Transistor formulas

N-channel JFET ($I_G = 0$, $V_{DS} > 0$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{GS} < V_P$$

in this case we have the following:

$$I_D = 0$$

2. Biased in the ohmic (linear) region if and only if:

$$V_P < V_{GS} < 0$$
$$0 < V_{DS} < V_{GS} - V_P$$

in this case we have the following:

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

3. Biased in the pinch-off (amplification) region if and only if:

$$V_P < V_{GS} < 0$$
$$V_{DS} > V_{GS} - V_P$$

in this case we have the following:

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

N-channel depletion type MOSFET ($I_G = 0$, $V_{DS} > 0$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{GS} < V_P$$

in this case we have the following:

$$I_D = 0$$

2. Biased in the ohmic (linear) region if and only if:

$$V_P < V_{GS}$$
$$0 < V_{DS} < V_{GS} - V_P$$

in this case we have the following:

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

3. Biased in the pinch-off (amplification) region if and only if:

$$V_P < V_{GS}$$
$$V_{DS} > V_{GS} - V_P$$

in this case we have the following:

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

N-channel enhancement type MOSFET ($I_G = 0$, $V_{DS} > 0$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{GS} < V_t$$

   in this case we have the following:

$$I_D = 0$$

2. Biased in the ohmic (linear) region if and only if:

$$V_t < V_{GS}$$
$$0 < V_{DS} < V_{GS} - V_t$$

   in this case we have the following:

$$I_D = K\big(2V_{DS}(V_{GS} - V_t) - V_{DS}^2\big)$$

3. Biased in the pinch-off (amplification) region if and only if:

$$V_t < V_{GS}$$
$$V_{DS} > V_{GS} - V_t$$

   in this case we have the following:

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

P-channel JFET ($I_G = 0$, $V_{SD} > 0$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{SG} < -V_P$$

   in this case we have the following:

$$I_D = 0$$

2. Biased in the ohmic (linear) region if and only if:

$$-V_P < V_{SG} < 0$$
$$0 < V_{SD} < V_{SG} + V_P$$

   in this case we have the following:

$$I_D = I_{DSS}\left(\left(\frac{2V_{SD}}{V_P}\right)\left(\frac{V_{SG}}{V_P} + 1\right) - \left(\frac{V_{SD}}{V_P}\right)^2\right)$$

3. Biased in the pinch-off (amplification) region if and only if:

$$-V_P < V_{SG} < 0$$
$$V_{SD} > V_{SG} + V_P$$

   in this case we have the following:

$$I_D = I_{DSS}\left(1 + \frac{V_{SG}}{V_P}\right)^2$$

P-channel depletion type MOSFET ($I_G = 0$, $V_{SD} > 0$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{SG} < -V_P$$

in this case we have the following:

$$I_D = 0$$

2. Biased in the ohmic (linear) region if and only if:

$$-V_P < V_{SG}$$
$$0 < V_{SD} < V_{SG} + V_P$$

in this case we have the following:

$$I_D = I_{DSS}\left(\left(\frac{2V_{SD}}{V_P}\right)\left(\frac{V_{SG}}{V_P} + 1\right) - \left(\frac{V_{SD}}{V_P}\right)^2\right)$$

3. Biased in the pinch-off (amplification) region if and only if:

$$-V_P < V_{SG}$$
$$V_{SD} > V_{SG} + V_P$$

in this case we have the following:

$$I_D = I_{DSS}\left(1 + \frac{V_{SG}}{V_P}\right)^2$$

P-channel enhancement type MOSFET ($I_G = 0$, $V_{SD} > 0$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{SG} < -V_t$$

in this case we have the following:

$$I_D = 0$$

2. Biased in the ohmic (linear) region if and only if:

$$-V_t < V_{SG}$$
$$0 < V_{SD} < V_{SG} + V_t$$

in this case we have the following:

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

3. Biased in the pinch-off (amplification) region if and only if:

$$-V_t < V_{SG}$$
$$V_{SD} > V_{SG} + V_t$$

in this case we have the following:

$$I_D = K\left(V_{SG} + V_t\right)^2$$

BJT NPN ($V_{CE} > 0$, $I_E = I_B + I_C$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{BE} < 0.7 \text{ volt}$$

   in this case we have the following:

$$I_B = I_C = I_E = 0$$

2. Biased in the saturation region if and only if:

$$0 < I_C < \beta I_B$$

   in this case we have the following:

$$\begin{aligned} V_{BE} &= 0.7 \text{ volt} \\ V_{CE} &= 0.2 \text{ volt} \end{aligned}$$

3. Biased in the active (amplification) region if and only if:

$$\begin{aligned} V_{CE} &> 0.2 \text{ volt} \\ I_B &> 0 \end{aligned}$$

   in this case we have the following:

$$\begin{aligned} V_{BE} &= 0.7 \text{ volt} \\ I_C &= \beta I_B \end{aligned}$$

BJT PNP ($V_{EC} > 0$, $I_E = I_B + I_C$):

1. Biased in the cut-off region (open circuit) if and only if:

$$V_{EB} < 0.7 \text{ volt}$$

   in this case we have the following:

$$I_B = I_C = I_E = 0$$

2. Biased in the saturation region if and only if:

$$0 < I_C < \beta I_B$$

   in this case we have the following:

$$\begin{aligned} V_{EB} &= 0.7 \text{ volt} \\ V_{EC} &= 0.2 \text{ volt} \end{aligned}$$

3. Biased in the active (amplification) region if and only if:

$$\begin{aligned} V_{EC} &> 0.2 \text{ volt} \\ I_B &> 0 \end{aligned}$$

   in this case we have the following:

$$\begin{aligned} V_{EB} &= 0.7 \text{ volt} \\ I_C &= \beta I_B \end{aligned}$$