NAME ____SOLUTIONS____

MIDTERM EXAM 2 - SOLUTIONS

(Closed book)

ECE 342

July 30, 2020

9:00 a.m. – 9:50 a.m.

Instructions : This examination consists of 10 multiple choice questions. Select the most nearly correct answer for each question. You are allowed to use a calculator.

Note 1. It is suggested that you answer the questions you consider easiest first.

Note 2. Choose only ONE answer per problem. Points will be taken off for multiple answers.

Formula Sheet

DIODE

$$I_D = I_S(e^{V_D/V_T} - 1)\text{, where } V_T = \frac{k_B T}{q} = 26\text{ mV}$$

NMOS	PMOS
Cut-off $V_{GS} < V_{tn}\ ,\quad I_D = 0$ Triode Region (Linear) $V_{GS} > V_{tn}\ \&\ V_{DS} < V_{DSP} = V_{GS} - V_{tn}$ $I_D = \frac{W}{L}\mu_n C_{ox}\left((V_{GS} - V_{tn})V_{DS} - \frac{V_{DS}^2}{2}\right)$ Active Region (Saturation) $V_{GS} > V_{tn}\ \&\ V_{DS} \geq V_{DSP} = V_{GS} - V_{tn}$ $I_D = \frac{W}{L}\frac{\mu_n C_{ox}}{2}(V_{GS} - V_{tn})^2\left[1 + \lambda V_{DS}\right]$	Cut-off $V_{SG} < \lvert V_{tp}\rvert\ ,\quad I_D = 0$ Triode Region (Linear) $V_{SG} > \lvert V_{tp}\rvert\ \&\ V_{SD} < V_{SDP} = V_{SG} - \lvert V_{tp}\rvert$ $I_D = \frac{W}{L}\mu_p C_{ox}\left((V_{SG} - \lvert V_{tp}\rvert)V_{SD} - \frac{V_{SD}^2}{2}\right)$ Active Region (Saturation) $V_{SG} > \lvert V_{tp}\rvert\ \&\ V_{SD} \geq V_{SDP} = V_{SG} - \lvert V_{tp}\rvert$ $I_D = \frac{W}{L}\frac{\mu_p C_{ox}}{2}(V_{SG} - \lvert V_{tp}\rvert)^2\left[1 + \lvert\lambda\rvert V_{SD}\right]$

Body Effect

$$V_t = V_{to} + \gamma\left(\sqrt{|V_{SB}| + 2\phi_F} - \sqrt{2\phi_F}\right)$$

Small Signal Characteristics (NMOS):

$$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D};\quad r_{ds} = \frac{|V_A|}{I_D} = \frac{1}{\lambda I_D}$$

BIPOLAR (NPN forward active $I_B > 0$, $V_{CE} > V_{CE,sat}$)

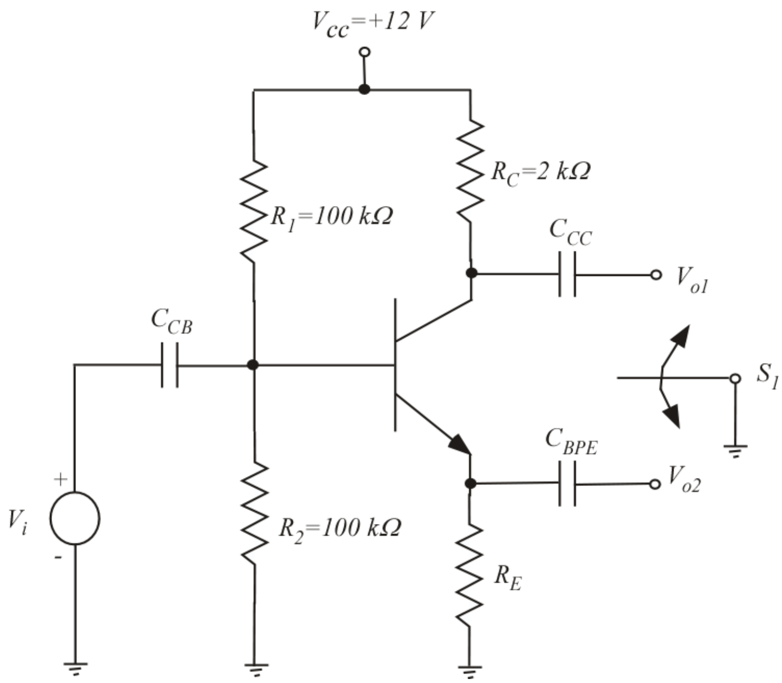
$$I_C = I_S e^{V_{BE}/V_T}\cdot\left(1 + \frac{V_{CE}}{V_A}\right) \cong I_S e^{V_{BE}/V_T}\ \text{ where } V_T = \frac{k_B T}{q} = 26\text{ mV}$$

$$I_C = \alpha I_E = \beta I_B\cdot\left(1 + \frac{V_{CE}}{V_A}\right) \cong \beta I_B \qquad \alpha = \frac{\beta}{\beta + 1}$$

