Large-Signal Operation of the MOSFET Differential Pair

Consider now the **MOSFET differential pair**:

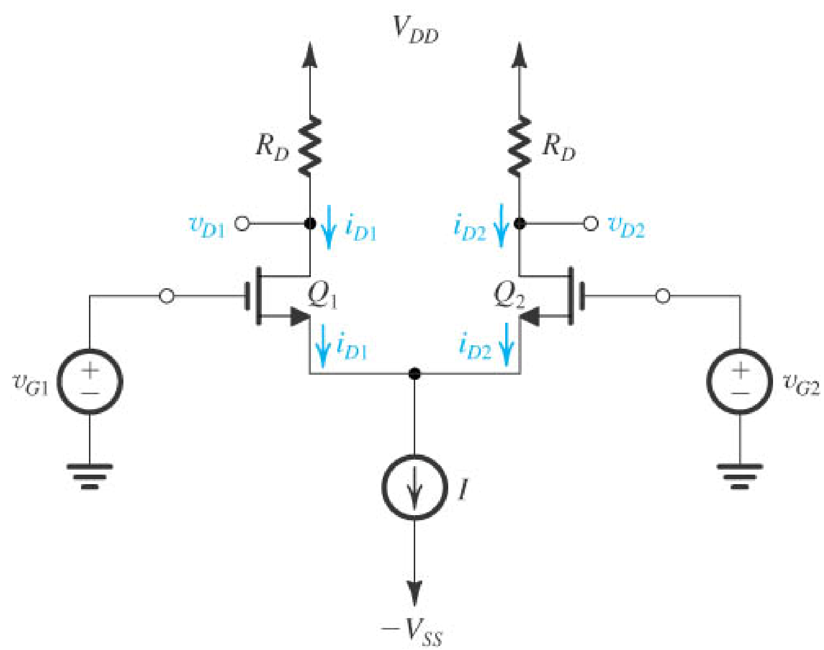
Note:

$$v_{S1} = v_{S2} = v_S$$

and

$$i_{D1} + i_{D2} = I$$

Figure 7.1 *The basic MOS differential-pair*



If each of the transistors are in **saturation**, then each drain current must be:

$$i_{D1} = K\left(v_{GS1} - V_t\right)^2 \quad \text{and} \quad i_{D2} = K\left(v_{GS2} - V_t\right)^2$$

where

$$v_{GS1} = v_1 - v_S \quad \text{and} \quad v_{GS2} = v_2 - v_S$$

Therefore, we define the **differential input voltage** as:

$$v_{GS1} - v_{GS2} = v_1 - v_2 \doteq v_D$$

Now, doing just a **bunch** of algebra, we can combine all of the above equations to find the **drain current** for each transistor:

$$i_{D1} = \frac{I}{2} + \sqrt{\frac{K\,I}{2}}\, v_D \sqrt{1 - \frac{K}{2I} v_D^2}$$

$$i_{D2} = \frac{I}{2} - \sqrt{\frac{K\,I}{2}}\, v_D \sqrt{1 - \frac{K}{2I} v_D^2}$$

Note this result shows that the drain current of each transistor is dependent ***only*** *on the* ***differential*** *signal $v_D = v_1 - v_2$ —the drain currents are* ***independent*** *of the* ***common-mode*** *(i.e., average) input signal!*

Note then, that if:

$v_D = 0$

Both transistors will be in saturation and will share the available current **evenly**:

$$i_{D1} = i_{D2} = \frac{I}{2}$$

$v_D < -\sqrt{\frac{2I}{K}}$

For this case, Q_1 is in **cutoff** and we find that:

$$i_{D1} = 0$$

whereas transistor Q_2 remains in **saturation** and "takes" all the available current:

$$i_{D2} = I$$

$v_D > +\sqrt{\frac{2I}{K}}$

For this case, Q_2 is now in **cutoff** and we find that:

$$i_{D2} = 0$$

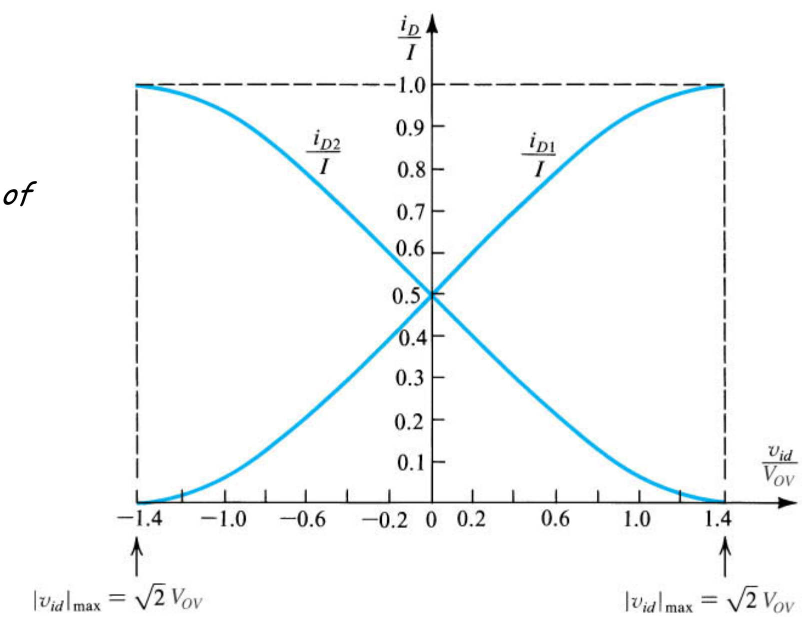
whereas Q_1 is the transistor that remains in **saturation** and "takes" all the available current:

$$i_{D1} = I$$

$$-\sqrt{\frac{2I}{K}} < v_D < +\sqrt{\frac{2I}{K}}$$

In this region, **both** transistors are in **saturation**, and the drain current through each transistor is described using the two equations given earlier. Plotting these equations, we find:

Figure 7.6 *Normalized plots of the currents in a MOSFET differential pair.*



Note that the derivates (i.e., **slopes**) of these curves are approximately **constant** in the center region of the plot (i.e., the region where $|v_D|$ is small).

This should not surprise us! If we look at the two equations for drain current:

$$i_{D1} = \frac{I}{2} + \sqrt{\frac{K\,I}{2}}\, v_D \sqrt{1 - \frac{K}{2I} v_D^2}$$

$$i_{D2} = \frac{I}{2} - \sqrt{\frac{K\,I}{2}}\, v_D \sqrt{1 - \frac{K}{2I} v_D^2}$$

we find that the last product term will approximately equal **one**:

$$\sqrt{1 - \frac{K}{2I} v_D^2} \approx 1 \qquad \text{when} \qquad |v_D| \ll \sqrt{\frac{2I}{K}}$$

Thus, we can **approximate** the drain currents for the case when the differential voltage $|v_D| \ll \sqrt{2I/K}$ as:

$$i_{D1} \simeq \frac{I}{2} + \sqrt{\frac{K\,I}{2}}\, v_D$$

$$i_{D2} \simeq \frac{I}{2} - \sqrt{\frac{K\,I}{2}}\, v_D$$

Now we can find the slope of the curves above by taking the **derivative** with respect to differential voltage v_D:

$$\frac{d\,i_{D1}}{d\,v_D} \simeq +\sqrt{\frac{K\,I}{2}}$$

$$\frac{d\,i_{D2}}{d\,v_D} \simeq -\sqrt{\frac{K\,I}{2}}$$

The slopes (derivatives) are approximately **constant** for small v_D–just as we **observed** they were in the plots above!

Q: *These **derivative** values likewise tell us something very important about the behavior of the MOSFET differential pair, do you know what these derivatives tell us ?*

A: