Electronic Circuits

Operational Amplifier

Lecture 8

Dr. Roaa Mubarak

Op-Amp Applications

- **Non linear Applications**

9- Logarithmic Amplifier

10- Anti-Logarithmic Amplifier

11- Analog Multiplier

12- Analog Divider

13- Voltage Regulator

14- Comparator

15- Schmitt Trigger

16- Digital to Analog Converter

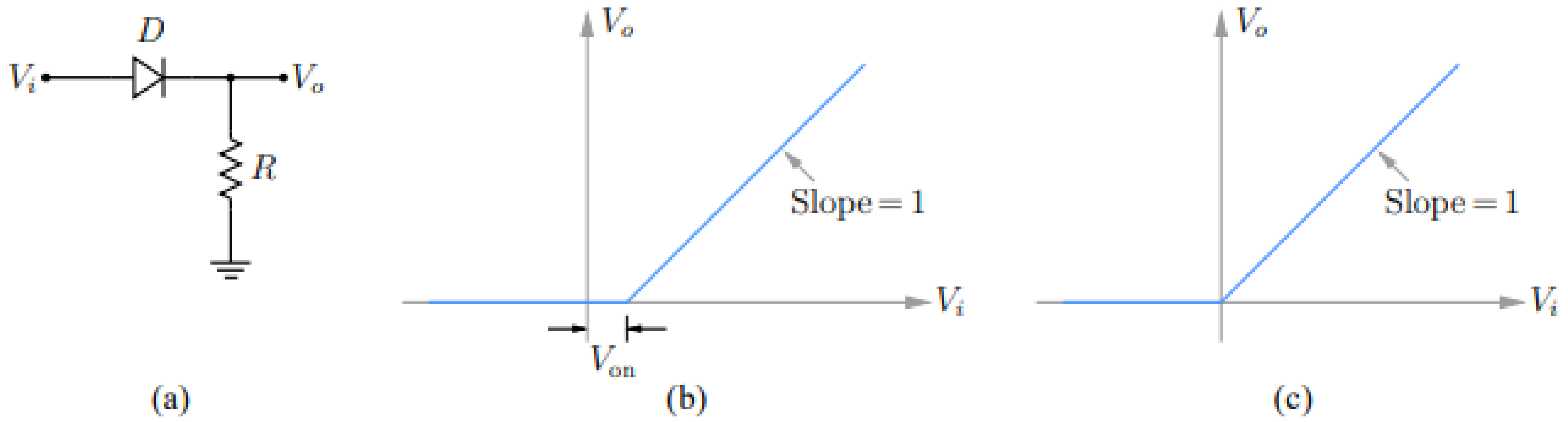
17- Rectifying using Op-Amp

18- Clipping using Op-Amp

19- Instrumentation Amplifier

17- Precision half-wave rectifier

- **Half wave rectifier**



Vi < Von → D is OFF (open circuit)

Vo=0

Vi > Von → D is ON (replace diode with Von)

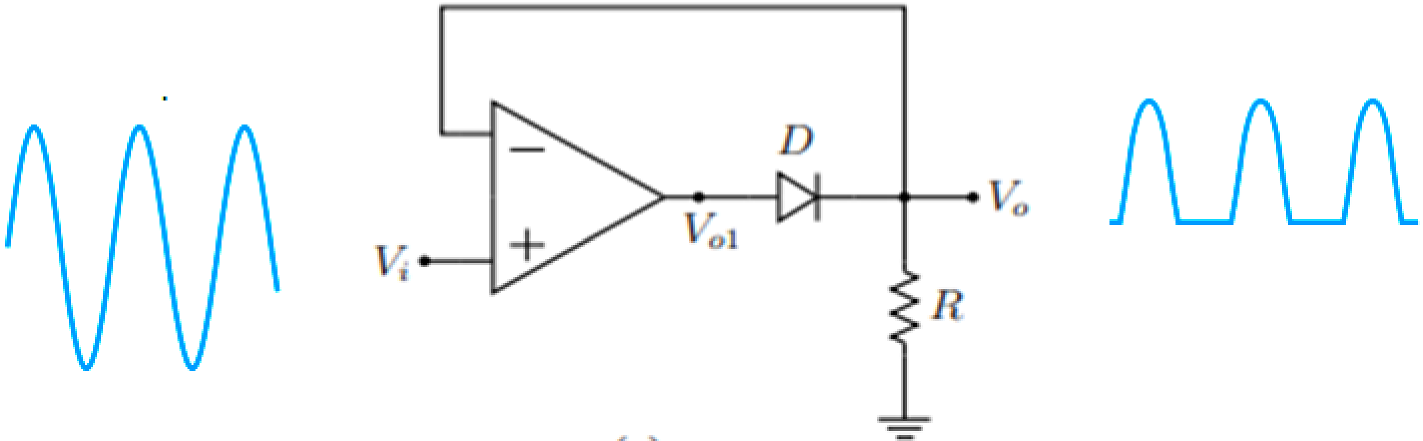
By KVL

-Vi + Von + Vo = 0

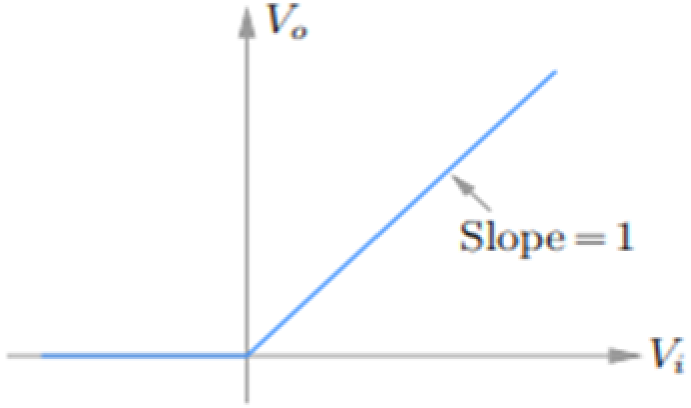
Vo= Vi - Von

17- Precision half-wave rectifier (Super Diode)

- An improved half-wave rectifier, also known as the “super diode” since it behaves like an ideal diode with Von = 0 V.



(a)



(b)

Vi > 0 → D is ON (short circuit)

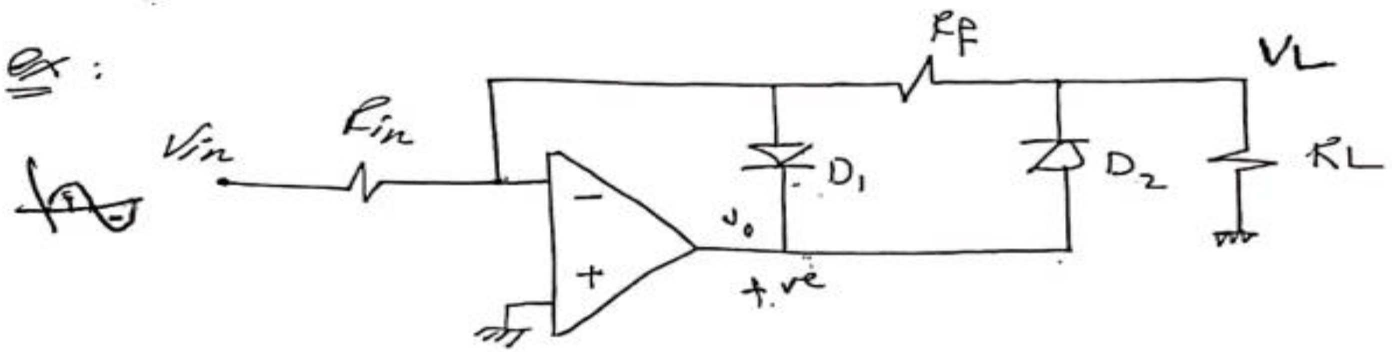
Vo= Vi

Vi < 0 → D is OFF (open circuit)

Vo=0

17- Precision half-wave rectifier (Super Diode)

Example

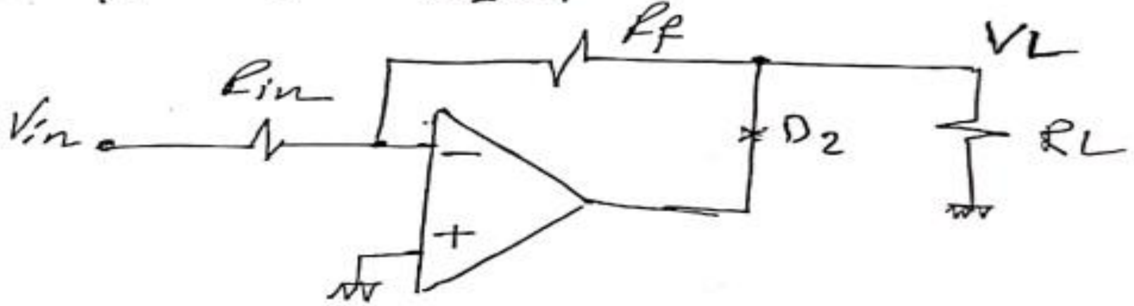


find VL

Solution:

Sol : $\underline{V_i < 0}$: $V_o = +ve$

D_1 off , D_2 on

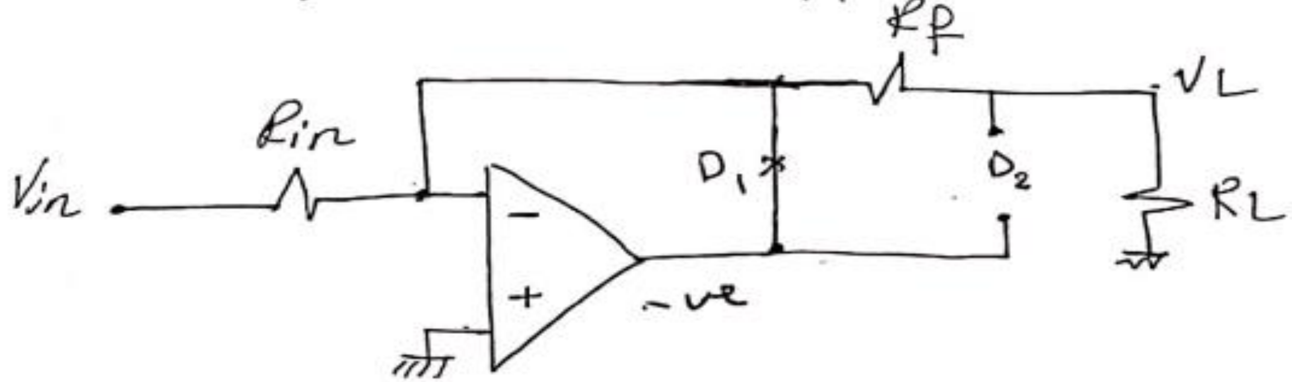


$$\boxed{V_L = \frac{-R_f}{R_{in}} V_{in}}$$

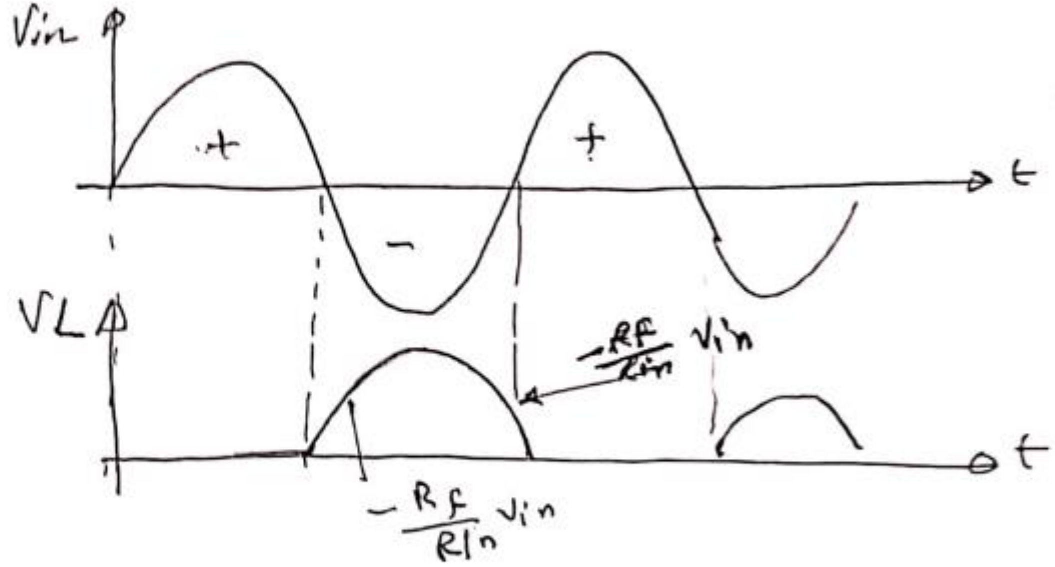
17- Precision half-wave rectifier (Super Diode)

$\underline{V_i > 0}$: $V_o = -ve$

D_1 on , D_2 off

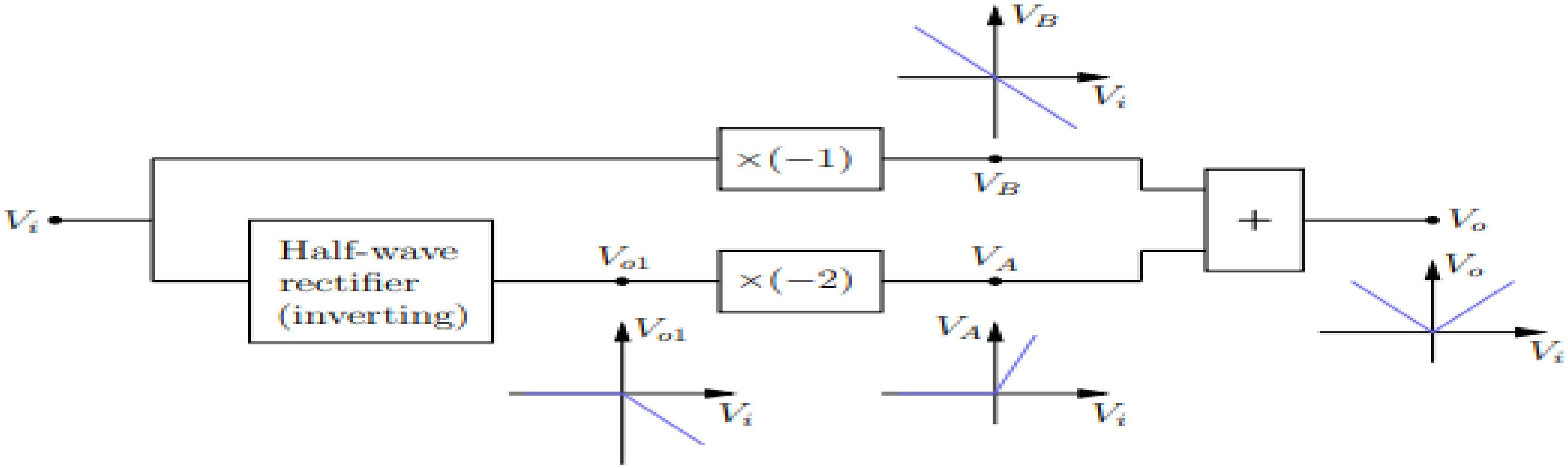


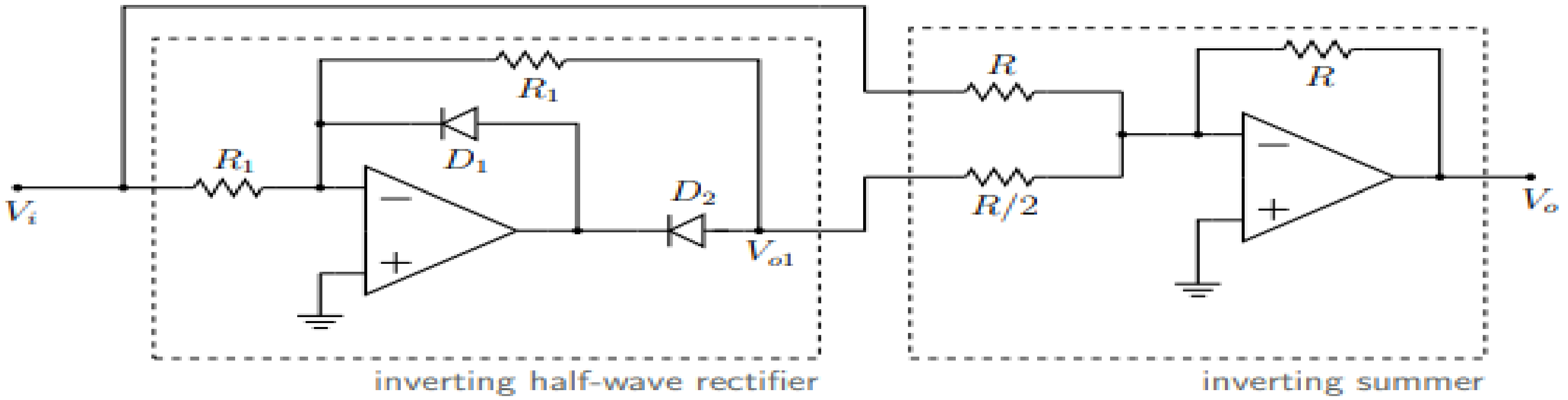
$\boxed{VL = 0}$



18- Precision full-wave rectifier

It is possible to implement a precision full-wave rectifier by suitably combining the previous circuits.

