ECE 65: Components & Circuits Lab

Lecture 17

Transistor Amplifiers – Introduction

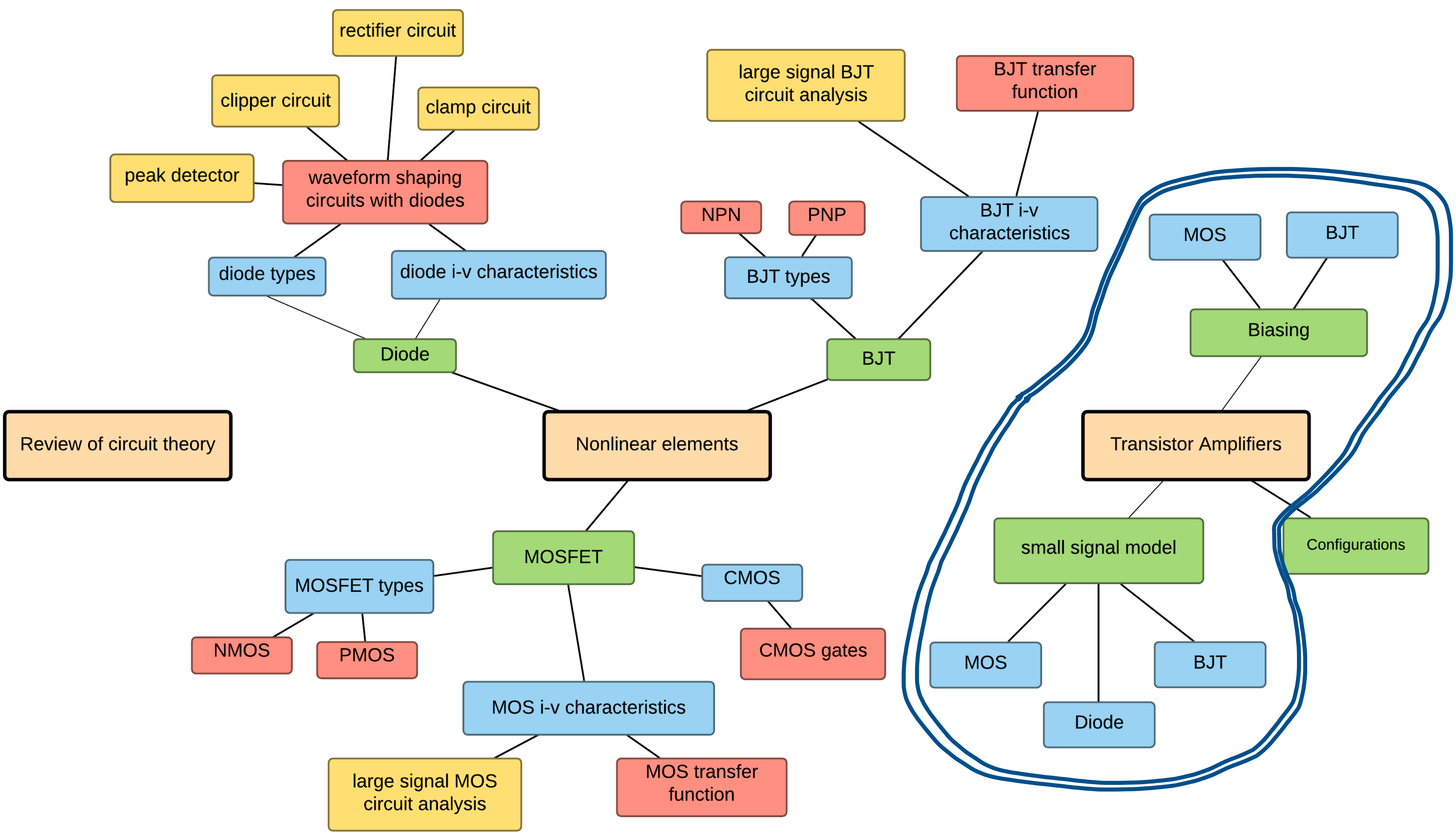
Reference notes: sections 5.1, 5.2

Sedra & Smith (7^{th} Ed): sections 7.1

Saharnaz Baghdadchi

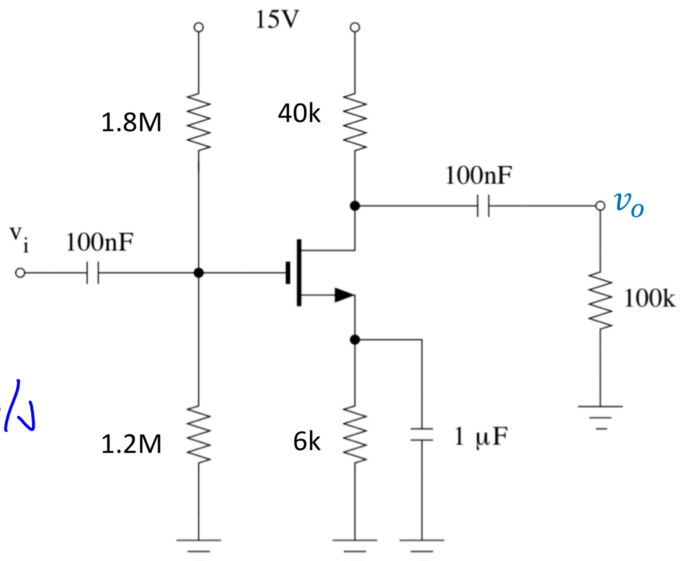
Course map

5. Transistor Amplifiers – Bias and small signal

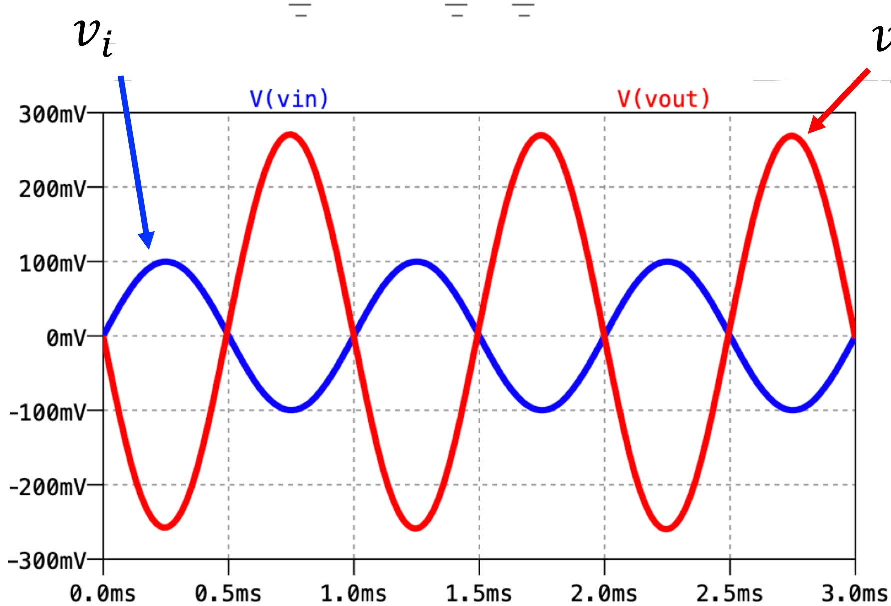


Transistor Amplifiers

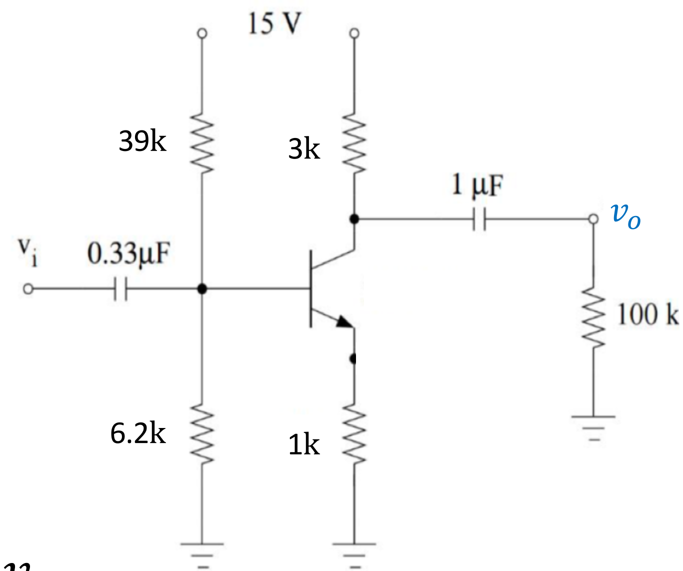
MOSFET as an amplifier

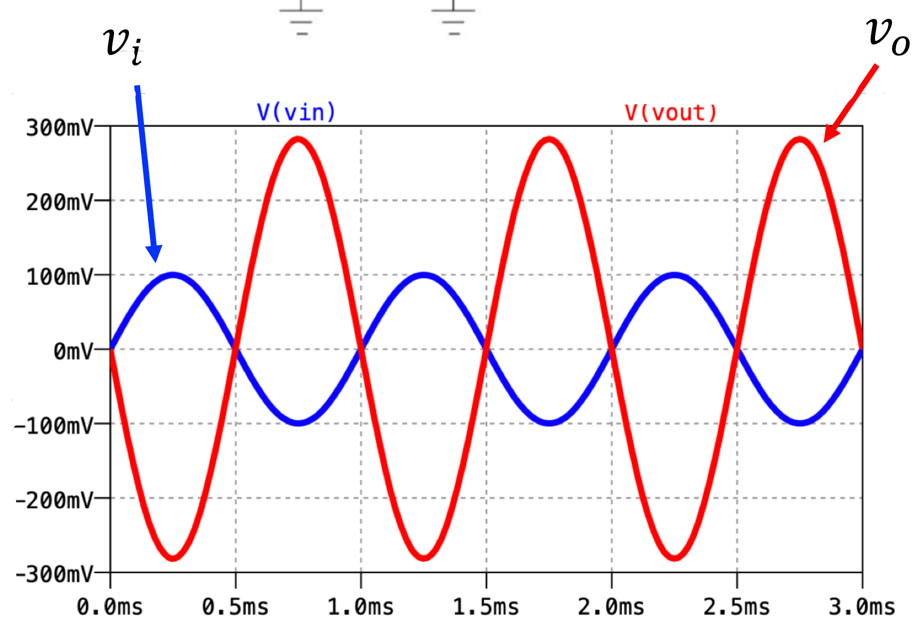


$\left|\frac{V_o}{V_i}\right| \simeq 3\ V/V$

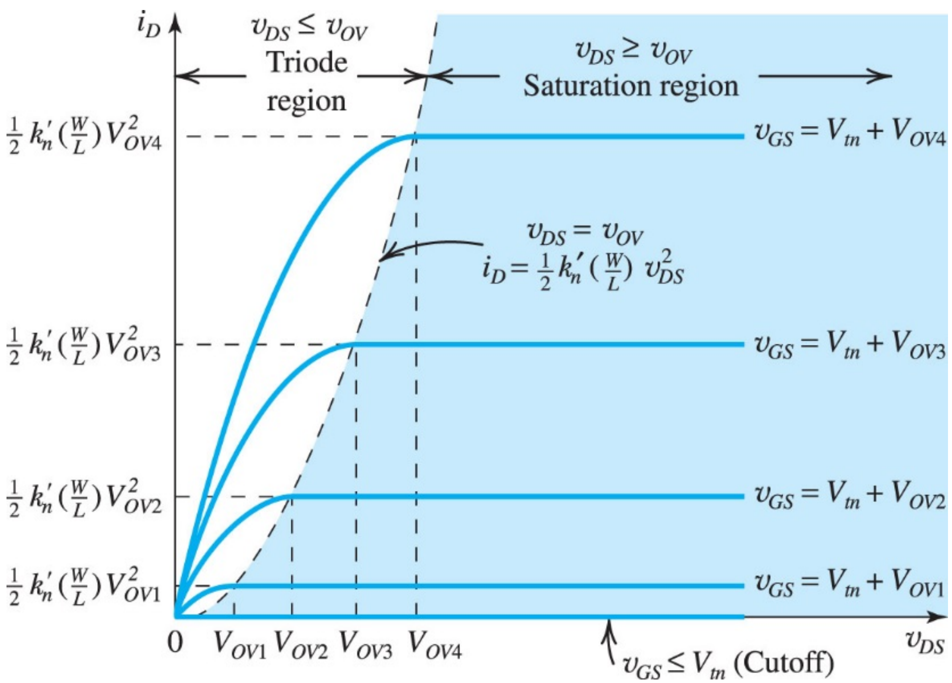


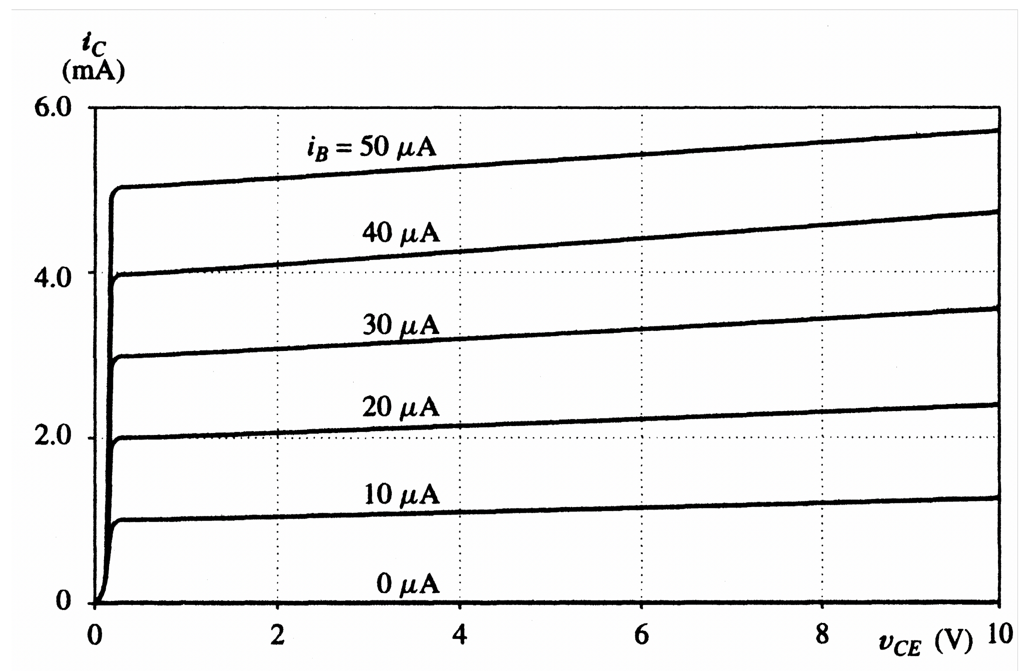
