Exam #3
Chapters 5 and 6
Solutions

I. MOSFET Parameters (6 points)

An NMOS transistor with $k_n = 2$ mA/V^2 and $V_t = 1.0$ V is operated with $I_D = 16$ mA. Find the following assuming that the FET is operating in the saturation regime (don't forget units):

V_{OV} ________________ $$V_{OV} = \sqrt{\frac{2I_D}{k_n}} = \sqrt{\frac{2(16\text{mA})}{2\frac{\text{mA}}{\text{V}^2}}} = \sqrt{16\text{V}^2} = 4\text{V}$$

V_{GS} $\underline{V_{GS} = V_t + V_{OV}}$ $= 4.0\text{V} + 1.0\text{V} = 5\text{V}$

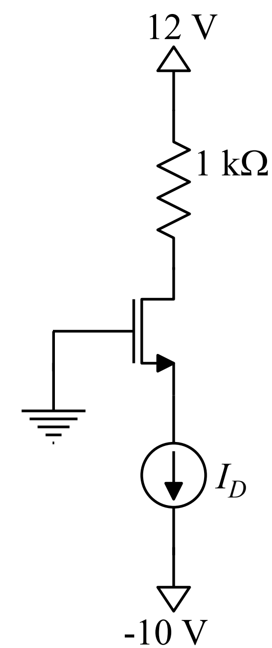
At what value of V_{DS} does the transistor enter the saturation region?

The NMOS FET enters saturation when $V_{DS} = V_{OV}$

V_{DSsat} $\underline{V_{DSsat} = V_{OV} = 4\text{V}}$

II. MOSFET Voltages(10 points)

In this circuit the source voltage is -3.5 V and the transistor is characterized by V_t = 0.5 V, $k'_n\,(W/L)$ = 1 mA/V^2, and λ = 0. Determine the following (don't forget units):



V_{GS} ______________

$$V_{GS} = V_G - V_S = 0\text{V} - (-3.5\text{V}) = 3.5\text{V}$$

V_{OV} ______________

$$V_{OV} = V_{GS} - V_t = 3.5\text{V} - 0.5\text{V} = 3.0\text{V}$$

I_D ______________

$$I_D = \frac{1}{2}k_v V_{OV}^2 = \frac{1}{2}\left(\frac{1\text{mA}}{\text{V}^2}\right)(3\text{V})^2 = 4.5\text{mA}$$

-10 V

V_D ______________

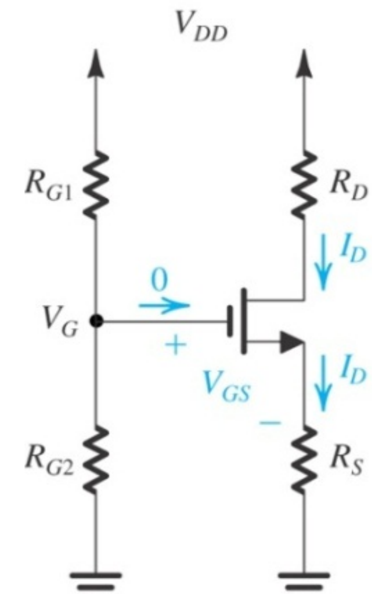
$$V_D = V_{DD} - I_D R_D = 12\text{V} - 4.5\text{mA}(1\text{k}\Omega) = 7.5\text{V}$$

r_o ______________

$$r_o = \frac{V_A}{I_D} = \frac{1}{\lambda I_D} = \infty\ \Omega$$

III. FET Biasing (18 points)

Consider the classical biasing scheme shown below using a 15-V supply. For the MOSFET, $V_t = 1$ V, $\lambda = 0$, and $k_n = 0.25$ mA/V^2. Arrange that the drain current is 2 mA, with one-third of the supply voltage across each of R_S and R_D. **Use 10 MΩ for the total bias resistance (i.e $R_{G1} + R_{G2} = 10$ MΩ).** Determine the following:



V_S ____5.0V____

V_D ____10.0V____

V_{OV}: ________

$$V_{OV} = \sqrt{\frac{2I_D}{k_n}} = \sqrt{\frac{2(2\text{mA})}{\frac{0.25\text{mA}}{\text{V}^2}}} = \sqrt{16}\text{V} = 4.0\text{V}$$

V_{GS}: ________

$$V_{GS} = V_t + V_{OV} = 1\text{V} + 4.0\text{V} = 5.0\text{V}$$

V_G ________

$$V_G = V_S + V_{GS} = 5\text{V} + 5.0\text{V} = 10.0\text{V}$$

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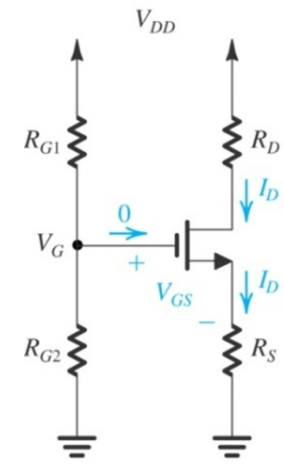

