Number: ______________ Name: ______________

ECE 246
FINAL EXAM

07.06.2012

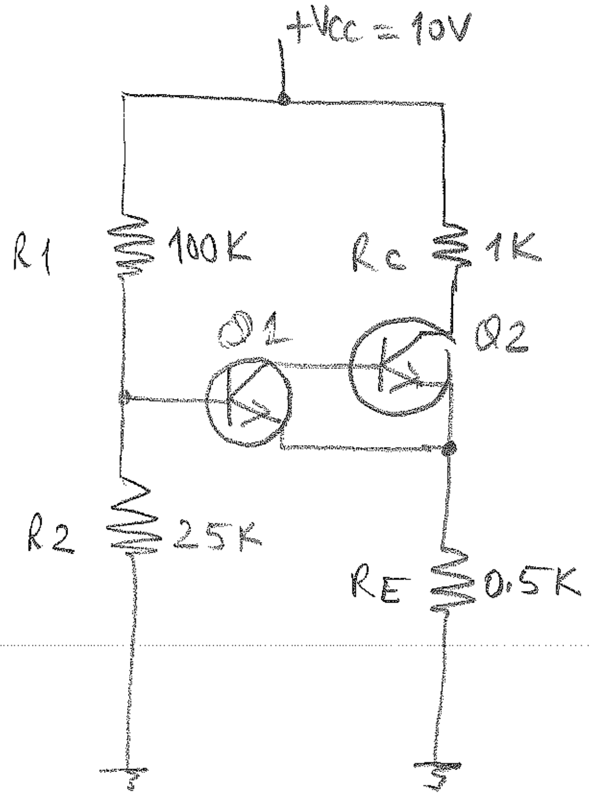
Exam is closed-book/notebook. You can use a A-3 full of your handwritten notes (photocopy is not allowed). No mobile device will be used. You can use a calculator. There are 4 questions. Please print your name on every page. Also fill in the answer boxes given. Solve every question in the space given. No answer on the question pages. Exam duration 2.5 hours. Use the universal characteristics given for FET calculations.

Question ①

For the circuit given below calculate

a) I_{C2}

b) V_{CE2}.



Q1 and Q2 are identical transistors.

$V_{BE1} = V_{BE2} = 0.6V$

$\beta_1 = \beta_2 = 20$

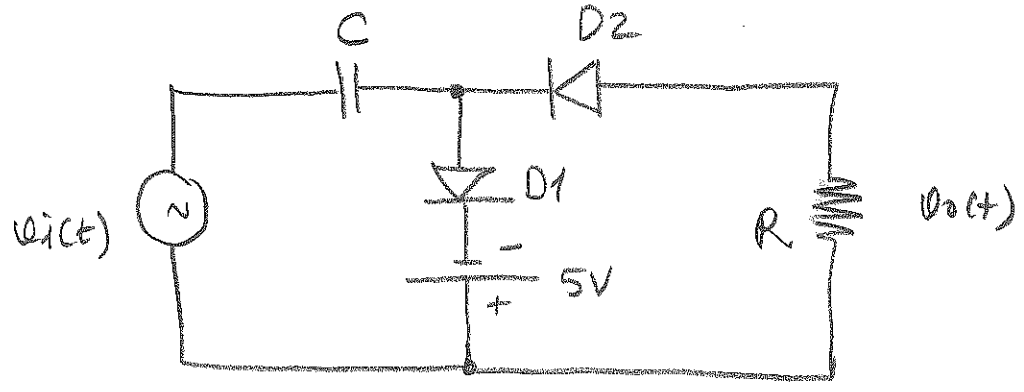
$T = 300K$

Answer ①:

I_{C2}	V_{CE2}

Question ②

For the circuit given below sketch the output signal.



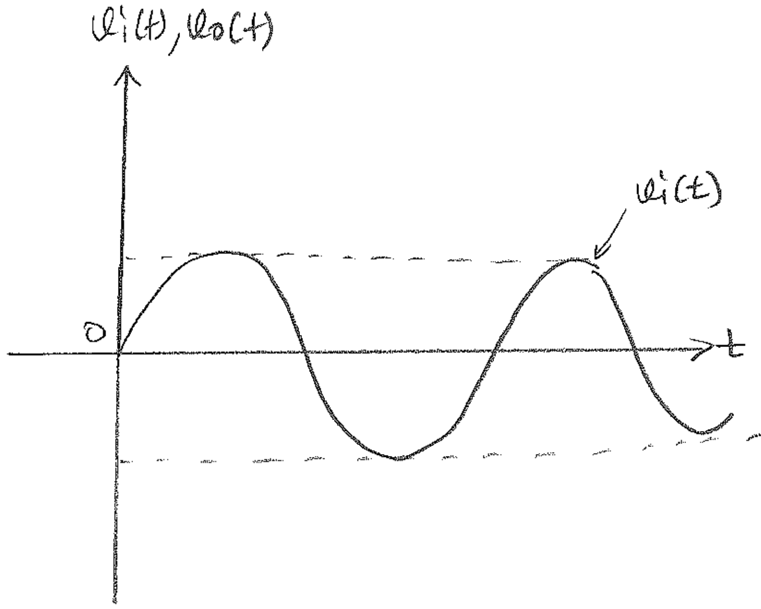
$v_i(t) = 10 \sin 200\pi t$

$R = 10K$

$C = 100nF$

Diodes are ideal.

Answer (2)



Question (3)

For the amplifier circuit given below, calculate

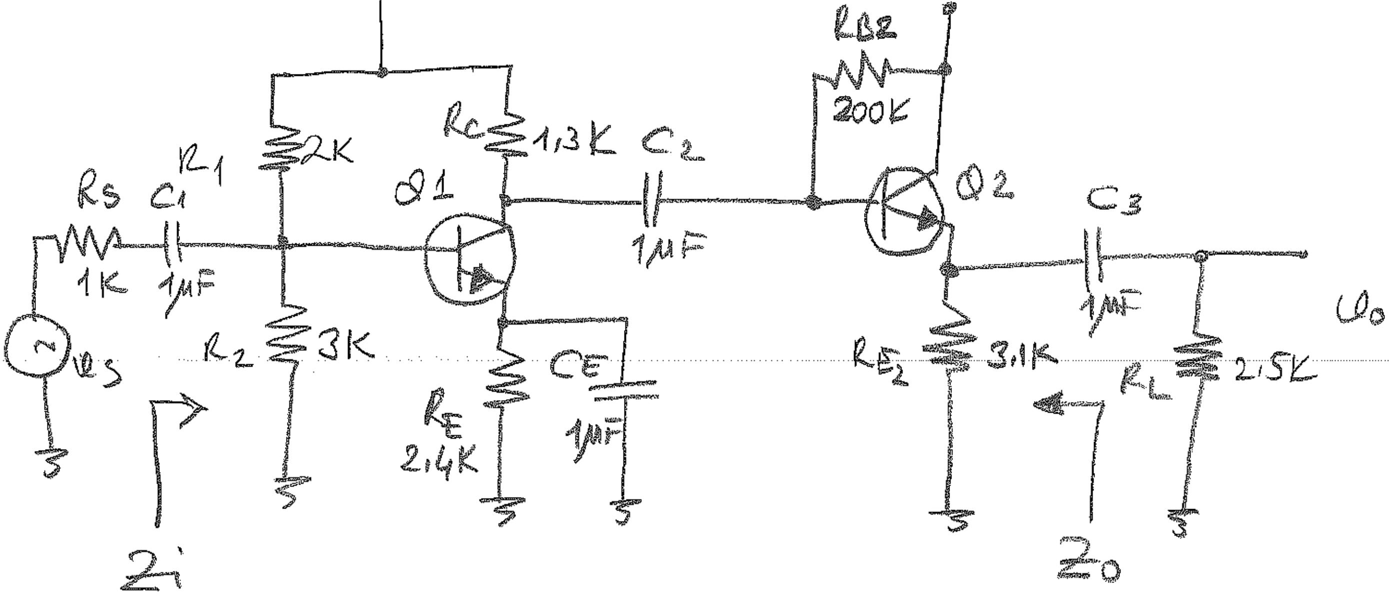
a) The overall voltage gain $A_{vT} = \frac{v_o}{v_s}$

b) Z_i and Z_o.

$V_{BE_1} = V_{BE_2} = 0.6V$

$\beta_1 = \beta_2 = 200$

$T = 300K$



Answer ③

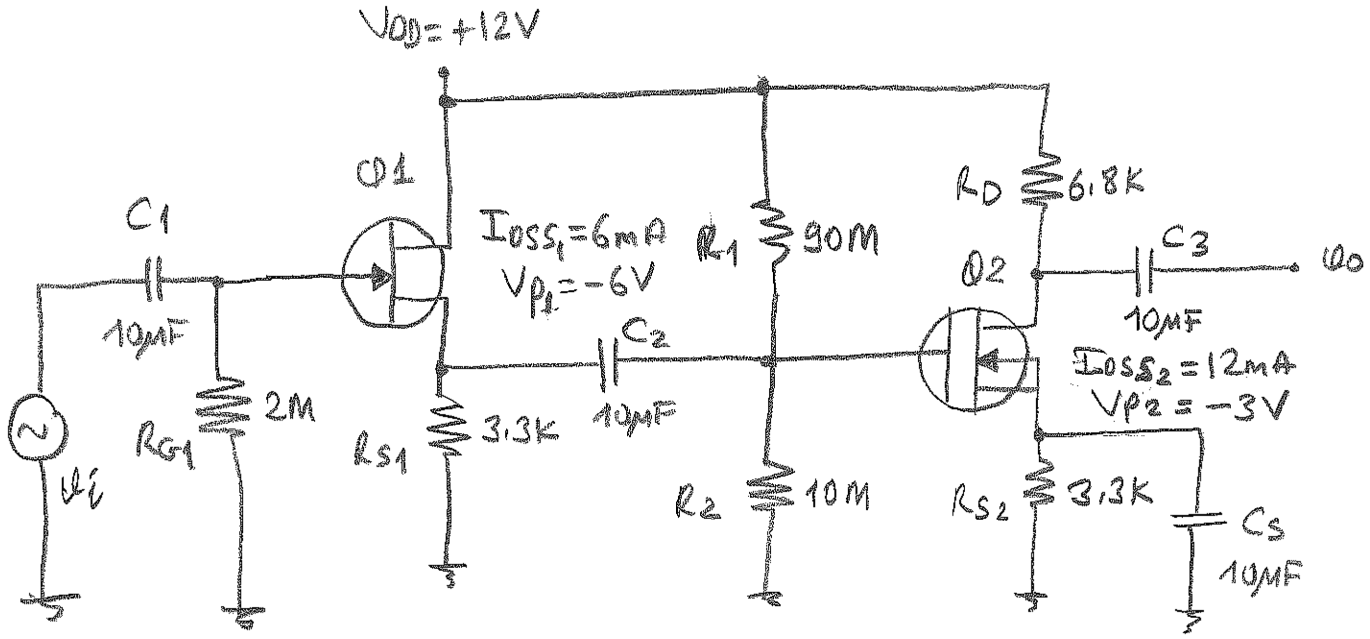
Answer (3) -continued

Fill the table:

I_{E1}	I_{E2}	r_{e1}	r_{e2}	A_{v1}	A_{v2}	A_{v3}	A_{vT}	Z_i	Z_o

Answer (3) - continued

Question (4) For the circuit given below, calculate the overall gain $A_{vT} = \frac{v_o}{v_i}$.

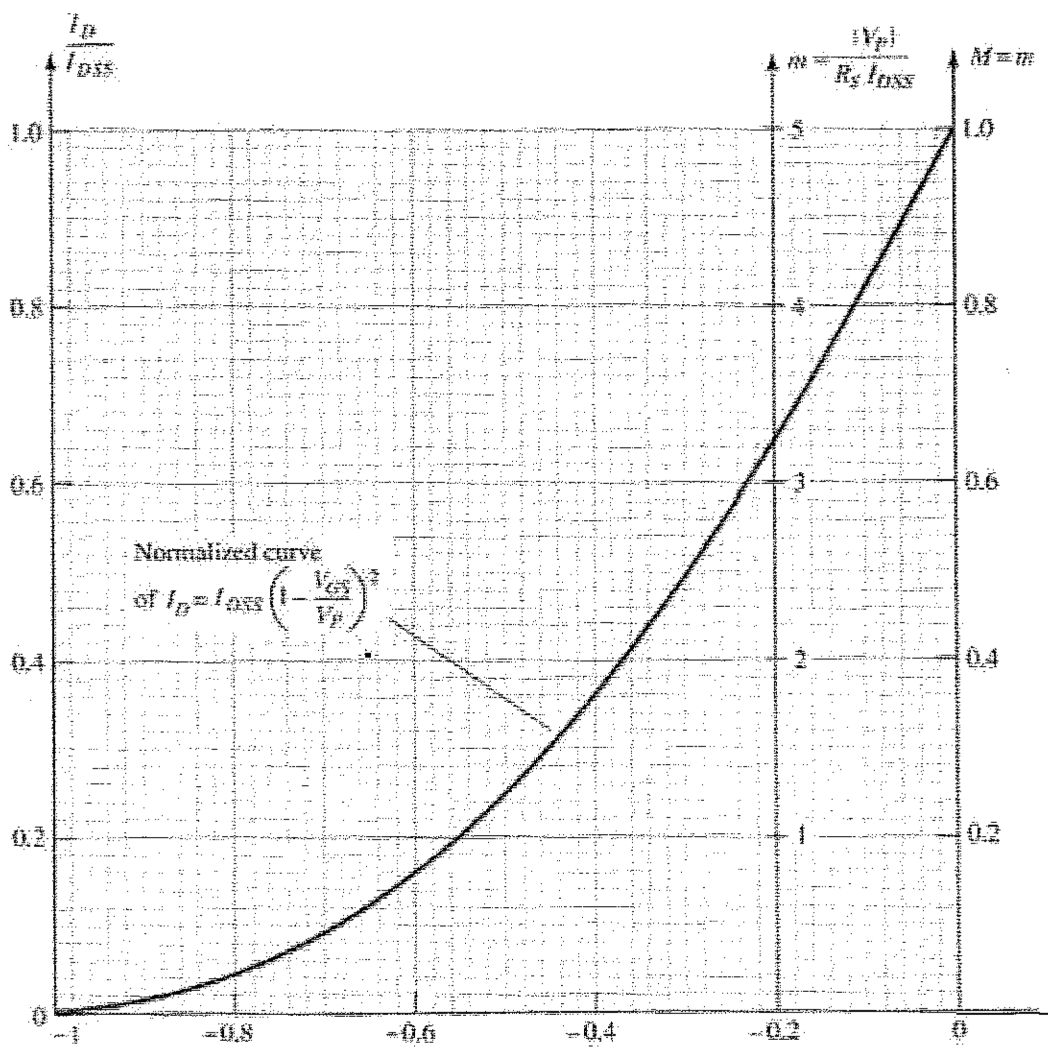


Answer (4)

Answer (4) - continued

Fill the table:

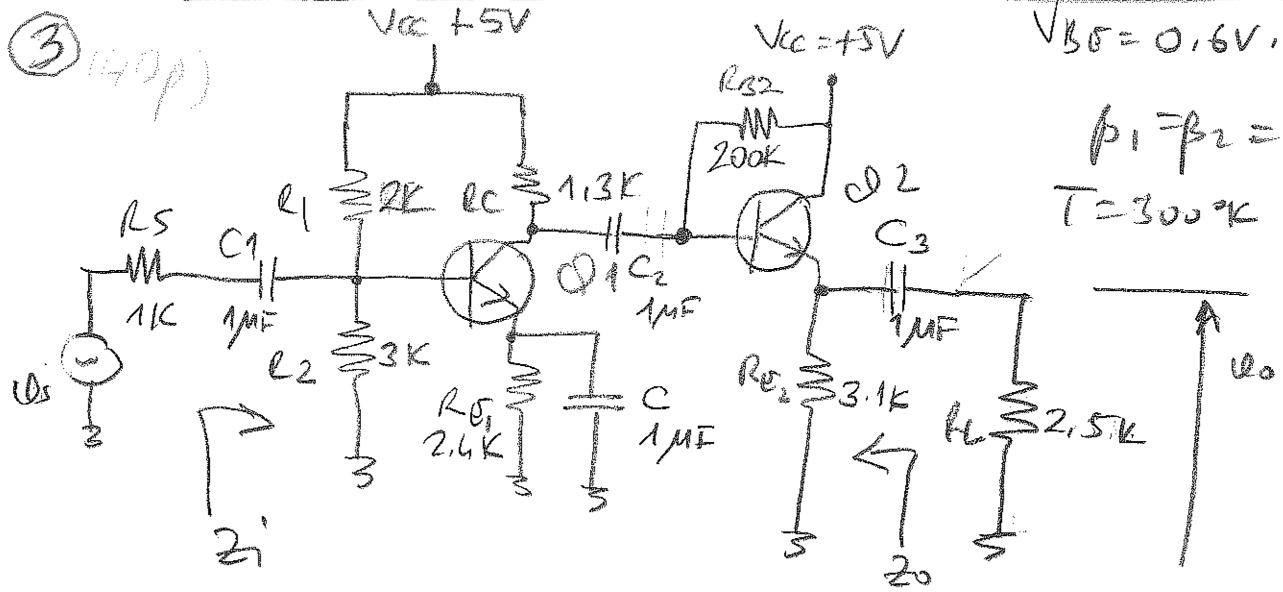
V_{GSQ1}	V_{GSQ2}	g_{m1}	g_{m2}	Av_1	Av_2	Av_T


$\frac{I_D}{I_{DSS}}$
$m = \frac{|V_P|}{R_S I_{DSS}}$
$M = m$
1.0
0.8
0.6
0.4
0.2
0
5
4
3
2
1
−1
−0.8
−0.6
−0.4
−0.2
Normalized curve
of $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

ECE-246 FINAL SOLUTION SET

07.06.2012

3 (40p)



$V_{BE} = 0.6V$.

$\beta_1 = \beta_2 = 200$

$T = 300°K$

For the amplifier circuit given above, calculate

a) The overall voltage gain $Av_T = \frac{v_o}{v_s}$

b) Calculate Z_i and Z_o.

SOLUTION

a) The DC analysis for Q1

$V_{B_1} = \frac{V_{CC}}{R_1+R_2} \cdot R_2 = \frac{5}{(3+2)\times 10^3} \times 3\times 10^3 = \frac{15}{5} = 3V$.

$V_{E_1} = V_{B1} - V_{BE} = 3 - 0.6 = 2.4V$.

$I_{E_1} = \frac{V_{E1}}{R_{E1}} = \frac{2.4}{2.4\times 10^3} = \underline{1mA}$

$r_{e_1} = \frac{V_T}{I_{E_1}} = \frac{26\times 10^{-3}}{10^{-3}} = \underline{\underline{26\Omega}}$.

for Q2

$V_{CC} - I_{B_2}R_B - V_{BE} - I_{E_2}R_{E_2} = 0$

$I_{B2} = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_{E2}}$

$I_{B_2} = \frac{5-0.6}{200\times 10^3 + 201\times 3.1\times 10^3}$

$I_{B2} = \frac{4.4}{823\times 10^3}$

$I_{B2} = 5.3\times 10^{-6} A$

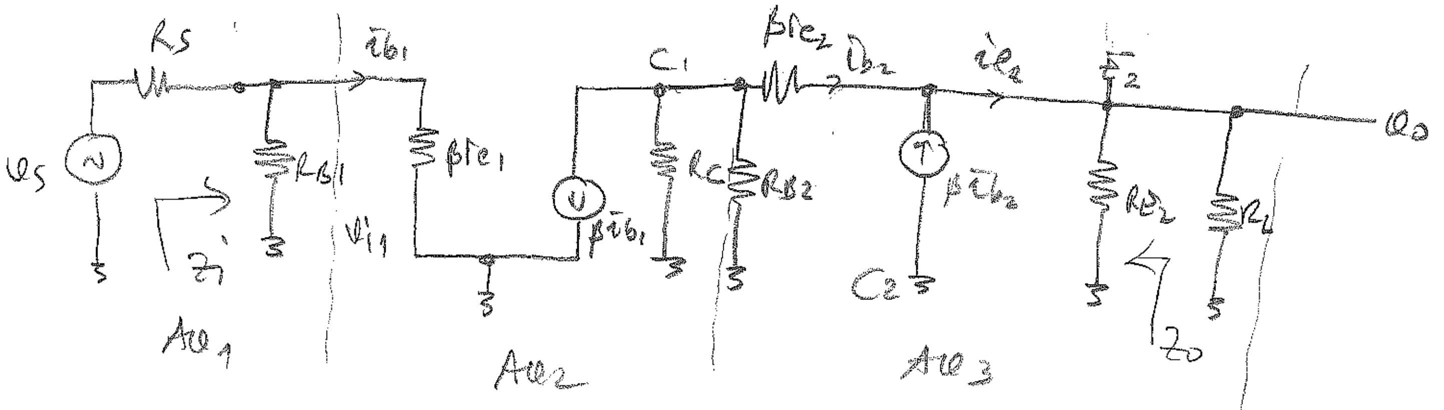
$I_{E_2} = (\beta+1)\times I_{B2}$

$I_{E2} = 201\times 5.3\times 10^{-6}$

$\boxed{I_{E_2} = 1.07 mA}$

$r_{e_2} = \frac{26mV}{1.07\times 10^{-3}} = \underline{24\Omega}$

AC ANALYSIS



Common emitter amplifier

Common collector amplifier (emitter follower)

$$Av_T = Av_1 \cdot Av_2 \cdot Av_3$$

$$Av_1 = \frac{v_{i1}}{v_s} = \frac{Z_i'}{R_S + Z_i'}$$

$$v_{i2} - v_o = i_{b2} \cdot \beta r_{e2} \Rightarrow i_{b2} = \frac{v_{i2} - v_o}{\beta r_{e2}}$$

$$v_o = i_{e2} \cdot (R_{E2} // R_L)$$

$$Av_2 = -\frac{R_C'}{r_{e1}}$$ Common emitter

$$v_o = (\beta+1)\, i_{b2}\, (R_{E2}//R_L)$$

$$v_o = (\beta+1)\left(\frac{v_{i2} - v_o}{\beta r_{e2}}\right)\cdot(R_{E2}//R_L)$$

$$R_C' = R_C // R_{B2} \simeq \frac{1{,}3\times10^3 \times 200\times10^3}{(1{,}3+200)\times10^3} = 1{,}3K$$

$$v_o = (\beta+1)\, v_{i2}\left(\frac{R_{E2}//R_L}{\beta r_{e2}}\right) - (\beta+1)\, v_o\left(\frac{R_{E2}//R_L}{\beta r_{e2}}\right)$$

$$Z_i = R_{B1} // \beta r_{e1} \leftarrow R_{B1} = R_1 // R_2$$

$$\beta+1 \simeq \beta, \quad \beta = 200$$

$$Z_i = \frac{\left(\frac{2K\times3K}{2K+3K}\right)(201\times26)}{\left(\frac{2K\times3K}{2K+3K}\right) + 201\times26}$$

$$v_o \simeq v_{i2}\,(R_{E2}//R_L) - v_o\,(R_{E2}//R_L)$$

$$v_o\,(1 + R_{E2}//R_L) = v_{i2}\,(R_{E2}//R_L)$$

$$Z_i = \frac{1{,}2\times10^3 \times 5{,}2\times10^3}{(1{,}2+5{,}2)\times10^3} = \frac{6{,}24\times10^3}{6{,}4\times10^3}$$

$$\frac{v_o}{v_{i2}} \simeq Av_3 \simeq \frac{R_{E2}//R_L}{1 + R_{E2}//R_L}$$

Emitter Follower

$$Z_i \simeq 975\,\Omega$$

$$Av_1 = \frac{975\,\Omega}{10^3 + 975} \simeq 0{,}5$$

$$Av_3 = \frac{\frac{3{,}1\times10^3 \times 2{,}5\times10^3}{(3{,}1+2{,}5)\times10^3}}{1 + \frac{3{,}1\times10^3\times2{,}5\times10^3}{(3{,}1+2{,}5)\times10^3}} = \frac{1{,}38\times10^3}{1+1{,}38\times10^3}$$

$$Av_2 = -\frac{1{,}3\times10^3}{26}$$

$$Av_3 \simeq 1$$

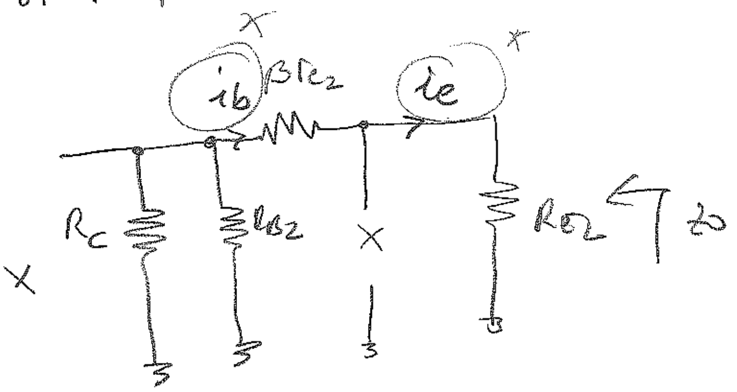
$$Av_2 = -50$$

$$Av_T = 0{,}5 \times (-50) \times 1$$

$$Av_T \simeq -25$$

b) $Z_i = R_{B1} // \beta r_{e1} = 975\ \Omega$

$Z_o =$



$Z_o = R_{E2} // \left(\frac{\beta r_{e2} + R_C // R_{B2}}{\beta}\right)$

$$\boxed{Z_o = R_{E2} // \left(r_{e2} + \frac{R_C // R_{B2}}{\beta}\right)}$$

$R_C // R_{B2} = 1.3K$

$Z_o = R_{E2} // \left(26 + \frac{1.3 \times 10^3}{200}\right)$

$Z_o = R_{E2} // (26 + 6.5)$

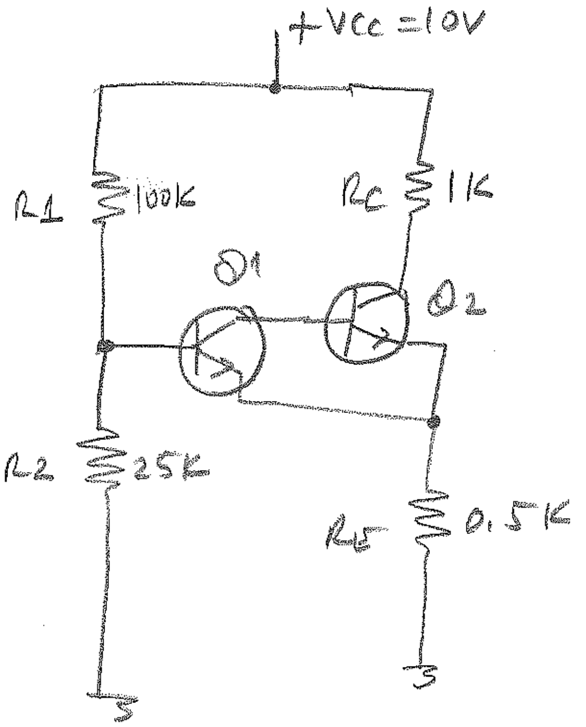
$Z_o = R_{E2} // 32.5$

$Z_o \cong \frac{3.1 \times 10^3 \times 32.5}{(3.1 \times 10^3 + 32.5)}$

$$\boxed{Z_o \cong 32.5\ \Omega}$$

I_{E1}	I_{E2}	r_{e1}	r_{e2}	A_{v1}	A_{v2}	A_{v3}	A_{vT}	Z_i	Z_o
1mA	1,07mA	26 Ω	24 Ω	0,5	-50	1	-25	975 Ω	32,5 Ω

(2) (15p)



Q1 and Q2 are identical transistors.

$V_{BE_1} = V_{BE_2} = 0.6V$.

$\beta_1 = \beta_2 = 20$

a) Calculate I_{C_2}

b) Calculate V_{CE_2}.

Sol

$$I_E = \frac{V_{B_1} - V_{BE}}{R_E}$$

$$V_{B1} = \frac{V_{CC}}{R_1 + R_2} \cdot R_2 = \frac{10}{125 \times 10^3} 25 \times 10^3$$

$$V_{B1} = \frac{10}{5} = 2V.$$

$$V_E = V_{B1} - V_{BE} = 2 - 0.6 = 1.4V.$$

$$I_E = \frac{V_E}{R_E} = \frac{1.4V}{0.5 \times 10^3} = 2.8mA$$

a) $I_E = I_{E1} + I_{E2}$

$$\left.\begin{aligned} I_{C_2} &= \beta \cdot I_{B2} \\ I_{B2} &= \beta \cdot I_{B1} \end{aligned}\right\} \quad I_{C_2} = \beta^2 \cdot I_B$$

$$I_E = (\beta+1) I_{B_1} + (\beta+1)^2 I_{B_1}$$

$$I_{B_1} = \frac{I_E}{(\beta+1) + (\beta+1)^2} = \frac{I_E}{(\beta+1)(1+\beta+1)} = \frac{2.8 \times 10^{-3}}{21 \cdot 22}$$

$$I_{B1} = 6.06 \times 10^{-6} A$$

$$I_{C_2} = \beta^2 \cdot I_{B_1} = (20)^2 \cdot 6.06 \times 10^{-6}$$

$$I_{C_2} = 2.4 \times 10^{-3} A$$

(4)

output KVL:

b) $V_{CC} - I_{C2}R_C - V_{CE2} - I_E R_E = 0$

$$\boxed{V_{CE2} = V_{CC} - I_{C2}R_C - I_E R_E}$$

(2.2)

$V_{CE2} = 10 - 2.4\times10^{-3}\times10^{3} - 2.8\times10^{-3}\times0.5\times10^{3}$

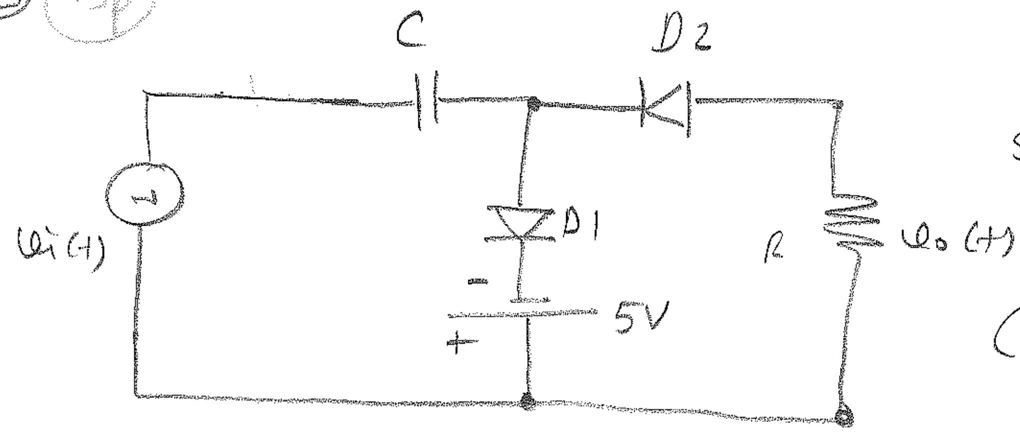
$V_{CE2} = 10 - 2.4 - 1.4$

$$\boxed{V_{CE2} = 6.2V}$$

I_{C2}	V_{CE2}
2.4 mA	6.2 V

---

(1) (15p)



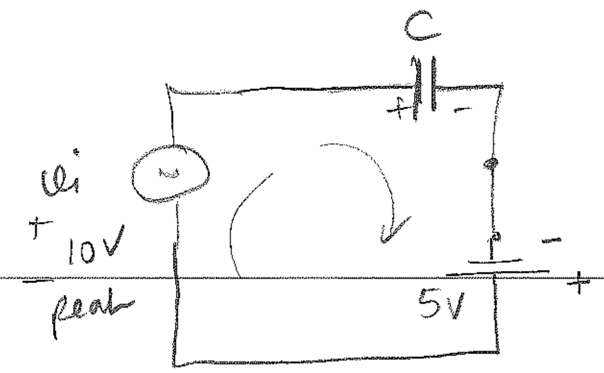
Sketch the output signal $v_o(t)$

(Diodes are ideal)

$v_i(t) = 10\sin 200\pi t$, $R = 10k$, $C = 100nF$

SOL First lets charge the capacitor:

when $v_i > -5V$ the capacitor charges (D_1 is forward biased)



$v_i - v_c + 5V$

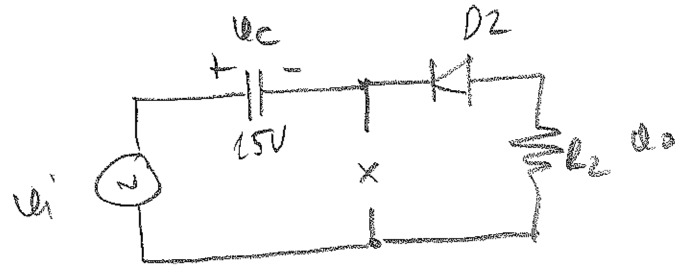
$v_c = v_i + 5$

in the end of charging period

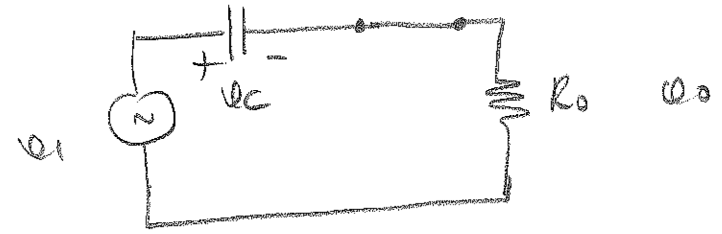
$$\boxed{v_c = 15V}$$

v_c is charged to this voltage.

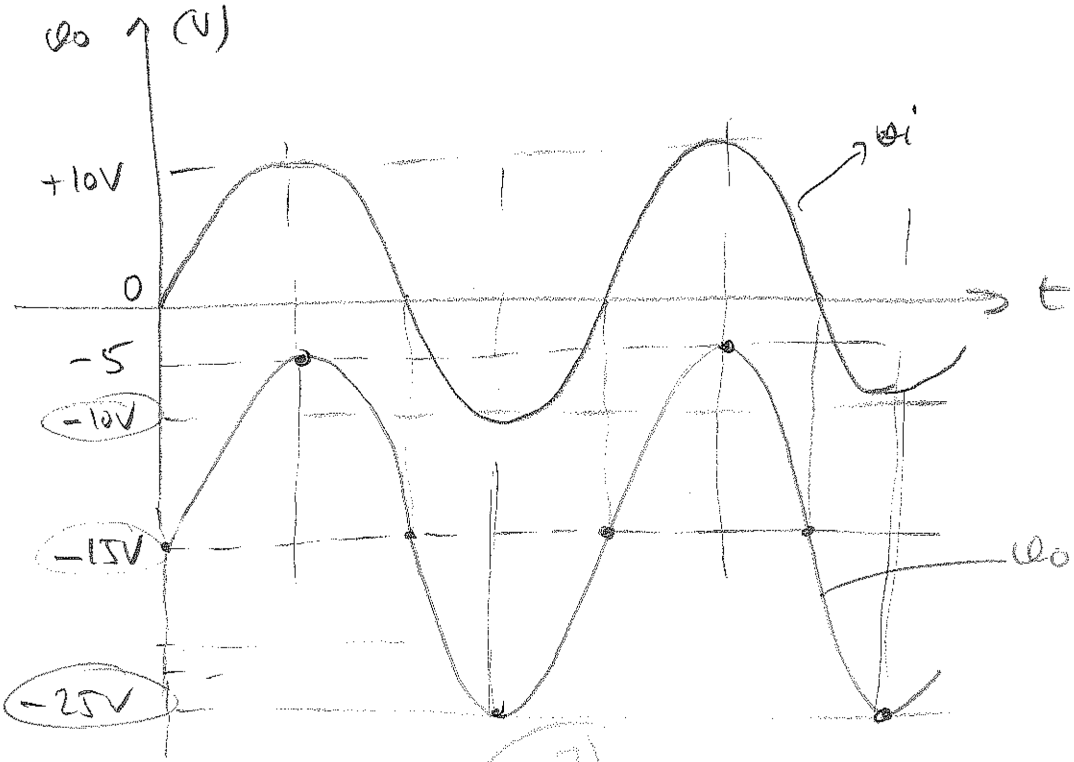
After the capacitor is charged to this voltage, D1 becomes reverse biased and will never be forward biased again.



D2 will always be forward biased after that point



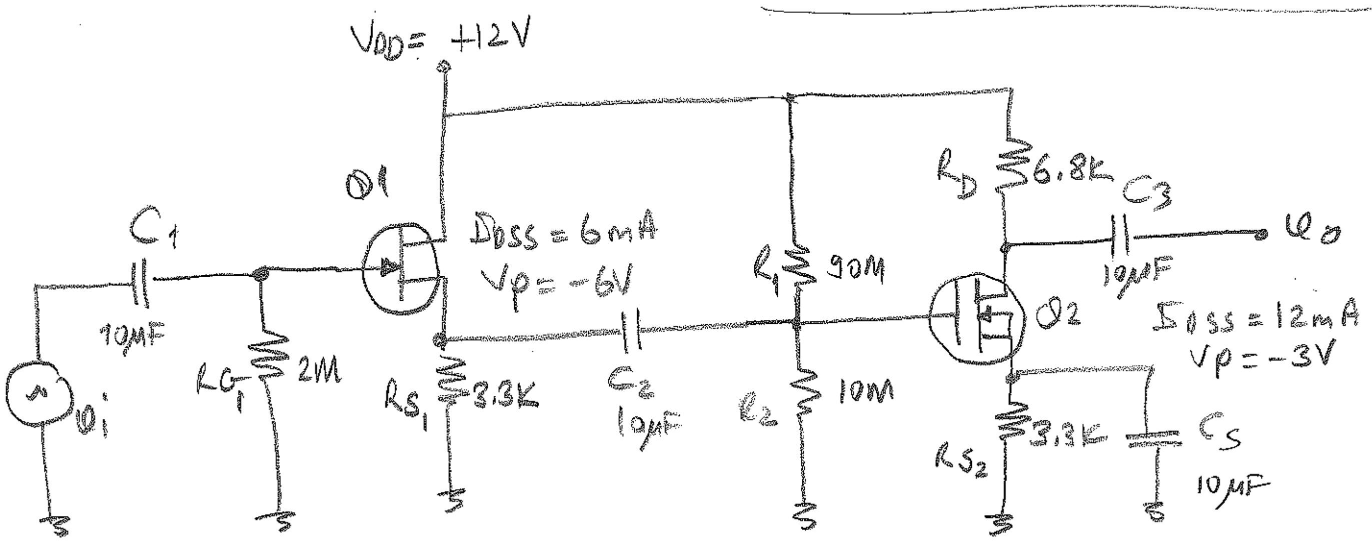
$v_o = v_i - v_c$



0.7

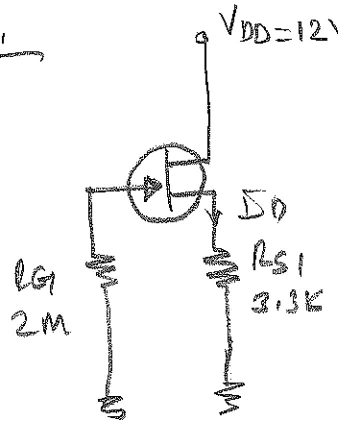
④ For the circuit given below calculate
(30p)

The overall voltage gain
$A_{v_T} = \frac{v_o}{v_i}$



DC analysis to find the gm's :

Q1 :



Input KVL

$V_G - V_{GS} - V_S = 0$

$V_{GS} = V_G - V_S$

$V_{GS} = 0 - V_S$

$\boxed{V_{GS} = -I_D R_S}$

using the JFET characteristics curve

$\boxed{V_{GS} = -I_D \times 3.3\times10^3}$ Load line

1st point: $V_{GS} = 0$, $I_D = 0$

2nd point: $V_{GS} = -6V$

$I_D = \frac{6}{3.3\times10^3} = 1.8mA$

$\boxed{V_{GS_{1Q}} = -3.5V}$

$g_{m1} = \frac{2 I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right)$

$g_{m1} = \frac{2\times6\times10^{-3}}{6}\left(1 - \frac{3.5}{6}\right)$

$\boxed{g_{m1} = 0.84mS}$ ←

Q2

$V_{GS} = V_G - V_S$

$V_G = \frac{V_{DD}}{R_1+R_2} \cdot R_2$

$V_G = \frac{12}{100\times10^6} \cdot 10\times10^6$

$V_G = 1.2V.$

$V_{GS} = 1.2 - I_D \cdot R_S$

$\boxed{V_{GS} = 1.2 - I_D\times3.3\times10^3}$ Load line

$V_{GS} = 0$ $\quad I_D = \frac{1.2}{3.3\times10^3} = 3.63\times10^{-4}A$

$V_{GS} = -2.4V$ $\quad I_D = \frac{-3.6}{3.3\times10^3} \cong 1.1mA$

$\boxed{V_{GS2_Q} = -2.1V.}$

$g_{m2} = \frac{2 I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right)$

$$g_{m2} = \frac{2 \times 12 \times 10^{-3}}{3}\left(1 - \frac{2.1}{3}\right)$$

$$= 8 \times 10^{-3} \times 0.3$$

$$\boxed{g_{m2} = 2.4\,mS}$$

1st circuit is a common-drain circuit

$$\boxed{Av_1 = \frac{g_{m1} R_s'}{1 + g_{m1} R_s'}}$$

$R_s' = R_s // (R_1 // R_2)$

$R_s' = 3.3k // (10M // 90M) \approx \underline{3k}$

$$Av_1 = \frac{0.84 \times 10^{-3} \times 3 \times 10^{3}}{1 + 0.84 \times 10^{-3} \times 3 \times 10^{3}} = \frac{2.52}{1 + 2.52} = \frac{2.52}{3.52} = \underline{0.72}$$

2nd circuit is a common source circuit

$$\boxed{Av_2 = -g_{m2} R_D}$$

$$Av_2 = -2.4 \times 10^{-3} \times 6.8 \times 10^{3}$$

$$\boxed{Av_2 = -16.3}$$

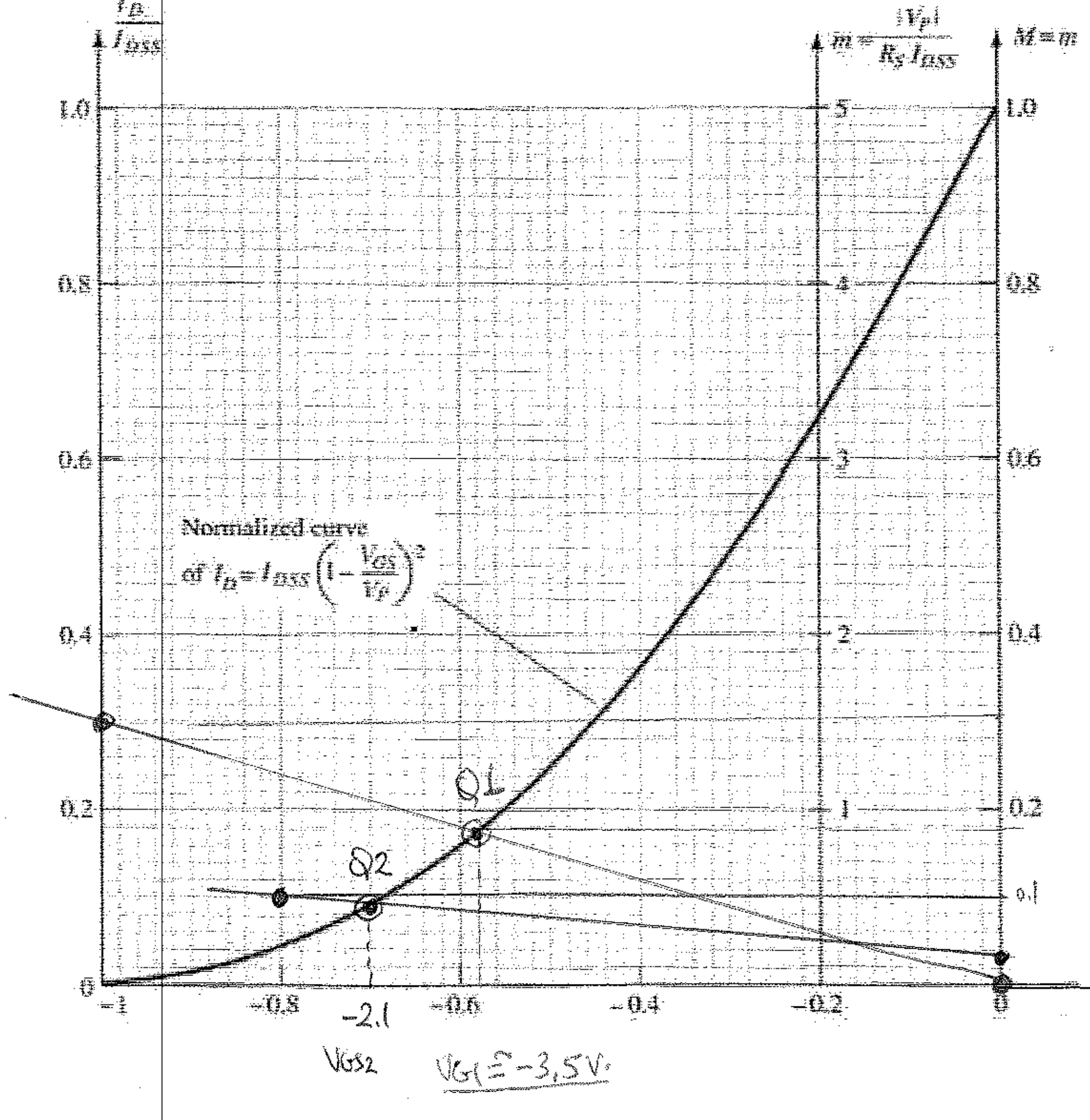
overall gain $Av_T = Av_1 \times Av_2$

$Av_T = 0.72 \times (-16.3)$

$$\boxed{Av_T \cong -11.7}$$

V_{GSQ1}	V_{GSQ2}	g_{m1}	g_{m2}	Av_1	Av_2	Av_T
−3.5V	−2.1V	0.84mS	2.4mS	0.72	−16.3	−11.7

9



$\frac{I_D}{I_{DSS}}$
$m = \frac{|V_P|}{R_S I_{DSS}}$
$M = m$
1.0
0.8
0.6
0.4
0.2
0
5
4
3
2
1
0.1
Normalized curve
of $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$
Q1
Q2
−1
−0.8
−0.6
−0.4
−0.2
0
−2.1
VGS2
VG1 ≅ −3.5V.