Special Problem 4.5-3

In the circuit below, Q_1 has K =1.0 mA/V^2 and V_{t1} = **1.0** V.

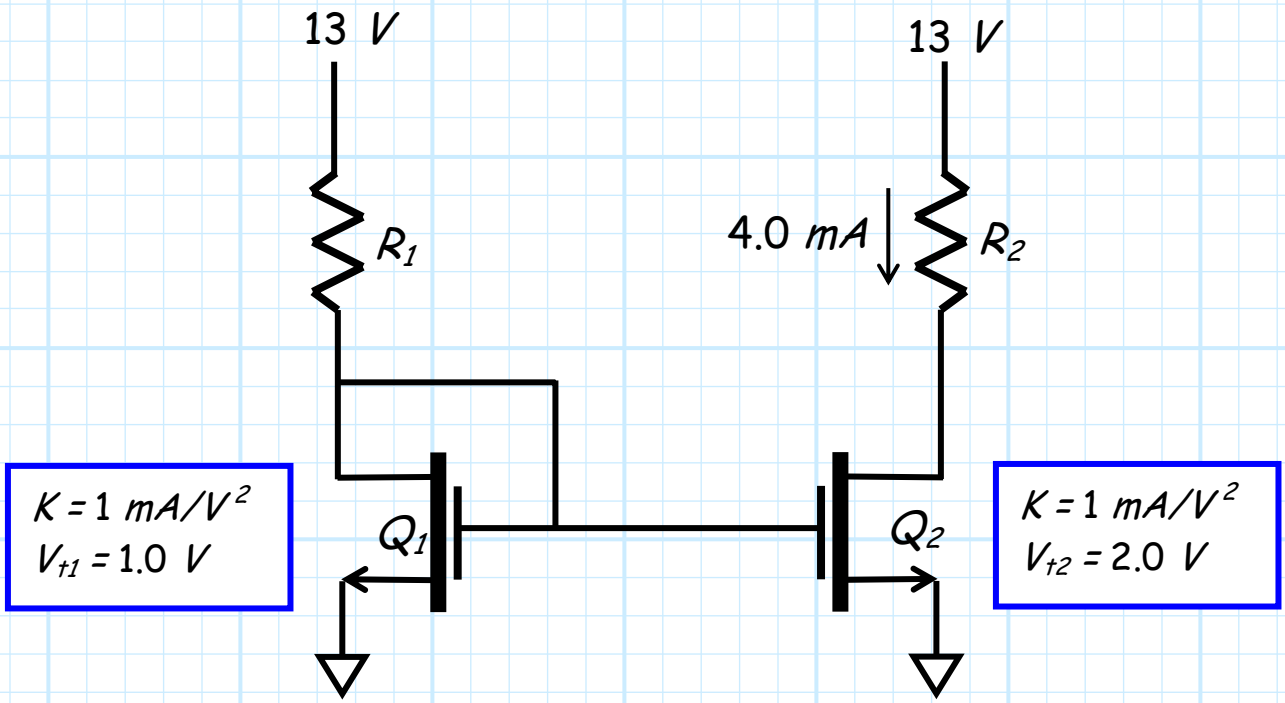
The transistor Q_2 likewise has K = 1 mA/V^2, **but** has a threshold voltage of V_{t2} = **2.0** V.

In other words Q_1 and Q_2 are **not** identical!

The resistor R_2 has been selected such that Q_2 is in saturation.

1) Determine R_1 (note I said R_1 !) so that the **drain current** of Q_2 (note I said Q_2 !) **is 4.0 mA**.

2) What is the **largest** possible value of resistor R_2 so that Q_2 remains in **saturation**?



Solution

1) If Q_2 (note I said Q_2!) is in **saturation**, then:

$$I_{D2} = K\left(V_{GS2} - V_{t2}\right)^2 \quad \Rightarrow \quad V_{GS2} = \sqrt{\frac{I_{D2}}{K}} + V_{t2} = \sqrt{\frac{4}{1}} + 2 = 4.0\,V$$

