Elektronik I

Uygulama dersi: BJT ve MOSFET devre analizi

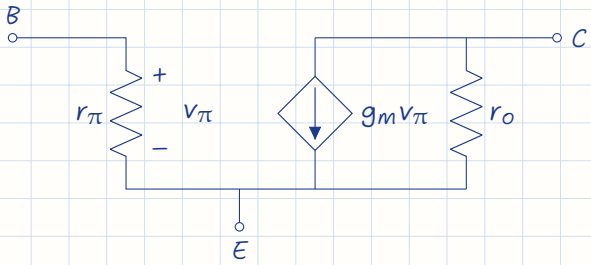
Orijinal not: Elektronik1-Uygulama-dersi.pdf

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.

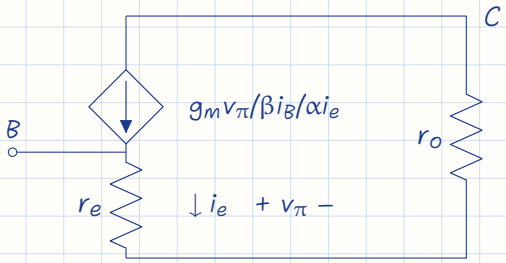
NOTICE *This document was transcribed from handwritten lecture notes with the help of Claude (Anthropic). It is meant as a supplementary resource and may contain errors or omissions. Always check against the original notes and official course material.*

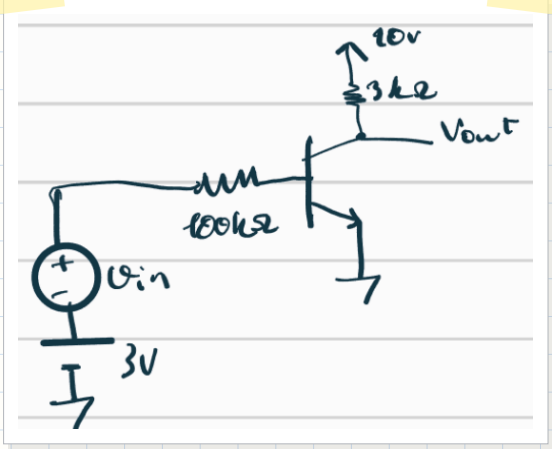
orj. s. 1

Uygulama



$$r_o = \frac{V_A}{I_C}$$





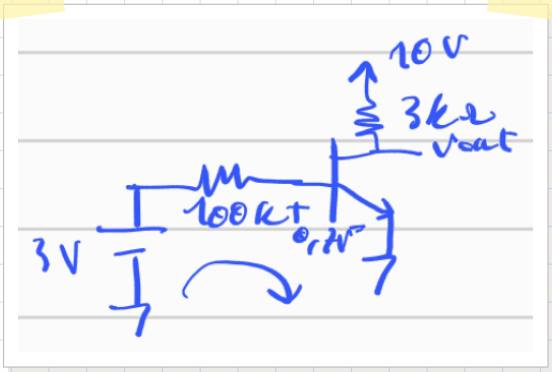
orijinal çizim, s. 1

Örnek

Analyze the circuit at left. Assume $\beta = 100$, $V_A = 100\,V$. Calculate the voltage gain $\left(\frac{v_{out}}{v_{in}}\right)$, R_{in}, and R_{out}

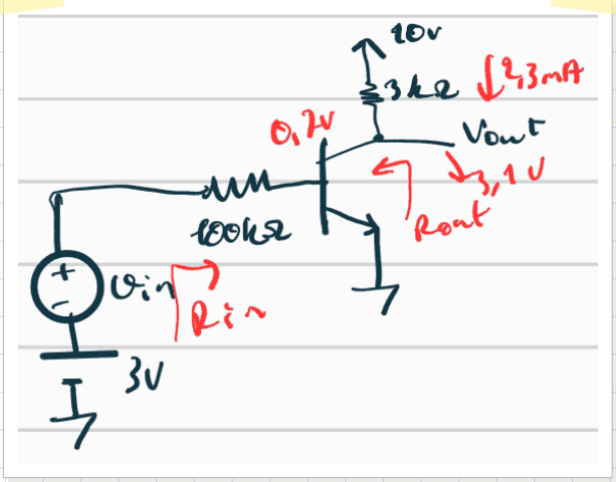
- Determine the type of amplifier
  - Common-Emitter (Use π model)
- DC analysis (to find small signal param?eters)

⇓ @DC



orijinal çizim, s. 1

$$-3\,V + 100\,k\Omega\, I_B + 0{,}7 = 0$$
$$100\,k\Omega\, I_B = 2{,}3\,V$$
$$I_B = 23\,\mu A$$
$$I_E = 2{,}32\,mA$$
$$I_C = 2{,}3\,mA$$



orijinal çizim, s. 1

$$V_{CB} \geq 0{,}4 \quad \text{(for linear)}^{1}$$

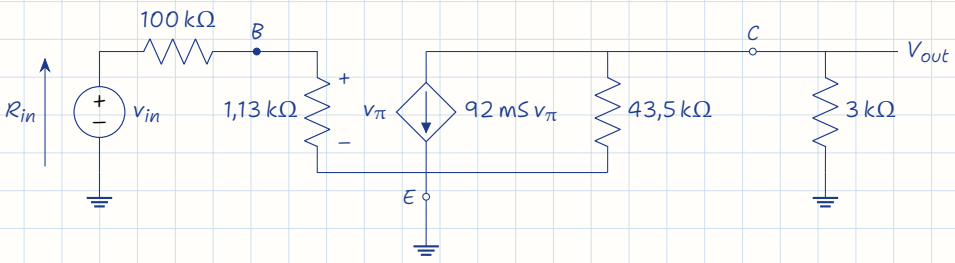
$$r_o = \frac{100\ \text{V}}{2{,}3\ \text{mA}} \approx 43{,}5\ \text{k}\Omega$$

$$g_m = \frac{I_C}{V_T} = \frac{2{,}3\ \text{mA}}{25\ \text{mV}} = 92\ \text{mS}$$

$$r_e = \frac{?26\ \text{mV}}{2{,}32} \approx 11{,}2\ \Omega^{2}$$

$$r_\pi = 1{,}13\ \text{k}\Omega \qquad = (\beta + 1)\, r_e$$

orj. s. 2



$$R_{in} = 100 + 1{,}13 = 101{,}13\ \text{k}\Omega$$

$$R_{out} = r_o \parallel R_C \approx 2{,}8\ \text{k}\Omega$$

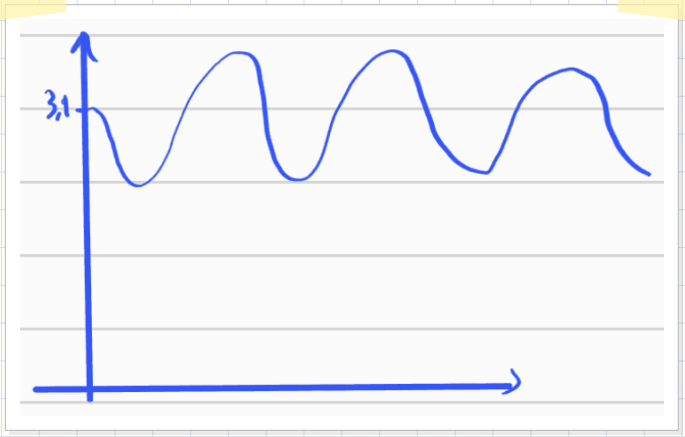
$$V_{out} = -2{,}8\ \text{k}\Omega \times 92\ \text{mS}\ v_\pi$$

$$v_\pi = \frac{v_{in} \times 1{,}13\ \text{k}}{101{,}3\ \text{k}\Omega}$$

(ok: v_π ifadesi V_{out} denkleminin sonundaki v_π'ye yerleştiriliyor)

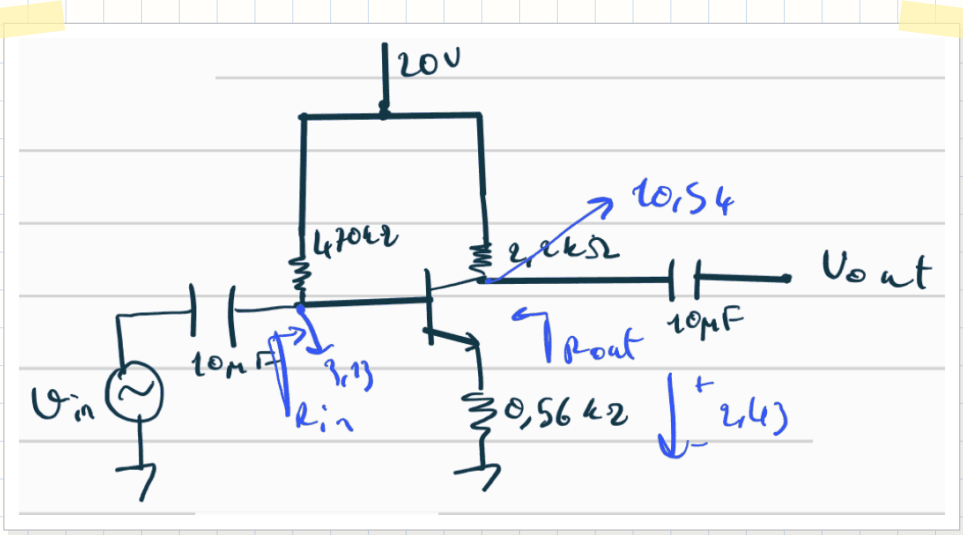
$$V_{out} = \frac{-257{,}6 \cdot v_{in} \cdot 1{,}13\ \text{k}}{101{,}3\ \text{k}} = -2{,}68\ \text{V/V}^{3}$$

[1] Claude notu: muhtemelen $V_{CB} \geq -0{,}4$ V olmalı.
[2] Claude notu: pay 26 mV ise 26/2,32 ≈ 11,2 Ω olur; 25 mV ile ≈ 10,8 Ω çıkardı.



orijinal çizim, s. 2

Soru 2



orijinal çizim, s. 2

$\beta = 120$ $V_A = \infty$ C-E with R_E (T model)

orj. s. 3

DC

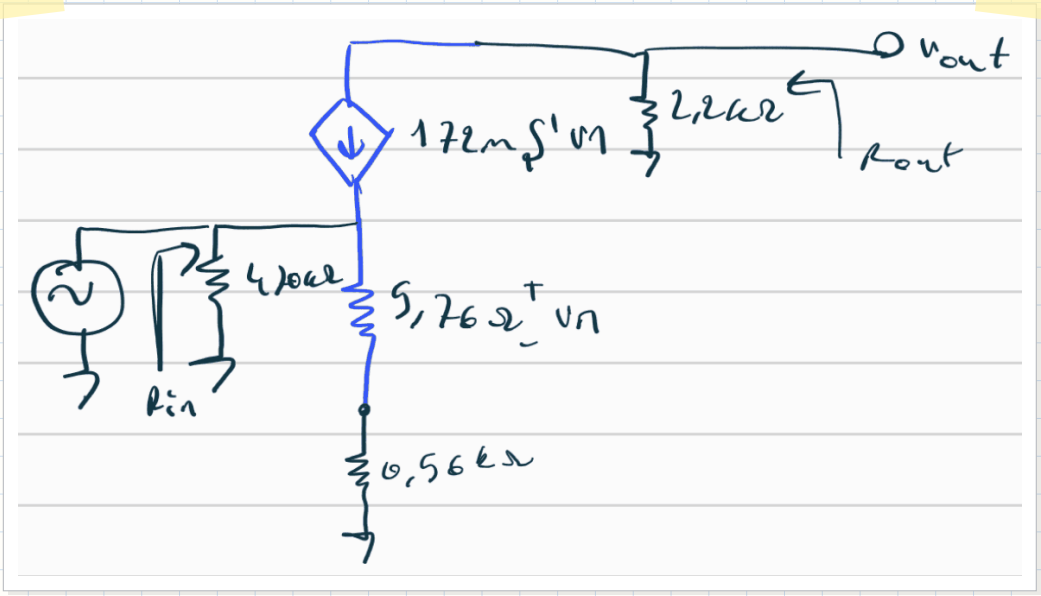
$$-20 + 470k\,I_B + 0{,}7 + 121 \cdot 0{,}56k\,I_B = 0$$

$$I_B = 0{,}035\,\text{mA}$$
$$I_C = 4{,}3\,\text{mA}$$
$$I_E = 4{,}34\,\text{mA}$$

$$V_C = 20 - 2{,}2\,\text{k}\Omega \times 4{,}3\,\text{mA} = 10{,}54$$

[3] Claude notu: 257,6 · 1,13/101,13 ≈ 2,88 olduğundan muhtemelen −2,88 V/V olmalı.

$$r_e = \frac{25\,mV}{4{,}34\,mA} = 5{,}76\,\Omega$$
$$g_m = \frac{4{,}3}{25} = 172\,mS$$
$$r_o = \infty$$



orijinal çizim, s. 3

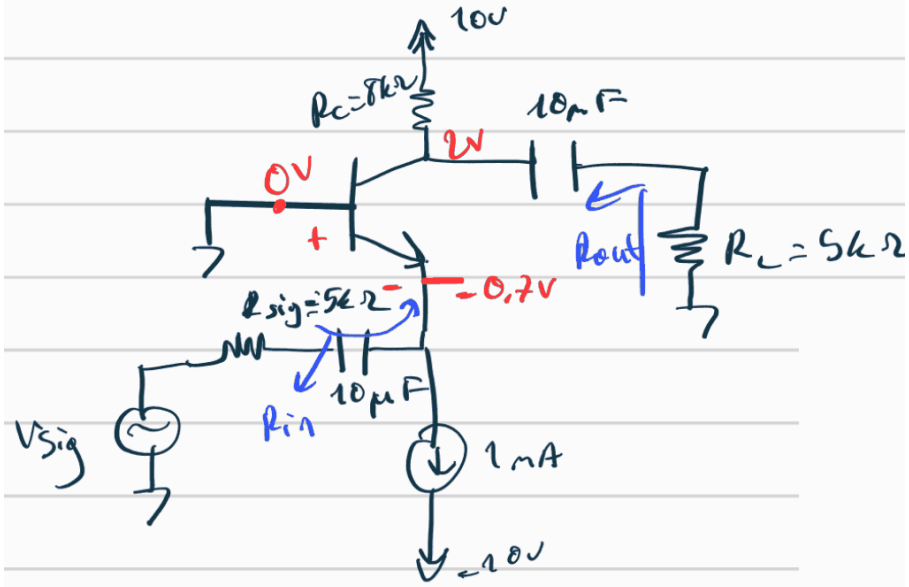
$$R_{in} = 470\,k\Omega \parallel \underbrace{(121)(565{,}76\,\Omega)}_{68{,}4\,k\Omega} \qquad R_{out} = 2{,}2\,k\Omega$$
$$R_{in} = 59{,}8\,k\Omega$$

$$v_{out} = -172\,mS \cdot 2{,}2\,k\Omega\, v_\pi$$
$$v_\pi = \frac{v_{in}}{565} \times 5{,}76$$
$$v_{out} = -378{,}4\, v_{in} \times 0{,}01$$
$$\frac{v_{out}}{v_{in}} \approx -3{,}784\ [V/V]$$

orj. s. 4

Soru

R_{in}, R_{out}, $A_v \left(\frac{v_{out}}{v_{sig}}\right)$ CB Amplifier



orijinal çizim, s. 4

$\beta = 100 \qquad V_A = \infty$

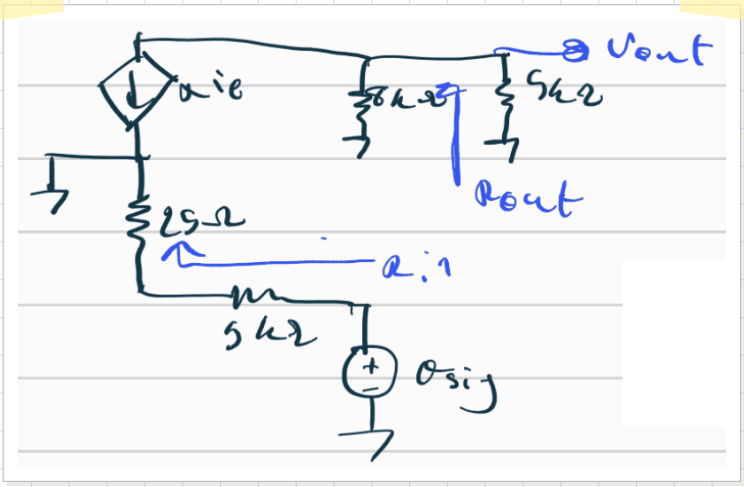
$I_C = 1\,\text{mA}$

$V_T = 25\,\text{mV}$

$r_e \simeq 25\,\Omega$

$r_\pi \simeq 2{,}5\,\text{k}\Omega$

$$g_m = \frac{1\,\text{mA}}{25\,\text{mV}} = 40\,\text{mS}$$



orijinal çizim, s. 4

$R_{in} = r_e = 25\,\Omega$

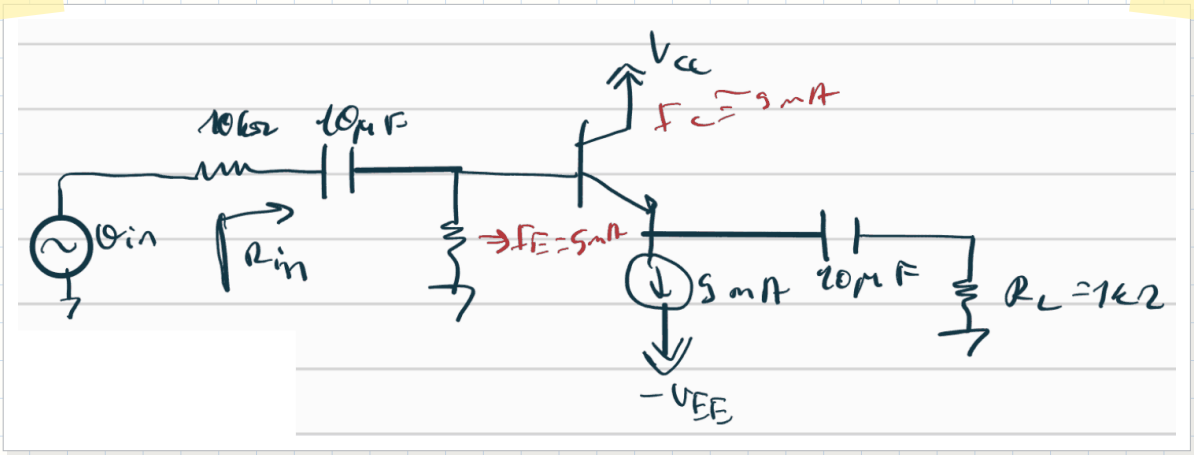
$R_{out} = 8\,\text{k}\Omega$

Common emitter de sadece ?faz farkı var!

$$v_{out} = -3{,}07\,k\Omega\,\alpha \cdot i_e$$
$$i_e = \frac{-v_{sig}}{5{,}025\,k\Omega}$$
$$\frac{v_{out}}{v_{sig}} = \frac{3{,}07 \cdot 0{,}99}{5{,}025} \approx 0{,}6\ [V/V]$$

orj. s. 5

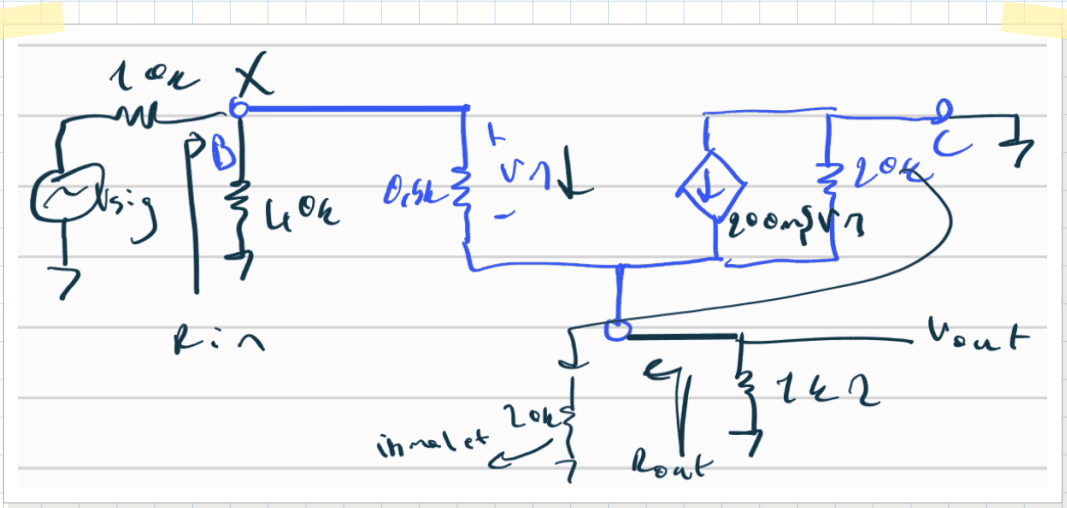
Soru



orijinal çizim, s. 5

$$\beta = 100 \qquad V_A = 100\,V$$

$$r_e = \frac{25\,mV}{5\,mA} = 5\,\Omega$$
$$r_\pi = 0{,}5\,k\Omega$$
$$g_m = \frac{5\,mA}{25\,mV} = 200\,mS$$
$$r_o = \frac{100\,V}{5\,mA} = 20\,k\Omega$$



orijinal çizim, s. 5

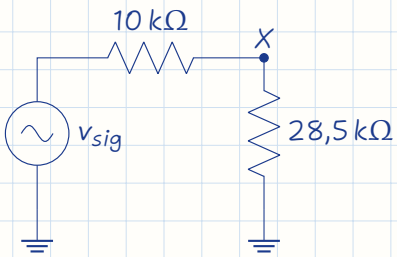
$$R_{in} = 40\,k\Omega \parallel (0{,}5\,k\Omega + 101\,k\Omega)$$
$$R_{in} \approx 28{,}5\,k\Omega$$
$$R_{out} = \frac{(10\,k\Omega \parallel 40\,k\Omega) + 0{,}5\,k\Omega}{\beta + 1}$$
$$R_{out} \approx 80\,\Omega$$

$$V_{out} = \left(\frac{v_\pi}{0{,}5k} + 200\,mS\,v_\pi\right) 1k$$
$$= 2\,v_\pi + 200\,v_\pi$$
$$= 202\,v_\pi$$

orj. s. 6 $R_{sig} = 0$ ise $\Rightarrow v_{sig} = v_\pi + v_{out}$

$$\frac{v_{out}}{v_{sig}} = \frac{202\,v_\pi}{203\,v_\pi} \approx 0{,}99\ [V/V]$$

$R_{sig} = 10\,k\Omega$

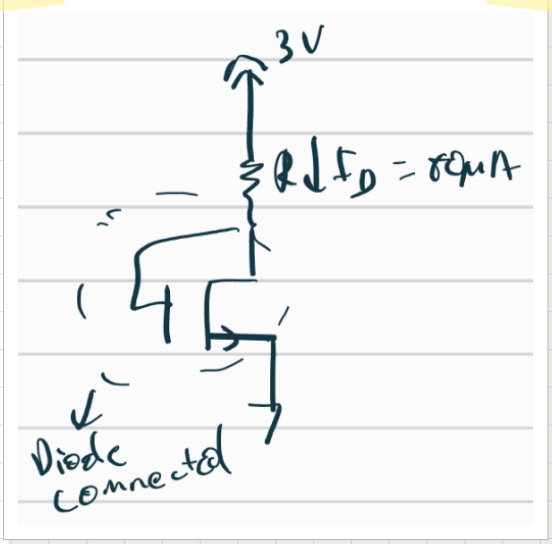


$$V_X = \frac{28{,}5}{38{,}5} v_{sig} \approx 0{,}74\,v_{sig}$$

$$v_\pi = V_X - v_{out}$$
$$v_\pi = 0{,}74\, v_{sig} - 202\, v_\pi$$
$$203\, v_\pi = 0{,}74\, v_{sig}$$
$$v_{sig} = 273{,}4\, v_\pi$$
$$\Rightarrow \quad \frac{v_{out}}{v_{sig}} = \frac{202\, v_\pi}{274{,}3\, v_\pi} \approx 0{,}734 \ [V/V]$$

Örnek

Design the circuit given below to obtain a current of 80 µA. Find the value of R_D and V_D. Let the NMOS have $V_T = 0{,}6$ V, $\mu_n C_{ox} = 200\ \mu A/V^2$, $L = 0{,}8$ µm, $W = 4$ µm. Neglect channel length modulation.



orijinal çizim, s. 6

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$$
$$80\ \mu A = \frac{1}{2}\cdot 200\ \mu A/V^2 \cdot \frac{4}{0{,}8}(V_{ov})^2$$
$$\frac{160}{1000}(V_{ov})^2 = 0{,}16$$

↙ 0,4 ↘ −0,4 (kırmızıyla çizilmiş)

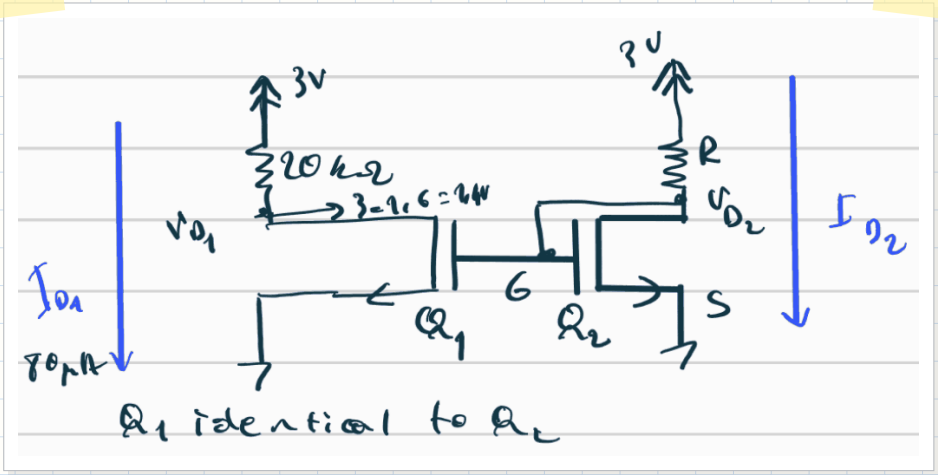
orj. s. 7

$$V_{GS} - V_T = 0{,}4\ V$$
$$V_{GS} = 0{,}4\ V + 0{,}6\ V = 1\ V$$
$$V_G = 1\ V + V_S = 1\ V$$
$$V_G = V_D = 1\ V$$
$$R_D = \frac{3-1}{80\cdot 10^{-6}}$$
$$= \frac{2}{80\cdot 10^{-6}} = \frac{2\cdot 10^6}{80} = 25\ k\Omega$$

Sat

$V_{GS} \geq V_T$

$V_{DS} \geq V_{GS} - V_T$



orijinal çizim, s. 7

$I_{D1} = 80\,\mu A$

$V_{D1} = ?$

$I_{D2} = ?$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS1} - V_T)^2$$

$$I_{D2} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS2} - V_T)^2$$

$$I_{D1} = I_{D2} = 80\,\mu A$$

(İlk iki satırda $\frac{1}{2}\mu_n C_{ox}\frac{W}{L}$ çarpanı çizilmiş; V_{GS1} ve V_{GS2} daire içine alınmış.)

$$R_{min} \leq R \leq R_{max}$$

$$V_T = 0{,}6\,V$$

Sat $\begin{cases} V_G \geq V_T \quad \text{Sat} & \dfrac{3-0{,}6}{80\,\mu A} = 30\,k\Omega \\ V_{DS} \geq V_{GS} - V_T & \dfrac{3-2}{80\,\mu A} = 12{,}5\,k\Omega \\ V_D = V_G - V_T & \\ V_G = V_D + V_T = 2\,V & \end{cases}$

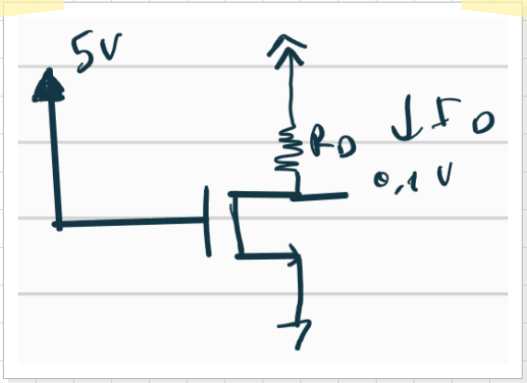
$\left.\begin{matrix} V_{DS} \leq V_{GS} - V_T \\ V_{GS} \geq V_T \end{matrix}\right\}$ triode $\qquad \left.\begin{matrix} V_{GS} \geq V_T \\ V_{DS} \geq \underbrace{V_{GS} - V_T}_{V_{ov}} \end{matrix}\right\}$ SA

$V_{GS} < V_T$ } cutoff

orj. s. 8

Örnek

Design the circuit to obtain a drain voltage of 0,1 V. What is the effective resistance between drain and source at this point $V_T = 1\,V$ and $\frac{1}{2}\mu_n C_{ox}\frac{W}{L} = 1\,mA/V^2$.



orijinal çizim, s. 8

$V_{DS} < V_{GS} - V_T \qquad 0{,}1 < 5\,V$ } triode

(İlk ifadenin altında dalgalı çizgi ve "X" işareti var.)

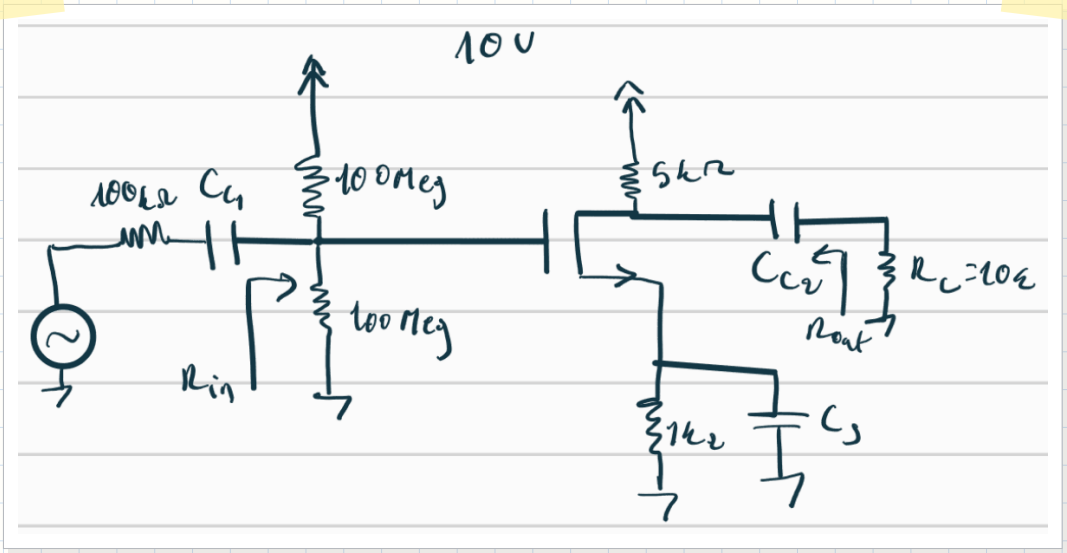
$$I_D = \mu_n C_{ox}\frac{W}{L}\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right)V_{DS}$$

$$\frac{V_{DS}}{I_D} = r_{DS} = r_x =$$

$$\Rightarrow \frac{1000}{7{,}9} \approx 125\,\Omega$$

R_D'yi bul =?

Soru



orijinal çizim, s. 8

orj. s. 9

Örnek

$|V_T| = 2\,V$, $\mu_n C_{ox} = 125\,\mu A/V^2$, $W = 4\,\mu m$, $L = 1\,\mu m$

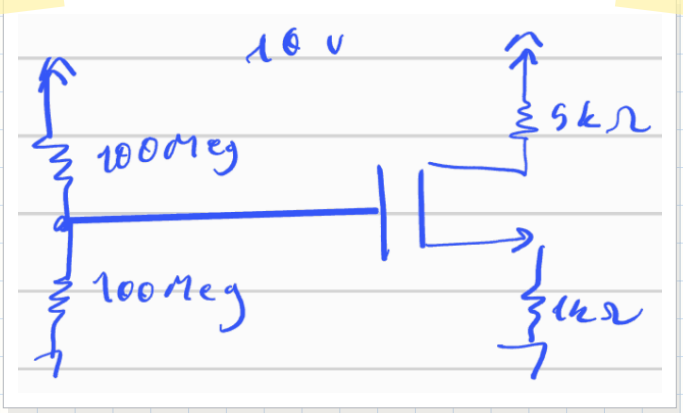
- Perform DC analysis, calculate small signal params
- Estimate the voltage gain $\left[\frac{v_{out}}{v_{sig}}\right]$, R_{in}, R_{out}

$V_A = 50\,V$

DC: $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$

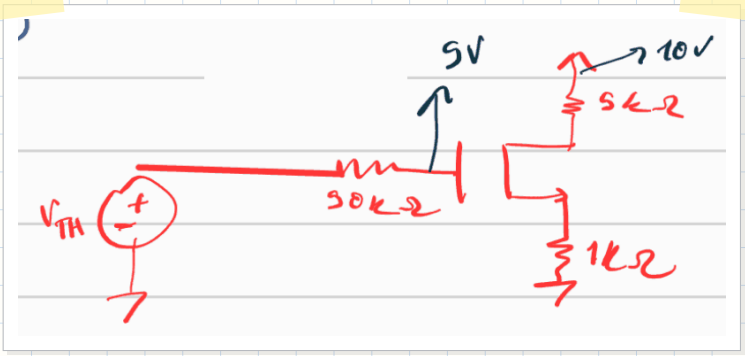
Small signal: $r_o = V_A/I_D$

$g_m = 2I_D/V_{ov}$



orijinal çizim, s. 9

$V_{TH} = 5\,V$ $R_{TH} = 50\,k\Omega$ [4]



orijinal çizim, s. 9

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$$

$$\left.\begin{aligned} V_G &= 5\,V \\ V_S &= I_D \end{aligned}\right\} \quad I_D = \frac{1}{2}\cdot 125\ \mu A/V^2 \cdot 4\,(5 - I_D - 2)^2$$

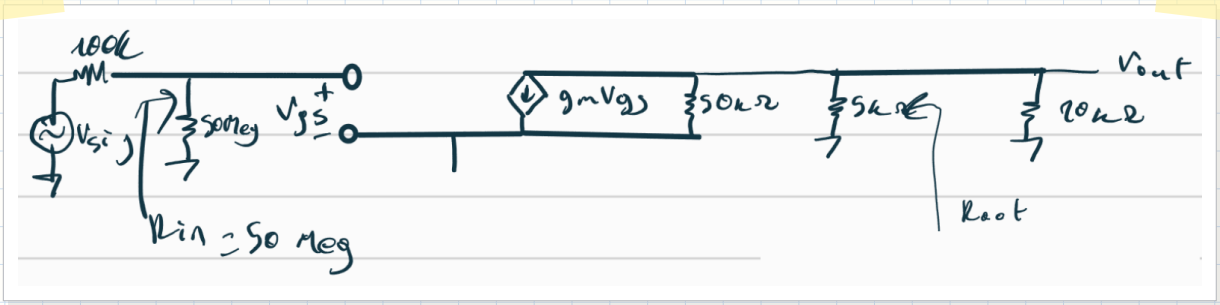
$$I_D = 250\ \mu A/V^2\,(5 - I_D - 2)^2$$

$$I_D = 1\,mA$$

$$r_o = \frac{50}{1\,mA} = 50\,k\Omega$$

$$g_m = \frac{2 \times 1\,mA}{2} \qquad g_m = 1\,mS$$

orj. s. 10



orijinal çizim, s. 10

$$R_{out} = 5 \parallel 50\,k\Omega = 4{,}54\,k\Omega$$

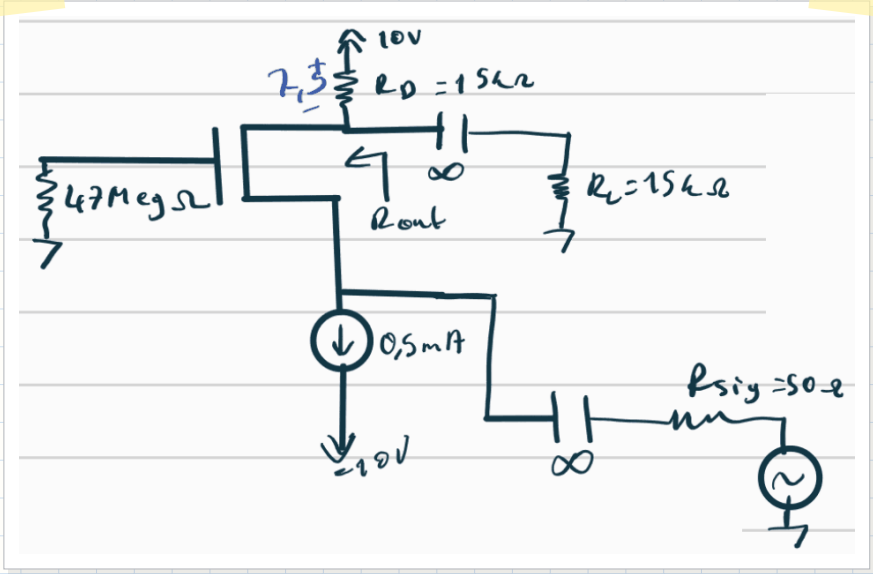
$$v_{gs} = \frac{v_{sig}\cdot 50\,M\Omega}{50{,}1} \approx v_{sig}$$

$$v_{out} = -\underbrace{(50\,k\Omega \parallel 5\,k\Omega \parallel 10\,k\Omega)}_{-3{,}12\,k\Omega}\cdot 1\,mS \cdot \overset{v_{sig}}{v_{gs}}$$

$$\frac{v_{out}}{v_{sig}} = -3{,}12\ V$$

[4] Claude notu: 100 MΩ ∥ 100 MΩ = 50 MΩ olduğundan muhtemelen 50 MΩ olmalı.

Soru



orijinal çizim, s. 10

Örnek

$V_T = 1{,}5\,V$ $\quad \mu_n C_{ox}\frac{W}{L} = 1\,mA/V^2$ $\quad |V_A| = \infty$

a) DC analysis
b) Draw small signal equivalent circuit
c) Calculate gain, R_{in}, R_{out}

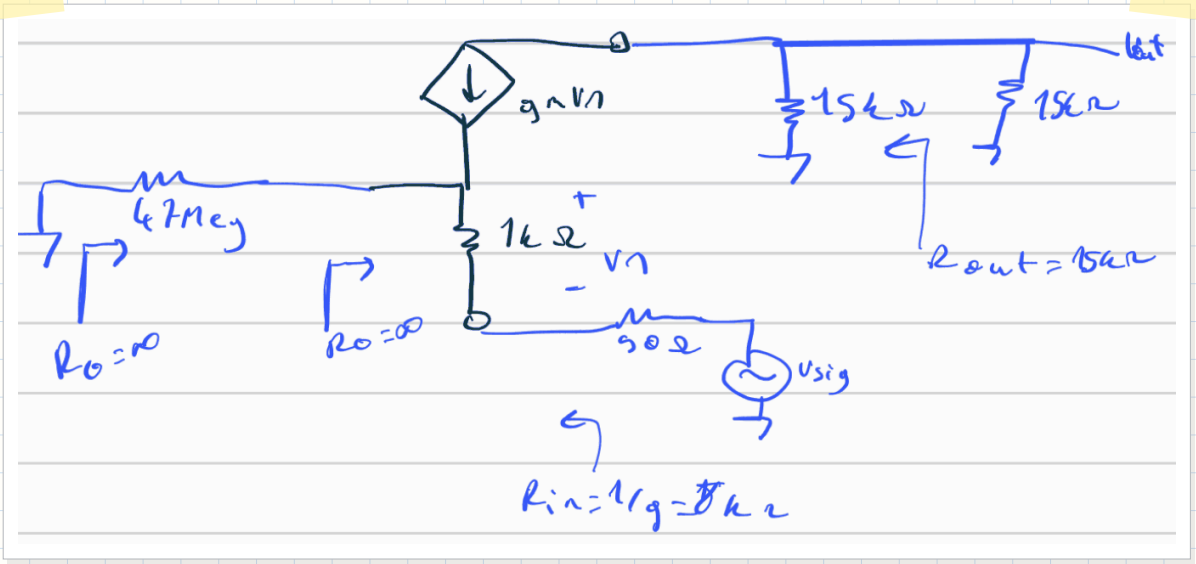
$I_D = 0{,}5\,mA$ Common-Gate (T model)

$$V_D = 2{,}5\,V$$
$$V_G = 0\,V$$
$$0{,}5\,mA = \frac{1}{2}\,1\,mA/V^2\,(V_{ov})^2$$
$$V_{ov} = 1\,V$$
$$V_{GS} - V_T = 1\,V$$
$$0 - V_S - 1{,}5 = 1\,V \qquad V_S = -2{,}5\,V$$

orj. s. 11

$$V_{DS} \geq V_{ov}$$
$$5\,V \geq 1\,V \quad \checkmark \text{ Sat}$$

$$r_o = \infty$$
$$g_m = \frac{2I_D}{V_{ov}} = \frac{2 \cdot 0{,}5\,mA}{1\,V}$$
$$g_m = 1\,mS$$



orijinal çizim, s. 11

$$v_{out} = -7{,}5\,k\Omega \cdot 1\,mS\, v_\pi$$
$$= -7{,}5\, v_\pi$$
$$v_{sig} \approx v_\pi$$
$$\frac{v_{out}}{v_{sig}} = -7{,}5\ [V/V]$$