Elektronik II

Fark yükselteci: küçük sinyal, CMRR, ortak mod aralığı

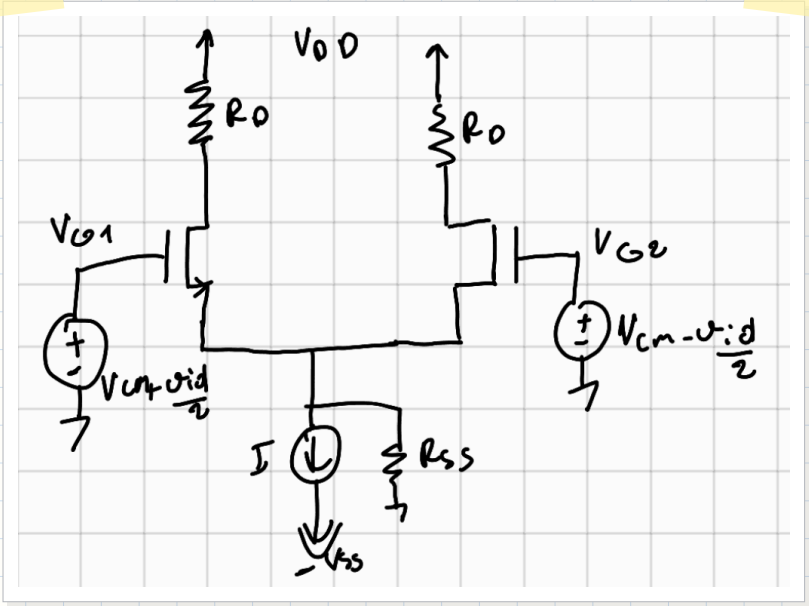
Orijinal not: Ders5.pdf

UYARI Bu belge, el yazısı ders notlarından Claude (Anthropic) yardımıyla dijitale aktarılmıştır. Yardımcı kaynak olarak hazırlanmıştır; hata veya eksik içerebilir. Lütfen orijinal notları ve ders kaynaklarını esas alın.

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orj. s. 1

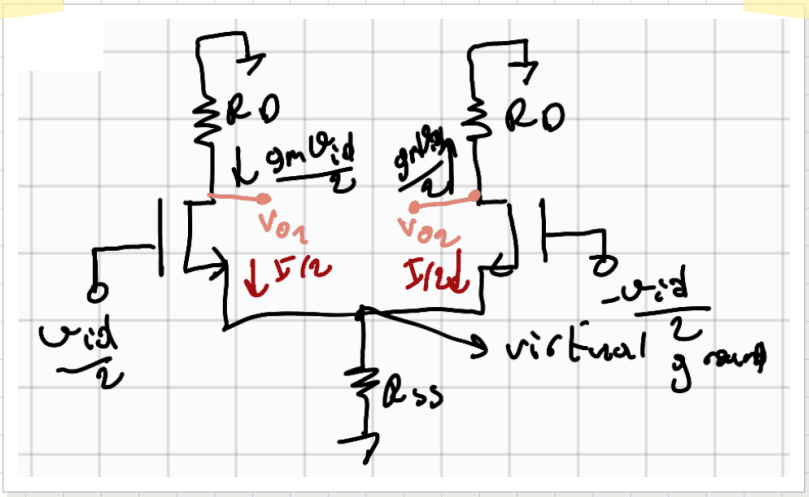
Small-Signal Operation of MOS Differential Pair



orijinal çizim, s. 1

$$V_{G1} = V_{CM} + \frac{v_{id}}{2}$$
$$V_{G2} = V_{CM} - \frac{v_{id}}{2}$$

In ac



orijinal çizim, s. 1

$$v_{O1} = -\frac{g_m v_{id} R_D}{2}$$
$$v_{O2} = \frac{g_m v_{id} R_D}{2}$$

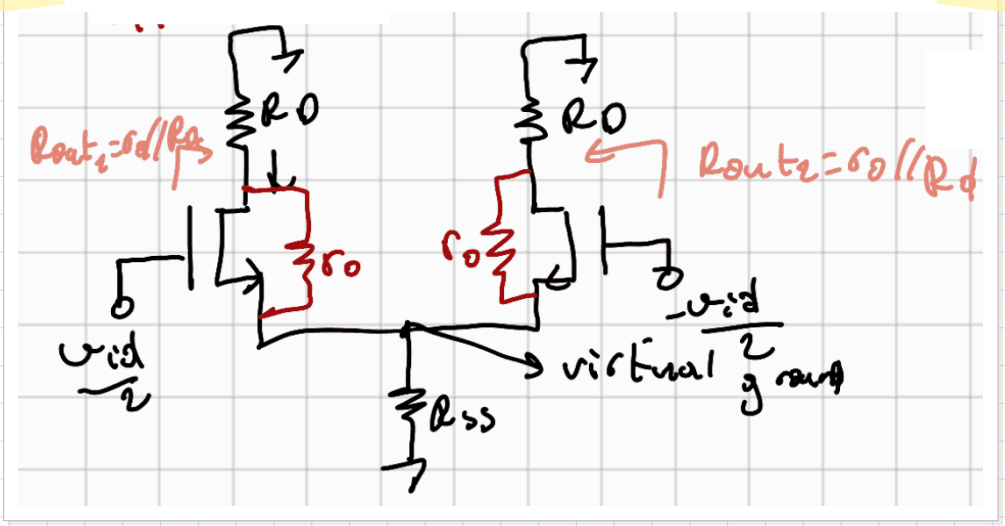
$$|A_{single}| = |v_{O1}| = |v_{O2}| = g_m R_D/2$$
$$|A_{diff}| = \frac{|v_{O1} - v_{O2}|}{v_{id}} = g_m R_D$$

$$g_m = \frac{2I_D}{V_{ov}} = \frac{I}{V_{ov}} \quad \hookrightarrow \quad |A_{diff}| = \frac{I \cdot R_D}{V_{ov}}$$

no channel length modulation ("r_o is ignored")

orj. s. 2

Effect of r_O



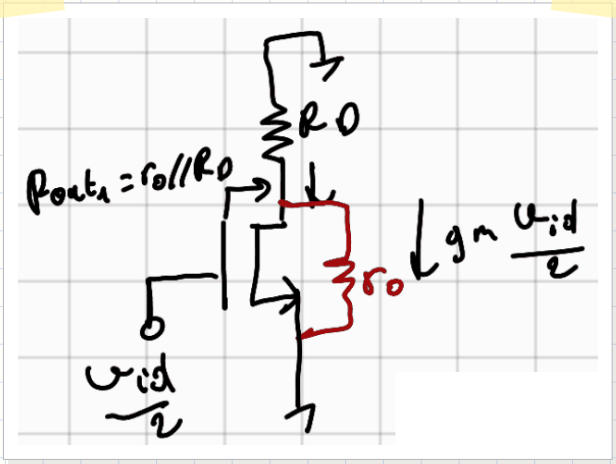
orijinal çizim, s. 2

$$v_{O2} = |v_{O1}| = g_m \frac{v_{id}}{2} (r_o \parallel R_D)$$

$$|A_{single}| = \frac{1}{2} g_m (r_o \parallel R_D)$$

$$|A_{diff}| = g_m (r_o \parallel R_D)$$

The differential half circuit



orijinal çizim, s. 2

$$v_{O1} = -g_m \frac{v_{id}}{2} (R_D \parallel r_o)$$

$$\frac{v_{O1}}{(v_{id}/2)} = -g_m (R_D \parallel r_o)$$

$$\frac{v_{O1}}{v_{id}} = -\frac{1}{2} g_m (R_D \parallel r_o)$$

orj. s. 3

8.2.3

Şekil: Kitaptan yapıştırılmış basılı şekil ve formül: $A_d = \frac{v_{od}}{v_{id}} = g_{m1}(r_{o1} \parallel r_{o3})$. (a) Aktif yüklü MOS fark yükselteci: iki NMOS giriş transistörü Q_1, Q_2 (girişleri $V_{CM} + v_{id}/2$ ve $V_{CM} - v_{id}/2$, ortak source'ta I akım kaynağı ve $-V_{SS}$), iki PMOS yük Q_3, Q_4 (gate'leri V_G'ye bağlı, V_{DD} altında), diferansiyel çıkış v_{od}. (b) Yarım devre: üst üste Q_3 (gate'i toprakta) ve Q_1 (girişi $v_{id}/2$), çıkış orta düğümde.
(orijinal notta, s. 3)



orijinal çizim, s. 3

$$V_{O1} = -g_{m1} v_{gs1} (r_{o1} \parallel r_{o3})$$
$$\frac{V_{O1}}{v_{id}} = -\frac{1}{2} g_m (r_{o1} \parallel r_{o3})$$
$$\frac{v_{O2} - v_{O1}}{v_{id}} = g_m (r_{o2} \parallel r_{o3})$$

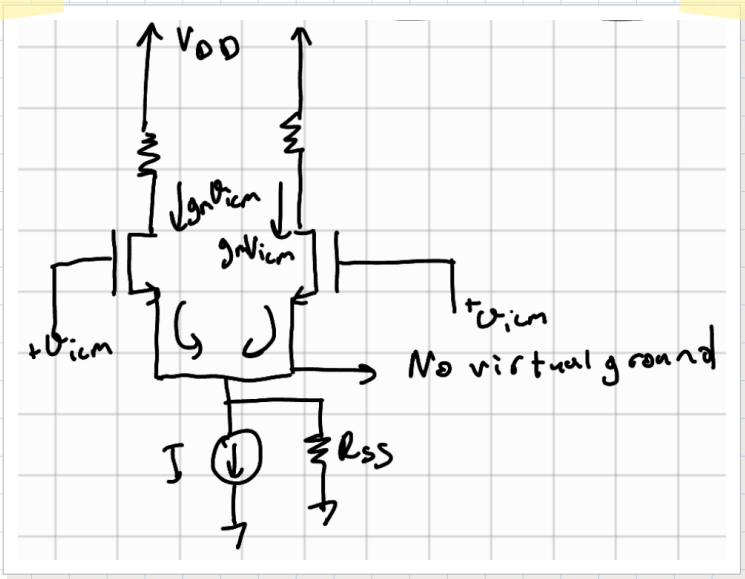
orj. s. 4

Şekil: Kitaptan yapıştırılmış basılı şekil: (a) kaskod aktif yüklü MOS fark yükselteci; giriş çifti Q_1, Q_2 (girişleri $V_{CM} + v_{id}/2$ ve $V_{CM} - v_{id}/2$; ortak source'ta I akım kaynağı ve $-V_{SS}$), üstlerinde Q_3, Q_4 (gate V_{G1}), Q_5, Q_6 (gate V_{G2}) ve Q_7, Q_8 (gate V_{G3}) kaskod transistörleri, V_{DD} altında; çıkış v_{od}. (b) Yarım devre: Q_7, Q_5, Q_3, Q_1 üst üste, çıkış düğümünde yukarı bakan $\mathcal{R}_{op}$ ve aşağı bakan $\mathcal{R}_{on}$ okları, çıkış $-v_{od}/2$.
(orijinal notta, s. 4)

$$\mathcal{R}_{on} = \mathcal{R}_{op} = g_m r_o^2$$
$$A_d = g_m (g_m r_o^2 \parallel g_m r_o^2)$$
$$A_d = \frac{1}{2} g_m^2 r_o^2$$

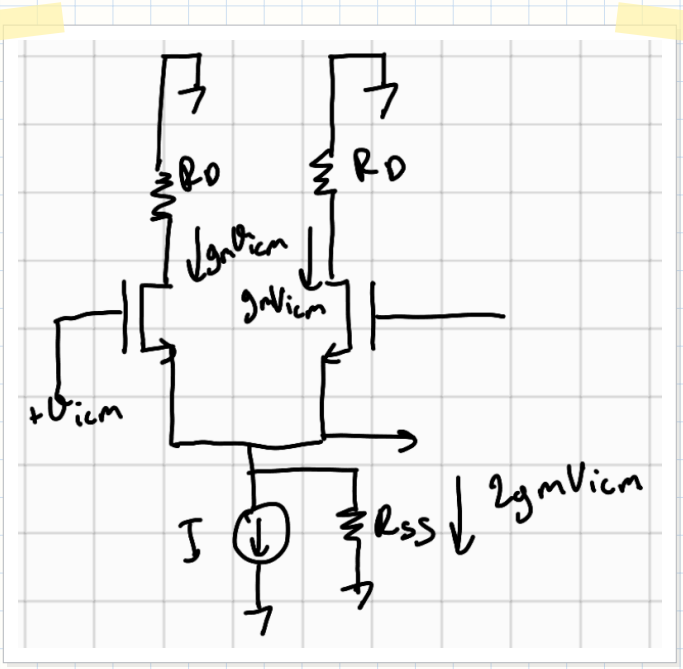
Şekil: Elle çizilmiş büyük bir dikdörtgen, sol üst köşesinde küçük bir kare; kareyi gösteren siyah bir okun yanında $\mathcal{R}_D$, kırmızı bir okun yanında "MOS" yazıyor; dikdörtgenin sağ üstünde i_c yazıyor. Sağda kitaptan yapıştırılmış basılı formüller: $A_d \equiv \frac{v_{od}}{v_{id}} = g_{m1}(\mathcal{R}_{on} \parallel \mathcal{R}_{op})$, $\mathcal{R}_{on} = (g_{m3} r_{o3}) r_{o1}$, $\mathcal{R}_{op} = (g_{m5} r_{o5}) r_{o7}$.
(orijinal notta, s. 4)

Common-Mode Gain and Common-Mode Rejection Ratio

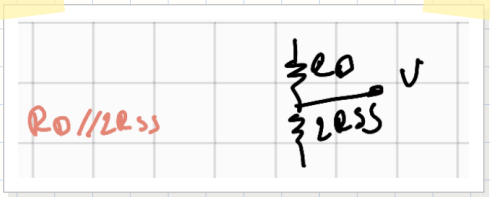


orijinal çizim, s. 4

orj. s. 5



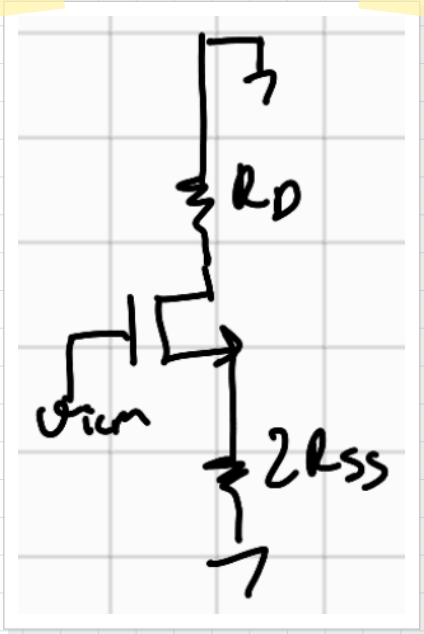
orijinal çizim, s. 5



orijinal çizim, s. 5

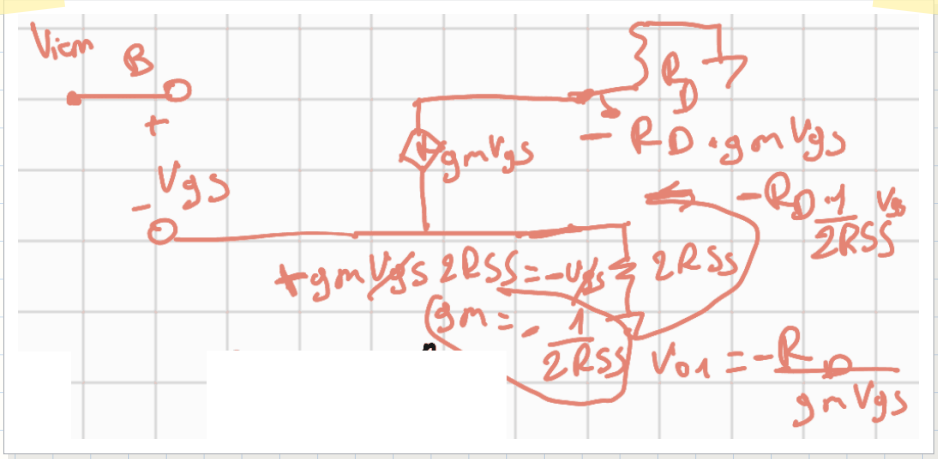
$$v_{O1} = \frac{-R_D}{2R_{SS}} v_{icm}$$
$$v_{O2} = \frac{-R_D}{2R_{SS}} v_{icm}$$
$$|A_{cm\,single}| \simeq \frac{R_D}{2R_{SS}}$$
$$|A_{cm\,diff}| = 0$$

half circuit



orijinal çizim, s. 5

$$\frac{v_{o1}}{v_{icm}} = -\frac{R_D}{2R_{SS}}$$



orijinal çizim, s. 5

Pembe kalemle yazılmış notlar (okunuşu kısmen belirsiz):

$$-R_D \cdot g_m V_{gs}$$

$$-R_D \frac{1}{2R_{SS}} V_{gs}$$

$$+ g_m V_{gs} 2R_{SS} = -V_{gs}$$

$$g_m = -\frac{1}{2R_{SS}}$$

$$V_{O1} = -\frac{R_D}{g_m V_{gs}}$$

$$V_o = 2 g_m V_{gs} R_{SS}$$

C M R R: C → Common, M → mode, R → Rejection, R → ratio

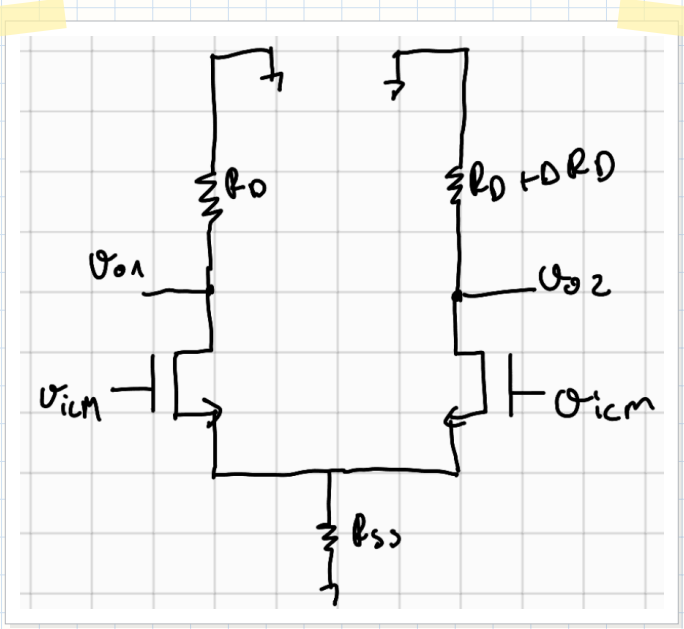
in theory

$$CMRR_{single} = \frac{|A_{single\ diff}|}{|A_{single\ common}|} = \frac{\frac{1}{2} g_m R_D}{\frac{R_D}{2R_{SS}}} = g_m R_{SS}$$

$$CMRR_{diff} = \frac{|A_{diff\ diff}|}{|A_{diff\ cm}|} = \frac{g_m R_D}{0} = \infty$$

CMRR'ın maksimum olmasını isteriz

orj. s. 6



orijinal çizim, s. 6

$$v_{O1} = -\frac{R_D}{2R_{SS}} v_{icm}$$

$$v_{O2} = -\frac{R_{D1} + \Delta R_D}{2R_{SS}} v_{icm}$$

$$v_{O2} = -\frac{R_{D1} + \Delta R_D}{2R_{SS}} v_{icm}$$

$$v_{O2} - v_{O1} = \frac{\Delta R_D}{2R_{SS}} v_{icm}^{1}$$

$$A_{cm\,diff} = \frac{\Delta R_D}{2R_{SS}} = \left(\frac{R_D}{2R_{SS}}\right)\frac{\Delta R_D}{R_D}$$

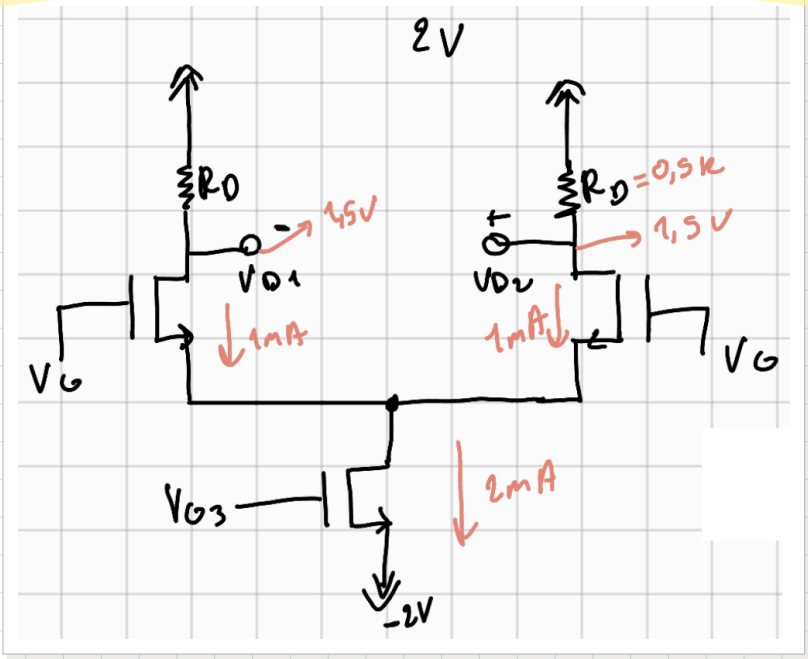
$$CMRR = \left|\frac{A_{diff\,diff}}{A_{cm\,diff}}\right| = \frac{g_m R_D}{\frac{\Delta R_D}{2R_{SS}}} = \frac{2\,g_m R_{SS}}{\Delta R_D/R_D}$$

Effect of g_m mismatch on CMRR $g_{m1} \neq g_{m2}$

$$CMRR_{diff} = \frac{2\,g_m R_{SS}}{\Delta g_m/g_m}$$

$g_m \Rightarrow$ typical value

orj. s. 7



orijinal çizim, s. 7

$$I_{D1}, I_{D2} = 1\,mA$$

$$1 = \frac{1}{2}\,8\,mA/V^2\,(V_{ov})^2$$

$$V_{ov1,2} = \pm 0{,}5\,V$$

Örnek 1

Calculate V_D, V_S, V_{DS} and V_{GS} if $I_{D3} = 2$ mA, $R_D = 0{,}5$ kΩ and $V_{ov3} = 0{,}5$ V. Assume that Q_1 and Q_2 are identical with $\mu_n C_{ox}(W/L) = 8\,mA/V^2$, $V_{tn} = 0{,}5$ V, $\lambda = 0$

[1] Claude notu: yukarıdaki satırlara göre işaret muhtemelen eksi olmalı: $-\frac{\Delta R_D}{2R_{SS}} v_{icm}$.

Çözüm:

$$V_{GS1} - V_{tn} = 0{,}5\,V$$
$$0 - V_S - 0{,}5 = 0{,}5\,V$$
$$\boxed{V_S = -1\,V}$$

$$V_{DS} = 1{,}5 - (-1) = 2{,}5\,V$$
$$V_{GS} = 1\,V$$

In saturation

if $\lambda \neq 0$ $\lambda = 0{,}1$

$$I_{D1,2} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{ov})^2(1 + \lambda V_{DS1})$$
$$1\,mA = \frac{1}{2}\cdot 8\cdot (V_{ov})^2\cdot(1 + \lambda V_{DS1})$$
$$(V_{ov})^2(1 + \lambda V_{DS1}) = 0{,}25$$
$$V_{DS} = V_D - V_S = V_D + (V_{GS} - V_G)$$
$$= V_D + (V_{GS} - V_{Tn} - V_G) + V_{tn}$$

orj. s. 8

$$V_{DS} = V_D + (V_{ov} - V_G) + V_{tn}{}^2$$
$$V_{DS} = V_{ov} + 2$$

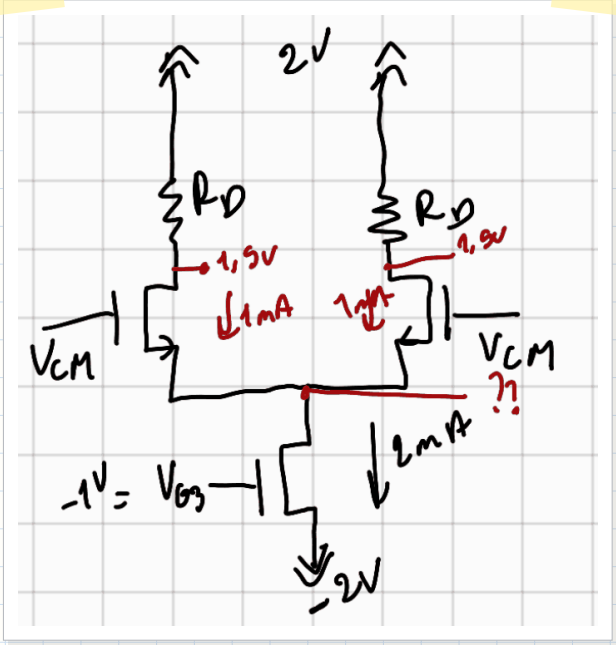
$$(V_{ov})^2(1 + 0{,}1(V_{ov} + 2)) = 0{,}25 \qquad V_{ov} = x \text{ olsun}$$

$$x^2(1 + 0{,}1x + 0{,}2) = 0{,}25$$
$$x^2(1{,}2 + 0{,}1x) = 0{,}25$$

$$V_{ov} = 0{,}448\,V$$
$$V_{GS1,2} = 0{,}948\,V$$
$$V_{S1,2} = -0{,}948\,V$$

[2] Satırın üzerinde oklarla $V_D \to 1{,}5$, $V_G \to 0$ ve $V_{tn} \to 0{,}5$ değerleri yazılmış.

Common mode Range



orijinal çizim, s. 8

Örnek

What is the input common mode range? Q_1 and Q_2 are identical.
$R_D = 0{,}5\,k\Omega$
$\mu_n C_{ox}\, W/L = 8\,mA/V^2$
$V_{t1,2,3} = 0{,}5\,V$
$V_{G3} = -1\,V$

Çözüm:

$$1 = \frac{1}{2} 8\,mA/V^2 (V_{ov})^2$$
$$V_{GS} - V_{tn} = 0{,}5$$
$$V_{GS} = 1\,V$$
$$V_D = 2 - 0{,}5 \cdot 1\,mA$$
$$= 1{,}5\,V$$

↗

$$V_{GS3} = -1 - (-2) = 1\,V$$
$$V_{ov} = 1 - 0{,}5 = 0{,}5\,V$$

↓

$$V_{DS3} \geq V_{ov3} \quad \text{sat koşulu}$$
$$V_{DS3} \geq 0{,}5\,V$$
$$V_{D3} \geq -1{,}5\,V$$

orj. s. 9

Çözüm:

$$V_{CM} - (-1{,}5) - 0{,}5 \geq 0$$

$$\boxed{V_{CM} \geq -1\,V}$$

Triodtan kaçınması lazım üsttekinin

$$V_{DS} \geq V_{GS} - V_t$$
$$V_D \geq V_{CM} - 0{,}5$$
$$V_D + 0{,}5 \geq V_{CM}$$
$$2 \geq V_{CM}$$

$$-1\,V \leq V_{cm} \leq 2\,V \qquad \text{input cm range}$$

Örnek 3

A MOS differential pair is operated at a bias current (I) of 0,4 mA. If $\mu_n C_{ox} = 0{,}2\,mA/V^2$, find the required values of (W/L) and the resulting g_m if the MOSFETs are operated at $V_{ov} = 0{,}2\,V$, 0,3 V and 0,4 V. For each value give the max v_{id}

Çözüm:

$$I = 0{,}4\,mA \rightarrow \begin{cases} I_{D1} = 0{,}2\,mA \\ I_{D2} = 0{,}2\,mA \end{cases}$$

$$0{,}2\,mA = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{ov})^2$$

$$2 = \left(\frac{W}{L}\right)(V_{ov})^2$$

For $V_{ov} = 0{,}2\,V$

$$\left(\frac{W}{L}\right) = \frac{2}{(0{,}2)^2} = 50 \Rightarrow W = 50\,\mu m, \quad L = 1\,\mu m$$

$$g_m = \frac{2I_D}{V_{ov}} = \frac{2 \cdot 0{,}2}{0{,}2} = 2\,mS^3$$

$$\max(v_{id}) = ?$$
$$-\sqrt{2}\,V_{ov} \leq v_{id} \leq \sqrt{2}\,V_{ov}$$
$$\simeq 0{,}2808 \simeq 280\,mV$$

Pay ve paydadaki 0,2 çizilerek sadeleştirilmiş.