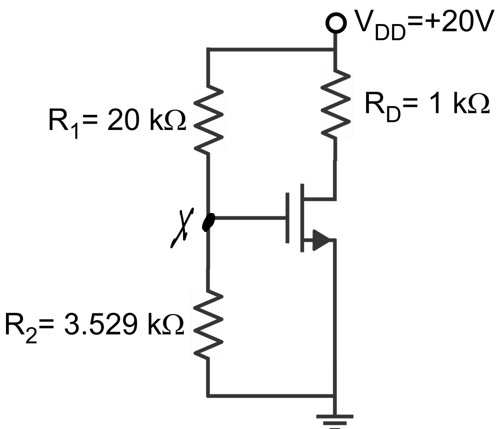
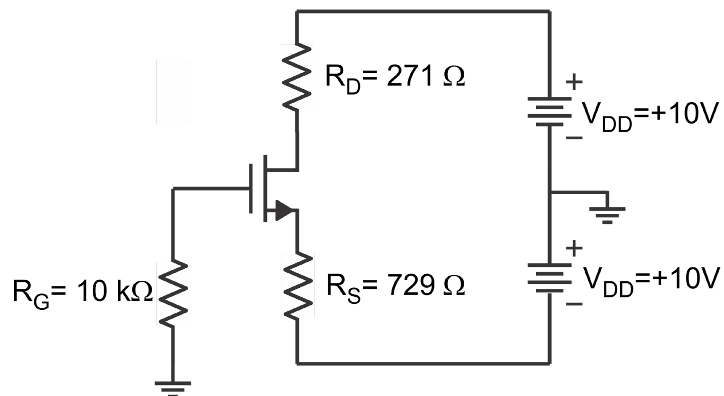
1) For the following four FET circuits, the FET parameters are $\boldsymbol{V_{TN} = 2.6V}$ and $\boldsymbol{k_N = 0.12\ A/V^2}$. For each circuit, the bias point (Q-point) is the same. You may use an online calculator to solve any quadratic equations.

   Find for $\boldsymbol{V_{GS}}$, $\boldsymbol{V_{DS}}$, $\boldsymbol{I_D}$. In all cases, verify that the transistor is "on" and operating in a saturated region.

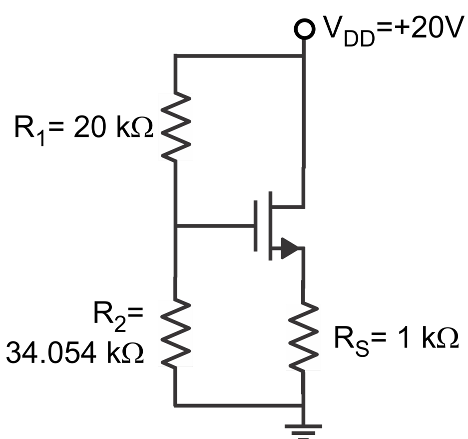
(a)



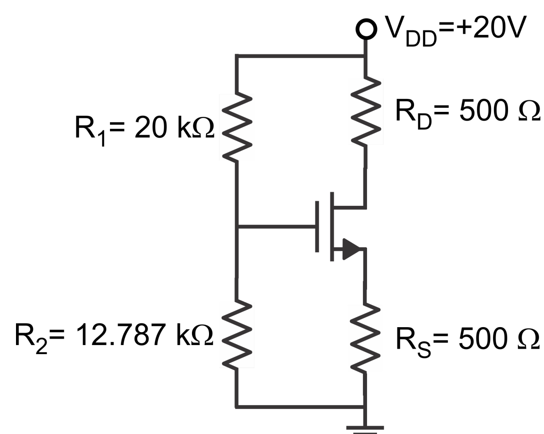
(b)



(c)



(d)



(1)