R_D 2.5 kΩ

R_S 2.5 kΩ

R_{G1} 3.333 MΩ

R_{G2} 6.667 MΩ

$$R_D = R_S = \frac{15\text{V}/3}{2\text{mA}} = \frac{5\text{V}}{2\text{mA}} = 2.5\text{k}\Omega$$

$$V_G = 9\text{V} = 15\text{V}\frac{R_{G2}}{R_{G1}+R_{G2}} = 15\text{V}\frac{R_{G2}}{10\text{M}\Omega}$$

$$\Rightarrow R_{G2} = \frac{10\text{V}}{15\text{V}}10\text{M}\Omega = 6.667\text{M}\Omega$$

$$R_{G1} = 10\text{M}\Omega - 6.66\text{M}\Omega = 3.333\text{M}\Omega$$

IV. Beta and Alpha (6 points)

In a particular BJT, the base current is 100 μA, and the collector current is 9.9 mA. Find the following for this device.

β ______________

$$\beta = \frac{I_C}{I_B} = \frac{9.9\text{mA}}{0.1\text{mA}} = 99$$

α ______________

$$\alpha = \frac{\beta}{\beta + 1} = \frac{99}{100} = 0.99$$

$$I_E = I_C + I_B = 9.9\text{mA} + 0.1\text{mA} = 10.0\text{mA}$$

$$I_E = (\beta + 1) I_B = (99 + 1)0.1\text{mA} = 10.0\text{mA}$$

I_E ______________

$$I_E = \frac{1}{\alpha} I_C = \frac{1}{0.99} 9.9\text{mA} = 10.0\text{mA}$$

V. Vocabulary/Definitions

A. Active
B. α, Alpha
C. Base
D. β, Beta
E. Bulk
F. CCVS
G. Channel length modulation parameter
H. CMOS
I. Collector
J. Cut-off
K. Diffusion
L. Drain
M. Drift
N. Emitter
O. Early voltage
P. Gate
Q. MOSFET transconductance parameter
R. NMOS MOSFET
S. *npn* BJT
T. Overdrive voltage
U. PMOS MOSFET
V. *pnp* BJT
W. Process transconductance parameter
X. Quiescent
Y. Saturation
Z. Source
AA. Thermal voltage
BB. Threshold voltage
CC. Transfer Characteristic
DD. Transfer Function
EE. Triode
FF. VCCS
GG. Vermont

1) BB V_t.
2) AA V_T
3) T $(V_{GS} - V_t)$.
4) Q k_p or k_n
5) W k'_p or k'_n
6) W $\mu_n C_{ox}$ or $\mu_p C_{ox}$
7) H Circuitry that contains both NMOS and PMOS transistors.

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8)_CC_ The output voltage as a function of input voltage.

9)_DD_ Relationship between the input and output of a linear time-invariant system with respect to frequency.

10)_FF_ Type of dependent source that describes a FET.

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GG. Vermont

11)__J___, 12)_EE_, 13)__Y__ The three modes/regions of operation of a FET.

14)_J___, 15)_Y___, 16)_A__ The three modes/regions of operation of a BJT.

17)_G__ λ 18)_B__ common-base current gain

19)_O__ V_A 20)_D__ common-emitter current gain .

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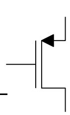
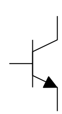
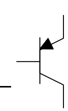
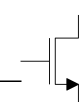
Transistor: 21) U
22) Z
23) P

24) L

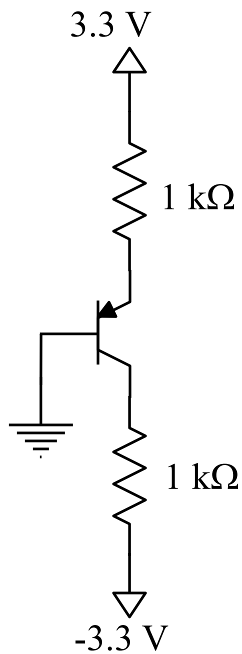
Transistor: 25) S
26) I
27) C

28) N

Transistor: 29) V
30) N
31) C

32) I

Transistor: 33) R
34) L
35) P

36) Z

VI. BJT Voltages (10 points)

Consider the circuit shown which has $|V_{BE}|$ of 0.7 V and a α is specified to be 0.96154. Find the following:



V_E:______ $V_E = V_B + V_{EB} = 0\text{V} + 0.7\text{V} = 0.7\text{V}$

I_E:______ $I_E = \dfrac{V_{CC} - V_E}{R_E} = \dfrac{3.3\text{V} - 0.7\text{V}}{1\text{k}\Omega} = \dfrac{2.6\text{V}}{1\text{k}\Omega} = 2.6\text{mA}$

I_C:______ $I_C = \alpha I_E = (0.96154)2.6\text{mA} = 2.5\text{mA}$

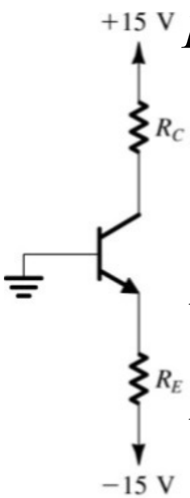
$$I_B = I_E - I_C = 2.6\text{mA} - 2.5\text{mA} = 0.1\text{mA}$$

I_B:______ $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.96154}{1-0.96154} = 25.0 \qquad I_B = \dfrac{I_C}{\beta} = \dfrac{2.5\text{mA}}{25} = 0.1\text{mA}$

V_C:______ $V_C = V_{EE} + I_C R_C = -3.3\text{V} + (2.5\text{mA})(1\text{k}\Omega) = -0.8\text{V}$

VII. BJT biasing (14 points)

The transistor in the circuit shown has $\beta = 50$ and exhibits a V_{BE} of 650 mV at I_C = 1 mA. Design the circuit so that the current of 5 mA flows through the collector and a voltage a +5 V appears at the collector. Remember that in active mode $I_C = I_S e^{V_{BE}/V_T}$ where V_T is the thermal voltage (~ 25 mV at RT).



I_S: $I_C = I_S e^{V_{BE}/V_T} \Rightarrow I_S = I_C e^{-V_{BE}/V_T} = (1\text{mA})e^{-650\text{mV}/25\text{mV}} = 5.1\text{fA}$

$$V_2 = V_1 + V_T \ln\left(\frac{I_2}{I_1}\right) = 650\text{mV} + (25\text{mV})\ln\left(\frac{5\text{mA}}{1\text{mA}}\right) = 690.2\text{mV}$$

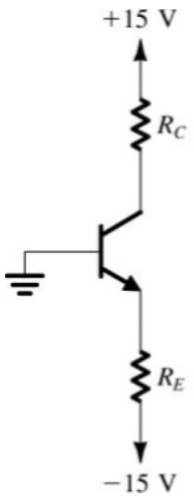
V_{BE} @ $I_C = 5\ mA$: $V_{BE2} = V_T \ln\left(\frac{I_C}{I_S}\right) = (25\text{mV})\ln\left(\frac{5\text{mA}}{5.1\text{fA}}\right) = 690.2\text{mV}$

V_E: $V_E = V_B - V_{BE} = 0\text{V} - 0.69\text{V} = -0.69\text{V}$

I_B: $I_B = \frac{I_C}{\beta} = \frac{5\text{mA}}{50} = 0.1\text{mA}$

VII. BJT biasing (14 points)

The transistor in the circuit shown has $\beta = 50$ and exhibits a V_{BE} of 650 mV at I_C = 1 mA. Design the circuit so that the current of 5 mA flows through the collector and a voltage a +5 V appears at the collector. Remember that in active mode $I_C = I_S e^{V_{BE}/V_T}$ where V_T is the thermal voltage (~ 25 mV at RT).



$$I_E = I_B + I_C = 0.1\text{mA} + 5.0\text{mA} = 5.1\text{mA}$$

I_E:

$$I_E = \frac{I_C}{\alpha} = \frac{\beta+1}{\beta}(5.0\text{mA}) = \frac{51}{50}(5.0\text{mA}) = 5.1\text{mA}$$

R_E:

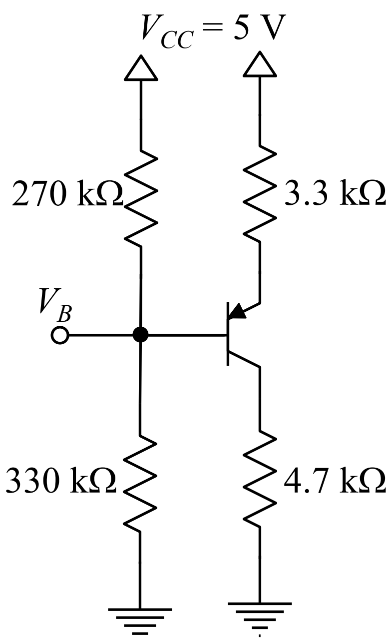
$$R_E = \frac{V_E - (-15\text{V})}{I_E} = \frac{-0.69\text{V} + 15\text{V}}{5.1\text{mA}} = \frac{14.31\text{V}}{5.1\text{mA}} = 2806\Omega$$

