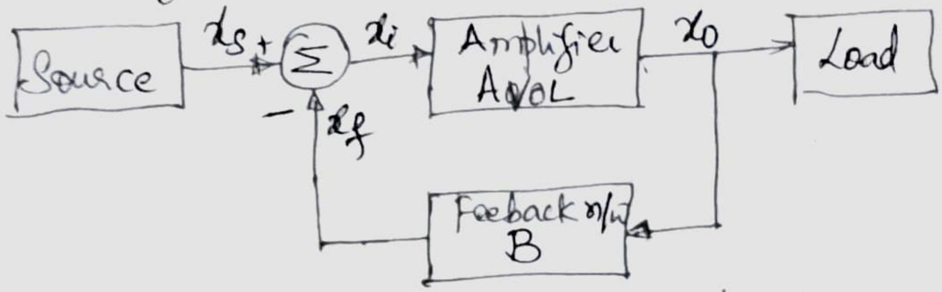
Module 4 negative feedback amplifiers

Electonic principles (JSS Academy of Technical Education)

NEGATIVE FEEDBACK:

* Most physical Systems employ some form of feedback.
* Feedback can be either negative (degenerative) or positive (regenerative).
* The negative feedback is used in amplifiers.

General Negative feedback Structure:



Fig(1): General feedback structure

* Fig(1) shows the general structure of feedback amplifier. It is a signal flow diagram and the quantities 'x' represent either a Voltage or a current signal.
* Amplifier has a open loop gain of A_{VOL}, its output x_o is

$$x_o = A_{VOL} x_i \quad \text{——(1)}$$

* The output x_o is fed to the load as well as to a feedback network, which produces a sample of the output. The sample x_f is related to x_o by feedback factor B by

$$x_f = B x_o \quad \text{——(2)}$$

* The feedback signal x_f is subtracted from the source signal x_s to produce the input to the amplifier x_i as

$$x_i = x_s - x_f \quad \text{——(3)}$$

Thus, negative feedback reduces the Signal that appears at the input of the amplifier.

Substituting (1) in (2), we get

$$x_f = A_{VOL} B x_i \quad \text{——} (4)$$

Substituting (4) in (3), we get

$$x_i = x_s - A_{VOL} B x_i$$

$$x_s = x_i + A_{VOL} B x_i$$

$$x_s = x_i (1 + A_{VOL} B) \quad \text{——} (5)$$

The gain of the feedback amplifier is

$$A_{CL} = \frac{x_o}{x_s} = \frac{A_{VOL} x_i}{x_i (1 + A_{VOL} B)}$$

$$\boxed{A_{CL} = \frac{A_{VOL}}{1 + A_{VOL} B}} \quad \text{——} (6)$$

It is clear from eqn (6), that the gain with negative feedback is Smaller than the open loop gain A_{VOL} by the quantity $1 + A_{VOL}B$ which is called the amount of feedback.

Types of Negative feedback:

There are four types of negative feedback

(i) Voltage Controlled Voltage Source (VCVS): In this type of negative feedback, input Signal is Voltage and output Signal is also Voltage. It is a ideal Voltage amplifier as it has Stabilized Voltage gain, infinite input impedance and zero output impedance.

(ii) Current Controlled Voltage Source (ICVS): In this type input Signal is Current and the output Signal is Voltage. It is also called a transresistance amplifier as gain is transresistance, $r_m = \frac{V_{out}}{I_{in}}$

(iii) Voltage Controlled Current Source (VCIS): In this type of feedback, input signal is voltage and output signal is current. This is also called transconductance amplifier as $g_m = i_{out}/V_{in}$.

(iv) Current Controlled Current Source ICIS): In this type of feedback, input signal is current and output signal is current. This is an ideal current amplifier which has stabilized current gain, zero input impedance and infinite output impedance.

Table (1). Summarizes the four types of negative feedback.