BJT as an amplifier





In the active region, BJT and MOSFET operate as a voltage-controlled current source

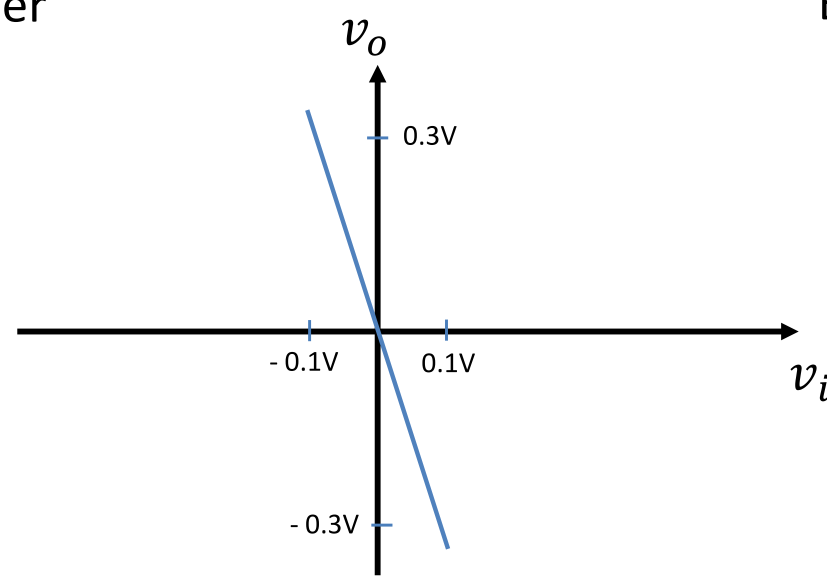


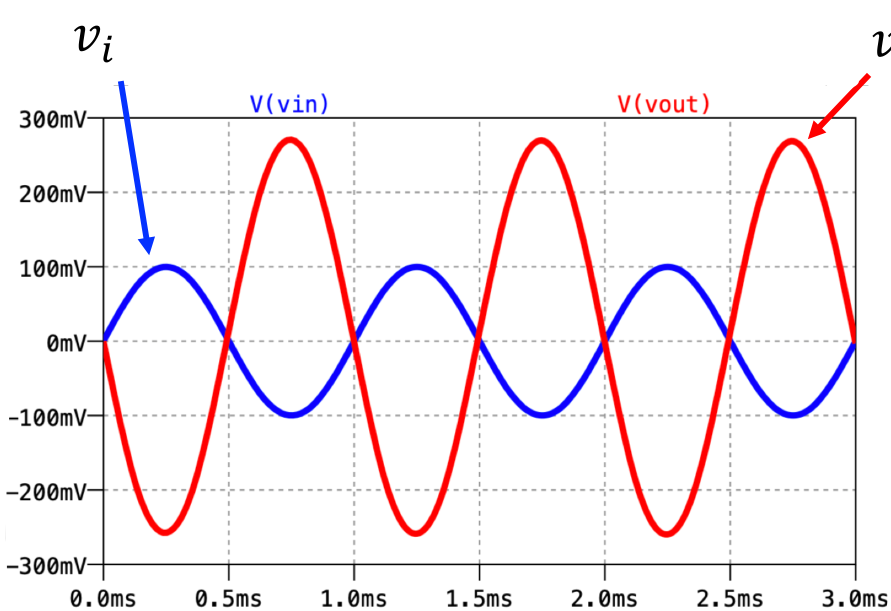


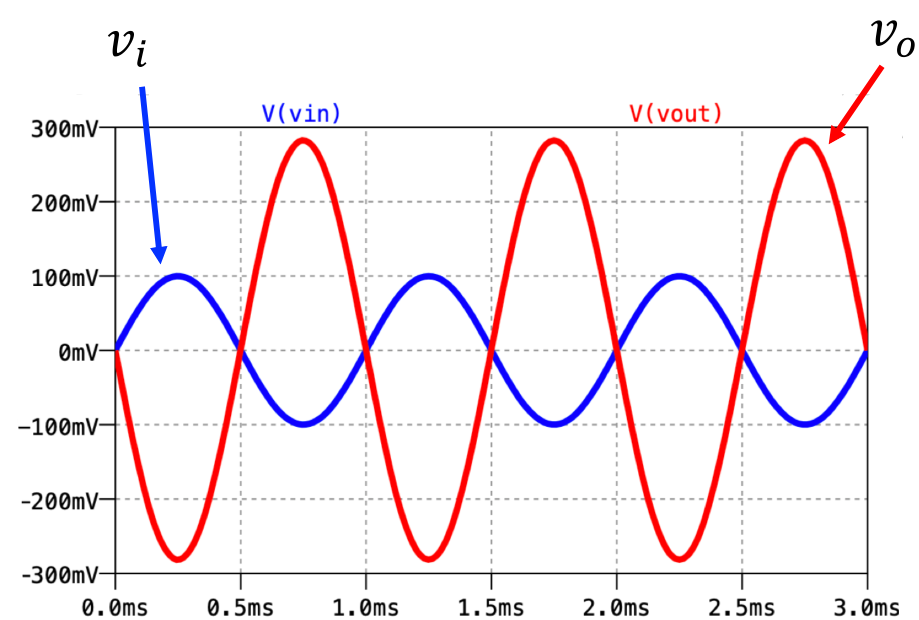
Transistor Amplifiers

MOSFET as an amplifier

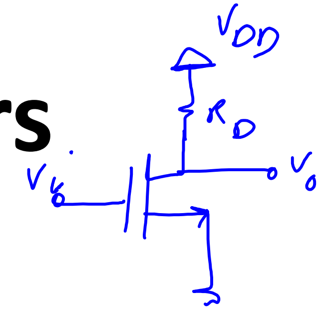
BJT as an amplifier



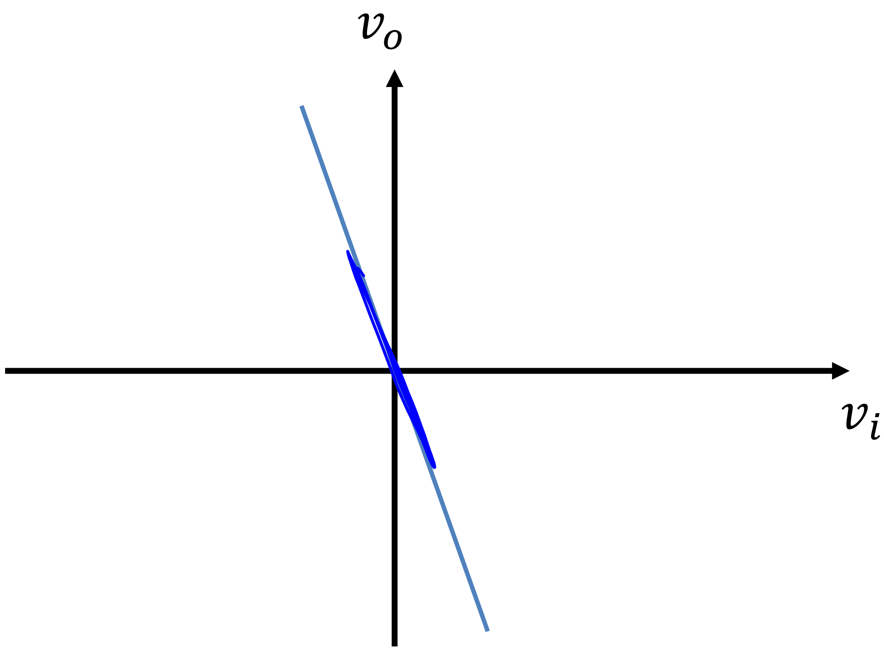




Foundation of Transistor Amplifiers

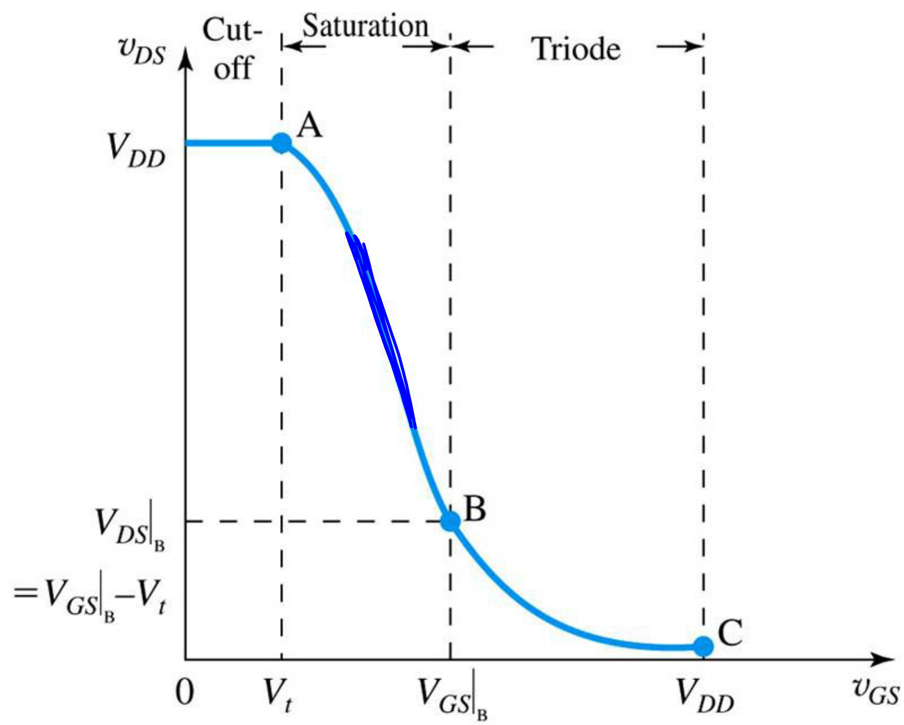


A voltage amplifier requires
$v_o/v_i = \text{const.}$



v_o/v_i can be negative (minus sign represents a 180° phase shift)

