Imperial College London

Lecture 5

Applications of Operational Amplifiers

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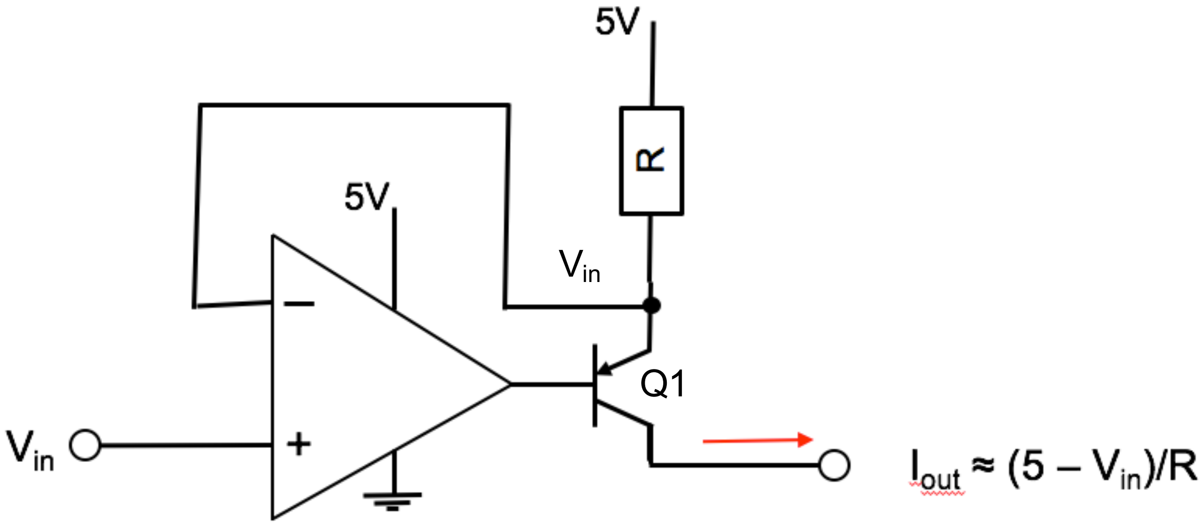
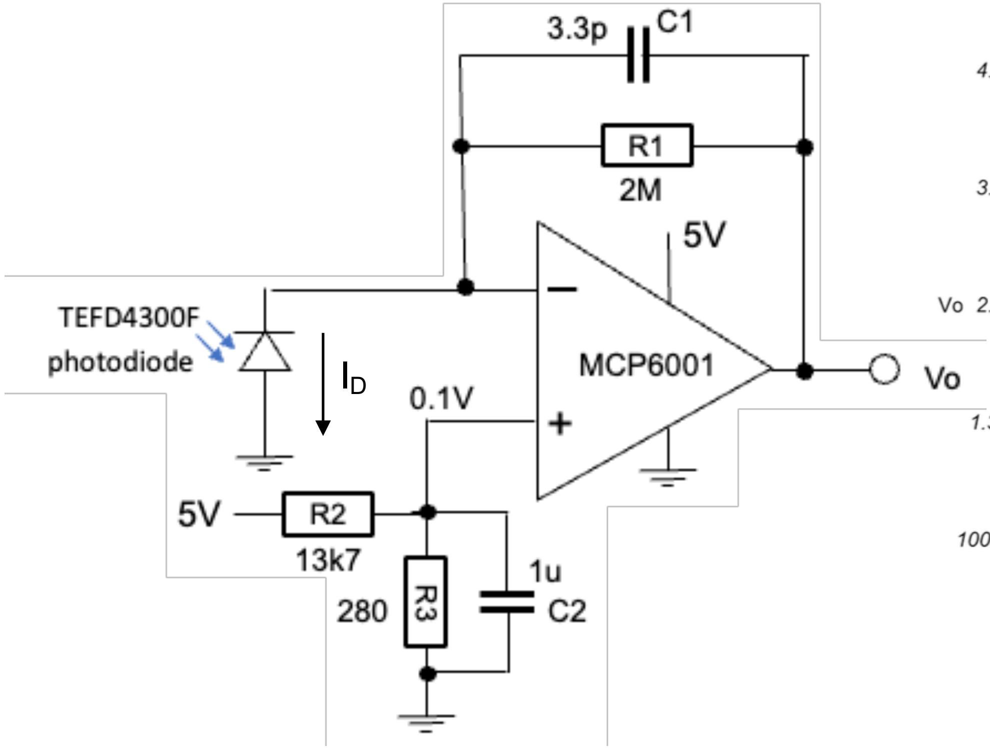
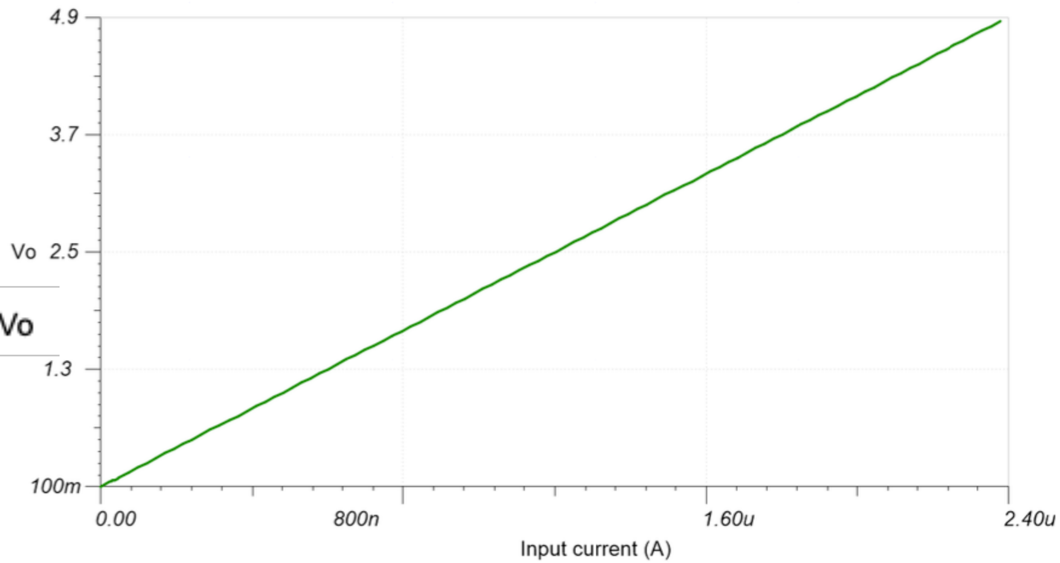
Voltage to current converter