Table 1: Ideal Negative feedback

Input	output	Circuit	Z_{in}	Z_{out}	Converte	Ratio	Symbol	Type of Amplifier
V	V	VCVS	∞	0	—	V_{out}/V_{in}	A_V	Voltage Amplifier
I	V	ICVS	0	0	i to V	V_{out}/i_{in}	r_m	Transresistance Amplifier
V	I	VCIS	∞	∞	V to i	i_{out}/V_{in}	g_m	Transconductance amplifier
I	I	ICIS	0	∞	—	i_{out}/i_{in}	A_I	Current Amplifier

* VCIS is also called a Voltage-to-Current Converter and ICVS is also called a Current-to-Voltage Converter.

* The four types of negative feedback amplifier is as shown in fig (1).

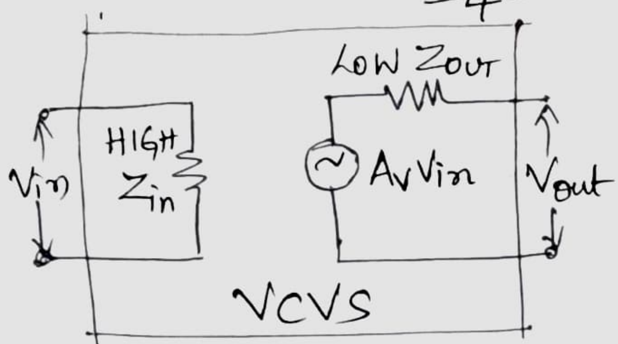


Fig 1(a) VCVS amplifier

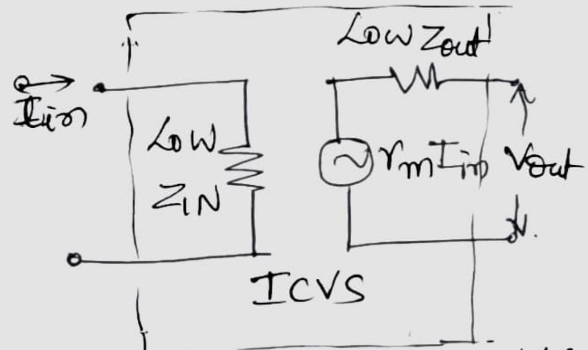


Fig 1(b) ICVS amplifier

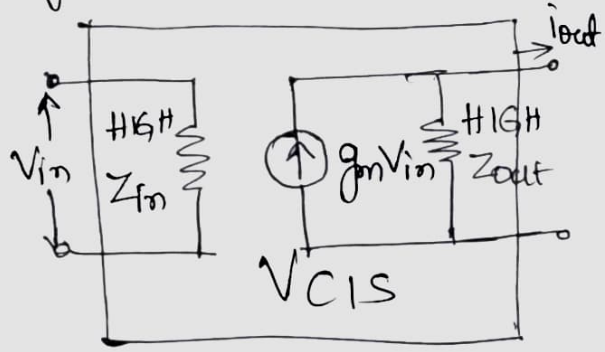


Fig 1(c) VCIS amplifier

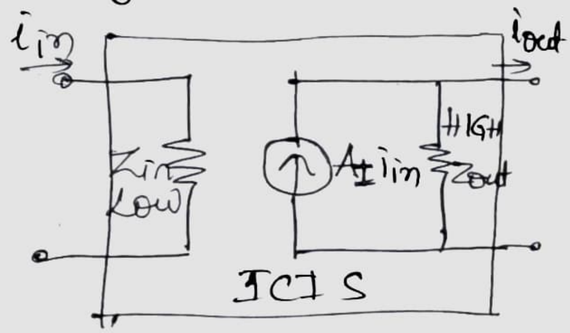
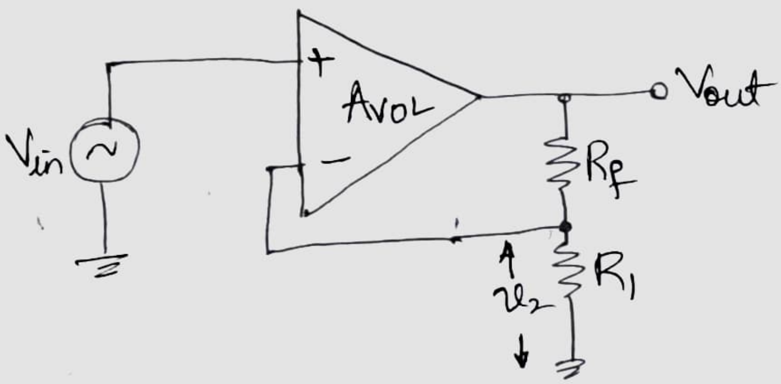


Fig 1(d) ICIS amplifier

VCVS amplifier:

* Fig(2) Shows a noninverting amplifier which is an example of VCVS amplifier.



Fig(2) VCVS amplifier.

* opamp has open loop Voltage gain of A_{VOL} which is 100,000 or more. As in fig(2), R_f and R_1 forms a Voltage divider to feed part of the output Voltage to the inverting input.

* The feedback fraction B of VCVS circuit is defined as feedback voltage divided by the output voltage.

$$B = \frac{V_2}{V_{out}} \quad \text{--- (1)}$$

B is also called feedback attenuation factor.

* From fig (2), $V_1 - V_2 = V_{id}$

$$\therefore \quad V_{out} = A_{VOL}(V_1 - V_2) = A_{VOL} V_{id} \quad \text{--- (2)}$$

Substituting (2) in (1),

$$B = \frac{V_2}{A_{VOL} V_{id}}$$

$$V_2 = A_{VOL} B V_{id}$$

Closed-loop voltage gain is $A_{VCL} = \frac{V_{out}}{V_{in}}$

The actual input to opamp input.

$$V_{id} = V_{in} - V_2 = V_{in} - A_{VOL} B V_{id}$$

$$V_{in} = V_{id}(1 + A_{VOL} B)$$

$$\therefore \quad A_{VCL} = \frac{A_{VOL} V_{id}}{V_{id}(1 + A_{VOL} B)} = \frac{A_{VOL}}{1 + A_{VOL} B}$$

$$\boxed{A_{VCL} = \frac{A_{VOL}}{1 + A_{VOL} B}}$$

$A_{VOL} B$ is called loop gain as it is the voltage gain of the forward and feedback paths. Practically, loop gain is large. The larger the loop gain it stabilizes the voltage gain and effects gain stability, distortion, input impedance and output impedance.

Ideal closed loop voltage gain:

$A_{VOL}B >> 1$. $\therefore 1 + A_{VOL}B \simeq A_{VOL}B$

$$\therefore A_{VCL} = \frac{A_{VOL}}{1 + A_{VOL}B} = \frac{A_{VOL}}{A_{VOL}B}$$

$$\therefore \boxed{A_{V(ideal)} = \frac{1}{B}}$$

The exact closed loop voltage gain is less than ideal closed-loop voltage gain

$$\% \text{ Error} = \frac{100\%}{1 + A_{VOL}B}$$

If ~~error~~ $1 + A_{VOL}B$ is 1000, error is only 0.1%. This means the exact answer is only 0.1% less than the ideal answer.

$$B = \frac{V_2}{V_{out}}$$

From Voltage ÷ n/w

$$V_2 = \frac{V_{out} R_1}{R_1 + R_f}$$

$$\therefore B = \frac{\cancel{V_{out}} R_1}{(R_1 + R_f)\cancel{V_{out}}}$$

$$B = \frac{R_1}{R_1 + R_f}$$

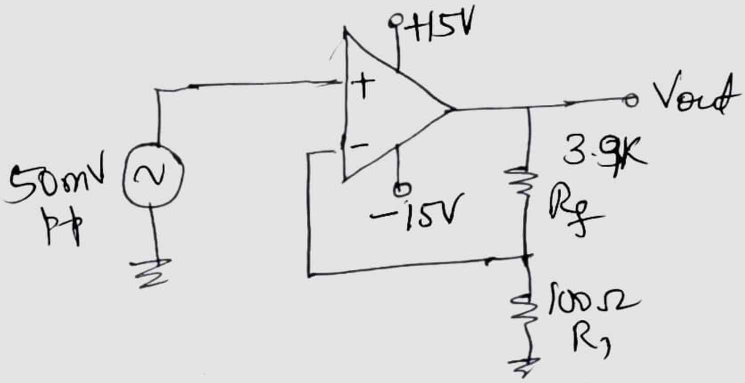
$$A_{V(ideal)} \simeq \frac{1}{B} \simeq \frac{1}{\frac{R_1}{R_1 + R_f}} \simeq \frac{R_1 + R_f}{R_1}$$

$$\therefore \boxed{A_{V(ideal)} \simeq \frac{R_f}{R_1} + 1}$$

The above equation is the closed loop voltage gain of opamp in noninverting configuration.

Example:

For the Circuit Shown, Calculate the feedback fraction, the ideal closed loop Voltage gain, the percent error and the exact closed-loop Voltage gain. Use $A_{VOL} = 100,000$



Sol^n:

$$B = \frac{R_1}{R_1 + R_f} = \frac{100}{100 + 3.9K} = 0.025$$

$$A_V = \frac{1}{B} = \frac{1}{0.025} = 40$$

$$\%\ \text{Error} = \frac{100\%}{1 + A_{VOL}B} = \frac{100\%}{1 + 10,0000 \times 0.025} = 0.04\%$$

$$A_{V exact} = A_V - 0.04\% \times A_V$$

$$= 40 - 0.04\% \times 40 = 39.984$$

or

$$A_{V exact} = \frac{A_{VOL}}{1 + A_{VOL}B} = \frac{100,000}{1 + 100,000 \times 0.025} = 39.984$$

It's clear from above calculations,

$A_V \simeq A_{V exact}$ ∴ We can use A_V eq^n to find $A_{V exact}$.

Other VCVS equations:

The advantages of negative feedback are
1) Gain Stability
2) Reduces Non linear distortion
3) Increases input impedance
4) Decreases output impedance

Gain Stability:

* the gain stability depends on having a very low percent error between the ideal and the exact closed-loop voltage gains. The smaller the percent error, the better is the stability.
* The worst-case error of closed-loop voltage gain occurs when the open-loop voltage gain is minimum.

WKT, $\% \text{ maximum error} = \dfrac{100\%}{1 + A_{VOL(min)}B}$

where $A_{VOL(min)}$ is the minimum or worst-case open-loop voltage gain. $A_{VOL(min)} = 20{,}000$ for 741C.

Ex: If $1 + A_{VOL(min)}B = 500$.

$\% \text{ Maximum error} = \dfrac{100\%}{500} = 0.2\%$

∴ the gain will be within 0.2% of the ideal value.

Closed-Loop Input Impedance:

The closed loop input impedance of non inverting amplifier is given by

$$Z_{in(CL)} = (1 + A_{VOL}B)R_{in} \| R_{CM}$$

where, R_{in} = open-loop input resistance of the opamp.

R_{CM} = the common-mode input resistance of the opamp.

In case of opamp, R_{CM} is extremely large and hence R_{CM} is ignored to obtain the approximate equation

$$Z_{in(CL)} = (1 + A_{VOL}B)R_{in}$$

Thus closed loop input impedance of VCVS amplifier is high.

In a voltage follower, $B = 1$ & ∴ $Z_{in(CL)} = R_{CM}$

& [Ideally, $Z_{in(CL)} = \infty$]

Closed loop output Impedance:

The closed loop output impedance of VCVS amplifier is

$$Z_{out(CL)} = \frac{R_{out}}{1 + A_{VOL}B}$$

where, R_{out} = Open loop output resistance of the opamp

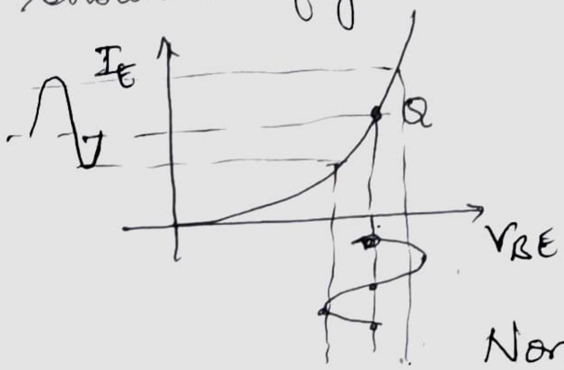
Since $(1 + A_{VOL}B) >> 1$, $Z_{out(CL)} < 1\Omega$.

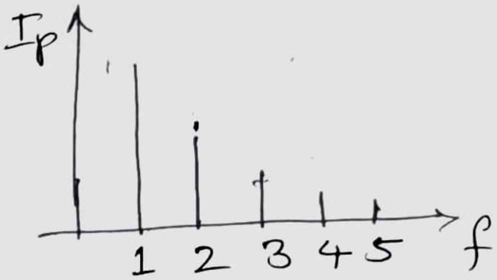
If Voltage follower is used, then $Z_{out(CL)} \simeq 0$.

Since, $Z_{out(CL)}$ is low, the output Side of a VCVS amplifier approaches an ideal Voltage Source.

Nonlinear Distortion:

* Negative feedback reduces distortion. In later Stages of an amplifier, nonlinear distortion will occur with large Signals because the input/output response of the amplifying devices become nonlinear thereby elongating the positive half cycle and Compressing the negative half cycle as Shown in fig below.





Nonlinear distortion and harmonics.

* Nonlinear distortion produces harmonics of the input Signal. Ex: If a Sinusoidal Voltage Signal has a frequency of 1KHZ, the distorted output current will contain Sinusoidal Signals with frequencies of 1, 2, 3, KHZ ~~etc~~... The fundamental frequency is 1KHZ and all others are harmonics.

* Nonlinear distortion is called harmonic distortion.
* The total harmonic Distortion is defined as

$$THD = \frac{\text{Total harmonic Voltage}}{\text{Fundamental Voltage}} \times 100\%$$

* Negative feedback reduces harmonic distortion.

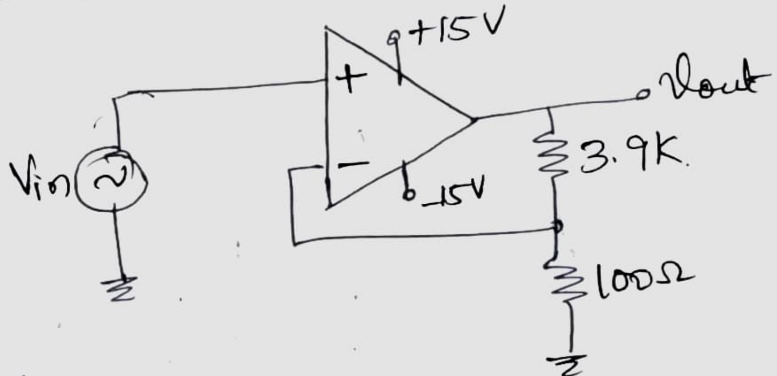
The closed-loop harmonic distortion is:

$$THD_{CL} = \frac{THD_{OL}}{1 + A_{VOL}B}$$

where, THD_{OL} = open loop harmonic distortion

THD_{CL} = closed loop harmonic distortion.

<u>Example:</u> In the ckt shown, opamp has R_{in} of $2M\Omega$ and an R_{cm} of $200M\Omega$. What is the closed-loop input impedance? Assume A_{VOL} is 100,000 and Rout of 75Ω. Also find CL output impedance



<u>Solution:</u>

$$Z_{in(CL)} \simeq (1 + A_{VOL}B)R_{in}$$

$$\simeq (1 + 100{,}000\,B)R_{in}$$

$$B = \frac{R_1}{R_1 + R_f} = \frac{100}{100 + 3900} = 0.025$$

$$\therefore Z_{in(CL)} = (1 + 100{,}000 \times 0.025)\, 2 \times 10^6$$

$$Z_{in(CL)} = 5000\, M\Omega$$

when $Z_{in(CL)} > 100M\Omega$ use

$$Z_{in(CL)} = (1 + A_{VOL}B)R_{in} \,\|\, R_{CM}$$

$$= 192M\Omega$$

$$Z_{out}(CL) = \frac{R_{out}}{1+A_{VOL}B} = \frac{75}{1+100{,}000\times 0.025} = 0.03\Omega.$$

