Difference-mode & Common-mode Gains

$$V_{CM} = \frac{V_1 + V_2}{2}$$

$$V_o = A_1 V_1 + A_2 V_2$$

where A_1 is the voltage amplification from i/p 1 to the o/p with i/p 2 grounded

A_2 is the voltage amplification from i/p 2 to the o/p with i/p 1 grounded.

→ Since $V_{CM} = (V_1 + V_2)/2$ & $V_d = (V_1 - V_2)$

$$V_1 = V_{CM} + \frac{1}{2} V_d$$

$$V_2 = V_{CM} - \frac{1}{2} V_d$$

→ So

$$V_o = A_{DM} V_d + A_{CM} V_{CM}$$

where $A_{DM} = \frac{1}{2}(A_1 - A_2)$

and $A_{CM} = A_1 + A_2$

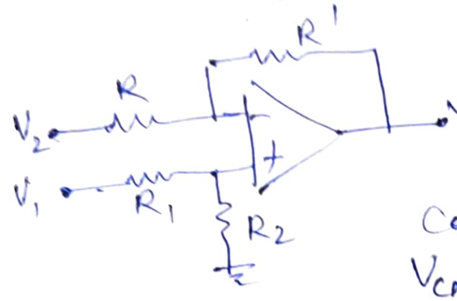
A_{DM} → voltage gain for difference signal

A_{CM} → voltage gain for common-mode signal

Common-Mode Rejection Ratio

- Relative sensitivity of an op-amp to a difference signal as compared to a common-mode signal is called common-mode rejection ratio
- CMRR gives the figure of merit ρ for differential amplifiers
- So CMRR is given by $\rho = \left|\frac{A_{DM}}{A_{CM}}\right|$

Q.



(a) Find the o/p voltage V_o
(b) Show that the o/p corresponding to common mode voltage $V_{CM} = \frac{V_1 + V_2}{2}$ is zero if $\frac{R'}{R} = \frac{R_2}{R_1}$. Find V_o in this case
(c) Find CMRR of amplifier if $\frac{R'}{R} \neq \frac{R_2}{R_1}$

(a) $V_o = -\frac{R'}{R} V_2 + \left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2} V_1\right)$

(b) $V_{CM} = \frac{1}{2}(V_1 + V_2)$; $V_1 = V_{CM} + \frac{V_d}{2}$

$V_d = V_1 - V_2$; $V_2 = V_{CM} - \frac{V_d}{2}$

$$V_o = -\frac{R'}{R}\left(V_{CM} - \frac{V_d}{2}\right) + \left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right)\left(V_{CM} + \frac{V_d}{2}\right)$$

$$= V_{CM}\left[\left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right) - \frac{R'}{R}\right] + \frac{V_d}{2}\left[\frac{R'}{R} + \left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right)\right]$$

If $\frac{R'}{R} = \frac{R_2}{R_1} \Rightarrow \frac{R'}{R} + 1 = \frac{R_2}{R_1} + 1$

$\Rightarrow \frac{R'+R}{R} = \frac{R_1+R_2}{R_1}$ then $V_{CM} = 0$

So $V_o = \frac{V_d}{2}\left[\frac{R'}{R} + \frac{R_2}{R_1}\right] = \left(\frac{R_2}{R_1}\right) V_d$

(c) $CMRR = \frac{A_{DM}}{A_{CM}}$

$A_{DM} = \frac{V_o}{V_d}$ by putting $V_{CM} = 0$

$$= \frac{1}{2}\left[\frac{R'}{R} + \left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right)\right] = \frac{1}{2}\left[\frac{R'R_1 + 2R'R_2 + RR_2}{R(R_1+R_2)}\right]$$

$$A_{cm} = v_o / v_{cm} \text{ by putting } v_d = 0$$

$$= \left[\left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right) - \frac{R'}{R}\right] = \left[\frac{R R_2 - R'R_1}{R(R_1+R_2)}\right]$$

$$CMRR = \frac{A_{DM}}{A_{CM}} = \frac{1}{2}\left[\frac{R'R_1 + 2R'R_2 + RR_2}{RR_2 - R'R_1}\right]$$

→ Determine the o/p voltage of a differential amplifier for the i/p voltages of 300 μV & 240 μV. The differential gain of the amplifier is 5000 & the value of CMRR is i) 100 & ii) 10^5

i) CMRR = 100

$V_d = V_1 - V_2 = 60\,\mu V$

$V_{cm} = \frac{V_1 + V_2}{2} = 270\,\mu V$

$$CMRR = \frac{A_{DM}}{A_{CM}} \Rightarrow 100 = \frac{5000}{A_{CM}} \Rightarrow A_{CM} = 50$$

$$V_o = A_{DM} V_d + A_{CM} V_{CM}$$

$$\Rightarrow V_o = 5000 \times 60\mu + 50 \times 270\mu$$

$$= 313500 \mu V = 0.3135 V$$

ii) $CMRR = 105$

$$10^5 = \frac{5000}{A_{CM}} \Rightarrow A_{CM} = 0.05$$

$$V_o = 5000 \times 60\mu + 0.05 \times 270\mu$$

$$= 300013.5 \mu V = 0.3 V$$