Electronics
EECE2412 — Spring 2013
Exam #2 with Solutions

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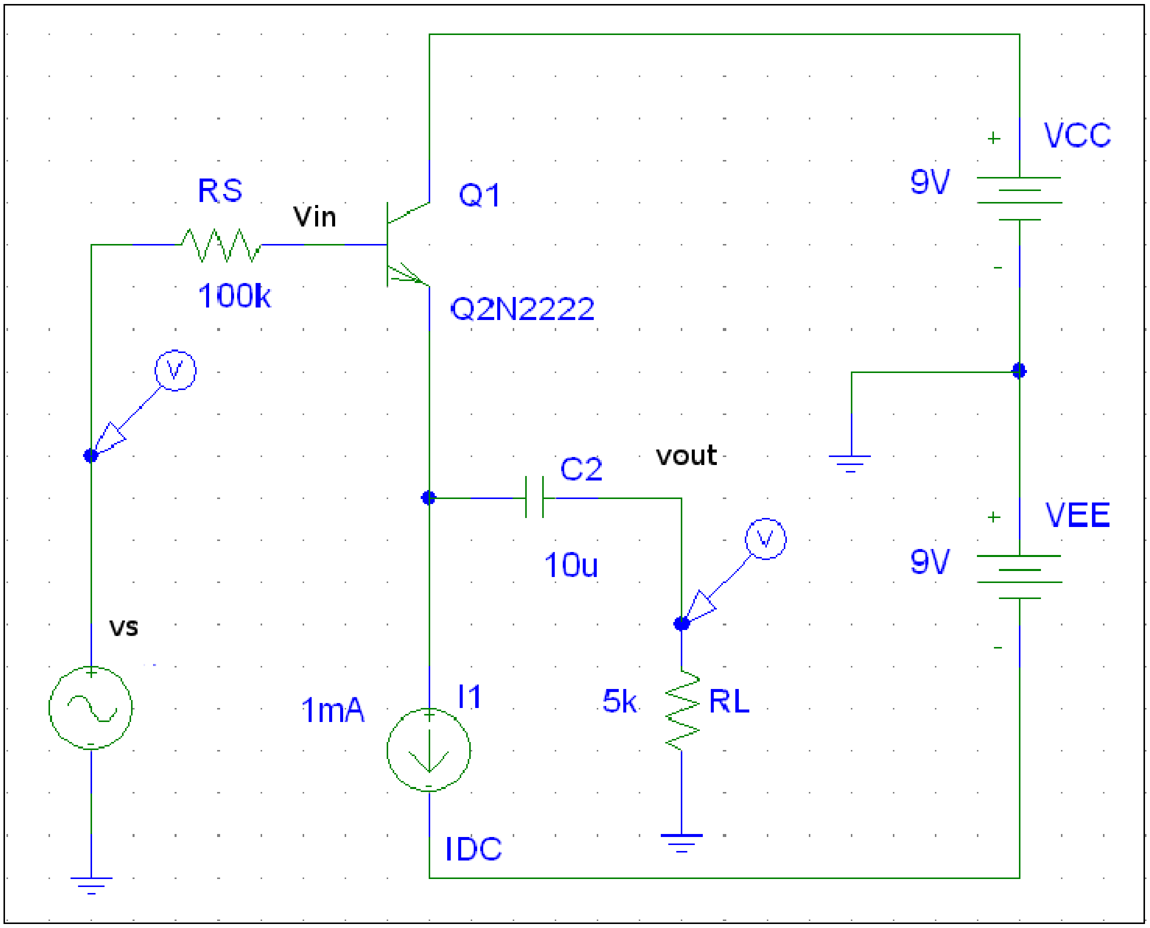
23 April 2013

1 BJT Amplifier

The following figure shows a BJT amplifier, which we are going to analyze. The transistor has $\beta = 160$, and $V_A = 100$ Volts. RS is part of the source. The input and output voltages are at the indicated locations, vin and $vout$, respectively.



1.1 Amplifier Type

What type of amplifier is it? Common Collector or Emitter Follower

What is the typical situation in which this amplifier is used?

Used when unity voltage gain is needed

and source alone cannot supply current.

