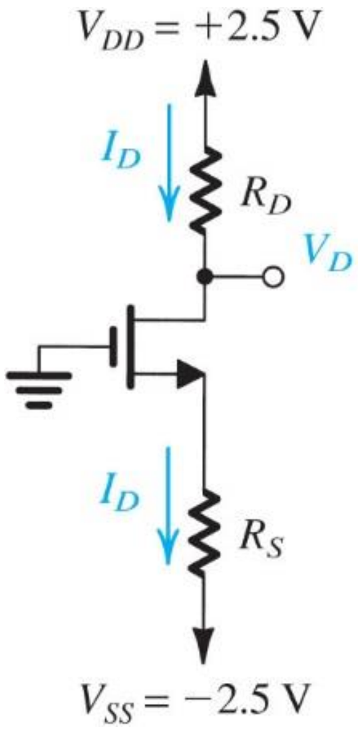
MOSFET at DC

Exercise

- Design the circuit in the figure to have $I_D = 0.3$ mA and $V_D = 0.3$V.
- Assume
  - $V_T = 0.5$ V
  - $\mu_n C_{ox} = 400\ \mu A V^{-2}$
  - $L = 0.4\ \mu m$
  - $W = 5\ \mu m$



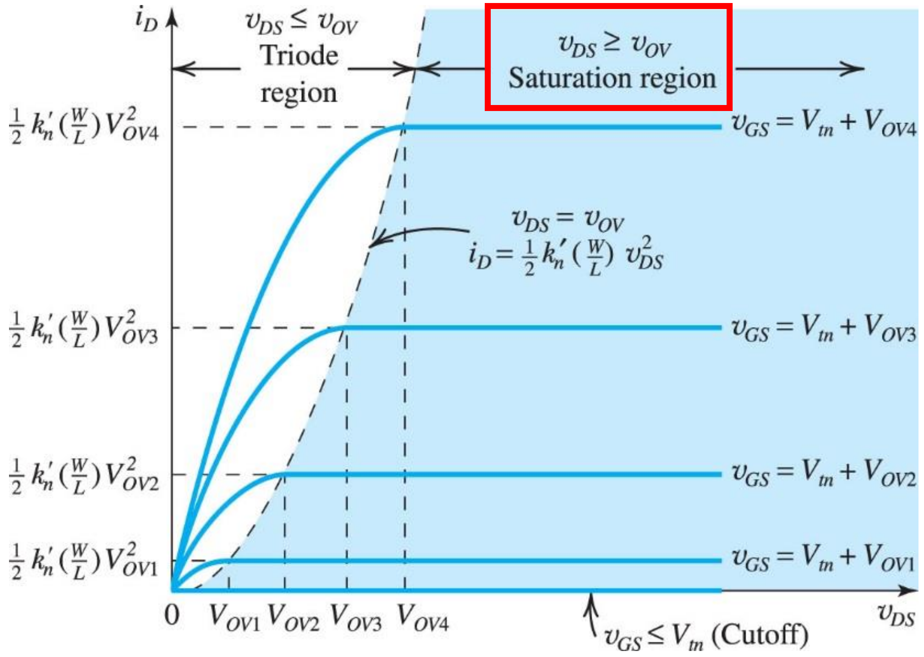
MOSFET as amplifier

MOSFET as amplifier

- Transistors can be used as switches and as amplifier, depending in which region of their IV characteristic they are operated in

- To use a MOSFET as an amplifier, it has to be operated in saturation where it behaves as a voltage controlled current source

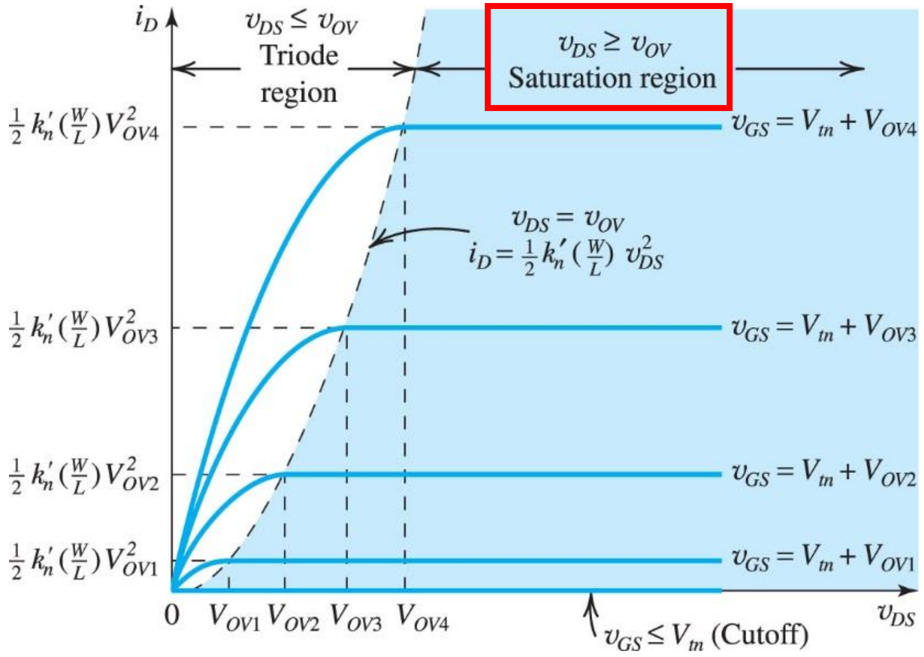
$$i_D = \frac{1}{2}(\mu_n C_{OX})\left(\frac{W}{L}\right)(v_{GS} - V_t)^2$$



MOSFET as amplifier

- MOSFET in saturation
  - The voltage between gate and source, v_{GS}, controls the drain current, i_D
  - In first approximation, ignoring the channel length modulation effect, i_D in saturation does not depend on v_{DS} because the channel is pinched off at the drain end

$$i_D = \frac{1}{2}(\mu_n C_{OX})\left(\frac{W}{L}\right)(v_{GS} - V_t)^2$$



MOSFET as amplifier

- For the transistor to work in saturation $v_{DS} \geq v_{OV}$
  - This implies that that $v_{GD} \leq V_t$
  - No charge left at drain end → the channel is pinched off

- How do we design a linear amplifier using such a non-linear device? → Bias and small signal model

Saturation Region

Pinched-off channel, obtained by:

$$v_{GD} \leq V_{tn}$$

or equivalently:

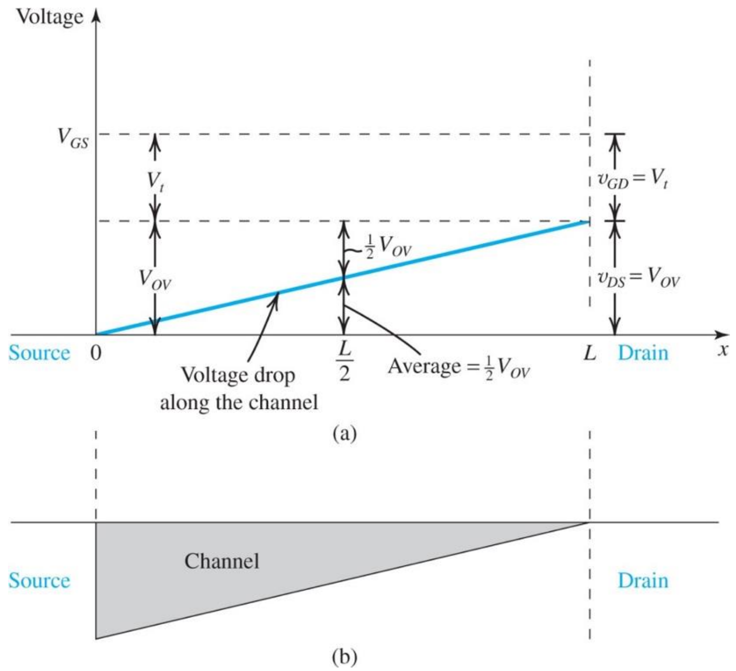
$$v_{DS} \geq v_{OV}$$

Then

$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)(v_{GS} - V_{tn})^2$$

or equivalently,

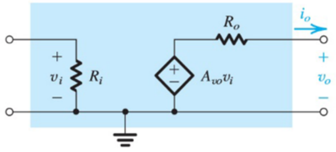
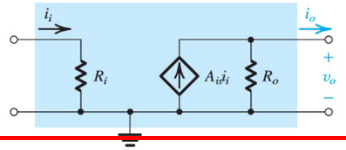
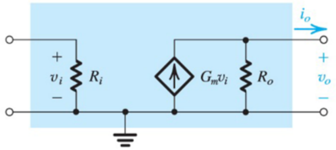
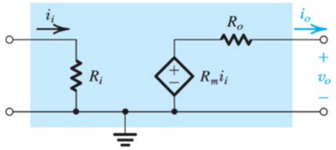
$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)v_{OV}^2$$



Voltage amplifier

- The MOSFET is a transconductance amplifier, i.e. an amplifier whose input signal is a voltage and whose output signal is a current

Table 1.1 The Four Amplifier Types

Type	Circuit Model	Gain Parameter	Ideal Characteristics
Voltage Amplifier		Open-Circuit Voltage Gain $A_{vo} \equiv \frac{v_o}{v_i}\Big\rvert_{i_o=0}$ (V/V)	$R_i = \infty$ $R_o = 0$
Current Amplifier		Short-Circuit Current Gain $A_{is} \equiv \frac{i_o}{i_i}\Big\rvert_{v_o=0}$ (A/A)	$R_i = 0$ $R_o = \infty$
Transconductance Amplifier		Short-Circuit Transconductance $G_m \equiv \frac{i_o}{v_i}\Big\rvert_{v_o=0}$ (A/V)	$R_i = \infty$ $R_o = \infty$
Transresistance Amplifier		Open-Circuit Transresistance $R_m \equiv \frac{v_o}{i_i}\Big\rvert_{i_o=0}$ (V/A)	$R_i = 0$ $R_o = 0$

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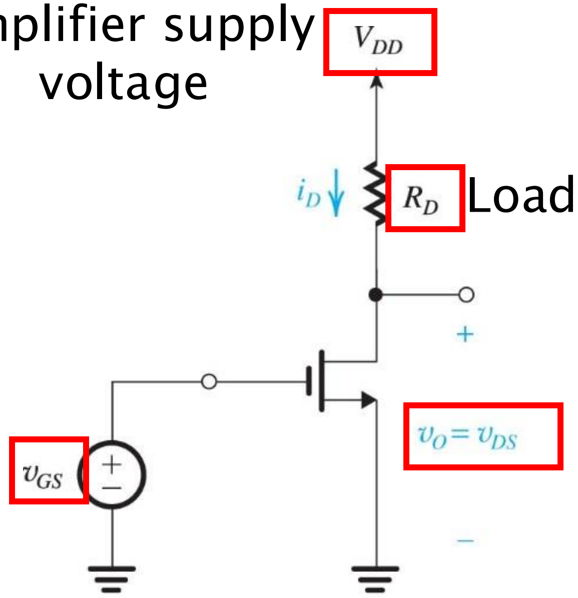
Voltage amplifier

- To obtain a voltage amplifier, make i_D flow into a resistor

Common source configuration

Amplifier supply voltage

Load resistance



(a)

Input voltage

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

DC bias

Signal

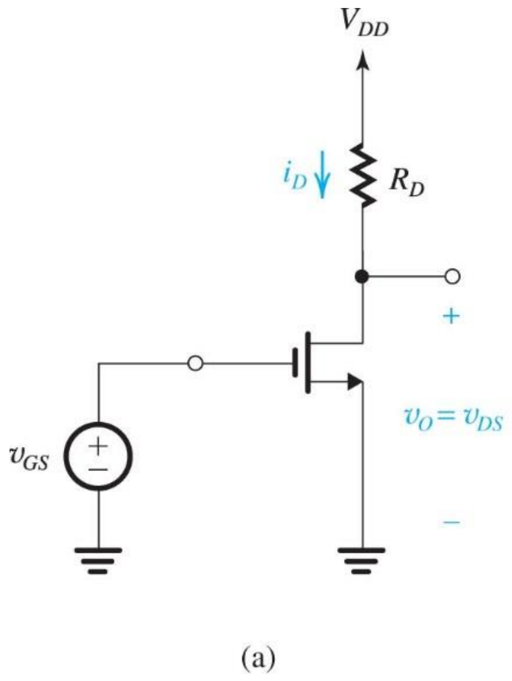
Output voltage

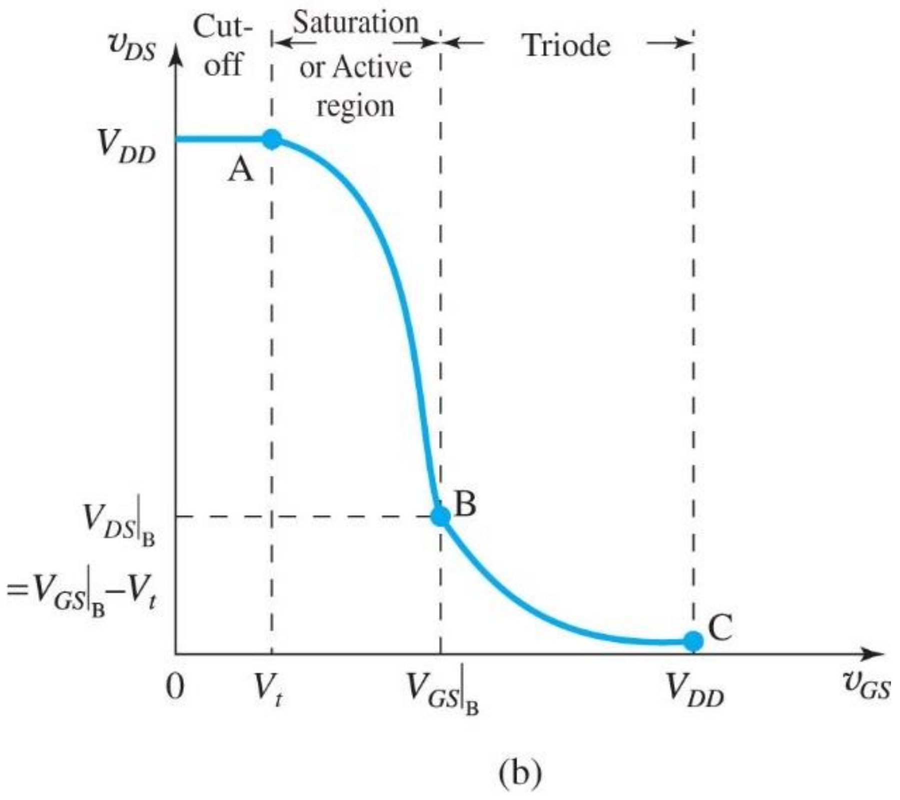
$v_O = v_{DS} = V_{DD} - i_D R_D = V_{DD} - \frac{1}{2} k_n (v_{GS} - V_t)^2 R_D$

$[k_n = (\mu_n C_{OX})]$

Voltage amplifier

- The voltage transfer characteristics (VTC) plots output voltage vs input voltage





Output voltage

$$v_O = v_{DS} = V_{DD} - i_D R_D = V_{DD} - \frac{1}{2} k_n (v_{GS} - V_t)^2 R_D$$

Obtaining linear amplification

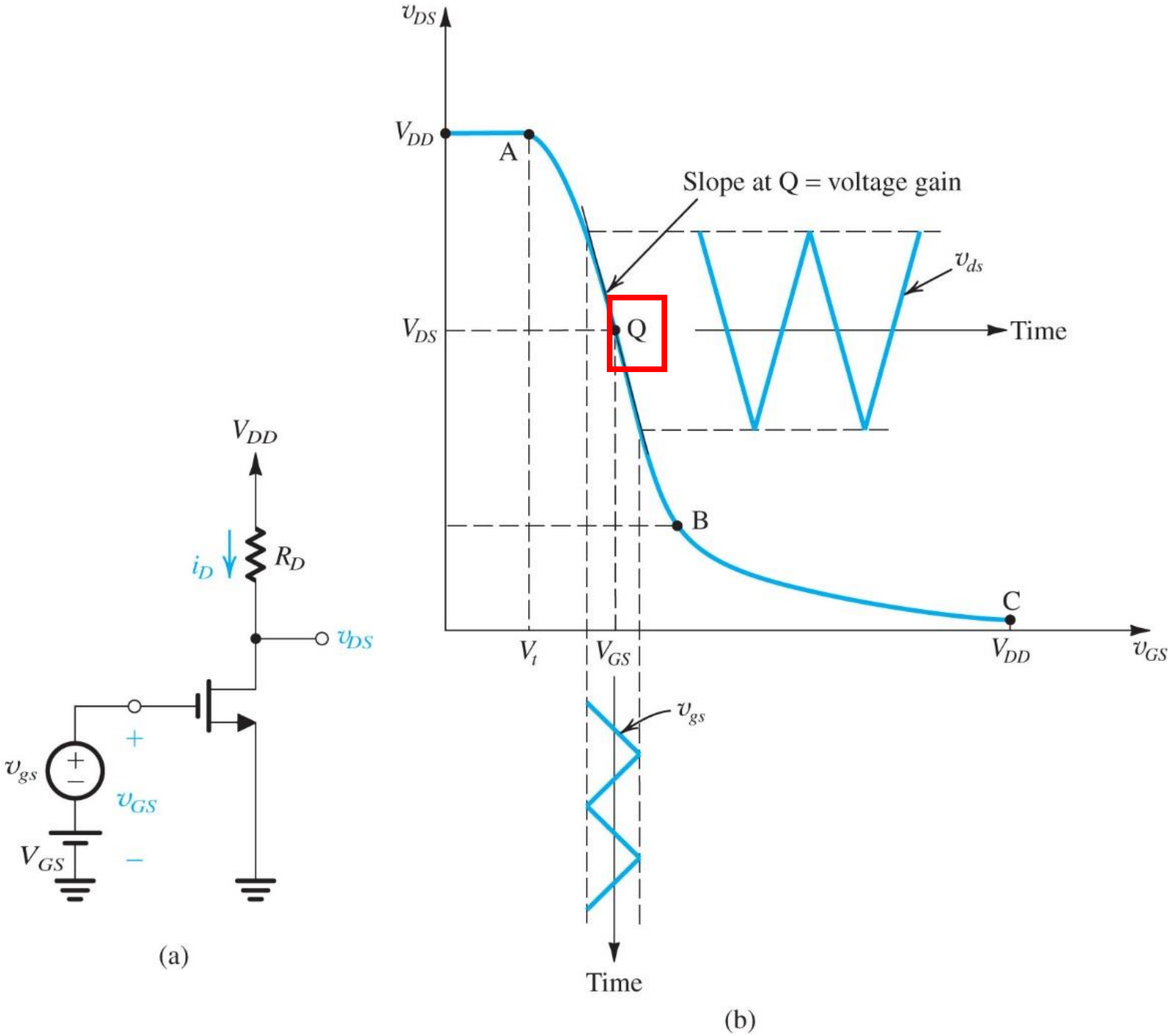
- Let's first consider the DC component of the input signal, V_{GS}

- This is chosen to select operation at a point Q in the saturation region of the VTC

- Q is known as bias point/dc operating point/quiescent point

- This V_{GS} defines

$$V_{DS} = V_{DD} - \frac{1}{2} k_n \left(V_{GS} - V_t\right)^2 R_D$$



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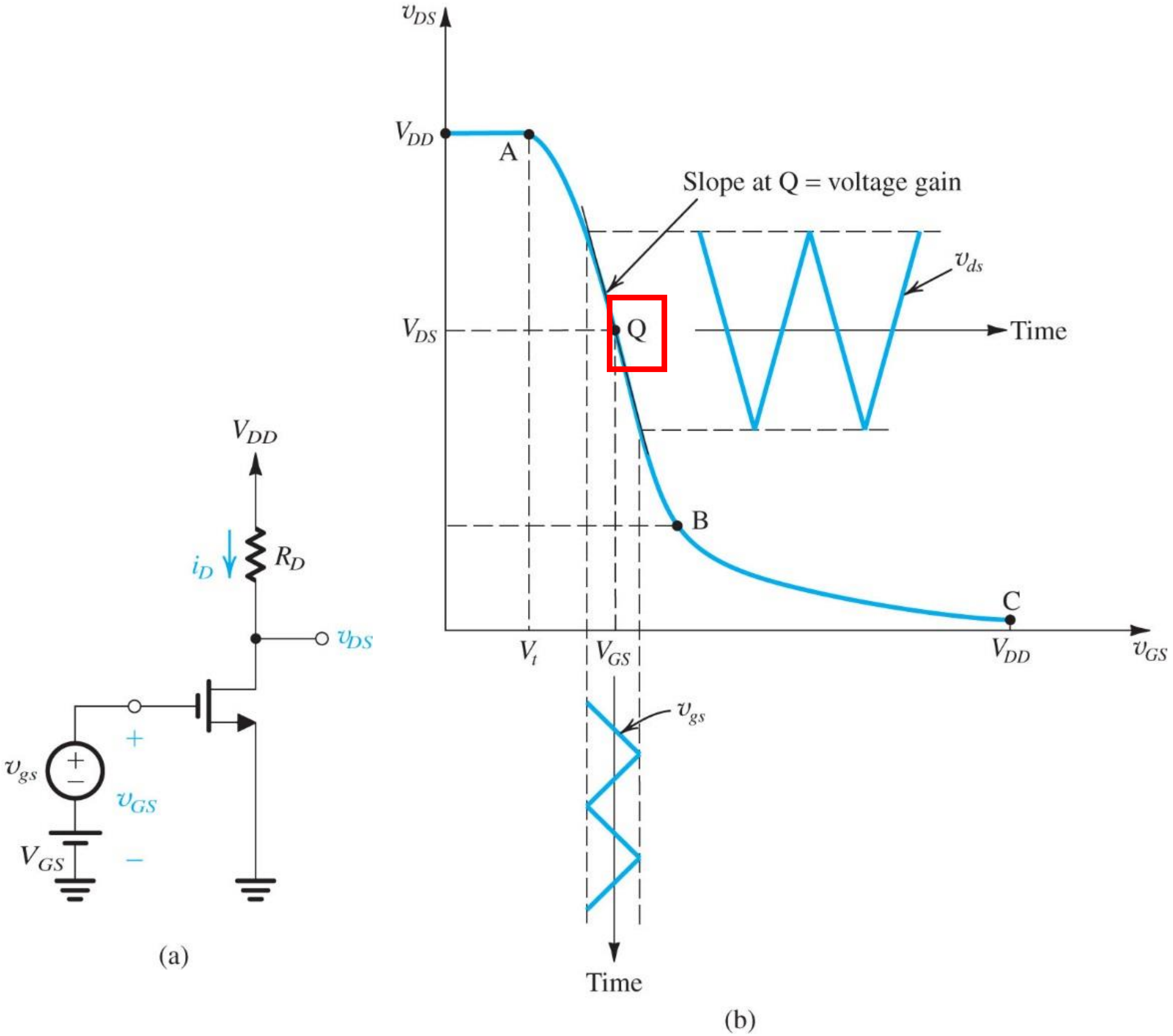
Obtaining linear amplification