MOS transfer function is NOT linear

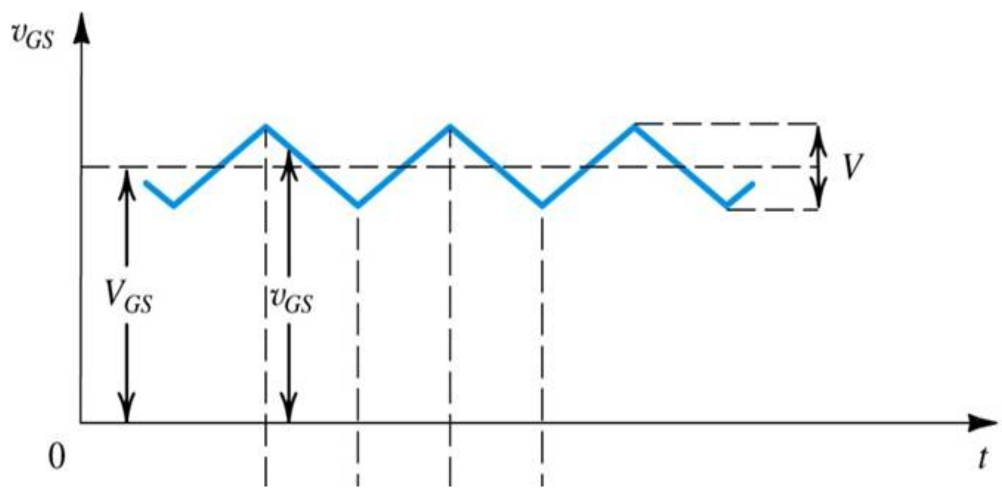


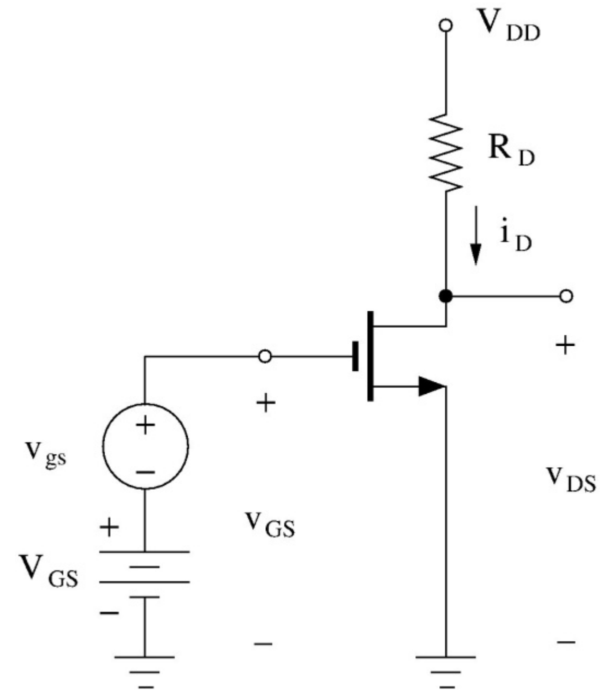
In saturation, however, transfer function looks linear (but shifted)

Foundation of Transistor Amplifiers

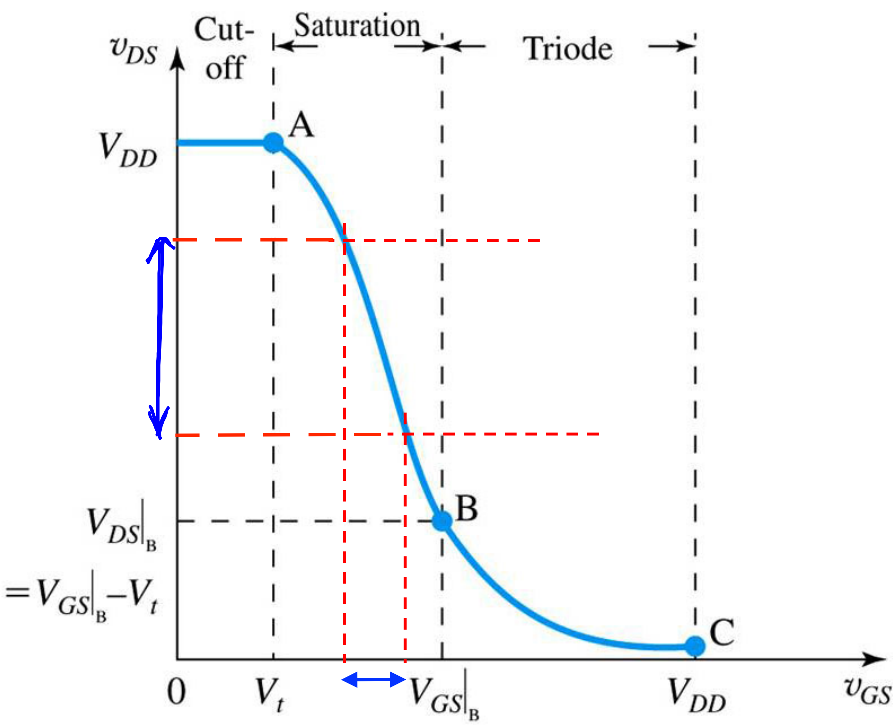
Let us consider the response, if NMOS remains in saturation at all times and v_{GS} is a combination of a **constant value** (V_{GS}) and a **<u>signal</u>** (v_{gs}):

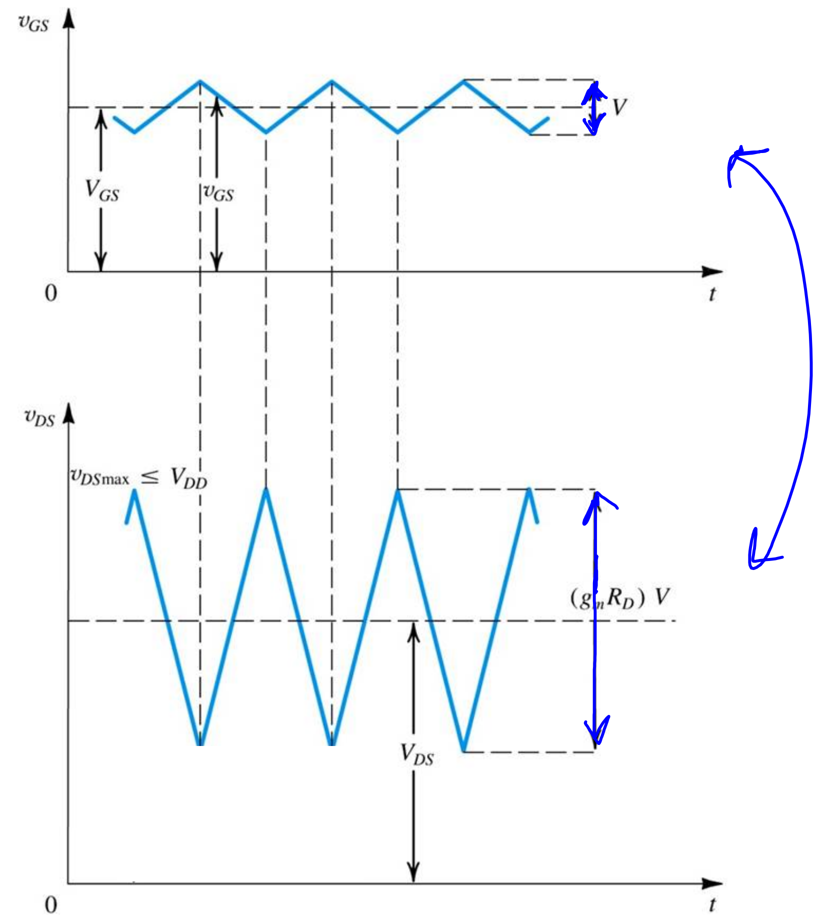
$$v_{GS} = V_{GS} + v_{gs}$$



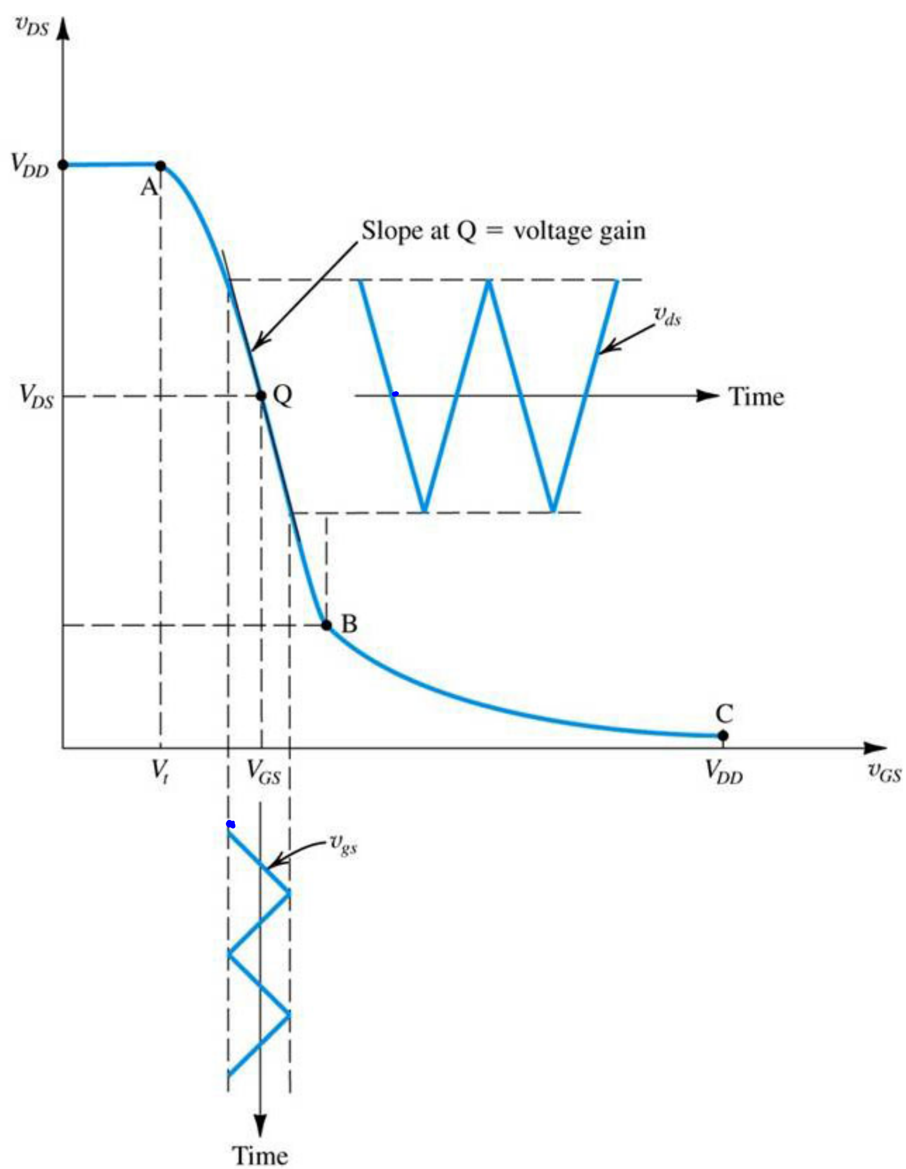


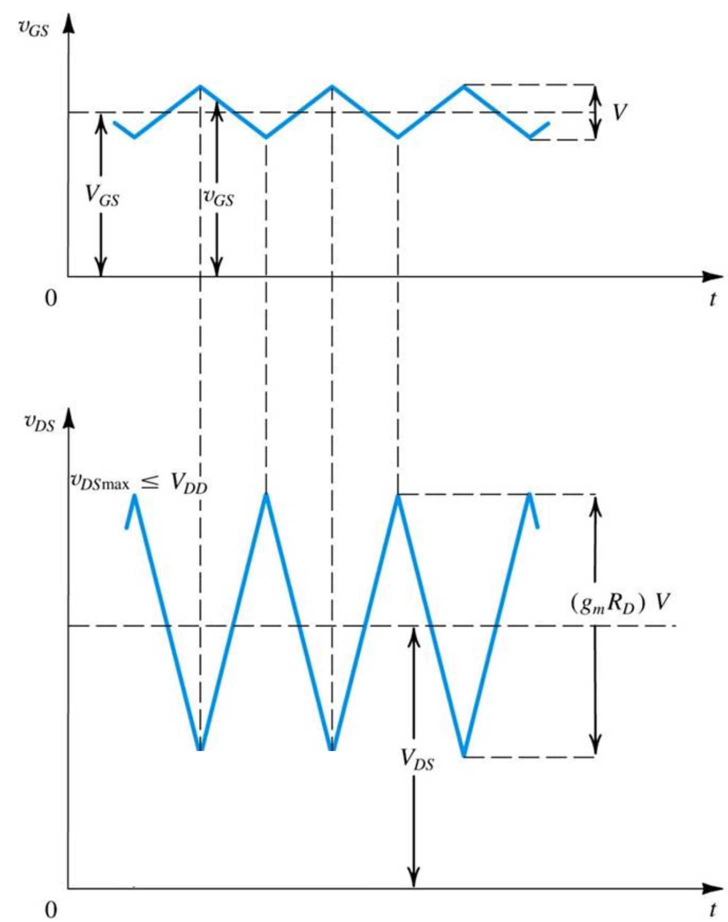
The response to a combination of $v_{GS} = V_{GS} + v_{gs}$ can be found from the transfer function



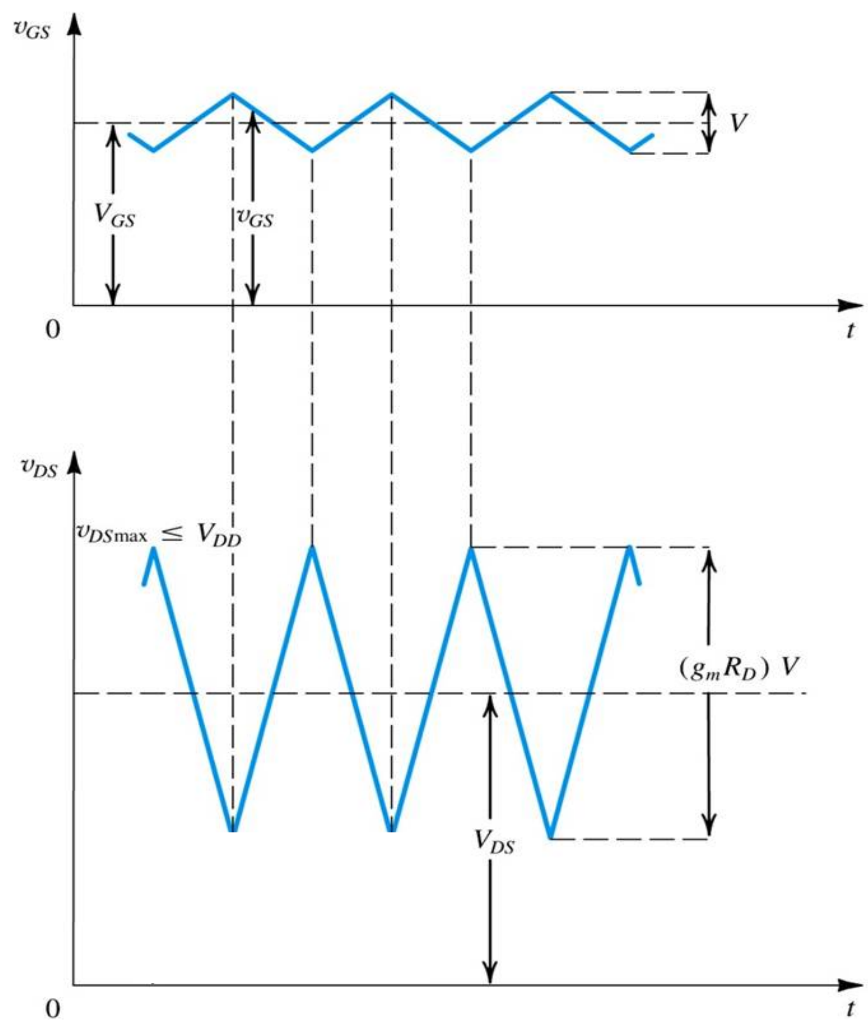


The response to a combination of $v_{GS} = V_{GS} + v_{gs}$ can be found from the transfer function





Response to the signal appears to be linear



Response ($v_o = v_{DS}$) is also made of a constant part (V_{DS}) and a signal response part (v_{ds}).

Constant part of the response, V_{DS}, is ONLY related to V_{GS}, the constant part of the input (Q point on the transfer function of previous slide).

- i.e., if $v_{gs} = 0$, then $v_{ds} = 0$

The shape of the time varying portion of the response (v_{ds}) is similar to v_{gs}.

- i.e., v_{ds} is <u>proportional</u> to the input signal, v_{gs}

Although the overall response is non-linear, the transfer function for the signal is linear!

Constant: Bias

Signal and response

$$v_{GS} = V_{GS} + v_{gs}$$

$$v_{DS} = V_{DS} + v_{ds}$$

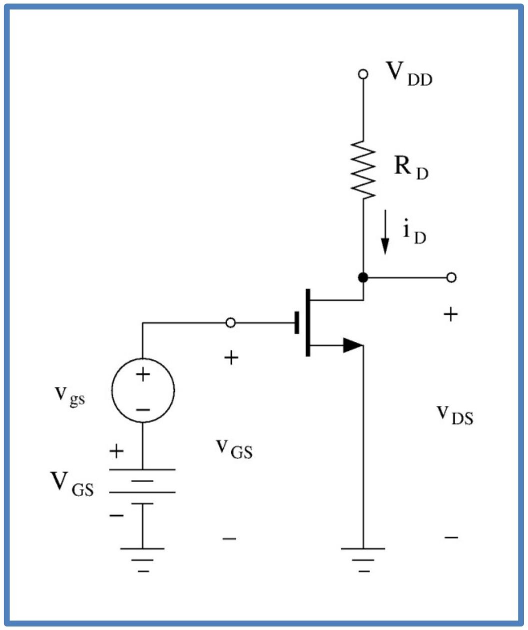
$$i_D = I_D + i_d$$

Under small signal approximation

$$v_{ds} = -\, g_m R_D v_{gs}$$

$$i_d = g_m v_{gs}$$

$$v_{ds} = -\, i_d R_D$$



NMOS $(V_{OV} = v_{GS} - V_{tn})$

Cut - Off : $V_{OV} < 0$ $\quad i_D = 0$

Triode : $V_{OV} \geq 0$ and $v_{DS} \leq V_{OV}$ $\quad i_D = 0.5\mu_n C_{ox} \dfrac{W}{L}\left[2V_{OV}v_{DS} - v_{DS}^2\right]$

Saturation : $V_{OV} \geq 0$ and $v_{DS} \geq V_{OV}$ $\quad i_D = 0.5\mu_n C_{ox} \dfrac{W}{L} V_{OV}^2 \left[1 + \lambda v_{DS}\right]$

Lecture 17 reading quiz

If in a MOSFET amplifier $V_{DS} = 1\ V$ and $V_{OV} = 0.6\ V$ where $V_{GS} = 1\ V$ and $V_t = 0.4\ V$

and the voltage gain of the amplifier ($A_v = \frac{v_{ds}}{v_{gs}}$) is $-10\ V/V$, Which one of the given

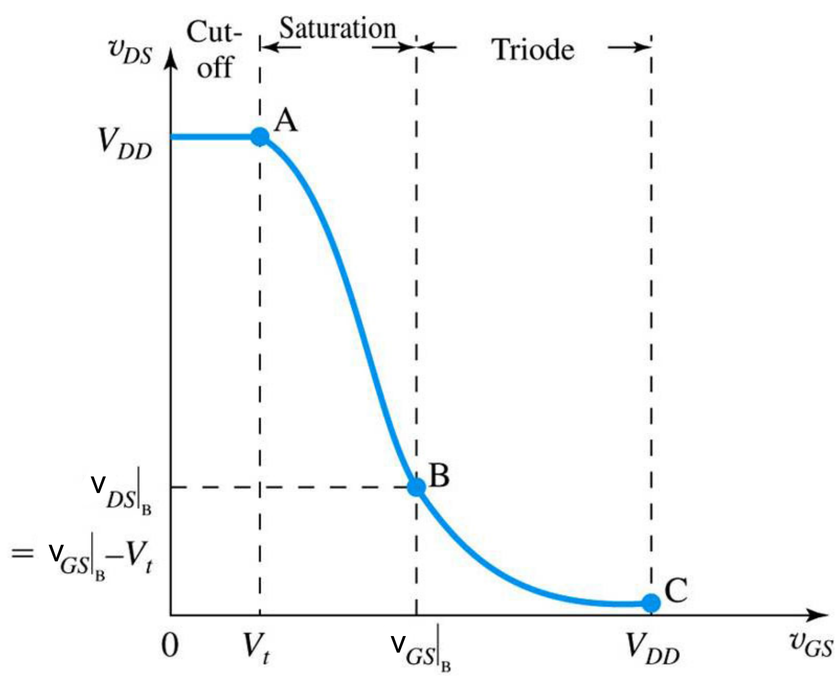
input AC signals can be amplified without distortion?

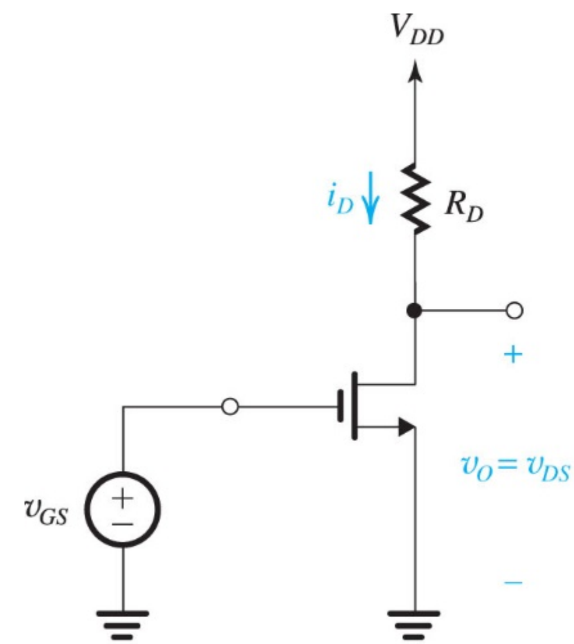
Discussion Question 1.

In the following circuit,

$V_{DD} = 5\,V, R_D = 20\,k\Omega, V_t = 0.5\,V, k_n = 10\,mA/V^2$ and $\lambda = 0$.

Determine the coordinates of the saturation-region segment (AB) of the curve for the voltage transfer function.

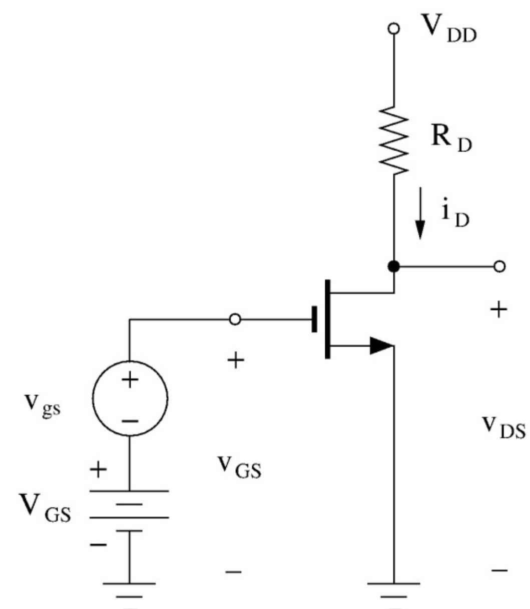




Hints:

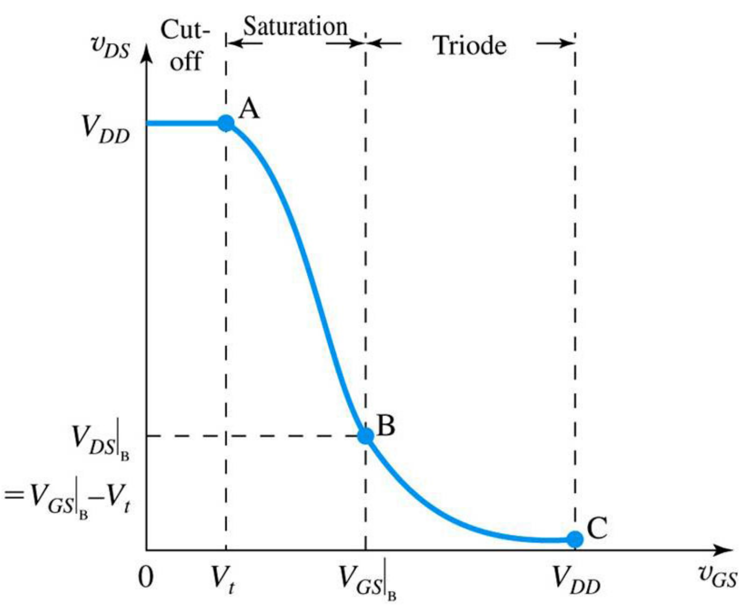
Discussion Question 1.

$$V_{DD} = 5\ V, R_D = 20\ k\Omega, V_t = 0.5\ V, k_n = 10\ mA/V^2 \text{ and } \lambda = 0.$$



- To find the V_{GS} and V_{DS} at point A, you can use the threshold of On/Cut-off in MOSFETs and the DS KVL (or the transfer characteristic graph).

- To find the V_{GS} and V_{DS} at point B, You can solve the MOSFET at the edge of saturation. This is when MOSFET is in saturation and V_{DS} = V_{GS} -V_{t}. By solving the characteristic drain current equation and the DS KVL, you can get the values of V_{GS} and V_{DS}.

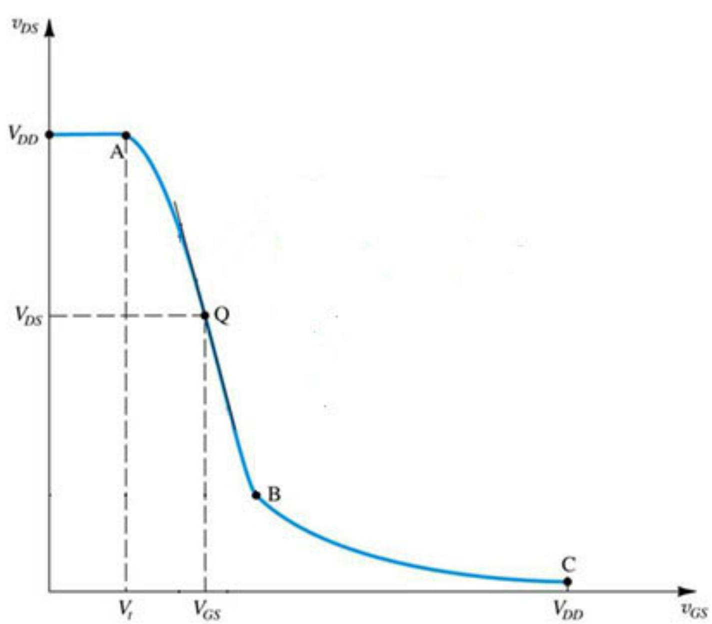


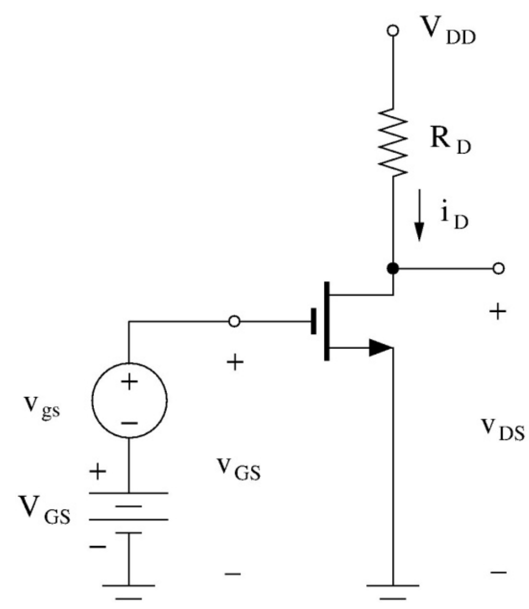
Clicker Question 1.

In the following circuit, $V_{GS} = 0.6\ V, V_{DD} = 1.8\ V, R_D = 17.5\ k\Omega, V_t = 0.4\ V, k_n = 4\ mA/V^2$ and $\lambda = 0$.

What is the maximum symmetrical signal swing allowed at the drain (what is the maximum allowable peak amplitude of v_{ds})?

A. 0.4 V
B. 0.6 V
C. 0.2 V





Hints:

Clicker Question 1.

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What is the maximum symmetrical signal swing allowed at the drain (what is the maximum allowable peak amplitude of v_{ds})?

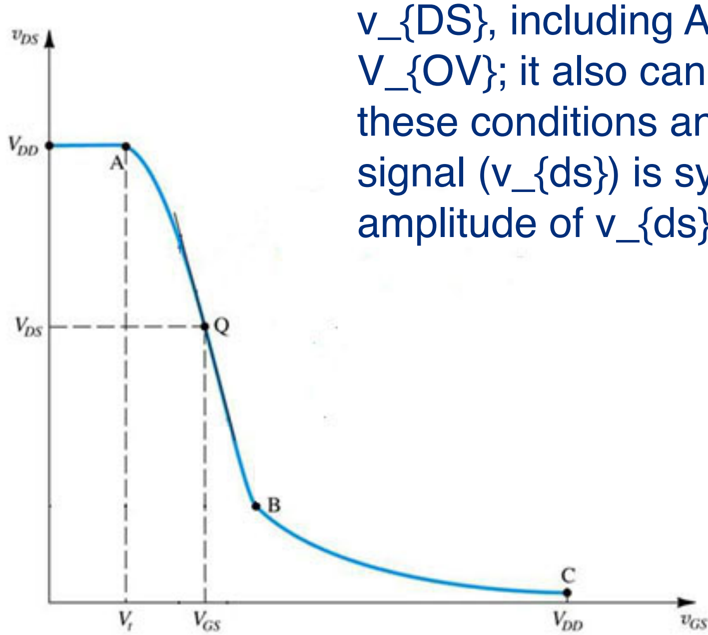
A. 0.4 V

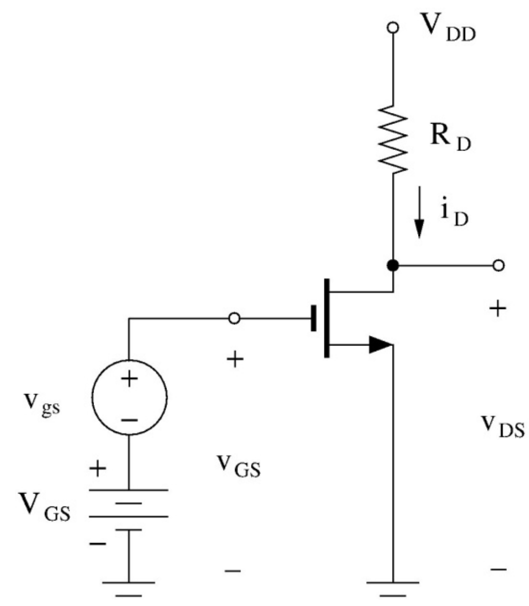
B. 0.6 V

C. 0.2 V

- Find V_{OV} and V_{DS}.

- After adding an AC signal, v_{gs}, an AC signal v_{ds} will be superimposed on V_{DS}. The total v_{DS}, including AC and DC should not go below V_{OV}; it also cannot exceed V_{DD}. Knowing these conditions and assuming that the AC output signal (v_{ds}) is symmetric, how large the amplitude of v_{ds} can be?





Simulation results for the Clicker Question 1

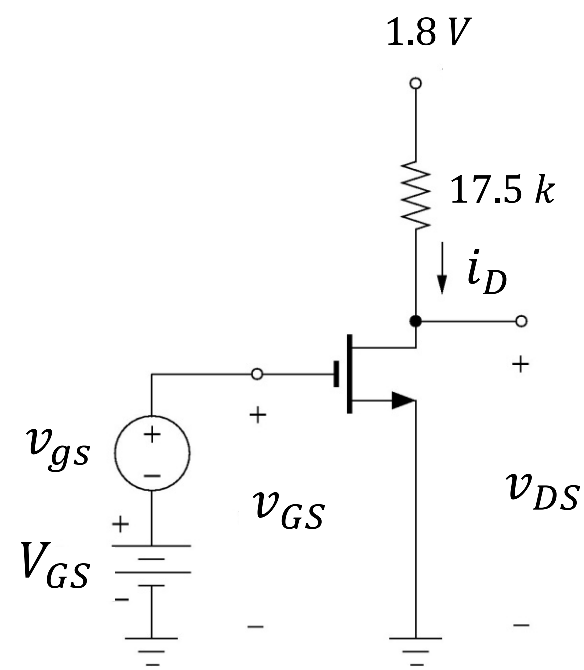
In the following circuit, $V_{GS} = 0.6\ V, V_t = 0.4\ V, k_n = 4\ mA/V^2$ and $\lambda = 0$.

Draw the graph of v_{GS}, v_{DS}, and I_D for

1. $v_{gs} = 0.005\ sin(2\pi ft)\ (V)$

2. $v_{gs} = 0.010\ sin(2\pi ft)\ (V)$

Use $f = 1$ kHz.



Simulation results for the Clicker Question 1

In the following circuit, $V_{GS} = 0.6\,V, V_t = 0.4\,V, k_n = 4\,mA/V^2$ and $\lambda = 0.$

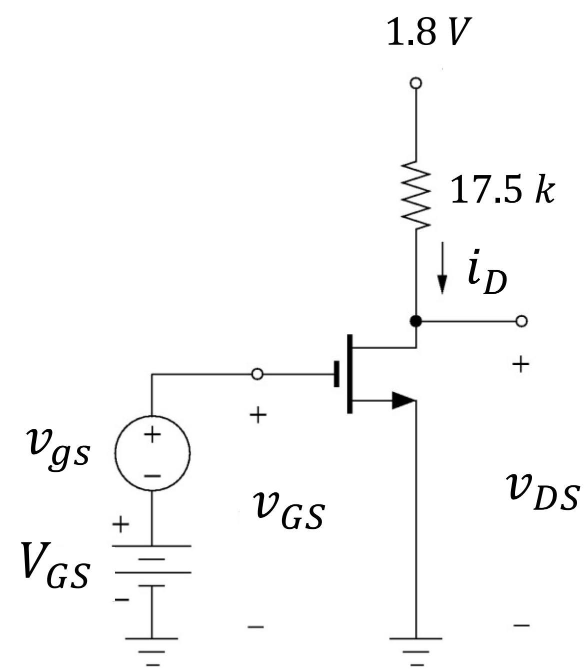
Draw the graph of $v_{GS}, v_{DS},$ and I_D for

Bias point, or the operation point, or the Q point:

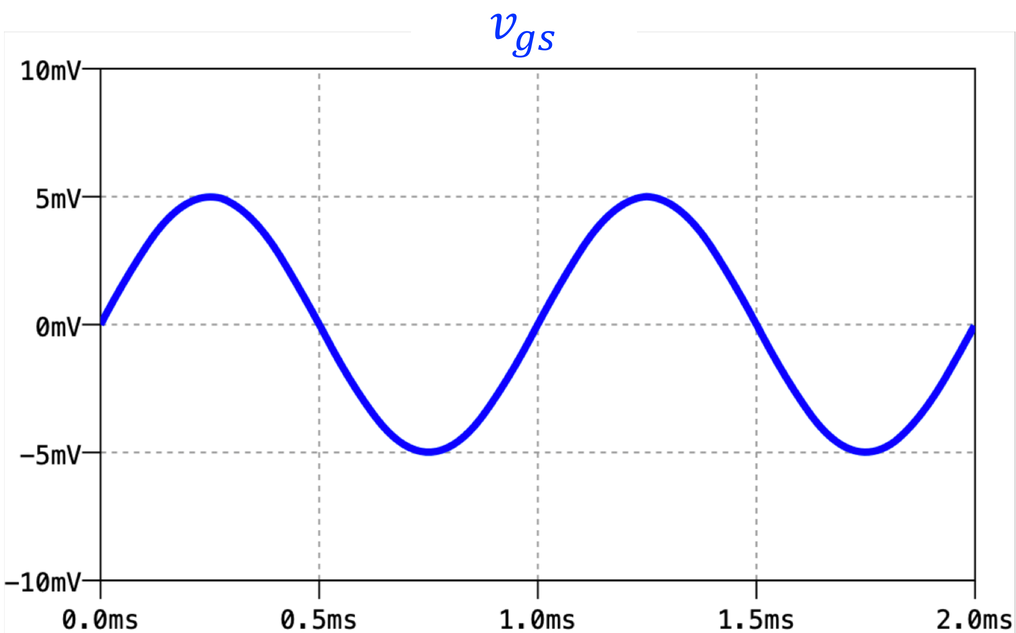
$$V_{GS} = 0.6\,V$$

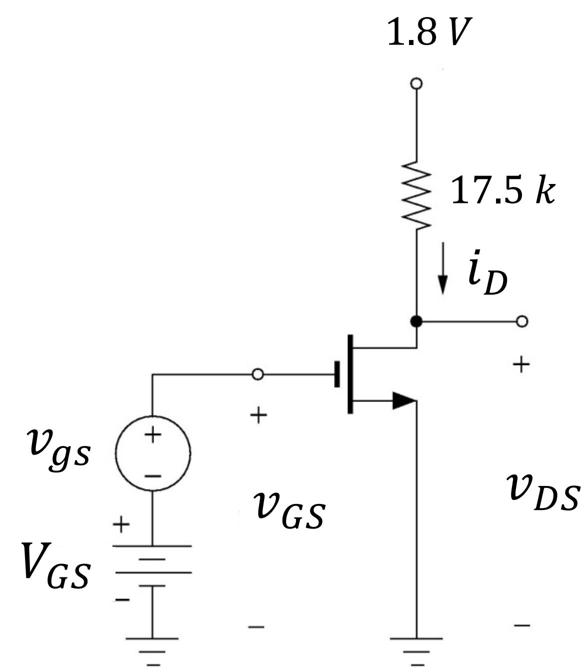
$$V_{DS} = 0.4\,V$$

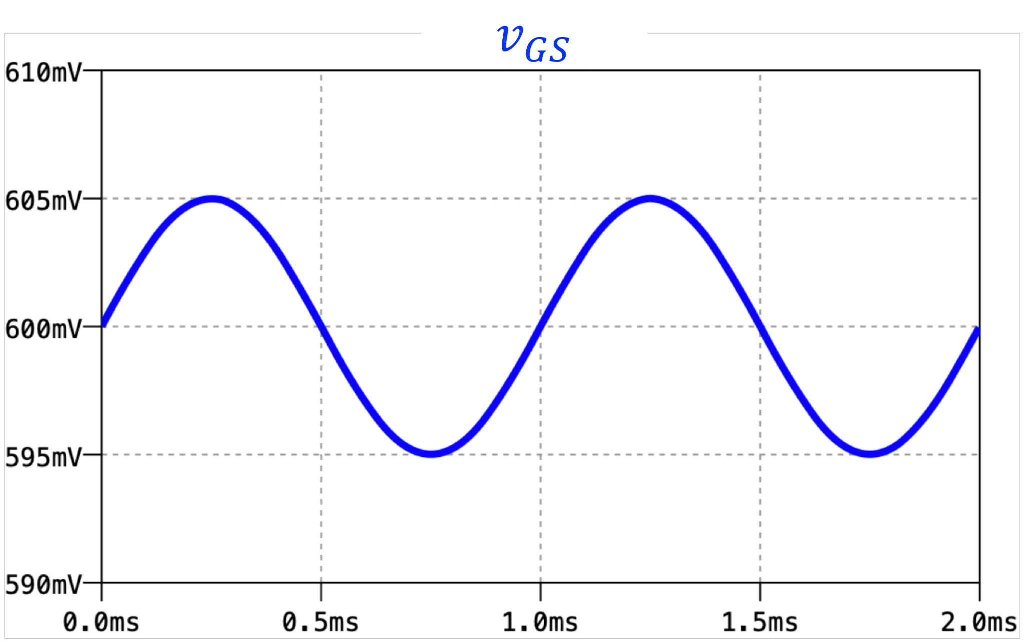
$$I_D = 0.08\,mA$$



$$v_{gs} = 0.005\ sin(2\pi f t)\ (V)$$





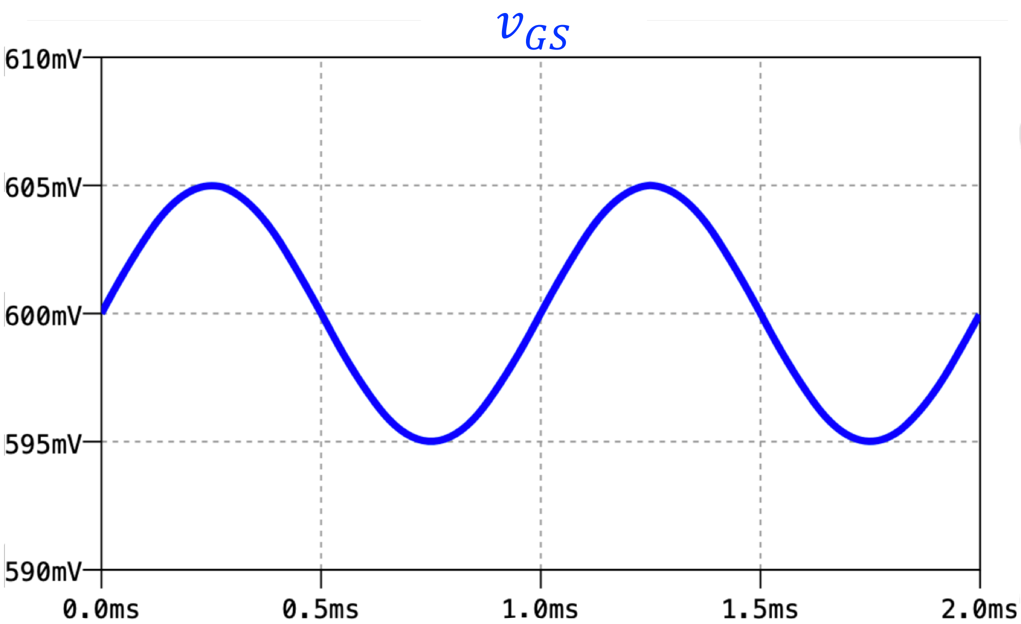


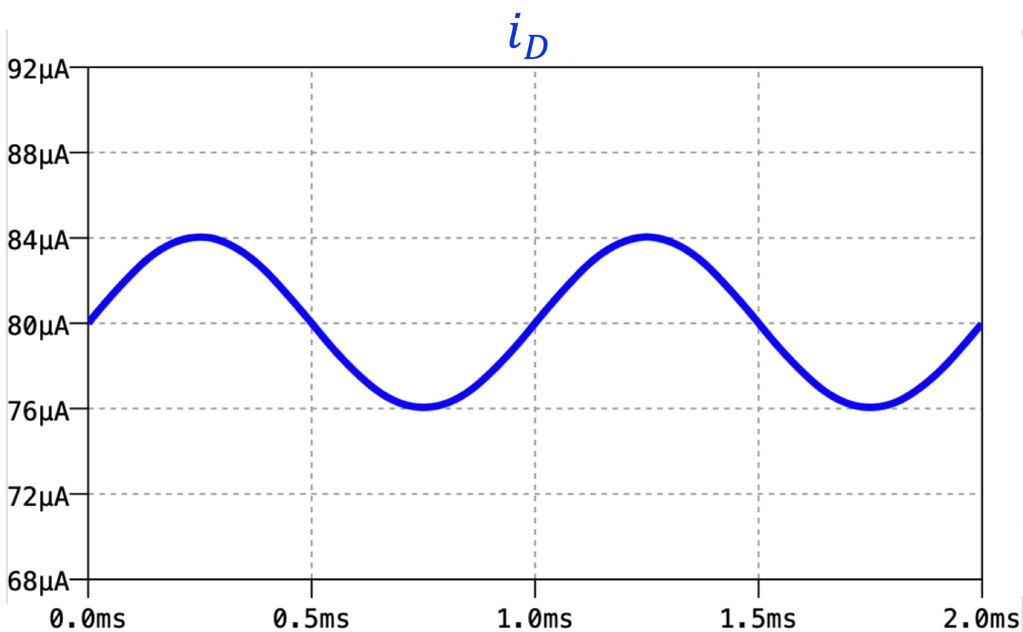
@ Q: $V_{GS} = 0.6\ V$

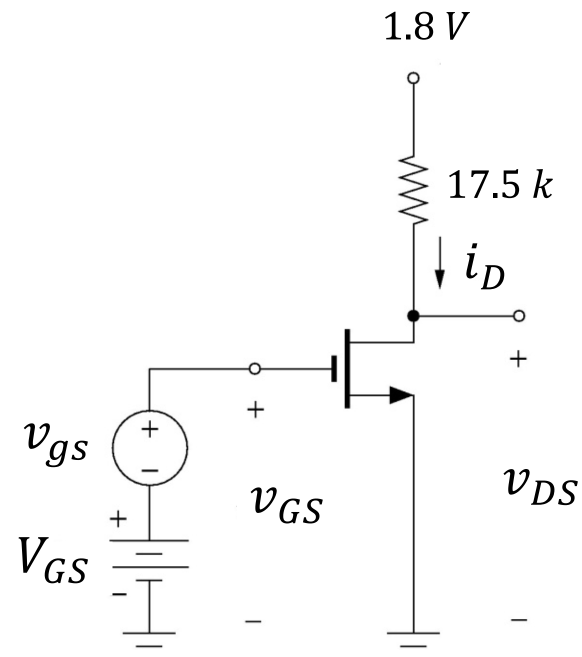
$V_{DS} = 0.4\ V$

$I_D = 0.08\ mA$

$$v_{gs} = 0.005\, sin(2\pi f t)\ (V)$$







@ Q: $V_{GS} = 0.6\ V$

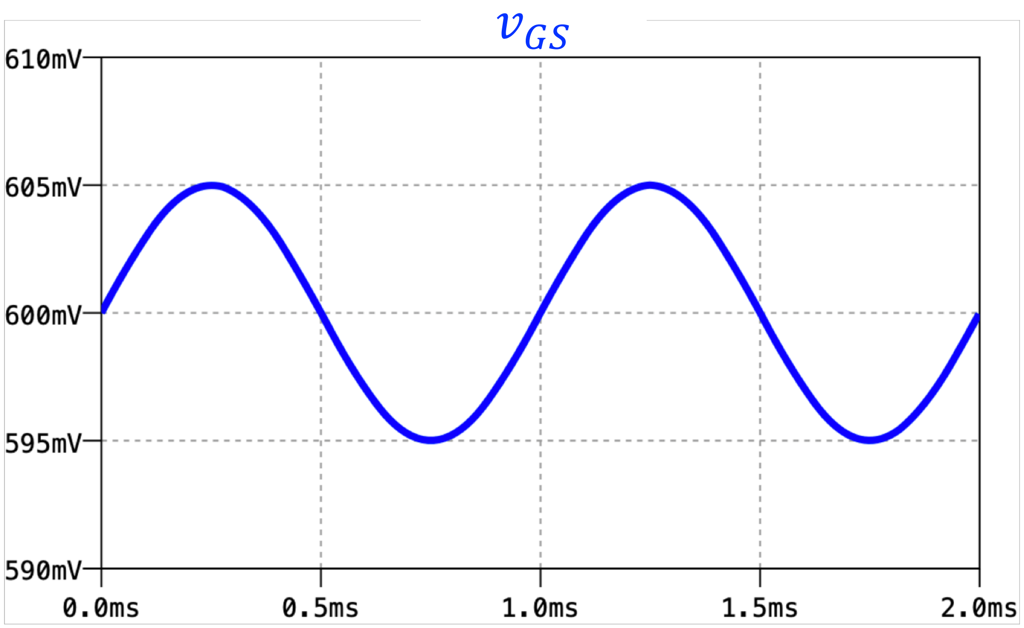
$V_{DS} = 0.4\ V$

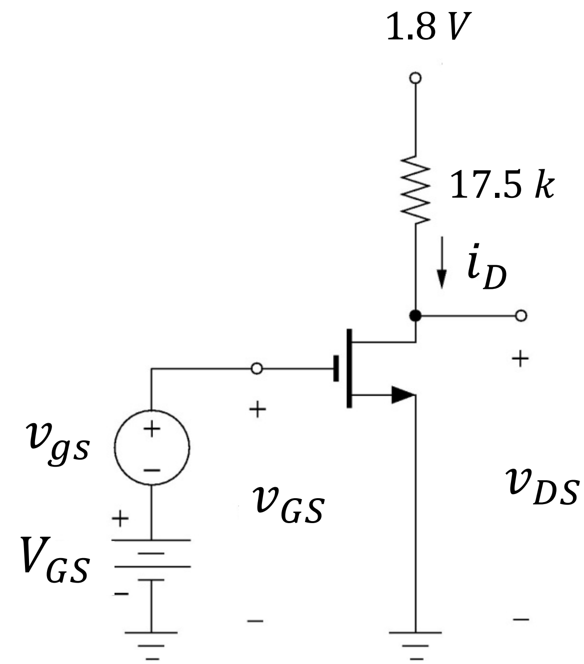
$I_D = 0.08\ mA$

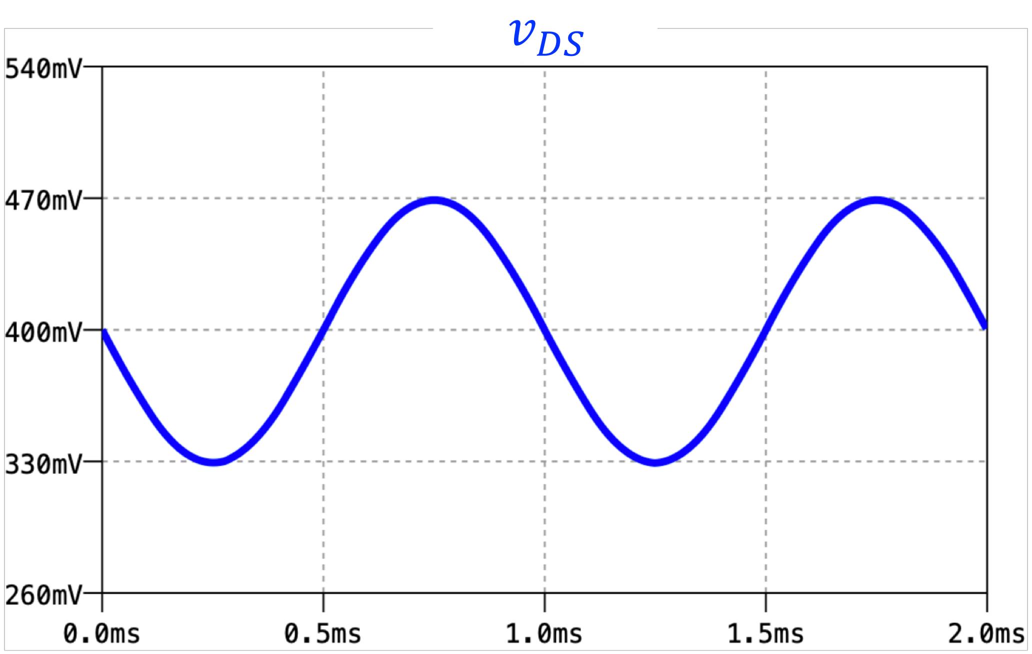
$$g_m = \frac{2 I_D}{V_{ov}}$$

$$g_m = \frac{i_d}{v_{gs}} = 0.08\ \ mA/V$$

$$v_{gs} = 0.005\, sin(2\pi f t)\ (V)$$







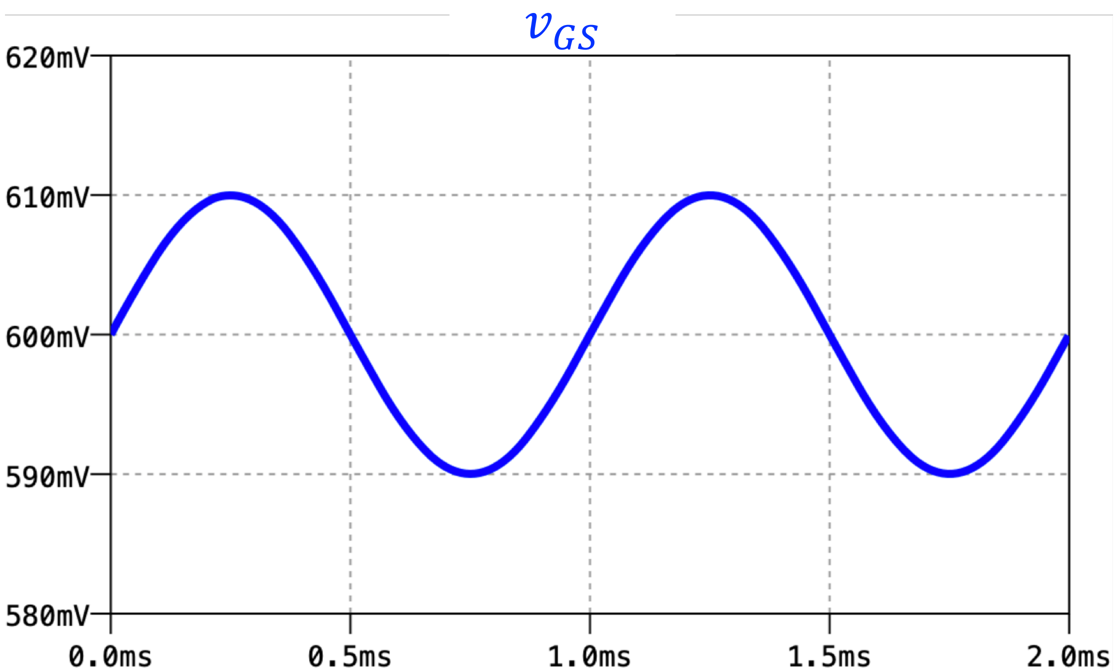
@ Q: $V_{GS} = 0.6\ V$

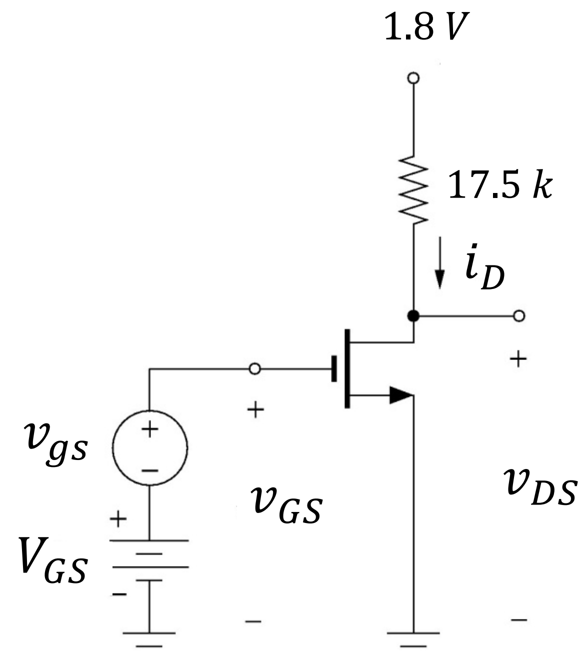
$V_{DS} = 0.4\ V$

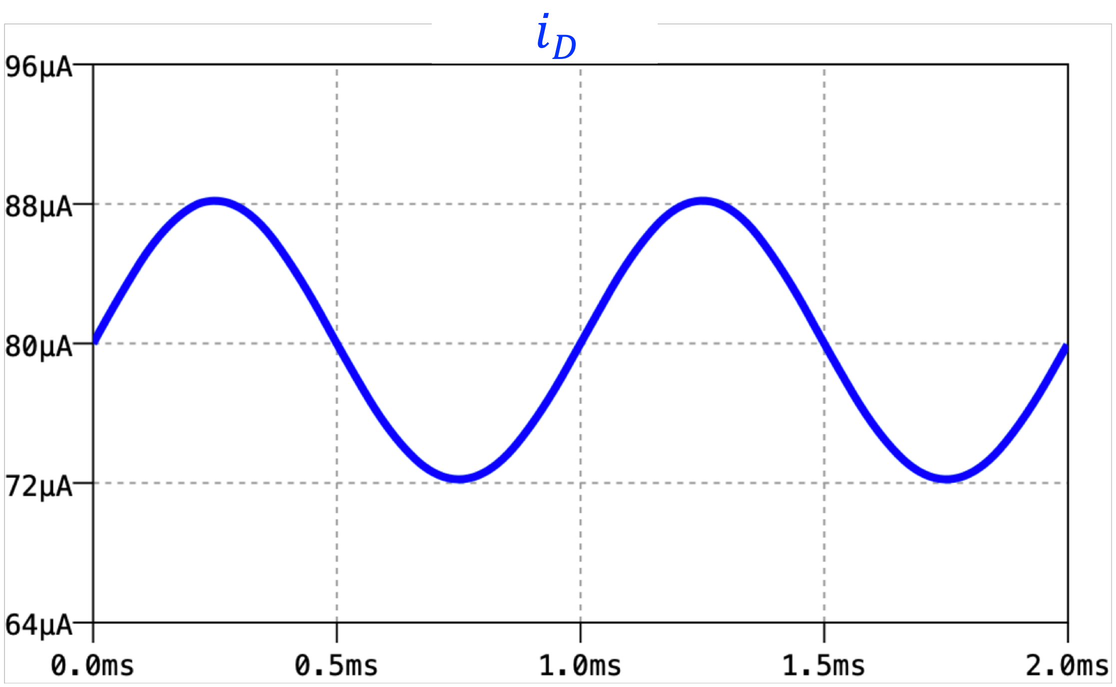
$I_D = 0.08\ mA$

$$A_v = \frac{v_{ds}}{v_{gs}} = -14\ V/V$$

$$v_{gs} = 0.01\, sin(2\pi f t)\ (V)$$







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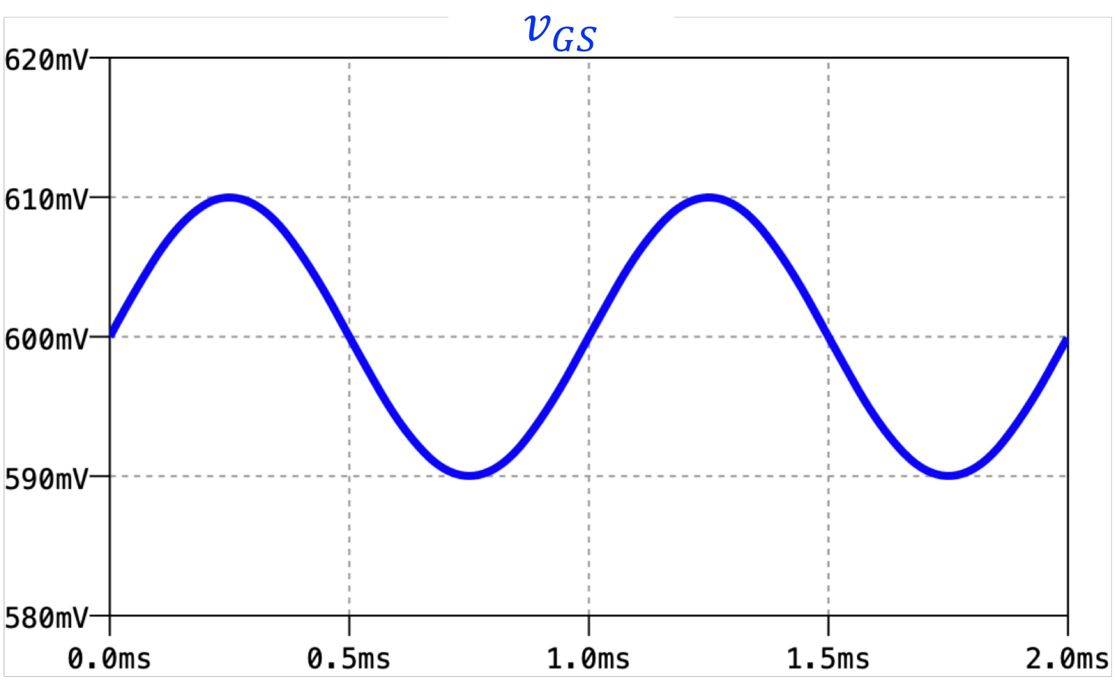
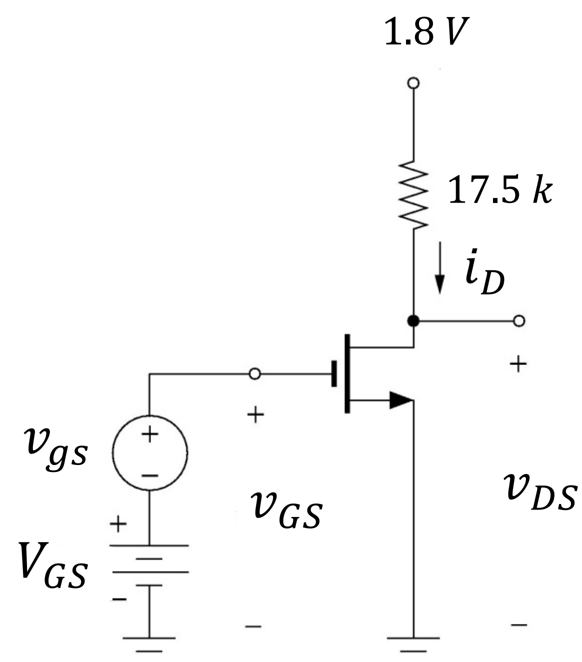
$V_{DS} = 0.4\ V$