R_C:

$$R_C = \frac{V_{CC} - V_C}{I_C} = \frac{15\text{V} - 5\text{V}}{5.0\text{mA}} = \frac{10\text{V}}{5.0\text{mA}} = 2.0\text{k}\Omega$$

VIII. BJT Voltages (8 points)

Consider the circuit shown which has $|V_{BE}|$ of 0.7 V and a β that is very high (i.e. $I_B = 0$ mA). Find the following:



V_B: $$V_B = V_{EE} + (V_{CC} - V_{EE})\frac{330\text{k}\Omega}{600\text{k}\Omega} = 0\text{V} + 5\text{V}\left(\frac{330\text{k}\Omega}{600\text{k}\Omega}\right) = 2.75\text{V}$$

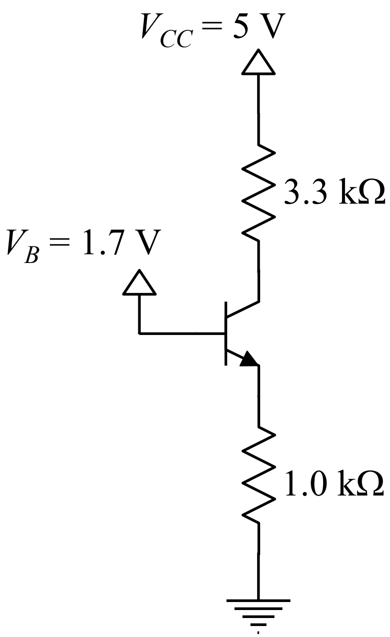
V_E: $$V_E = V_B + |V_{BE}| = 2.75\text{V} + 0.7\text{V} = 3.45\text{V}$$

$I_E = I_C$: $$I_E = \frac{V_{CC} - V_E}{R_E} = \frac{5\text{V} - 3.45\text{V}}{3.3\text{k}\Omega} = 0.47\text{mA}$$

V_C: $$V_C = V_{EE} + I_C R_C = 0\text{V} + (0.47\text{mA})(4.7\text{k}\Omega) = 2.21\text{V}$$

IX. BJT Voltages (10 points)

Consider the circuit shown which has $|v_{BE}|$ of 0.7 V and a β is specified to be 49. Find the following:



V_E: $V_E = V_B - V_{BE} = 1.7\text{V} - 0.7\text{V} = 1.0\text{V}$

I_E: $I_E = \dfrac{V_E}{R_E} = \dfrac{1\text{V}}{1\text{k}\Omega} = 1.0\text{mA}$

I_C: $I_C = \alpha I_E = \dfrac{49}{50} 1.0\text{mA} = 0.98\text{mA}$

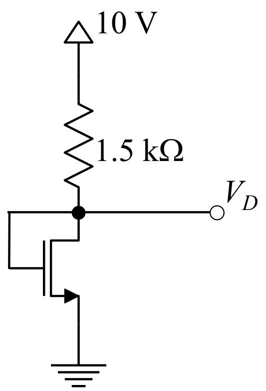
$$I_B = I_E - I_C = 1.0\text{mA} - 0.98\text{mA} = 0.02\text{mA}$$

I_B: $I_B = \dfrac{I_C}{\beta} = \dfrac{0.98\text{mA}}{49} = 0.02\text{mA}$

V_C: $V_C = V_{CC} - I_C R_C = 5\text{V} - (0.98\text{mA})(3.3\text{k}\Omega) = 1.77\text{V}$

Extra Credit (4 points)

Find the following voltages where $k_n = 2$ mA/V^2, $V_t = 2.0$ V, and $\lambda = 0$.



$$V_D = V_{GS} \qquad V_D = 10\text{V} - (1.5\text{k}\Omega)(I_D) \Rightarrow I_D = \frac{10\text{V} - V_D}{1.5\text{k}\Omega}$$

$$I_D = \frac{1}{2}k_n\left(V_D - V_t\right)^2 = \frac{1}{2}\frac{2\text{mA}}{\text{V}^2}\left(V_D - 2\text{V}\right)^2 = \left(V_D - 2\text{V}\right)^2 \text{mA}$$

$$10\text{V} - V_D = 1.5V_D^2 - 6V_D + 6$$

$$1.5V_D^2 - 5V_D - 4 = 0 \Rightarrow V_D = 4\text{V}, -0.666\text{V}$$

I_D:__________ $$I_D = \frac{1}{2}\frac{2\text{mA}}{\text{V}^2}\left(V_D - 2\text{V}\right)^2 = (4-2)^2 \text{mA} = 4\text{mA}$$

V_D:__________ $$V_D = 4\text{V}$$

Class Results Exam #3

Exam #3

- Avg 86.1%
- High 102% (8)
- Low 40%