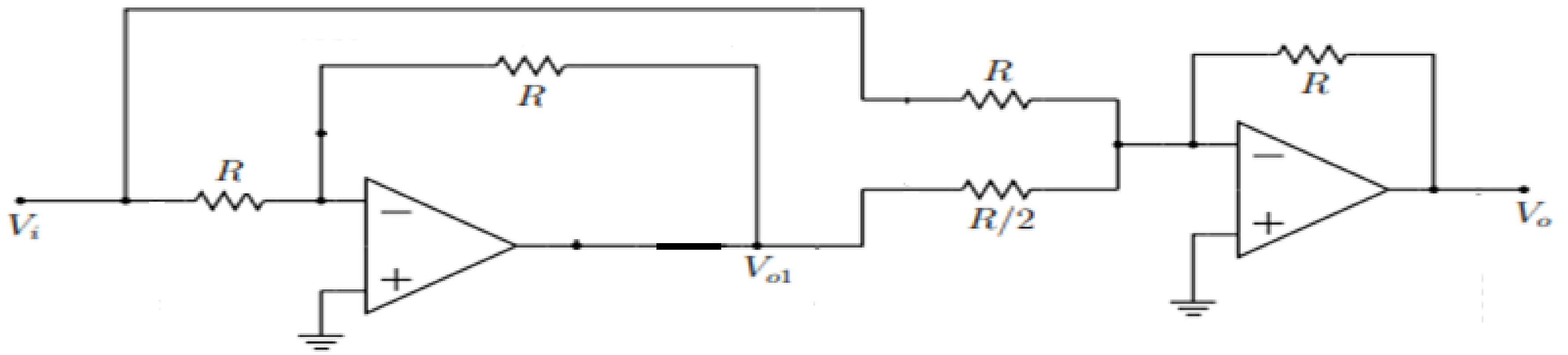




18- Precision full-wave rectifier

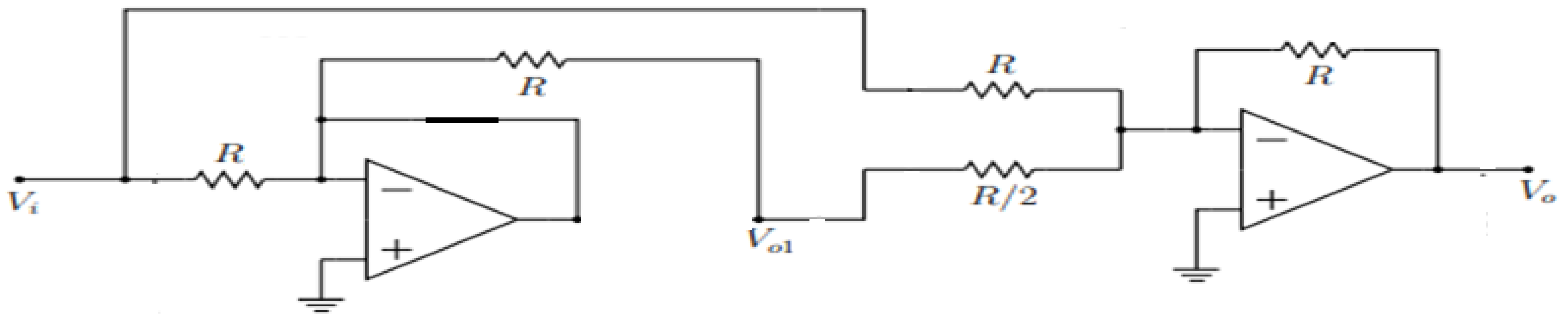
Vi > 0 → D1 is Off & D2 is On

$$V_o = -\left[\frac{R}{R/2}(-V_i) + \frac{R}{R}V_i\right] = -[-2V_i + V_i] = V_i$$

