0.0.1 First Current Mirror Circuit

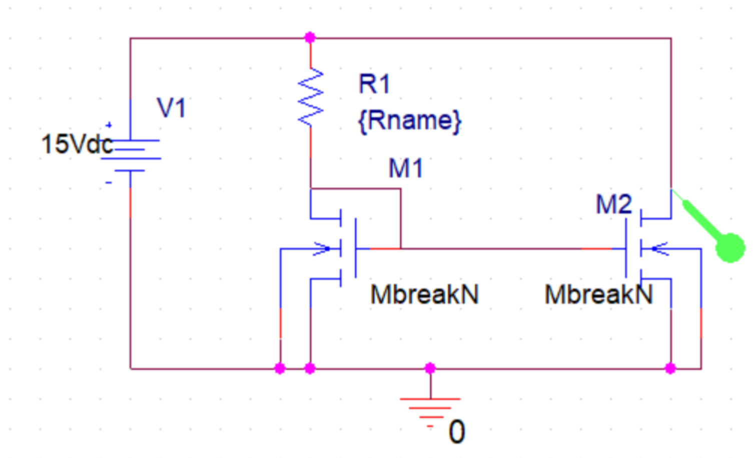

Figure 1: First Current Mirror Circuit

Assume transistors M_1 and M_2 in figure (1) are identical. Because M_1 is a diode-connected MOSFET, if $V_{DS} = V_{GS} >= V_T$, then M_1 operates in saturation. If R_1 is sufficiently small, then V_R can be small enough that $V_{DS} >= V_T$. M_1's drain current shall be called i_{ref}, and M_2's i_{out}.

Because the gates of M_1 and M_2 are connected and both of their sources are grounded, V_{GS} is the same for each. Since M_1 and M_2 are identical transistors, their V_T values are identical as well. So, if current can flow through M_1's drain, then M_2 must also be active because $V_{GS} >= V_T$ in both cases. M_2's V_{DS} certainly exceeds M_1's V_{DS} since M_2's drain is directly connected to the supply voltage rather than an intermediary resistor. Since M_1 is in saturation, $V_{DS} >= V_{GS} - V_T$ is the condition for saturation, and M_2's V_{DS} exceeds M_1's V_{DS}, then M_2 must also be in saturation.

Since both transistors are in saturation, have the same V_{GS} value, and have identical structures, the following must be true:

$$\frac{i_{ref}}{i_{out}} = \frac{\frac{k_n}{2}(V_{GS} - V_T)^2}{\frac{k_n}{2}(V_{GS} - V_T)^2} = 1 \rightarrow i_{ref} = i_{out} \tag{1}$$

This circuit is called a "current mirror" because of the property demonstrated in equation (1). Given any input current i_{ref}, the output current i_{out} must be the same. Changing the dimensions of the transistors relative to one another can alter the output current by a constant factor (source 1).

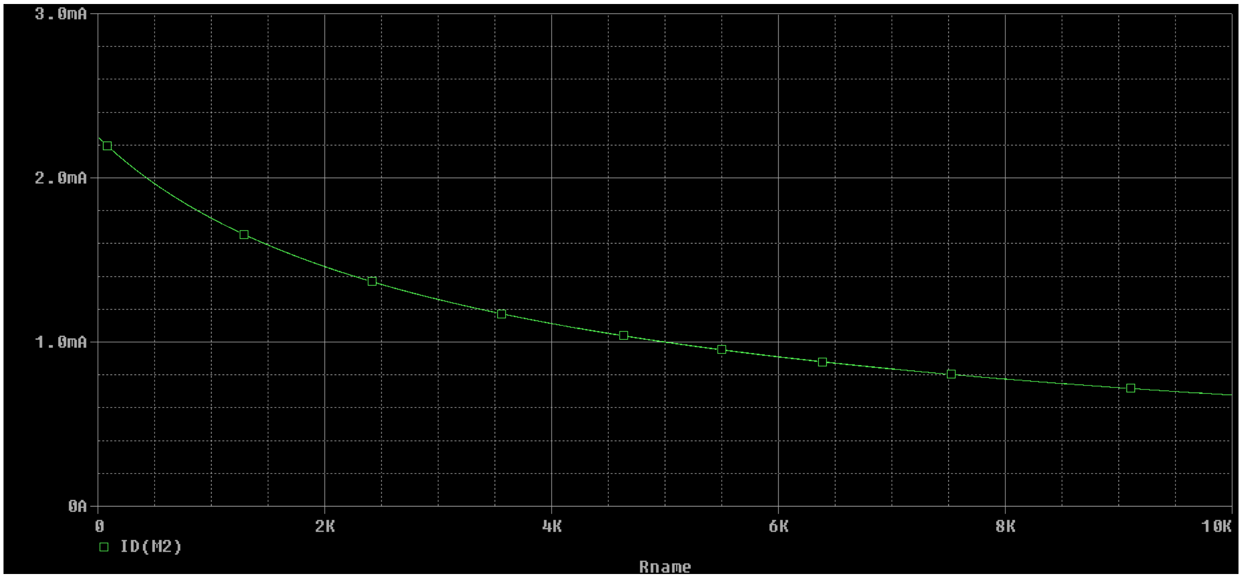

Figure 2: i_{out} versus R_1 for Current Mirror in Figure (1)

