Lecture 15

Small-Signal Equivalent Circuit for FETs

Output signal from an amplifier using FET can be effectively modulated by small changes of input signal current. In this way it is possible to make small changes from the Q point.

Symbols:
The total quantities: $i_D(t)$, $v_{GS}(t)$
The dc point values: I_{DQ}, V_{GSQ}
The signal $i_d(t)$, $v_{gs}(t)$

$$v_{GS}(t) = V_{GSQ} + v_{gs}(t)$$

$$i_D(t) = I_{DQ} + i_d(t)$$

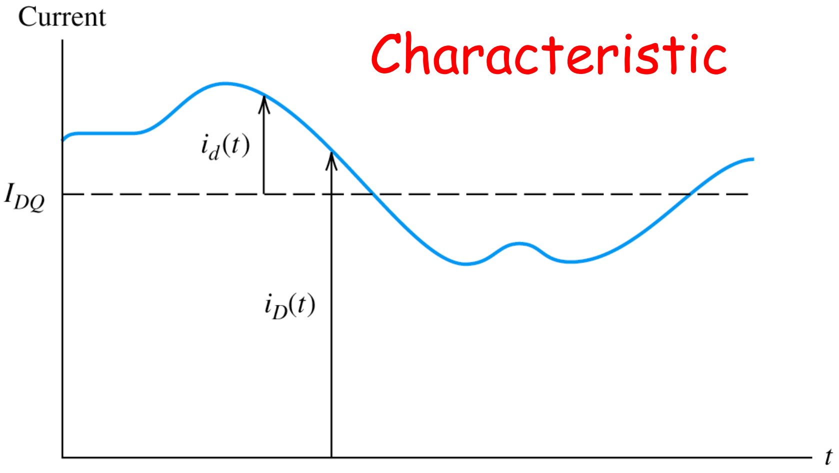


Figure 12.18 Illustration of the terms in Equation 12.15.

Small-Signal Equivalent Circuit -Transconductance

Schematic

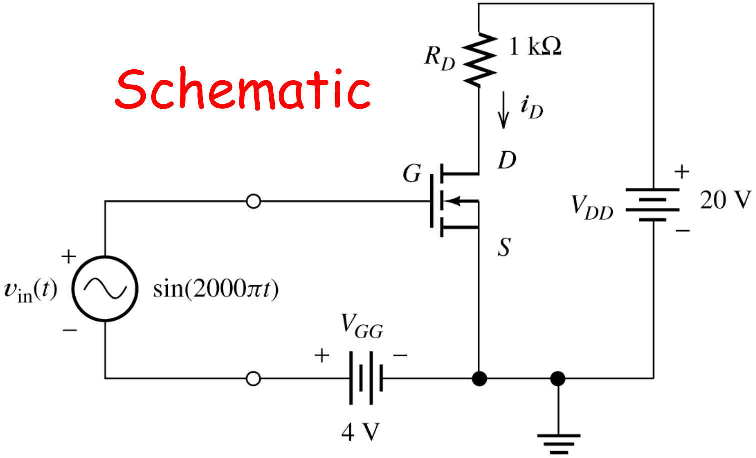


Figure 12.10 Simple NMOS amplifier circuit.

Analysis... (a little bit of math)

$$i_D = K\left(v_{GS} - V_{t0}\right)^2$$

$$I_{DQ} + i_d(t) = K\left[V_{GSQ} + v_{gs}(t) - V_{t0}\right]^2$$

$$I_{DQ} + i_d(t) = K\left(V_{GSQ} - V_{t0}\right)^2 + 2K\left(V_{GSQ} - V_{t0}\right)v_{gs}(t) + Kv_{gs}^2(t)$$

We know that $$I_{DQ} = K\left(V_{GSQ} - V_{t0}\right)^2 \quad *$$

Also we assume that $$\left|v_{gs}(t)\right| << \left|\left(V_{GSQ} - V_{t0}\right)\right|$$

Small-Signal Equivalent Circuit -Transconductance

Schematic

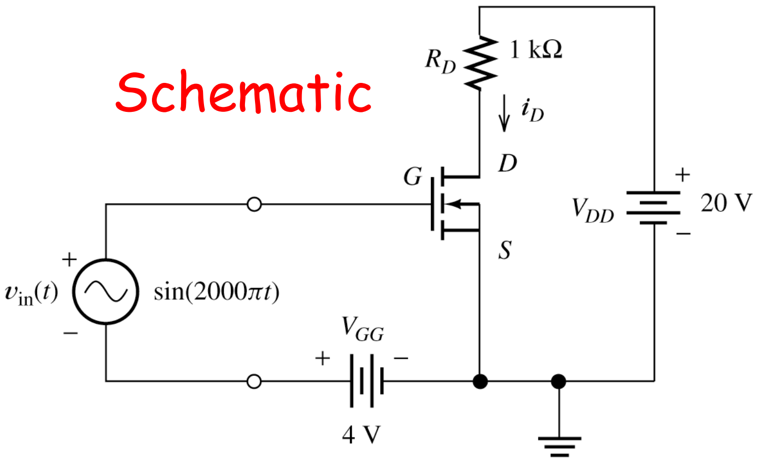


Figure 12.10 Simple NMOS amplifier circuit.

$$\cancel{I_{DQ}} + i_d(t) = \cancel{K\left(V_{GSQ} - V_{t0}\right)^2} + 2K\left(V_{GSQ} - V_{t0}\right)v_{gs}(t) + \cancel{Kv_{gs}^2(t)}$$

We know that $$I_{DQ} = K\left(V_{GSQ} - V_{t0}\right)^2 \; *$$

Also we assume that $$\left|v_{gs}(t)\right| << \left|\left(V_{GSQ} - V_{t0}\right)\right|$$

Drain current generated by signal

$$\boxed{i_d(t) = 2K\left(V_{GSQ} - V_{t0}\right)v_{gs}(t)}$$

Small-Signal Equivalent Circuit -Transconductance

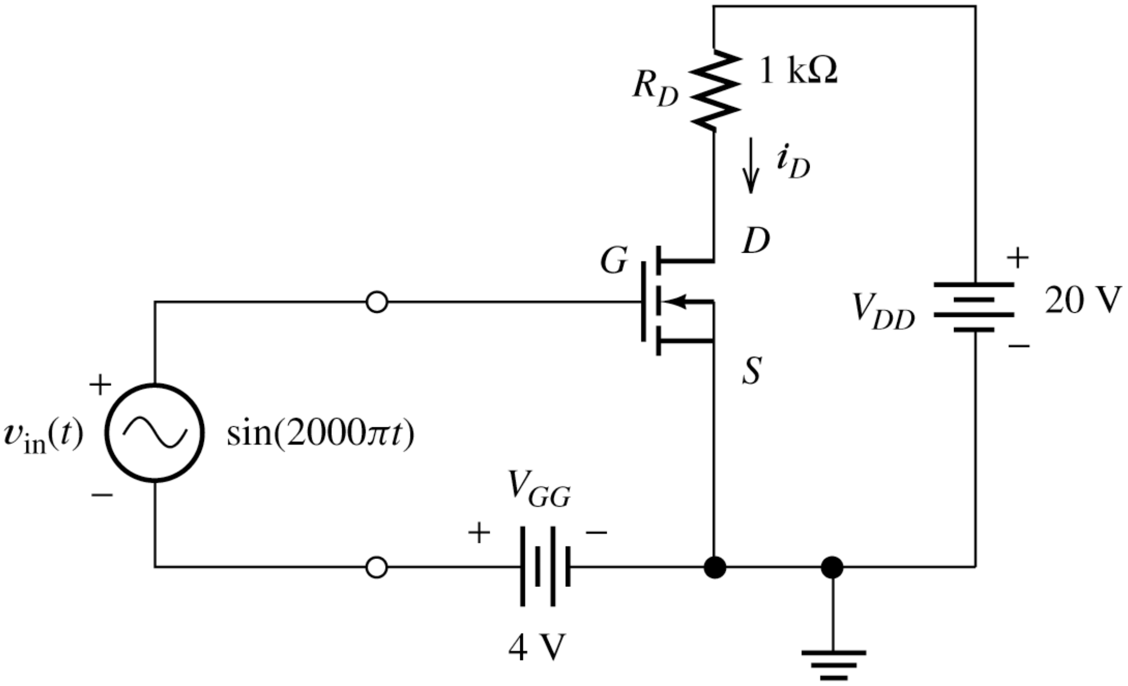


Figure 12.10 Simple NMOS amplifier circuit.

We define the transconductance as

$$g_m = \frac{i_d(t)}{v_{gs}(t)}$$

or

$$i_d(t) = g_m v_{gs}(t)$$

so

$$g_m = 2K\left(V_{GSQ} - V_{t0}\right)$$

Small-Signal Equivalent Circuit -Transconductance

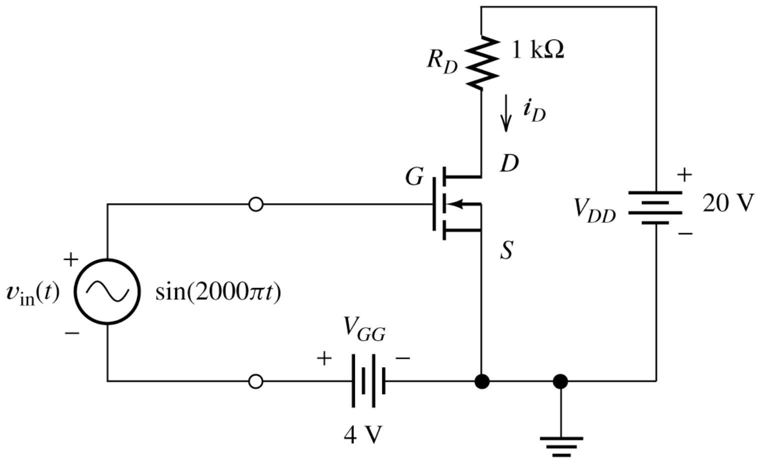


Figure 12.10 Simple NMOS amplifier circuit.

$$i_D = K\left(v_{GS} - V_{t0}\right)^2$$

so

$$\left(v_{GS} - V_{t0}\right) = \sqrt{\frac{I_{DQ}}{K}}$$

Thus the transconductance

$$g_m = 2K\left(V_{GSQ} - V_{t0}\right) = 2\sqrt{KI_{DQ}}$$

Small-Signal Equivalent Circuit -Transconductance

Exercise

The transistor has $KP=50\mu A/V^2$, $V_{to}=2V$, $L=10\mu m$, and $W=400\mu m$

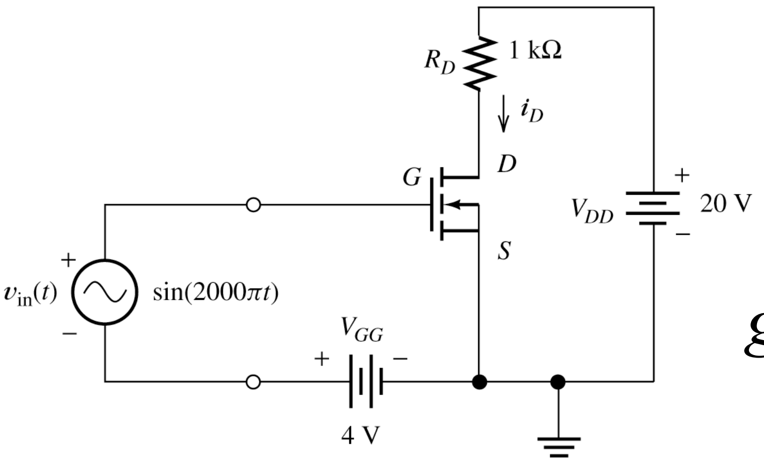


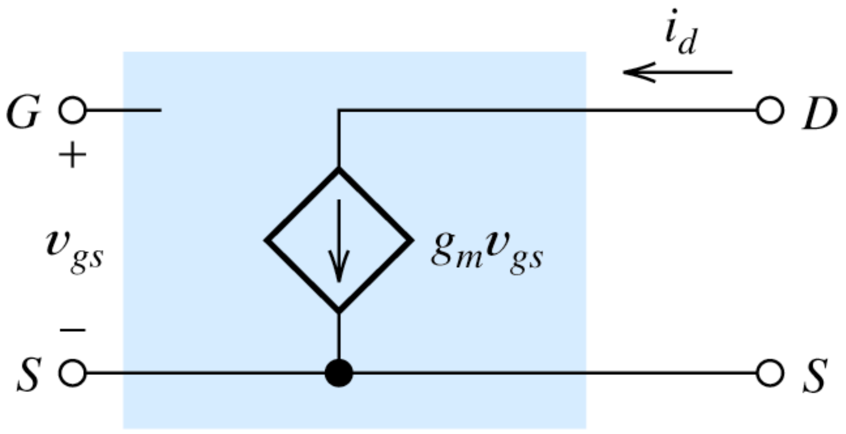
Figure 12.10 Simple NMOS amplifier circuit.

$$K = \left(\frac{W}{L}\right)\frac{KP}{2} = 1mA/V2$$

$$g_m = 2K\left(V_{GSQ} - V_{t0}\right) = 2(4-2) = 4mS$$

Small-Signal Equivalent Circuit

Also we assume that $i_g(t) = 0$



$$g_m = 2\sqrt{KI_{DQ}}$$

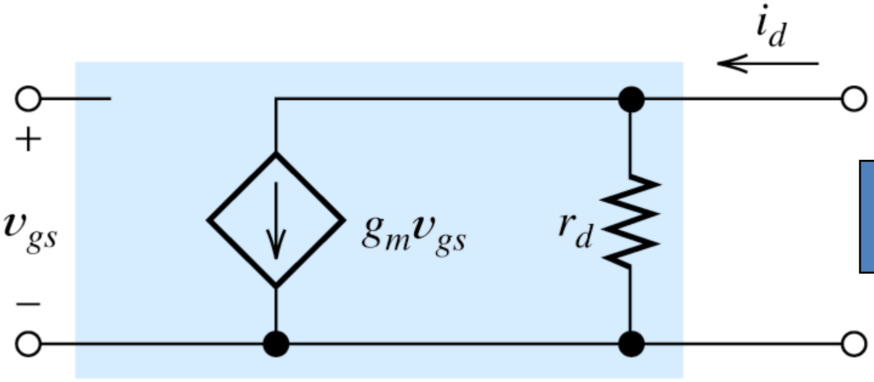
$$K = \left(\frac{W}{L}\right)\frac{KP}{2}$$

Figure 12.19 Small-signal equivalent circuit for FETs.

Better performance is obtained with higher values of g_m. Please notice that g_m is proportional to the square root of the Q point drain current. Simply, we can increase g_m by choosing a higher value of I_{DQ}.

More Complex Equivalent Circuits

For more accurate analyses of FET transistor we have to add more components to an equivalent circuit.
Small capacitance: for high response FET amplifiers
Drain resistor: account for the effect of v_{DS} on the drain current



Correction for i_d

$$i_d(t) = g_m v_{gs}(t) + v_{ds} / r_d$$

Figure 12.20 FET small-signal equivalent circuit that accounts for the dependence of i_D on v_{DS}.

Please read section: Transconductance and … pp.591
Example 12.3