- Now let's apply an input signal, v_{gs}, that is superimposed on the DC bias, V_{GS}

$$v_{DS} = V_{DD} - \frac{1}{2} k_n R_D (V_{GS} + v_{gs} - V_t)^{2}$$

- As long as v_{gs} is small, the excursion of the instantaneous operation point is restricted to a small, almost linear portion of the VTC around Q → The output v_{DS} is a linear function of the input

- The smaller the signal, v_{gs}, the greater the linearity

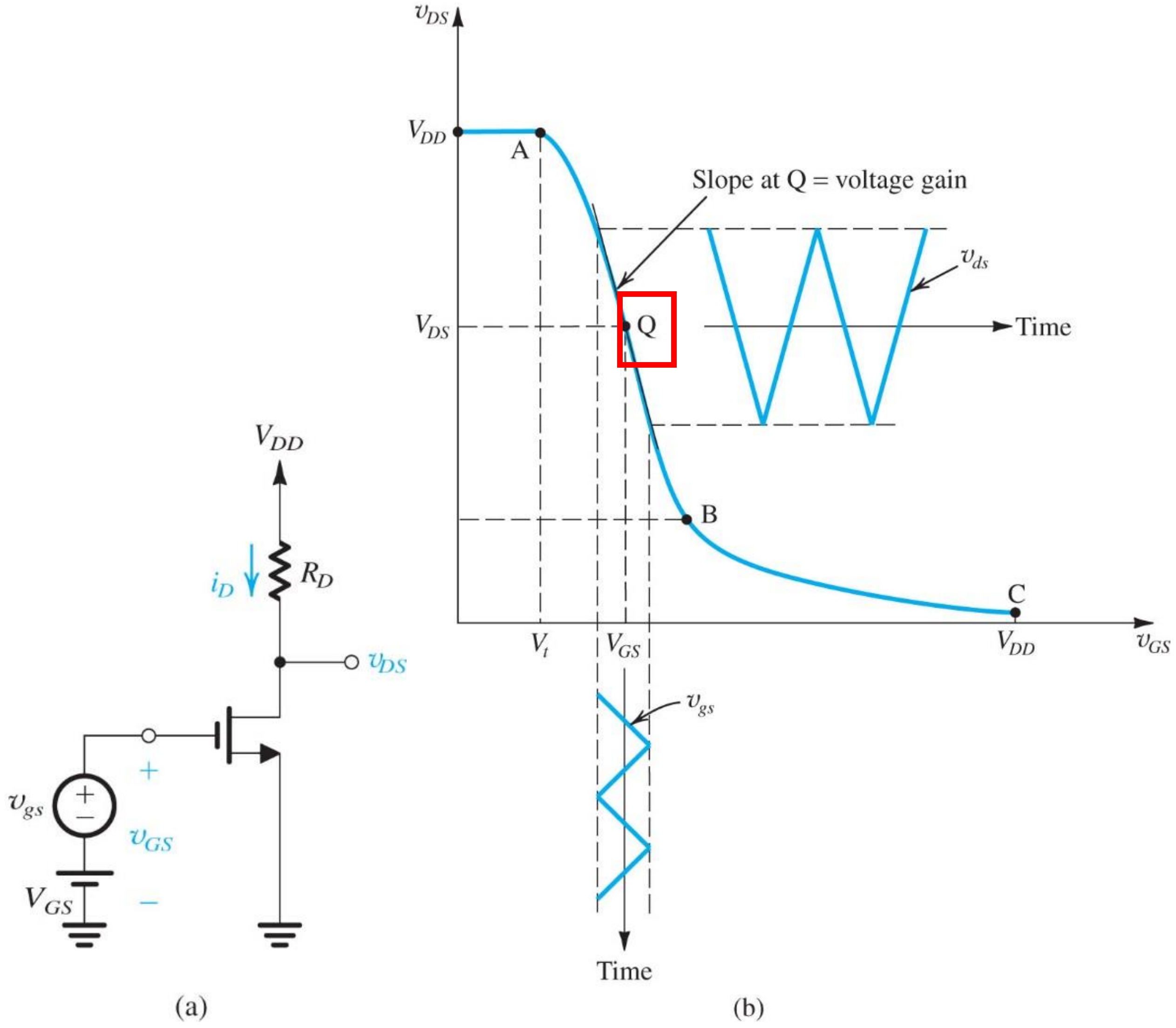


The small-signal voltage gain

- The gain of the amplifier is the slope of the VTC at the bias point Q, i.e. $v_{GS} = V_{GS}$

$$A_v = \frac{dv_{DS}}{dv_{GS}} = -k_n(V_{GS} - V_t)R_D = -k_n V_{OV} R_D$$

- Negative gain = there is a 180º phase shift between input and output → this amplifier is inverting

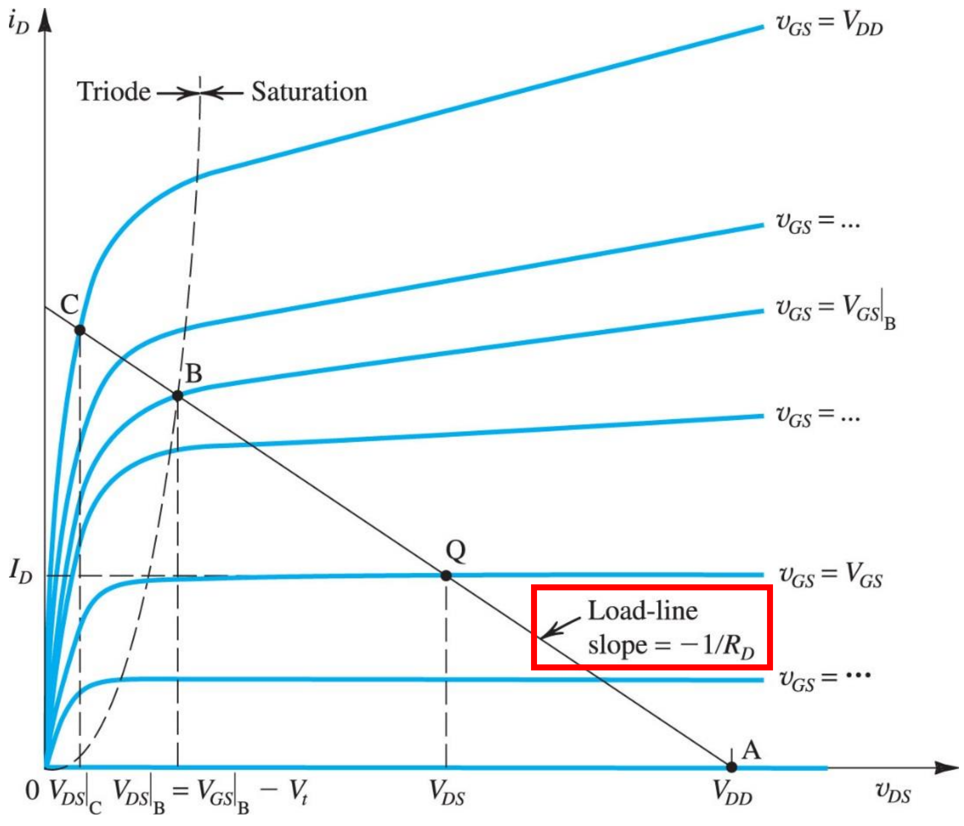


Fixing the bias point Q

- Q needs to be chosen to maximise the allowable output signal swing and the gain

- Q can be obtained graphically as the point where the VTC curve for a certain v_{GS} intersects the load line

- Load line equation: $i_D = \frac{1}{R_D}(V_{DD} - v_{DS})$



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