Problems of Op-Amp.

Problem 1. An op-Amp has CMRR of 90dB. If its differential voltage gain is 3×10^4. Calculate its common mode voltage gain.

Soln: $CMRR = \left|\frac{A_d}{A_c}\right|$

where A_d = difference mode voltage gain

and A_c = Common mode voltage gain of op-Amp.

In dB

$$CMRR = 20\log_{10}\left|\frac{A_d}{A_c}\right|$$

$$= 20\log_{10}\left|\frac{3\times10^4}{A_c}\right|$$

$$\Rightarrow 90 = 20\log_{10}\left|\frac{3\times10^4}{A_c}\right|$$

$$\Rightarrow 9 = 2\left[\log_{10} 3\times10^4 - \log_{10} A_c\right]$$

$$\Rightarrow \left[4\log_{10}10 + \log_{10}3 - \log_{10}A_c\right] = 9/2$$

$$\Rightarrow 4 + 0.477 - \log_{10}A_c = 4.5$$

$$\Rightarrow -\log_{10}A_c = 4.5 - 4.477 = 0.023$$

$$\Rightarrow +\log_{10}A_c = -0.023 \Rightarrow A_c = 10^{-0.023} = 0.9484$$

$$\boxed{\therefore A_c = 0.9484}$$

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Problem 2 : Find the expression of the output voltage v_o of the following circuit of Fig-1.

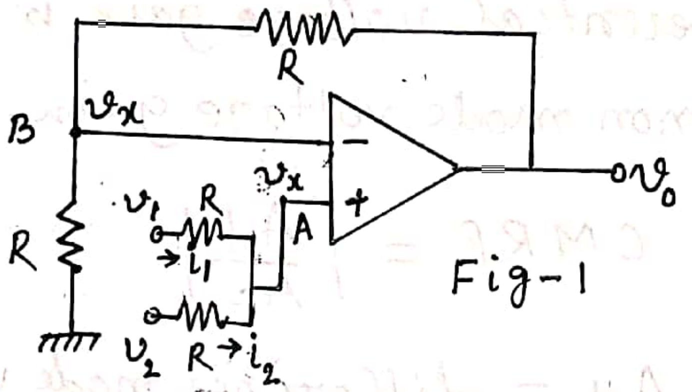

Fig-1

Soln : Let v_x be the potential at A. v_x is also the potential at B as per characteristic of an ideal op-Amp.

$$\therefore \; i_1 = \frac{v_1 - v_x}{R} \text{ and } i_2 = \frac{v_2 - v_x}{R}$$

$$\therefore \; i = i_1 + i_2 = 0$$ [No current will flow into the op-Am because op-Amp has infinite input impedance or resistance]

$$\therefore \; \frac{v_1 - v_x}{R} + \frac{v_2 - v_x}{R} = 0$$

$$\Rightarrow \frac{v_1}{R} - \frac{v_x}{R} + \frac{v_2}{R} - \frac{v_x}{R} = 0$$

$$\Rightarrow -2v_x = -(v_1 + v_2) \Rightarrow v_x = \frac{1}{2}(v_1 + v_2)$$

On the basis of the concept of non-inverting amplifier, the output voltage is

$$v_0 = \left(1 + R/R\right) v_x = 2 \times \frac{1}{2}(v_1 + v_2) = v_1 + v_2$$

$$\Rightarrow \boxed{v_0 = v_1 + v_2}$$

Problem 3: Design a differential amplifier using op-Amp which will give an output voltage $v_0 = 0.5v_1 - 2v_2$ where v_1 and v_2 are inputs of non-inverting and inverting termins respectively

Soln:

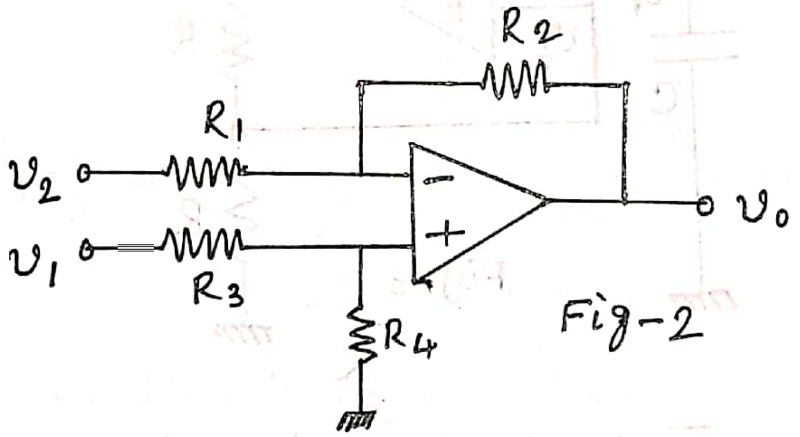

Fig-2

The expression of output v_0 is given by

$$v_0 = \left(\frac{R_1 + R_2}{R_3 + R_4}\right)\frac{R_4}{R_1} v_1 - \frac{R_2}{R_1} v_2$$

Let $R_2 = 2R_1$ and $R_3 = 5R_4$

$$\therefore v_0 = \left(\frac{R_1+2R_1}{R_4+5R_4}\right)\cdot\frac{R_4}{R_1}v_1 - \frac{2R_1}{R_1}v_2$$

$$\Rightarrow v_0 = \frac{3}{6}v_1 - 2v_2$$

$$\Rightarrow \boxed{v_0 = 0.5v_1 - 2v_2}$$

Problem 4 : Find the expression of v_0 of the circuit shown in Fig-3.

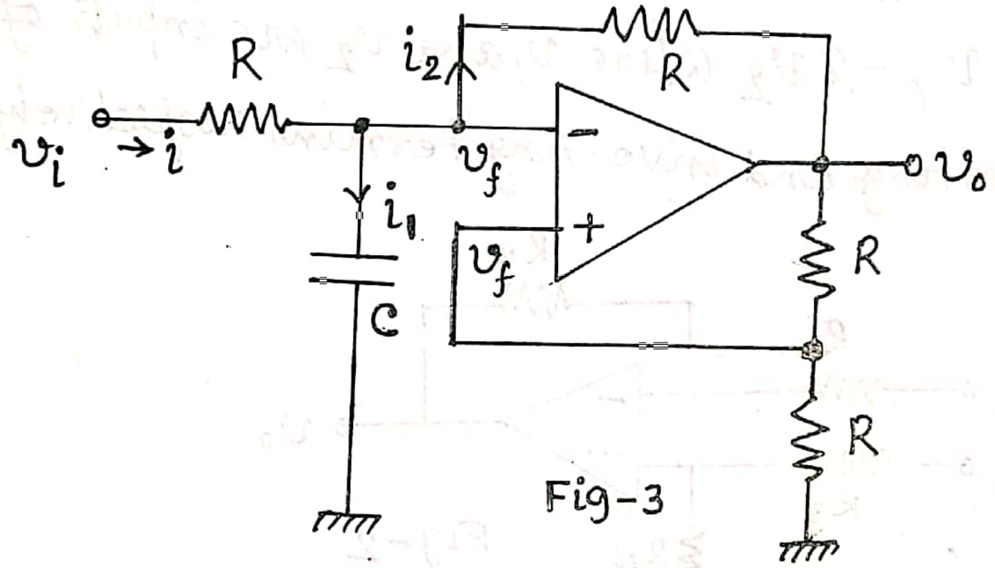

Fig-3

Sol$\underline{n}$: On the basis of the circuit we can write

$$v_f = \frac{v_0 R}{R+R} = \frac{v_0}{2}$$

Again $\quad i = i_1 + i_2$

$$\therefore \frac{v_i - v_f}{R} = \frac{v_f - 0}{\frac{1}{sC}} + \frac{v_f - v_o}{R}$$

Let $r = e^{j\omega t}$

$\therefore \frac{dr}{dt} = j\omega e^{j\omega t} = j\omega r$

$\therefore \frac{d}{dt} = j\omega = s$

$\therefore \frac{1}{s} = \int dt$

$$\Rightarrow \frac{v_i - v_f}{R} = \frac{v_f}{\frac{1}{sC}} + \frac{v_f - v_o}{R}$$

$$\Rightarrow v_i - v_f = sCR\, v_f + v_f - v_o$$

$$\Rightarrow v_i = sCR\, v_f + 2v_f - v_o$$

$$= (sCR + 2)\, v_f - v_o$$

$$= (sCR + 2)\, \frac{v_o}{2} - v_o$$

$$= v_o \left\{ \frac{sCR}{2} \right\}$$

$$\therefore v_o = \frac{2}{CR} \cdot \frac{1}{s}\, v_i = \frac{2}{CR} \int v_i\, dt$$

$$\therefore \boxed{v_o = \frac{2}{CR} \int v_i\, dt}$$

Problem 5: An operational amplifier has an open-loop gain of 10^6 and open-loop upper cut-off frequency of 10 Hz. If the op-Amp is connected as an amplifier with a closed-loop gain of 100, what will be the new upper cut-off frequency?

Sol^n: Negative feedback amplifier always increases the upper cut-off frequency and hence increases the bandwidth of the amp.

The close-loop gain is $A_f = \dfrac{A}{1+\beta A}$

Here $A = 10^6$ and $A_f = 100$ and upper cut-off frequency $f_2 = 10\ Hz$

$$\therefore (1+\beta A) = \frac{A}{A_f} = \frac{10^6}{10^2} = 10^4$$

$\therefore$ Upper cut-off frequency of close-loop amplifier is

$$f_{2f} = f_2(1+A\beta) = 10 \times 10^4\ Hz$$
$$= 100\ KHz$$

Problem 6: Find the output v_o of the following circuit of Fig-4

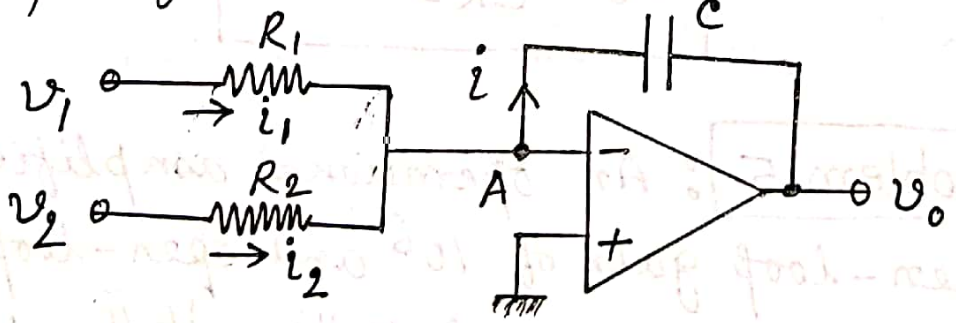

Fig-4: Summing integrator

Soln : The point A is at virtual ground so that:
$v_A = 0$ (op-Amp is used in inverting mode).

Now $i_1 + i_2 = i$

$$\Rightarrow \frac{v_1 - v_A}{R_1} + \frac{v_2 - v_A}{R_2} = \frac{v_A - v_o}{\frac{1}{sC}}$$

$$\Rightarrow \frac{v_1}{R_1} + \frac{v_2}{R_2} = -sC\,v_o$$

$$\Rightarrow v_o = -\frac{1}{sCR_1}v_1 - \frac{1}{sCR_2}v_2$$

$$\Rightarrow \boxed{v_o = -\frac{1}{C}\int\left(\frac{v_1}{R_1} + \frac{v_2}{R_2}\right)dt}$$

Problem 7 : Prove That The operational amplifier circuit as shown in Fig-5 is an integrator. Assuming op-Amp is an ideal one.

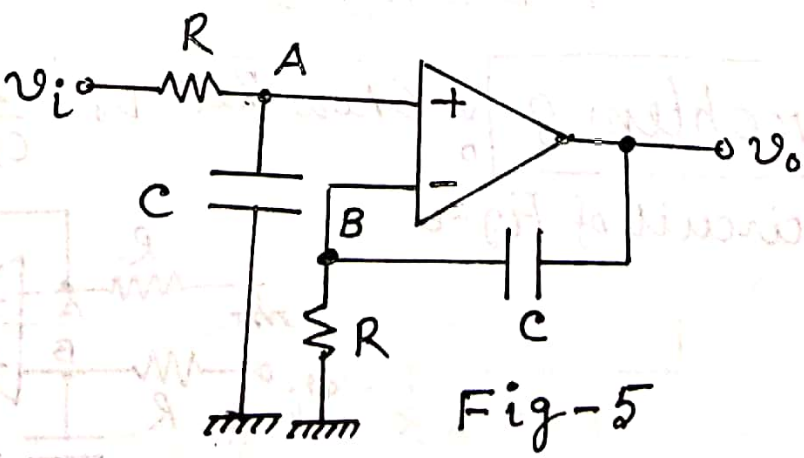

Fig-5

Sol^n: The voltage at the node A is

$$v_A = \frac{\frac{1}{sc}}{R+\frac{1}{sc}} v_i = \frac{1}{1+sCR} v_i \quad \text{---} (1)$$

As op-Amp is an ideal one $v_A = v_B = \frac{1}{1+sCR} v_i$

For non-inverting mode of op-Amp, the output voltage is

$$v_o = \left(1 + \frac{\frac{1}{sc}}{R}\right) v_A$$

$$= \frac{1+sCR}{sCR} v_A$$

$$= \frac{(1+sCR)}{sCR} \cdot \frac{v_i}{(1+sCR)} \quad \text{(using (1))}$$

$$= \frac{v_i}{sCR} = \frac{1}{CR}\int v_i(t)\,dt$$

as $\frac{1}{s} = \int dt$

Problem 8: Show that $v_o = \frac{2}{CR}\int v_i\, dt$ of the circuit of Fig-6

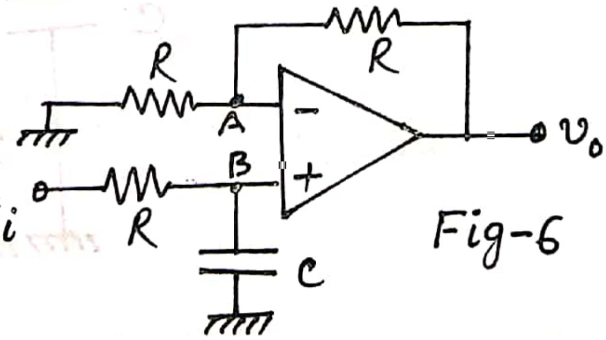

Fig-6

Soln:
$$v_B = \frac{\frac{1}{sC}}{R+\frac{1}{sC}} v_i = \frac{1}{1+sCR} v_i$$

We assume The op-Amp is an ideal one Then

$$v_A = v_B = \frac{1}{1+sCR} v_i$$

Considering The non-inverting op-Amp we can write The output voltage

$$v_0 = \left(1+\frac{R}{R}\right) v_B = 2v_B$$

$$= \frac{2}{1+sCR} v_i$$

assuming $sCR >> 1$

$$v_0 = \frac{2}{CR} \cdot \frac{1}{s} v_i = \frac{2}{CR}\int v_i\, dt$$

Problem 9: Calculate The output voltage v_o of The circuit of Fig-7

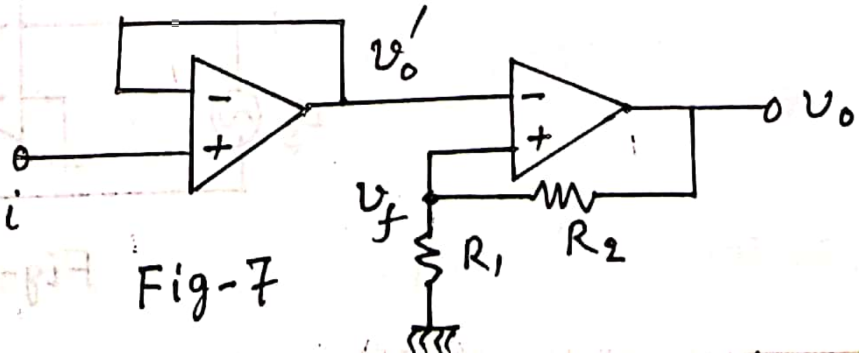

Fig-7

Soln :- Since the 1st stage is a unity gain buffer so that $v_o' = v_i$

Now $v_f = \dfrac{v_o R_1}{R_1 + R_2}$

For an ideal op-Amp $v_f = v_o' = v_i$

$$\therefore \frac{v_o R_1}{R_1+R_2} = v_i$$

$$\Rightarrow v_o = \left(\frac{R_1+R_2}{R_1}\right) v_i = \left(1+\frac{R_2}{R_1}\right) v_i$$

$$\therefore \boxed{v_o = \left(1+\frac{R_2}{R_1}\right) v_i}$$

Problem 10 : A feedback amplifier circuit is shown in fig – 8 with the gain of amplifier $A = 100\angle 180^\circ$, $R_1 = 10\,K\Omega$ and $R_2 = 150\,K\Omega$. Calculate output voltage and source voltage when input voltage of amplifier is $1\angle 0^\circ$

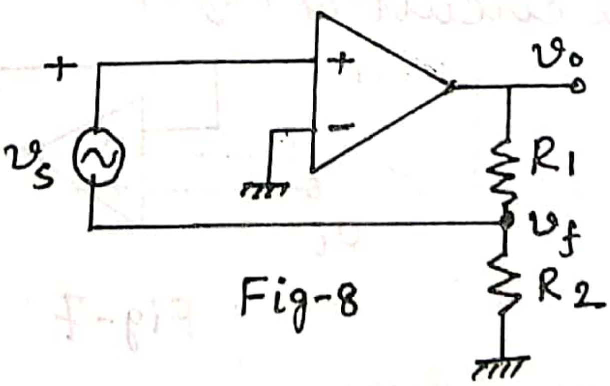

Fig-8

Sol^n: The given circuit Configuration is voltage series feedback. The feedback voltage is

$$v_f = \frac{R_2}{R_1+R_2} v_o = \frac{150}{160} v_o = \beta v_o$$

The feedback path gain is $\beta = \frac{150}{160}$

The overall voltage gain

$$A_f = \frac{v_o}{v_s} = \frac{A}{1+\beta A} = \frac{100\angle 180^\circ}{1+\frac{150}{160}\times 100\angle 180^\circ}$$

$$= \frac{-100}{1+\frac{150}{160}\times(-100)}$$

$$= 1.078$$

Hence $v_o = 1.078\, v_s$

The input voltage of the basic amplifier is

$$v_i = v_s - v_f = v_s - \beta v_o$$

$$= v_s - \frac{150}{160}\times 1.078\, v_s$$

$$= -0.010625\, v_s$$

As $v_i = 1\angle 0^\circ$, The source voltage is

$$v_s = -\frac{v_i}{0.010625} = -\frac{1\angle 0^\circ}{0.010625} = -94.11\angle 0^\circ$$

$$\therefore v_o = 1.078\, v_s = 1.078\times(-94.11\angle 0^\circ) = -101.45\angle 0^\circ$$

Problem 11: An amplifier has a gain of -100 and feedback ratio is $\beta = -0.05$. Determine (1) The close-loop voltage gain (2) The amount of feedback in dB (3) The feedback factor and (4) feedback voltage. Assume $v_s = 50\,mV$

Soln: Given $A = -100$, $\beta = -0.05$

(1) Close-loop voltage gain $A_f = \dfrac{A}{1+\beta A} = \dfrac{-100}{1+(-0.05)\times(-100)}$

$$= -16.67$$

(2) Amount of feedback in dB $= 20\log_{10}\left|\dfrac{A_f}{A}\right|$

$$= 20\log_{10}\left|\frac{-16.67}{-100}\right|$$

$$= 20\left[\log_{10}16.67 - \log_{10}10^2\right]$$

$$= 20\left[1.223 - 2\right]$$

$$= -15.56\,dB$$

(3) The feedback factor or feedback gain

$$\beta A = (-100)\times(-0.05) = 5$$

(4) $v_f = \beta v_o = \beta A_f v_s = (-0.05)\times(-16.67)\times 50\,mV = 41.675\,mV$

Problem 12: In a voltage-series feedback amplifier $A = 400$, $R_i = 2K$ & $R_o = 100K\Omega$ and $\beta = 0.1$, determine overall gain, input resistance and output resistance of the feedback amplifier.

Soln: Given $A = 400$, $R_i = 2K\Omega$, $R_o = 100K\Omega$ and $\beta = 0.1$.

In voltage-series feedback amplifier

overall gain is $A_f = \frac{A}{1+A\beta} = \frac{400}{1+0.1\times400} = 9.756$ --(1)

Input resistance $R_{if} = R_i(1+A\beta)$ --(2)

$= 2\times10^3\times(1+0.1\times400)$

$= 82\ K\Omega$

output resistance $R_{of} = \frac{R_o}{1+A\beta} = \frac{100\times10^3}{1+0.1\times400}$ --(3)

$= 2.439\ K\Omega$

All three expressions for A_f, R_{if} and R_{of} are also applicable to current-series feedback amplifiers. They are $A_f = \frac{A}{1+A\beta}$; $R_{if} = R_i(1+A\beta)$ and

$R_{of} = R_o(1+A\beta)$.

Problem 13: Determine overall gain, input impedance and output impedance of a voltage-shunt feedback amplifier. Assume the following parameters of feedback amplifier. open-loop gain $A = -1000$, input resistance $R_i = 10\,K\Omega$, output resistance $R_o = 20\,K\Omega$ and $\beta = -0.1$.

Soln:

$$A_f = \frac{A}{1+A\beta} = \frac{-1000}{1+(-0.1)\times(-1000)}$$
$$= -9.90$$

$$R_{if} = \frac{R_i}{1+A\beta} = \frac{10\,K\Omega}{1+(-0.1)\times(-1000)}$$
$$= 99\,\Omega$$

$$R_{of} = \frac{R_o}{1+A\beta} = \frac{20\times10^3}{1+(-0.1)\times(-1000)}$$
$$= 198\,\Omega$$

Problem 14: Compute the input and output impedances for an amplifier in a current-shunt feedback configuration with $A = 500$, $R_i = 1000\,\Omega$, $R_o = 5000\,\Omega$ and $\beta = 0.075$

Soln: Given $A = 500$, $R_i = 1000\,\Omega$, $R_o = 5000\,\Omega$ and $\beta = 0.075$

In current-Shunt Configuration feedback amplifier

$$R_{if} = \frac{R_i}{1+A\beta} = \frac{1000\,\Omega}{1+0.075\times 500}$$
$$= 25.97\,\Omega$$

$$R_{of} = R_o(1+A\beta) = 5000\times(1+0.075\times 500)\,\Omega$$
$$= 192.5\,K\Omega.$$

Voltage Series Negative Feedback Amplifier:

Non-inverting op-Amp:

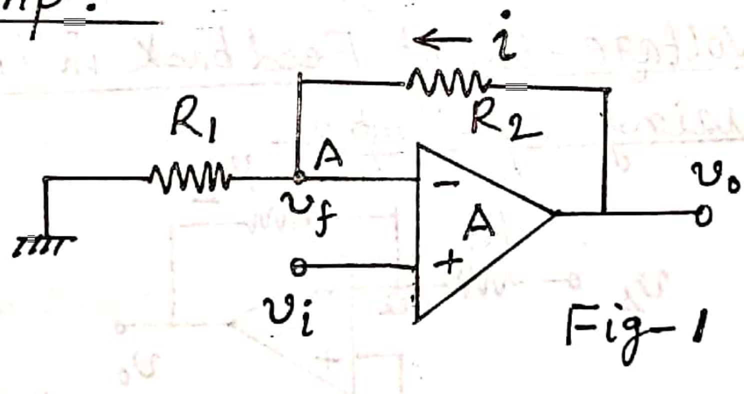

Fig-1

From Fig-1

$$i = \frac{v_o - v_f}{R_2} = \frac{v_f}{R_1}$$

$$\Rightarrow v_f = \frac{R_1}{R_1+R_2} v_o = \beta v_o$$

where $\beta = \dfrac{v_f}{v_o}$ = feedback factor for voltage-series feedback

Let A and $(v_i - v_f)$ be the open-loop voltage gain and differential input to basic amplifier respectively.

$$\therefore v_o = A(v_i - v_f) = A(v_i - \beta v_o)$$

$$\Rightarrow v_o(1+A\beta) = A v_i$$

Therefore close-loop voltage gain of the voltage-series amplifier is

$$A_f = \frac{v_o}{v_i} = \frac{A}{1+A\beta} = \frac{1}{\frac{1}{A}+\beta}$$

In the limit $A \to \infty$; $A_f = \frac{1}{\beta} = \frac{R_1+R_2}{R_1}$

$$\boxed{\therefore A_f = \frac{R_1+R_2}{R_1} = 1+\frac{R_2}{R_1}}$$

Voltage-Shunt Feedback in inverting amplifier using op-Amp :-

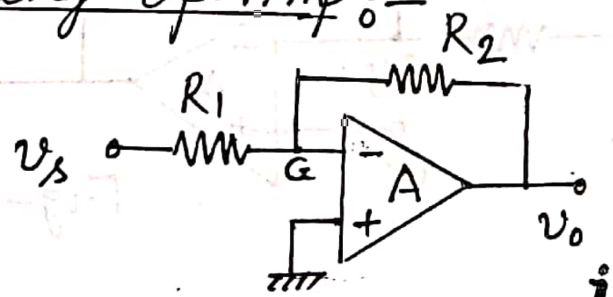

Fig-2

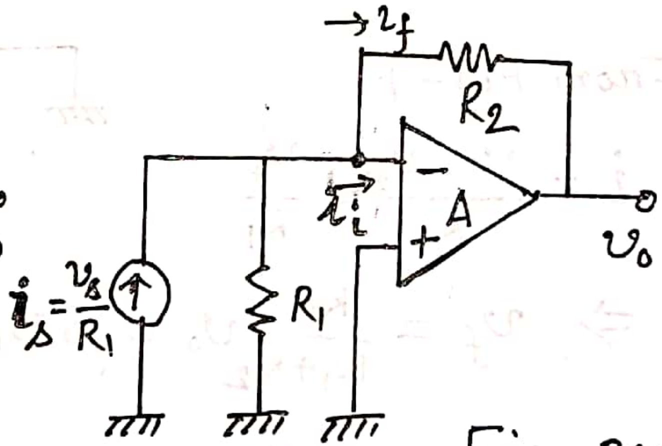

Fig-2(a)

Fig-2 shows the voltage-shunt feedback. Its equivalent circuit is shown in Fig-2(a)

The gain of the amplifier

$$A = \frac{v_o}{i_i}\ ; \quad A \to \infty \text{ as } i_i \to 0$$

The feedback gain is $\beta = \frac{i_f}{v_o} = -\frac{1}{R_2}$

The block-diagram representation of Fig-2(a) is shown in Fig-2(b).

The overall loop gain is

$$A_f = \frac{v_o}{i_s} =$$

$$= \frac{A}{1+A\beta}$$

$$= \frac{A}{1 - A/R_2}$$

$$= \frac{1}{\frac{1}{A} - \frac{1}{R_2}} = -R_2$$

As $A \to \infty$ and $i_i \to 0$

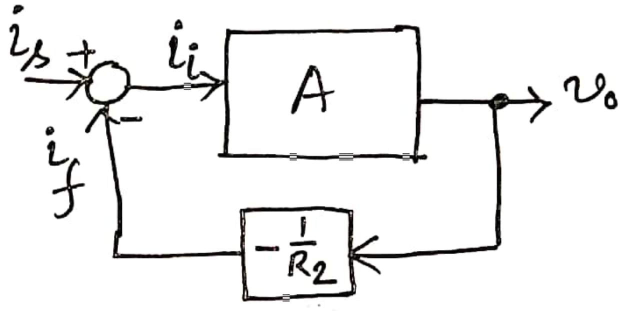

Fig-2(b)

The voltage gain (closed-loop)

$$A_{vf} = \frac{v_o}{v_s} = \frac{v_o}{i_s} \cdot \frac{i_s}{v_s} = -\frac{R_2}{R_1} \quad \text{as } \frac{v_o}{i_s} = -R_f$$

$$\text{and } \frac{i_s}{v_s} = \frac{1}{R_1}$$

Feedback Connection types

(1)

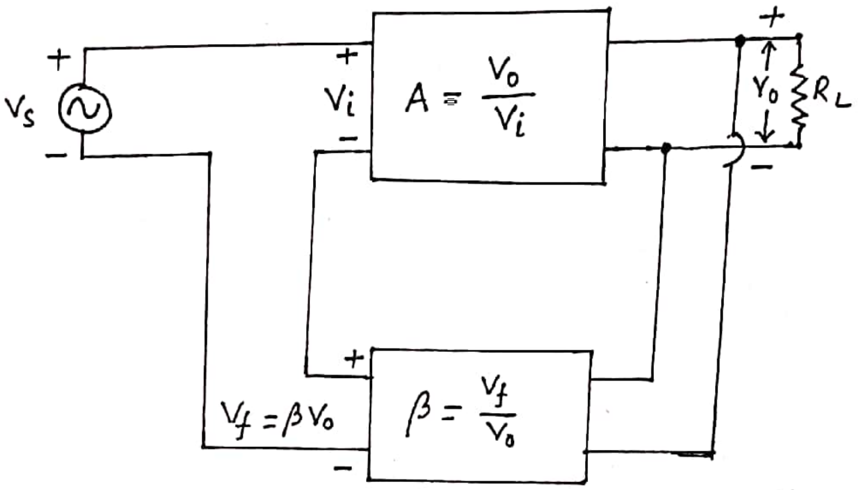

Fig-1 : Voltage-Series feedback : $A_f = \frac{V_o}{V_s} = \frac{A}{1+A\beta}$

(2)

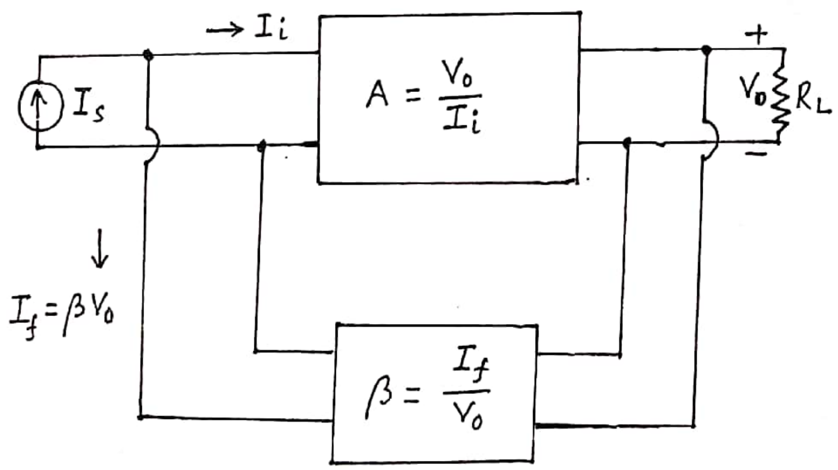

Fig-2 : Voltage-Shunt feedback : $A_f = \frac{V_o}{I_s} = \frac{A}{1+A\beta}$

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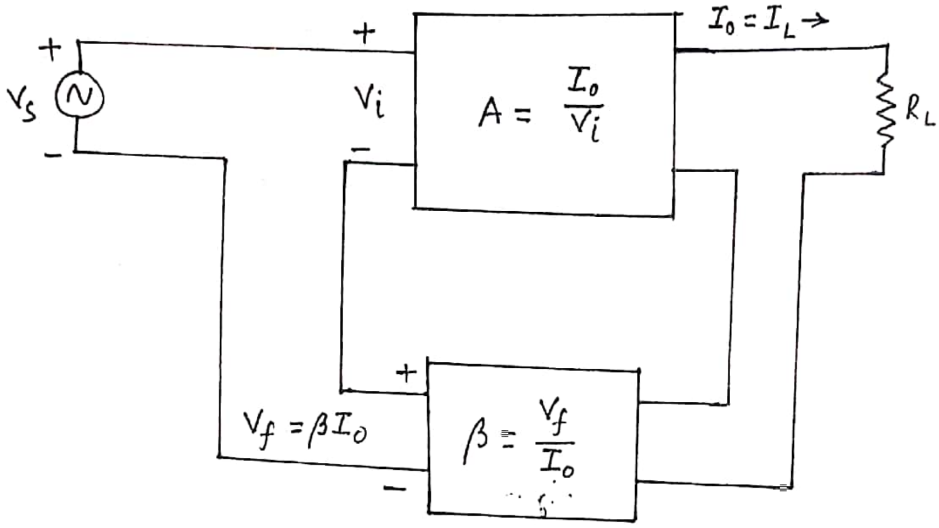

Fig-3: Current-Series feedback ; $A_f = \frac{I_o}{V_s}$

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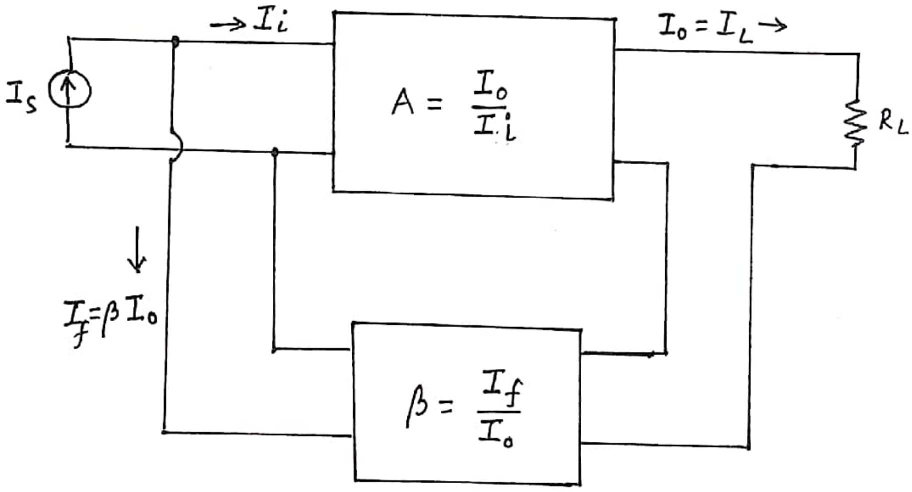

Fig-4: Current-Shunt feedback : $A_f = \frac{I_o}{I_s}$