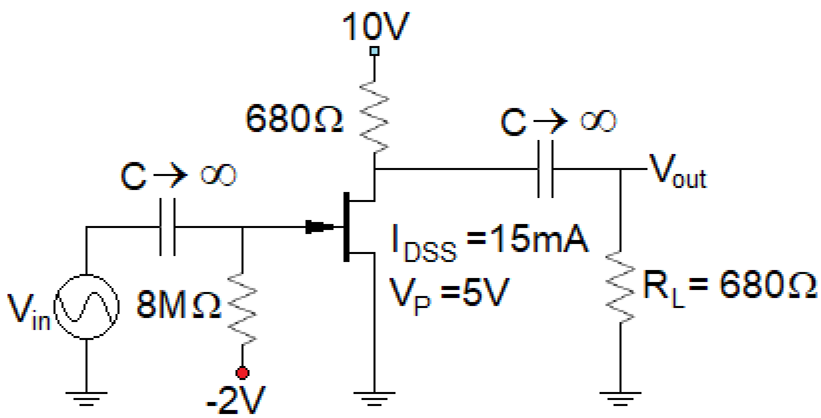
Electronics

FET amplifier

Problem 1.- This is an amplifier based on a J-FET. Check that the transistor is in the active region and find the voltage gain of this configuration.



Solution: To check that the transistor is in the active region notice that

$$I_D = I_{DSS}\left(1+\frac{V_{GS}}{V_p}\right)^2 = 15mA\left(1+\frac{-2}{5}\right)^2 = 5.4mA$$

Then the voltage drain-source is: $V_{DS} = 10V - 680\Omega I_D = 10V - 680\Omega \times 5.4mA = 6.3$V, which is in the active region.

To find the gain notice that the transconductance is:

$$g = \frac{2I_{DSS}}{V_p}\left(1+\frac{V_{GS}}{V_p}\right) = \frac{2\times 15mA}{5V}\left(1+\frac{-2}{5}\right) = 3.6mS$$

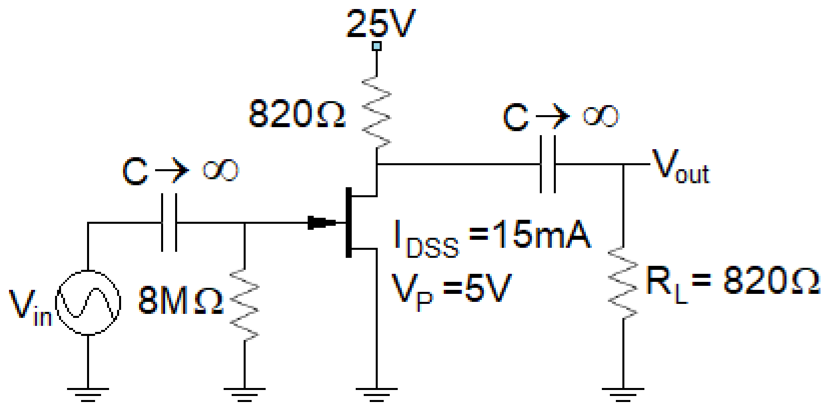
Then, the AC drain current will be: $i_D = gV_{in} = 3.6mSV_{in}$

The load resistance is in parallel with the drain resistance and they give an equivalent of 340 ohms. Then the output voltage will be:

$$V_{out} = -i_D \times 340\Omega = -3.6mSV_{in} \times 340\Omega = -1.22V_{in}$$

So, the gain is **-1.22**

Problem 2.- Find the voltage gain of the following amplifier:



Solution: The strategy here is to first find the Q point to calculate the transconductance and then do the small signal analysis:

Notice that the gate is grounded through an 8-Mohm resistor. Since the input resistance of the J-FET is much larger, the current through this resistor is negligible and the gate voltage can be considered zero:

$$V_G = 0$$

Notice that the source is grounded too, so the source voltage is also zero. This means that the voltage gate-source is zero.

$$V_{GS} = 0$$

This simplifies the small signal analysis since the transconductance is:

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)$$

So, in this case $g_m = g_{m0}$, which is given by:

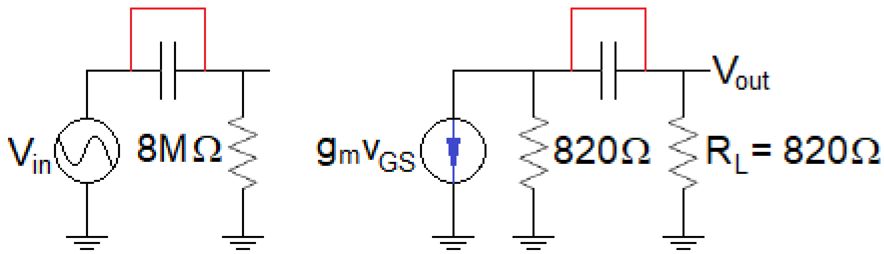
$$g_{m0} = -\frac{2I_{DSS}}{V_{GS(off)}} = -\frac{2(15mA)}{-5V} = 6mS$$

With the value of I_{DSS}, the voltage drain-source is:

$$V_{DS} = 25V - 820\Omega(15mA) = 12.7V$$

This is much more than the pinch-off voltage of 5V, so we are in the active region.

The small signal analysis gives us the following circuit:



Notice that the capacitors behave like short circuits. The gate side of the circuit has the input voltage directly connected to the gate and recalling that the source is grounded, this means that:

$$v_{GS} = v_{in}$$

The drain side of the FET behaves like a current source with a value of:

$$i_D = g_m v_{GS}$$

The load resistance is in parallel with the drain resistance and they are equivalent to:

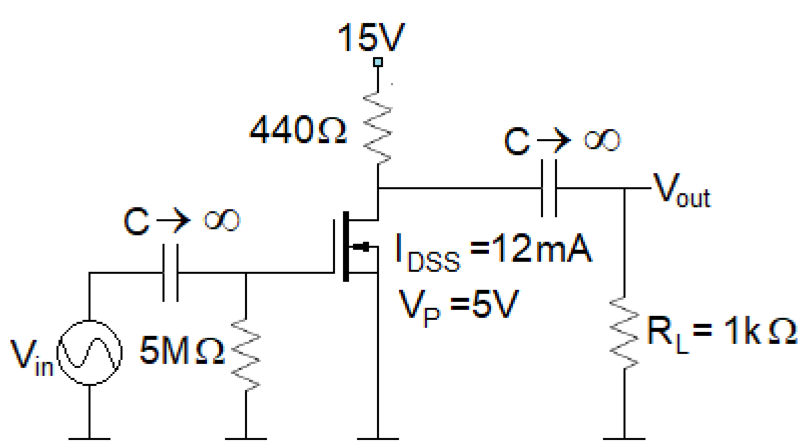
$$R = R_D // R_L = \frac{1}{\frac{1}{R_L} + \frac{1}{R_D}} = \frac{1}{\frac{1}{820\Omega} + \frac{1}{820\Omega}} = 410\Omega$$

So, the output voltage is:

$$v_{out} = -Ri_D = -Rg_m v_{GS} = -Rg_m v_{in} = -410\Omega(6mS)v_{in} = -2.46\, v_{in}$$

This is a gain of **-2.46**

Problem 3.- Find the voltage gain of the following amplifier:



Solution: Similar to the previous problem, the strategy here is to first find the Q point, then find the transconductance and finally do the small signal analysis:

Notice that the gate is grounded through a 5MΩ resistor. Since the input resistance of the MOSFET is much larger, the current through this resistor is negligible and the gate voltage can be considered zero:

$$V_G = 0$$

Notice that the source is grounded too, so the source voltage is also zero. This means that the voltage gate-source is zero.

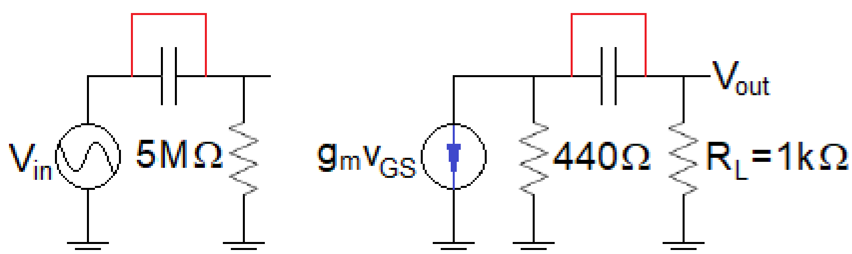
$$V_{GS} = 0$$

Similar to the previous problem, the transconductance is:

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right) == g_{m0}$$ which is given by:

$$g_{m0} = -\frac{2I_{DSS}}{V_{GS(off)}} = -\frac{2(12mA)}{-5V} = 4.8mS$$

The small signal analysis gives us the following circuit:



The capacitors behave like short circuits. The gate side of the circuit has the input voltage directly connected to the gate and because the source is grounded, this means that:

$$v_{GS} = v_{in}$$

The drain side of the MOSFET behaves like a current source with a value of:

$$i_D = g_m v_{GS}$$

The load resistance is in parallel with the drain resistance giving together:

$$R = R_D // R_L = \frac{1}{\frac{1}{R_L} + \frac{1}{R_D}} = \frac{R_L R_D}{R_L + R_D} = \frac{(440\Omega)(1000\Omega)}{1440\Omega} = 306\Omega$$

Then, the output voltage is:

$$v_{out} = -Ri_D = -Rg_m v_{GS} = -Rg_m v_{in} = -306\Omega(4.8mS)v_{in} = -1.47\, v_{in}$$

This is a gain of **-1.47**

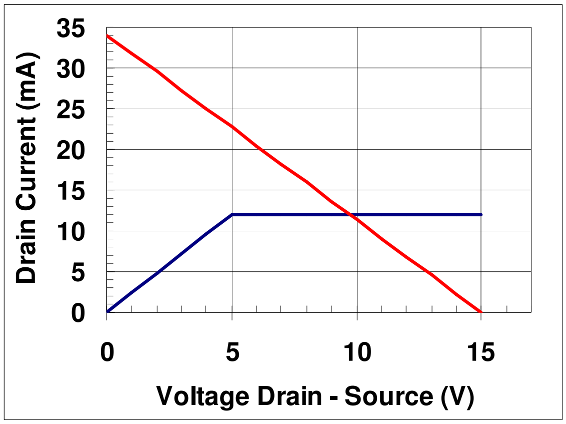
NOTE: We should check that the transistor is not saturated. To do this, notice that the load line is given by:

$$V_{DD} = R_D I_D + V_{DS}$$

Plugging in the values of the problem:

$$15V = 440\Omega I_D + V_{DS}$$

Two segments can model the characteristic ID vs. VDS of the transistor: for V_{DS} between 0 and Vp it is a straight line that goes from $I_D = 0$ to $I_D = I_{DSS}$ and after that it is constant $I_D = I_{DSS}$. As shown:



Notice that in this case the Q point falls inside the active region where the transistor should work very well.

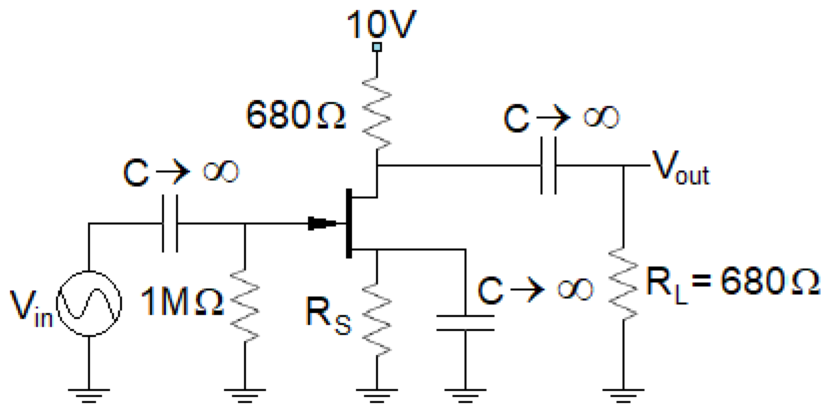
Problem 4.- State an advantage of the amplifiers based on J-FETs over those based on BJTs.

Solution: J-FETs have very high input impedance, so they do not perturb the signal that you want to measure and have very large power gain.

Problem 5.- What is the drain current of a correctly biased J-FET when V_{GS}=0? What about an E-MOSFET?

Solution: The drain current of a J-FET when V_{GS}=0 is I_{DSS}. In the case of an E-MOSFET the drain current is zero when V_{GS}=0.

Problem 6.- An amplifier based on a J-FET is shown below, with I_{DSS} = 15mA and V_p = -5V.
i) Find a value of the resistance R_S such that the drain current at the Q point be 5mA.
ii) In these conditions, calculate the voltage gain with load.