- PNP transistor Q1 must be in linear region
- Op-amp forces V- = Vin
- R (with 5V) determines the current as $I_R = (5 - V_{in})/R$
- Assume no current flows into input of op-amp
- $I_C = I_E - I_B$, assume current gain $\beta >> 1$, $I_C \approx I_E \approx I_R$
- Can use FET or MOSFET in place of BJT

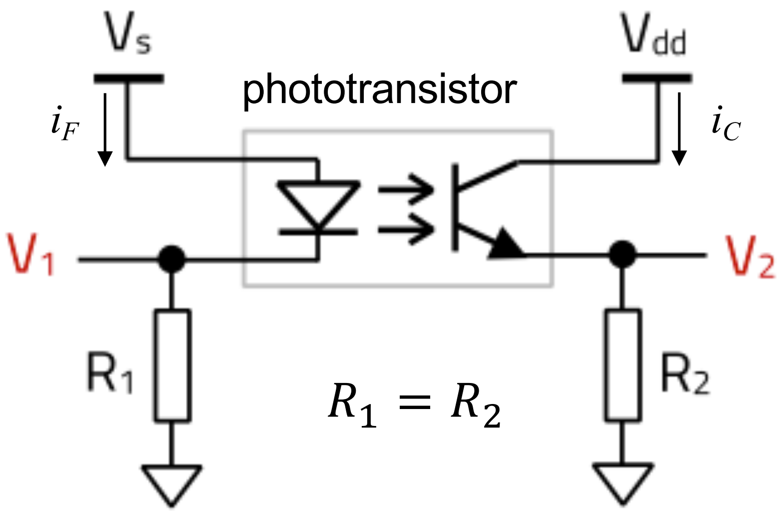
Current amplifier (photo detector)



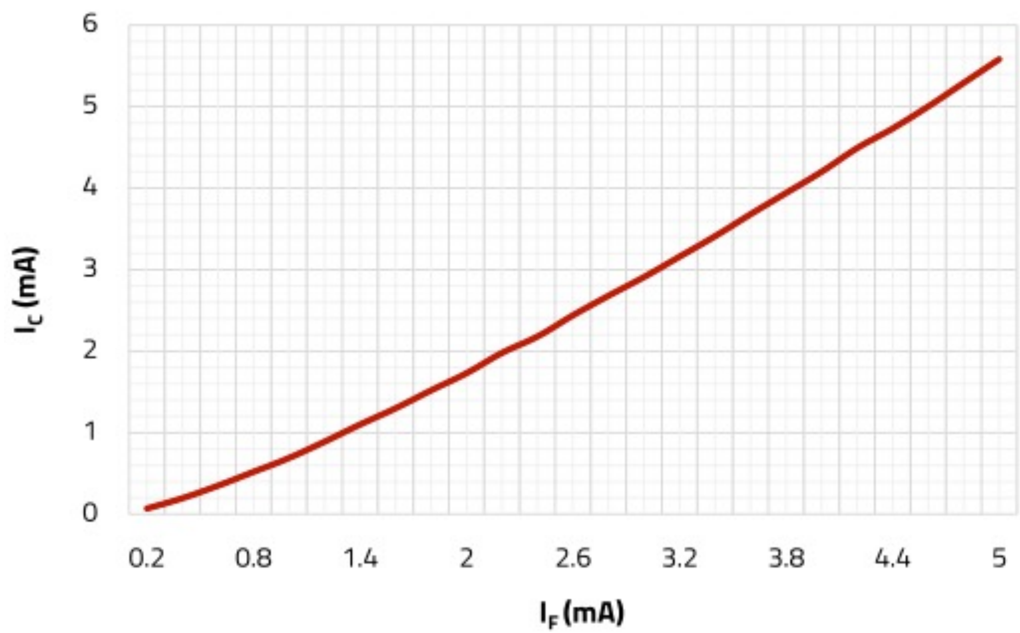


- Photodiode generates reverse current proportional to light intensity (visible or IR) received.
- Inverting op-amp used to convert diode current into a voltage.
- R2 and R3 provides an offset at the output when photodiode current is 0.