1.2 Small–Signal Parameters

What are the small–signal parameters?

$$g_m = I_C^{DC}/V_T = \frac{1 \text{ mA}}{25 \text{ mV}} = 0.04 \text{ A/V}$$
$$r_\pi = \beta/g_m = \frac{160}{0.04 \text{ A/V}} = 4000\ \Omega$$
$$r_e = I_E^{DC}/V_T = \frac{r_\pi}{\beta + 1} = 24.8\ \Omega$$
$$R_0 = \frac{V_A}{I_C^{DC}} = \frac{100 \text{ Volts}}{10^{-3} \text{ Amperes}} = 10^5\ \Omega$$

$g_m = \underline{0.04 \text{ A/V}}$

$r_\pi = \underline{4 \text{ k}\Omega}$

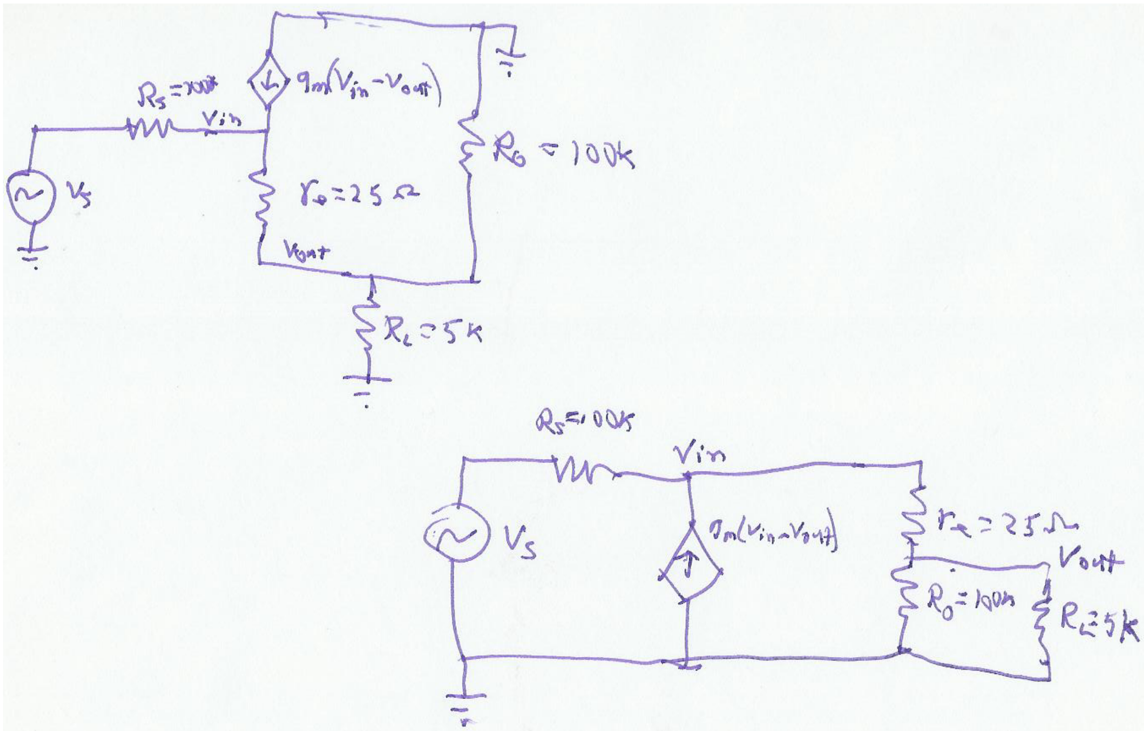
$r_e = \underline{24.8\ \Omega}$

$R_0 = \underline{100 \text{ k}\Omega}$

1.3 AC Circuit

Draw the AC circuit, using a T model for the transistor.

AC circuit in the following figure:



1.4 Amplifier Characteristics

What are the AC characteristics of this amplifier?

Voltage Gain: Look at the voltage divider. Neglect R_0 in comparison to $R_{:}$.

$$A_V = \frac{V_{out}}{V_{in}} = \frac{5000\ \omega}{5025\ \omega}$$

Current Gain: Note that the dependent source $g_m\,(v_{in} - v_{out})$ can also be written as $i_c^{ac} = \beta i_b^{ac}$. The current going to r_e and thus mostly to R_L is the sum of $i_b^{(ac)}$ and $i_c^{(ac)}$ or $\beta + 1$ times the input current.

Output resistance:

$$v_{out:oc} \approx v_{in}$$

$$i_{out:sc} \approx v_{in}/25\ \Omega$$
$$R_{out} = \frac{v_{out:oc2}}{i_{out:sc}}5\ \Omega$$

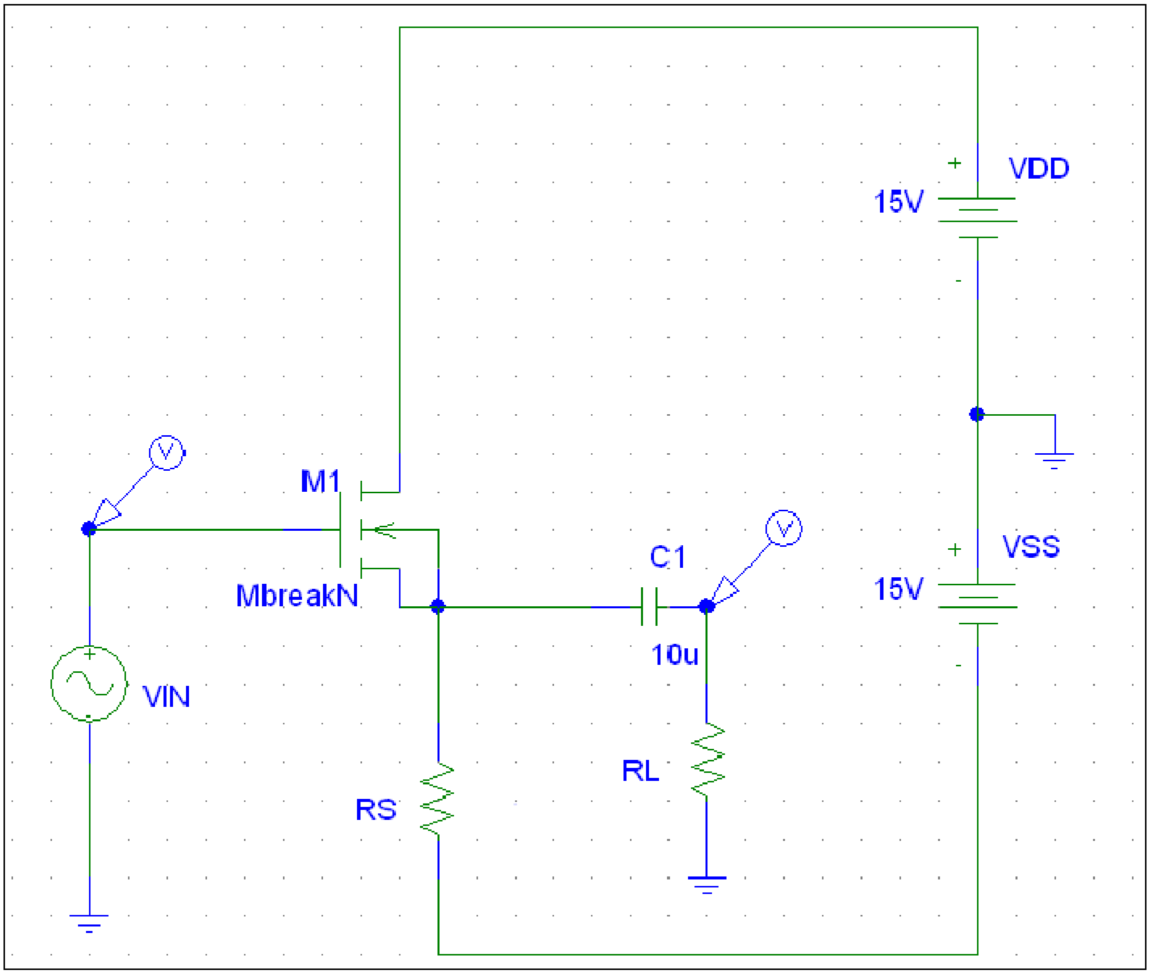
Voltage Gain (With Load) $\underline{0.995}$

Current Gain $\underline{161}$

Output Resistance $\underline{25\ \Omega}$

2 Discrete FET Amplifier

The following figure shows an amplifier using a discrete FET and a resistor. The transistor has a drain current of 250 μAmp when $V_{GS} = 5$ Volts, and the threshold voltage is zero. The Early Voltage is $V_A = 70$ Volts.



What type of amplifier is it? Common Drain

What is the typical situation in which this amplifier is used?

Unity Voltage gain is desired

and source cannot provide current

2.1 Circuit Design

We want a drain current of 250 μAmperes in this circuit. What resistance do we need for RS?

$$I_D^{(DC)} = 250\ \mu\text{Amperes} \rightarrow V_{GS}^{(DC)} = 5\ \text{Volts}$$

$$V_G^{(DC)} = 0 \rightarrow V_S^{(DC)} = -5\ \text{Volts}$$

$$R_S = \frac{10\ \text{Volts}}{250 \times 10^{-6}\ \text{Amperes}} = 4 \times 10^4\ \Omega$$

$R_S =$ $\underline{40\ \text{k}\Omega}$

2.2 Small–Signal Parameters

What are the small–signal parameters?

$$g_m = \frac{2I_D^{(DC)}}{V_{GS}^{(DC)}} = \frac{250 \times 10^{-6}\ \text{Amperes}}{5\ \text{Volts}} = 10^{-4}\ \text{A/V}$$

$$R_0 = \frac{V_A}{I_D^{(DC)}} = \frac{70\ \text{Volts}}{250\ \mu\text{A}} = 2.8 \times 10^{-5}\ \Omega$$

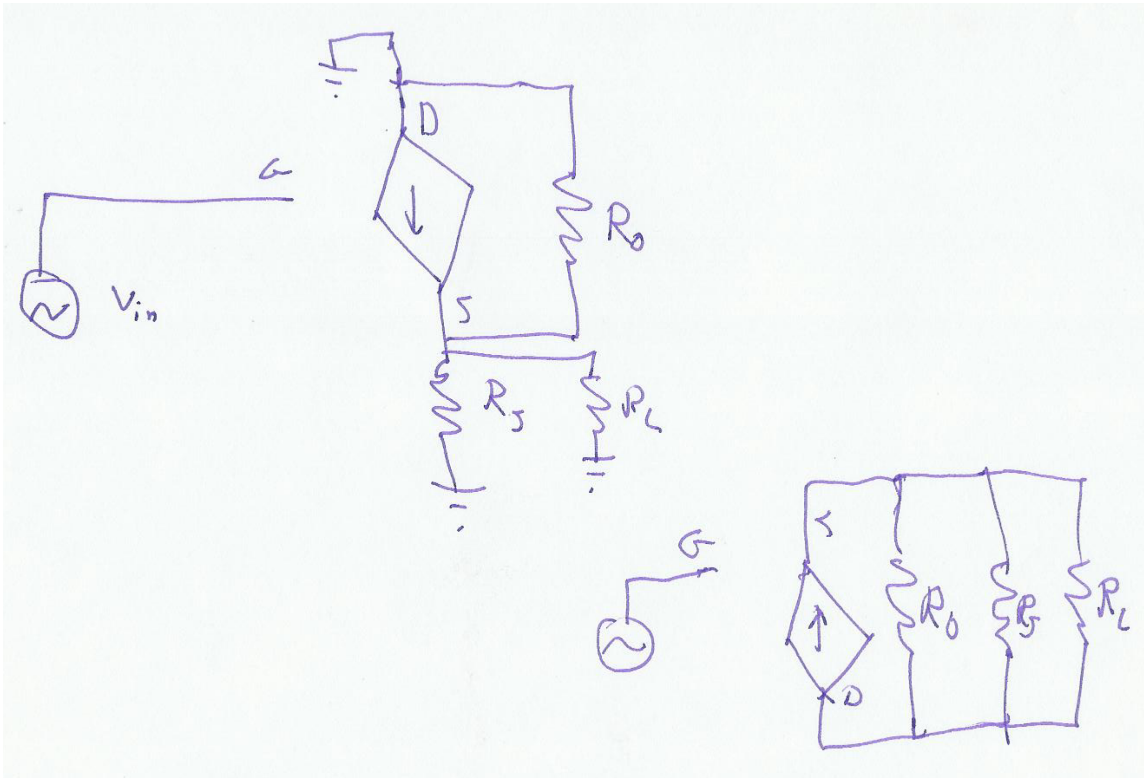
$g_m =$ $\underline{100\ \mu\text{A/V}}$

$R_0 =$ $\underline{280\ \text{k}\Omega}$

2.3 AC Circuit

Draw the AC circuit, using a Pi model for the transistor.

AC circuit is shown below



2.4 Amplifier Characteristics

What are the AC characteristics of this amplifier?

$$v_{out:oc}^{(AC)} = g_m \left(v_{in}^{(AC)} - v_{out:oc}^{(AC)} \right) (R_0 \parallel R_s)$$

$$v_{out:oc}^{(AC)} \left[1 + g_m (R_0 \parallel R_s) \right] = g_m v_{in}^{(AC)} (R_0 \parallel R_s)$$

$$v_{out:oc}^{(AC)} = \frac{g_m (R_0 \parallel R_s)}{1 + g_m (R_0 \parallel R_s)} v_{in}^{(AC)}$$

Neglect R_0 in comparison to R_S.

$$v_{out:oc}^{(AC)} = \frac{10^{-4}\ \mathrm{A/V} \times 4 \times 10^4\ \Omega}{1 + 10^{-4}\ \mathrm{A/V} \times 4 \times 10^4\ \Omega} v_{in}^{(AC)} = 0.80 v_{in}^{(AC)}$$

Input resistance is infinite because of the oxide between the gate and the channel.

Output resistance is $R_S \parallel R_0 \approx R_S$.

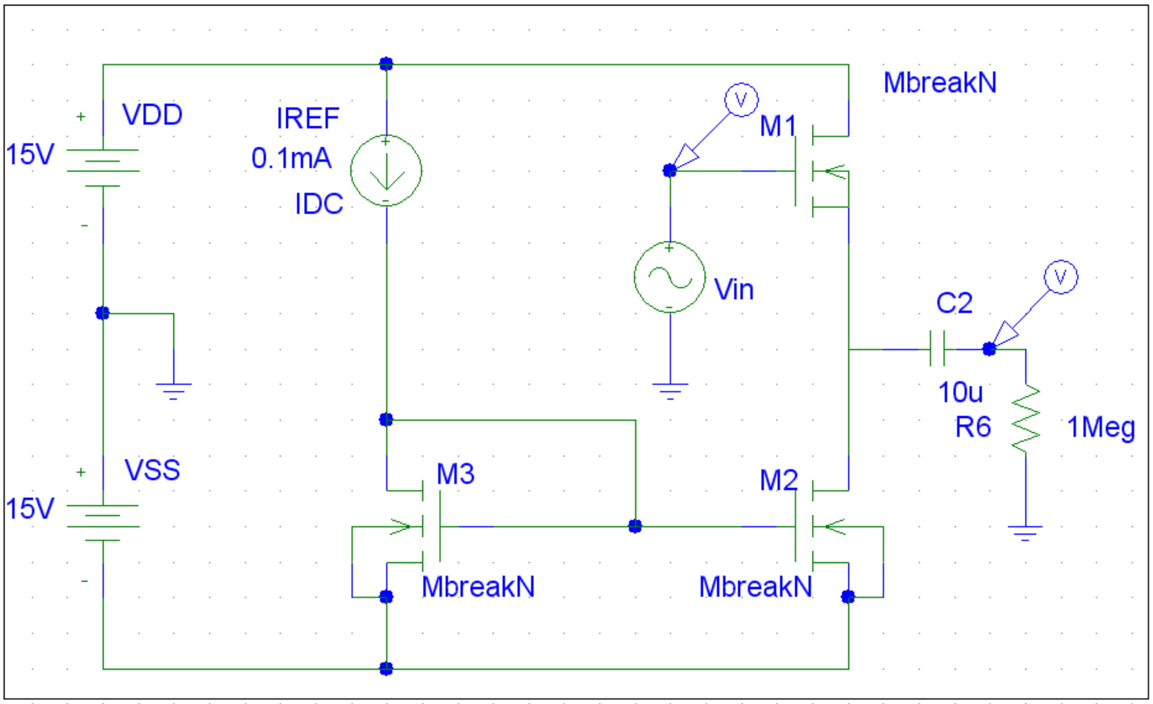
Open–Circuit Gain <u>0.80</u>

Input Resistance <u>Infinite</u>

Output Resistance <u>40 kΩ</u>

3 CMOS Amplifier

The figure below shows a CMOS amplifier. The transistors are all the same, and have a drain current of 250 μAmp when $V_{GS} = 5$ Volts, and the threshold voltage is zero (This is the same as in Problem 2). However, in this case, $V_A = 100$ Volts.



3.1 Amplifier Type

What type of amplifier is it? Common Drain

What is the typical situation in which this amplifier is used?

Unity Voltage gain is desired

and source cannot provide current.

3.2 Transistor Characteristics

What is the constant, $\mu_n C_{ox} W/L$ for this transistor?

In saturation,

$$i_D = \mu_n C_{ox} \frac{W}{L} \frac{(v_{GS} - v_{thr})^2}{2}$$

$$\mu_n C_{ox} \frac{W}{L} = \frac{2 i_D}{(v_{GS} - v_{thr})^2} = \frac{2 \times 250 \times 10^{-6}\ \text{A}}{(5\ \text{V}^2)} = 2{\times}10^{-5}\ \text{A/V}^2.$$

$\underline{20\ \mu\text{A/V}^2}$

3.3 Small–Signal Parameters

What are the small–signal parameters?

$$I_D^{(DC)} = 0.1\ \text{mA}$$

$$g_m = \frac{I_D^{(DC)}}{V_{GS}^{(DC)}} = \sqrt{2 I_D^{(DC)} \mu_n C_{ox} \frac{W}{L}} = 6.3 \times 10^{-5}\ \text{A}V$$

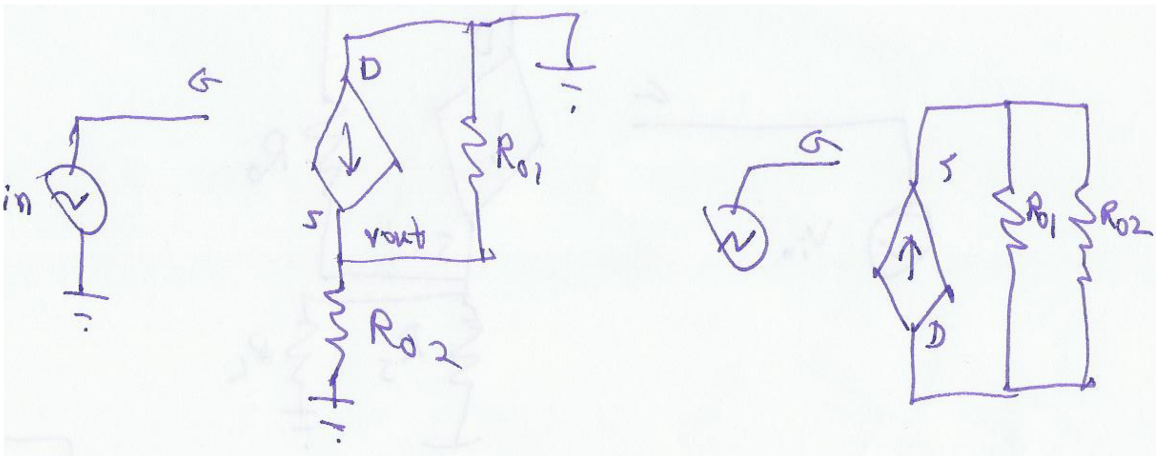
$$R_0 = \frac{V_A}{I_D^{(DC)}} = \frac{100\ \text{V}}{10^{-4}\ \text{A}} = 10^6\ \Omega$$

$g_m = \underline{63\ \mu\text{A/V}}$

$R_0 = \underline{1\ \text{M}\Omega}$

3.4 AC Circuit

Draw the AC circuit, using a Pi model for the transistor.



3.5 Amplifier Characteristics

What are the AC characteristics of this amplifier?

$$v_{out:oc} = \frac{R_0}{2} g_m \left(v_{in} - v_{out:oc} \right)$$

$$v_{out:oc} \left(1 + \frac{R_0}{2} g_m \right) = \frac{R_0}{2} g_m v_{in}$$

$$v_{out:oc} = \frac{\frac{R_0}{2}}{1 + \frac{R_0}{2} g_m} g_m v_{in} = \frac{32}{33} v_{in}$$

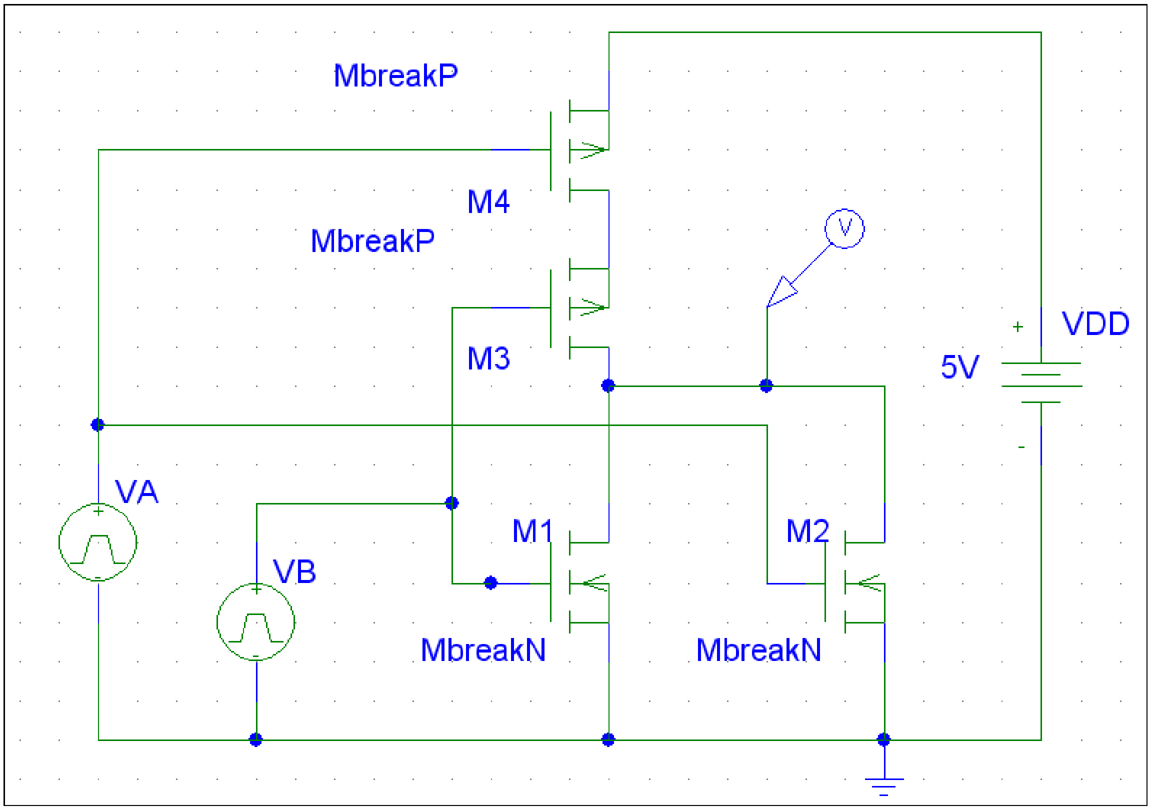
Again, the input resistance is infinite because the input is on the gate.

Open–Circuit Gain 0.97

Input Resistance Infinite

4 CMOS Logic

The following figure shows a CMOS digital logic circuit. As usual, +5 Volts represents "true," and zero represents "false." There are two inputs, VA and VB, and one output, V_{out} at the voltage probe shown in the figure.



4.1 Truth Table

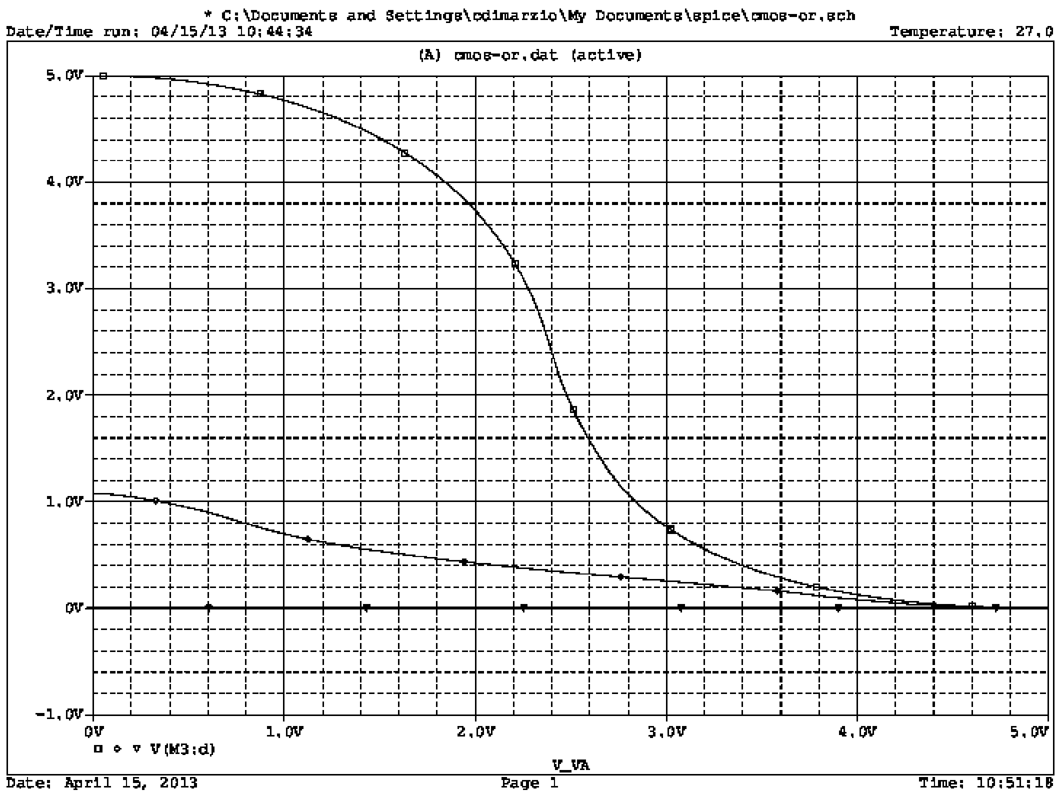
Construct the truth table for this circuit, for all possible combinations of inputs VA and VB being "true" or "false."

A	B	M1	M2	M3	M4	Out
H	H	O	O	X	X	L
H	L	X	O	O	X	L
L	H	O	X	X	O	L
L	L	X	X	O	O	H

What is the function of this circuit?
NOR

4.2 Output Voltages

The following figure shows output voltage as a function of input voltage, VA. In the figure, the bottom curve (along the $V_{out} = 0$ axis) is for $VB = 5$, the next curve is for $VB = 2.5$ Volts and the top curve is for $VB = 0$ Volts. Explain these curves in terms of what you know about FETs.



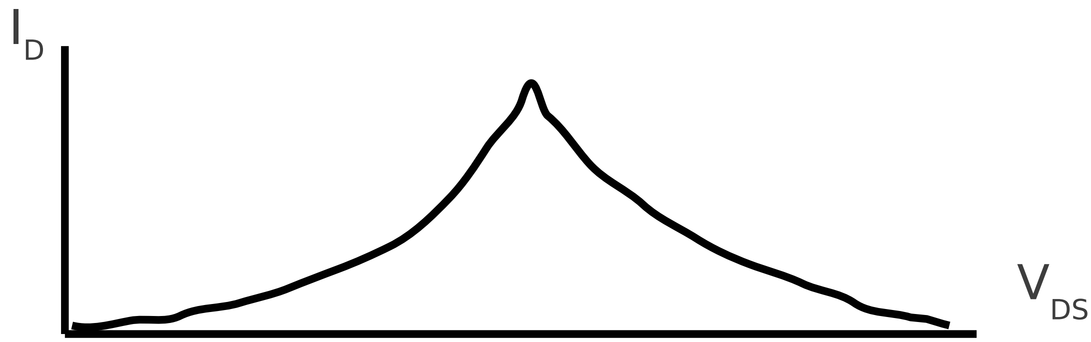
$V_B = 5$ V: Output Always Low

$V_B = 0$ V: Output changes with V_A.

Similar to $V_B = 0$ V but M4 is only partially on.

4.3 Current

Draw a plot of the current, i_D as a function of VA for $VB = 5$ Volts. You don't need to provide a correct current axis, because I have not given you the transistor parameters.



4.4 Alternative Output

With the addition of two transistors at the output, you can convert this to either an "AND" or "OR" gate. Which one? Draw the additional circuit.

Add an inverter.

"AND" or "OR?" OR