Small Signal Characteristics:

$$g_m = \frac{I_C}{V_T};\ \beta = g_m r_\pi;\ r_\pi = r_e(\beta + 1);\ r_e = \frac{V_T}{I_E};\ r_o = \frac{|V_A|}{I_C};\ \omega_T = \frac{g_m}{C_\pi + C_\mu}$$

For the circuit shown, assume that β is very large. Also C_μ = 1 pF and $\omega_T = 5\times10^9$ radians/sec. It is desired to have a dc collector current of 2 mA. Use V_{BEON} = 0.6 V and assume that all coupling and bypass capacitors are midband short circuits.



1. The approximate value for R_E is: **(1 point)**

   (a) 0.1 kΩ

   (b) 0.7 kΩ

   (c) 2.7 kΩ

   (d) 4.7 kΩ

   (e) 5.7 kΩ

$$V_B \simeq \frac{V_{CC}}{2} = \frac{12}{2} = 6V$$

$$V_E = V_B - 0.6 = 5.4V$$

$$I_C \approx I_E = 2mA \Rightarrow R_E = \frac{V_E}{I_E} = \frac{5.4}{2} = 2.7k\Omega$$

(c) is the correct answer

2. What is the value of the transistor's small-signal model transconductance g_m? **(1 pt)**

(a) 33 mA/V
(b) 77 mA/V
(c) 154 mA/V
(d) 308 mA/V
(e) 1 A/V

$$g_m = \frac{I_C}{V_T} = \frac{2}{26} = 76.9mA/V$$

(b) is correct answer

3. The switch S_1 is now connected to V_{o1} and the output is collected at V_{o2}. An approximate value for the midband voltage gain is: **(1 pt)**

(a) 0.1
(b) 1.0
(c) 10
(d) 100
(e) 1000

This is the emitter follower configuration. The midband gain is:

$$A_{MB} = \frac{R_E}{R_E + r_e} = \frac{2.7}{2.7 + 0.013} = 0.9952 \simeq 1$$

(b) is correct answer

4. Next, the switch S_1 is connected to V_{o2} and the output is collected at V_{o1}. What is the midband voltage gain? **(1 pt)**

(a) 1.5
(b) 150.0
(c) 200.0
(d) 1000
(e) 10000

This is the standard common-emitter configuration. The midband gain is:

$$A_{MB} = -g_m R_C = -76.9 \times 2 = -153.8$$

(b) is correct answer

5. What is the best estimate for the value of C_π? **(1 pt)**

(a) 1.3 pF

(b) 2.4 pF

(c) 7.2 pF

(d) 10.6 pF

(e) 14.4 pF

$$C_\pi = \frac{g_m}{2\pi f_T} - C_\mu = \frac{76.9\times10^{-3}}{5\times10^{+9}} - 10^{-12} = 14.38\ pF$$

(e) is correct answer

6. This circuit suffers from the Miller effect **(1 pt)**

(a) True

(b) False

R_{sig} is 0 ➔ NO Miller effect: ➔False

(b) is correct answer

7. Determine an approximate value for the upper 3dB corner frequency for the common-emitter configuration of this amplifier. **(1 pt)**

(a) 50 Hz

(b) 100 kHz

(c) 200 kHz

(d) 80 MHz

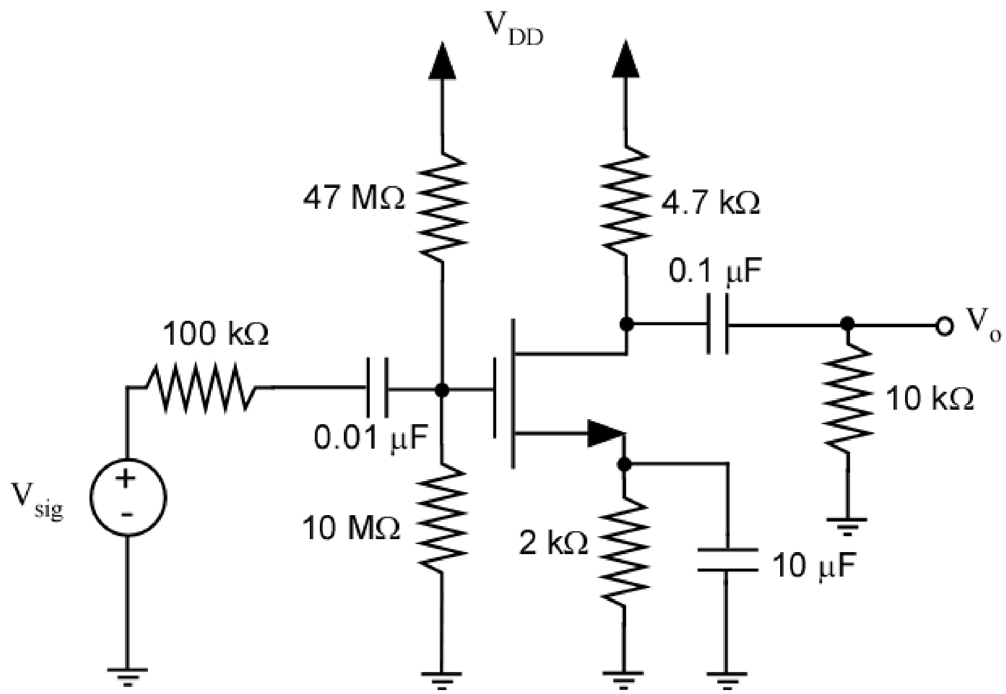
(e) 500 MHz

Since $R_{sig} = 0$

$$f_H \simeq \frac{1}{2\pi C_\mu R_C'} = \frac{1}{2\pi\times1\times10^{-12}\times2\times10^{3}} = 79.57\ MHz$$

(d) is correct answer

The NMOS transistor in the discrete CS amplifier circuit shown in the figure is biased to have g_m= 1 mA/V and r_o= 100 kΩ.



8. An approximate value for the midband voltage gain is: **(1 pt)**

(a) 3

(b) 6

(c) 9

(d) 12

(e) 15

$R_D^{'} = r_o \,||\, R_D \,||\, R_L = 100k \,||\, 4.7k \,||\, 10k = 3.09k\Omega$

$A_M \simeq -g_m R_D^{'} = -\left(1\times10^{-3}\right)\times 3.09\times10^3 = 3.09\,V/V$

A_{MB} = 3.09

(a) is correct answer

9. This circuit suffers from the Miller effect **(1 pt)**

(a) True

(b) False

R_{sig} is large ➔ Miller effect: True:

(a) is correct answer

10. If C_{gs} = 1 pF and C_{gd} = 0.2 pF, indicate the most correct value to approximate the 3dB upper-frequency point f_H . **(1 pt)**

(a) 100 kHz

(b) 150 kHz

(c) 300 kHz

(d) 550 kHz

(e) 850 kHz

$$f_H = \frac{1}{2\pi C_{in} R'_{sig}} \qquad R'_{sig} = R_{sig} \,||\, R_G$$

$$C_{in} = C_{gs} + (1 + A'_M) C_{gd} \quad \textit{Miller Effect}$$

$$C_{in} = 1p + (1 + 1m(100k \,||\, 4.7k \,||\, 10k)0.2 = 1.84\, pF$$

$$f_H = \frac{1}{2\pi 1.84 \times 10^{-12} \times 0.1 \times 10^{6}} = 865\ kHz$$

More Exact Formula:

$$f_H \simeq \frac{1}{2\pi \left\{ R_{sig} \left[C_{gs} + C_{gd} \left(1 + g_m R'_D \right) \right] + C_{gd} R'_D \right\}}$$

$$f_H \simeq \frac{1}{2\pi \left\{ 100 \times 10^{+3} \left[1 \times 10^{-12} + 0.2 \times 10^{-12} \left(1 + 3.09 \right) \right] + 0.2 \times 10^{-12} \times 3.09 \times 10^{3} \right\}}$$

$$f_H \simeq 0.8725\ MHz$$

f_H = 872.5 kHz

(e) is correct answer