Common-Mode rejection ratio

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8:57 PM

Difference Amplifier:

① Amplifies the difference between two signals

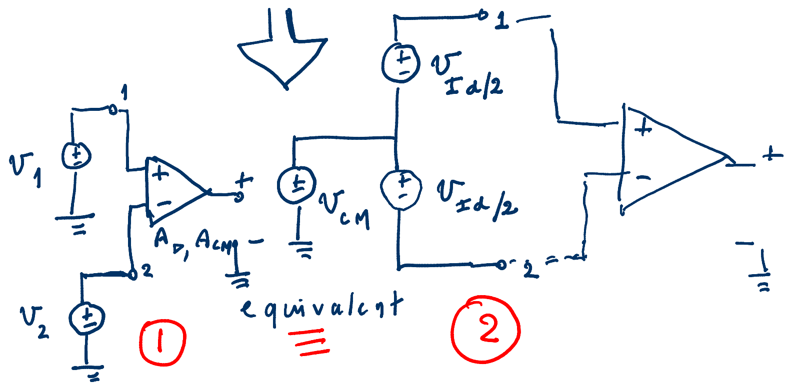
② Rejects common signals to the input (i.e. noise/interence signals)

let $v_{Id} = v_2 - v_1$ = differential input signal (1)

$v_{Icm} = \frac{1}{2}(v_1 + v_2)$ = average of

= common-mode input signal (2)

let
$$\begin{cases} v_1 = v_{I_{CM}} - v_{Id}/2 \\ v_2 = v_{ICM} + v_{Id}/2 \end{cases}$$



$$v_o = A_d v_{Id} + A_{cm} v_{ICM} =$$
$$= A_d\left(v_{Id} + \frac{A_{cm}}{A_d} v_{ICM}\right) = A_d\left(v_{Id} + \frac{v_{ICM}}{CMRR}\right)$$

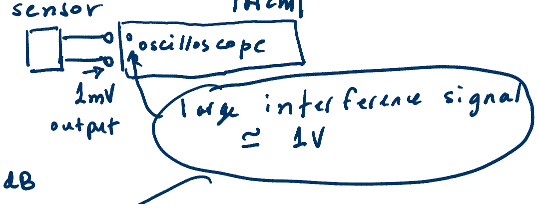
where A_d = amplifier differential gain

A_{cm} = common-mode gain

where

$$CMRR_{dB} = 20 \log \frac{|A_d|}{|A_{cm}|} \text{ dB}$$

example



$60 \leq CMRR \leq 120$ dB

dB

utilize a difference amplifier to remove the interference signal.

Examples

Refering to Fig (1)

> let $A_d = 2500$
> $CMRR = 80\ dB$
> $v_1 = 5.001V$
> $v_2 = 4.99V$
> Find v_o?

CMRR → convert to number

$$CMRR = 10e^{\frac{80\,dB}{10}} = \pm 10^4$$

let $CMRR = 10^4$

$$v_{Id} = 5.001V - 4.99V = 0.002V$$

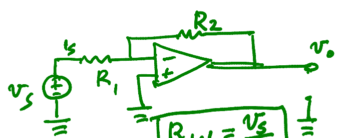
$$v_{ICM} = \frac{5001 + 4.999}{2}$$

$$v_o = A_D\left[v_{Id} + \frac{v_{ICM}}{CMRR}\right] = 2500\left[0.002 + \frac{5000}{10^4}\right] V$$

$$= 2500[0.002 + 0.0005V] = 6.25V$$

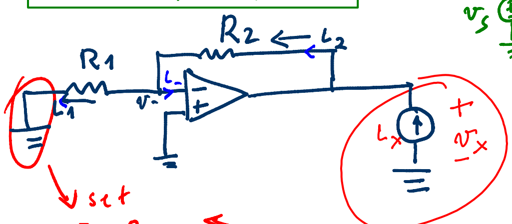
Inverting Amplifier - Input/output Resistance

① Calculate R_{IN}



$R_{IN} = \frac{v_s}{i_s}$

② $\boxed{\text{Calculate Rout}}$



set $v_s = 0$ (turn off)

introduce a current source to find the Thevenin equivalent resistance.

2 steps

$$R_{out} = \frac{v_x}{i_x}$$

> Assumption 1
> $v_{id} = 0$
> Assumption 2
> $i_+ = 0$
> $i_- = 0$

$$v_x = i_2 R_2 + i_1 R_1$$

$i_- = i_1 + i_2$

but $i_- = 0 \Rightarrow i_1 = i_2$

$$\Rightarrow v_x = i_1 (R_2 + R_1)$$

$\{i_1 = \frac{v_-}{R_1}\}$ but $i_1 = 0$ since $v_- = 0$ (assumption 1)

$\Rightarrow v_x = 0$ so $\boxed{R_{out} = 0}$

Design of an Inverting Amplifier

Choose R_1, R_2 so that to have an input resistance of $20\,k\Omega$ and a gain of $40\,dB$

recall
$$\boxed{R_{IN} = R_1 \qquad A_v = -\frac{R_2}{R_1}}$$

Steps: $R_{IN} = R_1 = 20\,k\Omega$ ✓

Convert dB to a number

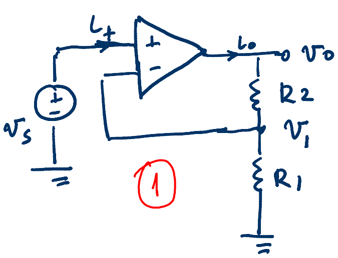
$$|A_v| = 10^{40dB/20dB} = 100$$

$$\Rightarrow A_v = -100$$

now, $\boxed{R_1 = R_{IN} = 20K}$

$$A_v = -\frac{R_2}{R_1} \Rightarrow \boxed{R_2 = 100 R_1 = 2\,M\Omega}$$

Non-Inverting Amplifier input/output Resistance

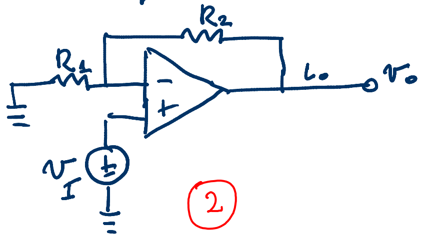


(1)

$$R_{IN} = \frac{v_s}{i_+} = \infty \quad (i_+ = 0)$$

$R_{OUT} = 0$ (apply again a test current source to the output)

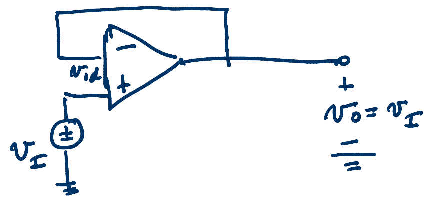
Recall the above diagram is equivalent to:



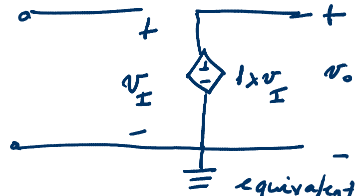
(2)

$$Gain = A_v = 1 + \frac{R_2}{R_1}$$

Unity-Gain Buffer



non-inverting amplifier (special case)



equivalent circuit

$$R_1 = \frac{v_+}{i_+} = \infty$$

$$R_2 = 0$$

Now $A_v = 1 + \frac{R_2}{R_1} = 1$

Alternative derivation:

$$v_I - v_{id} = v_o$$

but $v_{id} = 0$ (First criterion)

$$\Rightarrow v_I = v_o$$

$\boxed{\text{Design of a non-Inverting Amplifier}}$

Find: A_V

v_O

i_O

of the amplifier ② given:

$R_1 = 3\,k\Omega$

$R_2 = 43\,k\Omega$

$v_S = +0.1V$

$$A_v = 1 + \frac{R_2}{R_1} = 1 + \frac{43\,k\Omega}{3\,k\Omega} = +15.3$$

$$v_o = A_v v_s = (15.3)(0.1V) = 1.53V$$

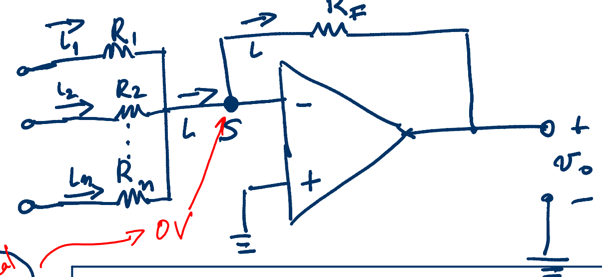
$$i_o = \frac{v_o}{R_2 + R_1} = \frac{1.53V}{43k + 3K} = 33.3\,\mu A.$$

Summary of the ideal inverting & non-inverting Amplifiers

	Inverting Amp	Noninverting Amp.

Voltage gain	$-\frac{R_2}{R_1}$	$1+\frac{R_2}{R_1}$
Input resistance	R_1	∞
Output resistance	0	0

The Summing Amplifier (Weighted Summer)



virtual ground

$v_o = 0 - iR_f = -iR_f$

virtual ground

it means that although voltage = 0 still there is a current flow.

$$v_o = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \dots \frac{R_f}{R_n}v_n\right)$$

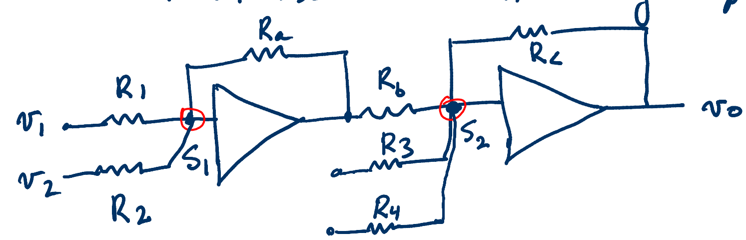
How did we find this formula?
[SUPERPOSITION PRINCIPLE].

Simply we have an array of inverting amplifiers, which produce currents $i_1, i_2 .. i_n$ that are added at

which are forced to flow through R_f.

what about if we sum signals that have opposite polarity?

we must use two inverting amplifiers.



$$v_o = v_1\left(\frac{R_a}{R_1}\right)\left(\frac{R_c}{R_b}\right) + v_2\left(\frac{R_a}{R_2}\right)\left(\frac{R_c}{R_b}\right) - v_3\left(\frac{R_c}{R_3}\right) - v_4\left(\frac{R_c}{R_4}\right)$$