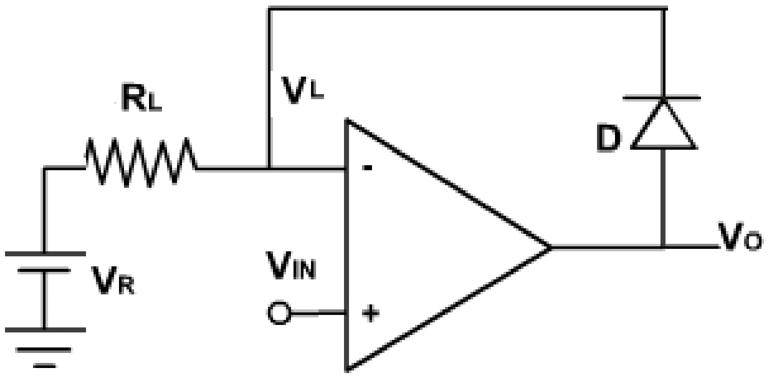


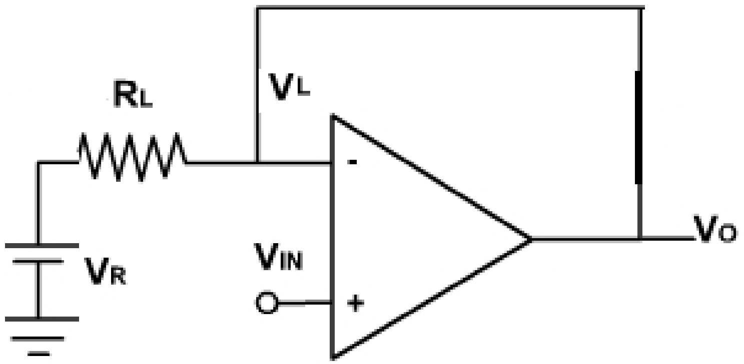
Vi < 0 →D1 is On & D2 is Off

$$V_o = -V_i$$



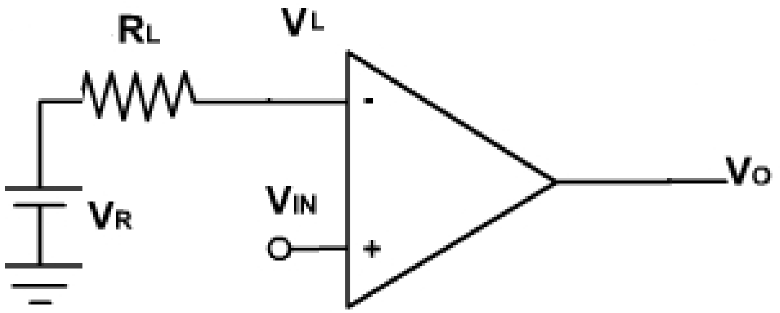
18- Clipping using Op-amp





Vi > VR → D is On , Vo +ve

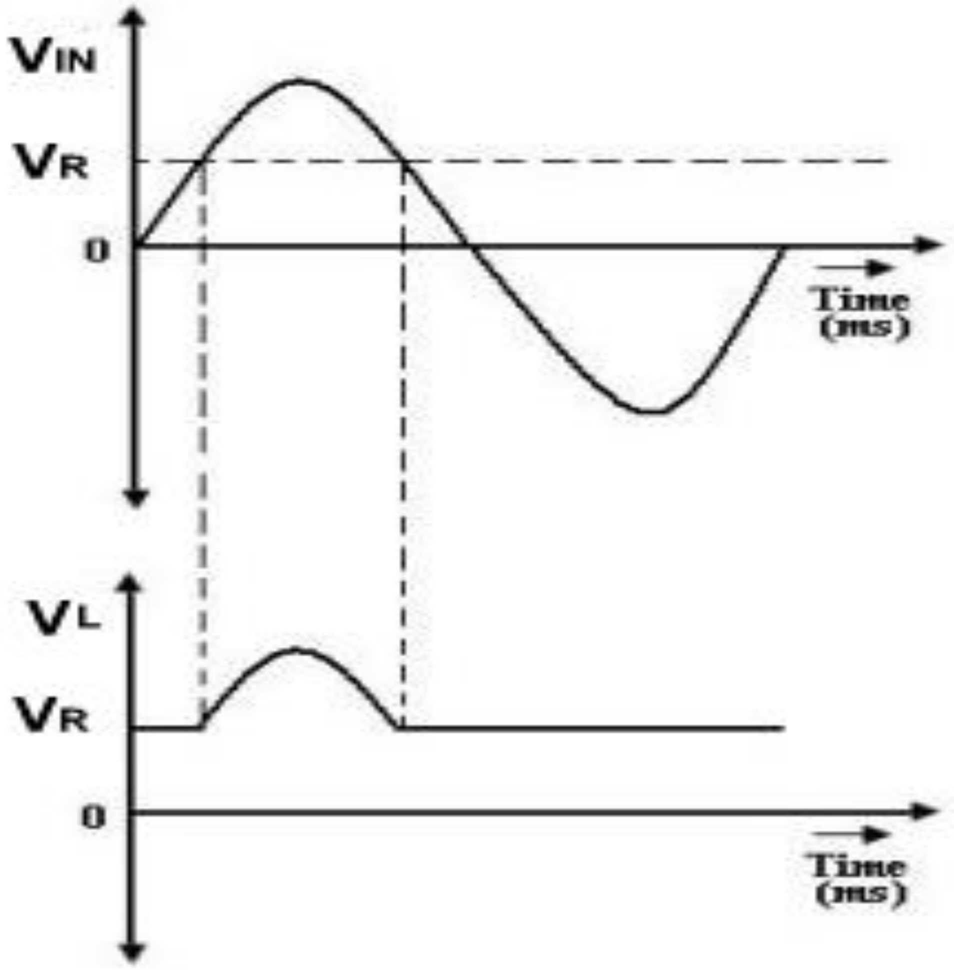
$V_l = V_o = V_{in}$



Vi < VR → D is Off , Vo -ve

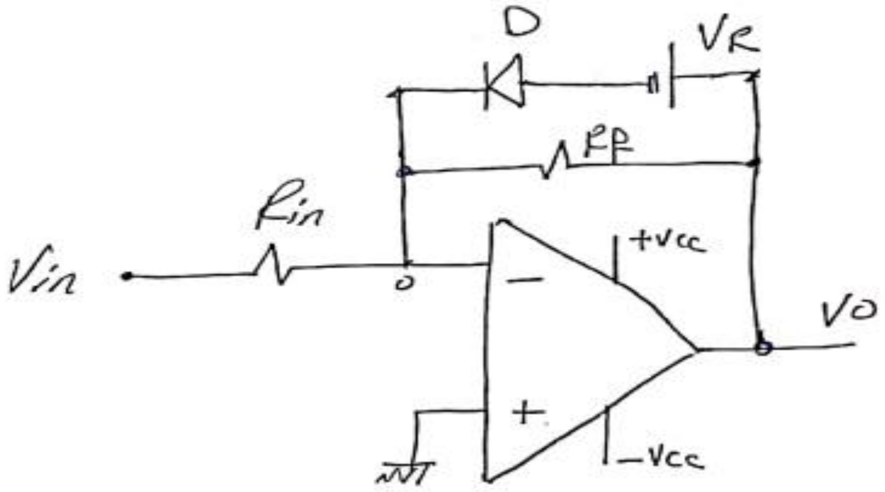
$V_l = V_R$

18- Clipping using Op-amp



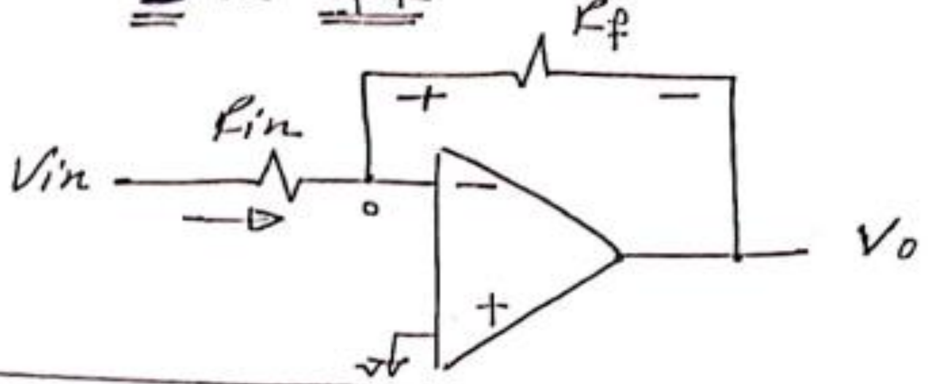
18- Clipping using Op-amp

Example1: Draw the output waveform



Solution

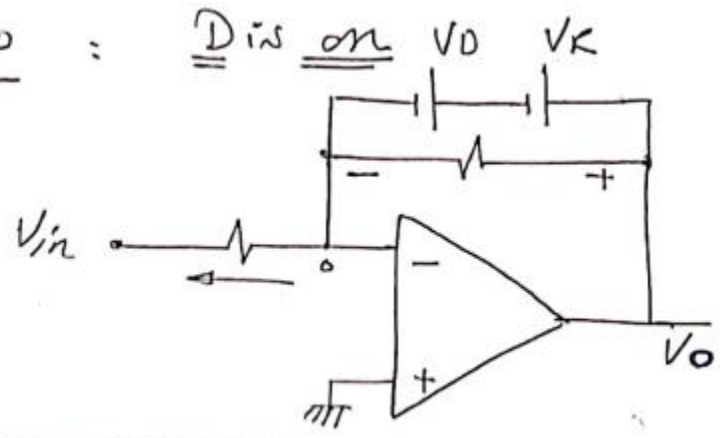
* $V_{in} > 0$: D is off



$$\boxed{V_o = -\frac{R_f}{R_{in}} V_{in}}$$

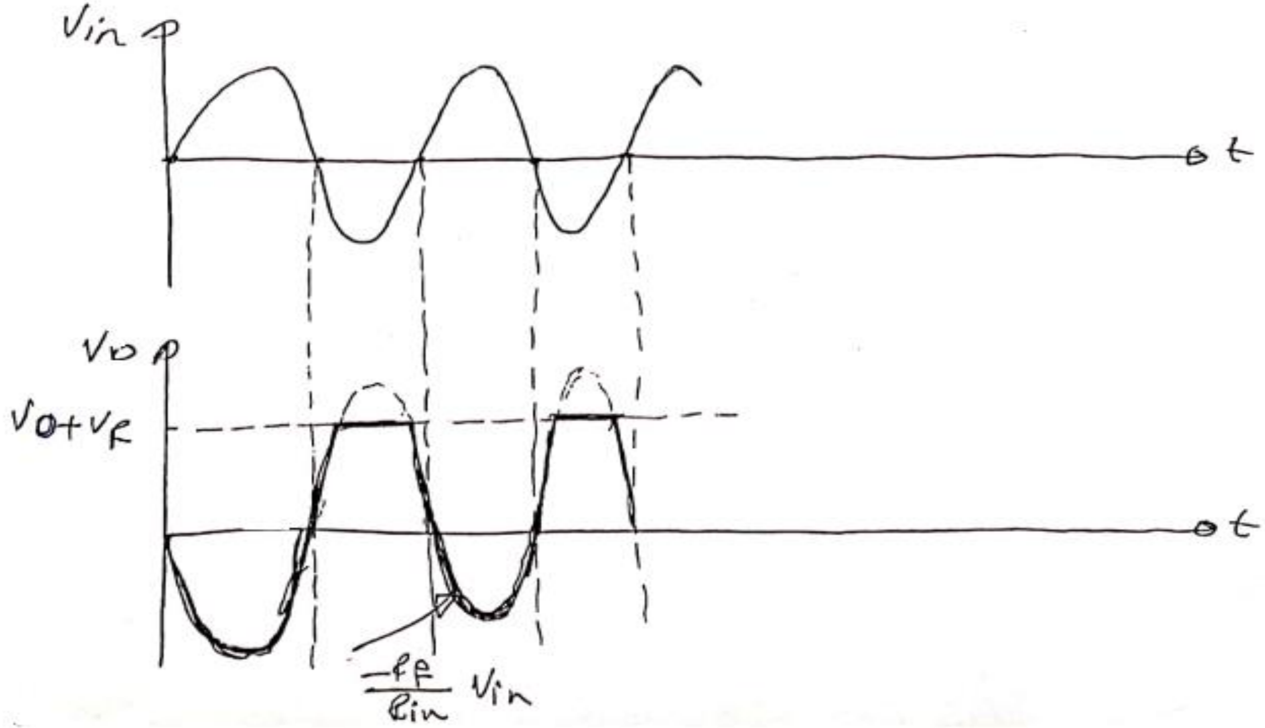
18- Clipping using Op-amp

* $\underline{V_{in} < 0}$: $\underline{\underline{D \text{ is on}}}$



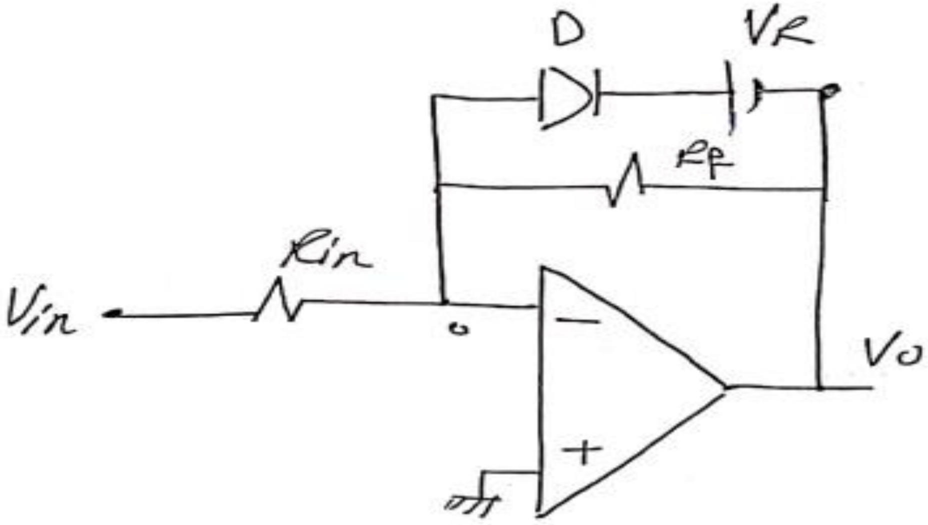
$$\boxed{V_o = V_D + V_R}$$

Note: if $V_o < V_D + V_R$
$\Rightarrow$ D off , $V_o = -\frac{R_f}{R_{in}} V_{in}$
- if $V_o > V_D + V_R$
$\Rightarrow$ D on , $V_o = V_D + V_R$



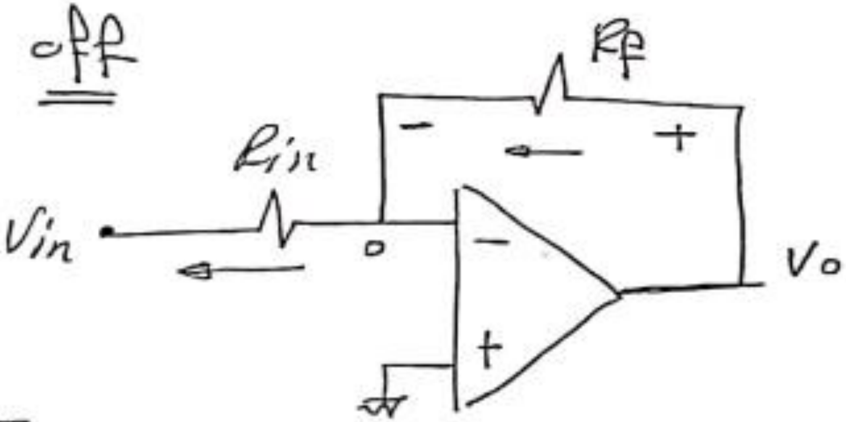
18- Clipping using Op-amp

Example 2: Draw the output waveform



Solution

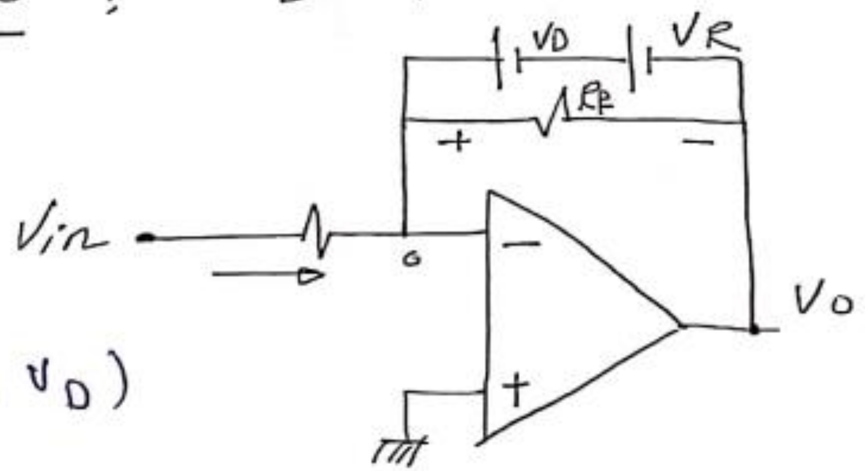
* $V_{in} < 0$: D is off



$$\boxed{V_o = -\frac{R_f}{R_{in}} V_{in}}$$

18- Clipping using Op-amp

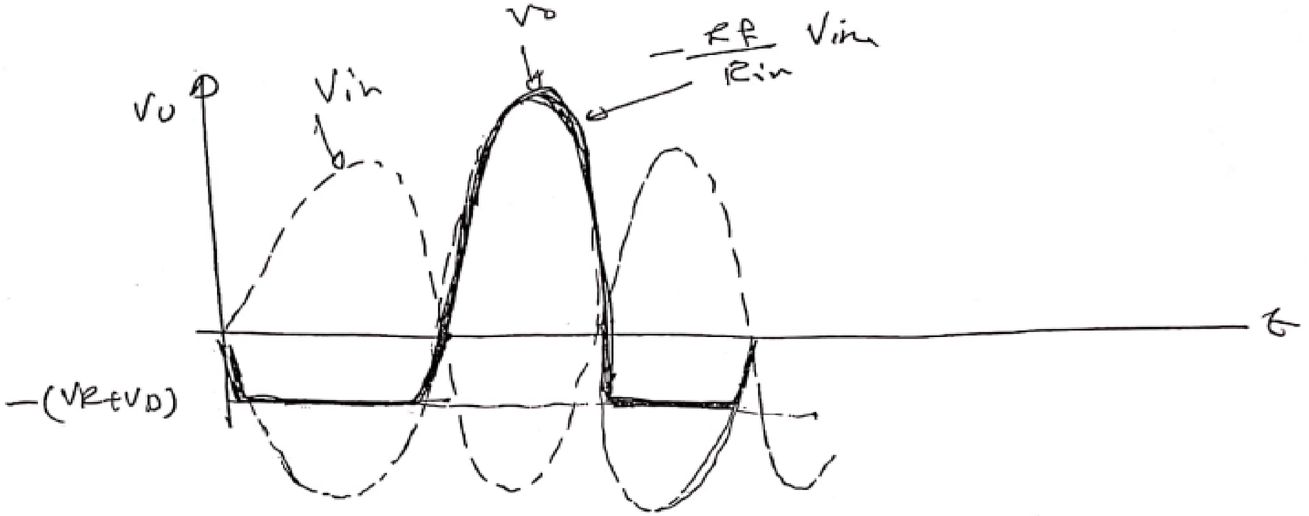
* $\underline{V_{in} > 0}$: D is on



$V_o = -(V_R + V_D)$

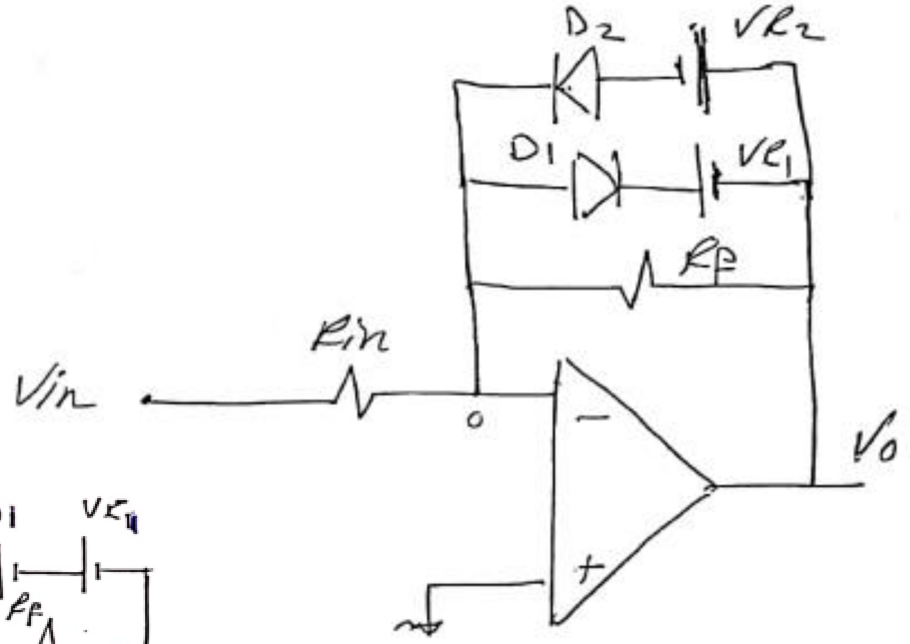
D is on when $V_o < -(V_R + V_D)$, $V_o = -(V_R + V_D)$

D is off ~ $V_o > -(V_R + V_D)$, $V_o = \frac{-R_f}{R_{in}} V_{in}$



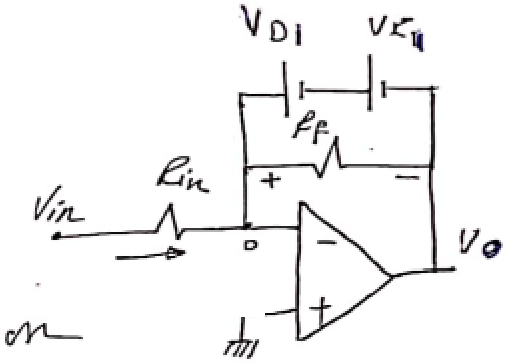
18- Clipping using Op-amp

Example 3: Draw the output waveform



Solution

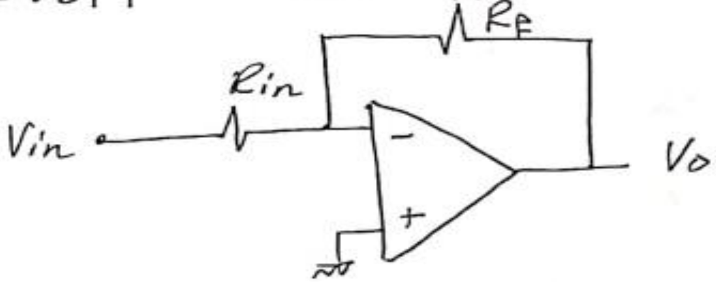
[1] if $V_i > 0$: $V_o = -ve$
then D2 off



(a) $|V_o| > |V_{R_1} + V_{D_1}|$ D1 is on

& $\boxed{V_o = -(V_{R_1} + V_{D_1})}$

(b) $|V_o| \leq |V_{R_1} + V_{D_1}|$ D is off



$$\boxed{V_o = -\frac{R_f}{R_{in}} V_{in}}$$

18- Clipping using Op-amp

[2] $V_i < 0$: $V_o = +ve$

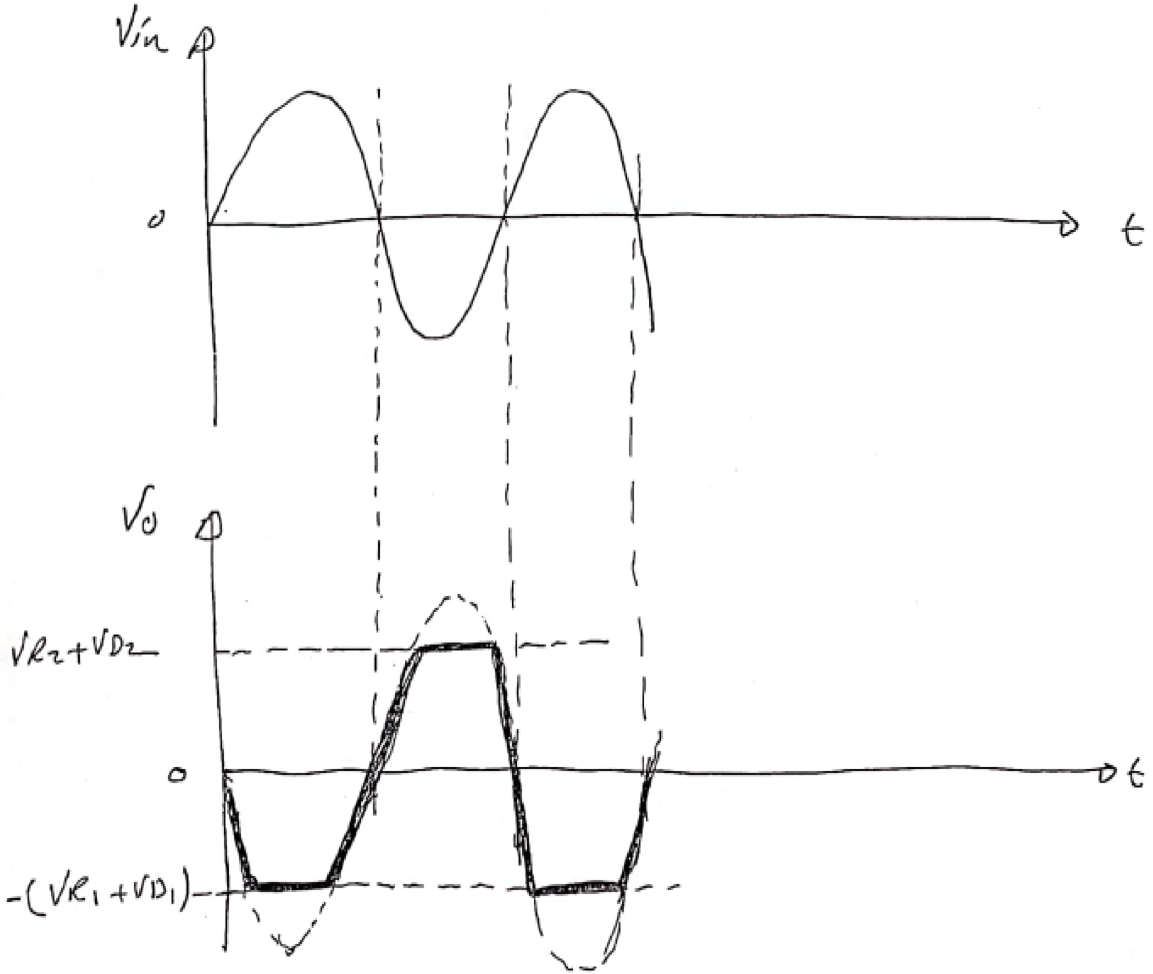
then D_1 off

(a) $|V_o| > |V_{R_2} + V_{D_2}|$ D_2 on

$\therefore \boxed{V_o = V_{R_2} + V_{D_2}}$

(b) $|V_o| < |V_{R_2} + V_{D_2}|$ D_2 off

$\therefore \boxed{V_o = -\frac{R_f}{R_{in}} V_{in}}$



19- Instrumentation Amplifier

- An instrumentation amplifier is an integrated circuit (IC) that is used to amplify a signal. This type of amplifier is in the differential amplifier family because it amplifies the difference between two inputs.
- The importance of an instrumentation amplifier is that it can reduce unwanted noise that is picked up by the circuit.
- The ability to reject noise or unwanted signals common to all IC pins is called the common-mode rejection ratio (CMRR). Instrumentation amplifiers are very useful due to their high CMRR. Other characteristics, such as high open loop gain, low DC offset and low drift, make this IC very important in circuit design.
- Instrumentation amplifiers are used in many different circuit applications. Their ability to reduce noise and have a high open loop gain make them important to circuit design.
- The objective of this application note is to instruct circuit designers how to design and build an instrumentation amplifier that will be suitable for any circuit design.

19- Instrumentation Amplifier

- **Designing an Instrumentation Amplifier**

1. Select an Op Amp.

Selecting an appropriate op amp is an important part in designing an instrumentation amplifier. The instrumentation amplifier will require three op amps. Almost any op amp will work for this design. However, with circuit size in mind, this design will use the LM324. The LM324 IC has four op amps on the chip, which will reduce size and amount of wires needed to build the circuit.

2. Select Resistor Values

A typical instrumentation amplifier will have seven resistors. These resistors are oriented between the op amps. Instrumentation amplifiers are unique in the fact that resistor values can be selected so that only one resistor will dictate the overall gain. This can be done if all other resistor values are chosen properly.

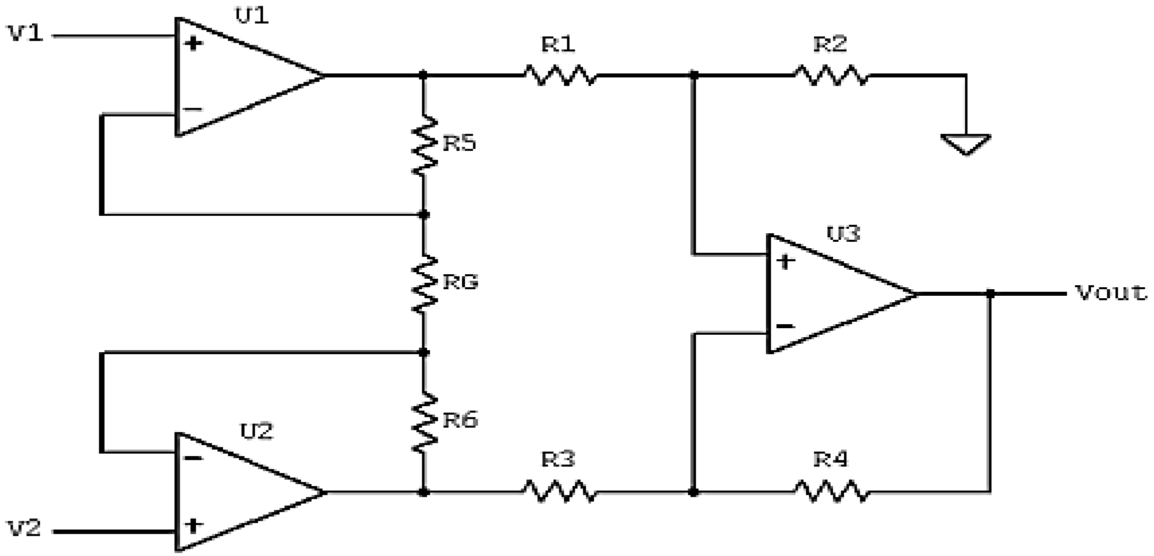
19- Instrumentation Amplifier

- The transfer function of a typical instrumentation amplifier is:

$$V_{out} = (V1 – V2)(R2/R1)(1+2R5/RG)$$

- This is the case if R5 = R6, R2 = R4 and R1 = R3.
- If R2 = R4 = R1 = R3 = R5 = R6 = R. The transfer function would then become:

$$V_{out} = (V1 – V2)(1+2R/RG)$$



This transfer function allows the gain to be decided by one resistor, RG. Finally, in order to allow large gain, select R to be between 25 KOhm and 1 MOhm

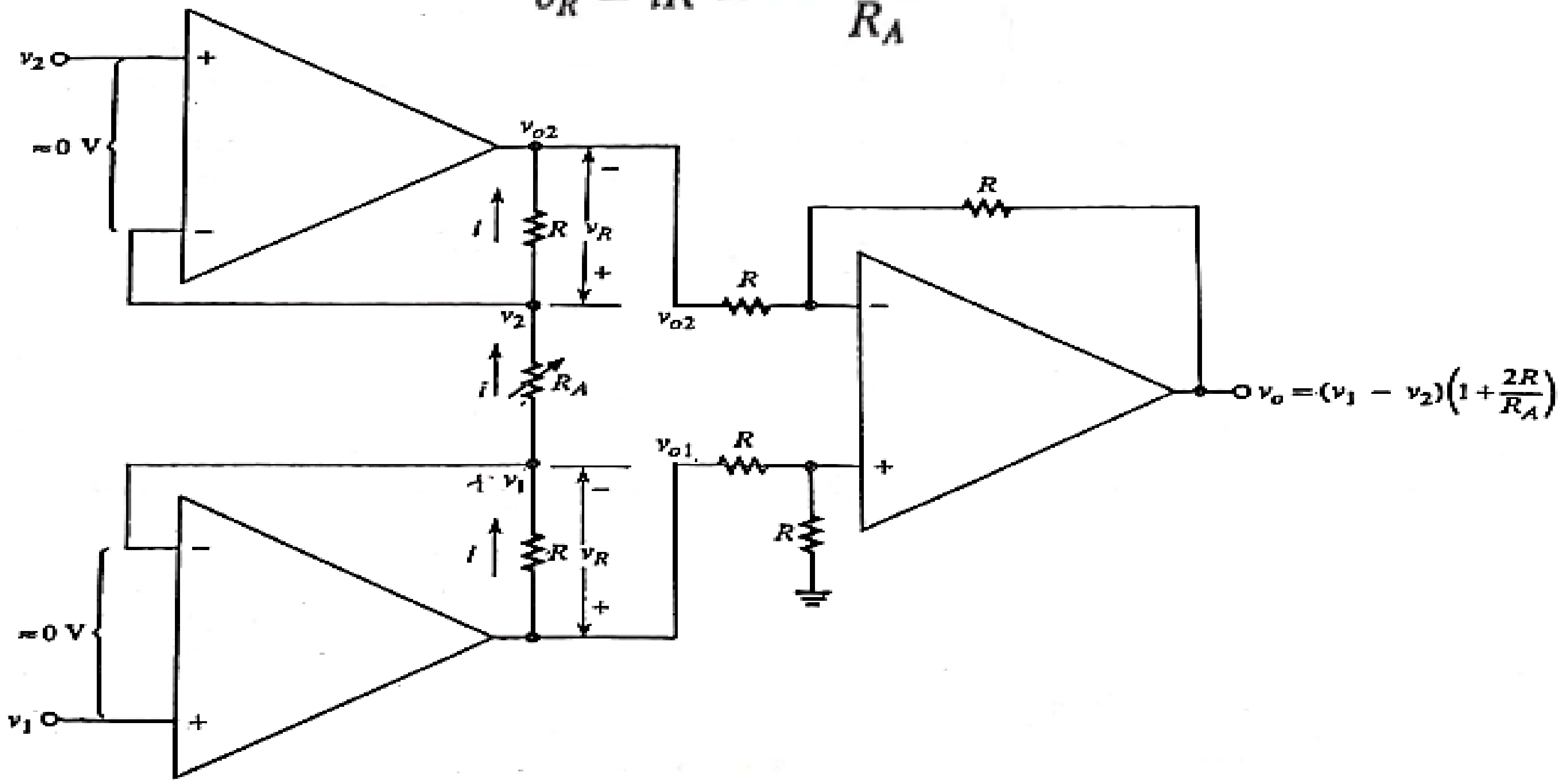
19- Instrumentation Amplifier

Assume v1>v2, the current I through RA:

$$i = \frac{v_1 - v_2}{R_A}$$

Since no current flows into either amplifier input terminal, the current I must also flow in each resistor R connected on opposite sides of RA, therefore, the voltage drop across each of those resistors is:

$$v_R = iR = \frac{(v_1 - v_2)R}{R_A}$$



19- Instrumentation Amplifier

$$i = \frac{v_1 - v_2}{R_A}$$

$$v_R = iR = \frac{(v_1 - v_2)R}{R_A}$$

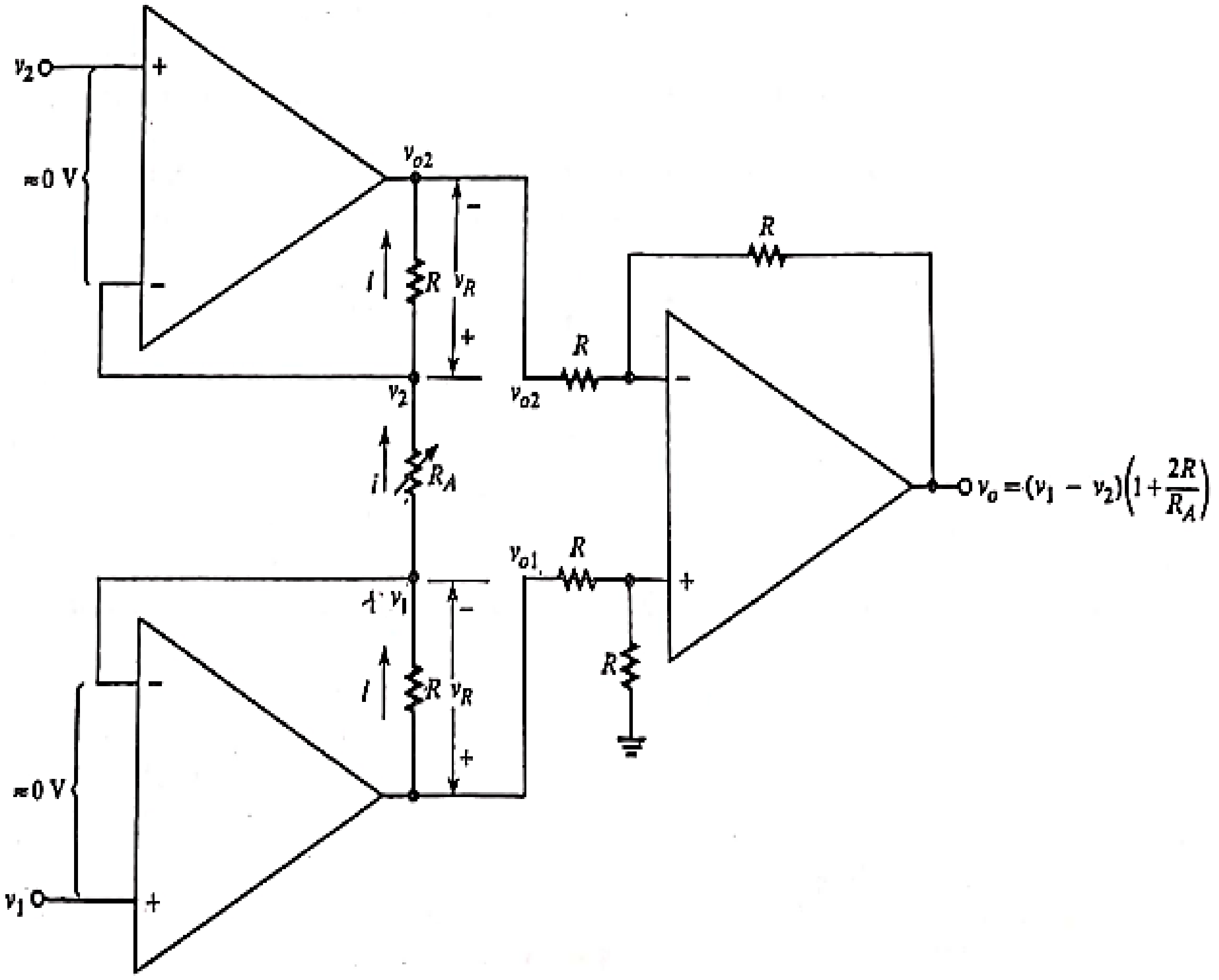
$$v_{o1} = v_1 + v_R$$

$$v_{o2} = v_2 - v_R$$

$$v_o = v_{o1} - v_{o2}$$

$$v_o = (v_1 + v_R) - (v_2 - v_R) = v_1 - v_2 + 2v_R$$

$$v_o = v_1 - v_2 + \frac{2(v_1 - v_2)R}{R_A} = (v_1 - v_2)(1 + 2R/R_A)$$



19- Instrumentation Amplifier

- 3. Calculating Gain

With R selected to be 25 KOhm the overall transfer function will be:

$$Vout = (V1 - V2)(1+50K/RA)$$

This simplifies the transfer function and allows one resistor (RA) to decide the overall gain. The smaller resistor selected for RA will create a large gain, while a large resistor will create a small gain. The table gives examples of different gain values and their associated RA value.

Desired Gain	RA (Ohm)
1	None
2	50K
5	12.5K
10	5.556K
20	2.632K
50	1.02K
100	505.1
200	251.3
500	100.2
1000	50.05
2000	25.01
5000	10
10000	5.001

17- Instrumentation Amplifier

- To ensure proper operation of the instrumentation amplifier, all three of the following inequalities must be satisfied at all times:

$$\left|\left(1+\frac{R}{R_A}\right)v_1-\frac{R}{R_A}v_2\right| < |V_{max(1)}|$$

$$\left|\left(1+\frac{R}{R_A}\right)v_2-\frac{R}{R_A}v_1\right| < |V_{max(1)}|$$

$$\left(1+\frac{2R}{R_A}\right)|v_1-v_2| < |V_{max(2)}|$$

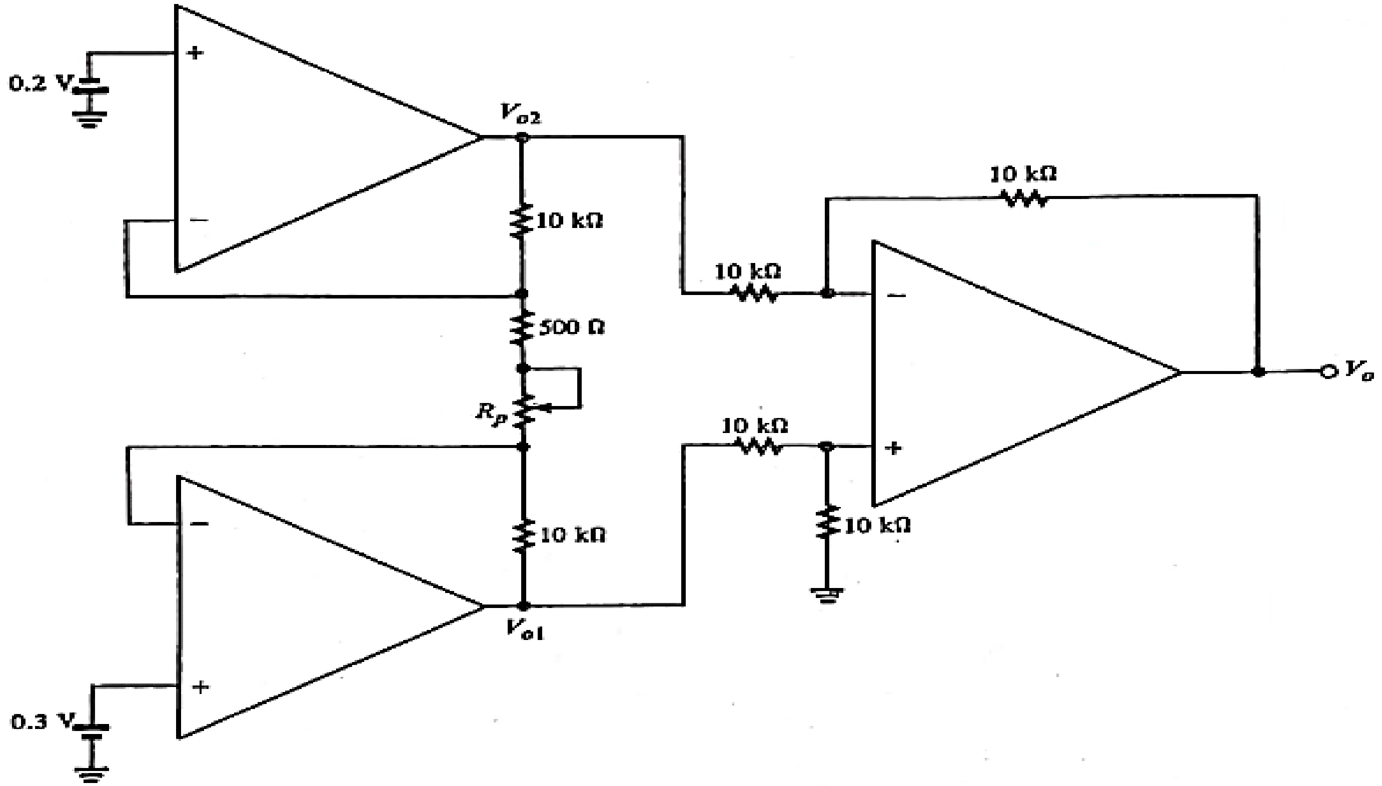
Where Vmax(1) is the maximum output voltage of each input stage and Vmax(2) is the maximum output voltage of the differential stage.

17- Instrumentation Amplifier

Example

1-Assuming ideal amplifiers, find the minimum and maximum output voltage Vo of the instrumentation amplifier shown, when the 10kΩ potentiometer Rp is adjusted through its entire range.

2-Find Vo1 and Vo2 when Rp is set in the middle of its resistance range.



17- Instrumentation Amplifier

Solution

1- In this example RA is the sum of Rp and fixed 500Ω resistor.

Assuming that Rp can be adjusted through a full range from 0 to 10kΩ,

RA(min) =500Ω and RA(max)= 500Ω + 10KΩ =10.5KΩ

The minimum and maximum value of Vo are :

$$v_o(\text{min}) = (V_1 - V_2)\left[1 + \frac{2R}{R_A(\text{max})}\right] = [0.3\text{ V} - (-0.2\text{ V})]$$

$$\times\left[1 + \frac{2(10\text{ k}\Omega)}{10.5\text{ k}\Omega}\right] = 1.45\text{ V}$$

$$v_o(\text{max}) = (V_1 - V_2)\left[1 + \frac{2R}{R_A(\text{min})}\right] = [0.3\text{ V} - (-0.2\text{ V})]$$

$$\times\left[1 + \frac{2(10\text{ k}\Omega)}{500\ \Omega}\right] = 20.5\text{ V}$$

17- Instrumentation Amplifier

2. When $R_A = 500\ \Omega + (\frac{1}{2})(10 \times 10^3\ \Omega) = 5.5\ k\Omega$,

$$V_R = \frac{(V_1 - V_2)R}{R_A} = \frac{[0.3\ V - (-0.2\ V)]10 \times 10^3\ \Omega}{5.5 \times 10^3\ \Omega} = 0.909\ V$$

$$V_{o1} = V_1 + V_R = 0.3\ V + 0.909\ V = 1.209\ V$$
$$V_{o2} = V_2 - V_R = -0.2\ V - 0.909\ V = -1.109\ V$$