RME 3102: OP-AMP for Interfacing & Control

Dr. Md. Zahurul Haq, *Ph.D., CEA, FBSME, FIEB*

Professor
Department of Mechanical Engineering
Bangladesh University of Engineering & Technology (BUET)
Dhaka-1000, Bangladesh

http://zahurul.buet.ac.bd/

RME 3102: Advanced Mechatronics Engineering
Department of Robotics and Mechatronics Engineering,
University of Dhaka

`http://zahurul.buet.ac.bd/RME3102/`

Operational Amplifier (Op-amp)

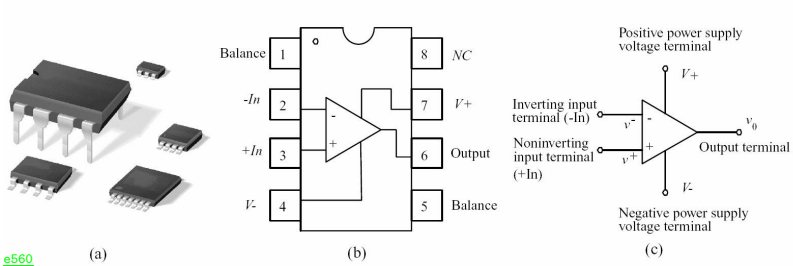
OP-Amp is a low-cost and versatile IC (Integrated Circuit) consisting of many internal transistors, resistors, and capacitors. These are basic building blocks for:

- Amplifier
- Integrator and Differentiator
- Summer
- Comparator
- A/D and D/A converter
- Active filter
- Sample and Hold circuit
- . . . etc.

OP-amp: Components

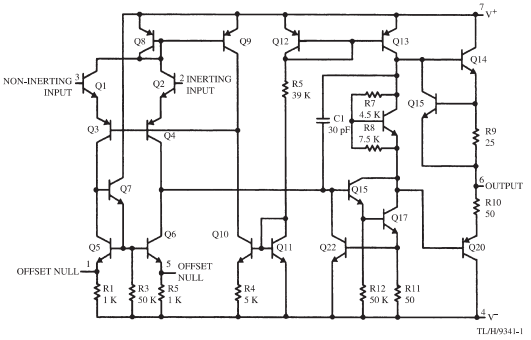
OP-amp has Single Output and Two Inputs:

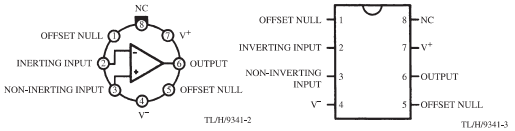
1. Noninverting input [+]: output is in phase with input.
2. Inverting input [-]: output is 180^o out of phase with input.



e560 (a) (b) (c)

Internal Design of LM 741





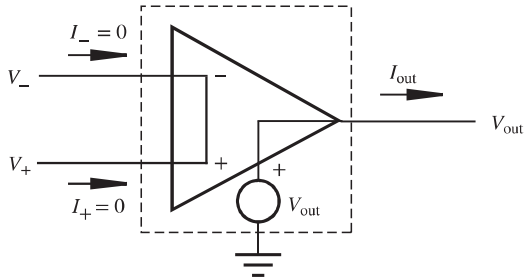
T1903

OP-amp: Equivalent Circuit

Rule 1. Infinite impedance at both inputs, $\Rightarrow I_+ = I_- = 0$

Rule 2. Infinite gain, $\Rightarrow V_+ = V_-$

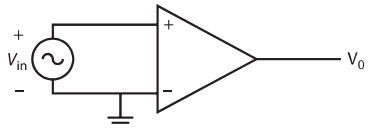
Rule 3. Zero output impedance, $\Rightarrow V_{out} \neq f(I_{out})$



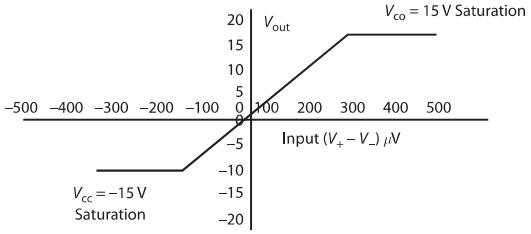
T1904

OP-amp: Voltage Comparator

In comparator circuit, there is no negative feedback, hence the circuit exhibits infinite gain and op-amp will saturate, i.e. output remains at the most positive or most negative output value.

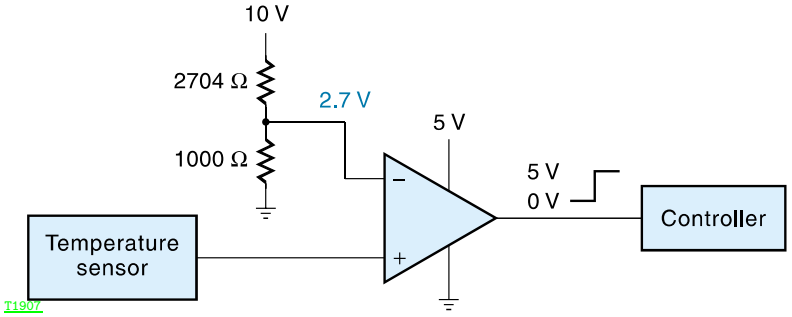


T1905



T1906

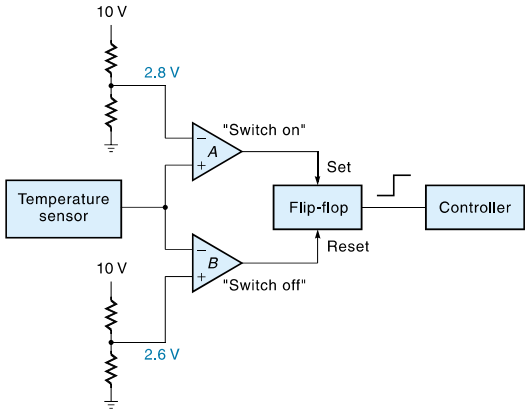
Comparator Circuit: Application (ON-OFF Control)



T1907

Chatter is a practical problem, output voltage oscillates back-and-forth when input voltage is near to the threshold.

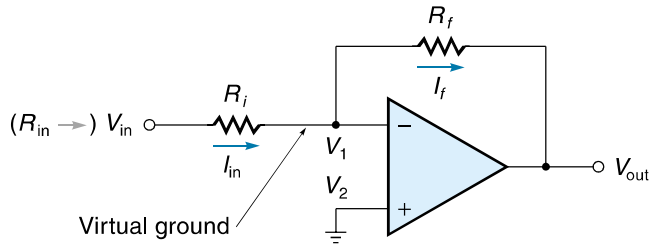
Window Comparator Circuit



T1908

Window Comparator is with inbuilt hysteresis; hysteresis means that switch-on voltage is greater than switch-off voltage.

OP-amp: Inverting Amplifier



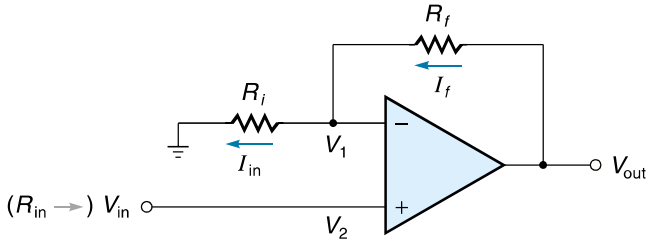
T1909

At virtual ground:

- $I_{in} = I_f$ (Rule 1)
- $V_1 = V_2 = 0$ (Rule 2)
- $I_{in}\left(=\frac{V_{in}-V_1}{R_i}\right) = I_f\left(=\frac{V_1-V_{out}}{R_f}\right)$

$\Rightarrow$ $\boxed{\text{gain, } G \equiv \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}}$

OP-amp: Noninverting Amplifier

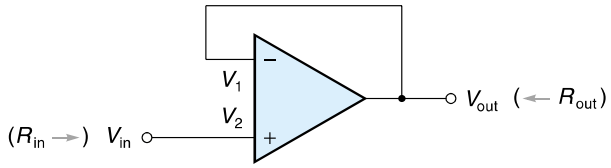


T1910

- $I_{in} = I_f$ (Rule 1)
- $V_{in} = V_2 = V_1$ (Rule 2)
- $I_{in}\left(=\frac{V_{in}}{R_i}\right) = I_f\left(=\frac{V_{out}-V_{in}}{R_f}\right)$

$\Rightarrow$ $\boxed{G = 1 + \frac{R_f}{R_i}}$

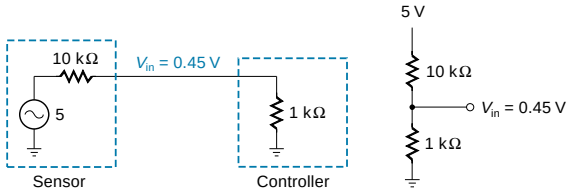
OP-Amp: Follower/Buffer



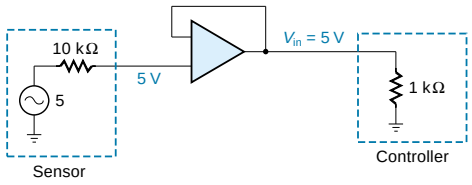
T1926

- In a noninverting amplifier with $R_i = \infty$ & $R_f = 0$:
  - Gain, $G = 1$, there is no voltage amplification.
  - This circuit is known as a buffer or follower.
- Buffer has a high input impedance and low output impedance. High input impedance effectively isolates the source from the rest of the circuit.

Op-amp: Voltage Follower Application



(a) Signal experiences voltage drop (b) Equivalent circuit

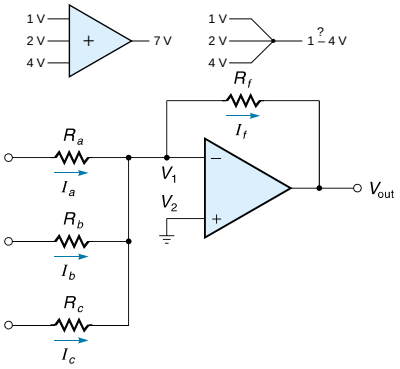


e178

(c) No signal voltage drop

Op-amp: Summing Amplifier

e179

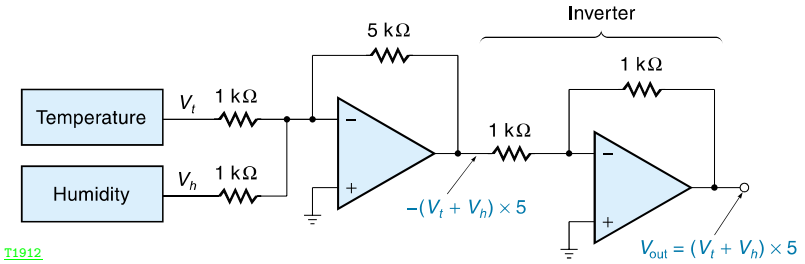


T1911

$$V_{out} = -R_f \left[\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} \right]$$

If $R_a \neq R_b \neq R_c \ldots$, V_{out} is a weighted sum of input voltages.

Summing Amplifier: Application

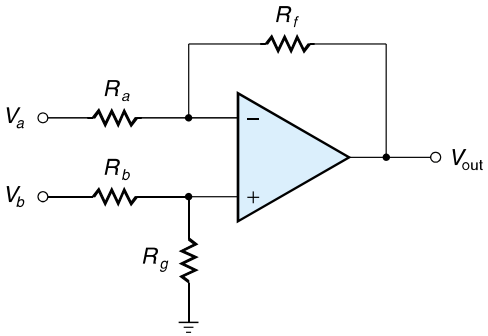


T1912

Example: Interface circuit for an air conditioning system

- when the sum of the voltages of temperature and humidity sensors goes above 1.0 V, &
- a threshold circuit in air conditioner require 5.0 V.

OP-amp: Differential Amplifier



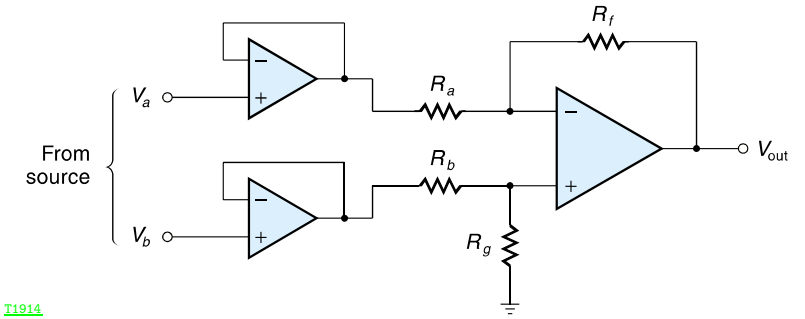
T1913

$$V^- = V^+ \Rightarrow V_a \left[\frac{R_f}{R_a + R_f} \right] + V_{out} \left[\frac{R_a}{R_a + R_f} \right] = V_b \left[\frac{R_g}{R_b + R_g} \right]$$

$$V_{out} = V_b \left[\frac{R_g}{R_b + R_g} \cdot \frac{R_a + R_f}{R_a} \right] - V_a \left[\frac{R_f}{R_a} \right]$$

$$V_{out} = (V_b - V_a) \left[\frac{R_f}{R_a} \right] = c(V_b - V_a) \text{ if } \frac{R_f}{R_a} = \frac{R_g}{R_b} = c$$

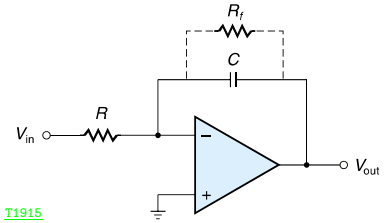
Instrument Amplifier



T1914

$$G = \frac{V_{out}}{V_b - V_a} = c = \frac{R_f}{R_a} = \frac{R_g}{R_b}$$

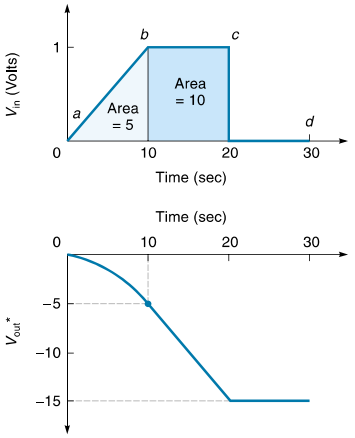
OP-amp: Integrator



T1915

- $I_i = \frac{V_{in}}{R}$
- $I_f = -C\frac{dV_{out}}{dt}$
- $I_i = I_f$

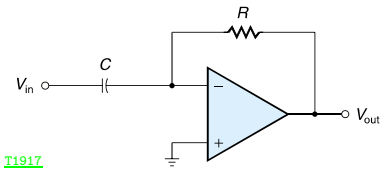
$$V_{out}(t) = -\frac{1}{RC}\int V_{in}(t)\,dt$$



T1916

Output of Integrator ckt (RC = 1)

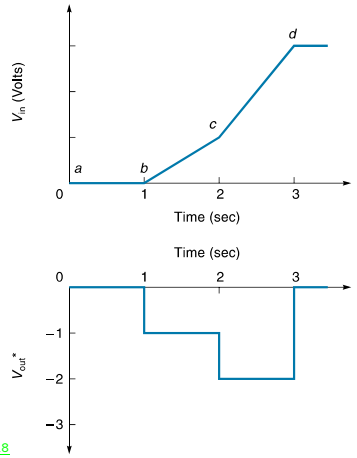
OP-amp: Differentiator



T1917

- $I_i = C\frac{dV_{in}}{dt}$
- $I_f = -\frac{V_{out}}{R}$
- $I_i = I_f$

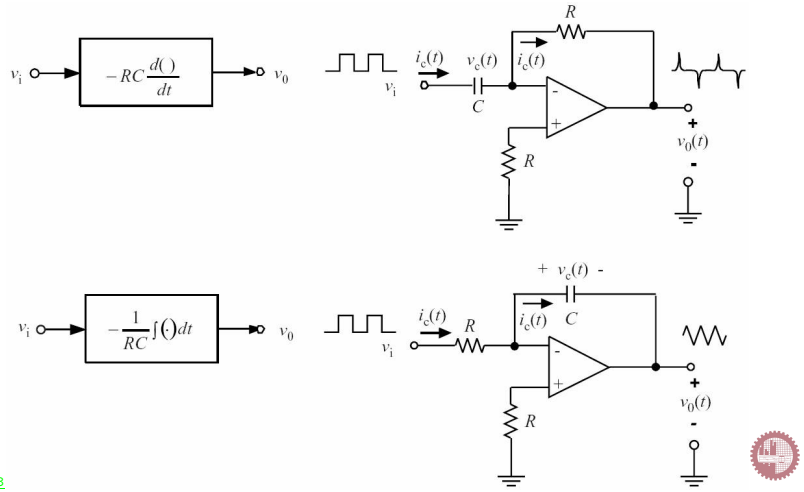
$$V_{out} = -RC\frac{dV_{in}}{dt}$$



T1918

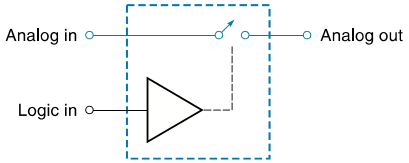
Output of differentiator ckt (RC = 1)

OP-amp: Differentiator & Integrator

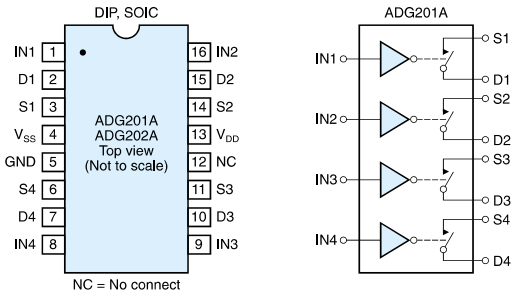


e428

Analog Switch

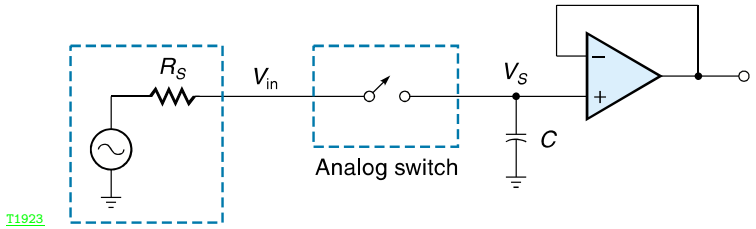


T1922



T1924

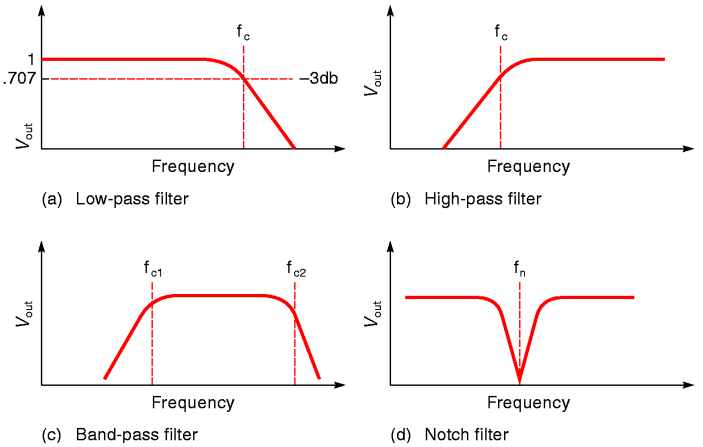
OP-amp: Sample and Hold Circuit



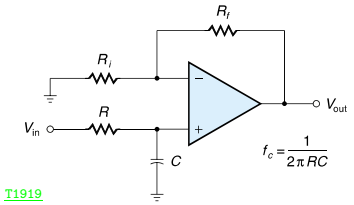
T1923

- S/H amplifier holds an analog value, until an A/D converter is ready to convert it to digital.
- The basic circuit consists of an electronic switch to the sample, with a capacitor for the hold and an op-amp voltage follower.

Characteristics of Real Filters

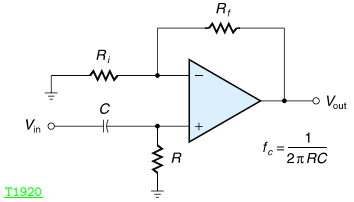


e051



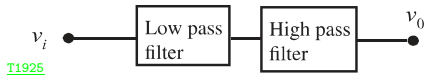
T1919

Low-Pass Filter Circuit



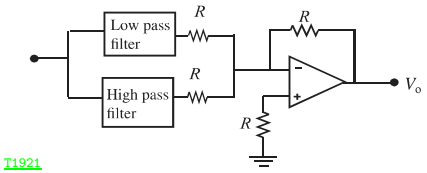
T1920

High-Pass Filter Circuit



T1925

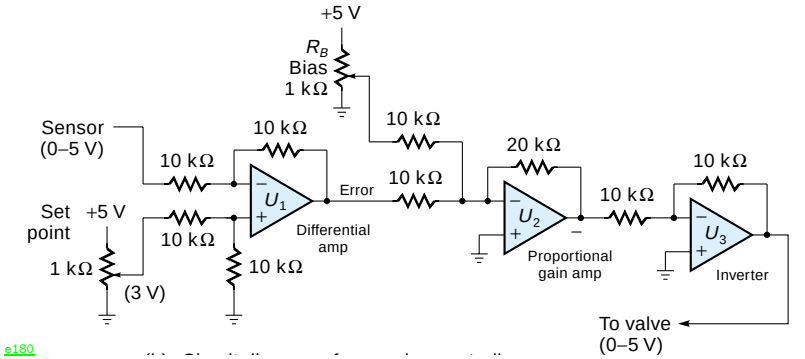
Band-pass Filter Circuit



T1921

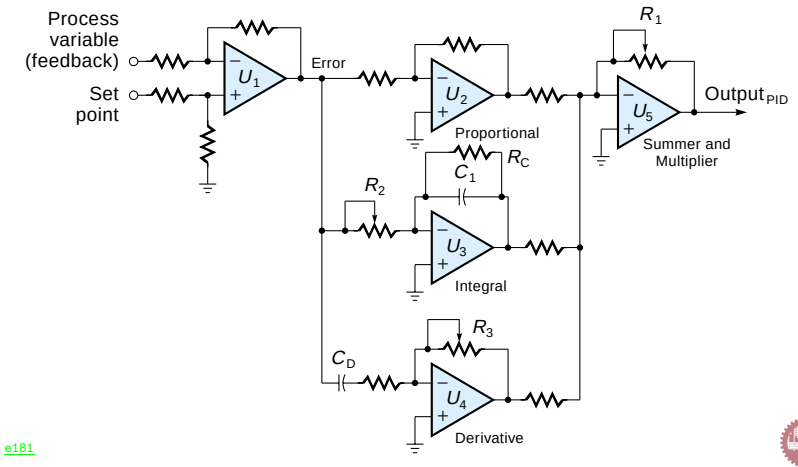
Band-reject Filter Circuit

OP-amp: Proportional (P) Controller



e180

OP-amp: PID Controller



e181