Optical isolating amplifier

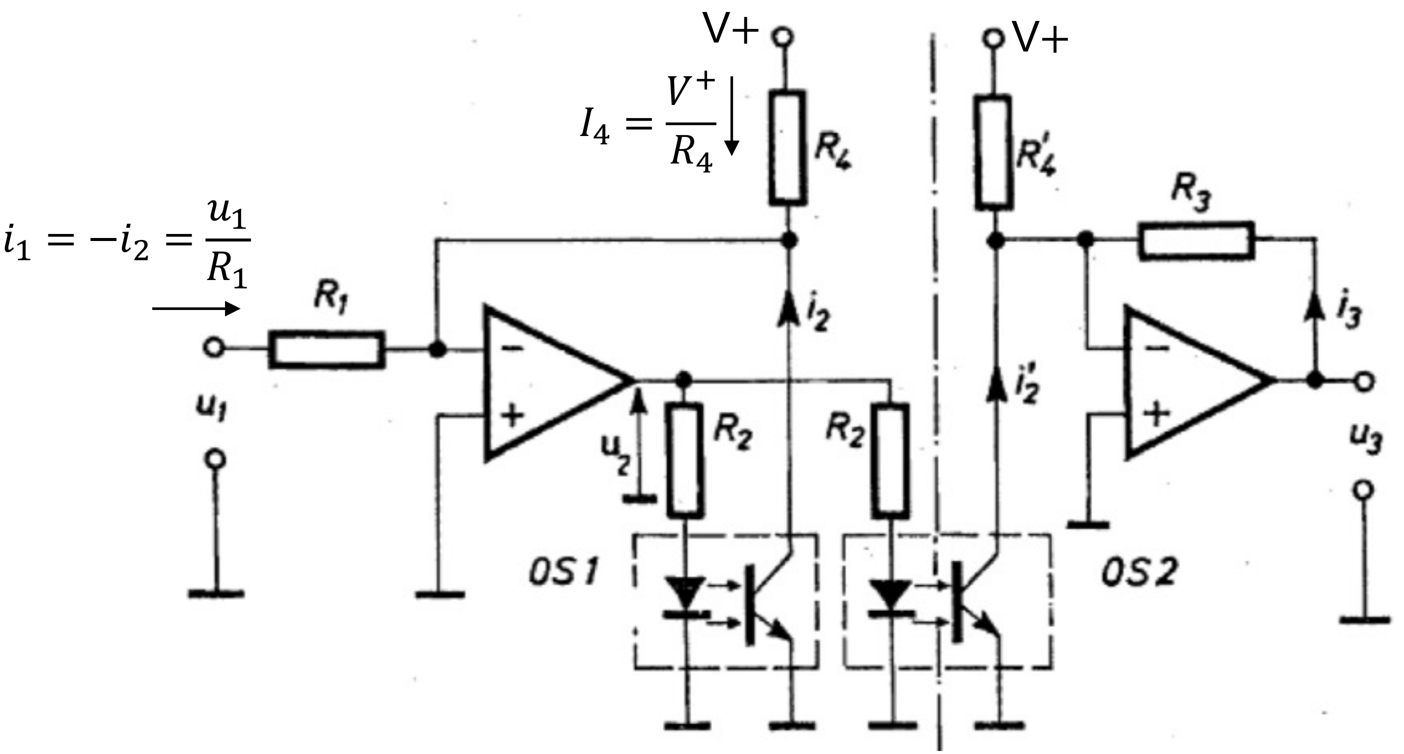


Current Transfer Ratio (CTR)
= V2/V1



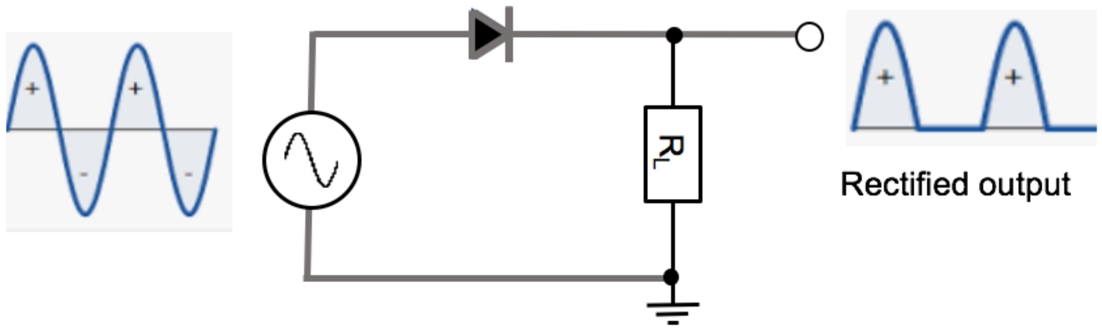
- Phototransistor provides electrical isolation (e.g. 5kV) between two part of circuit.
- Consist of a light emitting diode and a photosensitive transistor.
- Diode current, through light, is transferred to transistor output current (current transfer ratio, CTR).
- The relationship between the diode current i_F and transistor current i_C is **not** linear.

Optical isolating amplifier

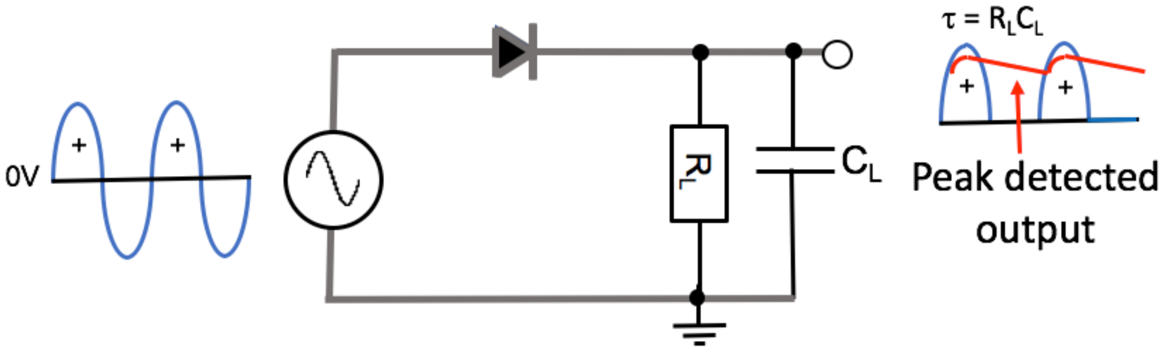


- To mitigate the non-linear characteristics of the phototransistor, use two "matching" phototransistors as shown above.
- Output of 1st op-amp u_2 is adjusted so that the current $i_2 = -i_1 = -\frac{u_1}{R_1}$.
- Assuming $R_4 = R_4'$, then $i_2' = \mathrm{i}_2$. Hence, $u_3 = -i_2' \times R_3 = \frac{R_3}{R_1} \times u_1$.

