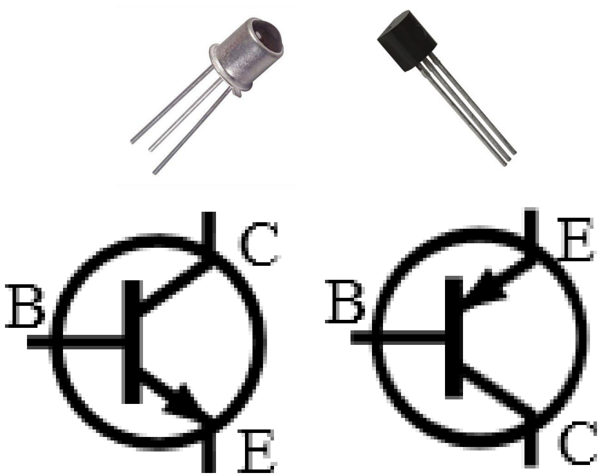
Lab 7 and 8: Characteristics of BJT and Amplification Behavior

EE316-08 Spring 2021

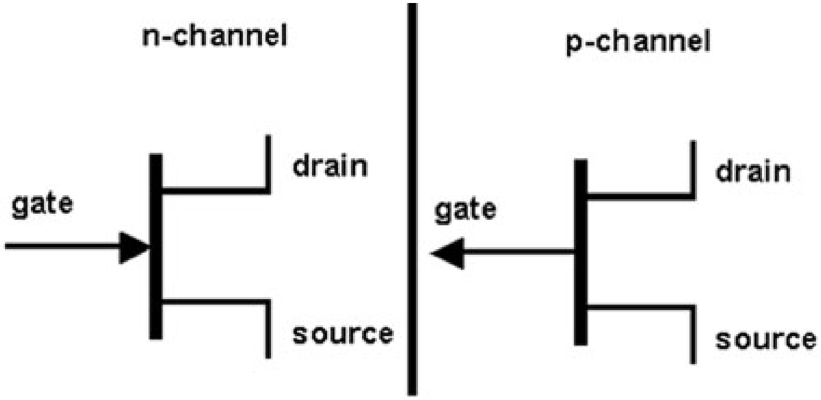
- **Purpose:** The concept and characteristics of **bipolar junction transistors (BJTs)** is introduced. The basic concepts investigated for BJTs carries over into future labs, especially for MOSFETs. Both **NPN** and **PNP constructions** will be considered. Constants and variables relating to BJTs will be discussed and utilized in the procedure section.

Transistors Background

- Transistor is a semiconductor device used as amplifier control or electrically controlled switch.
- Transistors can be found in switching circuits, amplifier circuits, voltage-regulator circuits, etc.
- Two basic types of transistors are **bipolar junction transistors (BJTs)** and **field-effect transistors (FETs).**
- The main difference between BJTs and FETs is that **BJTs are current-controlled** while **FETs are voltage-controlled**.



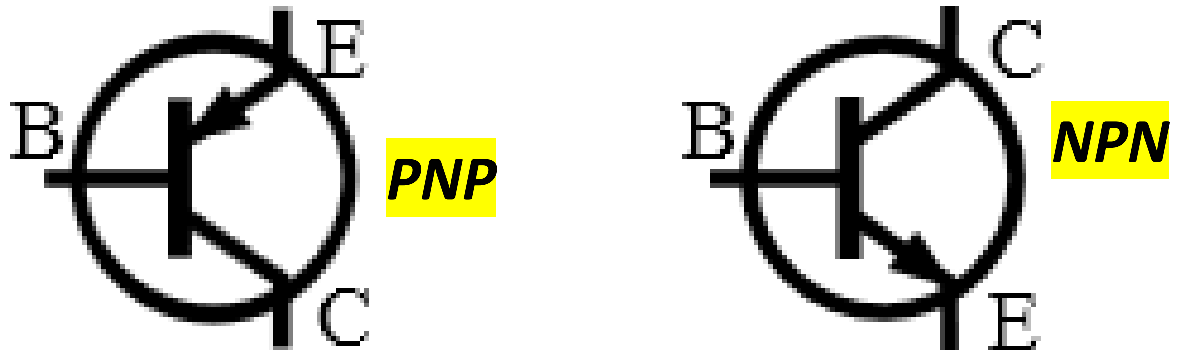
Physical and symbolic representation of BJTs



Symbolic representation of FETs

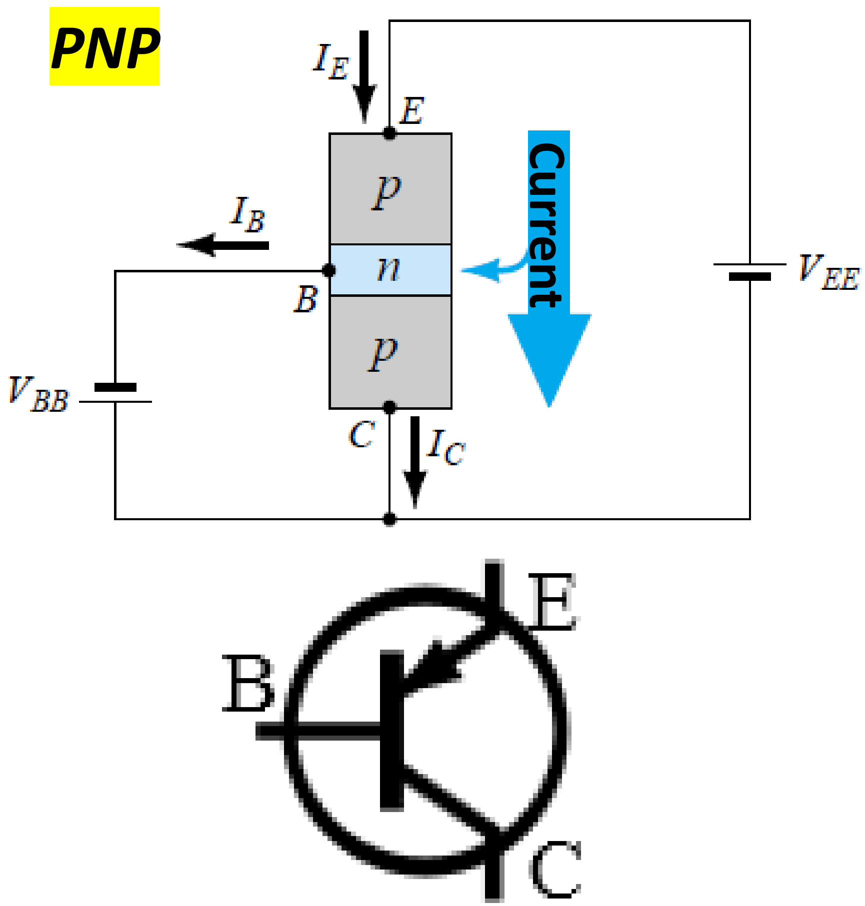
Bipolar Junction Transistors (BJTs)

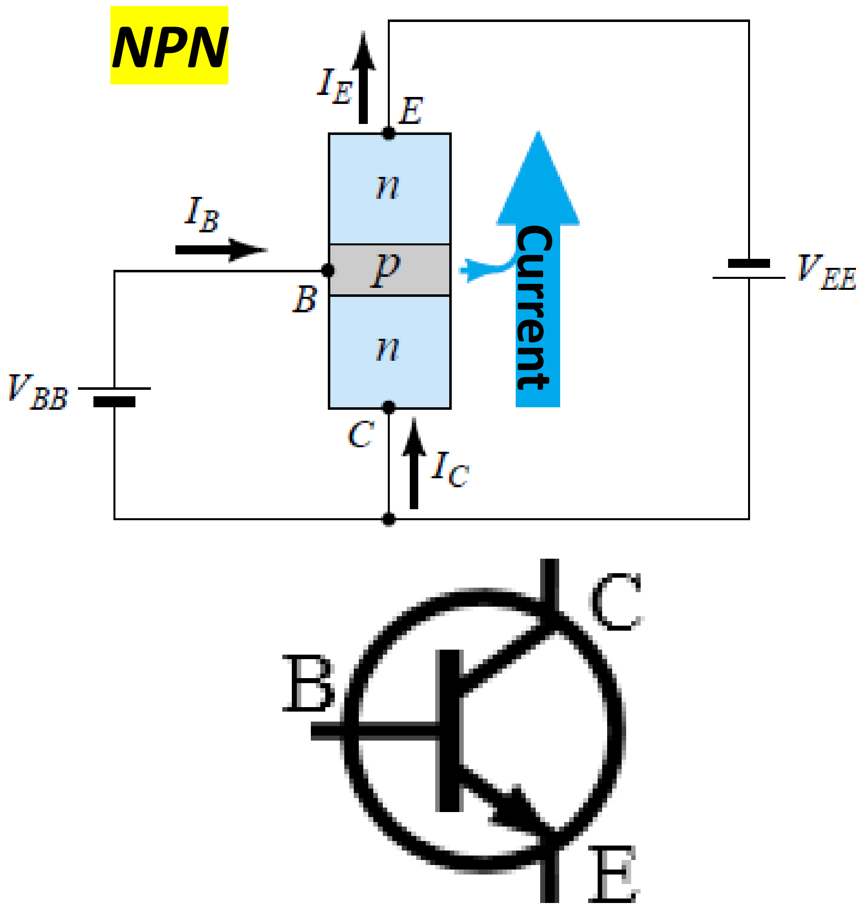
- BJT is the **oldest** and the **most basic** transistor.
- It is a solid-state **current-controlled** device used to electronically switch a circuit.
- BJT is a three-terminal device with **emitter (E)**, **base (B)**, and **collector (C).**
- The current applied to the base (B) controls the current flow through the emitter (E) and collector (C).



Symbolic representation of BJTs

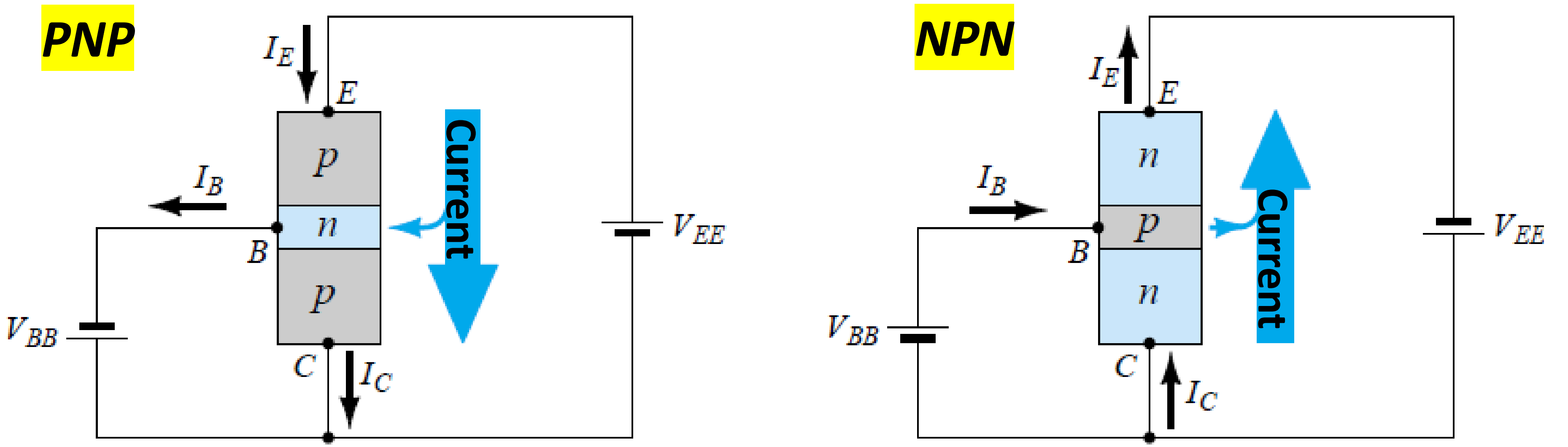
Physical Representation of BJTs



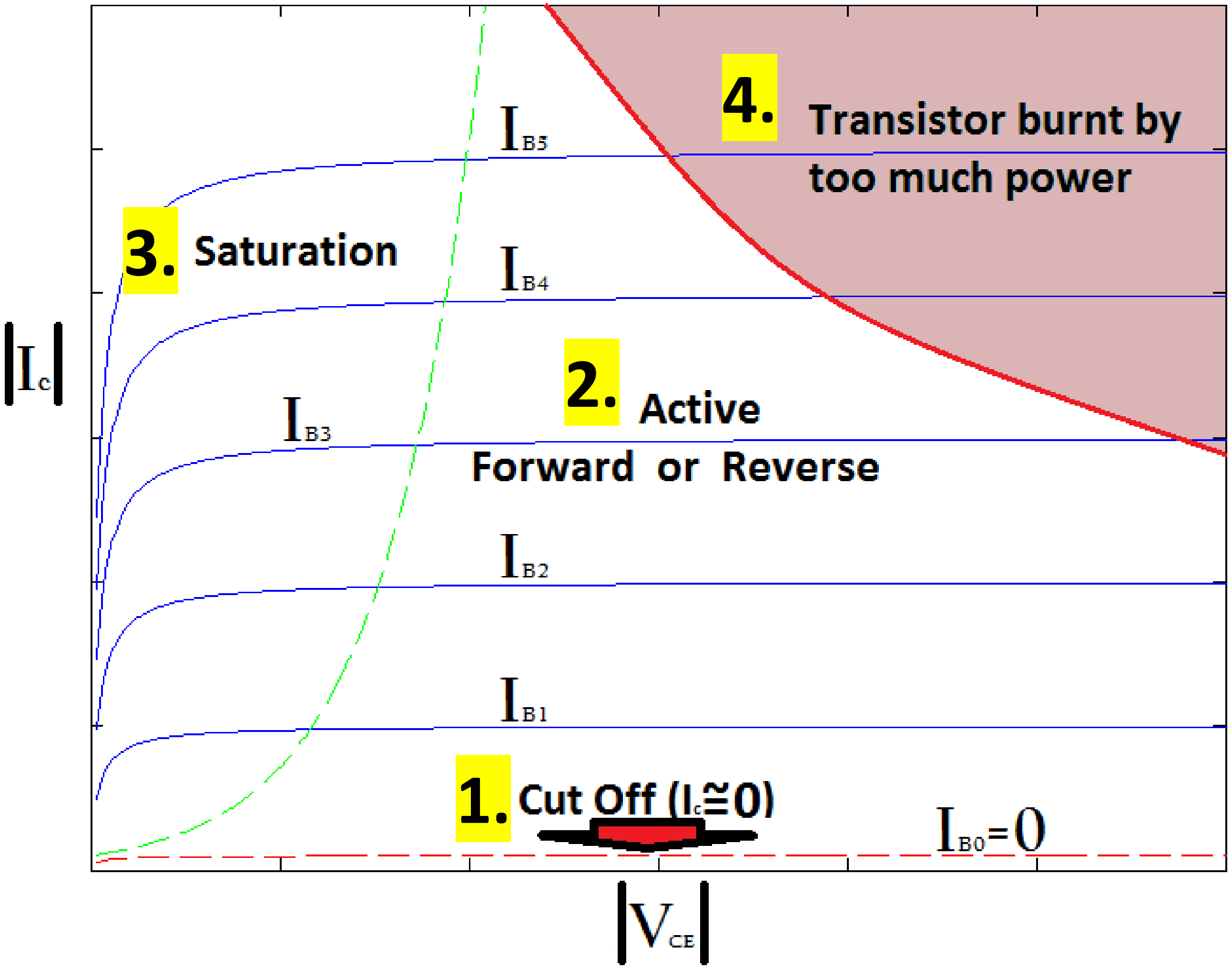


Bipolar Junction Transistors (BJTs)

- BJT is formed by **three layers** of semiconductor materials.
  - **PNP** transistor has **two P-type** regions and **one N-type** region.
  - **NPN** transistor has **two N-type** regions and **one P-type** region.



Characteristics of each region of operation

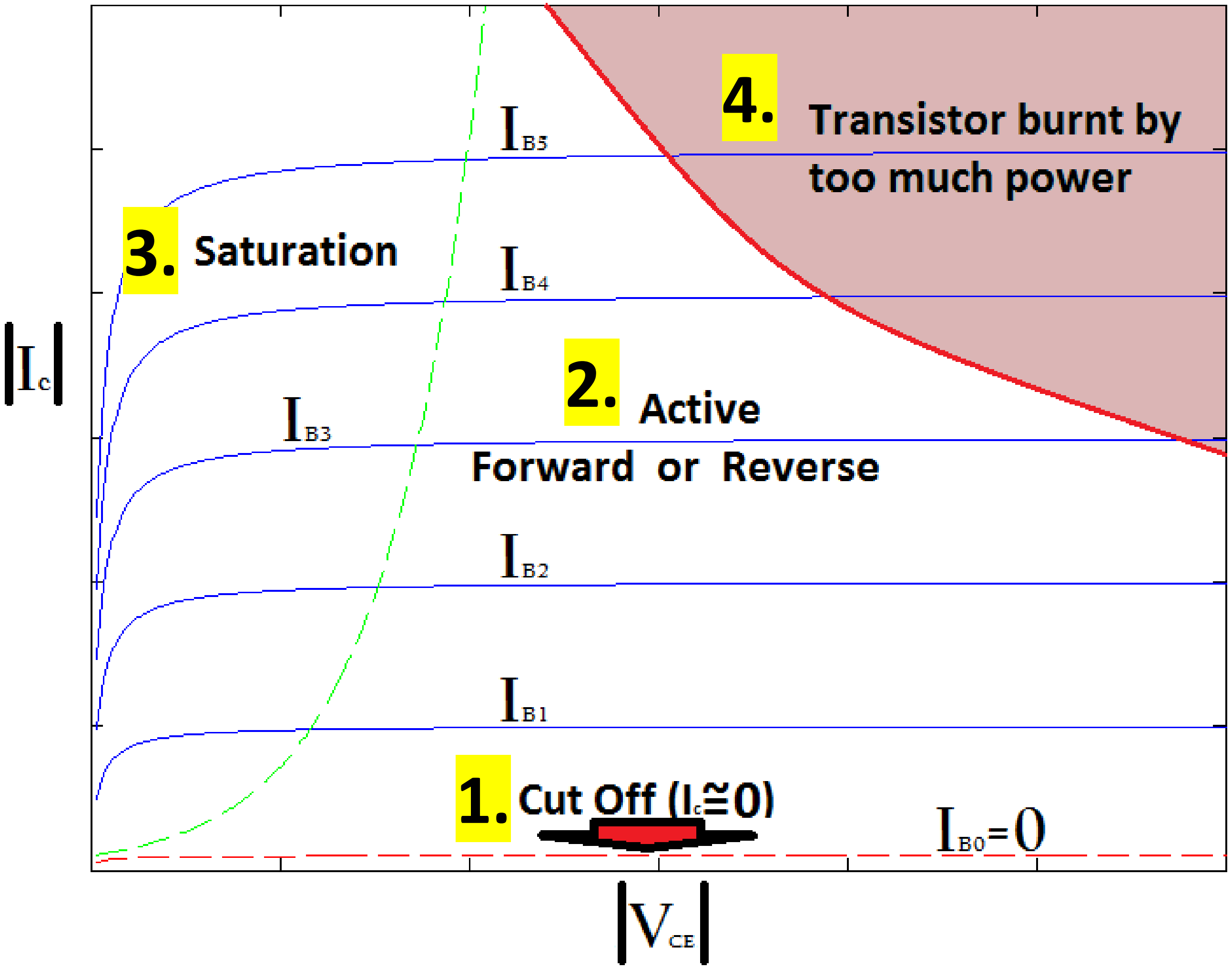


1. **Cuttoff Region**
   - Transistor acts like open switch.
   - No current flow through the device.
   - $I_B = 0$.
2. **Forward Active Region**
   - Transistor is on.
   - Transistor acts as a linear **amplifier**.
   - I_C is proportional to I_B by a constant called beta. Thus, we will observe the following equation

$$\beta = {}^{I_C}\!/_{I_B}$$

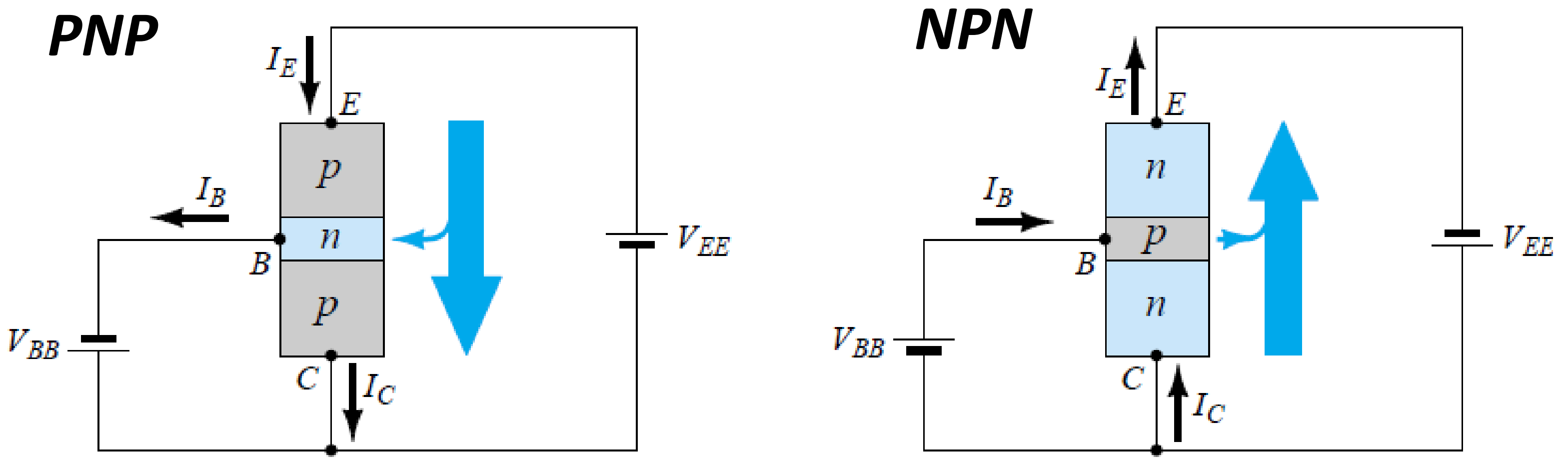
   - High voltage gain and high beta

Characteristics of each region of operation



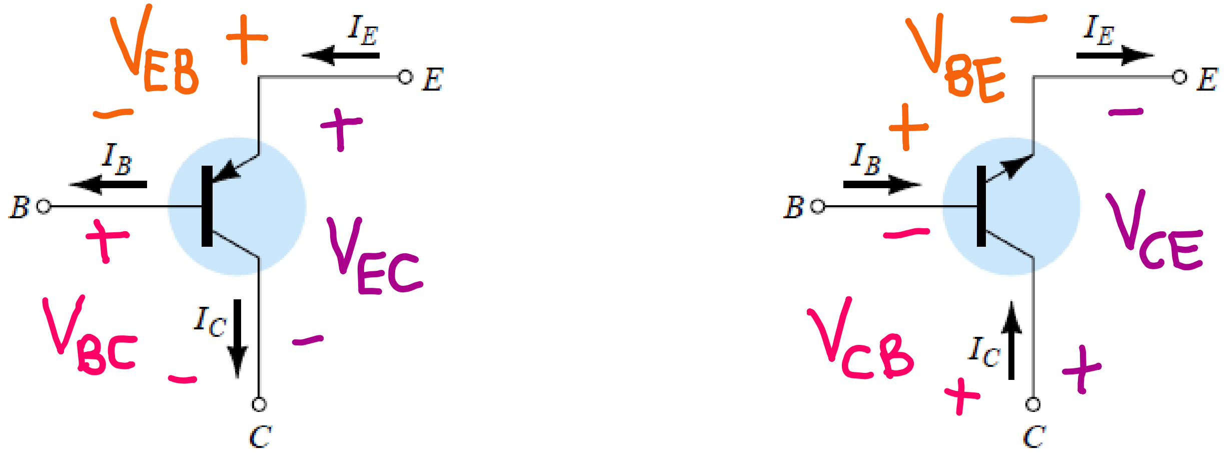
2. **Reverse Active Region**
   - Poor beta.
   - Not useful for any applications.
3. **Saturation Region**
   - Transistor acts like a closed switch.
   - I_C does not depend on I_B
   - I_C reaches a maximum.
4. **Breakdown Region**
   - I_C and V_{CE} exceed specification and cause damage to the transistor.

