Chapiter 4 : Opertional Amplifiers

1. Introduction

Electric circuits with operational amplifier can be used to perform various operations and functions such as phase inversion, addition, subtraction, derivation, integration, multiplication, taking exponentials and logarithms. They can be applied as comparators, discriminators, voltage followers, memory registers…

Operational amplifier (OA) or op-amp is a DC-coupled high-gain electronic voltage amplifier. OA amplifies DC signals, while AC signals are amplified only in a specific frequency interval (band). OA has differential input (two inputs) and usually a single-ended output.

Operational amplifier is a complex type of differential multi-stage amplifier that usually has at least three stages : I. Differential amplifier at input, II. Common-emitter transistor amplifier, III. Voltage follower at output.

2. Schematic sysmbo l

The schematic symbol for the op amp is a triangle having two inputs and one output. as shown. Note that all voltages shown in this diagram are node voltages, and they are measured relative to a common reference or ground node which is established by the power supplies, as described below.

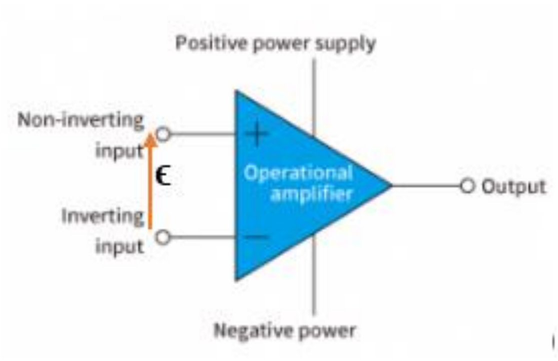


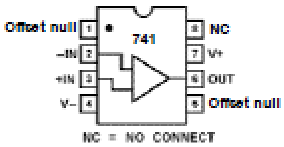
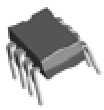
Figure 1 : ***Op amp schematic symbol***

- Two inputs
  V+ : non-inverting input
  V- : inverting input

- Need a source of tension symmetry ($\pm E$) avec E=10 à 15V
- Vout : output

3. Internal circuit of LM741

Most op-amps come in the form of an 8-pin integrated circuit (IC) (Figure 2)

  **Figure 2 National Semiconductor LM741 Wiring Diagram**	(+IN) ou (u): non-inverting input (-IN) ou (v): inverting input (OUT) ou (s): output (V+) ou (+Vcc) : Positive symmetrical power supply (V-) ou (-Vcc) : Negative symmetrical power supply (Offset null) : Input offset voltage cancellation (NC) : Not connected

The internal circuit of the LM741 (see figure below) includes around twenty bipolar transistors, around ten resistors and a so-called compensation capacitor (30pF).

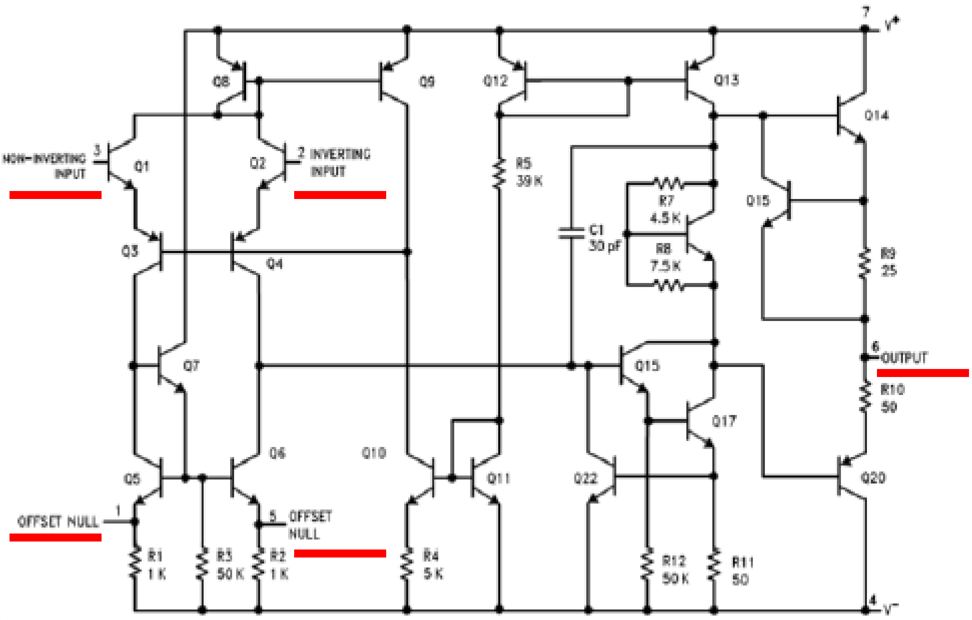


Figure 3 : Structure of the operational amplifier

Note :

The diagram is taken from the Texas Instruments data sheet. It is given for information purposes only, do not try to understand it!

4. Ideal operational amplifier characteristics

We define an ideal OA by OA which has the following properties:

1. 1. Infinite input impedance (Zin=∞)⟹ no current passes through the two inputs $i+ = i- = 0$ (Infinite input resistor)

2. Zero output impedance $Zout = 0$⟹All the output voltage of the OA passes across the load without any attenuation

3. OA has infinite gain in open loop (OL)

   - OL : absence of any external connection of electronic components

4. Bandwidth infinate

5. Identical entry ⟹ the volatge between the 2 OA entries is zero $\varepsilon = e^{+} - e^{-} = 0$

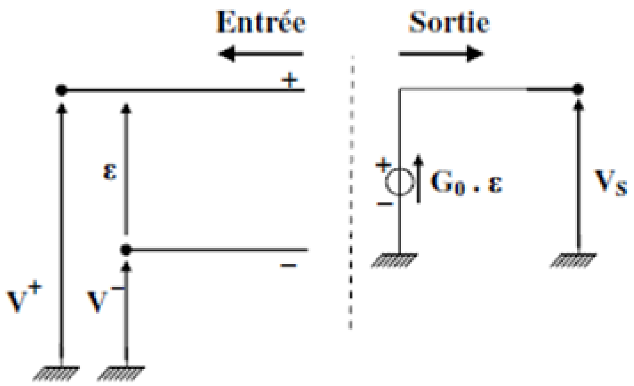


Figure 4 : Equivalent circuit of an ideal opeationnal amplifier

5. Operational amplifier in electric circuit with feedback

In the following sections we will express the output voltage as a function of the input voltage and the elements of the circuit.

5.1. Non Inverting circuit with an ideal operational amplifier

Consider the following OA-based circuit:

Input voltage that needs to be amplified is fed to the non-inverting input of the operational amplifier as can be seen in figure 6 of the non-inverting circuit of the OA.

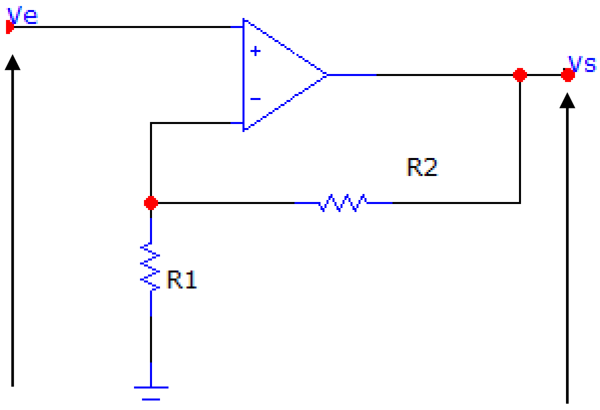


Figure 5 :Non inverting circuit

Work required: Express the voltage Vs/Ve as a function of R1 and R2.

$e^- = \frac{R1}{R1+R2} Vs$ (1)

We have : $e^- = e^+ = Ve$ (2)

We replace the equation (2) in equation (1) we obtain : $Ve = \frac{R1}{R1+R2} Vs$ so $\frac{Vs}{Ve} = \frac{R1+R2}{R1} = 1 + \frac{R2}{R1}$

- ✓ The non-inverting circuit is a voltage amplifier, because its closed loop gain is greater than 1
- ✓ Since A is positive, the output voltages Vs and input voltage Ve are in phase, hence the name non-inverting amplifier

5.2. The summing amplifier

Consider the following OA-based circuit:

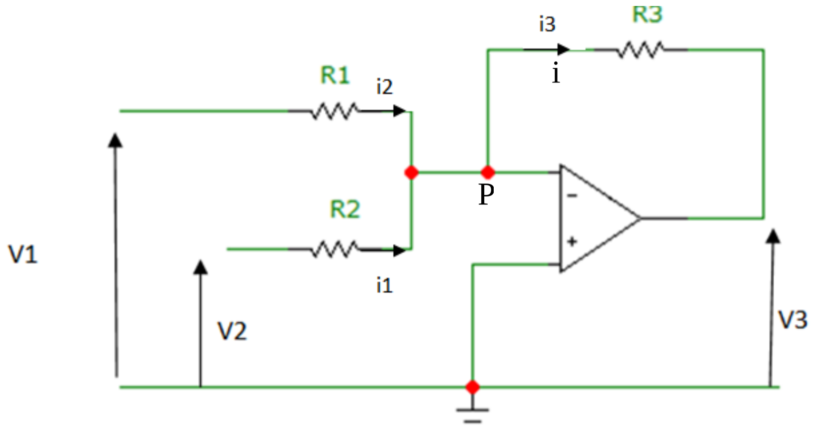


Figure 6 : The summing amplifier

Required work: Express the voltage Vs as a function of V1, V2, R1, R2 and R3.

We have $\begin{cases} i- = i+ = 0 \\ v+ = v- \end{cases}$

$i1 + i2 = i3$ (1)

Milman's theorem at the point P:

$\frac{v1}{R1} + \frac{v2}{R2} = -\frac{Vs}{R3} \Rightarrow Vs = -R3(\frac{v1}{R1} + \frac{v2}{R2})$

Method 2

$$\begin{cases} V3 + R3i3 = 0 \\ V2 - R2i2 = 0 \\ V1 - R1i1 = 0 \end{cases} \rightarrow \begin{cases} i3 = -\frac{Vs}{R3} \\ i2 = \frac{V2}{R2} \\ i1 = \frac{V1}{R1} \end{cases} \quad (2)$$

We replace the system of equation (2) in equation (1), we obtain :

$Vs = -R3(\frac{v1}{R1} + \frac{v2}{R2})$

Note : in the case where $R1 = R2 = R$

$$Vs = -\frac{R3}{R}(v1 + v2)$$

5.3. The voltage subtractor

We consider the following circuit :

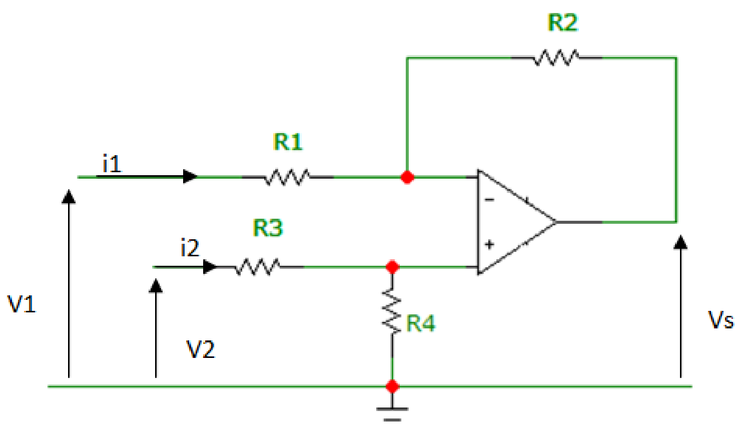


Figure 7 : Substractor circuit

Required work: Express the voltage Vs as a function of V1, V2, R1, R2, R3 and R4.

$v1 = R1i1 + R4i2$ (1)

$v2 = (R3 + R4)i2$ (2)

$Vs = -R2i1 + R4i2$ (3)

From equation (2) $\Longrightarrow i2 = \frac{v2}{R3+R4}$ (4)

We replace equation (4) in equation (1), we obtain :

$v1 = R1i1 + \frac{R4}{R3+R4}v2 \Longrightarrow i1 = \frac{v1}{R1} - \frac{R4}{R1(R3+R4)}v2$ (5)

We replace equation (4) & (5) in equation (3), we obtain:

$$vs = R2i1 + R4i2 = -R2\left(\frac{v1}{R1} - \frac{R4}{R1(R3+R4)}v2\right)$$

$$vs = \frac{R4(R1+R2)}{R1(R3+R4)}v2 - \frac{R2}{R1}v1$$

5.4. Integrator circuit

We consider the folling circuit :

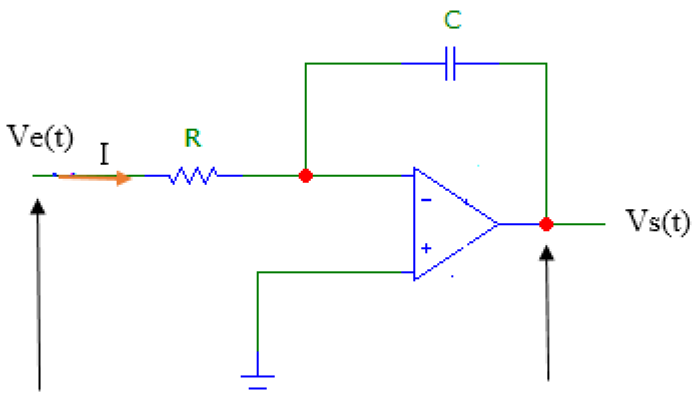


Figure 8 : Integrator circuit

Required work: Express the voltage Vs as a function of Ve(t), R and C.

