Final exam
Electronics & Signal processing
10-04-2018
Prof. Dr. G. Palasantzas

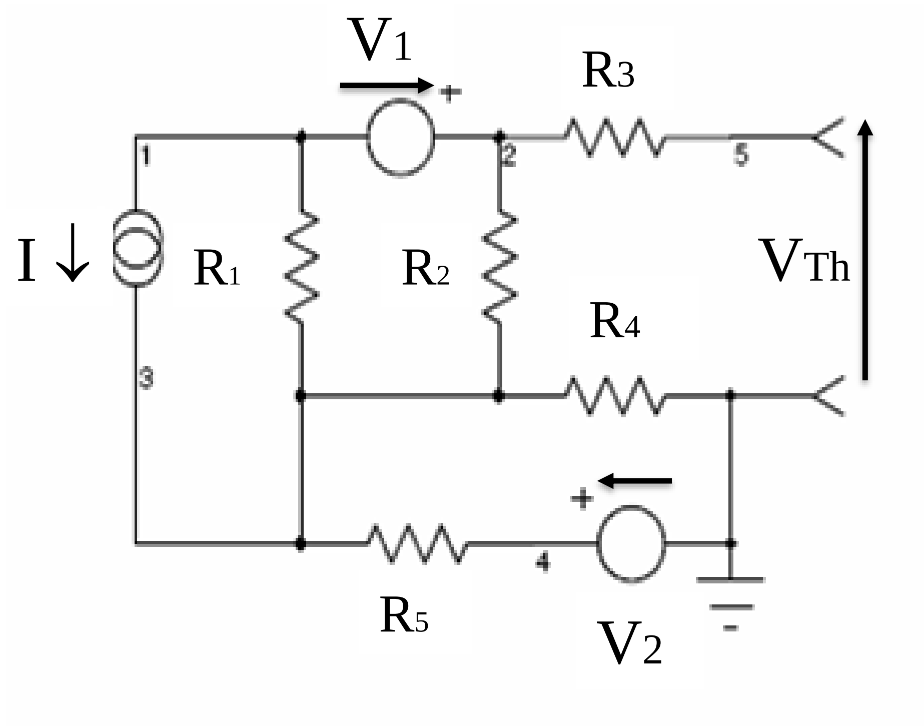
Grade of written exam:

Mark is the cummulative points scored for all problems

Total maximum score : 10

Problem 1 (1.5 points)

Consider the circuit:→



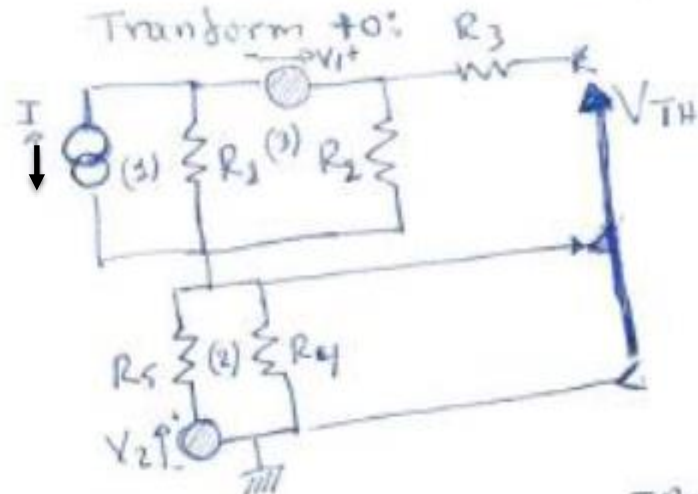
Derive the corresponding Thévenin equivalent and calculate:

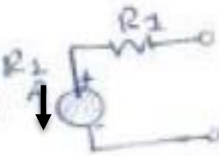
(a: 1 point) Thevenin voltage V_{Th}

(b: 0.5 points) Thevenin resistance R_{Th}

Solution

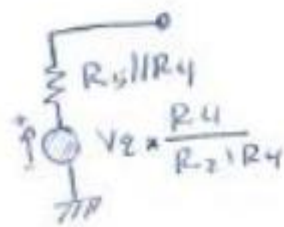
Tranform to:



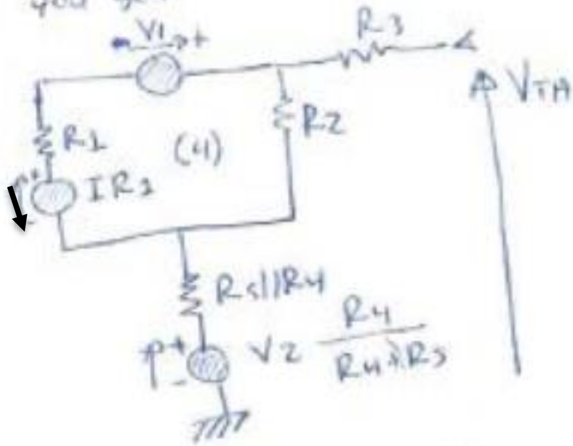


Replace (1) Norton with a thevenin

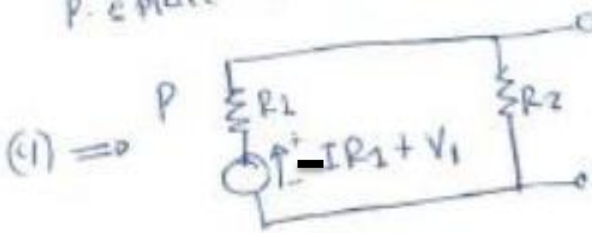
Replace (2) Norton with Thevenin

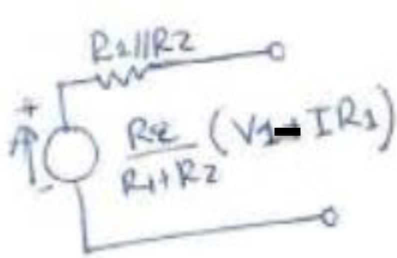


Then you get

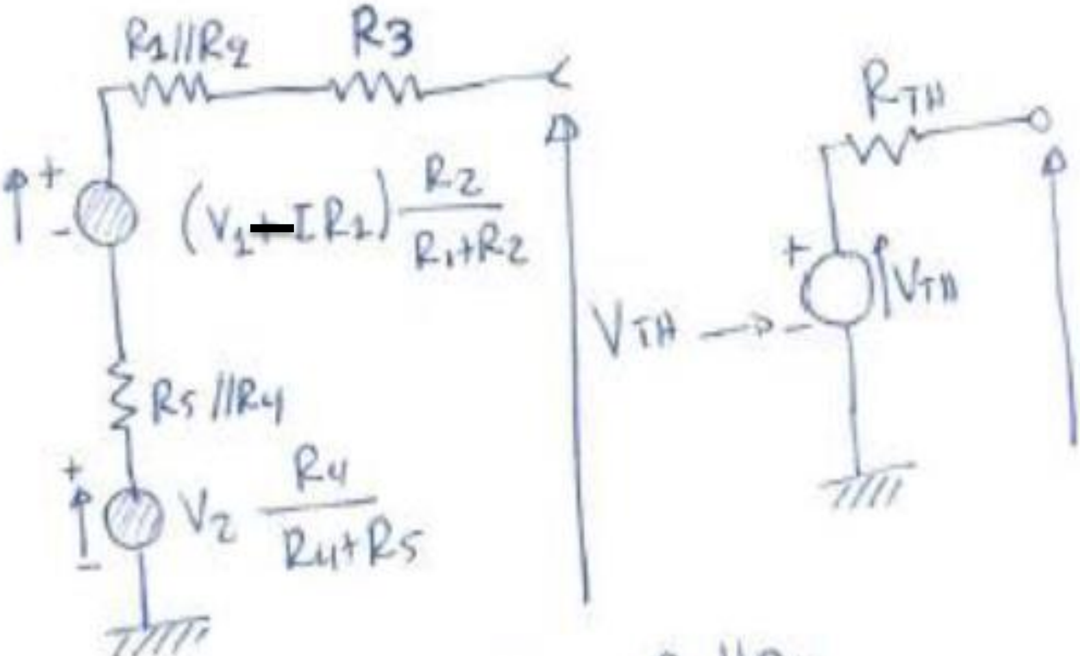


Replace (4) with the Thevenin





subsitution gives

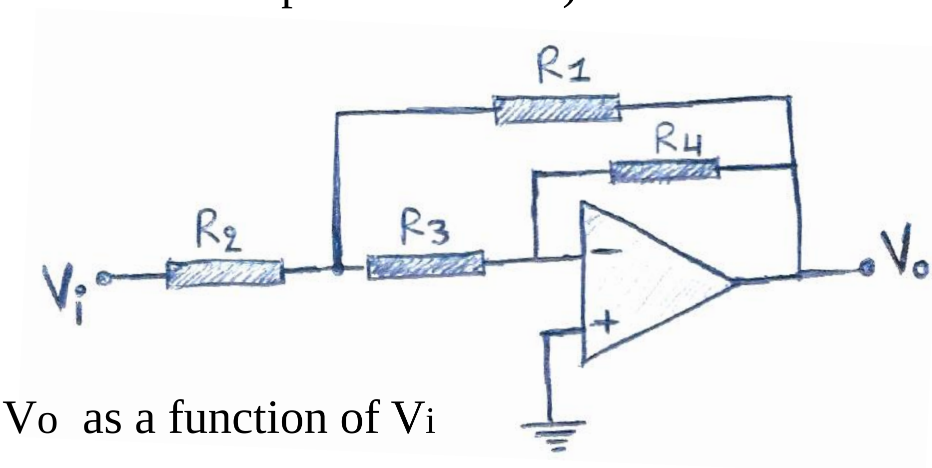


$$R_{TH} = R_3 + R_1||R_2 + R_5||R_4$$

$$V_{TH} = (V_1 - IR_1)\frac{R_2}{R_1+R_2} + V_2\frac{R_4}{R_4+R_5}$$

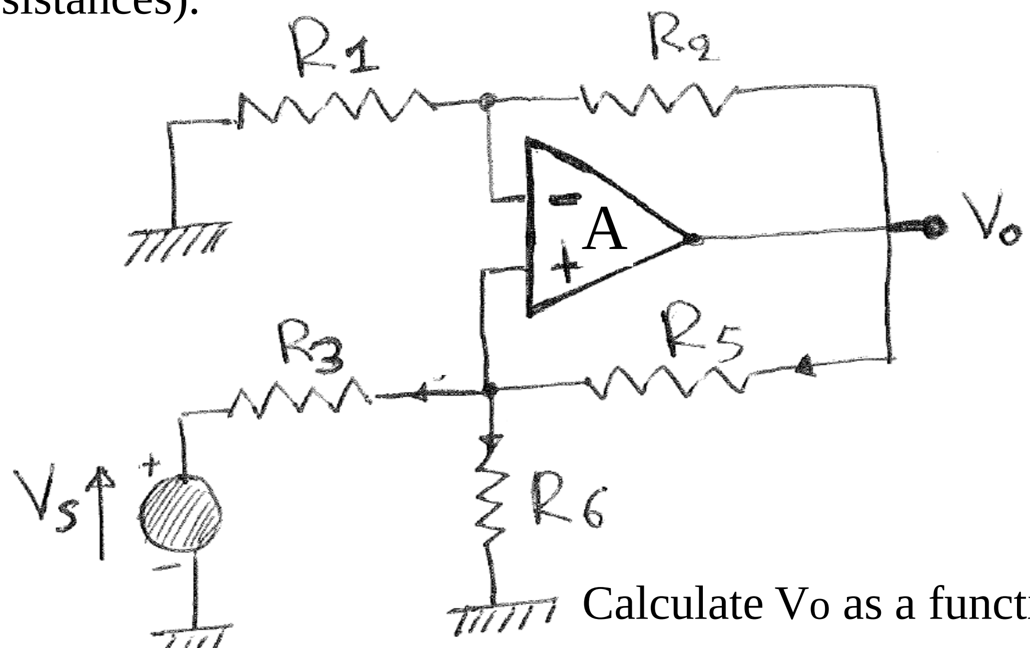
Problem 2 (2.5 points)

(a: 1 point) Consider the negative feedback circuit shown below with an ideal opamp so that V+ – V- =0 (assume for the opamp infinite input and zero output resistances)..



Calculate V_o as a function of V_i

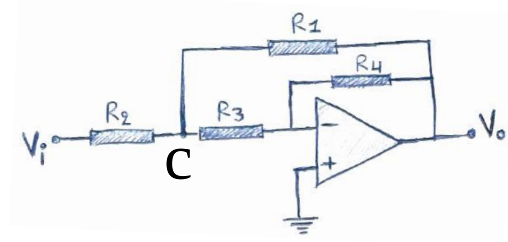