(a) $V_{DD} = 20V$

$$V_{gs} = \frac{3.529}{3.529 + 20} \times 20 = 2.9997V$$

Assume mosfet is in saturation mode:

$$I_D = \frac{1}{2} k_n [V_{gs} - V_t]^2 = \frac{1}{2} \times 0.12 [2.9997 - 2.6]^2 = 9.58mA$$

$$-V_{DD} + I_D R_D + V_{DS} = 0$$

$$V_{DS} = V_{DD} - I_D R_D = 20 - 9.58 \times 1 = 10.42V$$

$$V_{DS} \geq V_{gs} - V_t$$

$10.42 \geq 2.9997 - 2.6$ $\boxed{\checkmark}$ True

(b) $V_{DD} = 10V$

$$\cancel{I_G R_G}^{0} + V_{gs} + I_D 729 - V_{DD} = 0$$

$$I_D = \frac{10 - V_{gs}}{729}$$

Assume mosfet in saturation

$$I_D = \frac{1}{2} k_n [V_{gs} - V_t]^2$$

$$\frac{I_D - V_{gs}}{729} = \frac{1}{2} \times 0.5 [V_{gs} - 2.6]^2$$

$$\frac{10 - V_{gs}}{729} = 0.06 [V_{gs}^2 + 6.76 + 5.2 V_{gs}]$$

$$10 - V_{gs} = 43.79 V_{gs}^2 + 295.68 - 227.45 V_{gs}$$

$$43.74 V_{gs}^2 - 226.45 V_{gs} + 285.68 = 0$$

$V_{gs} = 3$ ✓ $\qquad V_{gs} = 2.171$

$$I_D = \frac{10-3}{729} = 9.6mA$$

KVL:

$$-V_{DD} + I_D 271 + V_D = 0$$

$$V_D = 10 - 271 \times 9.6$$

$$= 7.39$$

$$V_{DS} = V_D - V_S = 7.39 - (-3) = 10.39V$$

$$V_{DS} \geq V_{gs} - V_t$$

$$10.39 \geq 3 - 2.6$$ ☑ true

(c) $$V_g = \frac{34.054}{34.054+20} \times 20 = 12.59V$$

$$-V_g + V_{gs} + I_D R_s = 0$$

$$-12.59 + V_{gs} + I_D R_s = 0$$

$$\boxed{I_D = \frac{12.59 - V_{gs}}{1k}}$$

Assume saturation

$$I_D = \frac{1}{2} k_n [V_{gs} - V_t]^2$$

$$\frac{12.59 - V_{gs}}{1k} = \frac{1}{2} \times 0.12 [V_{gs}^2 + 6.76 - 5.2 V_{gs}]$$

$$12.59 - V_{gs} = 60V_{gs}^2 - 312V_{gs} + 405.6$$

$$60V_{gs}^2 - 311 V_{gs} + 393.01 = 0$$

$$V_{gs} = 2.99V \qquad V_{gs} = 2.18V$$

$$V_{gs} > V_t$$

$$I_D = \frac{12.59 - 2.99}{1} = 9.6mA$$

$$-V_S + I_D R_S = 0 \Rightarrow V_S = 9.6mA \times 1K = 9.6V$$

$V_{DS} = V_D - V_S = 20 - 9.6 = 10.4V$

$V_{DS} \geq V_{gs} - V_t$

$10.4 \geq 2.99 - 2.6$ $\boxed{\checkmark}$ true

(d) $V_g = \frac{12.787}{12.787 + 20} \times 20 = 7.8V$

KVL:

$-V_g + V_{gs} + I_D 500 = 0$

$I_D = \frac{7.8 - V_{gs}}{500}$

Assume saturation:

$I_D = \frac{1}{2} K_n [V_{gs} - V_t]^2$

$\frac{7.8 - V_{gs}}{500} = \frac{1}{2} \times 0.12 [V_{gs} - 2.6]^2$

$7.8 - V_{gs} = 30 V_{gs}^2 + 202.8 - 156 V_{gs}$

$V_{gs} = 3$ ✓ $\quad V_{gs} = 2.16$

$I_D = \frac{7.8 - 3}{500} = 9.6 mA$

$-V_S + I_D R_S = 0$

$V_S = I_D R_S = 4.8$

$-V_{DD} + 500 I_D + V_{DS} = 0$

$V_{DS} = 20 - 500 \times 9.6mA = 15.2V$

$V_{DS} \geq V_{gs} - V_t$

$10.4 \geq 3 - 2.6$ $\boxed{\checkmark}$ true