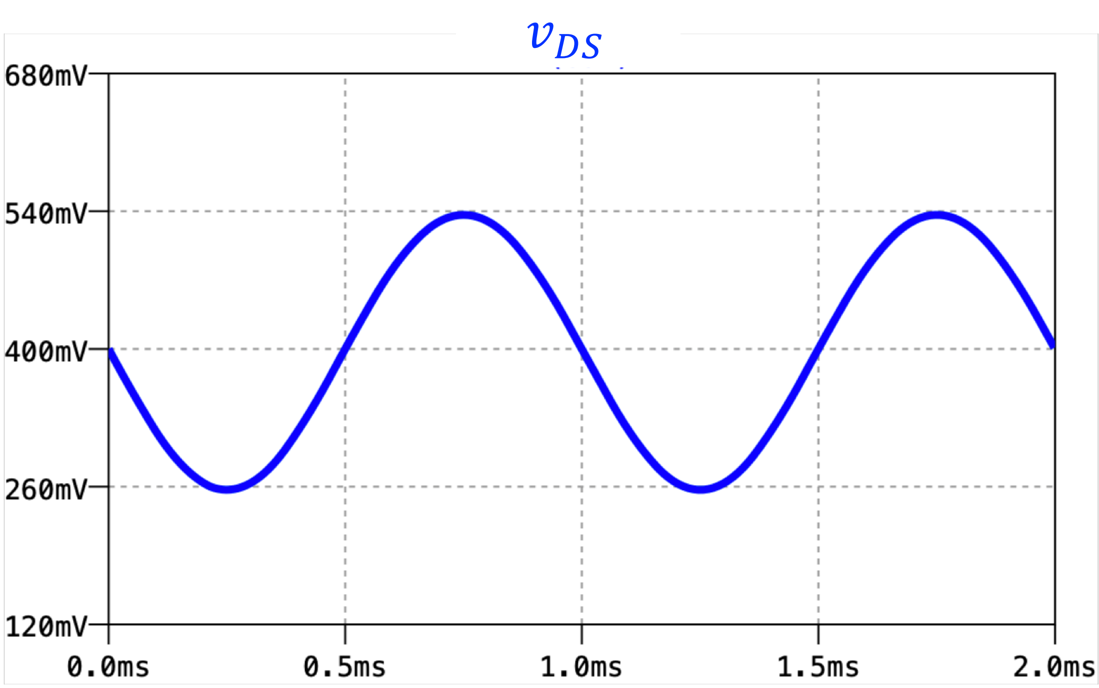
$I_D = 0.08\ mA$

$$g_m = \frac{i_d}{v_{gs}} = 0.08\ \ mA/V$$

$$v_{gs} = 0.01\ sin(2\pi f t)\ (V)$$







$$@\ Q{:}\quad V_{GS} = 0.6\ V$$

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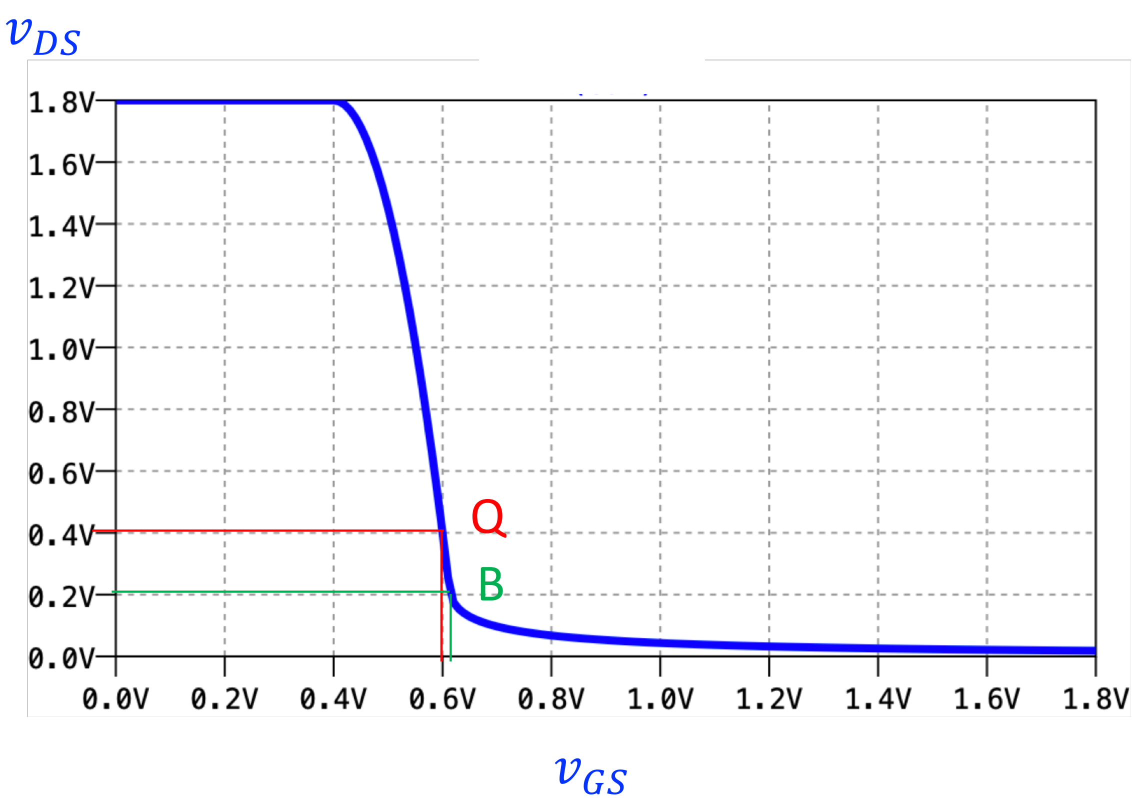
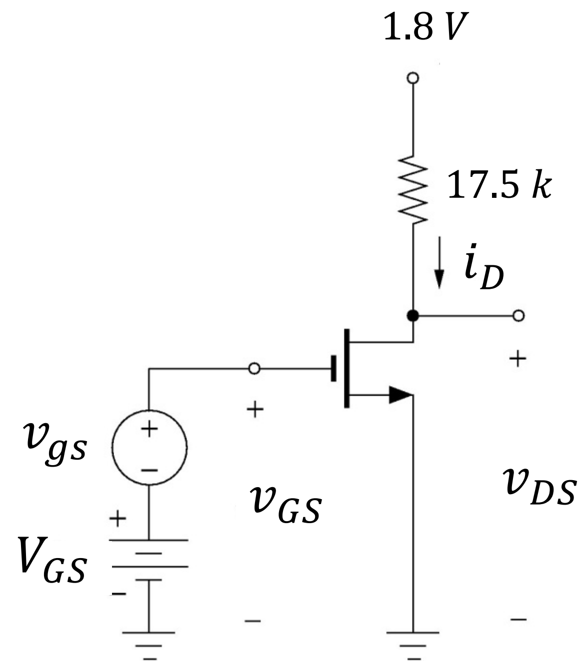
$$A_v = \frac{v_{ds}}{v_{gs}} = -14\ V/V$$





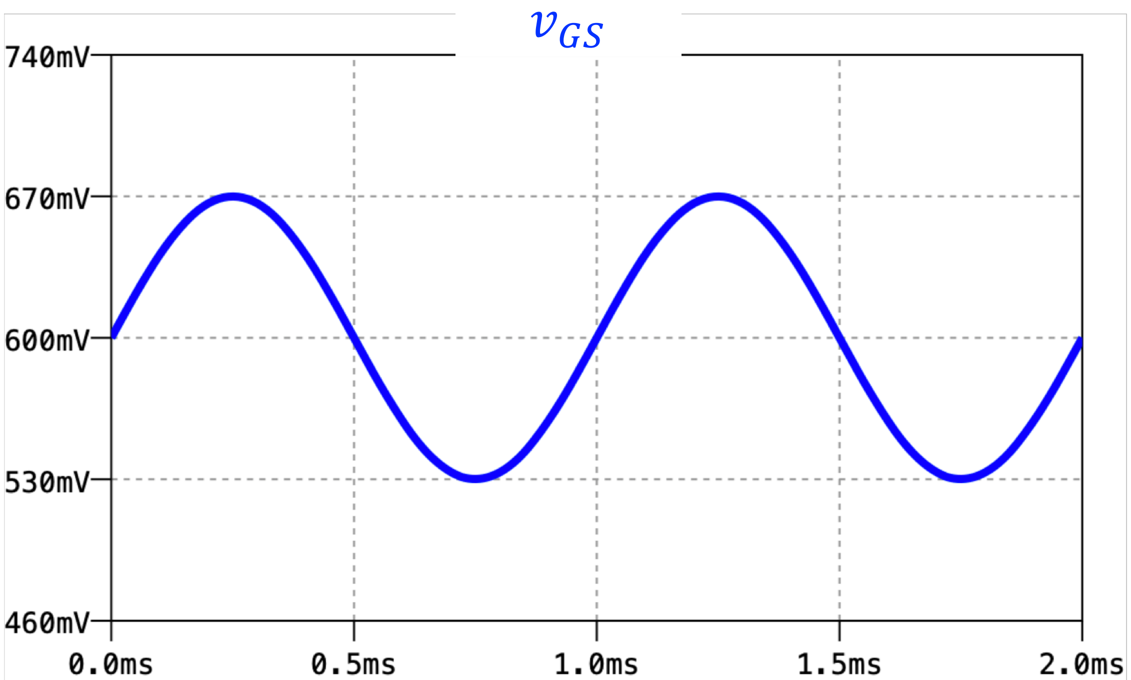
@ Q: $V_{GS} = 0.6\ V$

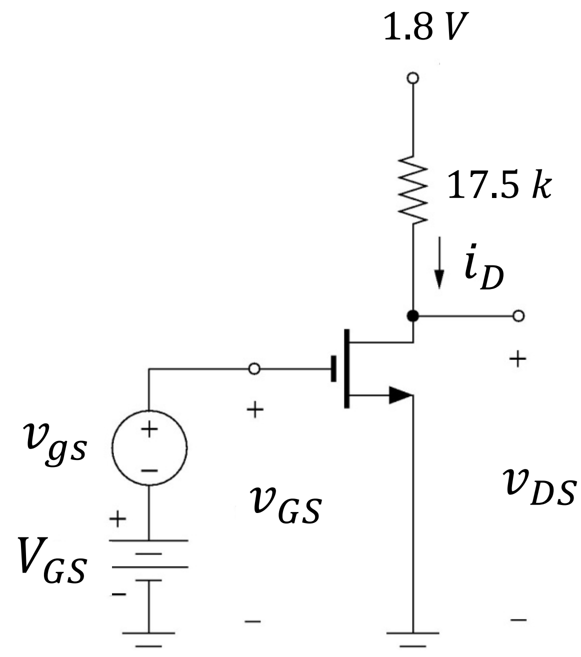
$V_{DS} = 0.4\ V$

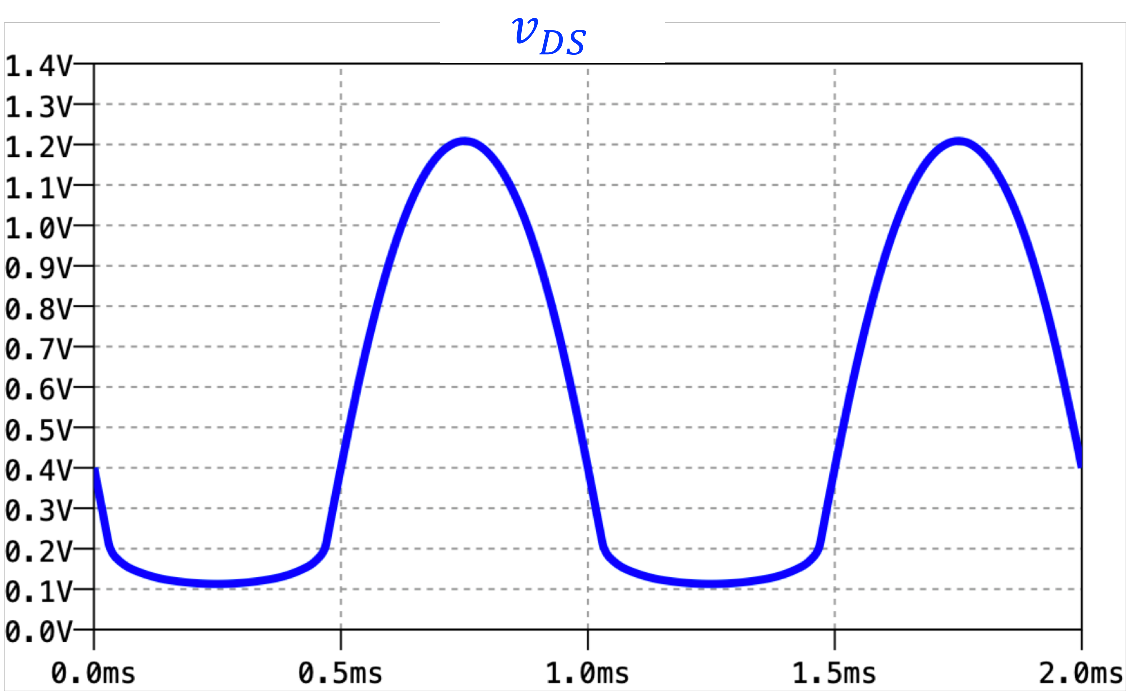
$I_D = 0.08\ mA$

$V_{OV} = 0.2\ V$

$v_{gs} = 0.07 \sin(2\pi f_1 t) \quad (V)$







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