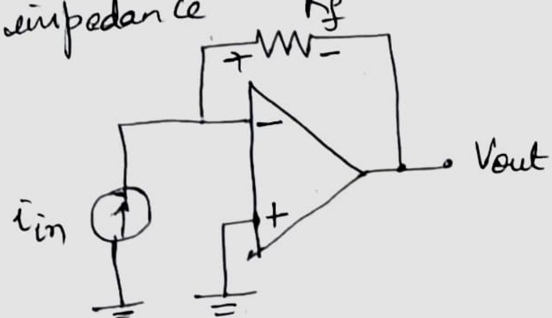
Example: Suppose the amplifier has an open-loop total harmonic distortion of 7.5%. What is the closed-loop total harmonic distortion?

Solution: $THD(CL) = \frac{\text{Total harmonic distortion.}}{1+A_{VOL}B}$

$$= \frac{7.5\%}{1+100{,}000\times 0.025} = 0.003\%$$

The ICVS amplifier:

Fig(1) Shows a transresistance amplifier. It has an input current and an output voltage. ICVS is an current-to-voltage converter. It has zero input impedance and zero output impedance



Fig(1) ICVS amplifier

The output voltage equation is given by

$$V_{out} = -\left(i_{in}R_f \frac{A_{VOL}}{1+A_{VOL}}\right)$$

As $A_{VOL} >> 1$, $1+A_{VOL} \simeq A_{VOL}$

$$\therefore \boxed{V_{out} = -(i_{in}R_f)}$$

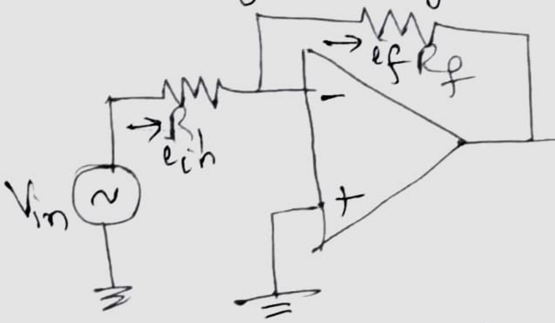
where R_f = transresistance.

the closed loop input and output impedances are given by

$$\boxed{Z_{in}(CL) = \frac{R_f}{1+A_{VOL}}}$$

$$\boxed{Z_{out}(CL) = \frac{R_{out}}{1+A_{VOL}}}$$

Inverting amplifier ~~uses a~~ ICVS negative feedback.



From Virtual ground Concept.

$i_{in} = i_f$

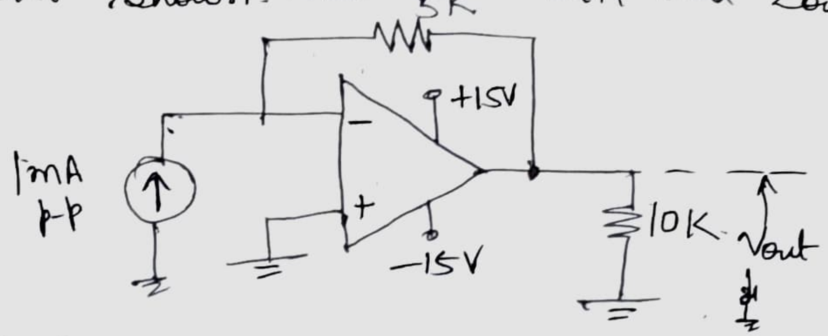
$i_{in} = -\dfrac{V_{out}}{R_f}$

$\therefore$ Input current is $i_{in} = \dfrac{V_{in}}{R_1}$

$\therefore \quad A_V = -\dfrac{R_f}{R_1}$

Example:

Find the output Voltage if the input frequency is 1KHZ for the ckt shown. Also find Zin and Zout.



Solution:

$V_{out} = -i_{in} R_f = -(1mA) \times 5k\Omega = -5V_{pp}$.

The o/p voltage is an ac Voltage with peak-to-peak Value of 5V and a frequency of 1kHz

$$Z_{in(CL)} = \frac{R_f}{1 + A_{VOL}} = \frac{5k}{1 + 100{,}000} = 0.05\Omega$$

$$Z_{out(CL)} = \frac{R_{out}}{1 + A_{VOL}} = \frac{75}{1 + 100{,}000} = 0.00075\Omega$$

[NOTE: $A_{VOL} = 100{,}000$ and $R_{out} = 75\Omega$ for 741C]

VCIS Amplifier:

* VCIS amplifier is a transconductance amplifier that converts input voltage to output current.
* It is similar to VCVS amplifier except that R_L is the load resistor and is also a feedback resistor as shown in fig(1). The active output is the current through R_L. A specific value of input voltage produces a precise value of output current.

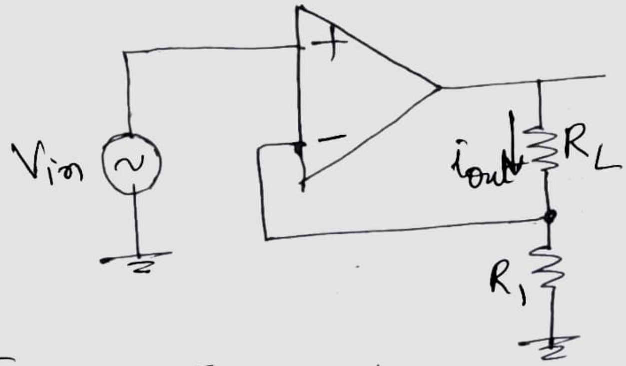


Fig (1) Transconductance amplifier (VCIS)

The output current equation is given by

$$i_{out} = \frac{V_{in}}{R_1 + (R_1+R_L)/A_{VOL}}$$

Since, $(R_1+R_L)/A_{VOL} << R_1$, $R_1 + (R_1+R_L)/A_{VOL} \simeq R_1$

$$\therefore\ i_{out} = \frac{V_{in}}{R_1}$$

Let $g_m = \frac{1}{R_1}$.

$$\therefore\ \boxed{i_{out} = g_m V_{in}}$$

Thus ckt is a voltage to current converter.

The closed loop input impedance of VCIS ampr is given by

$$\boxed{Z_{in(CL)} = (1 + A_{VOL}B) R_{in}}$$

where R_{in} = input resistance of the opamp.

The closed-loop output impedance is

$$Z_{out(CL)} = (1 + A_{VOL})R_1$$

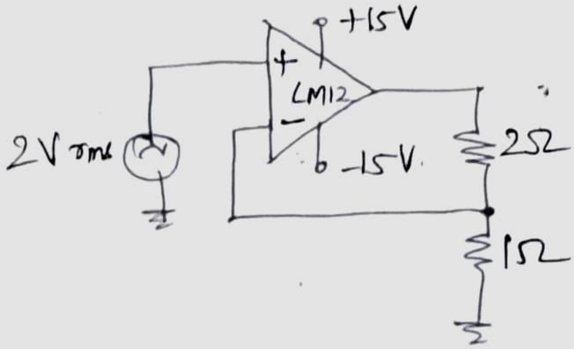
Thus VCIS ampr has high input and output impedance.

As $A_{VOL} = \infty$ in ideal opamp, an ideal VCIS ampr has ∞ input and output impedance.

Example:

For the circuit shown calculate load current and load power. Compute the same if $R_L = 4\Omega$.

~~Solution~~



Solution: (i) $R_L = 2\Omega$.

$$i_{out} = \frac{V_{in}}{R_1} = \frac{2V}{1} = 2A$$

$$P_L = i_{out}^2 R_L = 2^2 \times 2 = 8W$$

(ii) $R_L = 4\Omega$.

$$P_L = i_{out}^2 R_L = 2^2 \times 4 = 16W$$

The ICIS amplifier:

* An ICIS circuit amplifies the input current hence it is a current amplifier
* It has very low input impedance and a very high output impedance. Fig(1) shows inverting current amplifier.

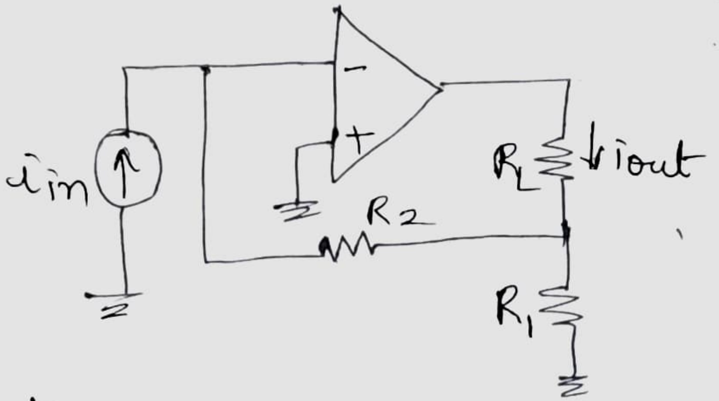


Fig (1) ICIS amplifier.

The closed loop current gain is given by

$$A_I = \frac{A_{VOL}(R_1+R_2)}{R_L + A_{VOL}R_1}$$

$A_{VOL}R_1 > R_L \quad \therefore R_L + A_{VOL}R_1 \simeq A_{VOL}R_1$

$$\therefore A_I = \frac{\cancel{A_{VOL}}(R_1+R_2)}{\cancel{A_{VOL}}R_1} = \frac{R_1+R_2}{R_1}$$

$$\therefore A_I = 1 + \frac{R_2}{R_1}$$

The closed loop input impedance of an ICIS ampr is

$$Z_{in(CL)} = \frac{R_2}{1+A_{VOL}B}$$

where feedback fraction is given by

$$B = \frac{R_1}{R_1+R_2}$$

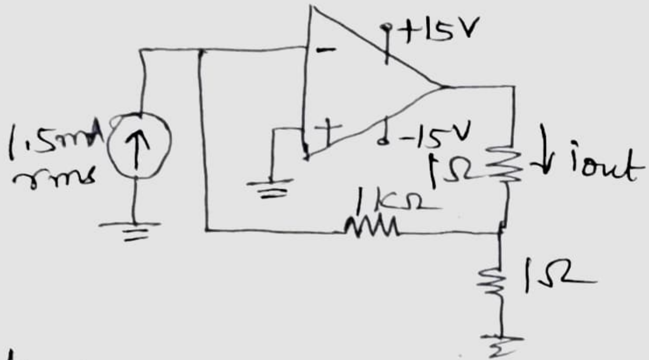
The closed loop output impedance is given by

$$Z_{out(CL)} = (1+A_{VOL})R_1$$

Thus, in ICIS ampr, Zin is low and Zout is large.

Example:

Find the load current for the circuit shown. Also find the load power. If the load resistance is changed to 2Ω, find load current and power?



Solution:

$$A_i = \frac{R_2}{R_1} + 1 = \frac{1k\Omega}{1} + 1 \simeq 1k\Omega$$

$$i_{out} = A_i\, i_i = 1000 \times 1.5mA = 1.5A \text{ rms}$$

$$P_L = i_{out}^2 R_L = 1.5^2 \times 1\Omega = 2.25W$$

when $R_L = 2\Omega$, $i_{out} = 1.5A$

$$\therefore P_L = i_{out}^2 R_L = 1.5^2 \times 2 = 4.5W.$$

Active Filters:

* A filter passes one band of frequencies while rejecting another.
* A filter can be either passive or active.
* Passive filters are built with resistors, capacitors, and inductors. They are used above 1MHZ, have no power gain and are difficult to tune.
* Active filters are built with resistors, capacitors and opamps. They are used below 1MHZ, have power gain and are easy to tune.

Ideal Responses:

* The frequency response of a filter is the graph of its Voltage gain Vs frequency. There are 5 types of filters (i) Low pass (ii) High pass (iii) Bandpass (iv) Bandstop (V) All-pass