Since the **source** terminal is at **ground** potential, we find that the **DC gate voltage** of Q_2 is:

$$V_{G2} = V_{GS2} + V_{S2} = 4 + 0 = 4.0\,V$$

Note the two gate terminals of each transistor are **connected,** so that:

$$V_{G1} = V_{G2} = 4.0\,V$$

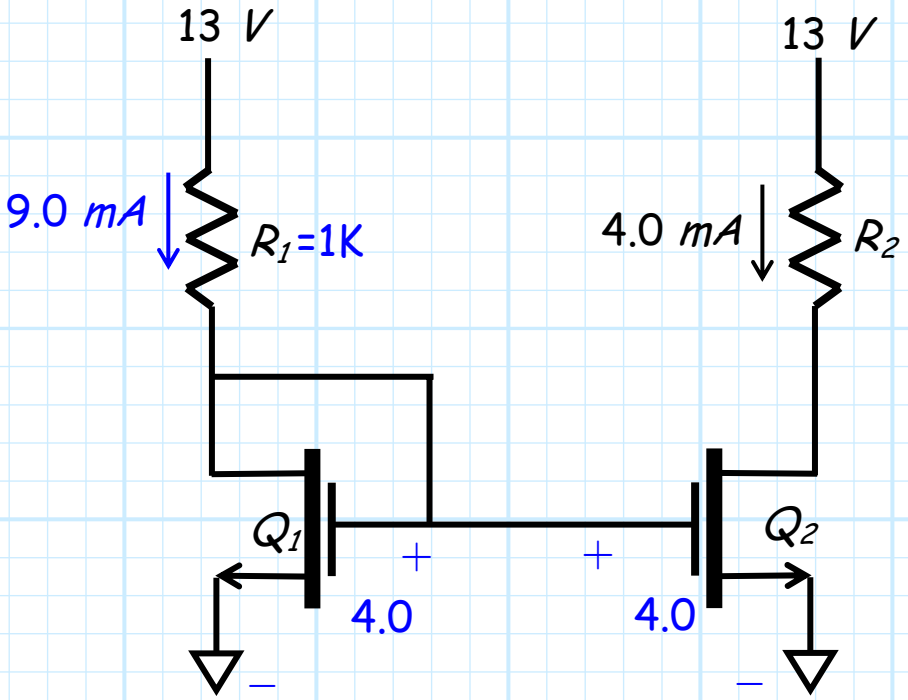
Since the source terminal of $\boldsymbol{Q_1}$ is likewise at ground potential, we can conclude that:

$$V_{GS1} = V_{G1} - V_{S1} = 4 - 0 = 4.0\,V$$

So, **if** MOSFET Q_1 is in saturation, then:

$$I_{D1} = K\left(V_{GS1} - V_{t1}\right)^2 = 1.0\left(4.0 - 1.0\right)^2 = 9.0\ mA$$

Note this is **not** (I said **not**!) equal to drain current $I_{D2} = 4\ mA$!!



Since the **gate** and **source** terminals of Q_1 are connected, we find:

$$V_{S1} = V_{G1} = 4.0\,V$$

And so from **Ohm's Law**:

$$R_1 = \frac{13 - V_{S1}}{I_{D1}} = \frac{13 - 4}{9} = \underline{\underline{1\,K\Omega}}$$

Finally, we **verify** that the MOSFET Q_1 **is** in saturation:

$$V_{DS1} = V_{D1} - V_{S1} = 4 - 0 = 4 > V_{GS1} - V_{t1} = 3.0$$

2) MOSFET Q_2 **is** in saturation if:

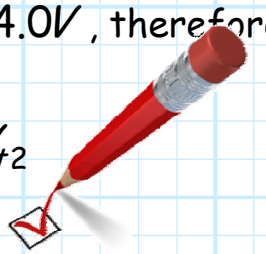
$$V_{GS2} > V_{t2}$$

And:

$$V_{DS2} > V_{GS2} - V_{t2}$$

For the **first** condition, we know that $V_{GS2} = 4.0V$, therefore:

$$V_{GS2} = 4.0 > 2.0 = V_{t2}$$



Thus:

$$V_{GS2} - V_{t2} = 4 - 2 = 2.0\,V$$

From **KVL**, we find:

$$V_{DS2} = 13.0 - 4R_2$$

So that for MOSFET Q_2 to be in **saturation**:

$$V_{DS2} > V_{GS2} - V_{t2} \quad \Rightarrow \quad 13.0 - 4R_2 > 2.0$$

Meaning:

$$R_2 \leq \frac{13.0 - 2.0}{4} = \frac{11}{4} = \underline{\underline{2.75\,K\Omega}}$$