Useful Equations



$V_{EC} = V_{EB} + V_{BC}$

$V_{CE} = V_{BE} + V_{CB}$



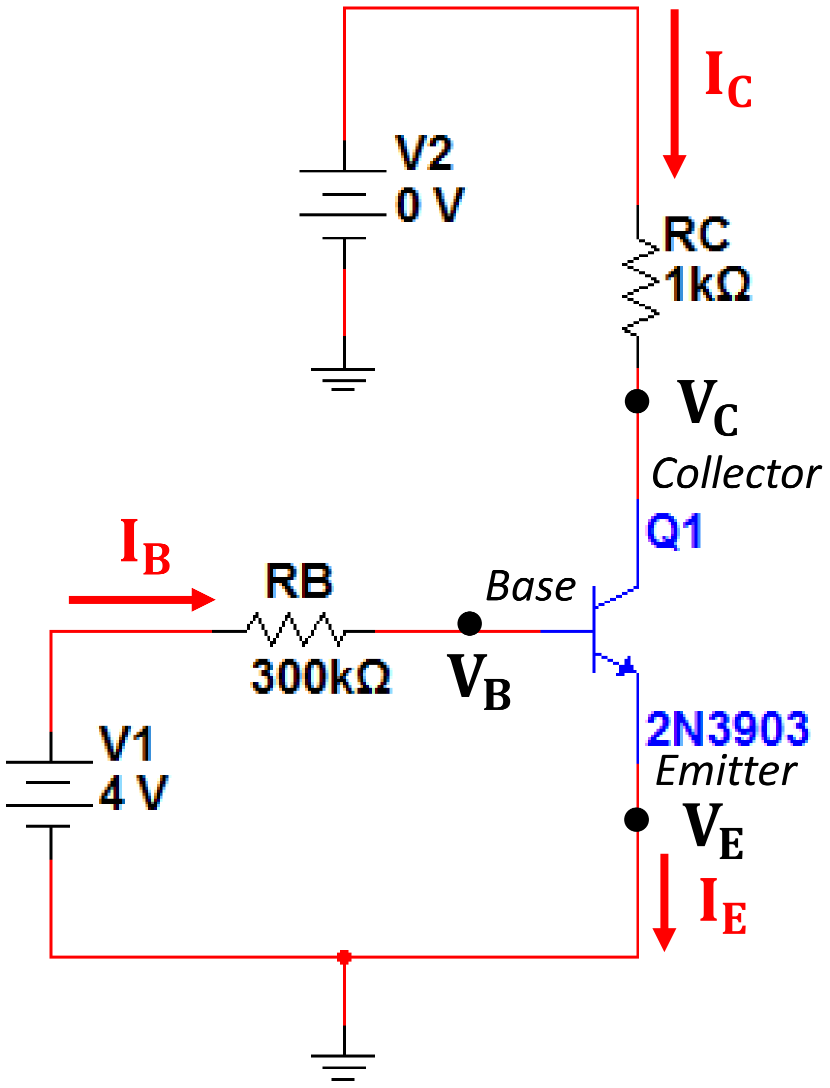
(a) (b)

BJT Kirchoff's Voltage Law: $V_{CE} = V_{CB} + V_{BE}$

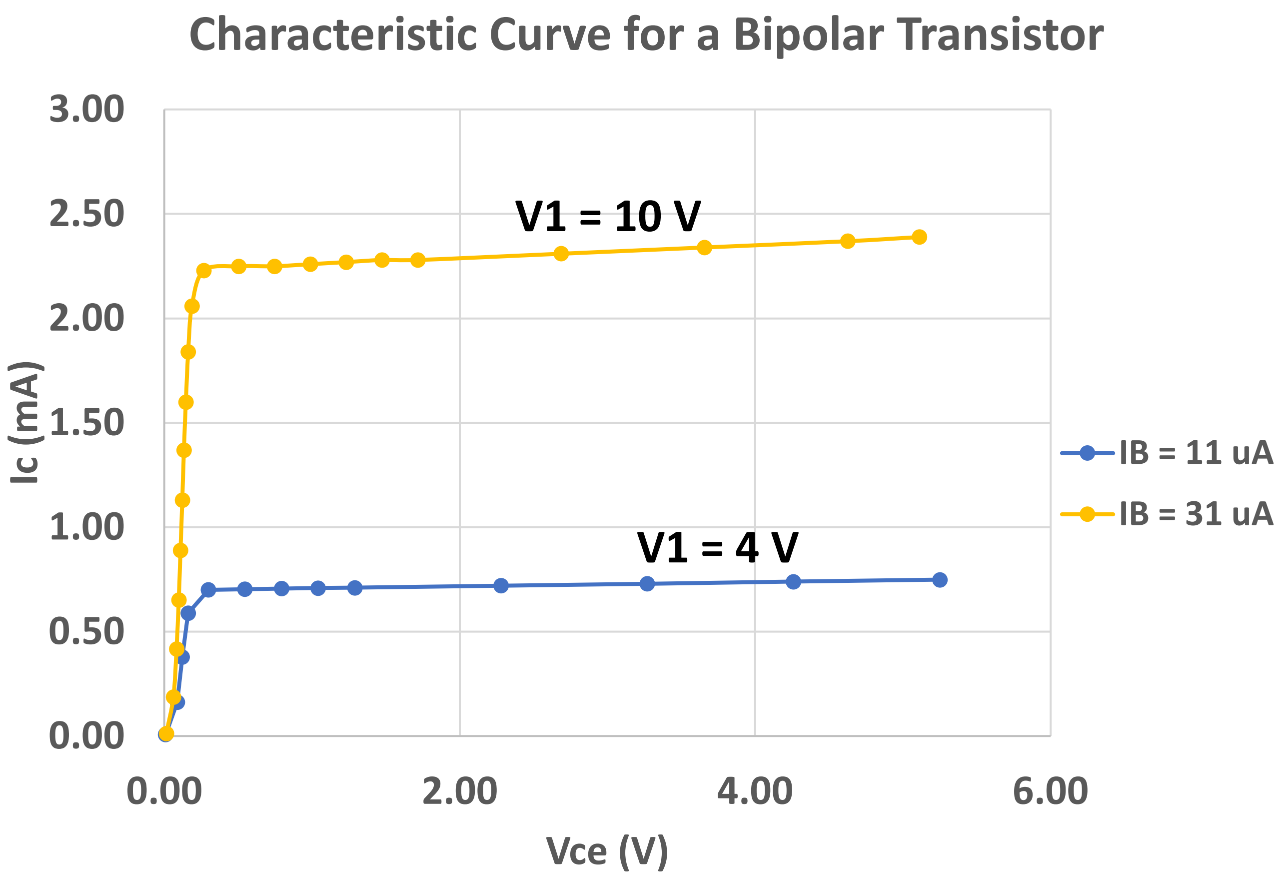
BJT Kirchoff's Current Law: $I_E = I_C + I_B$

Common Emitter Configuration: $\alpha = I_C / I_E$, $\beta = I_C / I_B$, $\alpha = \beta / (\beta + 1)$ and $\beta = \alpha / (1 - \alpha)$

Figure 7.3



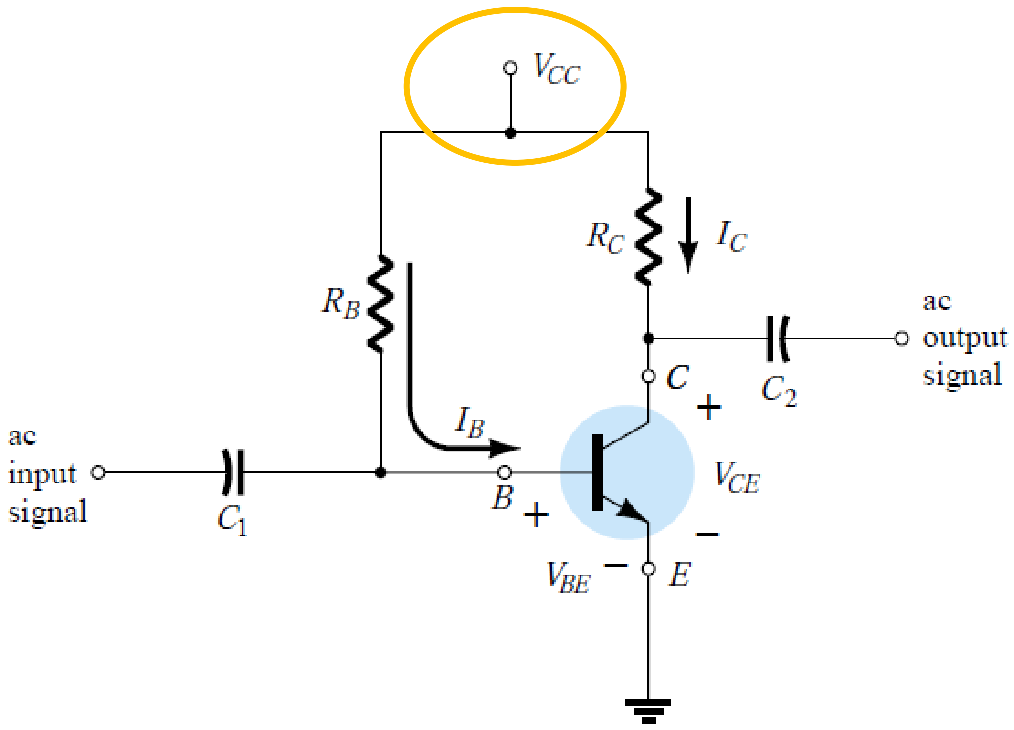
V2
0 V
RC
1kΩ
IC
VC
Collector
Q1
IB
RB
300kΩ
Base
VB
2N3903
Emitter
V1
4 V
VE
IE



Characteristic Curve for a Bipolar Transistor
V1 = 10 V
V1 = 4 V
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Ic (mA)
0.00
2.00
4.00
6.00
Vce (V)
IB = 11 uA
IB = 31 uA

Figure 8.1: Find Vout

Don't forget Vcc



$$Gain(dB) = 20\log\left(Gain(ratio)\right)$$

$$Gain(ratio) = 10^{\frac{Gain(dB)}{20}}$$

$$Gain(ratio) = \frac{V_{out}}{V_{in}}$$

$$V_{out} = Gain(ratio) \times V_{in}$$

$$\boldsymbol{V_{out} = 10^{\frac{Gain(dB)}{20}} \times V_{in}}$$

Table 8.1: Example

Given $V_{in} = 500mV_{peak\ to\ peak} = 250mV_{peak}$

Frequency (Hz)	<u>Calculated</u> Vout (mVpeak)	Gain (ratio)	Gain (dB)	<u>Simulated</u> Vout (mVpeak)
10	0.141	0.00056	-64.97	0.138
30	0.424	0.00169	-55.42	0.420

Step 1: Find Gain(ratio)

$$Gain(dB) = 20\log(Gain(ratio))$$

$$\boldsymbol{Gain(ratio) = 10^{\frac{Gain(dB)}{20}}}$$

$$Gain(ratio)_{at\ 10\ Hz} = 10^{\frac{-64.97}{20}} = 0.00056$$

$$Gain(ratio)_{at\ 30\ Hz} = 10^{\frac{-55.42}{20}} = 0.00169$$

Step 2: Find Vout

$$\boldsymbol{V_{out} = Gain(ratio) \times V_{in}}$$

$$V_{out\ at\ 10\ Hz} = (0.00056) \times (250\ mV_{peak}) = 0.141\ mV_{peak}$$

$$V_{out\ at\ 30\ Hz} = (0.00169) \times (250\ mV_{peak}) = 0.424\ mV_{peak}$$

Summary

- Lab 7 and 8 Report is due Thursday 25th March 2021 by midnight.
- Prelab 9 and 10 is due Tuesday 30th March 2021 by midnight.

- Fill out Table 7.1 and 8.1 with results from…
  - Simulation
  - ~~Experimental results~~

Reference

- Electronic Devices and Circuit Theory, 7th Ed. by Robert Boylestad and Louis Nashelsky.

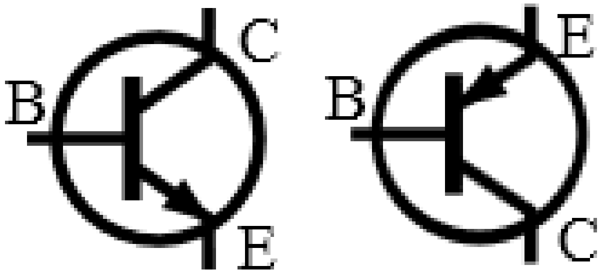
Lab 9 and 10: Operating Characteristics of JFETs

EE316-08 Spring 2021

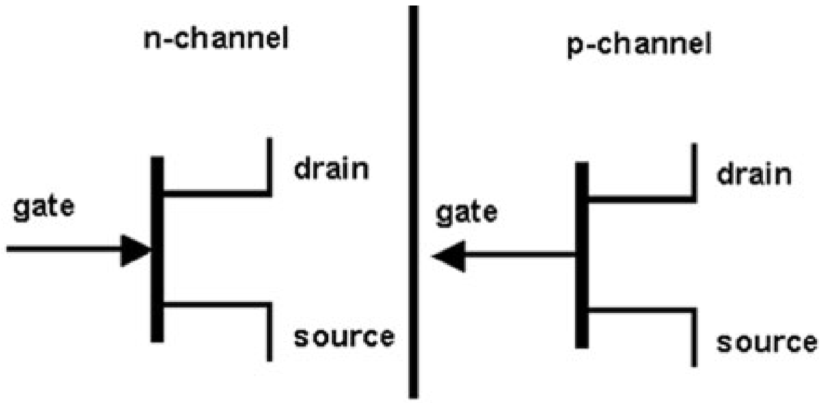
- **Purpose: The concept of the junction field effect transistor (JFET) is introduced.** Understanding the configuration and states of JFETs will aid in the understanding of MOSFETs which will be introduced in later labs. Both NPN and PNP constructions are considered. Constants and variables relating to JFETs are discussed and utilized to convey a full understanding of the material. JFETs have high input impedance and low output noise. These features make JFETs ideal for small signal amplification. Unlike BJTs current can flow from drain to source or vice versa equally.

Recall Transistors Background

- Transistor is a semiconductor device used as amplifier control or electrically controlled switch.
- Transistors can be found in switching circuits, amplifier circuits, and voltage-regulator circuits.
- Two basic types of transistors are **bipolar junction transistors (BJTs)** and **field-effect transistors (FETs).**
- The main difference between BJTs and FETs is that **BJTs are current-controlled** while **FETs are voltage-controlled**.



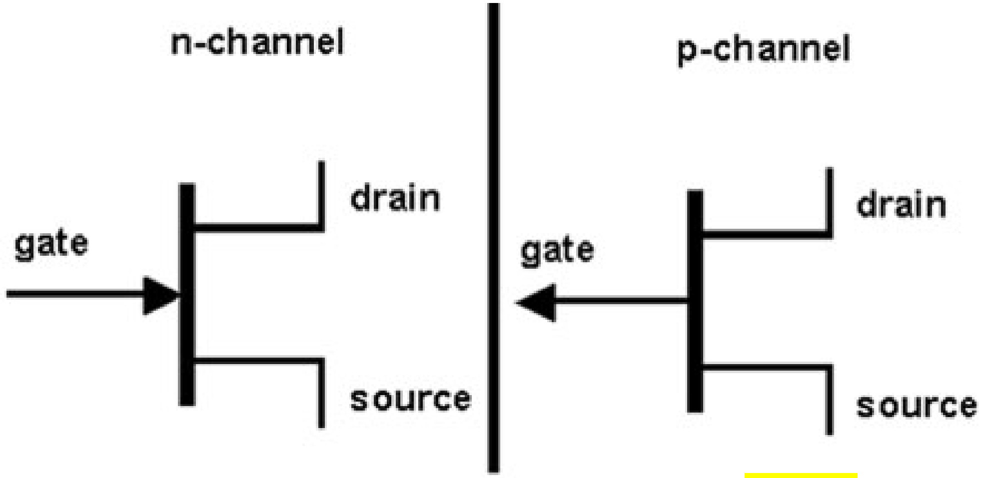
Physical and symbolic representation of BJTs



Symbolic representation of FETs

Junction Field-Effect Transistors (JFETs)

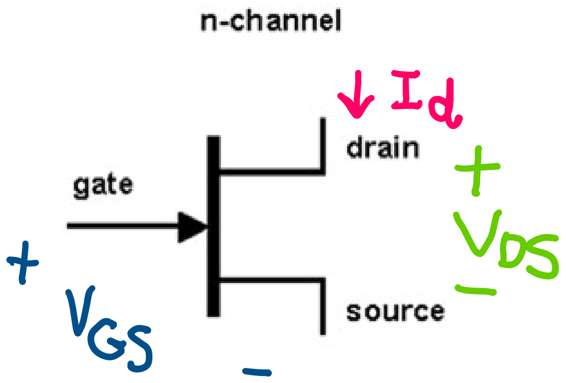
- JFETs are used to electrically control switches, voltage-controlled resistors, and amplifier controls.
- JFETs are three-lead semiconductor devices with **gate (G)**, **drain (D)**, and **source (S).**
- There are two types of JFETs, n-channel or p-channel.



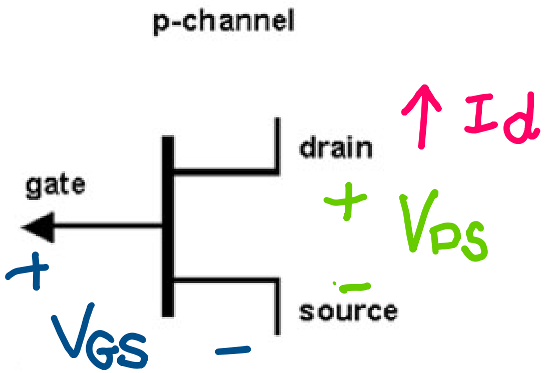
Symbolic representation of JFETs

Junction Field-Effect Transistors (JFETs)

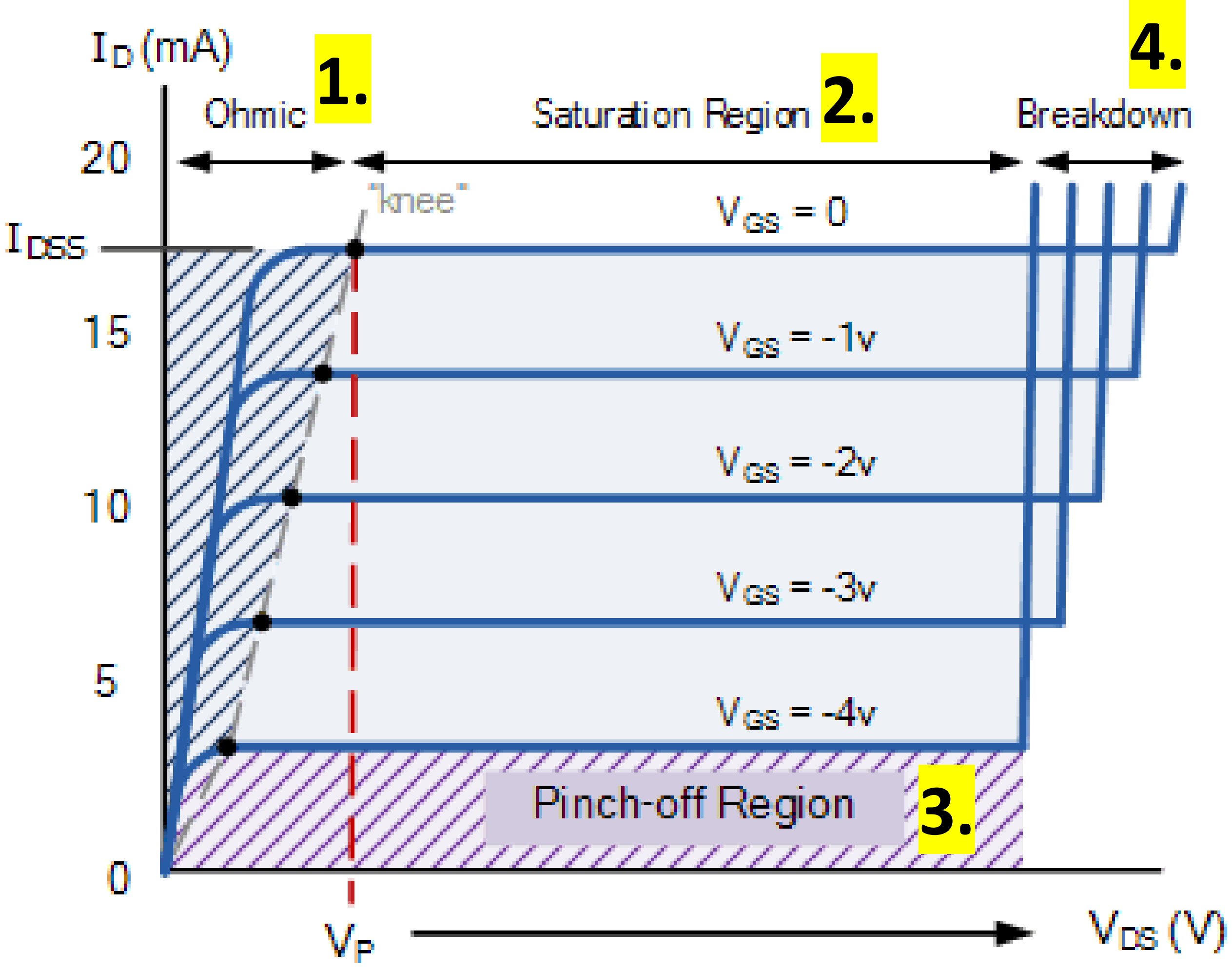
- For n-channel JFET, current flows into the channel region at the drain side and comes out at the source side.
- ***A negative*** voltage applied at the gate side reduces current flow from drain to source.



