<File: Exam #2 S'02>

EECS 245 - SPRING 2002

EXAM#2 – 4/8/02

NAME: ________________ CWRUnet e-mail address:____________

Solutions – 51 people took exam, 1 makeup

IMPORTANT INFORMATION:

1. All questions are not worth the same.
2. Exam is closed book, closed notes. Calculators are allowed.

		Possible	
1.		16	Large signal BJT models
2.		16	BJT small signal model (CE)
3.		20	DC biasing of BJTs
4.		20	DC characteristics of MOSFETs
5.		18	Biasing MOSFETs
6.		24	Small signal MOSFET amplifier
SCORE		114	

NOTE: Some formulas of potential interest

MOSFETs

$$I_D = K(V_{GS} - V_T)^2$$

$$g_m = 2K(V_{GS} - V_T)$$

BJTs

V_T=26mV @ 300˚ C

$$r_\pi = \frac{\beta V_T}{I_{C,Q}}$$

$$g_m = \frac{\beta}{r_\pi} = \frac{I_{C,Q}}{V_T}$$

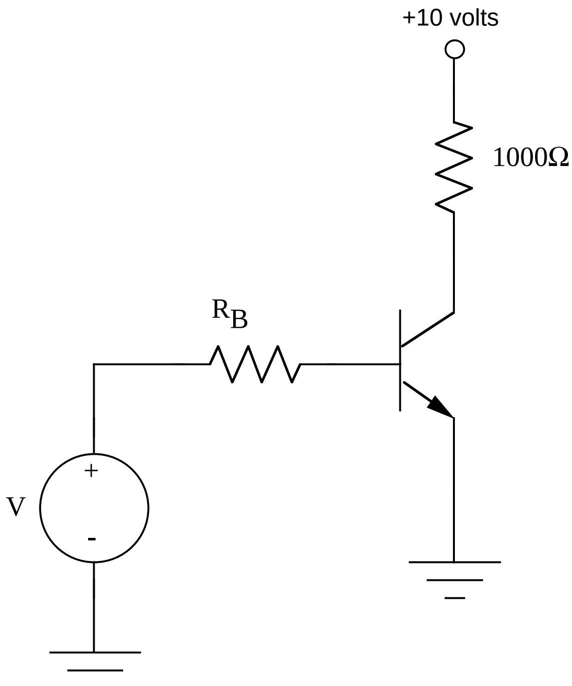
Name: ____________________ e-mail: ______________________
EECS 245: Exam #2 April 8, 2002

1. Large Signal BJT Models

The following BJT transistor amplifier uses a transistor with β=100 and V_{BE}=0.7 volts; R_B is 100kΩ. State any assumptions you use to answer the following questions.

(a) Assume the transistor is in cutoff. What are the collector current and collector-emitter voltage for the transistor in cutoff. For what range of input voltages is the transistor in the cutoff region?

(b) For what range of input voltage V will the transistor be in the active region?



ANSWER:

(a) If the transistor is cutoff, the collector-emitter junction is open giving V_{CE}=10 volts, I_C=0. The transistor will be cutoff as long as V≤0.7 volts.

(b) For the transistor in the active region the base current will be $I_B = \frac{V - V_{BE}}{R_B} = \frac{V - 0.7}{100k}$

The collector current is then $I_C = \beta I_B = \beta \frac{V - 0.7}{100k}$.

The saturation current is $I_{C(SAT)} = \frac{V_{CC} - V_{CE,SAT}}{R_C} = \frac{10volts - 0.2volts}{1k\Omega} = 9.8mA$

Name: ____________________ e-mail: ______________________

EECS 245: Exam #2 April 8, 2002

For active region operation $I_C = \beta \frac{V - 0.7}{100k} \le I_{C(SAT)} = 9.8mA$ which can be solved for V to give $(V - 0.7) \le \frac{I_{C(SAT)}}{\beta} R_C = \frac{9.8mA}{100} 100k\Omega = 9.8volts$, or $V \le 10.5volts$ for active mode operation. Together with (a), this defines the active region for $0.7volts \le V \le 10.5volts$

GRADING:

(a) 8 points

- I_C -3 points
- V_{CE} -2 points
- no input voltage, -3 points
- -1 if you identified the wrong voltage as less than 0.7 volts

(b) 8 points

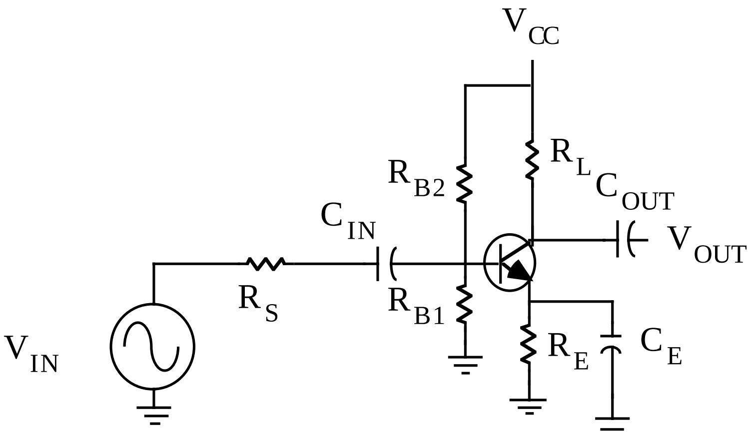
-6 points if you got I_B but not V_{in}

-4 points if no upper limit for V_{in}

Name: ___________________ e-mail: _____________________

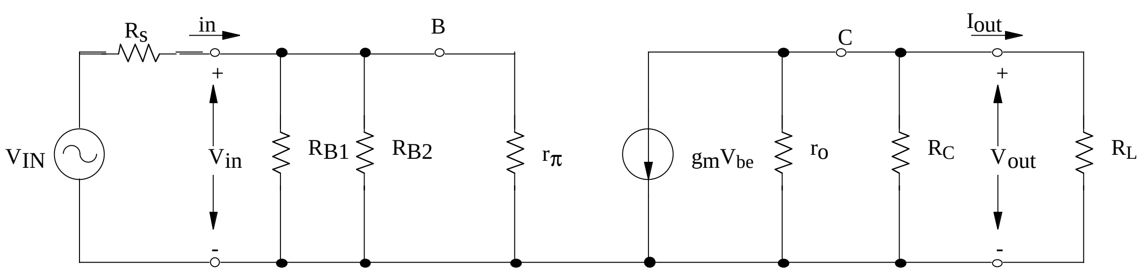
EECS 245: Exam #2 April 8, 2002

2. Small Signal BJT Equivalent Circuits



Consider the above BJT amplifier where R_S=500Ω, R_{B1}=2.7kΩ, R_{B2}=7.5kΩ, R_E=200Ω, R_L=100Ω. The transistor is characterized by β=80. The amplifier is biased such that $V_{CE,Q}$=10 volts, $I_{C,Q}$=15mA. You may assume that C_E, C_{IN} and C_{OUT} have a low impedance at mid-frequency. Draw the small-signal equivalent circuit for the BJT small signal amplifier at mid-frequency. Indicate the values of all small signal parameters in your circuit. DO NOT CALCULATE A_v, R_{in}, etc..

ANSWER:



The only values which need to be computed are g_m and r_π. Using the formulas we get

$$r_\pi = \frac{\beta V_T}{I_{C,Q}} = \frac{(80)(26mV)}{15mA} = 138.7\Omega \text{ and } g_m = \frac{\beta}{r_\pi} = \frac{I_{C,Q}}{V_T} = \frac{15mA}{26mV} = 0.576S$$

GRADING:

10 points for small signal circuit diagram;

-3 points each for g_m and r_π if you did not include them. NOTE you could use βi_b as well.

–1 for wrong resistor values

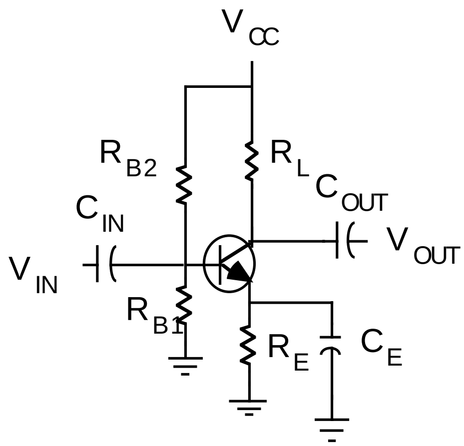
-2 for wrong values of small signal parameters

Name: ___________________ e-mail: _____________________

EECS 245: Exam #2 April 8, 2002

3. DC Biasing of BJTs

Draw the DC circuit for the following AC amplifier. Determine $I_{C,Q}$ and $V_{CE,Q}$.
The circuit parameters are R_L=1kΩ, R_E=1kΩ R_{B1}=4.7kΩ, R_{B2}=10kΩ and V_{CC}=18 volts. The transistor has a DC current gain β=130.



ANSWER:

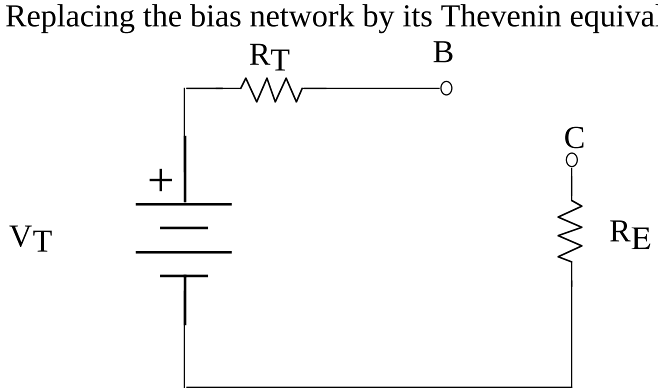
The problem is most easily solved by Thevenizing the input circuit. We can compute these as

$$R_T = \frac{R_{B1}R_{B2}}{R_{B1}+R_{B2}} = \frac{(10k\Omega)(4.7k\Omega)}{10k\Omega + 4.7k\Omega} = 3197\Omega$$

and

$$V_T = \frac{R_{B1}}{R_{B1}+R_{B2}}V_{CC} = \frac{4.7k\Omega}{10k\Omega+4.7k\Omega}(18Volts) = 5.755Volts$$

Replacing the bias network by its Thevenin equivalent we get the circuit:



Doing KVLaround this circuit we get $-V_T + I_B R_T + V_{BE} + (\beta+1)I_B R_E = 0$ which becomes $-5.755 + I_B(3197\Omega) + 0.7 + (130+1)I_B(1000\Omega) = 0$ or $I_B = \frac{5.055volts}{134197\Omega} = 37.67\mu A$. Then $I_{C,Q} = \beta I_B = (130)(36.67\mu A) = 4.897mA$. Using this value we can compute $V_{CE,Q}$ as

Name: ____________________ e-mail: ______________________

EECS 245: Exam #2 April 8, 2002

$V_{CC} = I_C R_L + V_{CE,Q} + (I_C + I_B) R_E$. Substituting gives

$18volts = (11.18mA)(1k\Omega) + V_{CE,Q} + (11.18mA + 86.067\mu A)(1k\Omega)$. Solving this equation gives

$V_{CE,Q} = 18volts - 4.897volts - 4.935volts = 8.168volts$

GRADING:

Getting the correct numerical value of the base current was worth 10 points.

V_T and R_T were worth 2 points each

You got 6 points if you got to a correct equation for the base current.

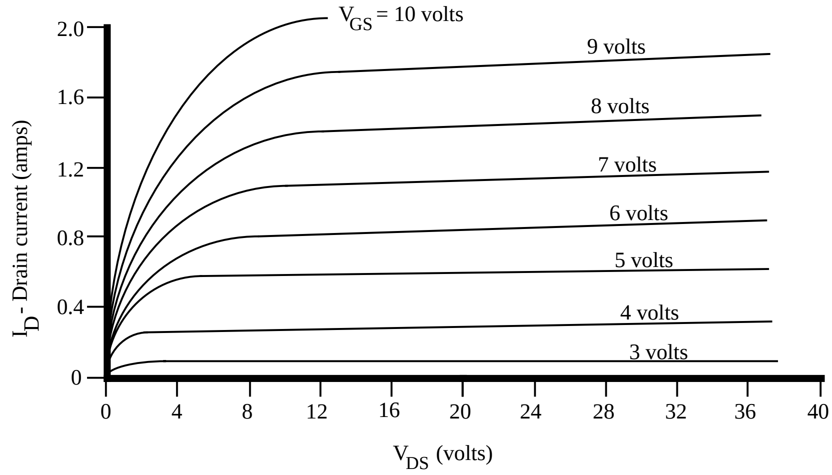
Getting the correct value for $I_{C,Q}$ and $V_{CE,Q}$ were worth 5 points each.

Name: ___________________ e-mail: _____________________

EECS 245: Exam #2 April 8, 2002

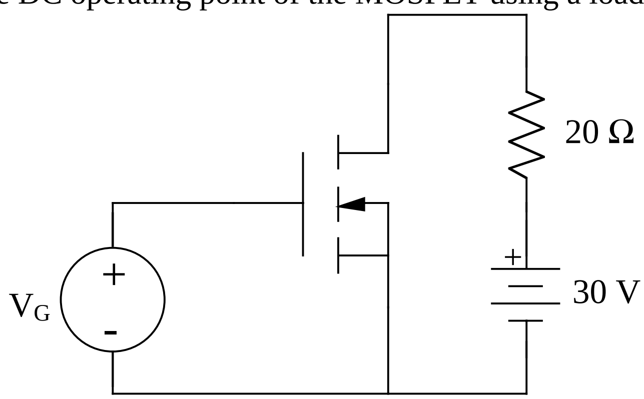
4. DC characteristics of MOSFETs

The following questions refer to the measured characteristics (shown below) of a 2N5447 MOSFET. The data was taken with a Tektronix 575 curve tracer.



(a) Graphically estimate the threshold voltage (V_{TO}) of the MOSFET from the data.

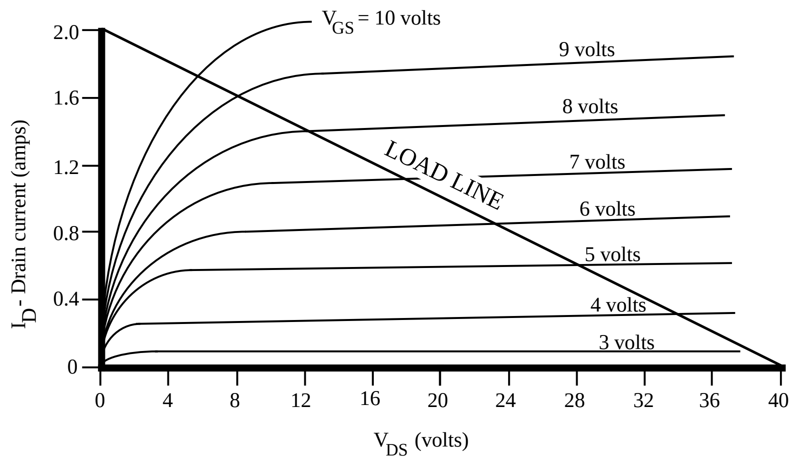
(b) The MOSFET described above is connected in the circuit shown below. For V_G=6 volts, determine the DC operating point of the MOSFET using a load line analysis.

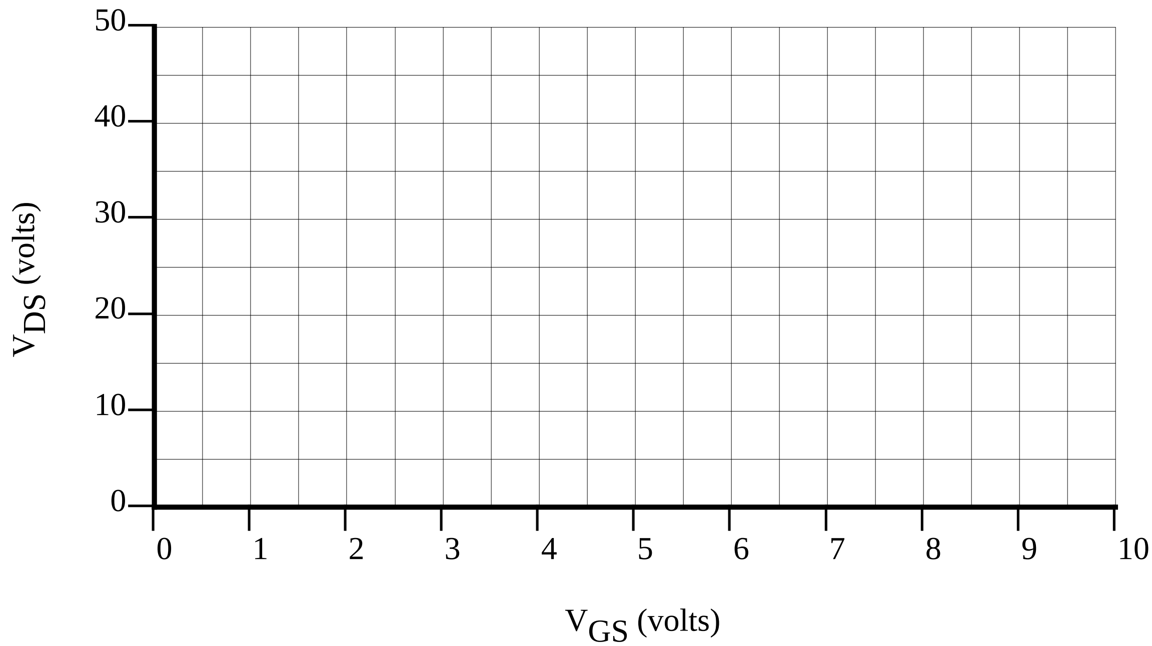


(a) ANSWER: By inspection the threshold voltage must be smaller than 3 volts. A good answers would be 2-3 volts although anything above zero would be probably OK,

(b) ANSWER: The x-intercept of the load line is 30 volts. The y-intercept of the load line is given by $i_D = \frac{30 \text{ volts}}{20\ \Omega} = 1.5$ amps . Drawing this line and estimating its intersection with the curve for V_{GS}=6 volts gives (12 volts, 0.8 amps) for the operating point.

(c) Assuming the operation of the MOSFET circuit is described by the characteristic data/load line shown below, determine V_{DS} as a function of V_{GS} for V_{GS} ranging from 0 to 10 volts. Using this plot sketch the change in V_{DS} as a function of V_{GS} if V_{GS}= 6 volts + 2cosωt,. Do you think this MOSFET circuit would make a good amplifier? Explain why or why not.

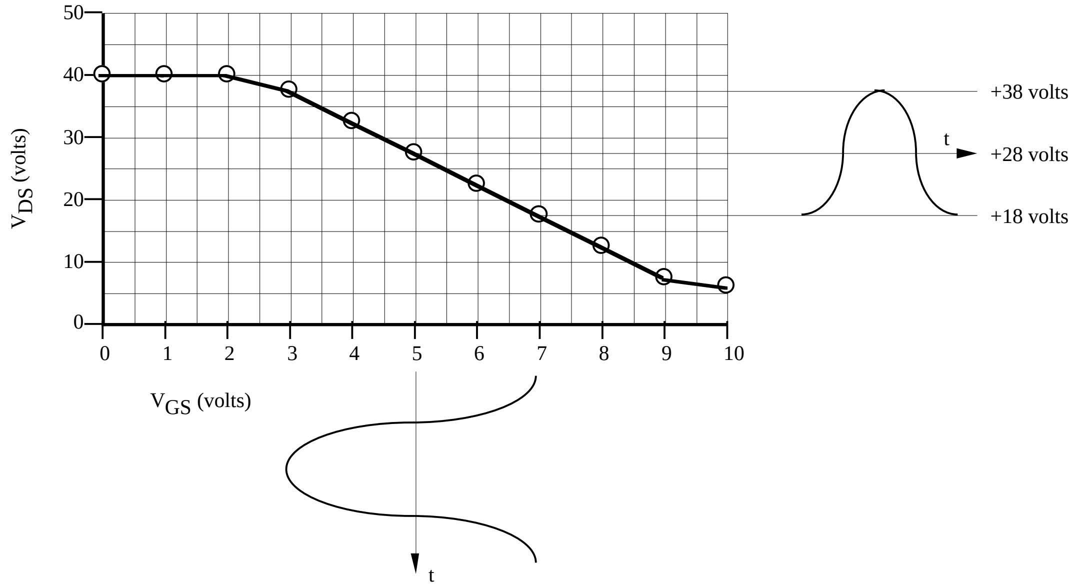




Name: ____________________ e-mail: ______________________

EECS 245: Exam #2 April 8, 2002

ANSWER:



This circuit would make an excellent amplifier. It has a nice, long transfer curve and the input signal is approximately in the middle of the region resulting in undistorted output with a gain of approximately 5.

GRADING:

(a) V_{TO} was worth 3 points

(b) 3 points for each end of the load line, 2 points for the actual Q point

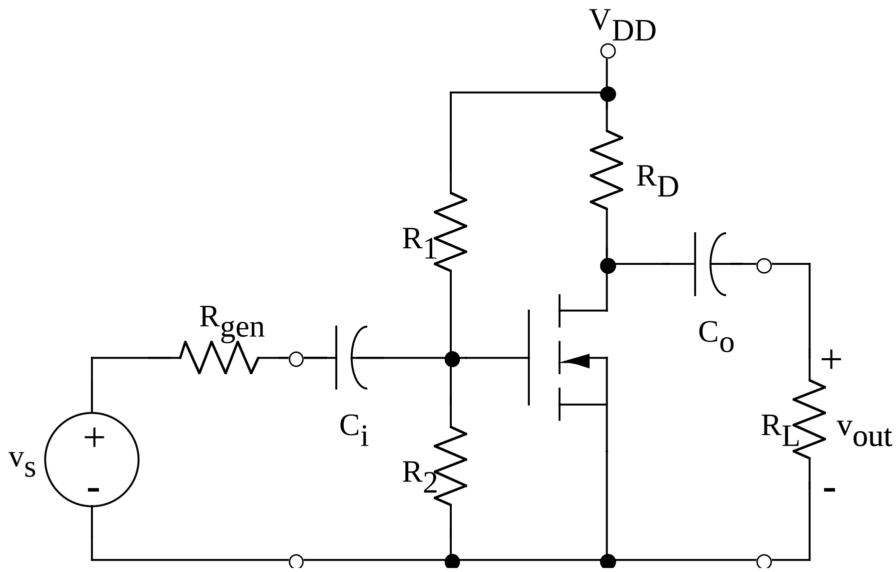
(c) The sketch was worth 6 points; sketching and/or describing the amplifier output was worth 4 points. A number of people had the wrong output voltage for V_{GS} less than 2-3 volts — you lost 1 point for the wrong value of V_{DS} in this region. You lost 2 points for not discussing the amplifier output

Name: ____________________ e-mail: ______________________

EECS 245: Exam #2 April 8, 2002

5. Biasing MOSFETs

For the MOSFET amplifier circuit shown below determine the DC operating point of the transistor, i.e. determine I_D, V_{DS}, and V_{GS}.



The circuit uses the values R_{gen}= 10kΩ, V_{DD}=18V, R_1=3.3MΩ, R_2=1.2MΩ, R_D=2kΩ, and R_L=5kΩ The MOSFET is characterized by K=0.96mA/V^2 and V_T=2.5 volts.

ANSWER:

There is no voltage at the source as it is connected directly to ground. V_{GS} is determined only by V_G which is set by the R_1-R_2 voltage divider.

$$V_{GS} = \frac{R_2}{R_1 + R_2} V_{DD} = \frac{1.2M\Omega}{1.2M\Omega + 3.3M\Omega}(18V) = (0.27)(18V) = 4.8Volts$$

With the transistor parameter K AND V_{GS} we can calculate the drain current as:

$$I_D = K(V_G - V_T)^2 = 0.96\frac{mA}{V^2}(4.8V - 2.5V)^2 = 5.08mA$$

Once the drain current is known we can apply KVL to the loop from ground through the transistor, through R_D, and through the power supply to ground to get:

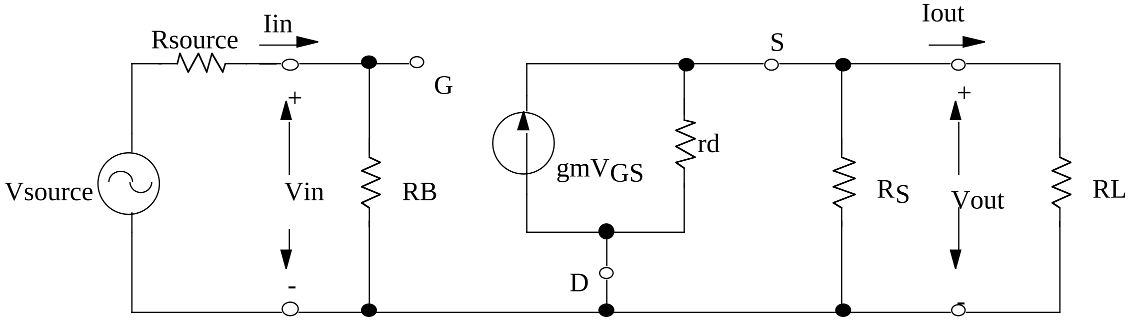
$$V_{DS} = V_{DD} - I_D R_D = 18 - (5.08mA)(2k\Omega) = 7.84Volts$$

GRADING:

V_{GS}, I_D and V_{DS} were worth 6 points apiece each.

Name: ____________________ e-mail: ______________________
EECS 245: Exam #2 April 8, 2002

6. Small Signal Amplifier Analysis



A student in EECS 245 has obtained the above small signal equivalent circuit for a MOSFET amplifier. The circuit parameters are R_{SOURCE}=100Ω, R_B=1.5MΩ, R_S=330Ω, and R_L=100Ω. The transistors small signal parameters are g_m=0.05S and r_d=100kΩ.

(a) Determine the small signal voltage gain of this amplifier.
(b) What is the input impedance R_{in} of this amplifier? The output impedance R_{out}?
(c) What is the current gain of this amplifier ASSUMING THAT R_{in} =200kohms, R_{out}=1000ohms, and $\frac{V_{out}}{V_{in}} = 1$?

Answer:
(a) Rd is so large compared to RS||RL that it can be neglected. Then

$$R_L' = R_S \parallel R_L = \frac{R_S R_L}{R_S + R_L} = \frac{(330\Omega)(100\Omega)}{330\Omega + 100\Omega} = 76.75\Omega$$

In the output circuit $V_{out} = +(g_m V_{GS})R_L' = +(0.05V_{GS})(76.75\Omega) = 3.84V_{GS}$ [1]

Using KVL around the circuit also gives $-V_{in} + V_{GS} + V_{out} = 0$. [2]

Substituting [1] into [2] gives $-V_{in} + \frac{V_{out}}{3.84} + V_{out} = 0$ which can be solved to give the voltage gain $-V_{in} + 1.26V_{out} = 0$, or $\frac{V_{out}}{V_{in}} = +0.79$

(b)
By inspection. $R_{in}=R_B$=1.5MΩ
Using the definition for thee output resistance and applying a test voltage source we get

$$R_{out} = \frac{V_T}{I_T} = \frac{V_T}{\frac{V_T}{r_d} + \frac{V_T}{R_S} + g_m V_T} = r_d \parallel R_S \parallel \frac{1}{g_m}$$

Name: ____________________ e-mail: ______________________

EECS 245: Exam #2 April 8, 2002

After substituting values we have $R_{out} = r_d \parallel R_S \parallel \frac{1}{g_m} = 100k\Omega \parallel 330\Omega \parallel 20\Omega \cong 18.85\Omega$

(c)

$$A_i = \frac{i_{out}}{i_{in}} = \frac{V_{out}/R_{out}}{V_{in}/R_{in}} = \frac{V_{out}}{V_{in}}\frac{R_{in}}{R_{out}} = (1)\frac{200k\Omega}{1k\Omega} = 200$$

GRADING:

(a)

A_V was worth 10 points

-4 points for using wrong R_L'

–5 points for calculating V_{GS} wrong. Typically, you forgot that $V_{GS} \neq V_{in}$ in this circuit.

(b) R_{in} and R_{out} were worth 4 points each

Failing to include g_m lost you 2 points. Math errors cost you 1 point.

(c)

This was worth 6 points.