ECE4902 Studio Lab 2 C2013

Carrier Mobility, Channel "on" Resistance R_{on}
MOSFET Threshold Voltage V_{TH}
SPICE Parameter Extraction

PURPOSE:

The purpose of this lab is to measure the resistive nature of the MOSFET drain-source channel. Upon completion of this lab you should be able to:

- Recognize that the channel of a MOSFET looks (mostly) resistive for small currents i_D and small values of drain-source voltage v_{DS}.
- Recognize that increasing the gate drive beyond the threshold voltage reduces the channel "on" resistance R_{on},
- Determine the carrier mobility and threshold voltage for the N- and P-channel MOSFETs in the MC14007
- Compare the measured data to predicted values based on extracted parameters

Prelab

P2-1. In the circuit of Fig. P2-1, a DVM is used to measure the drain-source resistance R_{on} as a function of applied gate-source voltage v_{GS}. The following data is obtained:

v_{GS}	R_{on}
1.5 V	∞
2.0	3180 Ω
2.5	710 Ω
3.2	330 Ω
4.5	180 Ω

Estimate the threshold voltage V_{TH} and $\mu_n C_{ox} \dfrac{W}{L}$ for this MOSFET (see Writeup section for procedure)

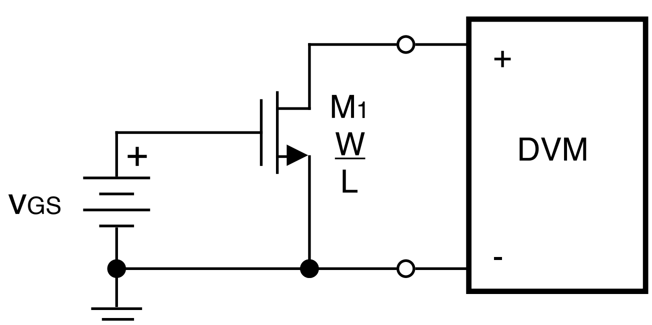

Figure P2-1.

Lab Exercise: REDUCING ON RESISTANCE R_{on} BY INCREASING GATE DRIVE v_{GS}

L2-1. Use the circuit of Fig. L2-2 (using the DVM in ohmmeter mode) to measure the on resistance R_{on} directly. As you vary v_{GS}, you will see variation in the on resistance. Resistor R_G is solely for protection of the MOSFET gate; the voltage drop across R_G is zero under normal conditions since the DC current into the MOSFET gate is zero.

NOTE: Use the AFG3021 function generator in DC output mode (access through the button sequence More ... > More Waveform Menu > DC). Be sure to set the numerical amplitude display to the "High Z" load condition so the displayed DC level is correct. As an additional check, use the scope to look at the gate voltage so you can see v_{GS} go up and down as you adjust the DC level.

ADDITIONAL NOTE: It's important to observe the DVM lead polarity shown in Fig. L2-2. If the DVM connection is reversed, the DVM current i_{DVM} will forward bias the substrate-to-drain diode when $V_{GS} < V_{TH}$.

ANOTHER ADDITIONAL NOTE: For this part, it's very important to leave the DVM on the 100kΩ range throughout. Changing the resistance range changes the current the DVM uses to measure resistance, which affects the resistance measured in the triode region. The problem: in the 10kΩ range, the DVM injects a larger test current than in the 100kΩ range. This causes a larger value of v_{DS}, violating the "small v_{DS}" condition for the resistive portion of the triode region. So, even though normal practice would be to use the 10kΩ range when measuring R_{on} less than 10kΩ (for better measurement resolution), in this case, we'll live with lower resolution so as not to violate the "small v_{DS}" condition.

L2-2. Set the AFG3021 voltage V_{DC} to provide v_{GS} of approximately +5V. Measure R_{on} and v_{GS}. The resistance R_{on} should be in the range of approximately 200Ω to 1kΩ. Reduce v_{GS} until R_{on} has increased by about a factor of two. Measure R_{on} and v_{GS} again. As v_{GS} decreases, you should see R_{on} increase. Continue decreasing the power supply voltage to decrease v_{GS} in increments of ~ 0.5V. Measure R_{on} and v_{GS} at each step and make a table of measurements in your lab notebook. As v_{GS} gets closer to the threshold voltage V_{TH}, R_{on} will start increasing rapidly. As R_{on} increases, take a few data points with R_{on} values of about 2kΩ, 5kΩ, and 10kΩ. You should end up with a total of about 5 to 10 data points.

In your lab notebook, plot R_{on} as a function of v_{GS} . Note that **increasing gate drive v_{GS} reduces the value of on-resistance**. Also, plot 1/ R_{on} as a function of v_{GS}. You should see an approximately linear relationship between 1/ R_{on} and v_{GS}; a line through the measured data points should intersect the v_{GS} axis at the threshold voltage.

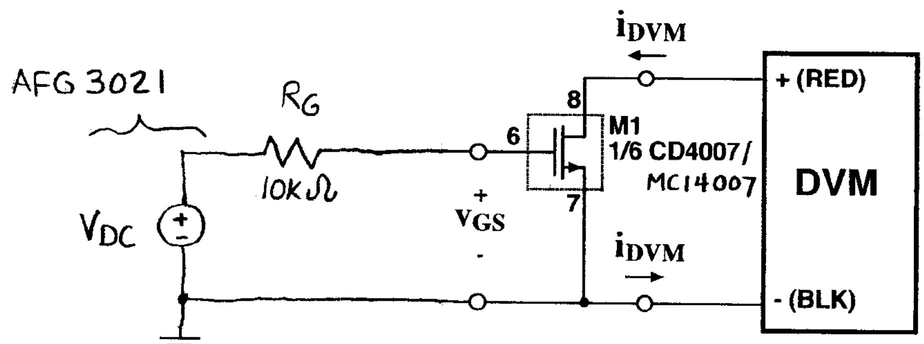

Figure L2-2.

L2-3. Repeat the above procedure for a P-channel MOSFET as shown in Figure L2-3 below. Double-check your connections with the AFG3021 and the DVM since you will now be measuring v_{SG} while applying a negative voltage to the gate. The range of resistances R_{on} should be similar to the previous part; follow the same procedure for gathering data.

In your lab notebook, plot R_{on} as a function of v_{SG} . Also, plot 1 / R_{on} as a function of v_{SG}. Note that, since your horizontal axis is v_{SG} rather than v_{GS}, some care is needed in interpreting the plots. For the P-channel MOSFET **making the gate drive voltage v_{GS} <u>more negative</u> reduces the value of on-resistance**. On the 1/ R_{on} plot, you should also see an approximately linear relationship between 1/ R_{on} and v_{SG}; however in this case a line through the measured data points should intersect the v_{SG} axis at the <u>negative</u> of the threshold voltage. So, for example, if the v_{SG}-intercept is at 2V, then the threshold voltage is V_{TH} = -2V.

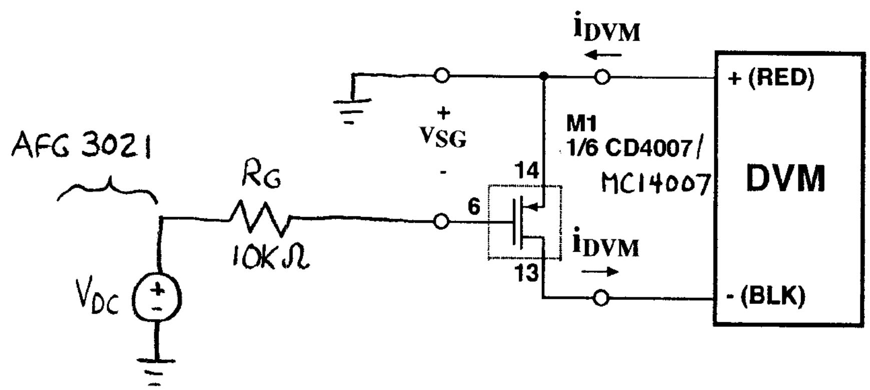

Figure L2-3.

WRITEUP

RELATIONSHIP BETWEEN ON RESISTANCE R_{on} AND GATE DRIVE v_{GS}

N-Channel MOSFET

W2-1. Plot R_{on} as a function of v_{GS}.

W2-2. Plot 1/ R_{on} as a function of v_{GS}. Using this plot, extract the slope $\mu_n C_{ox} \frac{W}{L}$, and the x-intercept (threshold voltage V_{TH}) for the triode region "on" resistance expression:

$$R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L}\left(v_{GS} - V_{TH}\right)} \qquad (2\text{-}1)$$

W2-3. From the slope $\mu_n C_{ox} \frac{W}{L}$, determine the value of mobility μ_n. Use your value of C_{ox} from Lab 1 and the W/L = 350/10 for the MC14007.

W2-4. Using your parameters from W2-2, plot the prediction of the MOSFET R_{on} model on the same axes with your measured data from part L2-2. How well does the model predict the measured data?

P-Channel MOSFET

W2-5. Plot R_{on} as a function of v_{SG}.

W2-6. Plot 1/ R_{on} as a function of v_{SG}. Using this plot, extract the slope $\mu_p C_{ox} \frac{W}{L}$, and the x-intercept (which will be -V_{TH} , the negative of the p-channel threshold voltage) for the triode region "on" resistance expression:

$$R_{on} = \frac{1}{\mu_p C_{ox} \frac{W}{L}\left(v_{SG} - \left(-V_{TH}\right)\right)} \qquad (2\text{-}1)$$

W2-7. From the slope $\mu_p C_{ox} \frac{W}{L}$, determine the value of mobility μ_p. Use your value of C_{ox} from Lab 1 and the W/L = 900/10 for the MC14007.

W2-8. Using your parameters from W2-6, plot the prediction of the MOSFET R_{on} model on the same axes with your measured data from part L2-3. How well does the model predict the measured data?

NOTE: The above procedure can be considerably simplified by using the MATLAB file `Ronplot.m`, available from the course website. Look at the source code to see where to put in your measurements. Your plots will look something like Figure L2-4 below.

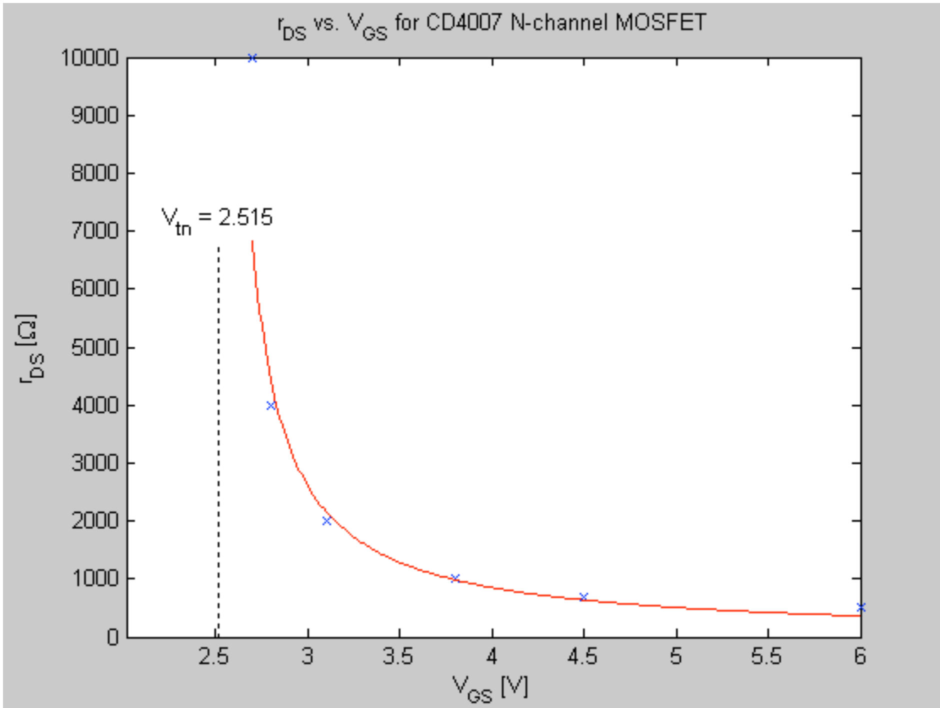

Fig. L2-4

Note that it will not be possible to find one set of parameters that captures the behavior of all the data points! This is a recurring theme in MOS modeling: simple models with few parameters are OK for understanding approximate behavior, but obscure the detail necessary for very accurate device modeling.