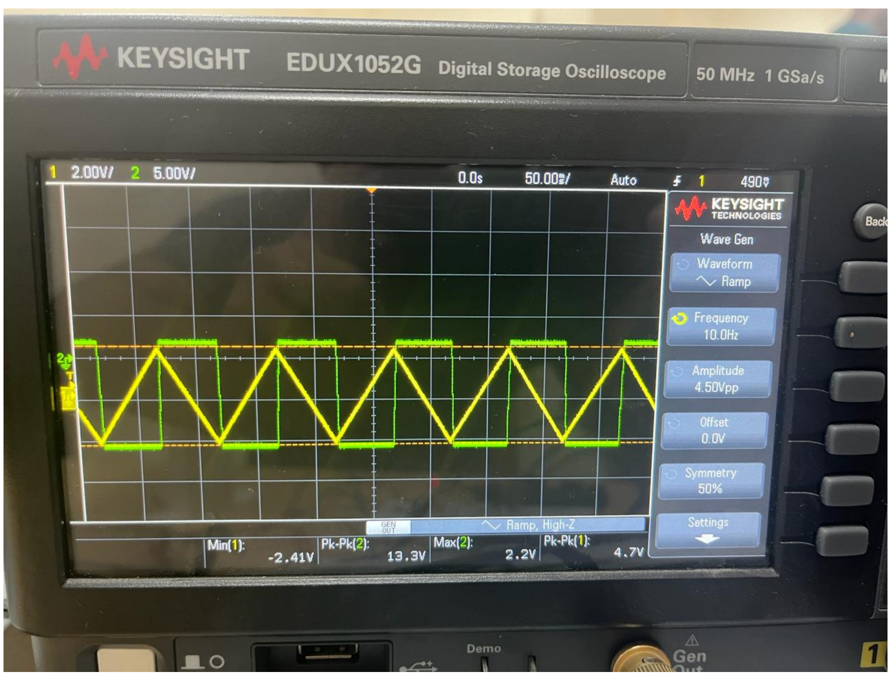
Output on LTspice:



Hardware circuit of full circuit:

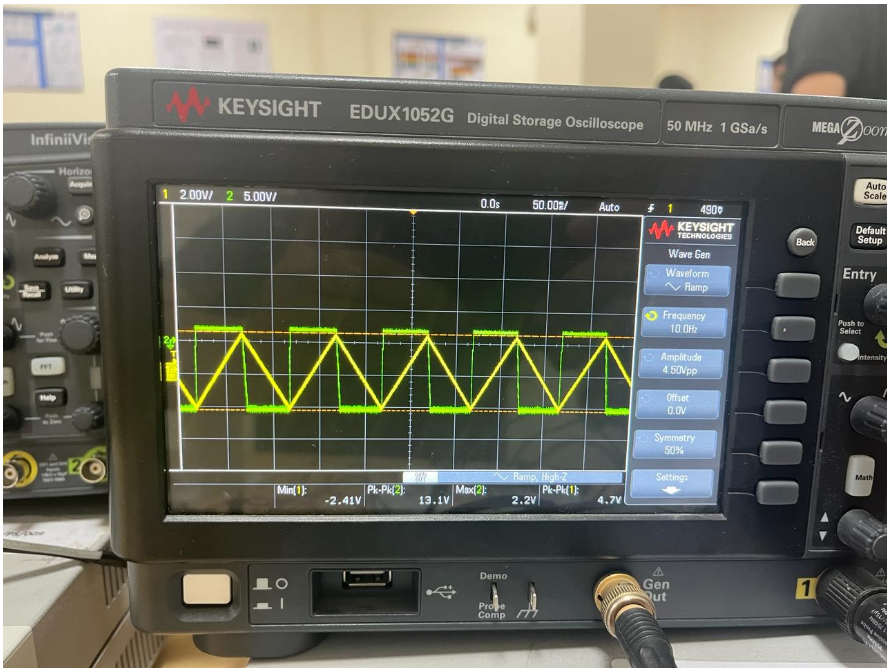


Output on DSO for fall detection (Triangle wave):



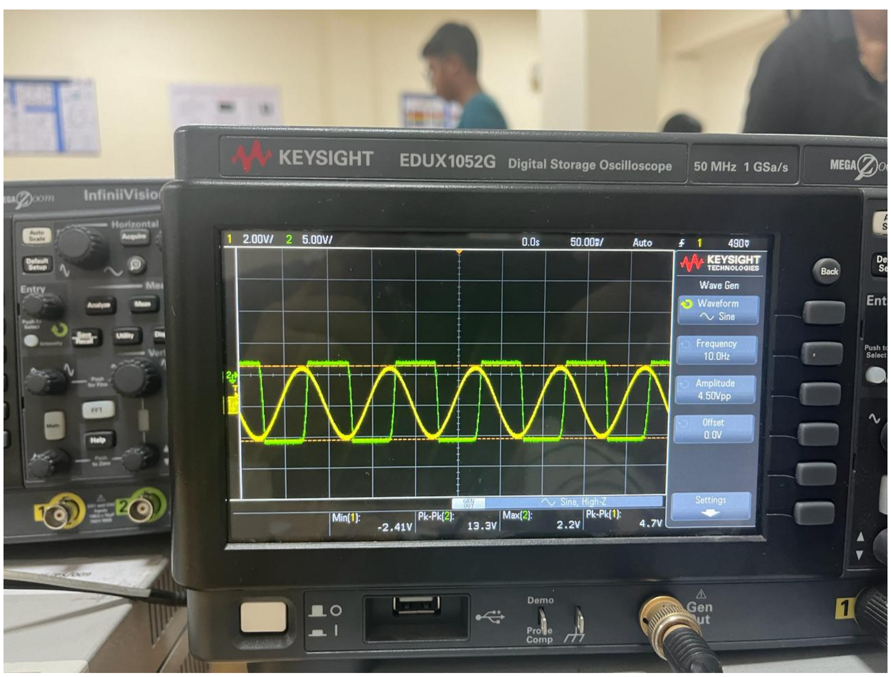
Here, input is a triangle wave from the wave gen and output is measured from the 1st comparator which give positive value when there is a fall in light intensity and negative when there is a rise in light intensity.

Output on DSO for rise detection (triangle wave):



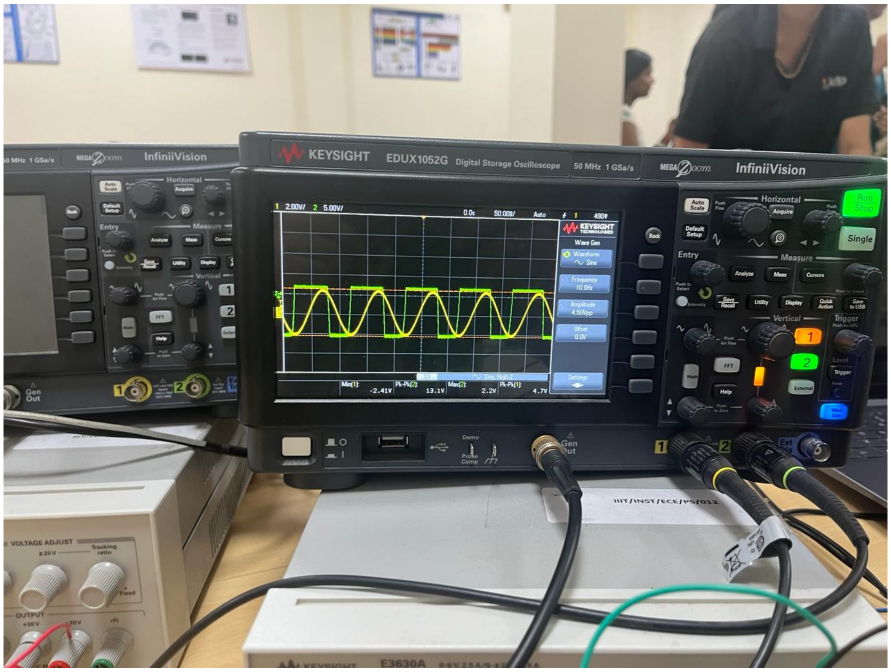
Here, input is a triangle wave from the wave gen and output is measured from the 2nd comparator which give positive value when there is a rise in light intensity and negative when there is a fall in light intensity

Output on DSO for fall detection (sine wave):



Here, input is a sine wave from the wave gen and output is measured from the 1st comparator which give positive value when there is a fall in light intensity and negative when there is a rise in light intensity.

Output on DSO for rise detection (sine wave):



Here, input is a sine wave from the wave gen and output is measured from the 2nd comparator which give positive value when there is a rise in light intensity and negative when there is a fall in light intensity.

5 IMPORTANCE OF TESTING, DEBUGGING, AND BIASING IN THE PROJECT

Testing:

- **Functionality Verification:** Testing is essential to verify that all components of the the arduino and op amps given work as intended. This includes checking inputs, outputs, signal processing stages, and power supply.
- **Performance Evaluation:** Through testing, engineers can evaluate the performance of the bjt, ldr , op amps under different conditions, ensuring that it meets specified criteria such as frequency response, distortion levels, and signal-to-noise ratio.
- **Reliability Assessment:** Rigorous testing helps identify potential issues that might lead to failures over time. This includes stress testing to ensure the circuit can handle prolonged use without degradation.

Debugging:

- **Issue Identification:** Debugging involves identifying and fixing any errors or malfunctions in the circuit's hardware. This includes addressing issues related to circuit design, component placement, and manufacturing defects.
- **Optimization:** Debugging allows engineers to optimize the circuit's performance by fine-tuning components, correcting errors, and improving efficiency.

Biasing:

- **Stability and Linearity:** Biasing is crucial for maintaining the stability and linearity of the op amp. Proper biasing ensures minimizing distortion and improving the fidelity of the input signal.
- **Temperature Stability:** Biasing also helps in achieving temperature stability, ensuring that the op amp's performance remains consistent across varying temperatures. This is especially important for reliable operation in different environments.

6 Parameters:

- Input Voltage: 0-15V
- Output Range: 0-20V
- Biasing: +12V and -12V to the op amps
- Delay: A Slight delay was observed due to LDR
- slew rate: At low frequencies (less than 5Hz) slew rate was very low which caused delays.
- Current consumption: Currrent consumption in our circuit was in the range of 0.01 to 0.03 Amps.

7 Challenges faced:

- **offsets in Op Amp:** One of the challenges we faced is when we give DC as input one of the LED use to glow. this was due to offsets present in op-amp,Offsets in operational amplifiers (op-amps) are undesirable DC levels that appear at the output of a circuit. They can cause uncertainty in readings. One way to keep output offsets to a minimum, it is important to match the input resistors and keep them low. This can significantly reduce offsets.However the couldn't find proper resistors to do so.
- **Delays:** A significant delay in low-frequency comparator.This can be because of various factors which includes, The slew rate of the comparator determines how fast it can respond to changes in the input signal. At low frequencies, if the slew rate is not sufficiently high, the comparator might take longer to transition between states, causing delays.Might be because of Propagation delays also Low-frequency signals might be more affected by fluctuations or noise in the power supply. Poor power supply stability can lead to erratic behavior or delays in the comparator's response.
- **Circuit has a particular range:**we observed that our circuit works well in the range of 5Hz -5KHz(roughly). This is because at high frequencies an op-amp differentiator circuit becomes unstable and will start to oscillate.This is due mainly to the first-order effect, which determines the frequency response of the op-amp circuit causing a second-order response which, at high frequencies gives an output voltage far higher than what would be expected. To avoid this the high frequency gain of the circuit needs to be reduced by adding an additional small value capacitor across the feedback resistor Rf.Now at low frequencies, Differentiators amplify high-frequency noise present in the input signal. At low frequencies, the signal-to-noise ratio may be lower, making the differentiator more susceptible to noise interference

8 Acknowledgment:

We express their gratitude to the International Institute of Information Technology, Hyderabad, for providing sponsored access to various scientific websites. Special thanks are extended to Prof. Anshu Sarje and prof.Spandan Roy for offering support and a platform to explore and discuss ideas pertaining to this subject matter. Additionally, we would like to acknowledge the invaluable assistance and insightful comments provided by the teaching assistants of the Electronic Workshop:2 who guided us and corrected our mistakes.

9 References:

The following are all the resources we followed for project.

- differentiator
- ldr
- ldr with bjt
- Comparator
- Book: Design of Analog CMOS IC by Razavi