(b: 1.5 points) Consider the negative feedback circuit shown below with an opamp of finite forward gain A so that Vo=A(V+ – V-) (assume for the opamp infinite input and zero output resistances).



Calculate V_o as a function of V_s

Solution

(a) Consider the K-law for currents



$R = R1//(R3+R4)$

$(Vi-Vc)/R2=[(Vc-Vo)/R]$ (1)

$(Vc-0)/R3=(0-Vo)/R4$ (2)

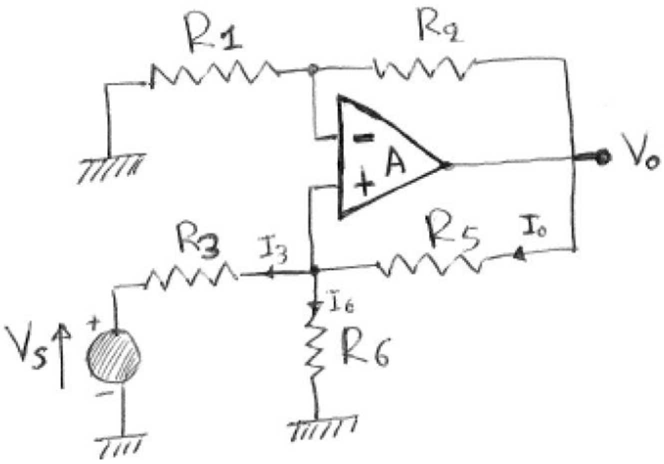
From (2) $Vc=-Vo(R3/R4)$ and substitution in (1) gives

$(Vi/R2) + Vo(R3/R4R2) = -Vo(1+R3/R4)/R$

$Vo\{(R3/R4R2)+(1+R3/R4)/R\}=-Vi/R2$

$Vo=-Vi/\{(R3/R4)+(1+R3/R4)R2/R\}$

(b)



$$V_- = V_o \frac{R_1}{R_1+R_2} \quad (1)$$ 0.5 p

$$I_o = I_3 + I_6 \quad (2)$$

$$\frac{V_o - V_+}{R_5} \qquad \frac{V_+ - V_S}{R_3} \qquad \frac{V_+ - 0}{R_6}$$

$$(2) \Rightarrow \frac{V_o - V_+}{R_5} = \frac{V_+ - V_S}{R_3} + \frac{V_+ - 0}{R_6} \Rightarrow$$

$$\Rightarrow \frac{V_o}{R_5} + \frac{V_S}{R_3} = V_+ \underbrace{\left(\frac{1}{R_5} + \frac{1}{R_3} + \frac{1}{R_6}\right)}_{1/\tilde{R}} =$$

$$\Rightarrow V_+ = V_o \frac{\tilde{R}}{R_5} + V_S \frac{\tilde{R}}{R_3} \quad (3)$$ 0.5 p

$$\frac{V_o}{A} = V_+ - V_-$$

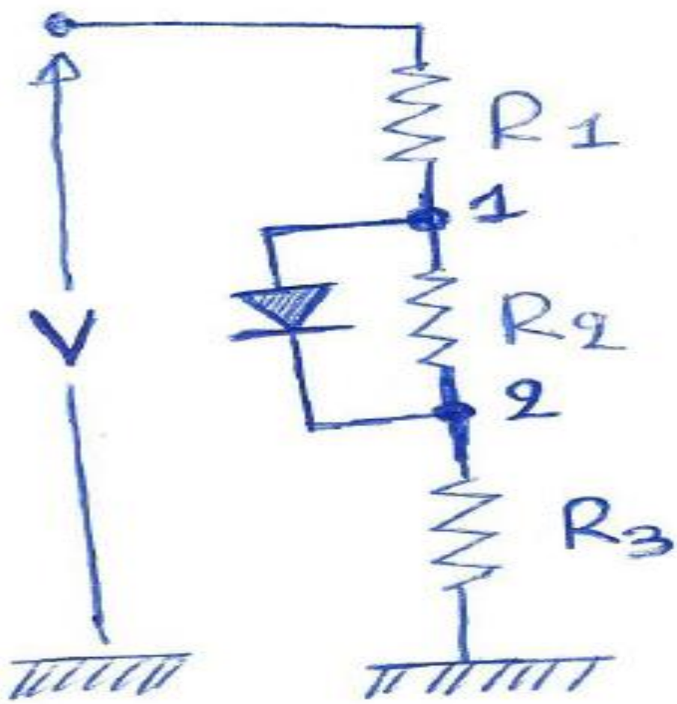
$$\frac{V_o}{A} = V_o \frac{\tilde{R}}{R_5} + V_s \frac{\tilde{R}}{R_3} - V_o \frac{R_1}{R_1+R_2}$$

$$V_o\left(\frac{1}{A} - \frac{\tilde{R}}{R_5} + \frac{R_1}{R_1+R_2}\right) = V_s \frac{\tilde{R}}{R_3} \Rightarrow$$

$$V_o = V_s \frac{\tilde{R}}{R_3} \Big/ \left(\frac{1}{A} - \frac{\tilde{R}}{R_5} + \frac{R_1}{R_1+R_2}\right)$$

Problem 3 (1.5 points)

Consider the circuit shown below. The diode is ideal with forward conduction voltage V_C (assume for the applied potential $V>0$).



(a: 1 point) Calculate the current via the resistor R_3

(b: 0.5 points) Calculate the current through the diode when it conducts current.

Solution

(a) In absence of the diode the volage difference $V12=V1-V2=V(R2/R)$ with $R=R1+R2+R3$

Case 1: If $V12 \geq Vc$ then the diode conducts

$(V-V1)/R1=V2/R3$, $V1-V2=Vc$ or $V1=V2+Vc$

$(V-Vc)/R1 = V2/(R1//R3)$ thus

$V2= (V-Vc) [(R1//R3)/R1]$ so we obtain

$I3= V2/R3= (V-Vc) [(R1//R3)/R3R1]$ or

$\underline{I3=(V-Vc)/(R3+R1)}$

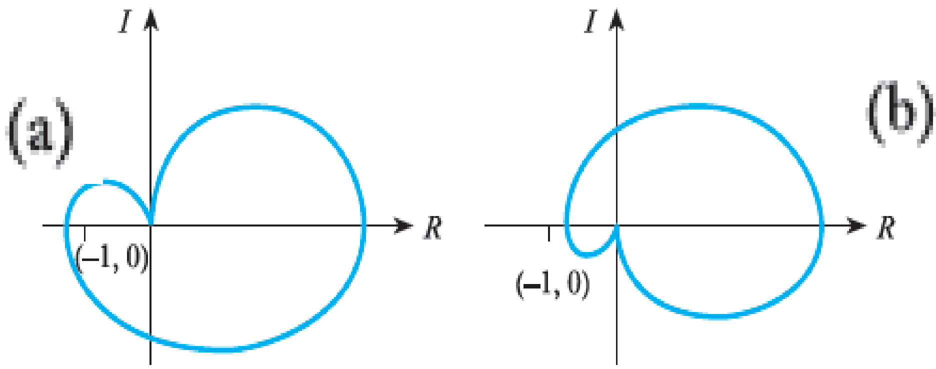
Case 2: If $V12<Vc$ then the diode does not Conduct so that we have $I3=V/R$

