VIVEKANANDA COLLEGE

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NAAC ACCREDITED ‘A’ GRADE

Course Title: Operational Amplifier and Application

Topic: Basic Operational Amplifier , Opamp application

Paper: CC8 theory

Unit: Fourth Semester

Semester:

Name of the Teacher: Debarati Sarkar

Name of the Department: Electronics

Operational Amplifiers

An operational amplifier is a dc coupled high-gain electronic voltage amplifier with a differential i/p and usually, a single ended output. In this configuration, an op-amp produces an output potential that is typically hundreds of thousands of times larger than the potential difference ~~betweel~~ between its i/p terminals.

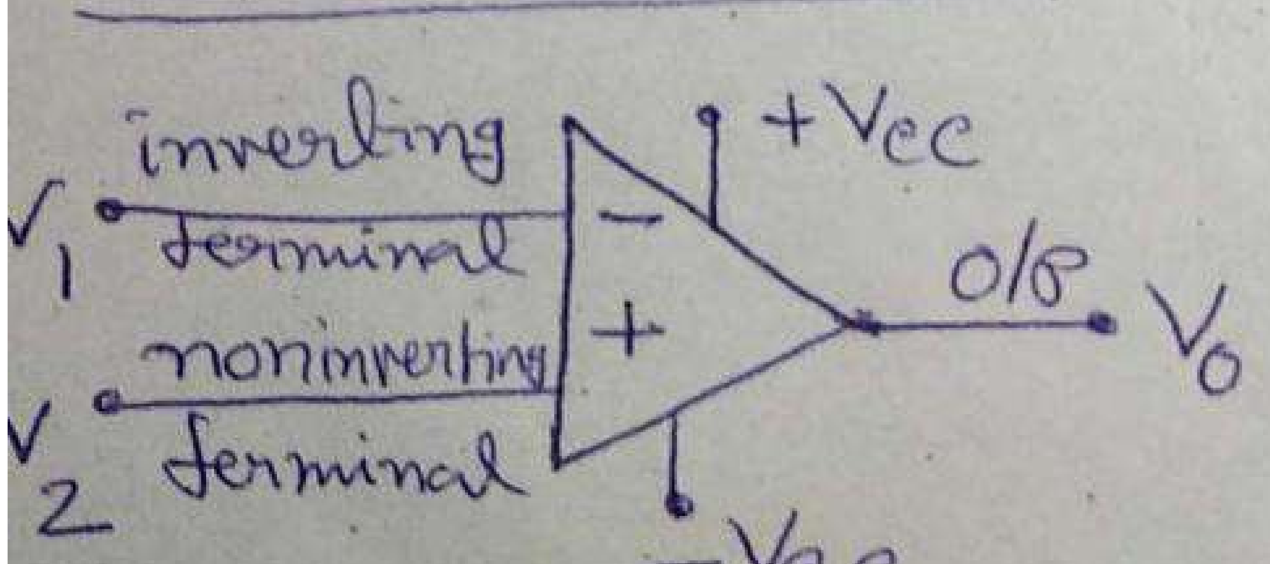
• Why is it called operational amplifier?

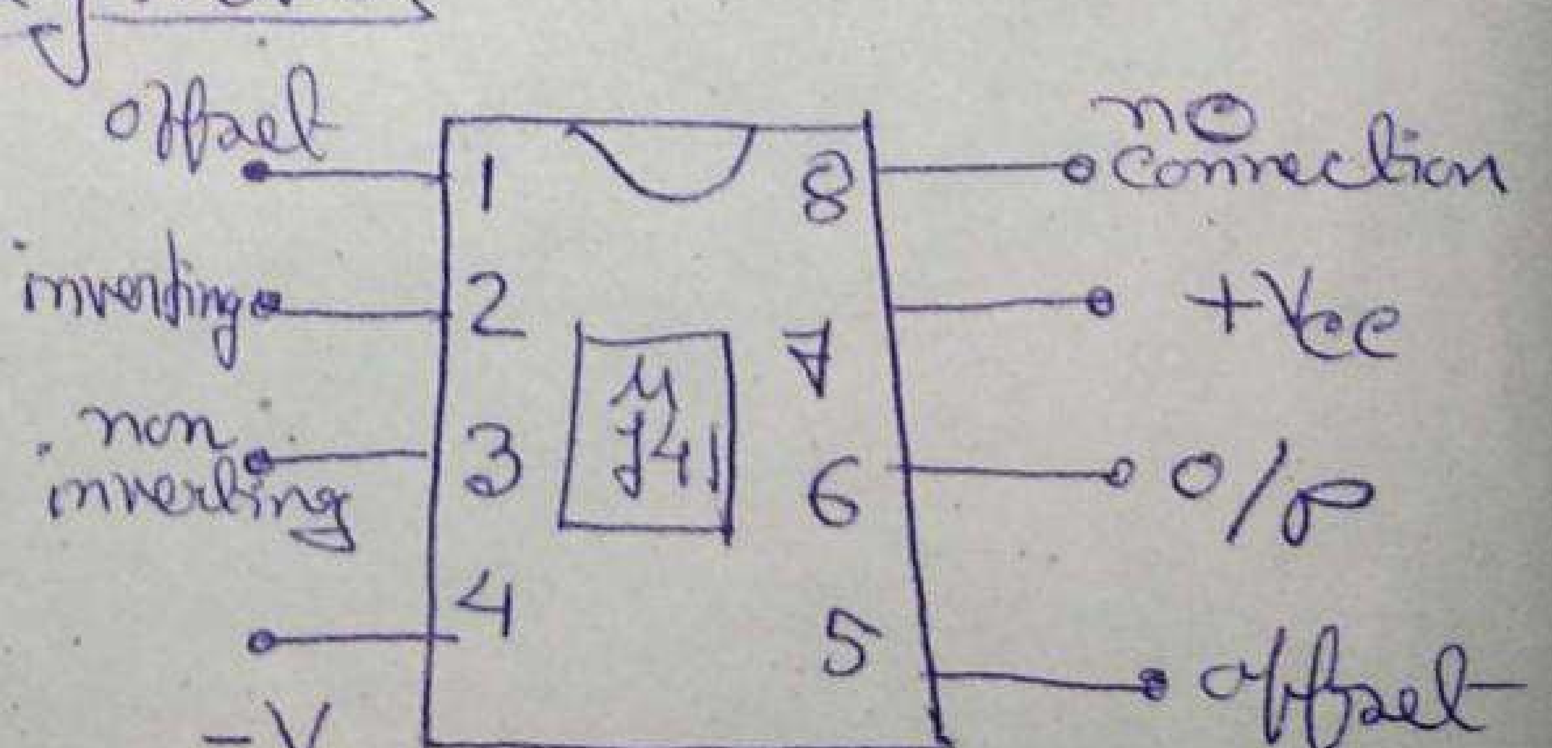
Op-amp stands for operational amplifier because they were used to model the basic mathematical operations of addition, subtraction, integration, differentiation etc in electronic analog computers.

Characteristics of Operational Amplifier

- Infinite open loop gain $G = V_{out}/V_{in}$
- Infinite i/p impedance R_{in}
- Zero i/p offset voltage range.
- Infinite o/p voltage range.
- Infinite bandwidth with zero phase shift and infinite slew rate.
- Zero output impedance R_{out}
- Zero noise
- Infinite common-mode rejection ratio (CMRR)

Op-AMP Block diagram





OP-Amp Application :-

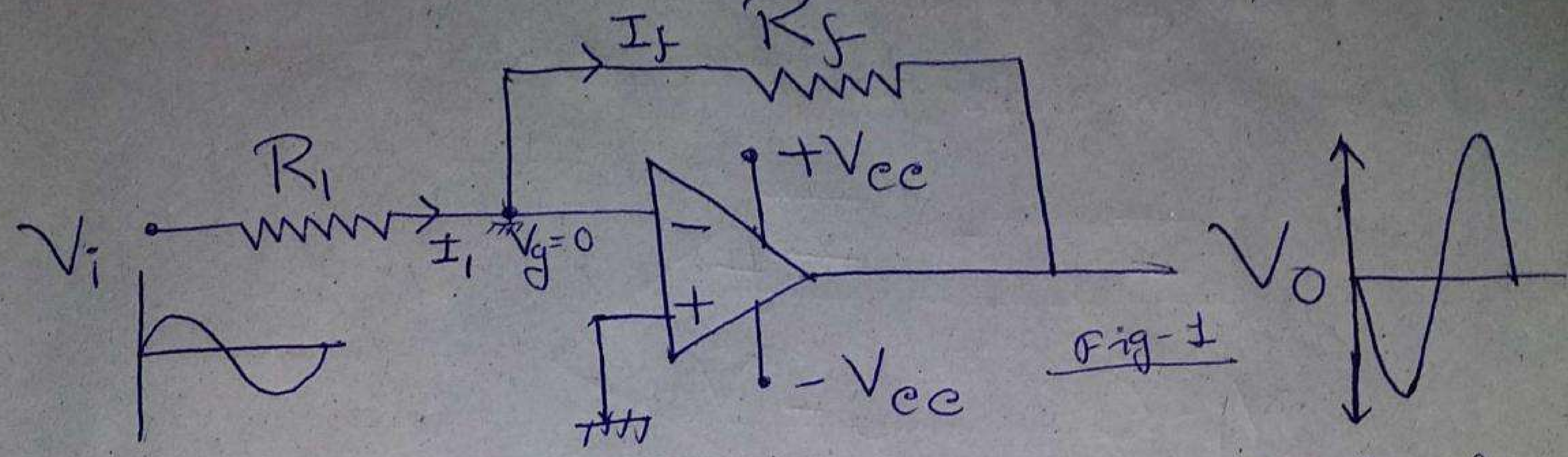


Fig-1

In this Inverting Amplifier circuit the operational amplifier is connected with feedback to produce a closed loop operation.

Here the i/p voltage V_i is connected to the negative terminal of the op-amp and the ~~posit~~ positive terminal is grounded. R_1 is called the i/p resistance b/w the input voltage and inverting terminal of the op-amp and the feedback resistance R_f is connected b/w the inverting terminal and O/P terminal of the op-amp. In this amplifier, the amplifier o/p is inverted and amplified. Here the o/p is 180° phase shift

Virtual ground :- In Op-Amps the term virtual ground means that the voltage at that particular node is almost equal to ground voltage (0V). It is not physically connected to ground. A virtual ground is a result of an op-amp trying to keep its two i/p terminals at the same potential when used in a feedback circuit. Real ground is when a terminal is connected physically to the ground or ~~eat~~ earthed to complete the circuit with phase.

According to the KCL

the entering currents in the circuit = the leaving currents ~~to~~ from the circuit.

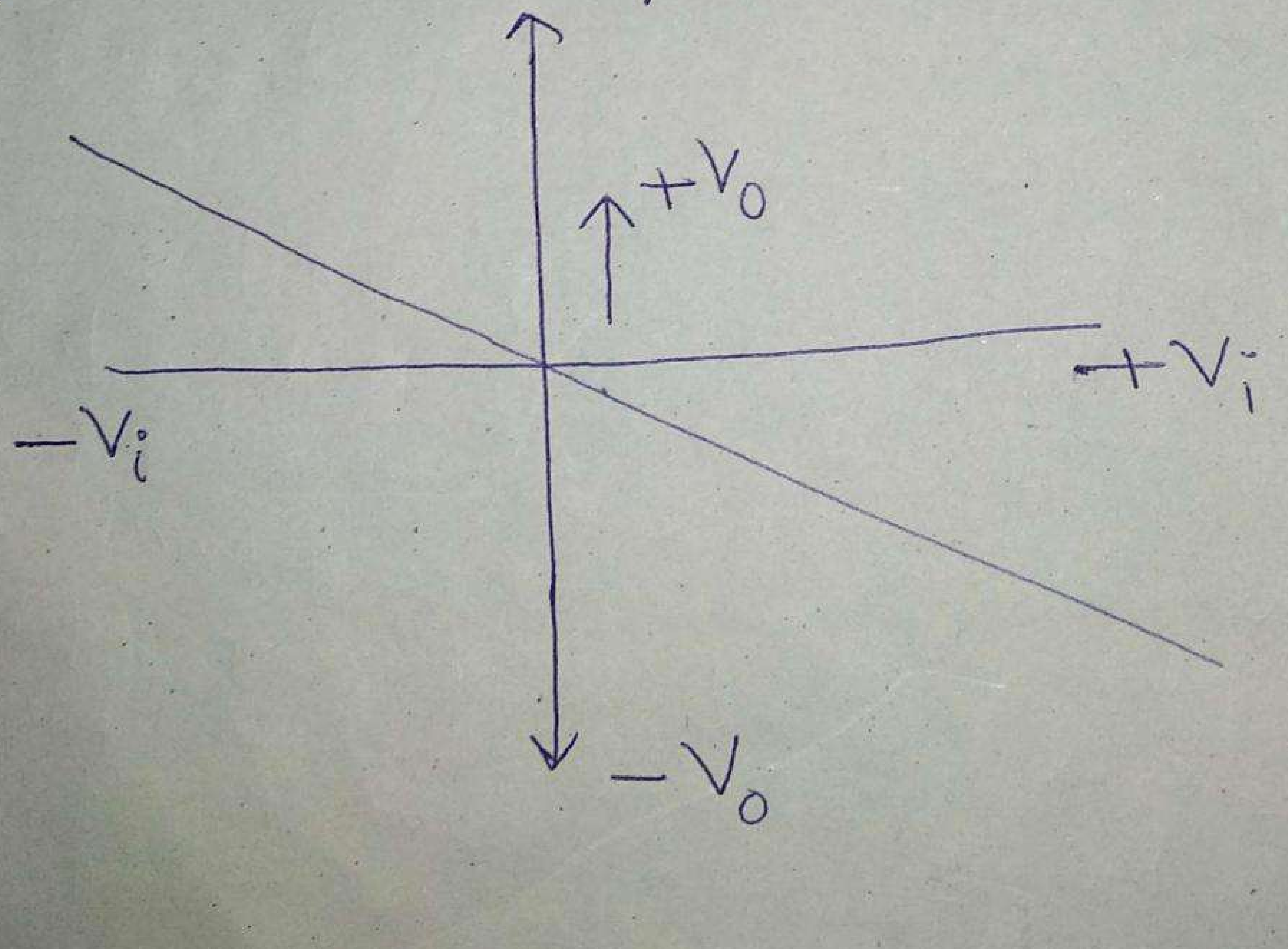
$$\therefore I_1 = I_f$$

$$\Rightarrow \frac{V_i - 0}{R_1} = \frac{0 - V_o}{R_f}$$

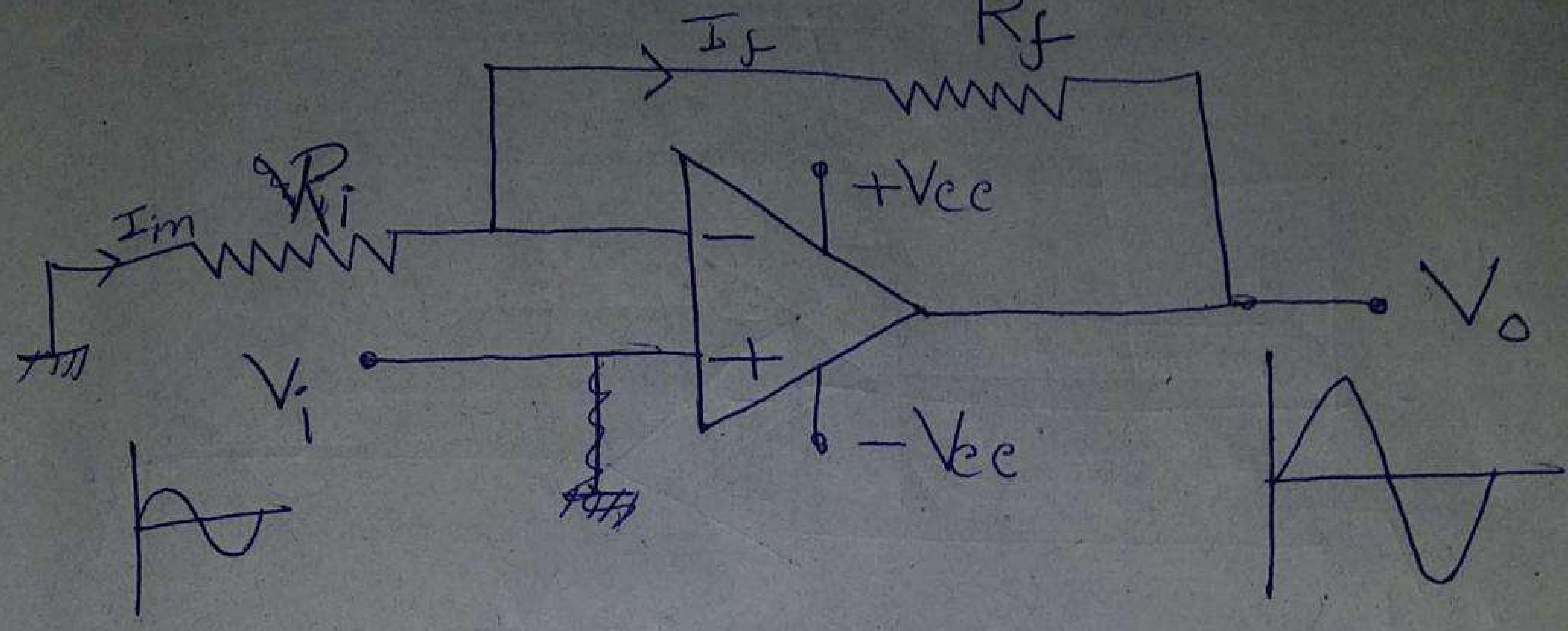
$$\Rightarrow \frac{V_i}{R_1} = -\frac{V_o}{R_f}$$

$$\Rightarrow \boxed{V_o = -\frac{R_f}{R_1} V_i}$$

$$\text{Gain} = A = \frac{V_o}{V_i} = -\frac{R_f}{R_1}$$



Non-Inverting Amplifier



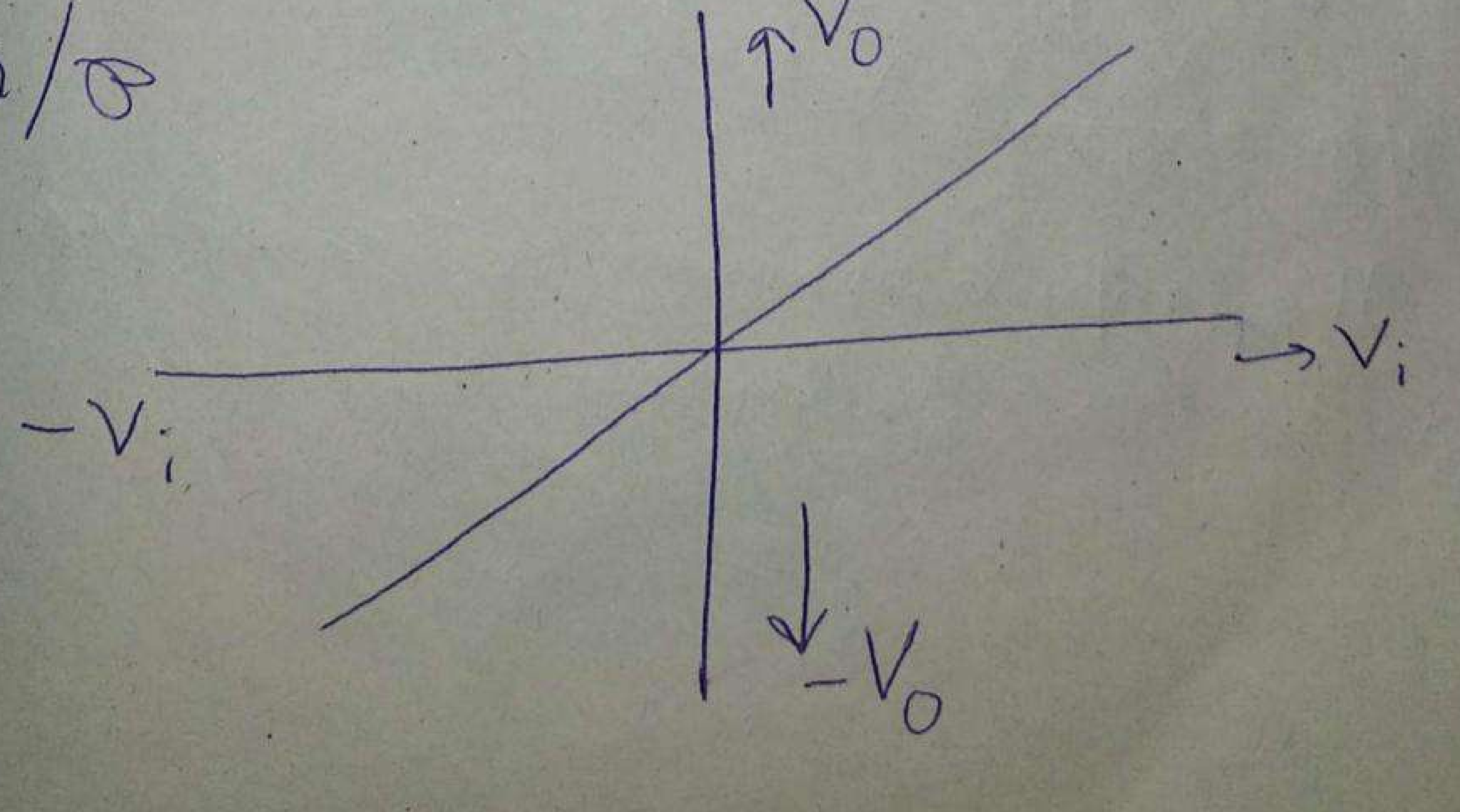
Here $$V_i = \frac{V_o R_f}{R_1 + R_f}$$

$$V_o = \left(\frac{R_1 + R_f}{R_1}\right) V_i$$

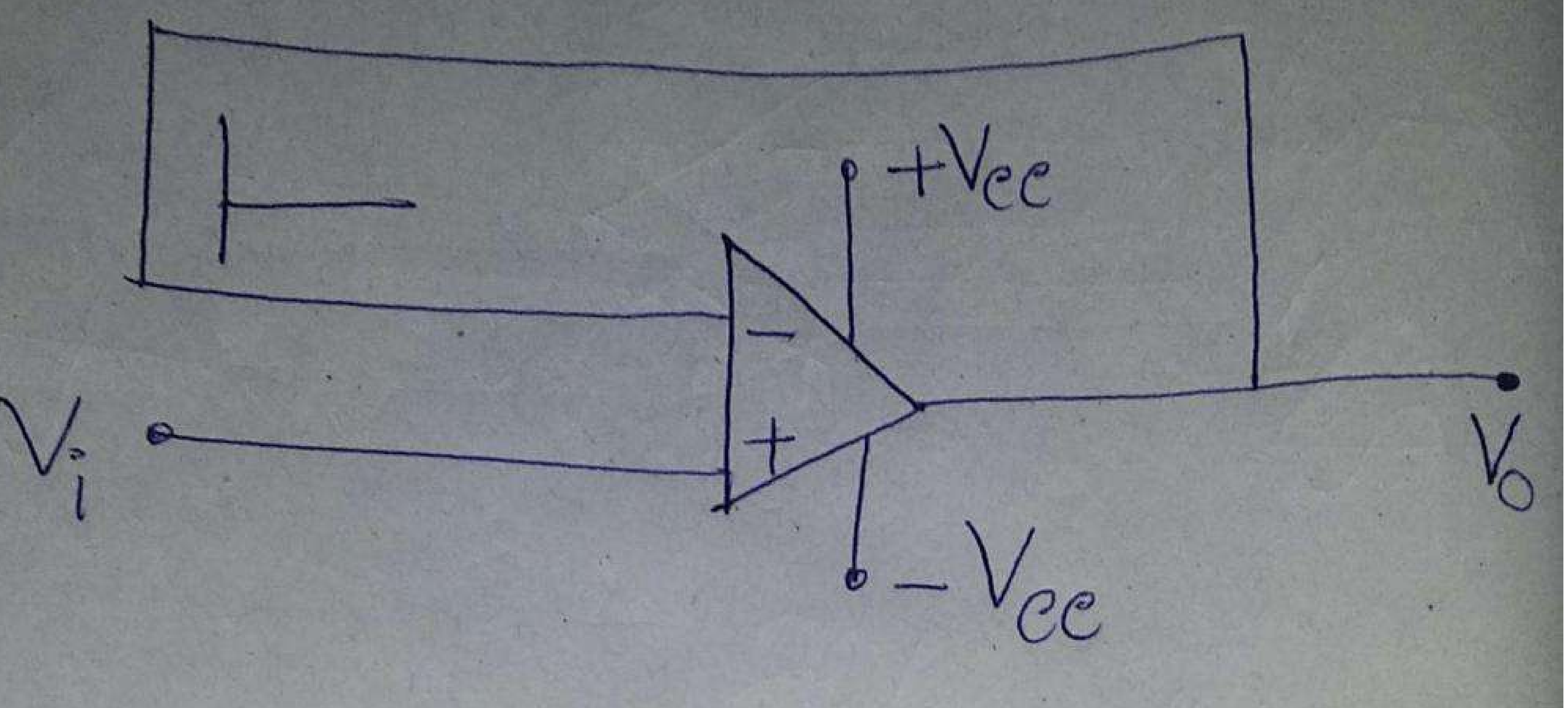
$$V_o = \left(1 + \frac{R_f}{R_1}\right) V_i$$

$$\text{gain} = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}$$

Here the o/p voltage is in phase to the i/p



Unity gain buffer / Voltage follower



A unity gain buffer / Voltage buffer:
~~Here~~ is a op-amp circuit which has a voltage gain of 1. This means that the op-amp doesnot provide any amplification to the signal. The reason it is called a unity gain buffer (or amplifier) is because it provides a gain of 1, meaning there is no gain, the o/p voltage signal is the same as the i/p ~~signal~~ voltage.

Here the input resistance is open and the feedback resistance closed.

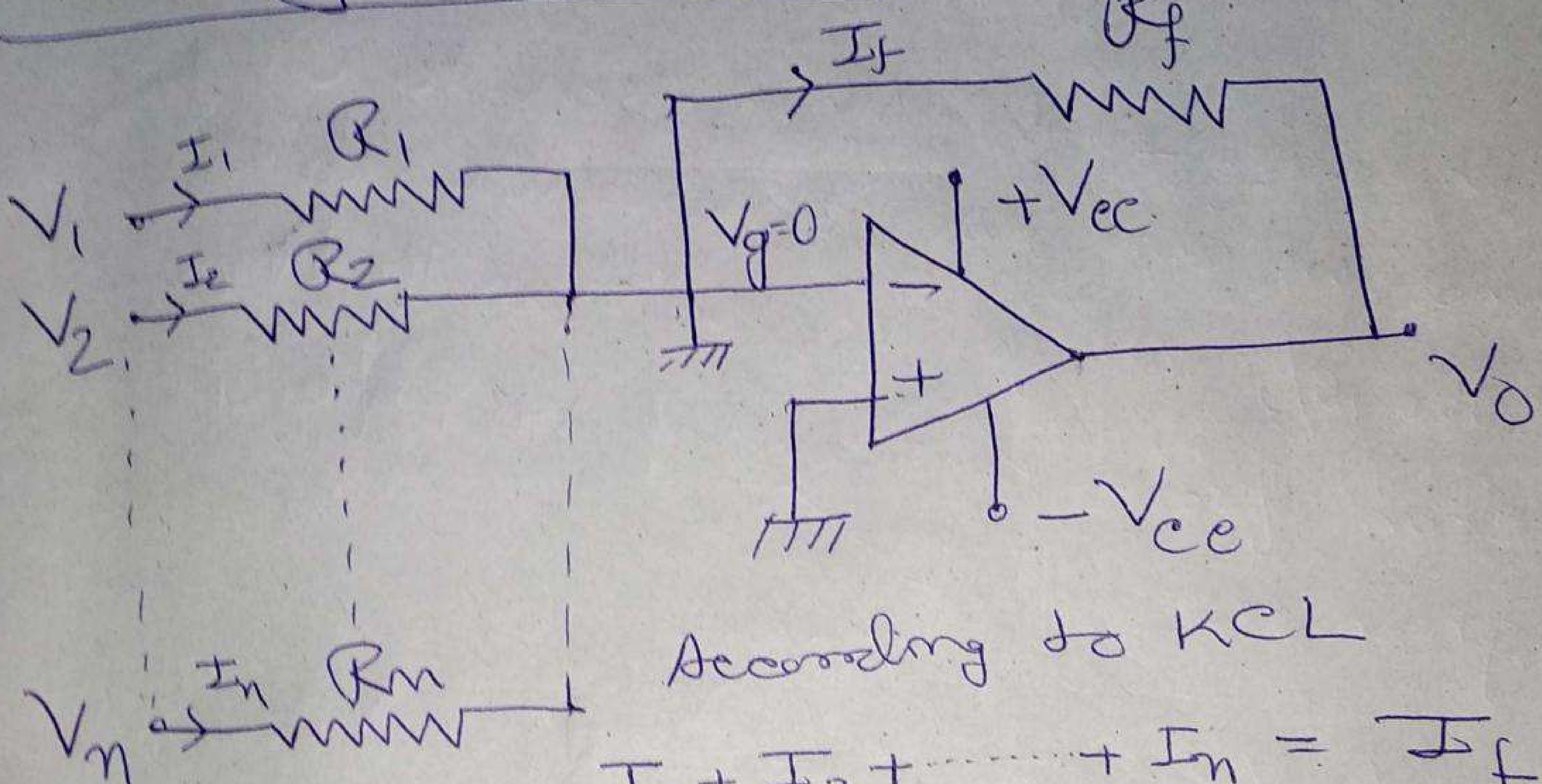
$R_1 = \alpha, R_f = 0$

$$V_0 = \left(1 + \frac{R_f}{R_1}\right) V_i$$

$$V_0 = \left(1 + \frac{0}{\alpha}\right) V_i$$

$$\boxed{V_0 = V_i}$$

Summing Amplifier :-



According to KCL

$$I_1 + I_2 + \cdots + I_n = I_f$$

$$\Rightarrow \frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n} = \frac{0 - V_0}{R_f}$$

$$\Rightarrow \frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n} = -\frac{V_0}{R_f}$$

$$\Rightarrow V_0 = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n}\right)$$