$I = \frac{Ve(t)}{R} = -C\frac{dVs(t)}{dt} \Longrightarrow \frac{Ve(t)}{R} = -C\frac{dVs(t)}{dt}$

$\Longrightarrow Vs(t) = -\frac{1}{RC}\int Ve(t)dt$

5.5. Montage dérivateur

Soit le circuit à base d'OA suivant :

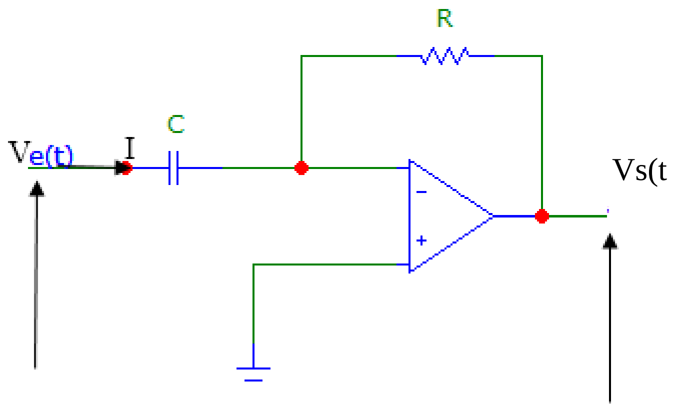


Figure 9: Differentiator circuit

Required work: Express the voltage Vs as a function of Ve(t), R and C.

$\boldsymbol{I} = \mathrm{c}\frac{\mathrm{dVe(t)}}{\mathrm{dt}} = -\frac{\mathrm{Vs(t)}}{\mathrm{R}} \Rightarrow Vs(t) = -Rc\frac{\mathrm{dVe(t)}}{\mathrm{dt}}$

5.6. Logarithmic amplifier

We consider the following circuit :

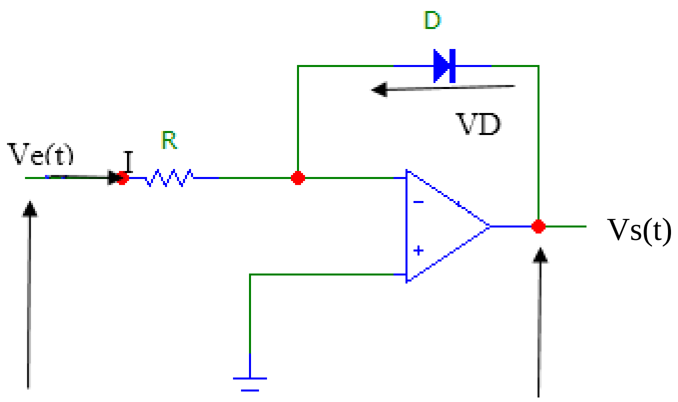


Figure 10 : Logarithmic circuit

$Ve = RI$ (1)

The equation which expresses the current flowing through a diode is:

$I = Is\left(exp\frac{VD}{VT} - 1\right) \approx Is.\,exp\frac{VD}{VT}$ (2)

o Is is the constant specific to the type of diode considered, homogeneous with a current. This constant is also called the “saturation current” of the diode.

o VD is the voltage across the diode;

- VT (called thermal voltage) is equal to $\frac{K_B T}{q}$, where kB is the Boltzmann constant, T the absolute temperature of the junction and q the charge of an electron.
- Is est la constante spécifique au type de diode considéré, homogène à un courant. Cette constante est aussi appelée « courant de saturation » de la diode.
- VD est la tension aux bornes de la diode ;

$VD = -Vs$ (3)

We replace equation (1) in equation (2), we obtain :

$Ve = R.Is.exp\frac{VD}{VT}$ (4)

We replace equation (3) in equation (4), we obtain :

$$Ve = R.Is.exp\frac{Vs}{VT} \Longrightarrow Vs = -VT\ln\frac{Ve(t)}{RIs} + cste$$

5.7. Exponential amplifier

We consider the following circuit :

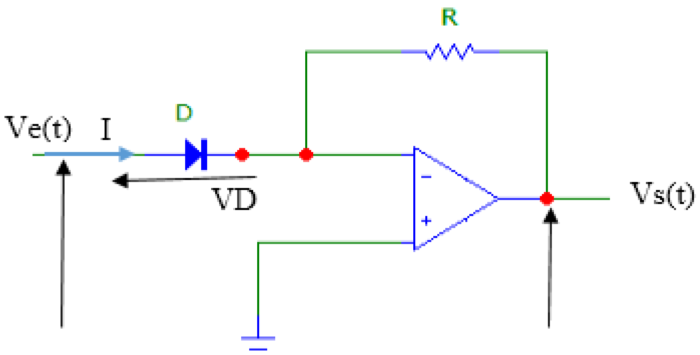


Figure 11: Exponential circuit

$Vs = -R.\text{I}$ (1)

$I = Is.exp\frac{Ve}{VT}$ (2)

$Ve = VD$ (3)

We replace equation (2) & (3) in equation (1), we obtain : $Vs = -R\ Is.exp\frac{Ve}{VT}$