(b) When diode conducts current ID (a: case 1) $ID+(Vc/R2)=I3$ thus we have

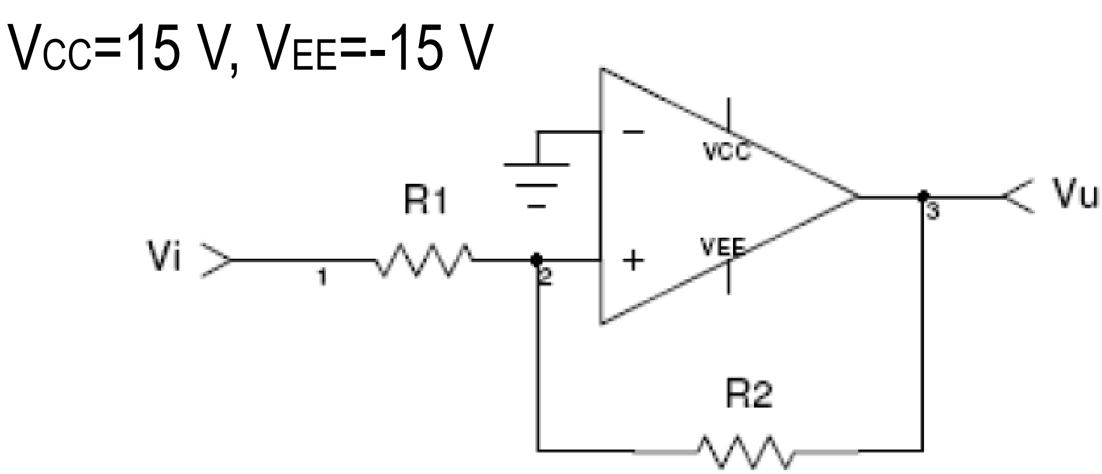
$ID=(V-Vc)/(R3+R1) - (Vc/R2)$

Problem 4 (1.5 points)

(a: 0.5 point) -The Nyquist diagrams below represent two circuits. Determine the number of low-frequency and high-frequency cut-offs and indicate which system is stable



(b:1 point) Consider the opamp to have has infinite input and zero output resistance



Assume R1=6 KΩ, R2=30 KΩ, and input potential Vi= Voi sin(ωt) with Voi= 5 V

<u>Draw the output potential Vu and justify briefly your answer</u>

Solution

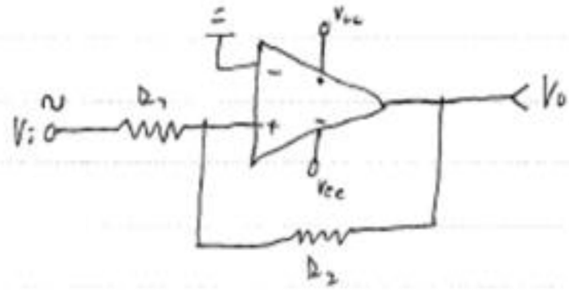
(a)

3 high cut-offs
1 low cut-off (a)
unstable

1 high cut-off
3 low cut-offs (b)
stable

(b) Positive feedback→ oscillation between -15 and +15 V

R1=6 K
R2=30
R1/R2=3/5

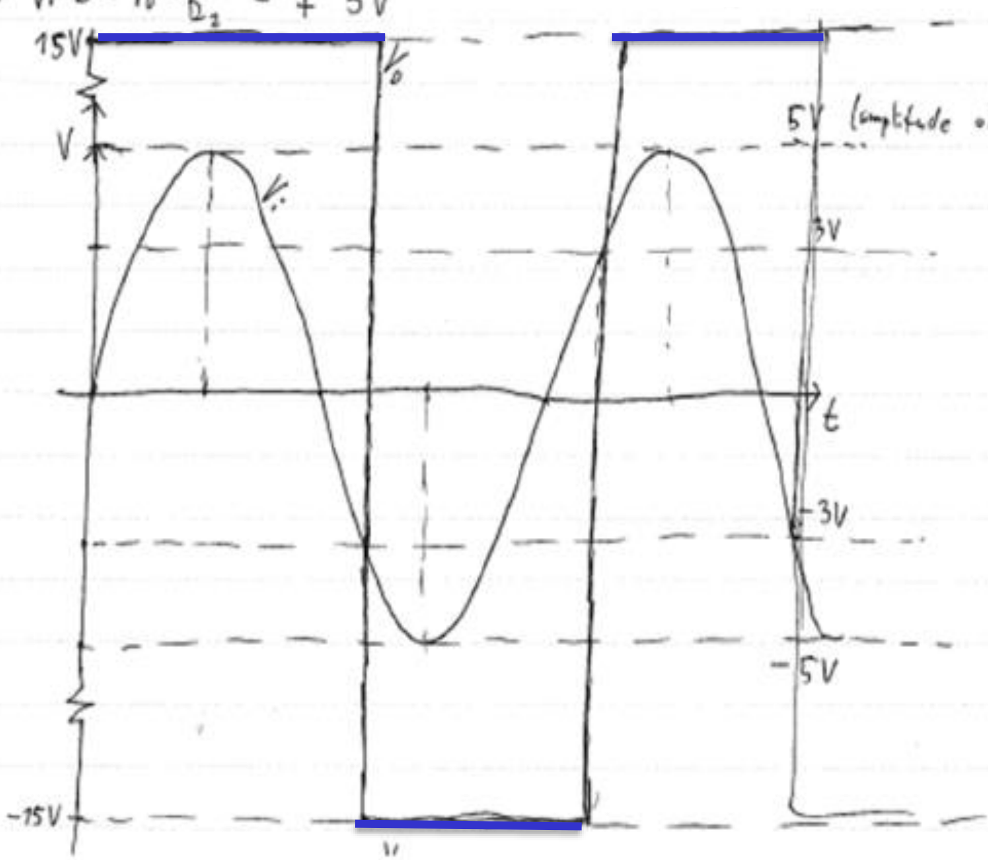


$$\frac{V_i - V_+}{R_1} = \frac{V_+ - V_o}{R_2} \rightarrow \frac{V_+}{R_2} + \frac{V_+}{R_1} = \frac{V_i}{R_1} + \frac{V_o}{R_2}$$

$$V_+ \frac{R_1 + R_2}{R_1 R_2} = \frac{V_i R_2 + V_o R_1}{R_1 R_2}$$

$$\boxed{V_+ = V_i \frac{R_2}{R_1 + R_2} + V_o \frac{R_1}{R_1 + R_2}}$$

$$\rightarrow V_i = -V_o \frac{R_1}{R_2} = \mp 3V$$



Problem 5 (1.5 points)

Design a synchronous counter (using J-K flip flops) that counts through the states 0, 4, 2, 1, 5, 3.

Q_{n-1}	Q_n	J	K
0	0	0	*
0	1	1	*
1	0	*	1
1	1	*	0

∗: don't care

J	K	Q_n
0	0	Q_{n-1}
0	1	0
1	0	1
1	1	$\overline{Q_{n-1}}$

Solution

5

	Before $Q_3Q_2Q_1$	After $Q_3Q_2Q_1$	J_3	K_3	J_2	K_2	J_1	K_1
0	000	100	1	x	0	x	0	x
4	100	010	x	1	1	x	0	x
2	010	001	0	x	x	1	1	x
1	001	101	1	x	0	x	x	0
5	101	011	x	1	1	x	x	0
3	011	000	0	x	x	1	x	1

J_3:

$Q_3 \backslash Q_2Q_1$	00	01	11	10
0	1	1	0	0
1	x	x	x	x

K_3:

$Q_3 \backslash Q_2Q_1$	00	01	11	10
0	x	x	x	x
1	1	1	x	x

J_2:

$Q_3 \backslash Q_2Q_1$	00	01	11	10
0	0	0	x	x
1	1	1	x	x

K_2:

$Q_3 \backslash Q_2Q_1$	00	01	11	10
0	x	x	1	1
1	x	x	x	x

J_1:

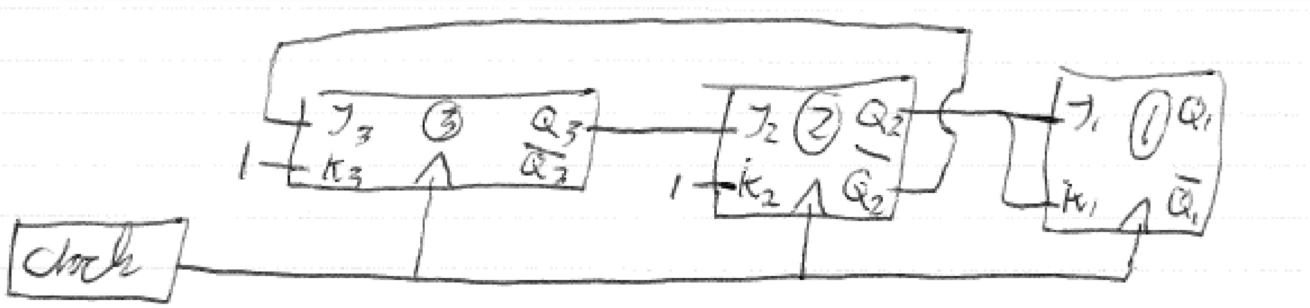
$Q_3 \backslash Q_2Q_1$	00	01	11	10
0	0	x	x	1
1	0	x	x	x

K_1:

$Q_3 \backslash Q_2Q_1$	00	01	11	10
0	x	0	1	x
1	x	0	x	x

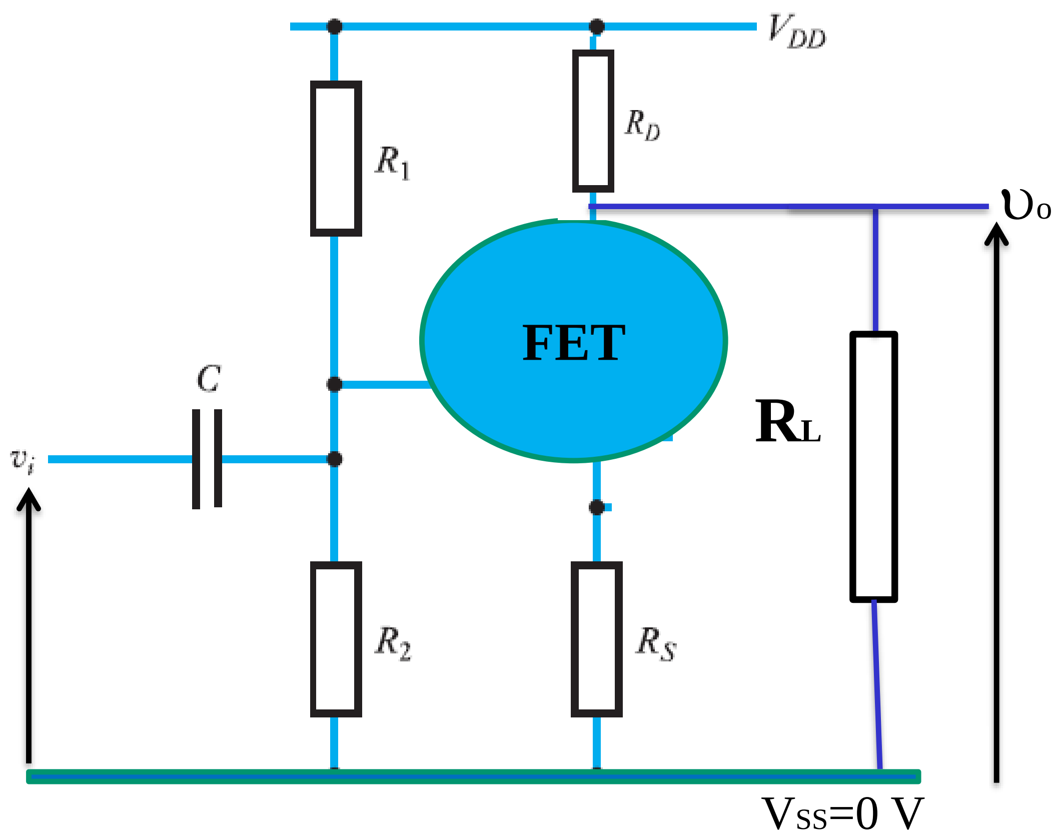
$J_3 = \overline{Q_2}$ $\quad K_3 = K_2 = 1$ $\quad J_2 = Q_3$ $\quad J_1 = K_1 = Q_2$

C



Problem 6 (1.5 points)

Consider a FET amplifier as it is shown bellow:

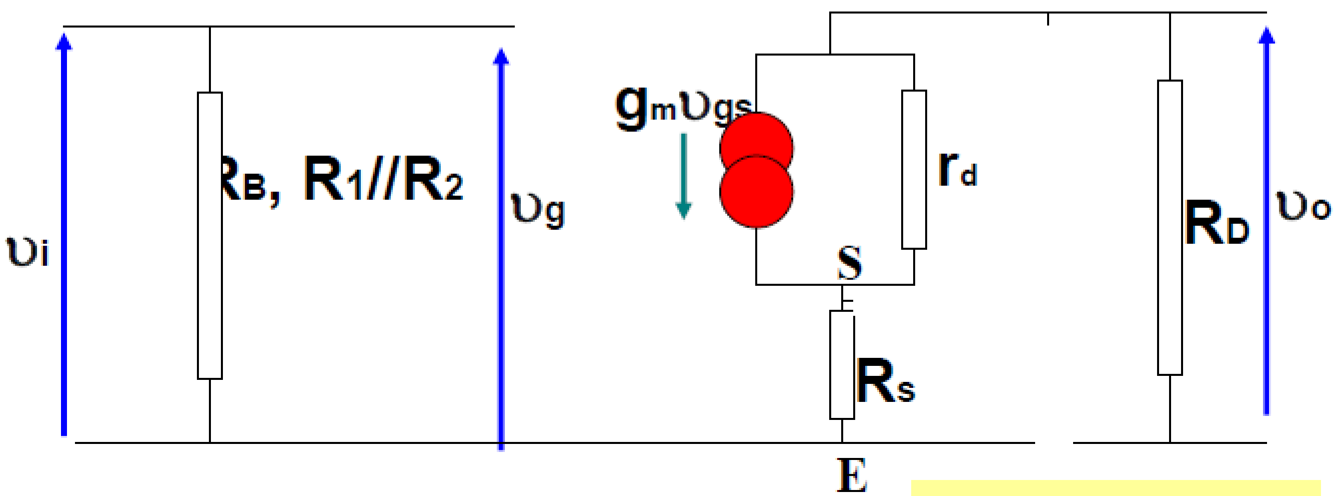


Calculate the amplification ratio υ_o / υ_i

Consider as known for the FET the transconductance g_m, and the differential resistance r_d when the FET operates at saturation.

(2-method: small signal cicuit) *This is for normal cookies!*

Replace in all shown bellow: R_D with $R_D//R_L$. This is because in this design R_D parallel with R_L



Apply K-law for the current at points S & E

$$g_m \upsilon_{gs} + (\upsilon_o - \upsilon_s)/r_d - \upsilon_s / R_s = 0 \qquad \text{(S)}$$

$$(\upsilon_o / R_D) + (\upsilon_s / R_s) = 0 \qquad \text{(E)}$$

$$\upsilon_{gs} = \upsilon_g - \upsilon_s$$

$$g_m \upsilon_{gs} + (\upsilon_o - \upsilon_s)/r_d - \upsilon_s / R_s = 0 \quad \text{(S)}$$

$$(\upsilon_o / R_D) + (\upsilon_s / R_s) = 0 \quad \text{(E)}$$

$$\upsilon_{gs} = \upsilon_g - \upsilon_s$$

$$\Downarrow$$

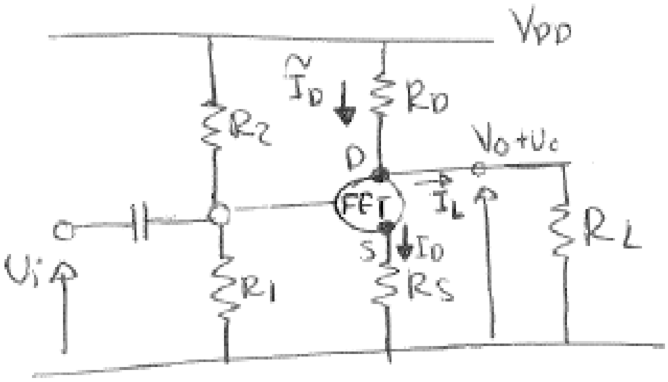
$$\upsilon_g = \upsilon_i$$

Gain: $\upsilon_o / \upsilon_i = -g_m R_D / [1 + g_m R_s + (R_s + R_D)/r_d]$

Replace in all shown bellow: R_D with $R_D//R_L$. This is because in this design R_D parallel with R_L

Solution

(2-method: first priciples analysis) *This is only for tough cookies: so you do it or you do not do it!*



$U_g \equiv U_i$

$U_o \equiv U_d$

$i_d = g_m(U_g - U_s) + \frac{U_d - U_s}{r_d}$

$$\tilde{I}_D = I_D + I_L \quad (1)$$

$V_o = V_{DD} - \tilde{I}_D \cdot R_D \Rightarrow$ take a variation $\Rightarrow \delta\tilde{I}_D = i_d + i_L$

$\delta V_o = U_o = \delta V_{DD}^{\,0} - \delta\tilde{I}_D \cdot R_D \Rightarrow$

$$U_o = -(i_d + i_L) R_D \quad (2)$$

$V_o = I_L \cdot R_L \Rightarrow \delta V_o = U_o = \underbrace{\delta I_L}_{i_L} \cdot R_L \Rightarrow$

$U_o = i_L \cdot R_L \Rightarrow$

$$i_L = U_o / R_L \quad (3)$$

$(2)\ \&\ (3) \Rightarrow U_o = -i_d R_D - U_o \frac{R_D}{R_L} \Rightarrow$

$$\Rightarrow U_o\left[1 + \frac{R_D}{R_L}\right] = -i_d R_D \quad (4)$$

we still need to eliminate in i_d the potential U_s

$(1) \Rightarrow \overbrace{\frac{V_{DD} - V_o}{R_D}}^{\tilde{I}_D} = \overbrace{\frac{V_s - 0}{R_S}}^{I_D} + \overbrace{\frac{V_o - 0}{R_L}}^{I_L}$, take a variation

$-\frac{\overbrace{\delta V_o}^{U_o}}{R_D} = \frac{\overbrace{\delta V_S}^{U_s}}{R_S} + \frac{\overbrace{\delta V_o}^{U_o}}{R_L} \Rightarrow -\frac{U_o}{R_D} = \frac{U_s}{R_S} + \frac{U_o}{R_L} \Rightarrow$

$\frac{U_s}{R_S} = -U_o\left[\frac{1}{R_D} + \frac{1}{R_L}\right] \Rightarrow$

$$U_s = -U_o \frac{R_S}{R_{DL}}, \quad R_{DL} = R_D \| R_L \quad (5)$$

substitute in (4) from (5) the V_s and replace also $V_g = V_i$, $V_d = V_o$

$$V_o\left[1 + \frac{R_D}{R_L}\right] = -\left[g_m\left(V_i + V_o\frac{R_S}{R_{DL}}\right) + V_o\frac{1 + \frac{R_S}{R_{DL}}}{r_d}\right]R_D$$

$$V_o\left[\frac{1}{R_D} + \frac{1}{R_L}\right] = -g_m V_i - g_m V_o\frac{R_S}{R_{DL}} - V_o\frac{R_{DL} + R_S}{r_d R_{DL}}$$

$$\frac{V_o}{R_{DL}} + g_m V_o\frac{R_S}{R_{DL}} + V_o\frac{R_{DL} + R_S}{r_d R_{DL}} = -g_m V_i \Rightarrow$$

$$V_o\left[1 + g_m R_S + \frac{R_{DL} + R_S}{r_d}\right]\frac{1}{R_{DL}} = -g_m V_i \Rightarrow$$

$$\frac{V_o}{V_i} = -\frac{g_m R_{DL}}{1 + g_m R_S + \frac{R_{DL} + R_S}{r_d}}$$

Although this looks complicated, this is what is happening in reality!

you can extend this approach beyond first order perturbation theory- a limitation for method-1.