Half-wave rectifier & Peak detector

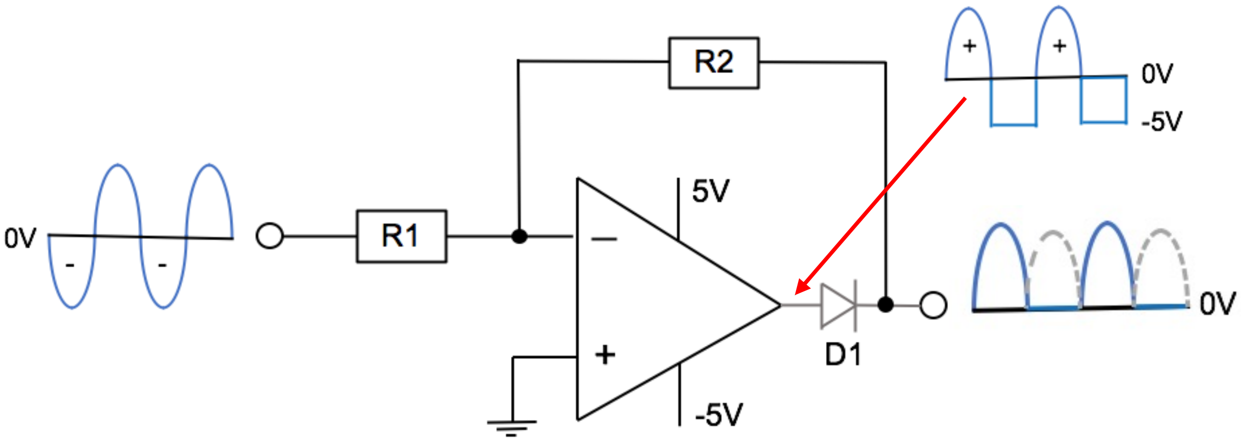


- Diode and resistor – simple half-wave rectifier
- Commonly used in power electronics or and multimeters

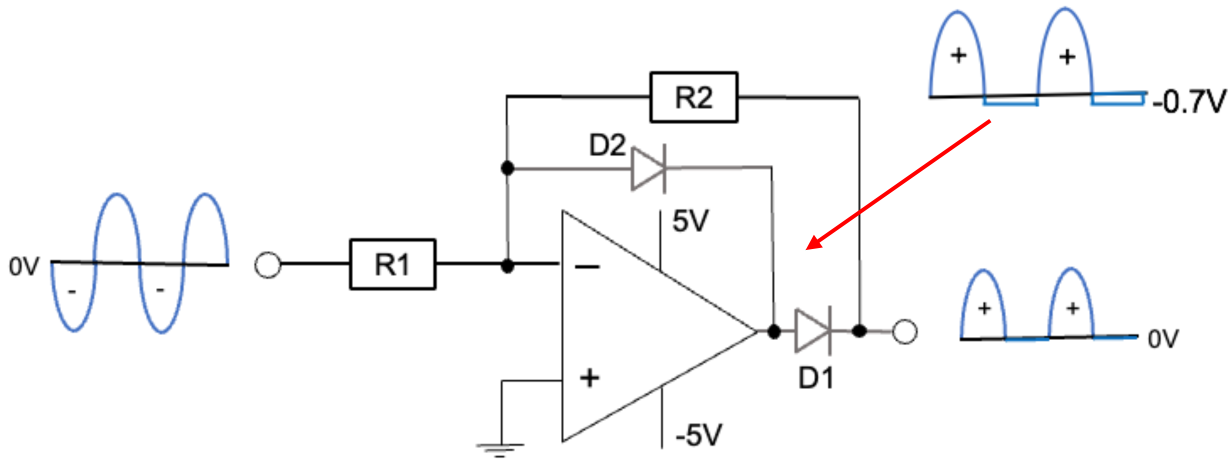


- C_L charges to V_{in} peak – V_D
- Diode prevents C_L discharging when V_{in} drops
- R_L discharges capacitor with time constant R_LC_L
- CL charges again on the positive cycle

Rectifier with op-amp buffering

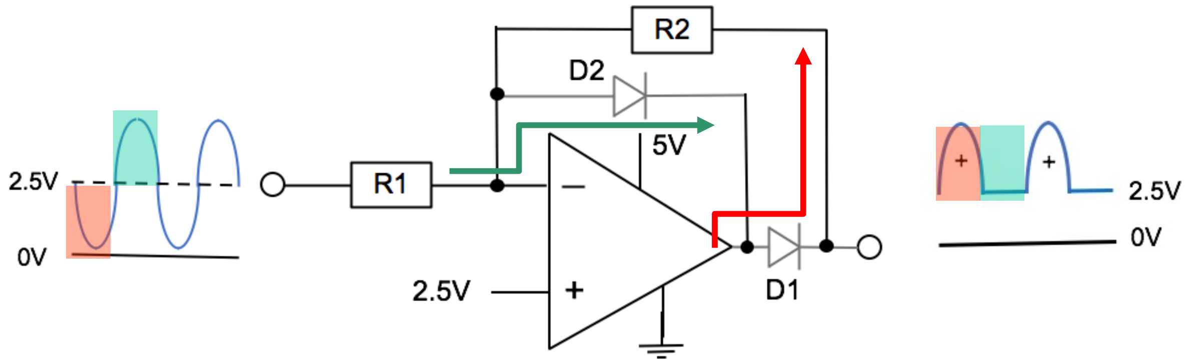


- Assume R1 = R2
- Negative cycles result in an inverting amplifier with gain = -1
- Op-amp drives output with low impedance
- Positive cycles, op-amp isolated from output
- Poor full-wave rectification



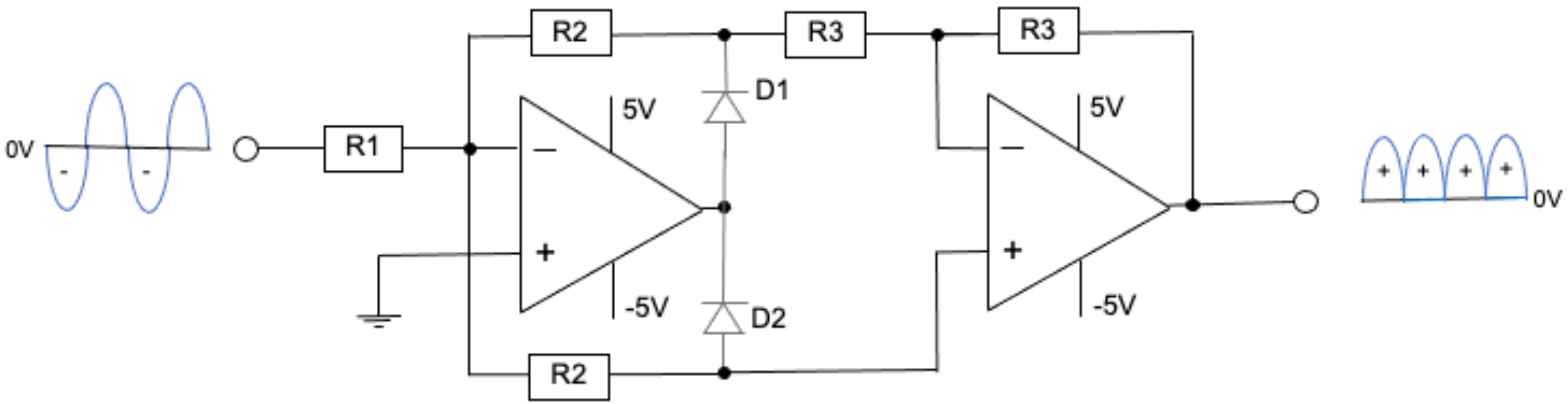
- D1 provides feedback path for negative input cycles
- D2 provides feedback path for positive input cycles
- Op-amp operating throughout entire cycle

Single power supply "rectifier"



- Single power supply rectifier is implemented by shifting the reference voltage to ½ V_{DD}

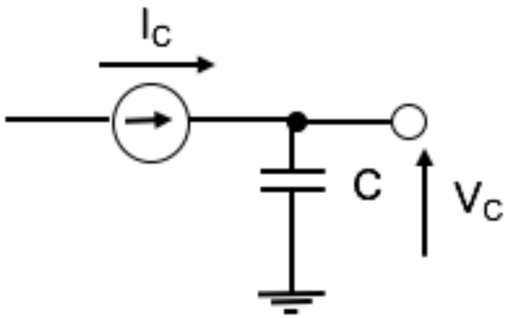
Full-wave rectifier

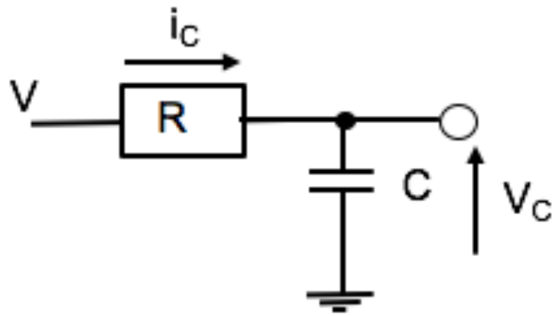


- Precision full-wave rectifier with two op-amps
- Op-amp 1 provides two separate half of the rectified signals
- Op-amp 2 sums two half cycles together

Integrator

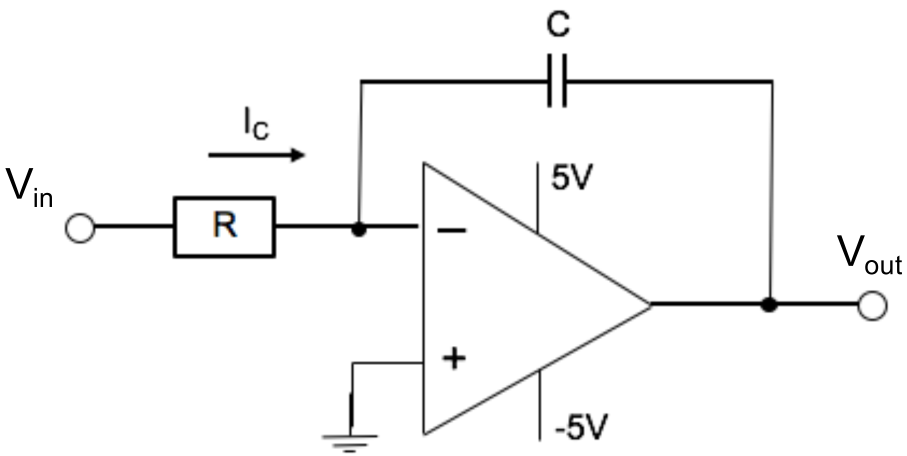
- $i_C = C\frac{dV_C}{dt} \Rightarrow V_C = \frac{1}{C}\int i_C dt + V_C(0)$

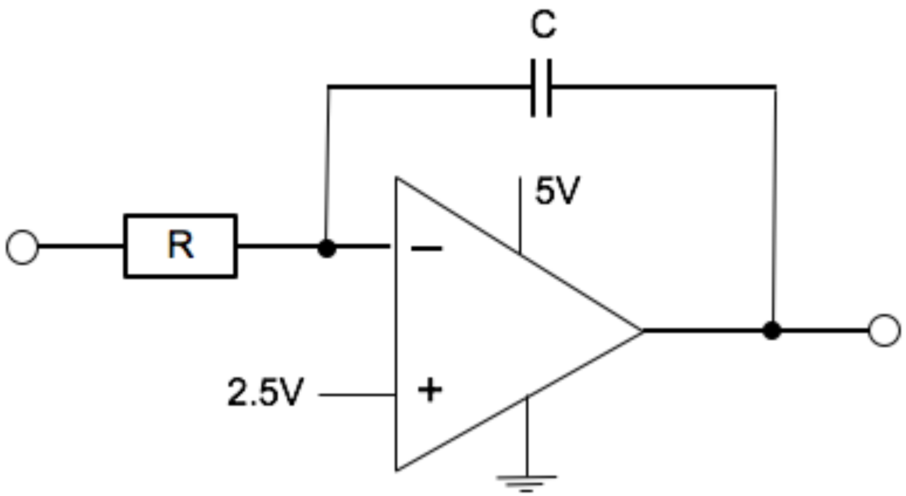




- I_C changes with V_C
- V_C is an exponential rise function (not perfect integral)

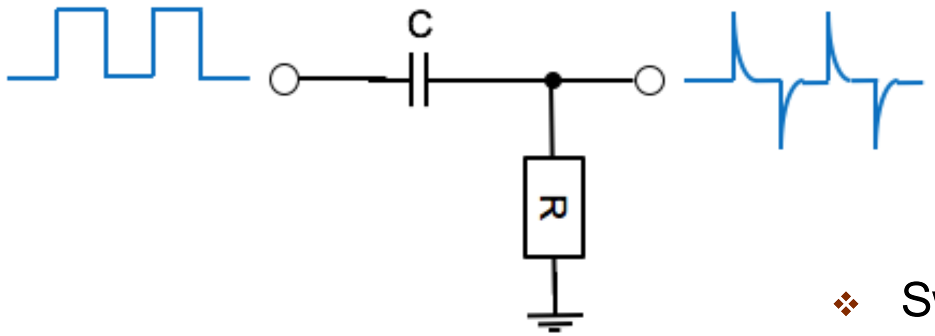
- Constant I_C, $V_C = \frac{i_C}{C}t + V_C(0)$



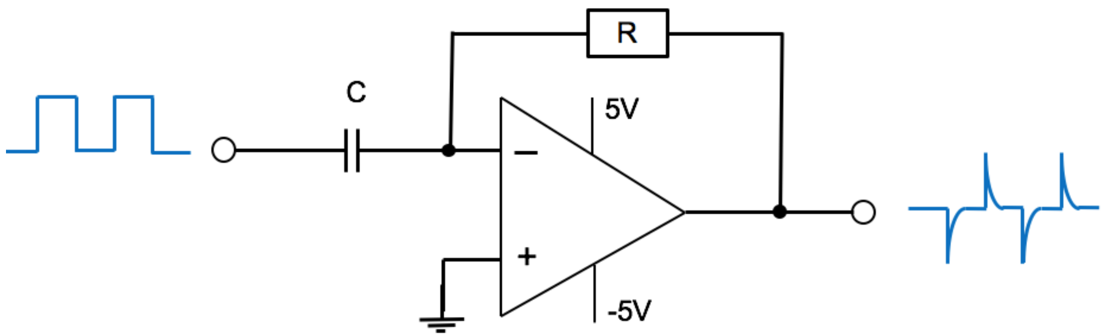


- $v_{out} = -\frac{V_{in}}{RC}t + V_C(0)$
- Single supply operation

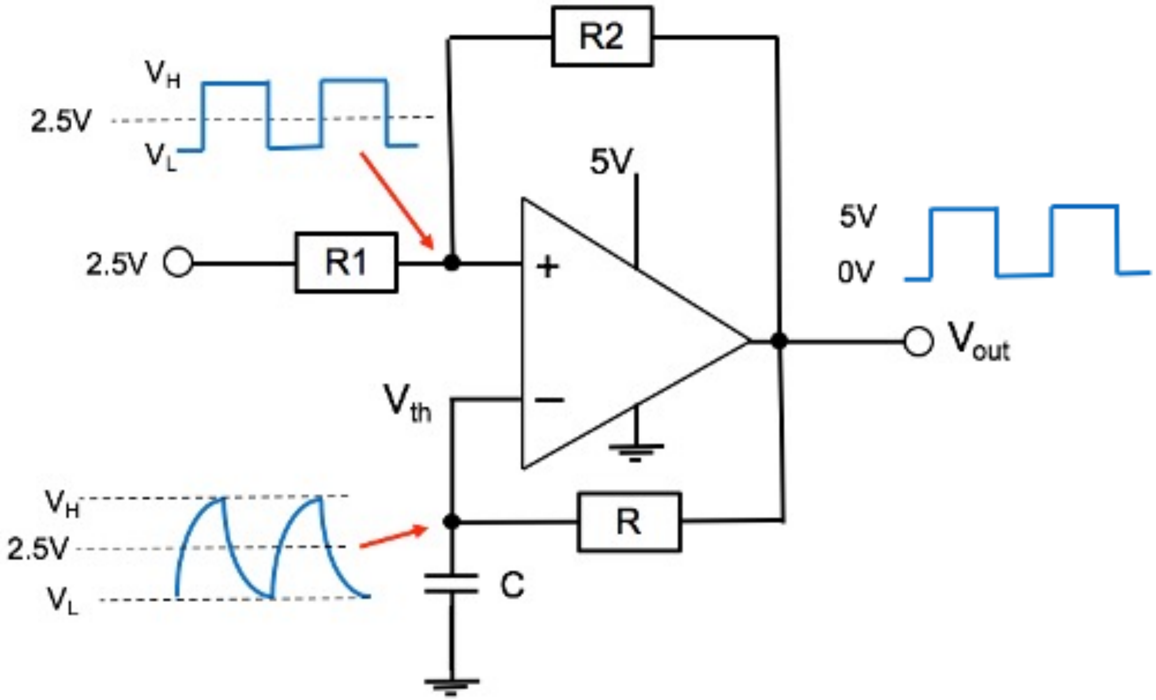
Differentiator



- Swap R and C
- Implement a differentiator
- Not used often because circuit tends to produce noisy output



Simple Oscillator



- Combine comparator with hysteresis and RC network = oscillator
- Voltage at V+ change instantly with V_{out}:

$$V_H = 2.5\left(1 + \frac{R1}{R1+R2}\right)$$

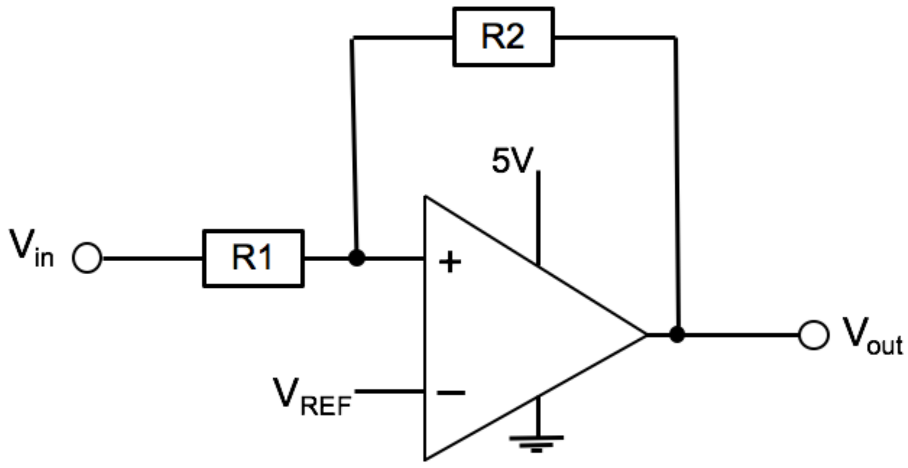
$$V_L = 2.5\left(\frac{R2}{R1+R2}\right)$$

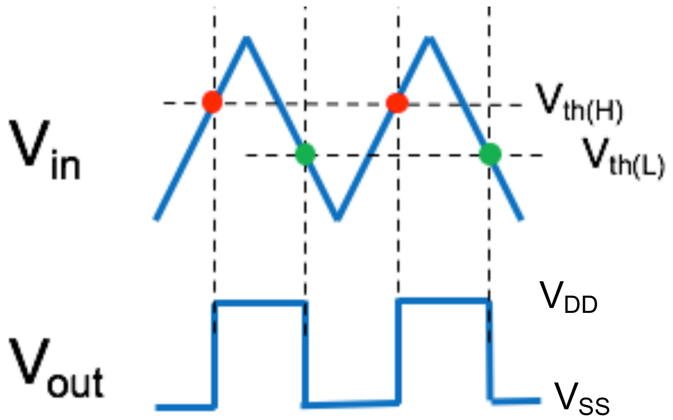
- V- = V_{th} rises and falls exponentially with a time constant of RC between V_H and V_L
- This is determined by the equation:

$$V_{th} = V_f + (V_i - V_f)e^{-\frac{t}{\tau}}$$

V_i = initial value, V_f = final value, τ = time constant RC

Comparator with hysteresis





- V_{out} swings between V_{DD} and V_{SS}
- V_{out} changes state when V+ reaches V_{REF}
- Apply KCL at V+:

$$\frac{V_{REF}-V_{in}}{R1} = \frac{V_{out}-V_{REF}}{R2}$$

$$\Rightarrow V_{in} = V_{REF}\left(1+\frac{R1}{R2}\right) - V_{out}\left(\frac{R1}{R2}\right)$$

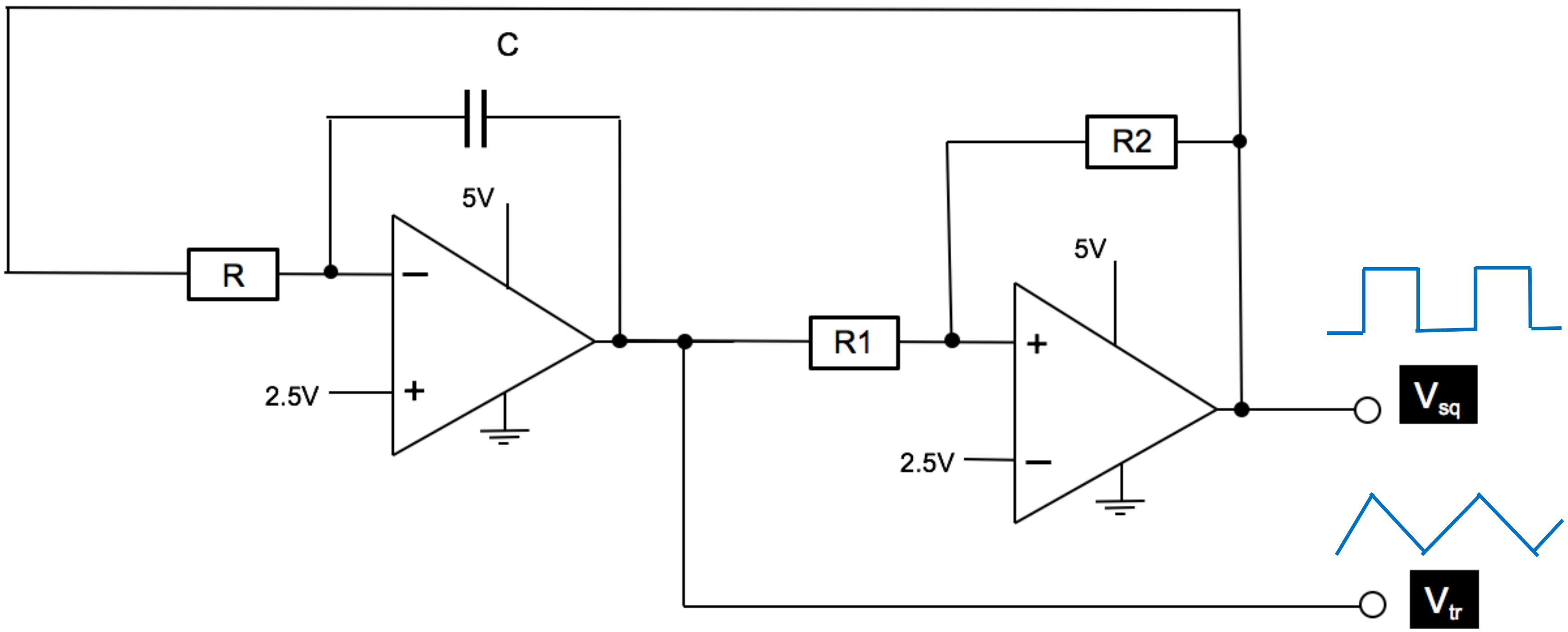
- If R1 = 0 or R2 = ∞, $V_{th} = V_{REF}$
- R1 > 0, R2 ≠ ∞

$$V_{th(H)} = V_{REF}\left(1+\frac{R1}{R2}\right) - V_{SS}\left(\frac{R1}{R2}\right)$$

$$V_{th(L)} = V_{REF}\left(1+\frac{R1}{R2}\right) - V_{DD}\left(\frac{R1}{R2}\right)$$

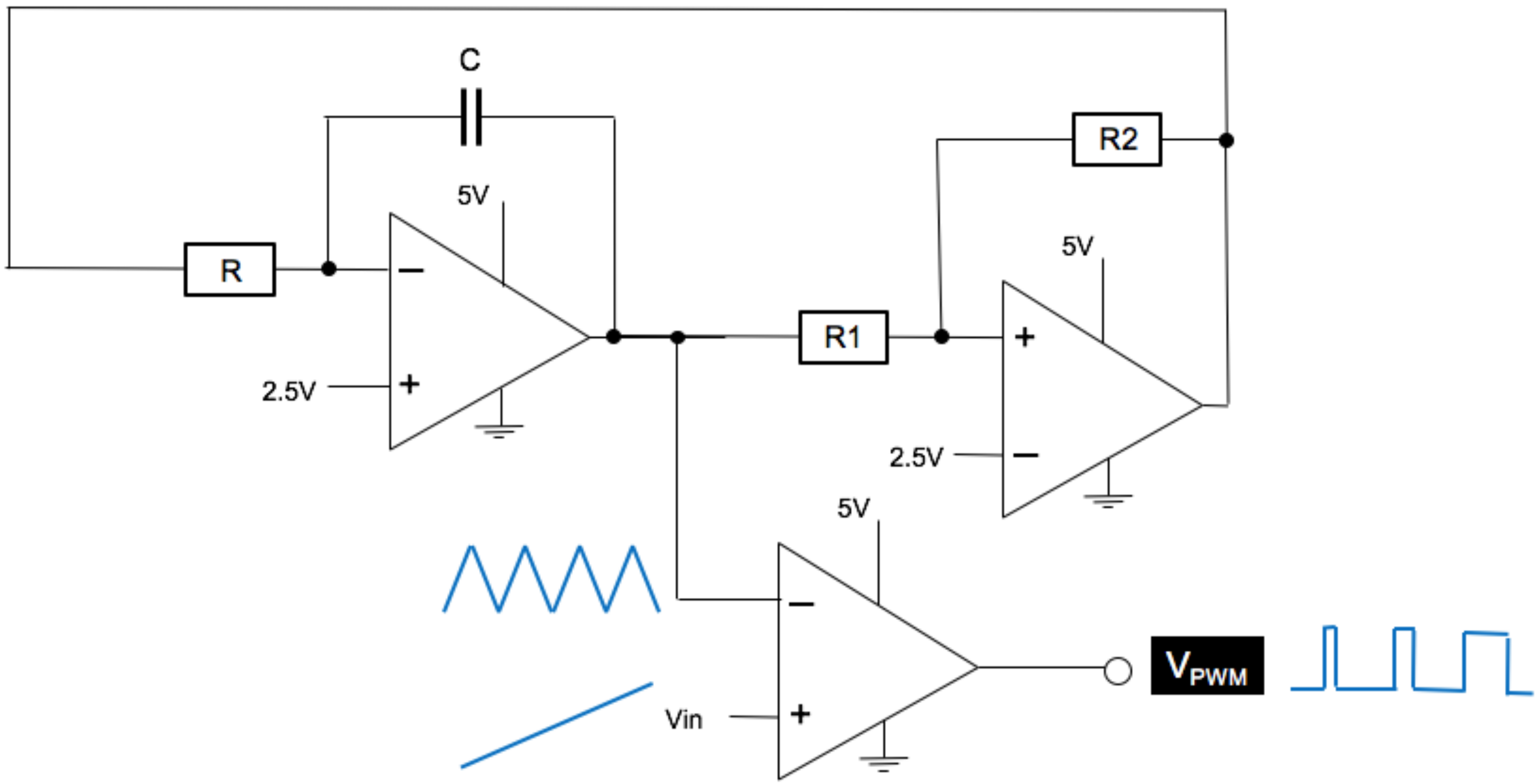
- Hysteresis = $V_{th(H)} - V_{th(L)}$

Triangular and Square wave generator



- Better oscillator circuit using integrator + comparator with hysteresis
- Integrator output produces a triangular signal
- Comparator (with hysteresis) produces a square signal
- Feedback circuit ensures oscillation is maintained

Pulse-width Modulator



- Comparing triangular signal with V_{in} -> pulse-width modulated output
- Frequency of triangular signal >> V_{in} frequency
- Output pulse width proportional to value of V_{in}
- Recover V_{in} by lowpass filtering V_{PWM}