DC Bias of FETs

∴ BJTs have the distinct convenience of $V_{BE} \sim 0.7V$ [or -0.7 if PNP] for Si transistors

∴ FETs, on the other hand, have a relationship between V_{GS} and I_D of either:

Shockley's equation!

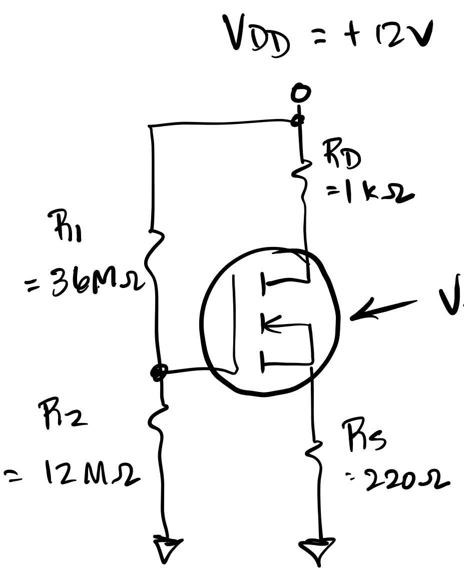
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2 \quad \text{[JFET and depletion MOS]}$$

or

$$I_D = K\left(V_{GS} - V_t\right)^2 \quad \text{[enhancement MOS]}$$

∴ this makes DC analysis awkward!

ex:



$V_t = 1.2V$, $K = 10\ mA/V^2$

note: we can have <u>very large</u> gate resistors due to no gate current!

∴ we can easily determine V_G:

$$V_G = 12\left[\frac{12M}{12M + 36M}\right] = 3V$$

∴ but since we don't know V_{GS} yet, we can't determine V_S to then determine I_S, which we could then use to determine V_{GS} !!! Oh no! (rats...)

∴ fortunately, Very Smart People have recognized that the parabolic locus formulae for both types of FETs can be solved for V_{GS} as a quadratic, knowing

$$V_S = I_S R_S = I_D R_S$$

no gate current!

$$V_{GS}\big|_{n\text{-channel}} = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

$$V_{GS}\big|_{p\text{-channel}} = \frac{+b - \sqrt{b^2 - 4ac}}{2a}$$

all FETs

for JFET and depletion MOSFET:

$$a = \frac{I_{DSS} R_S}{V_{GS(OFF)}^2} \qquad b = \frac{2 I_{DSS} R_S}{|V_{GS(OFF)}|} + 1 \qquad c = I_{DSS} R_S - |V_G|$$

for enhancement MOSFET:

$$a = K R_S \qquad b = 1 - 2 K R_S |V_t| \qquad c = K R_S V_t^2 - |V_G|$$

∴ So for this n-channel enhancement-type MOSFET example:

$$a = \underset{\substack{\uparrow \\ mA/V^2}}{10} \cdot \underset{\substack{\uparrow \\ k\Omega}}{0.220} = 2.2$$

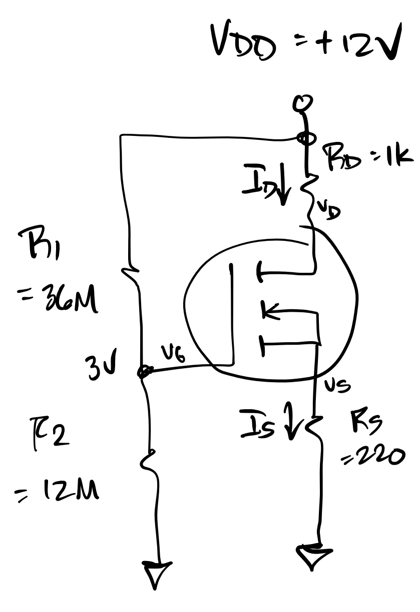
$$b = 1 - 2 \cdot 10 \cdot .22 \, |1.2| = -4.28$$

$$c = 10 \cdot .22 \cdot 1.2^2 - 3 = 0.168$$

$$V_{GS}\Big|_n = \frac{-(-4.28) + \sqrt{4.28^2 - 4 \cdot 2.2 \cdot 0.168}}{2 \cdot 2.2}$$

$$V_{GS} = 1.905\,V$$

∴ we may now proceed with D.C. analysis.



$$V_{GS} = V_G - V_S$$

$$\rightarrow V_S = V_G - V_{GS}$$

$$= 3 - 1.905 = 1.095\,V$$

$$I_S = \frac{V_S - 0}{R_S} = \frac{1.095}{.220}$$

$$I_S = 4.977 \text{ mA} = I_D$$

∴ let's check this with the original equation:

$$I_D = K\left(V_{GS} - V_t\right)^2$$

$$= 10\left(1.905 - 1.2\right)^2 = 4.97\,mA \quad \text{(yep!)}$$

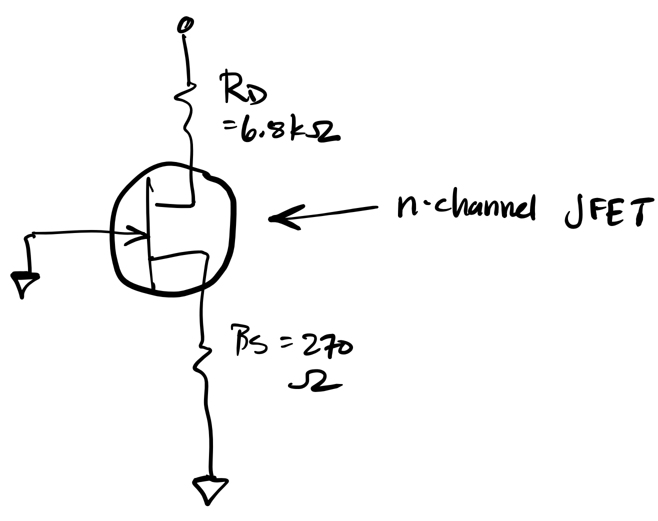
$$V_D = V_{DD} - R_D I_D = 12 - \underset{k\Omega}{1} \cdot \underset{mA}{4.977} = 7.023\,V$$

$$V_{DS} = V_D - V_S = 7.023 - 1.095 = 5.928\,V$$ ← yes, active region [$> V_{D(sat)} = V_{GS} - V_t$]

$$P_{diss} = V_{DS} \cdot I_D = 5.928 \cdot 4.977 = 29.50\,mW$$

ex:

$V_{DD} = +36V$



$I_{DSS} = 9mA$

$V_{GS(OFF)} = -1.0V$

- note that this n-channel JFET doesn't have a voltage divider at its input!

- that's because JFETs always have a negative V_{GS}; so we can set $V_G = 0$ by grounding it, and the drain current will drop a positive voltage across R_S, creating a negative V_{GS}; nice!!!

  - this is called self-bias, as opposed to voltage divider bias

- using eqn's for JFET/depletion-mode MOSFET:

$$a = \frac{I_{DSS} R_S}{V_{GS(OFF)}^2} = \frac{9 \cdot .270}{1^2} = \underline{2.43}$$

$$b = \frac{2 I_{DSS} R_S}{|V_{GS(OFF)}|} + 1 = \frac{2 \cdot 9 \cdot .270}{|1.0|} + 1 = \underline{5.86}$$

$$c = I_{DSS} R_S - |V_G| = 9 \cdot .270 - 0 = \underline{2.43}$$

$$V_{GS}\Big|_n = \frac{-b + \sqrt{b^2 - 4ac}}{2a} = \frac{-5.86 + \sqrt{5.86^2 - 4 \cdot 2.43 \cdot 2.43}}{2 \cdot 2.43}$$

$$\underline{V_{GS} = -0.5321 \text{ V}}$$

$V_S = 0 - {}^{-}0.5321 = +0.5321\ V$

$I_S = \frac{V_S - 0}{R} = \frac{0.5321}{0.270} = 1.971\ mA = I_D$

-- let's check this with Shockley's Equation:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(OFF)}}\right)^2$$

$$= 9\left(1 - \frac{-0.5321}{-1}\right)^2$$

$I_D = 1.97\ mA$ (yep!)

$V_D = V_{DD} - I_D R_D$

$= 36 - 1.971 \cdot 6.8 = 22.60\ V$

$V_{DS} = V_D - V_S = 22.60 - 1.971 = 20.63V$

$P_{diss} = V_{DS} \cdot I_D = 20.63 \cdot 1.971 = 40.65\ mW$