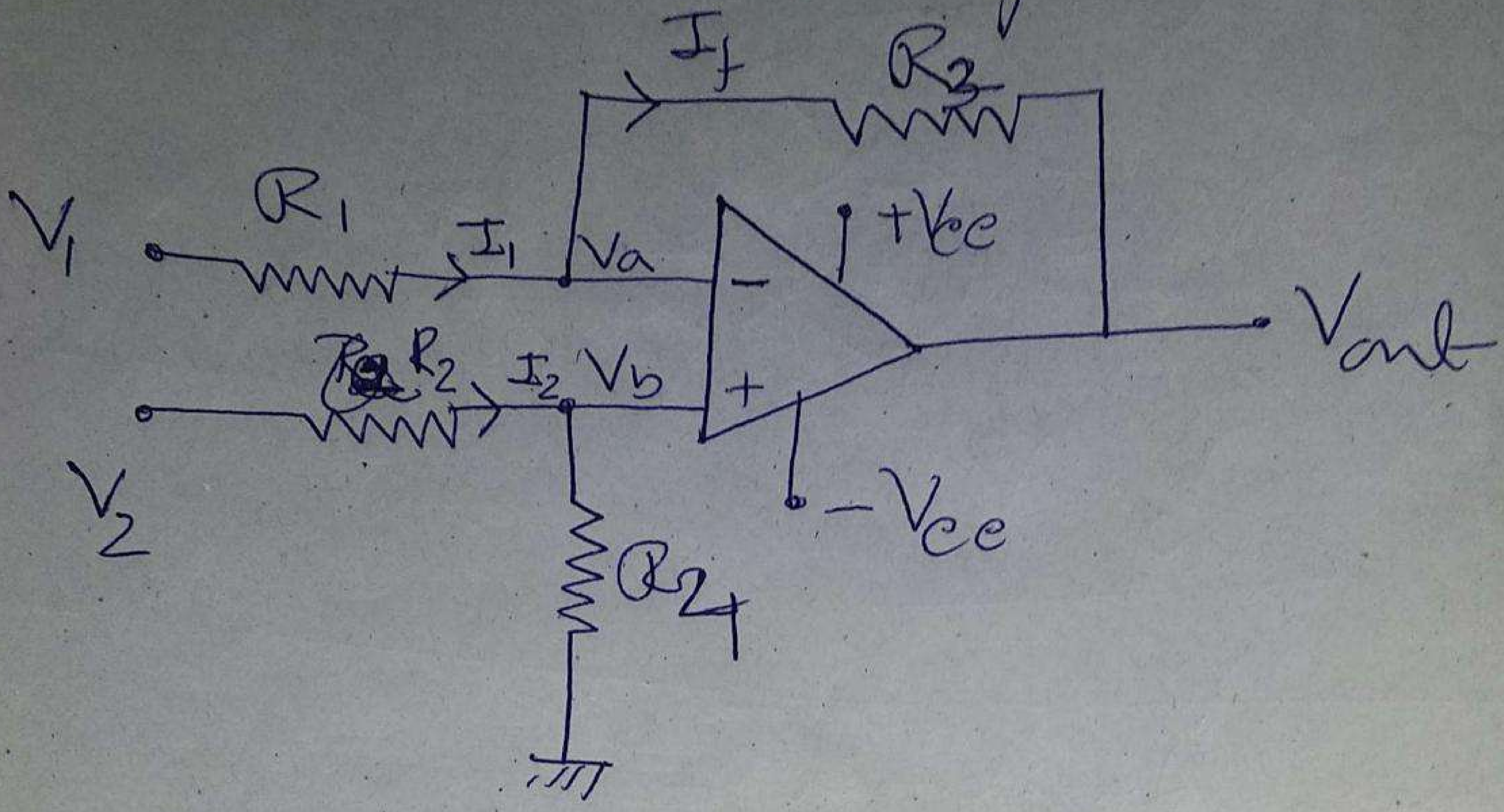
$\therefore R_1 = R_2 = \cdots = R_n = R$

$$\Rightarrow V_0 = -\frac{R_f}{R}(V_1 + V_2 + \cdots + V_n)$$

if $R_f = R$

$$\boxed{V_0 = -(V_1 + V_2 + \cdots + V_n)}$$

Differential Amplifier / Subtractor



By connecting each i/p in turn to 0V ~~ground~~ ground we can use superposition to solve for the o/p voltage V_{out}. Then the transfer function for a Differential Amplifier ckt is given as:

$$I_1 = \frac{V_1 - V_a}{R_1}, \quad I_2 = \frac{V_2 - V_b}{R_2},$$

$$I_f = \frac{V_a - V_{out}}{R_3}$$

Summing Point $V_a = V_b$

$$V_b = \frac{V_2 R_4}{R_4 + R_2}$$

If $V_2 = 0$ then $V_{out(a)} = -V_1\left(\frac{R_3}{R_1}\right)$

If $V_1 = 0$ $\quad V_{out(b)} = V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_1}\right)$

$$V_{out} = -V_{out(a)} + V_{out(b)}$$

$$= -V_1\left(\frac{R_3}{R_1}\right) + V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_1}\right)$$

When resistors, $R_1 = R_2$ and $R_3 = R_4$ the above transfer function for the differential amplifier can be simplified to the following expression

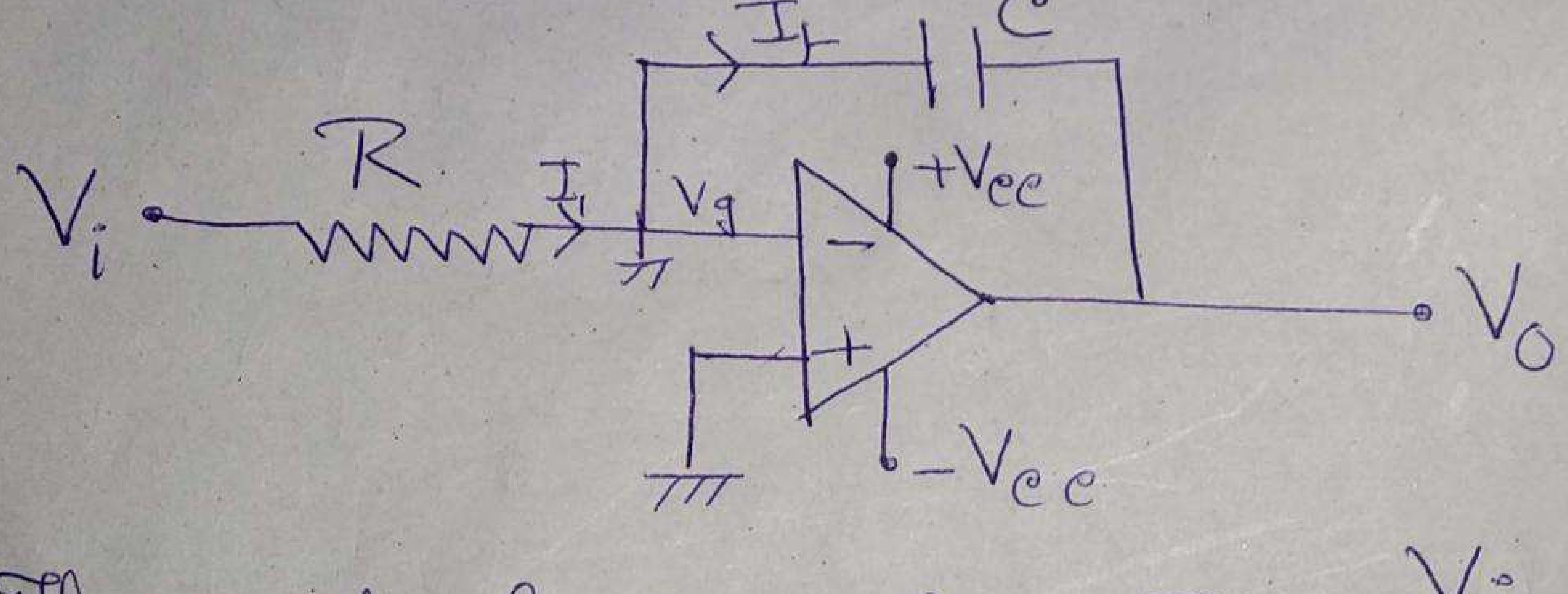
$$V_{out} = V_2\left(\frac{R_3}{\cancel{R_1 + R_3}}\right)\left(\frac{\cancel{R_1 + R_3}}{R_1}\right) - V_1\left(\frac{R_3}{R_1}\right)$$

$$V_{out} = V_2\left(\frac{R_3}{R_1}\right) - V_1\left(\frac{R_3}{R_1}\right)$$

$$\boxed{V_{out} = \frac{R_3}{R_1}\left(V_2 - V_1\right)}$$

If all the resistors are all of the same ohmic value, that is $R_1 = R_2 = R_3 = R_4$ then the circuit will become a Unity Gain Differential Amplifier and the voltage gain of the amplifier will be exactly one or unity. Then the o/p expression would simply be $\boxed{V_{out} = V_2 - V_1}$.

Op-AMP as Integrator



The input current $I_1 = \frac{V_i}{R}$

The feedback current $I_f = \frac{dq}{dt}$

$$\text{or, } I_f = -\frac{d(CV_0)}{dt}$$

$$\text{or, } I_f = C\frac{dV_0}{dt}$$

$\therefore \quad I_1 = I_f$

$$\Rightarrow \frac{V_i}{R} = -C\frac{dV_o}{dt}$$

$$\Rightarrow \frac{V_i}{RC} = -\frac{dV_o}{dt}$$

$$\Rightarrow \frac{dV_o}{dt} = -\frac{V_i}{RC}$$

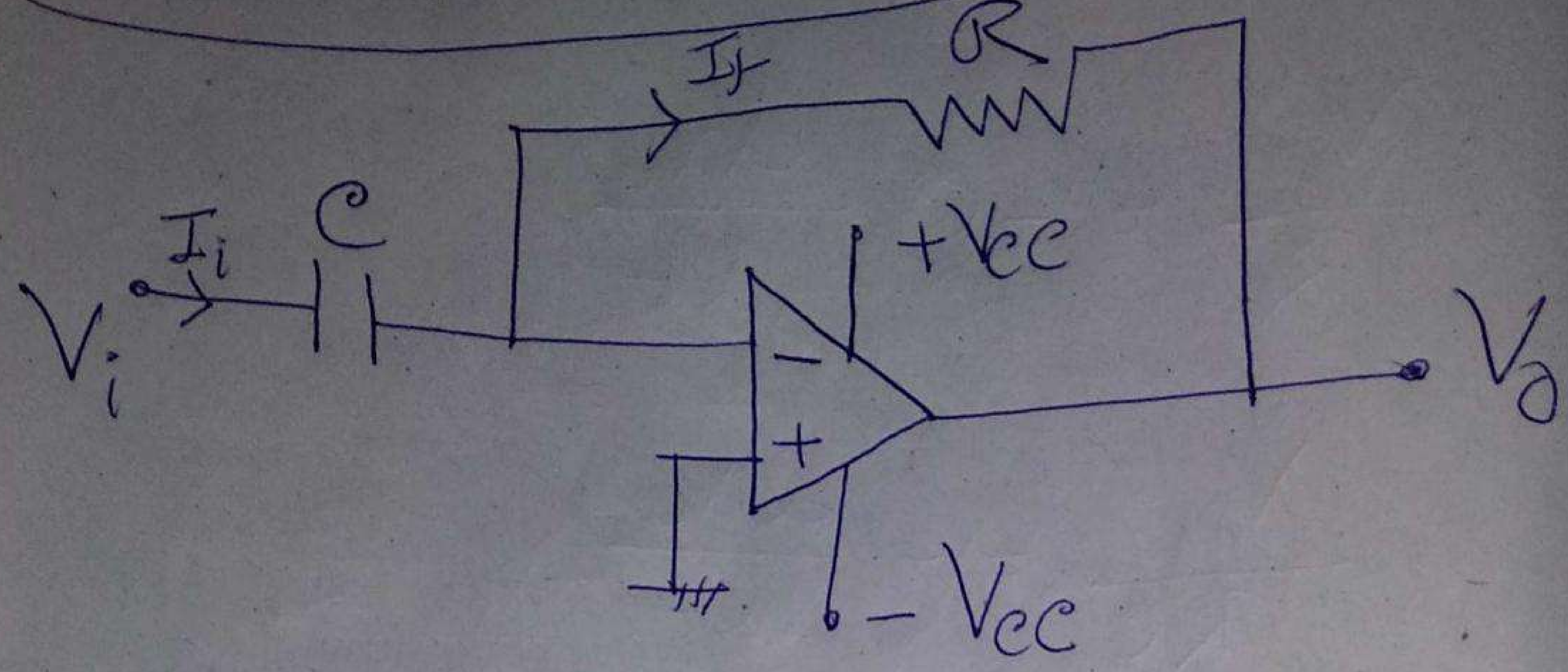
$$\Rightarrow \frac{dV_o}{dt} = -\frac{1}{RC}V_i$$

$$\Rightarrow dV_o = -\frac{1}{RC}V_i\,dt$$

$$\Rightarrow \int dV_o = -\frac{1}{RC}\int_0^t V_i\,dt$$

$$\Rightarrow \boxed{V_o = -\frac{1}{RC}\int_0^t V_i\,dt}$$

Op differentiator



$$I_1 = \frac{dq}{dt}$$

$$= \frac{d(CV_i)}{dt}$$

$$= C\frac{dV_i}{dt}$$

$$I_f = +\frac{0-V_0}{R} = -\frac{V_0}{R}$$

According to KCL

$$I_1 = I_f$$

or, $$C\frac{dV_i}{dt} = -\frac{V_0}{R}$$

or, $$\boxed{V_0 = -RC\frac{dV_i}{dt}}$$

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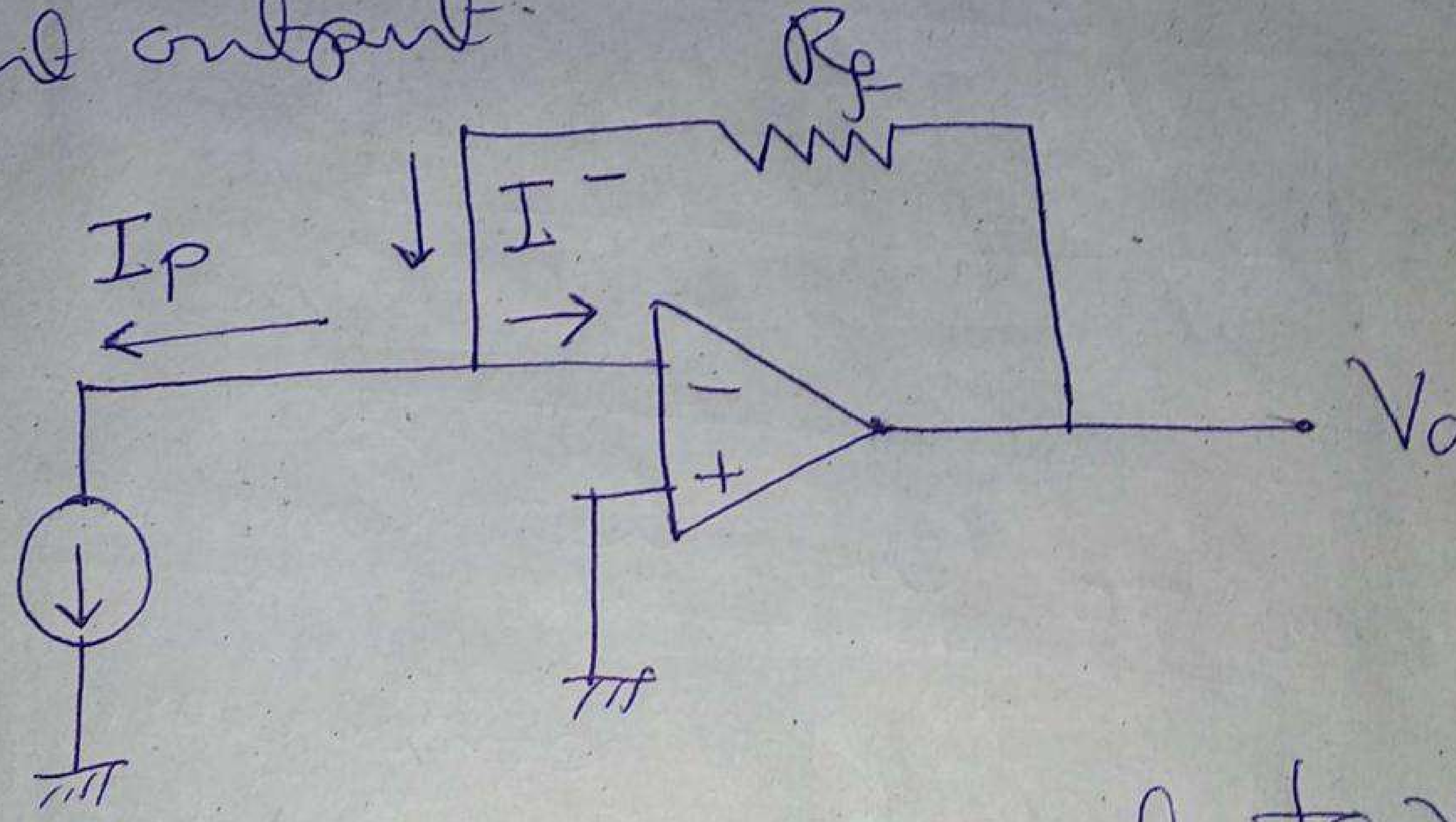
Current to Voltage Converter :-

A current to voltage converter will produce a voltage proportional to the given ~~circui~~ current. This circuit is ~~requi~~ required if your ~~measurm~~ measuring instrument is capable only of measuring the voltages and you need to measure the current output.



To analysis the current to voltage converter by inspection.

- If we apply KCL to the node at V^- (the inverting i/p) and let the i/p current to the inverting i/p be $I-$, then

$$\frac{V_{out} - V_-}{R_f} = I_p + I_-$$

• Since the output is connected to V - through R_f, the Op-Amp is in a negative feedback.

$$V_- = V_+ = 0$$

and ~~assumit~~ assuming that I^- is 0 and simplifying

$$\boxed{V_{out} = I_p R_f}$$

Voltage to Current Converter:-

Voltage to current converter in which load resistor R_L is floating (not connected to ground). Vin is applied to non-inverting input terminal, and the feedback voltage across R_1 devices the inverting input terminal.

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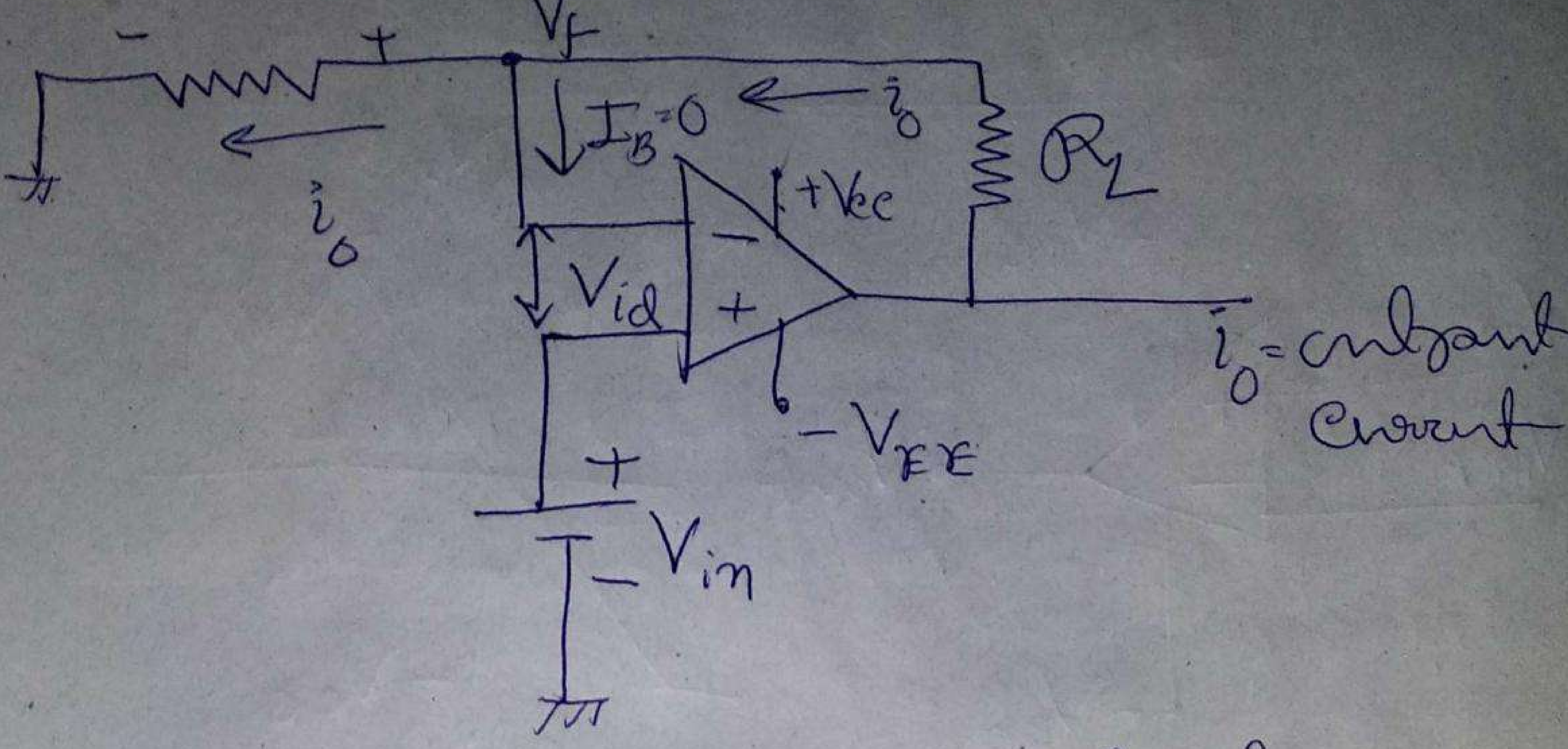


Writing KVL for the i/p loop.

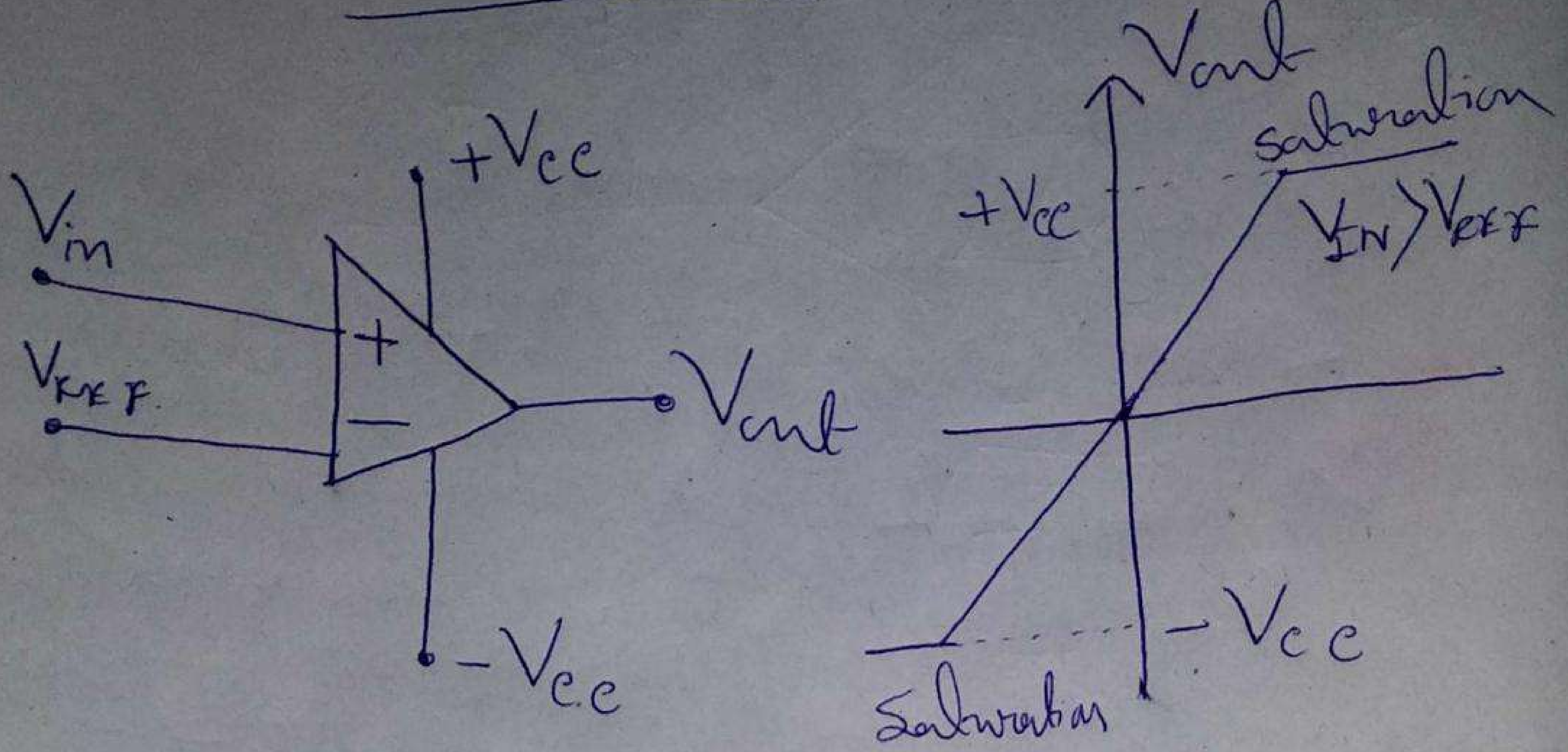
Voltage $V_{id} = V_f$ and $I_B = 0$,

$$v_i = R_L i_0$$

where $i_0 = V_i / R_L$

from the fig input voltage V_{in} is converted into output current of V_{in}/R_L. In other words, input volt appears across R_1. If R_L is a precision resistor, the output current $\left(i_0 = V_{in}/R_1 \right)$ will be precisely fixed.

Comparators



The Op-AMP comparator compares one analogue voltage level with another analogue voltage level or some present reference voltage, V_{REF} and produces an output signal based on this voltage comparison. In other words, the op-amp voltage comparator compares the magnitudes of two voltage i/ps and determines which is the largest of the two.

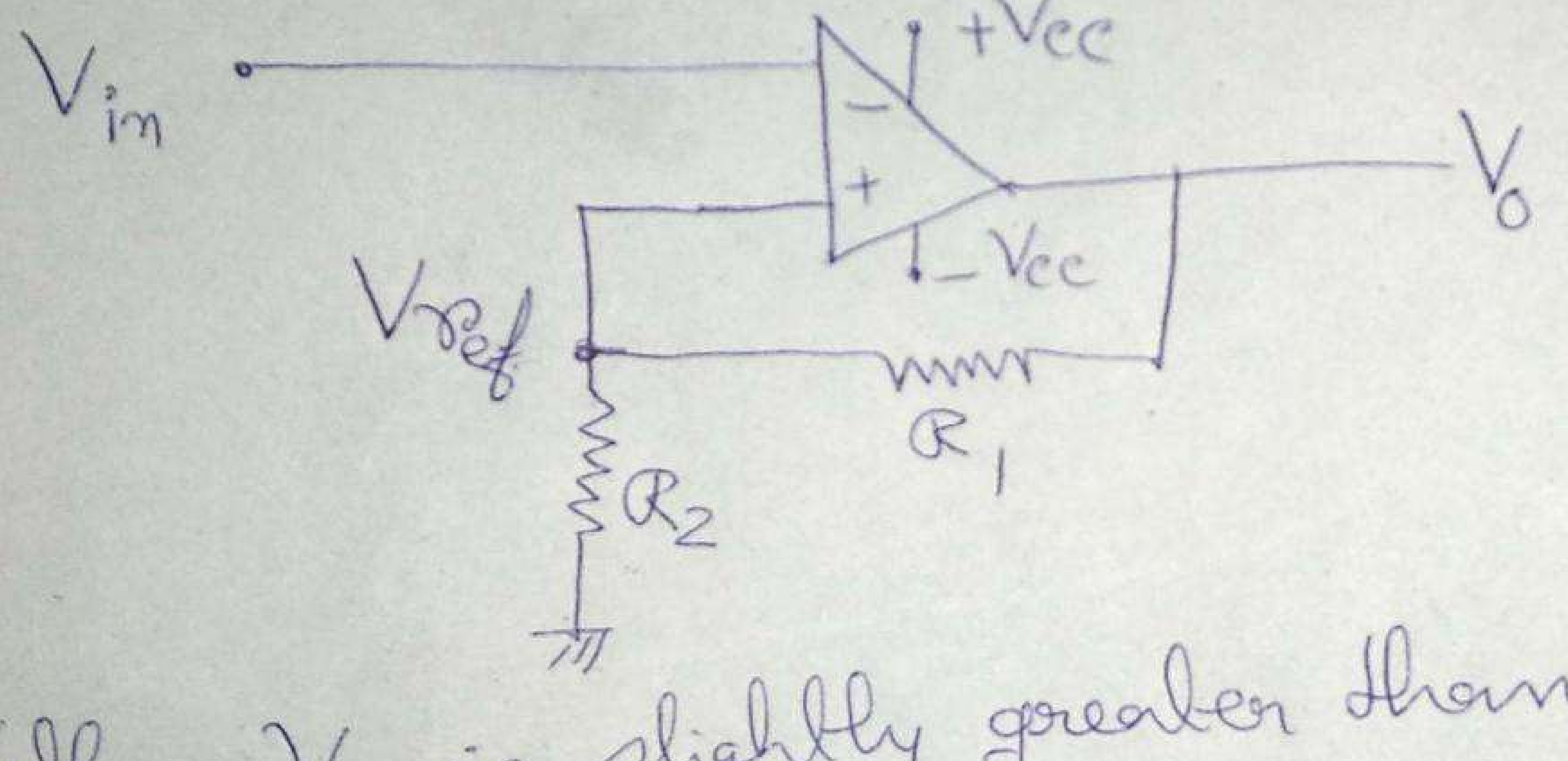
With reference to the op-amp comparator circuit above, lets first assume that V_{IN} is less than the DC voltage level at V_{REF}, ($V_{IN} < V_{REF}$). As the non-inverting (+ve) i/p of the comparator is less than the inverting (negative) i/p, the o/p will be LOW and at the negative supply voltage, $-V_{cc}$ resulting in a negative saturation of the o/p

If we now increase the i/p voltage, V_{IN} so that its value is greater than the reference voltage V_{REF} on the inverting i/p, the o/p voltage rapidly switch HIGH towards the +ve supply voltage, +Vcc resulting in a positive saturation of the o/p. If we reduce again the i/p voltage V_{IN}, so that it is slightly less than the reference voltage, the op-amp's o/p switches back to its negative saturation voltage acting as a threshold ~~dete~~ detector.

Schmitt Trigger

When operating an Op-Amp in the open loop mode where a feedback is not used, for example, in a Basic Comparator Circuit, the very large open loop gain of the Op-AMP will cause the smallest of noise voltage to trigger the comparator.

In an Inverting Schmitt Trigger, the i/p is applied to the inverting terminal of the Op-AMP. In this mode, the o/p produces is of opposite polarity.



When V_{IN} is slightly greater than V_{ref}, the o/p becomes $-V_{sat}$ and if V_{in} is slightly less than $-V_{ref}$, the o/p ~~bef~~ becomes V_{sat}. Hence the o/p voltage V_0 is either at V_{sat} or $-V_{sat}$ and the i/p voltage at which these state changes occur can be controlled using R_1 and R_2

The values of ~~V_{R2}~~ V_{ref} and $-V_{ref}$ can be formulated as:-

$$\cancel{V_{ref} = \frac{V_0 R_2}{R_1 + R_2}} \quad V_{ref} = \frac{V_0 R_2}{R_1 + R_2},$$

$$V_0 = V_{sat}$$

Hence $$V_{ref} = \frac{V_{sat} \times R_2}{R_1 + R_2}$$

$$-V_{ref} = \frac{V_0 R_2}{R_1 + R_2}$$

$$V_0 = -V_{sat}$$

$$\text{"}, \quad -V_{ref} = -\frac{V_{sat} R_2}{R_1 + R_2}$$

The reference voltage V_{ref} and $-V_{ref}$ are called Upper Threshold Voltage V_{UT} and Lower Threshold Voltage V_{LT}.

The following image shows the output voltage versus i/p voltage graph, also known as the Transfer Characteristic of Schmitt Trigger.