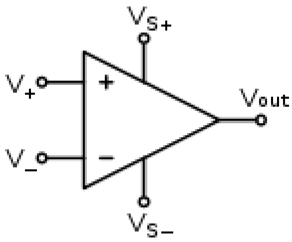
# Lab # 5: Implementing using Op-Amps

## Introduction:

The op-amp is basically a differential amplifier having a large voltage gain, very high input impedance and low output impedance. The op-amp has a "inverting" or (-) input and "non inverting" or (+) input and a single output. The op-amp is usually powered by a dual polarity power supply in the range of +/- 5 volts to +/- 15 volts.

The circuit symbol for an op-amp is shown to the right, where:

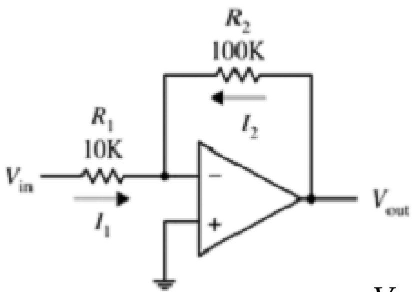


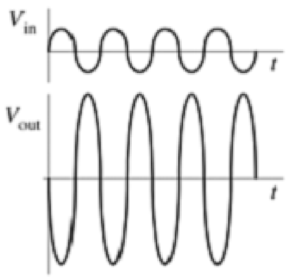

- **$V_+$ : non-inverting input**
- **$V_-$ : inverting input**
- **$V_{out}$ : output**
- **$V_{S+}$ : positive power supply**
- **$V_{S-}$ : negative power supply**

Operational amplifiers can be used to perform mathematical operations on voltage signals such as inversion, addition, subtraction, integration, differentiation, and multiplication by a constant.

## Operational Amplifier (Op-amp) Application:

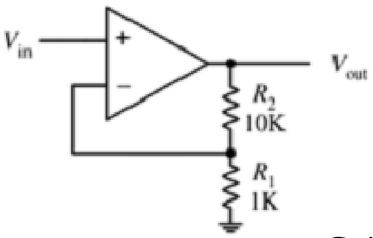
1. The inverting op-amp: *It can be used as K controller*

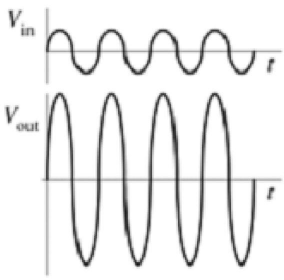



$$Gain = \frac{V_o}{V_i} = -\frac{R_2}{R_1}$$

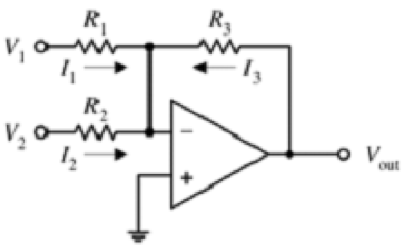
2. The non-inverting op-amp: *It can be used as K controller*

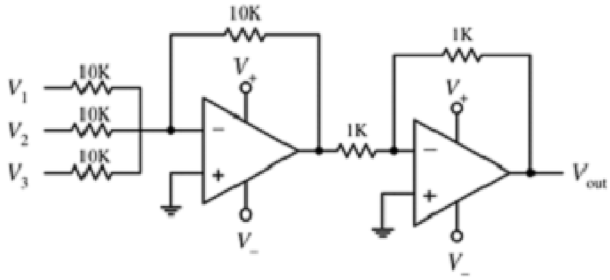



$$Gain = \frac{V_o}{V_i} = 1 + \frac{R_2}{R_1}$$

3. The summer (adder)

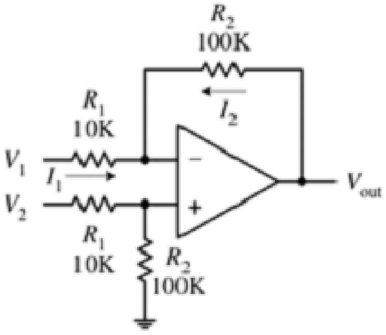



$$V_o = -(\frac{R_3}{R_1}V_1 + \frac{R_3}{R_2}V_2)$$

$$V_o = V_1 + V_2 + V_3$$

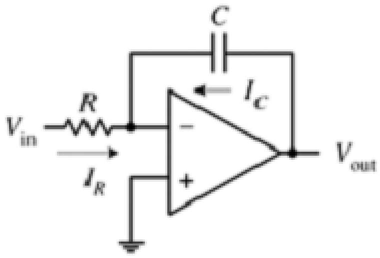
4. The differential amplifier

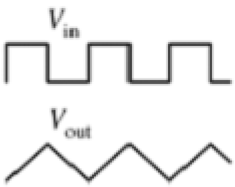



$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

If you set $R_1 = R_2$, then $V_{out} = V_2 - V_1$.

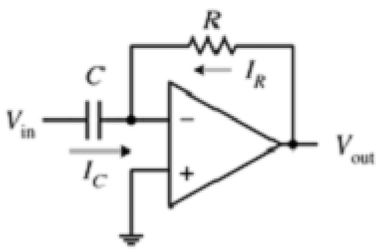
5. The integrator

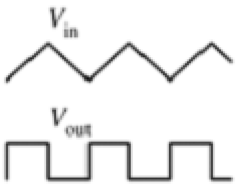



$$V_o = -\frac{1}{RC}\int V_{in} dt$$

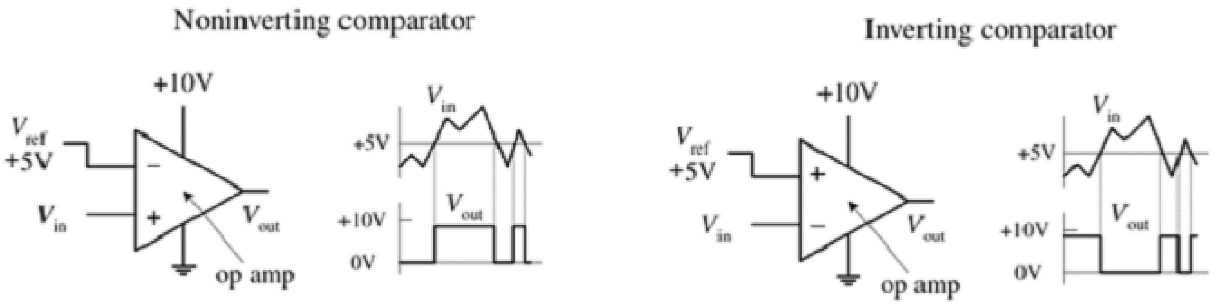
6. The differentiator




$$V_o = -RC\frac{\partial V_{in}}{\partial t}$$

7. The comparator




## System to All Integral Block Diagram:

### What is All integral block diagram?

It is another representation of a system but here integrators only used to represent it. This method introduce the conversion between the mathematical system to its corresponding physical one.

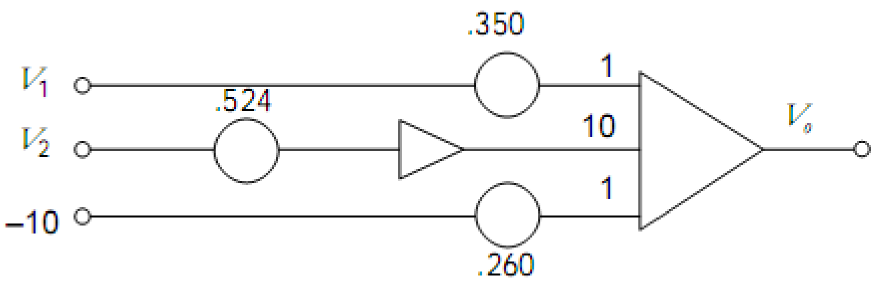
We first begin with the mathematical model of a system (Diff. Eq. , T.F. , S.S) and convert it by some ways to integrators and summers that can be implemented later by op-amp.

## Physical Realization of a system by op-amp :

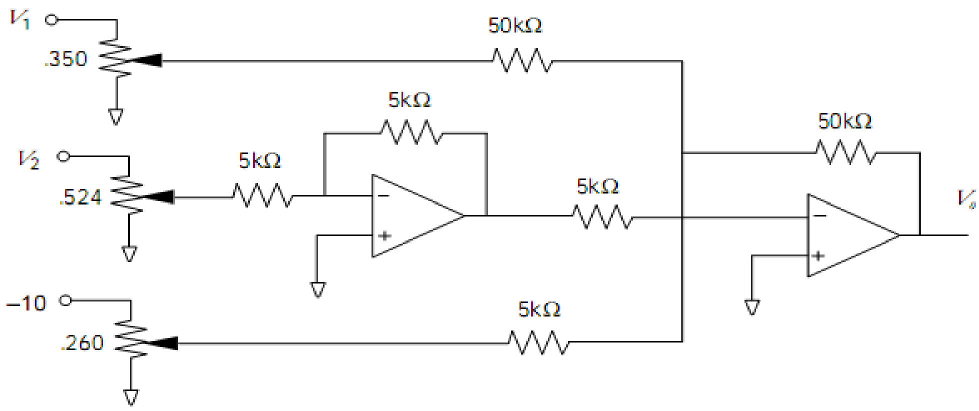
*Section 1* talked about op-amp application and saw that op-amp can operate as inverter, summer and integrator. *Section 2* talked about converting the system to All integral block diagram that depends on inversion, summing and integration. Then we can combine the two sections to implement any system by op-amps and it is the first step to transfer from theory to practice and from math to hardware component.

***<u>Example</u>*****: Determine the analog diagram and the circuit to implement the following equation**

$$V_o = -0.35V_1 + 5.24V_2 + 2.6.$$



Note the inversion operation of all inputs that is because the summer inverts the output as we introduced before and the inverter must have a unity gain.




## Implementing Transfer Function Using OP-Amps:

To implement the T.F using OP- AMPs there is some steps to do this , we will explain it as shown in the next example

**Example:** Given the T.F, implement it using OP-AMPs

$$T(s) = \frac{Y(s)}{U(s)} = \frac{6}{S^2 + 2S + 12}$$

**Firstly:** Convert the T.F to State Space the following Matlab code make this function:

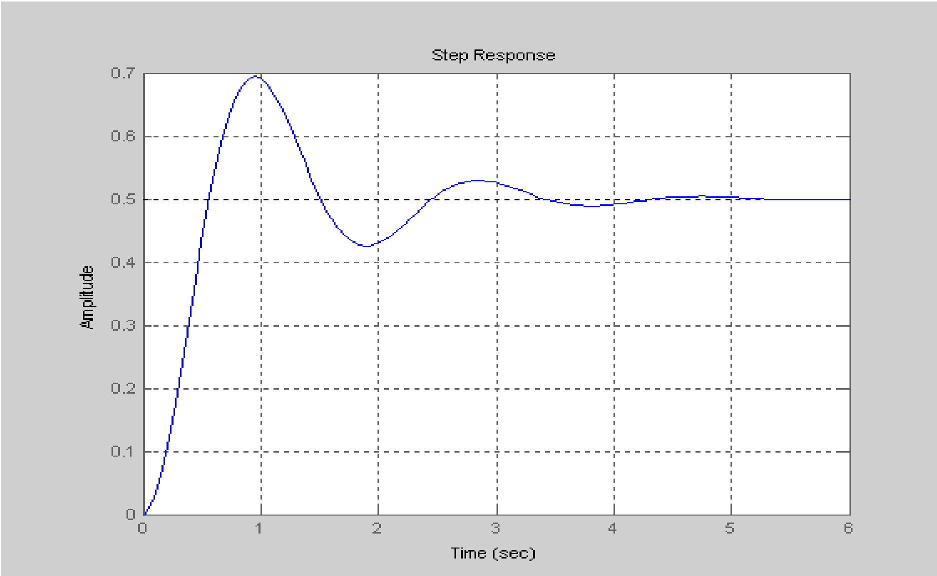
**By Matlab**

```
num=[6];

den=[1 2 12];

g=tf(num,den)

[a,b,c,d]=tf2ss(num,den)
```

**Results**

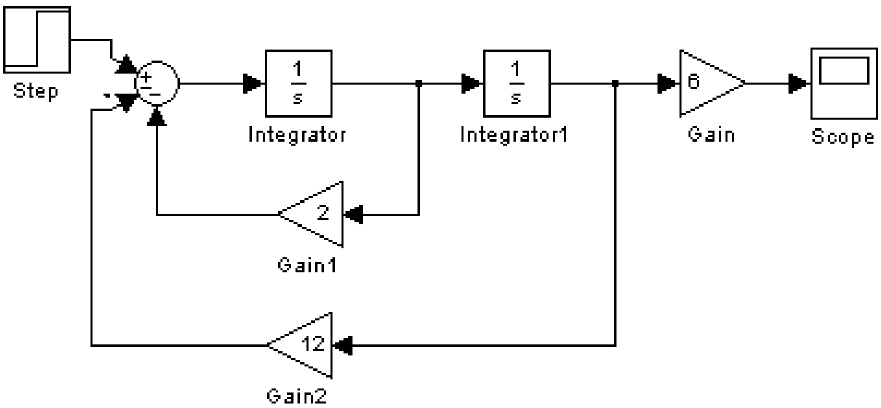
```
a =

   -2   -12

    1     0

b =

    1

    0

c =

    0     6

d = 0

    0
```

The step response of the T.F is as shown in the following Figure

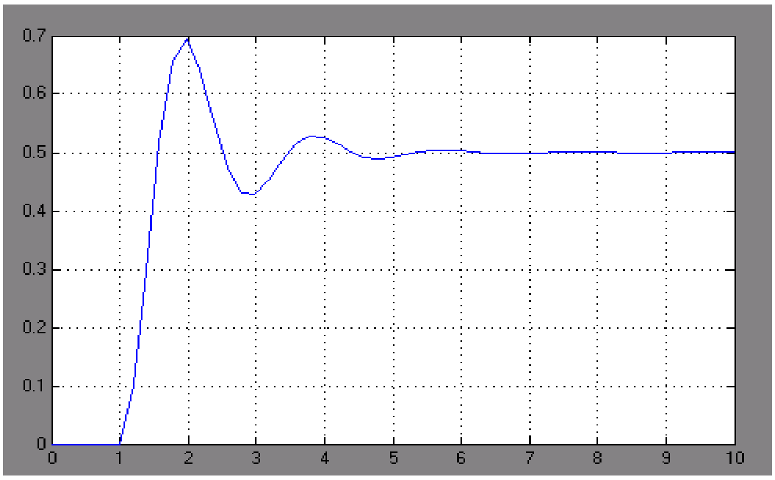



**Secondly**: Find the Block diagram of state space

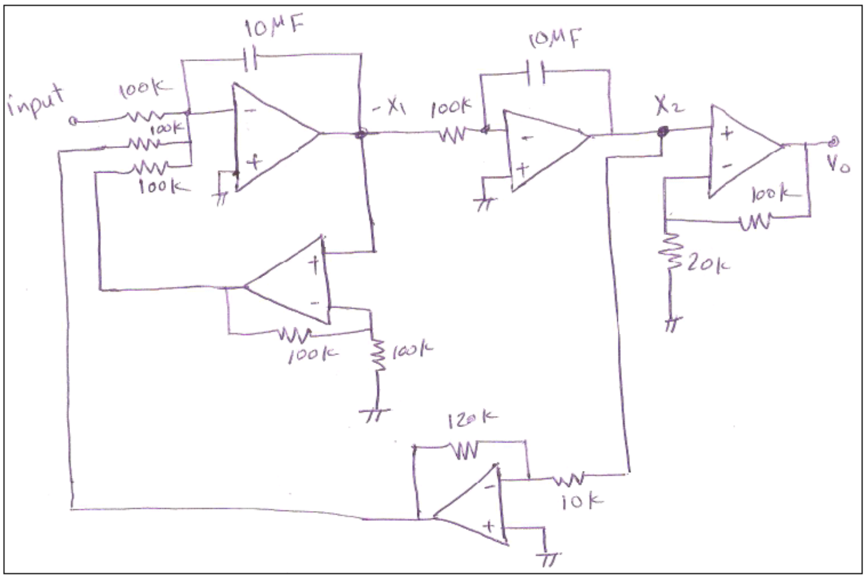
The following figure shows the block diagram of the state space by Matlab Simulink




Step response for the block diagram is shown below



**Thirdly**: Convert the block diagram to Op-Amps implementation




## Exercise:

**Implement the following T.F**

$$T(s) = \frac{3}{S^2 + 5S + 14}$$

1- Using Simulink
2- using OP- Amps