In the extreme case of an open circuit in the place of R_1, the open circuit absorbs the supply voltage, leaving none for M_1. So, $V_{DS} = V_{GS} = 0$. For n-channel enhancement-type MOSFETs, $V_T > 0$ (confirm detail with a reference). Therefore, $V_{GS} < V_T$. So, M_1 is operating in the cutoff region, and no current flows.

On the other hand, if R_1 is a short and $V_T < V_{DD}$ (as it should be), where V_{DD} is the supply voltage, then $V_{GS} = V_{DD} > V_T$. Thus, M_1 is enabled. Because M_1 is diode-connected, it operates in the saturation region. Thus, as R_1 is increased, it absorbs more and more of the supply voltage V_{DD} until M_1 operates in cutoff mode. Thus, the i_{ref} versus R_1 curve should be downward sloping.

0.0.2 Second Current Mirror Circuit

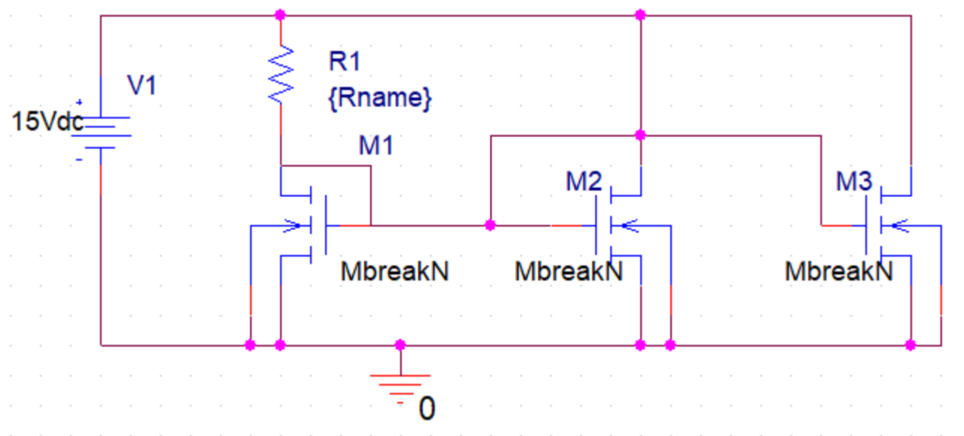

Figure 3: Second Current Mirror Circuit

Consider the transistor M_1. $V_G = 15\text{V}$ and $V_S = 0\text{V}$. Therefore, $V_{GS,M1}$ is likely much larger than $V_{T,M1}$. As a result, the transistor is active. Because M_1 is active and is diode-connected, M_1 must be in saturation. By the same arguments, M_2 and M_3 are also operating in saturation.

Both terminals of R_1 have the same potential due to the short path leading from the supply voltage lane to M_1's drain terminal. So, by Ohm's Law, no current flows through the resistor R_1. So, the circuit's operation is technically identical regardless of the value of R_1 in place. R_1 always acts as a short. Therefore, the plots of drain current versus R_1 should be constant for any of the transistors.

Because M_1 is in saturation, $i_{D,M1} = \frac{k_n}{2}(V_{GS,M1} - V_{T,M1})^2$. Because $V_{GS,M1}$ is so large in comparison to $V_{T,M1}$ due to M_1's terminals being directly connected to the supply voltage lane, $i_{D,M1}$ should not be 0mA. M_1 draws this current from the supply voltage through the short path to its gate to its drain, bypassing the resistor R_1.

All of the transistors are identical in the sense that the voltages applied at the gate, source, and drain are the same. Thus, the drain current through each transistor is the same. So, the drain current through M_1 should be significant and constant when varied with R_1. The sum of the drain currents through M_2 and M_3 should also be double the drain current through M_1 and constant when varied with R_1. This is because the drain current curves are the same for M_2 and M_3 as they are for M_1. Therefore, adding them together simply doubles the constant drain current for all R_1 values.

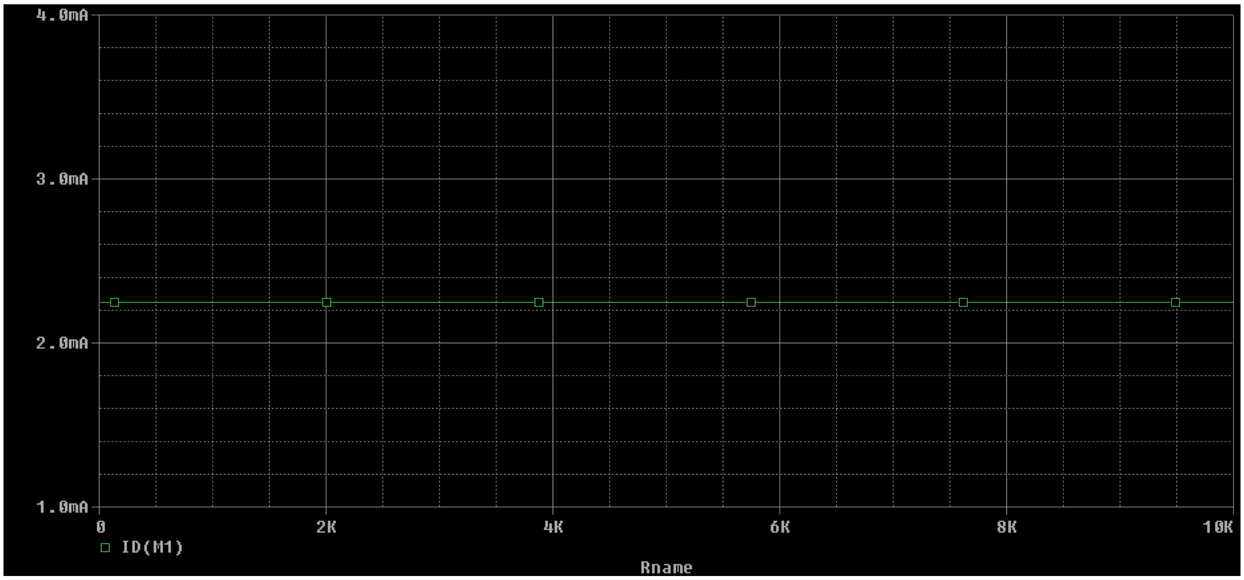

Figure 4: $i_{D,M1}$ versus R_1

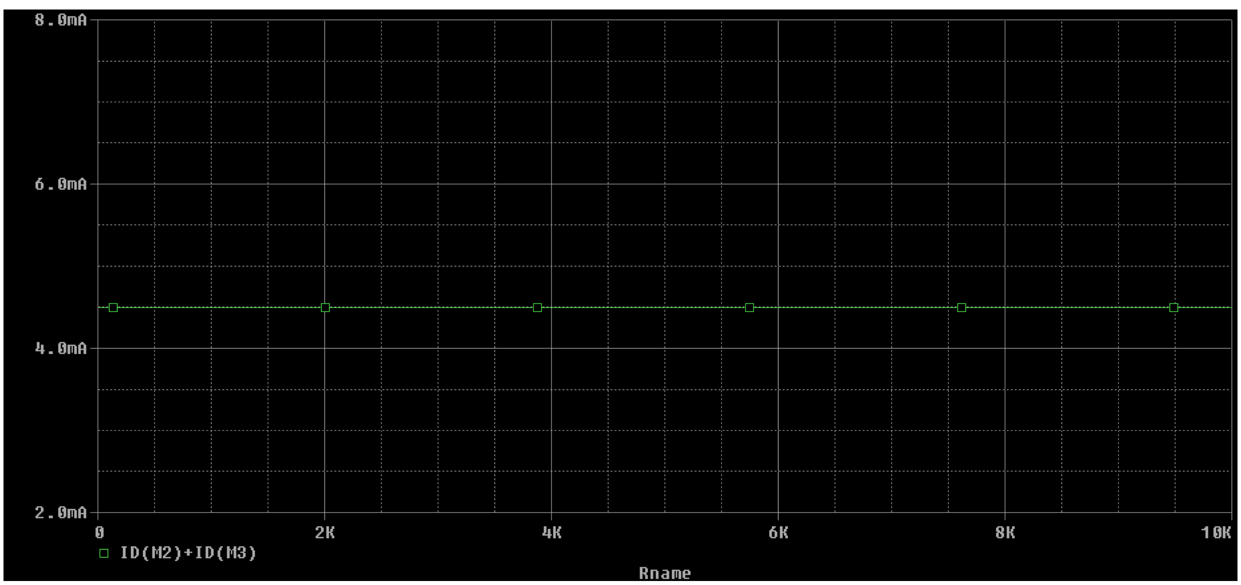

Figure 5: $i_{D,M2} + i_{D,M3}$ versus R_1

The results of the simulation are consistent with this analysis. In figure (4), the current value is essentially 2.25mA, a significant current value through the drain of M_1. In figure (5), the current value is nearly twice that, approximately

4.5mA. In both cases, the drain currents are not functions of the resistance R_1.