Solution: We have the drain current equation:

$$I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_p}\right)^2$$

With the values of the problem the necessary voltage V_{GS} is

$$5mA = 15mA\left(1-\frac{V_{GS}}{-5}\right)^2$$

$$\rightarrow 0.333 = \left(1-\frac{V_{GS}}{-5}\right)^2 \rightarrow 1-\frac{V_{GS}}{-5} = \sqrt{0.333} \rightarrow V_{GS} = 5(1-\sqrt{0.333}) = -2.11V$$

Besides, in this auto-biasing scheme, the DC voltage in the gate is zero and the source voltage is $V_S = R_S I_D$ so the voltage V_{GS} is:

$V_{GS} = -R_S I_D$

Then, the value of R_S is

$$R_S = \frac{2.11V}{5mA} = 422\Omega$$

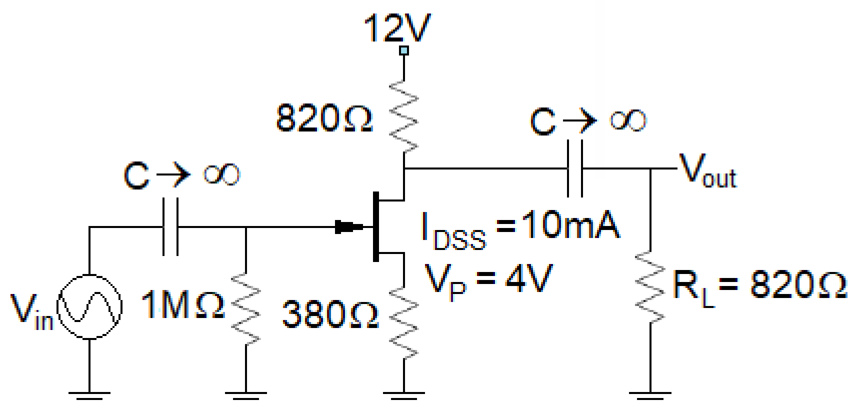
To find the gain, notice that the transconductance is

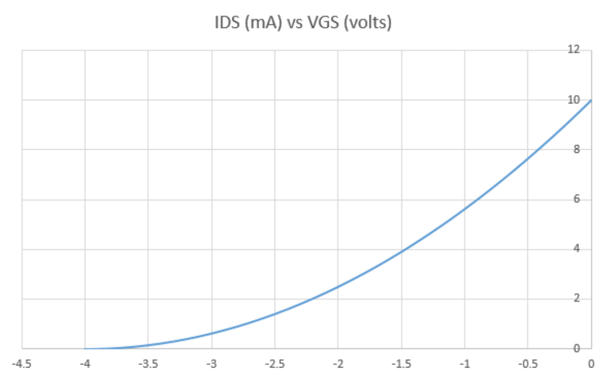
$$g_m = \frac{2\times I_{DSS}}{-V_p}\left(1-\frac{V_{GS}}{V_p}\right) = \frac{2\times 15mA}{-(-5V)}\left(1-\frac{-2.11}{-5}\right) = 3.46mS$$

The gain in this amplifier configuration is $A_{VL} = -g_m(680\Omega // 680\Omega) = -1.18$

Problem 7.- In the amplifier shown below $I_{DSS} = 10mA$ and $V_P = 4V$, calculate:

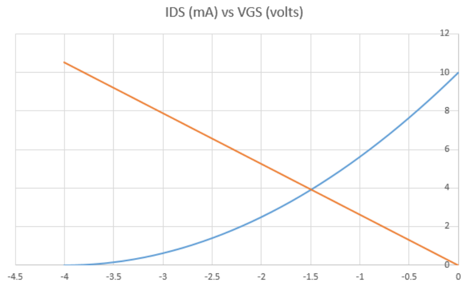
a) The operating point of the JFET (V_{GS}, I_{DS}, V_{DS}). This can be done graphically, with the figure given, or analytically.
b) g_m for the given conditions.
c) The voltage gain without load.
d) The voltage gain with load.





Solution: We notice that the transistor gate is grounded through the 1Mohm resistor, so $V_G = 0$. On the other hand, the source voltage is 380ohm times the drain current. Then, $V_{GS} = -380\Omega I_D$ or $I_D = -\dfrac{V_{GS}}{380\Omega}$.

If we draw this line in the graph above, we find the Q point.



It is:

$$V_{GS} = -1.5V$$
$$I_D = 4mA$$
$$V_{DS} = 12V - 4mA(820\Omega + 380\Omega) = 7.2V$$

In these conditions g_m is

$$g_m = \frac{2 \times I_{DSS}}{-Vp}\left(1 - \frac{V_{GS}}{V_p}\right) = \frac{2 \times 10mA}{-4}\left(1 - \frac{-1.5}{-4}\right) = 3.125mS$$

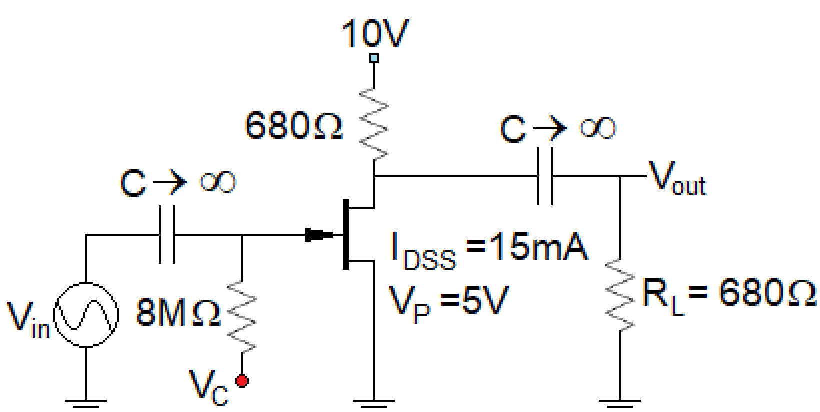
In the AC analysis we should be careful that $v_{gs} \neq v_i$, but instead:

$$A_{V-NL} = -\frac{820\Omega g_m}{1 + 380\Omega g_m} = -\frac{820\Omega \times 3.125mS}{1 + 380\Omega \times 3.125mS} = 1.17$$

And with load

$$A_{V-L} = -\frac{410\Omega g_m}{1 + 380\Omega g_m} = -\frac{410\Omega \times 3.125mS}{1 + 380\Omega \times 3.125mS} = 0.58$$

Problem 8.- An amplifier based on a J-FET is shown below. The voltage V_C is used to control the gain. Calculate what has to be its value to get a voltage gain A = 1.5 with the load indicated.



Solution: The small signal analysis shows that the gain is given by the product of the transconductance and the output resistance, which is 340Ω. Then:

$$g = \frac{1.5}{340\Omega} = 4.41mS$$

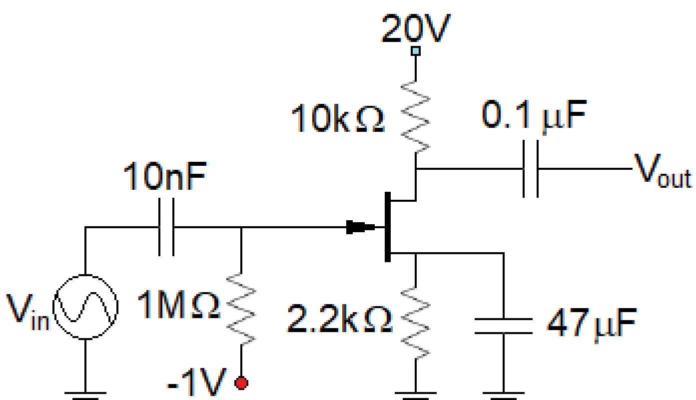
To obtain this transconductance we consider the voltage gate-source:

$$g = \frac{2I_{DSS}}{V_p}\left(1 + \frac{V_{GS}}{V_p}\right) = 4.41mS \rightarrow \frac{2\times 15mA}{5V}\left(1 + \frac{V_{GS}}{5V}\right) = 4.41mS \rightarrow V_{GS} = -1.33V$$

With this voltage in V_c we get the gain of 1.5

Problem 9.- For the amplifier shown in the figure, the transistor has I_{DSS} = 6mA and V_P = 4V. Calculate:

a) The operating point of the J-FET.
b) The voltage gain with a load R_L=10kΩ.
c) The current gain $A_i = i_o/i_i$.



Solution: To find the Q point we notice that the gate voltage is -1V and the source voltage is $V_S = 2.2k\Omega I_S$, so

$V_{GS} = -1V - 2.2k\Omega I_S$ … 1st equation

The drain current is given by the equation $I_{DS} = 6mA\left(1 - \frac{V_{GS}}{-4}\right)^2$ … 2nd equation

We can replace the first equation in the second with the proviso that we are in the active region (to be confirmed later):

$$I_D = 6(0.75 - 0.55 I_D)^2 \rightarrow I_D = 730\mu A$$

$$V_{GS} = -1V - 730\mu A \times 2.2k\Omega = -2.61V$$

$$V_{DS} = 20V - 730\mu A \times 12.2k\Omega = 11.1V$$

This calculation confirms that we are in the active region.
And the gain is:

$$g = \frac{2 \times 6mA}{4V}\left(1 - \frac{V_{GS}}{-4}\right) = \frac{2 \times 6mA}{4V}\left(1 - \frac{-2.61}{-4}\right) = 1.04mS$$

$$A_V = -1.04mS \times (10k // 10k) = -5.21$$

$$A_I = \frac{-5.21}{10k} \times 1M = -521$$

Graphically: