

Başkent University
Department of Electrical and Electronics Engineering
EEM 311 Electronics II
Experiment V

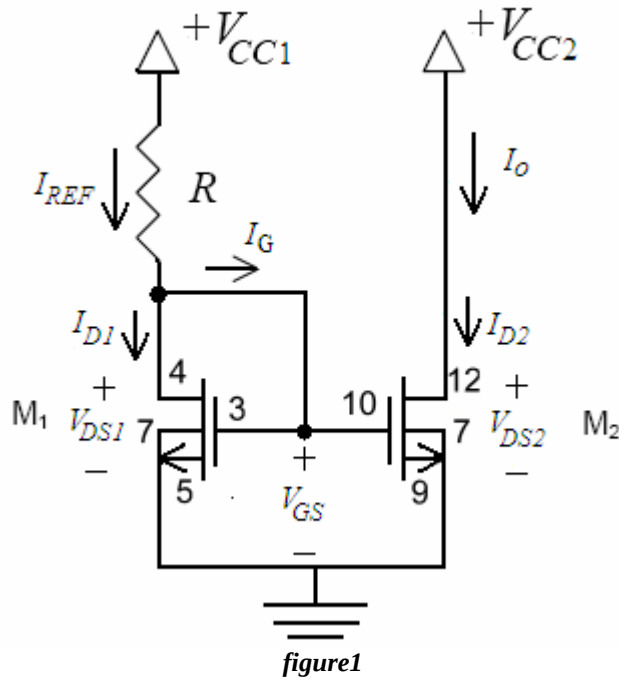
MOSFET Current Mirror

Aim:

The aim of this experiment is to observe the characteristics of the current mirror and to understand the usage areas of this current source.

Theory :

The current mirror circuit represents a fundamental building block in electronic circuit design. The strategy invoked in a current mirror is to set a desired current, I_{REF} , in one side and have that current mirrored through another transistor. **Current mirrors are used in circuit design so one can set a specific current without disturbing the circuitry biased by using this current source.**



A current mirror is shown in Fig.1. The analysis of current mirror begins by remembering that gate currents of both MOSFET's are zero. Notice that I_{REF} is equal to drain current of M1 and the I_o is equal to the drain current of M2, since transistor M1 and M2 have the exact same V_{GS} , then the two transistors conduct the almost the same amount of drain current. Hence $I_{REF} \approx I_o$. This assumes the transistors are "matched". When transistors are matched, then all their parameters are equal (i.e. μ_n , C_{ox} , W/L etc.).

Note that M1 is a diode-connected transistor which guarantees that it operates in saturation, as long as the gate voltage lies at least a threshold voltage above ground. The idea is that R is chosen to establish the desired reference current in M1, and then M2 simply mirrors this current exactly, as M1 and M2 have identical effective gate-source voltages (i.e., $V_{GS} - V_t$ is identical for both).

Analysis of this current mirror leads to :

$$V_{CC1} - I_{REF} R = V_{GS}$$

Reference current is ;

$$I_{D1} = I_{REF} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS1})$$

where $V_{DS1} = V_{GS}$.

Output current is :

$$I_{D2} = I_o = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS2})$$

Assumed matched devices and substituting $(V_{GS} - V_t)^2$

$$I_o = I_{REF} \frac{(1 + \lambda V_{DS2})}{(1 + \lambda V_{DS1})} \cong I_{REF}$$

For equal values of V_{DS} the output current is identical to the reference current. **Unfortunately in most circuit applications, $V_{DS1} \neq V_{DS2}$ therefore a slight mismatch exists between the output current and the reference current.**

In IC design, one has the additional benefit of being able to scale the reference current by choosing M2 to have a larger gate aspect ratio (W/L) than the reference. If the gate aspect ratio of M2 $(W/L)_2$ is 5 times the gate aspect ratio of the M1 $(W/L)_1$ then the above equation becomes ;

$$I_o = I_{REF} \frac{(W/L)_2}{(W/L)_1} \frac{(1 + \lambda V_{DS2})}{(1 + \lambda V_{DS1})} = 5 I_{REF} \frac{(1 + \lambda V_{DS2})}{(1 + \lambda V_{DS1})} \cong 5 I_{REF}$$

The output resistance

The output current I_o vary with the v_{DS} . Thus the current source appears to have a resistive component associated with it. This resistance is called **output resistance** of current mirror and it is equal to ;

$$R_o = \left(\frac{\partial v_o}{\partial i_o} \right)_{Q-point} = \frac{(1 + \lambda V_{DS})}{\lambda I_o}$$

where $v_o = v_{DS2}$ and $i_o = I_o$

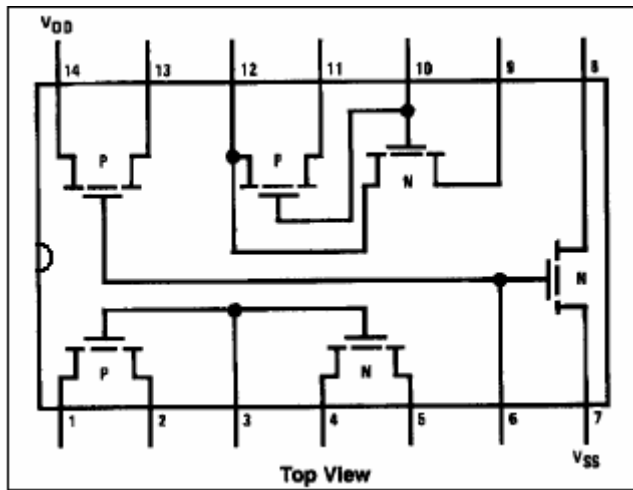
Preliminary Work:

Review the sections 4.10 from the Text Book.

In laboratory you will construct the circuit in Fig.1 using the MOSFET Chip CD4007 and following values ;

V_{CC1}	V_{CC2}	R
5 V	5 V	1 k Ω

The NMOS has $\mu_0 C_{ox} = 166.67 \mu A/V^2$, $W/L=3$ and $V_T = 1.45V$. Assume $V_A = 1/\lambda = 100V$. (You can download data sheet [CD4007C.pdf](#) from course web page). The Pin Diagram of the CD4007 Chip is in Fig.2.



Top View
figure2

Reference:

[1] The values given for the $\mu_0 C_{ox}(W/L)$ and V_T found using the measured data on the CD4007 chip were provided courtesy of Dr. David M. Binkley, Associate Professor at the University of North Carolina at Charlotte and Clark Hopper M.S, R.A. and Harold Hearne M.S., R. A. both also at the University of North Carolina at Charlotte.

- Make the DC analysis of the circuit given in the Fig.1;
 - Find the Q points of the NMOS transistors (I_D and V_{DS}) and their operation region
 - Find the reference current I_{REF} and output current I_O .
 - Find the output resistance.
- Simulate the current mirror using PSPICE. You will need to use a model for the CD4007 transistor. The models can be found in CD4007.LIB library.
 - Construct your circuit in Fig.1 in Pspice
 - Bias simulation. Simulate the circuit of Fig.1. Do a BIAS simulation and find the **DC voltages at each node (V_D , V_G ,)**, **current I_D** of the both transistor and the **reference current I_{REF} and output current I_O** . Compare the results with the one you calculated in preliminary work part1.
 - Next, do a DC Sweep simulation. Do a DC Sweep simulation and obtain a **V_{CC2} versus I_O and I_{REF}** on same graph where V_{CC2} is the voltage of the voltage source, feeding the transistor M2. Obtain the graph for V_{CC2} range 0V-8V. Comment on the relation between how the I_O changes with the V_{CC2} (V_{DS2}).
 - Summarize the **simulation results in table** in table form and hand it in together with the calculations and the **simulation print-outs**. Label each graph clearly.

Experimental Work:

You will be using CD4007 MOSFET array as in this lab. This array contains three NMOS and three PMOS transistors as shown in Fig.5. Again, the key point to remember is that the bulk (or substrates) of all NMOS transistors are connected to the VSS (pin 7) and all PMOS substrates are connected to VDD (pin 14). When using this array pin 7 should be connected to the most negative supply voltage or to the source of the transistor. Pin 14 is the substrate of the PMOS and must be connected to the most positive supply voltage in the circuit!

CD4007 MOSFET array should not be connected to circuits with the power on because high transient voltages may cause permanent damage. Therefore, do not apply input signals until you have connected PIN 7 and 14; otherwise, serious damage to the device could result.

It should be mentioned that the transistor characteristics of CD4007 could vary considerably from chip to chip. The transistors may come from a different batch, what can explain why the threshold voltage, the transconductance parameter and the output resistance is different from the one used in the hand calculations and Spice simulation.

Precaution: MOSFET transistors are very susceptible to breakdown due to electrostatic discharge. It is recommended that you always ground yourself before picking up the MOSFET chip. Do not touch any of the pins of the chip.

Note: Use jumper wires as possible as short on your board to connect the pins of the transistors.

Before constructing the circuit,

- Verify the values of the resistors that you are going to use by measuring their resistances with a multimeter. Make sure that all resistors are within 2% of their marked values. This will assure that your current measurements are accurate
- Prepare the power supply for V_{CC1} and V_{CC2} to ensure a DC voltages of 5V.

Construct the current mirror circuit using the values indicated in the preliminary work section.

Note: Always turn on the DC power supply before applying the AC signal. Always turn off the AC signal before turning off the DC power supply.

1. Measure the voltages and the currents that you calculated in your preliminary work.

$$V_{D1} =$$

$$V_{G1} =$$

$$I_{D1} =$$

$$I_{REF} =$$

$$V_{D2} =$$

$$V_{G1} =$$

$$I_{D1} =$$

$$I_O =$$

2. Measure the current I_O by changing the V_{CC2} , which is equal to V_{DS2} , from 0V to 8V with the increments at the following table. Draw I_O - V_{CC2} on a graph paper. Why is the output current decreasing with decreasing output voltage for small voltages? (**Hint:** what is the region of MOSFET)

$V_{CC2}=V_{DS} (v_O)$	$I_O (i_O)$
0V	
0.25V	
0.5V	
0.75V	
1V	
1.25V	
1.5V	
1.75V	
2V	
2.25V	
2.5V	
2.75V	
3V	
3.25V	
3.5V	
3.75V	
4V	
4.5V	
5V	
5.5V	
6V	
6.5V	
7V	
8V	

3. Estimate the **output resistance** of the current mirror: Adjust the supply voltage V_{CC2} to 4V. Measure and record the supply voltage and output current in following Table. Adjust the supply voltage V_{CC2} to 6V. Measure and record the supply voltage and output current in following Table. What does this resistance represent?

$V_{CC2}=V_{DS2} (v_O)$	$I_O (i_O)$

$$R_o = \left(\frac{\partial v_O}{\partial i_O} \right) =$$

Experiment Instruments: • Breadboard • Multimeter • DC Power Source	Experiment Components: 1 CD4007C Chip 1 1 kΩ
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Experiment Results

Part1	$V_{D1} =$ $V_{G1} =$ $I_{D1} =$ $I_{REF} =$	$V_{D2} =$ $V_{G1} =$ $I_{D1} =$ $I_O =$	
Part2			
Part3	$R_O =$		

Student Name :

Number :

Signature.....