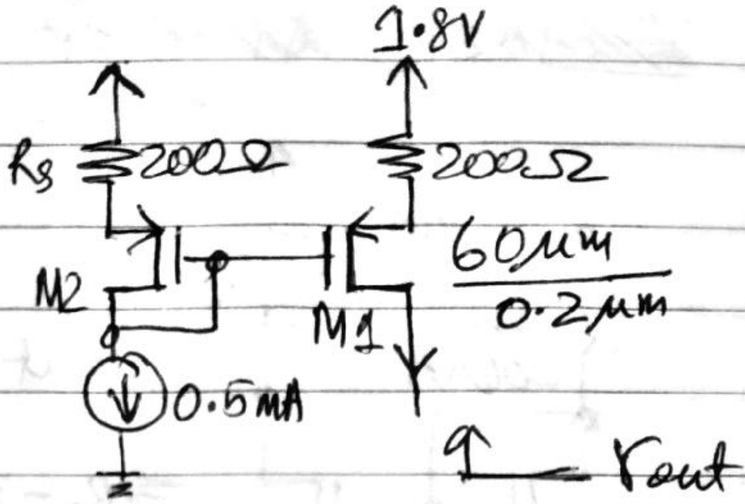
PROBLEM 3.18 (Converted to PMOS)

0.18 μm

$\mu_p C_{ox} = 70\,\mu A/V^2$

$V_{tp} = -0.45$

$\lambda \cdot L = 0.08\ \mu m/V$



(a)

$r_{out} \simeq r_{ds1}(1 + g_{m1} R_s)$

$r_{ds1} = \dfrac{1}{\lambda \cdot I_{out}} = \dfrac{L}{(\lambda \cdot L)\, I_{out}} = \dfrac{0.2\,\mu m}{0.08\,\frac{\mu m}{V} \times 0.5\,mA} = 5\,k\Omega$

$g_{m1} = \sqrt{2 I_D \mu_p C_{ox} \frac{W}{L}} = \sqrt{2 \times 0.5\,mA \times 70\,\frac{\mu A}{V^2} \times \frac{60}{0.2}} = 4.5\,m\mho$

$r_{out} = 5\,k\Omega(1 + 4.5 \times 0.2) = 5\,k\Omega \times 1.9 = \underline{\underline{9.5\,k\Omega}}$

(b) For $R_s = 0$, $r_{out} = r_{ds1} = \underline{\underline{5\,k\Omega}}$

(c) $V_o(max) = ?$ i.e. max voltage M1 is active

$g_m = \dfrac{2 I_D}{V_{eff}}$

$V_o(max) = 1.8V - I_{out} R_s - V_{eff1}$

$= 1.8V - 0.2 \times 0.5 - \dfrac{2 \times 0.5\,mA}{4.5\,m\mho}$

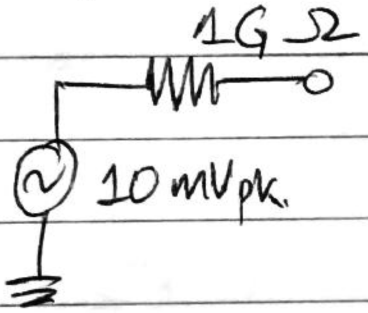
$= 1.8 - 0.1 - 0.22 = 1.48\,V$

DESIGN PROBLEM

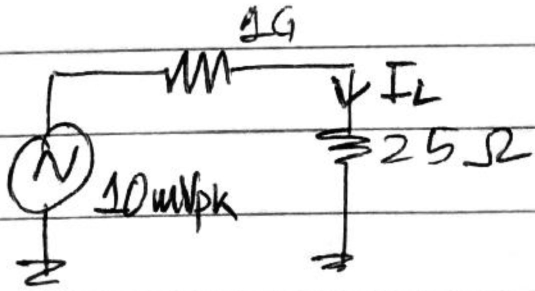
DESIGN A HEADPHONE AMP

.. Deliver 25 mW of peak power to a 25 Ω headphone.

Thevenin model of a MEMS microphone.



Let's see how much power can be delivered directly.

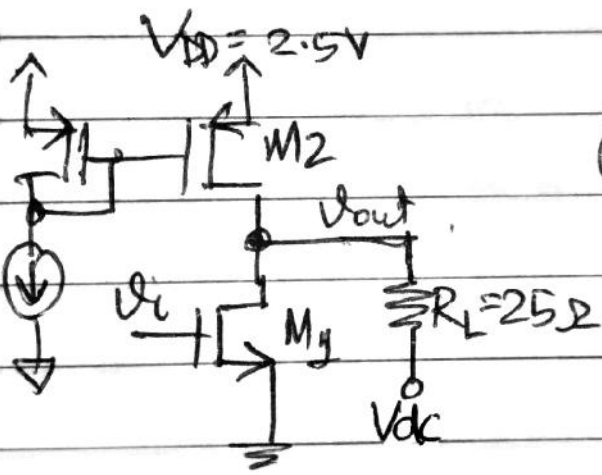


$$P_{out\,pk} = I_L^2 R = \left(\frac{10\text{ mVp}}{1G + 25\Omega}\right)^2 \times 25 \cong 0$$

How about common-source amplifier.
How much gain do we need.

$$P_{out} = \frac{V^2}{R} = 25\,mW \Rightarrow V \cong 0.8V$$

$\therefore$ Voltage gain $= \dfrac{0.8V}{0.01V} = \underline{\underline{80}}$



$$\text{Gain} = g_{m1} \cdot (r_{ds1} \,||\, r_{ds2} \,||\, R_L)$$

$\therefore R_L \ll r_{ds1,2}$

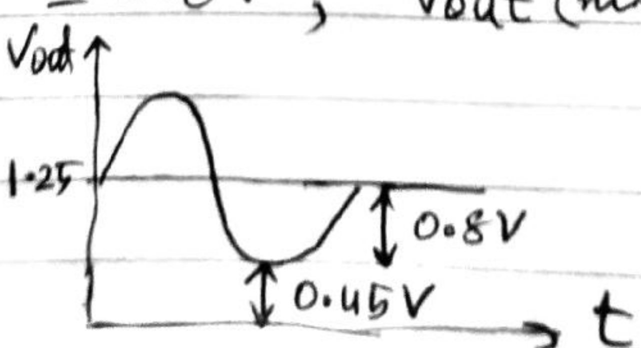
$$\text{Gain} \cong g_{m1} \cdot R_L$$

$$\Rightarrow g_{m1} = \frac{80}{25\Omega} = \underline{\underline{3.2}}$$

Too high

Let's calculate V_{eff1}

We can assume Vout(DC) = 1.25V when there is no signal. Since the output swings ± 0.8V, Vout (min) = 1.25 − 0.8V = 0.45V



So let's $\underline{V_{eff1} = 400\,mV}$

$\therefore\ g_{m1} = \dfrac{2 I_D}{V_{eff1}} \Rightarrow I_D = \dfrac{g_{m1} \times V_{eff1}}{2}$

$= \dfrac{3.2\,℧ \times 0.4V}{2} = \underline{\underline{0.64A}}$!!

Power consumed in the CS stage
$= 2.5V \times 0.64 \quad = \underline{1.6\ W}$ → TOO HIGH

Now what if the CS stage is not driving the load directly.

$A_v = g_{m1} \times (r_{ds1} \| r_{ds2}) \cong g_{m1} \cdot \dfrac{r_{ds}}{2}$

$A_v = \dfrac{\cancel{2} \cancel{I_D}}{V_{eff}} \times \dfrac{1}{\cancel{2} \cdot \lambda \cdot \cancel{I_D}} = \dfrac{L}{V_{eff} \cdot (\lambda \cdot L)}$

Let's design this 0.18 μm CMOS (see P3.10)
where $\lambda \cdot L = 0.08\ \mu m/V$

$\Rightarrow L = A_v \cdot V_{eff} \cdot (\lambda \cdot L) = 80 \times 0.4V \times 0.08\ \frac{\mu m}{V}$

$\boxed{L = 2.56\ \mu m.}$

* we can choose a much smaller current.

* NOTE M1 can be in subthreshold to save more power.

Now we follow the CS stage with source follower.

See Prob 3.15

$$A_V \simeq \frac{g_{m1}}{g_{m1} + 1/R_L} = 0.8 \Rightarrow g_{m1} = \frac{-A_V/R_L}{A_V - 1}$$

$$\Rightarrow g_{m1} = \frac{-0.8/25}{0.8-1} = 160\,m\mho$$

$$\text{as } g_{m1} = \frac{2I_D}{V_{eff}} = 160\,m\mho$$

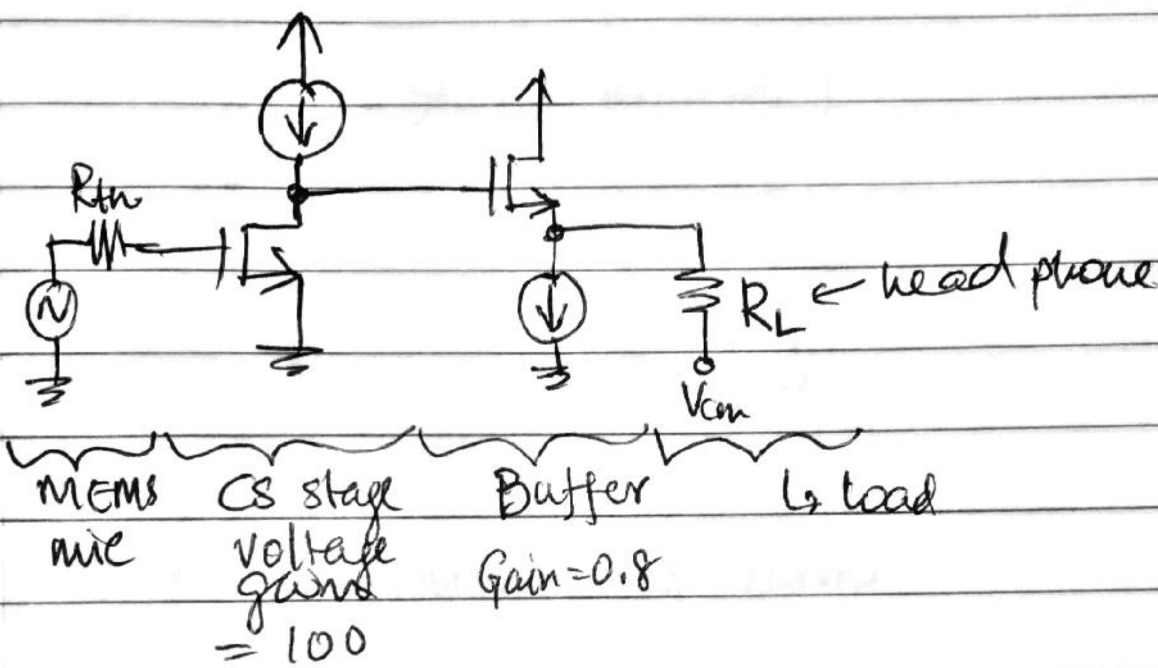
For $V_{eff} = 0.4\,V$

$$I_D = \frac{0.16 \times 0.4}{2} = \underline{\underline{32\,mA}}$$

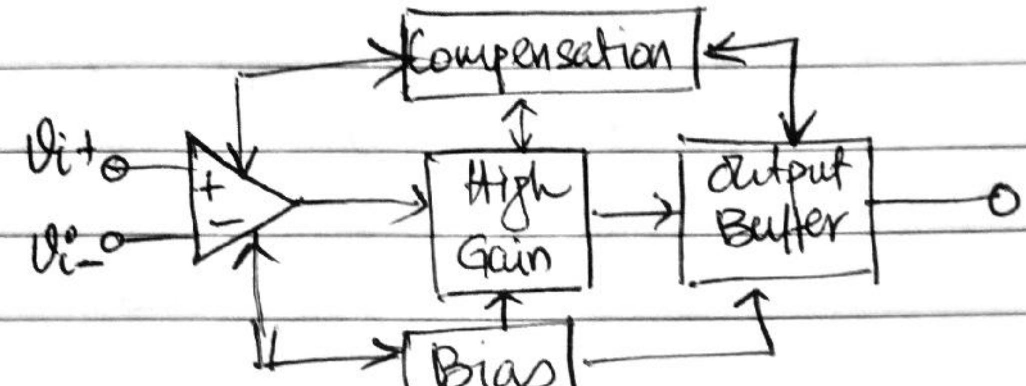
Peak current reqd. thru load $= \frac{0.8}{25} = 32m$

$= \underline{\underline{32\,mA}}$

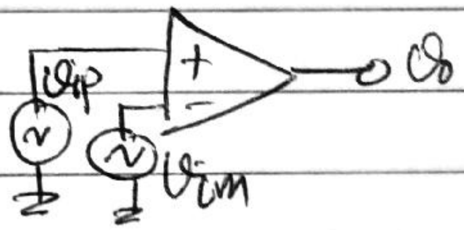
Solution


R_{th}
R_L ← head phone
V_{cm}
MEMS mic
CS stage voltage gain = 100
Buffer Gain = 0.8
↳ load

GENERAL BLOCK DIAGRAM OF A 2-STAGE OP-AMP



Some definition of terms



(1) Differential Input

$$v_{id} = v_{ip} - v_{im}$$

(2) Common-mode input

$$v_{cm} = \frac{v_{ip} + v_{im}}{2}$$

(3) Differential Gain $= A_d = \dfrac{v_o}{v_{id}}$

(4) Common-mode Gain $= A_{cm} = v_o / v_{cm}$

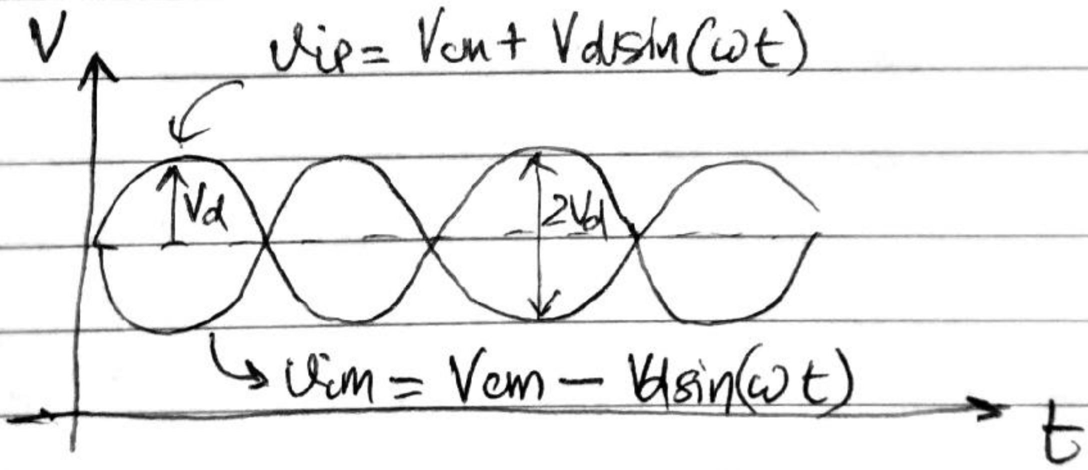
When ipnut has both diff. &
common-mode

$$v_o = A_d \cdot (v_{ip} - v_{im}) + A_{cm}\left(\frac{v_{ip} + v_{im}}{2}\right)$$

Ideally you want:

1. $A_d \to$ high $\to \infty$
2. $A_{cm} \to$ zero — why?

<u>Time-domain view of Diff & CM signal</u>



$v_{id} = 2V_d \sin(\omega t)$

$v_{icm} = V_{cm}$.

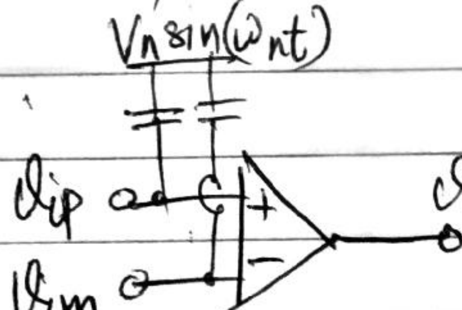
Now let's add a time-varying CM signal say $v_n \sin(\omega_n t)$

$v_{ip} = V_{cm} + v_n \sin(\omega_n t) + V_d \sin(\omega t)$
$v_{im} = V_{cm} + v_n \sin(\omega_n t) - V_d \sin(\omega t)$

$v_{id} = 2V_d \sin(\omega t)$
$v_{icm} = V_{cm} + \underbrace{v_n \sin(\omega_n t)}$

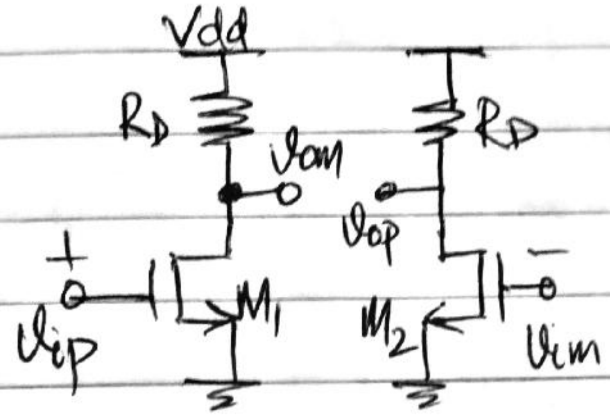
If this noise coupling to inputs then it will be rejected because

$v_o = A_d \cdot v_d + A_{cm} \cdot v_{icm}$
$\quad\quad\quad\quad\quad\quad \downarrow \quad\quad \downarrow$
$\quad\quad\quad\quad\quad\quad \approx 0 \quad\quad$ noise.



$v_o = A_d \cdot V_d \sin(\omega t)$
$+ \underbrace{A_{cm}}_{0} \cdot v_n' \sin \omega_n t$

Simple Differential Pair



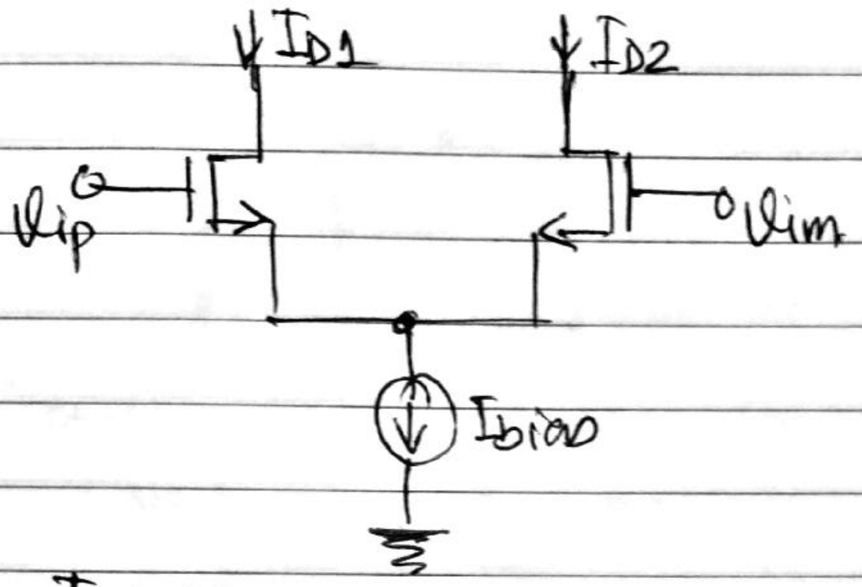
$$v_{op} = -g_m R_D v_{im}$$

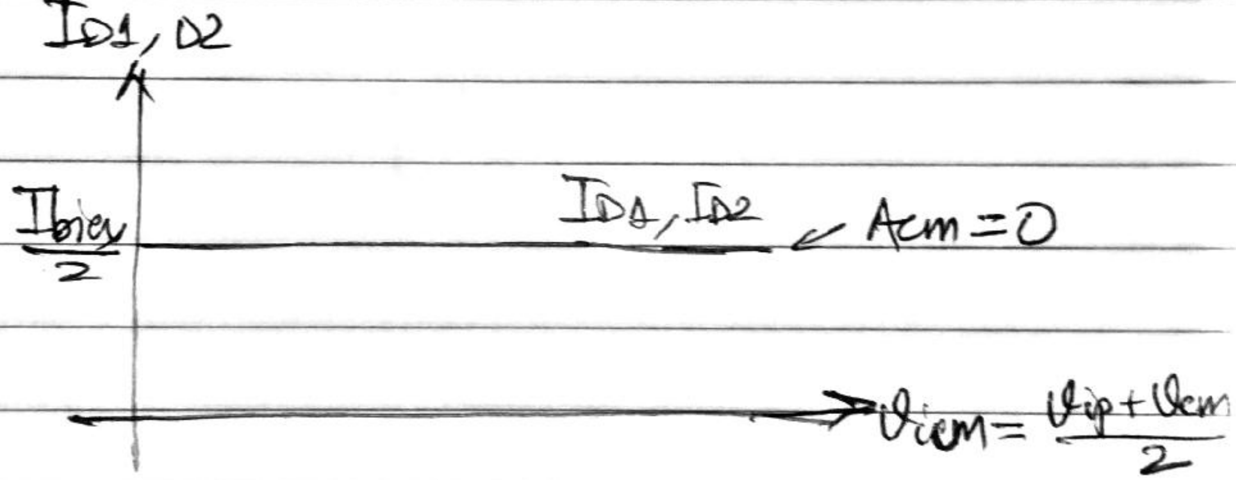
$$v_{om} = -g_m R_D v_{ip}$$

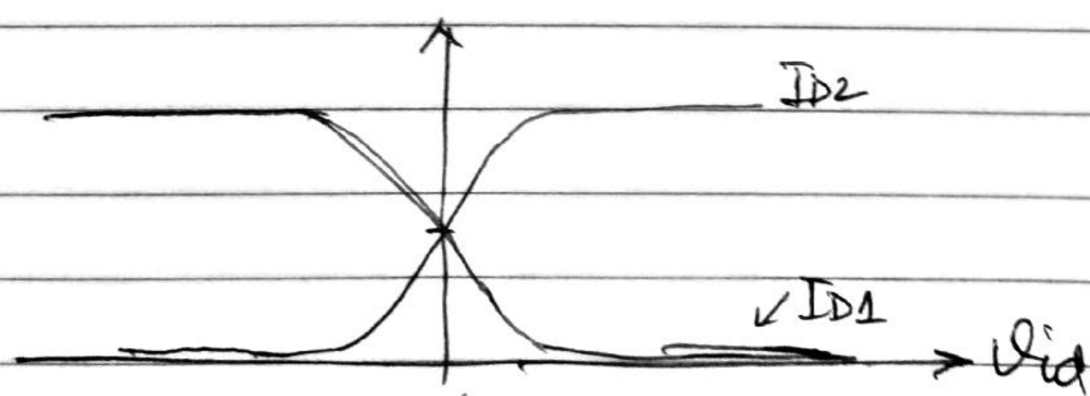
$$A_d = \frac{v_{op} - v_{om}}{v_{ip} - v_{im}} = \underline{g_m R_L}$$

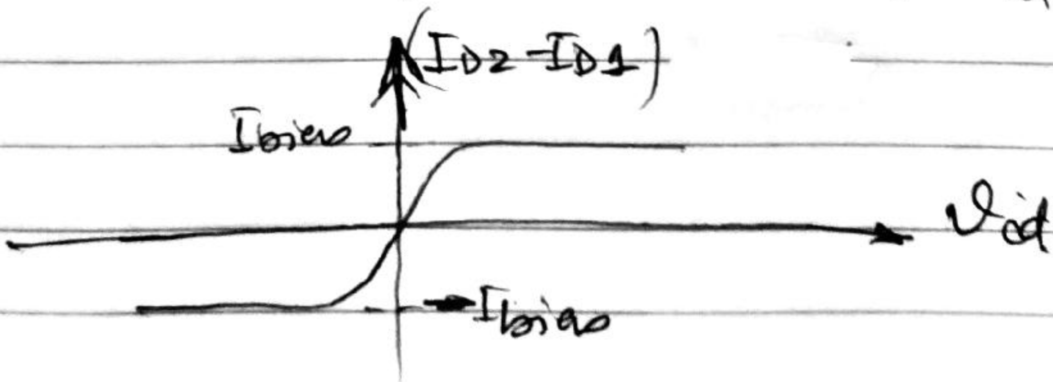
$$A_{cm} = \frac{(v_{op} + v_{om})/2}{(v_{ip} + v_{im})/2} = -\underbrace{g_m R_L}_{\neq 0}$$

Basic Differential Pair









Differential Pair with CM Load.