- For p-channel JFET, current flows into the channel region at the source side and comes out at the drain side.
- ***A positive*** voltage applied at the gate side reduces current flow from source to drain.



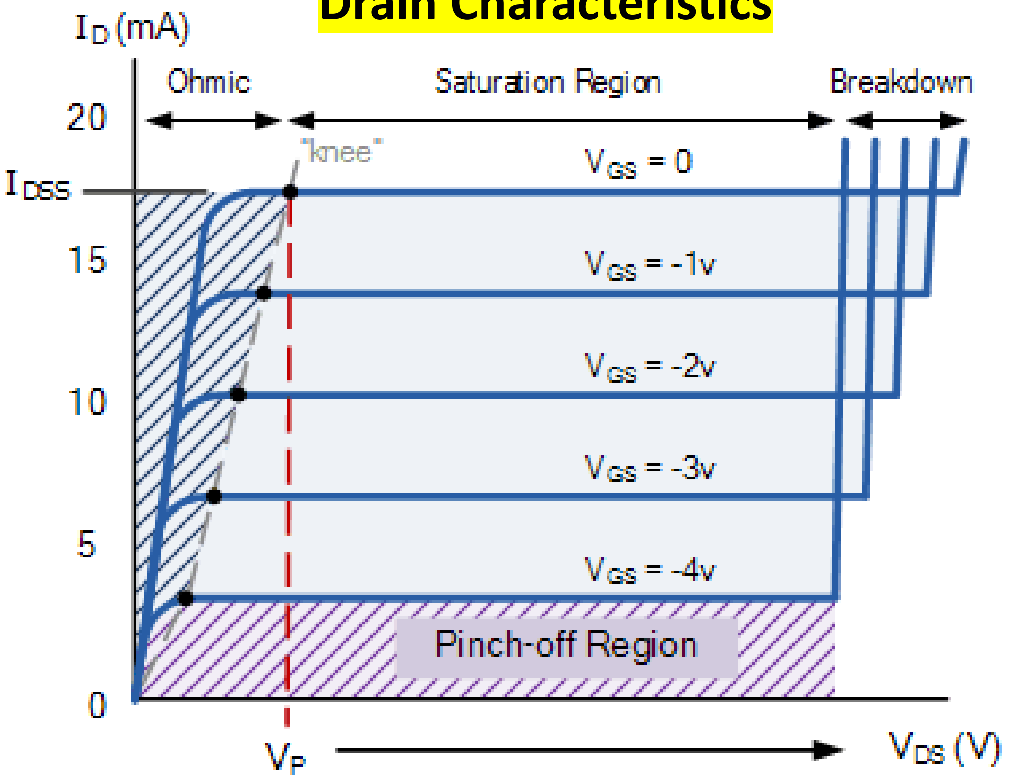
Operating States of JFETs



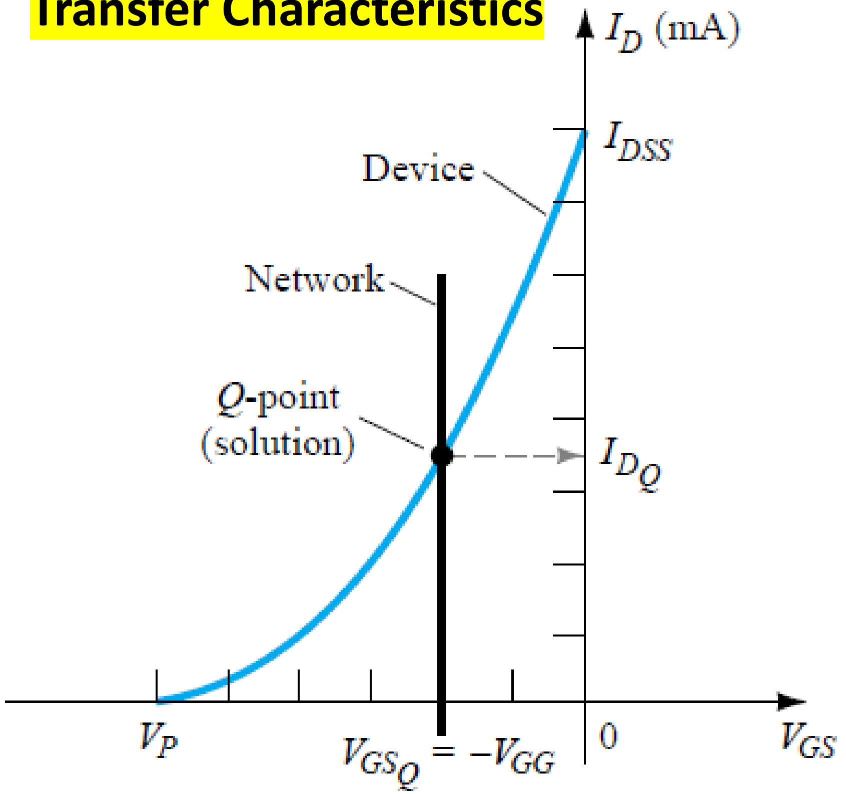
1. **Ohmic (linear)**
   - JFET behaves like a voltage-controlled resistor
2. **Saturation**
   - The drain current is strongly influenced by gate-source voltage but not influenced by drain-source voltage
3. **Pinch-off**
   - JFET acts like open circuit
   - No current flowing through the device
4. **Breakdown**
   - JFET loses ability to resist current because too much voltage applied across the drain-source terminals

Output characteristic V-I curves of a typical JFET

Drain Characteristics



Transfer Characteristics



- **The threshold voltage (V_{TH})** is used to represent the minimum voltage required between the gate and source (V_{GS}) in order to allow current to pass through the body
- **The pinch off voltage (V_P)** is the voltage beyond which the source current is constant (JFET is in saturation). It is defined when the gate to source voltage (V_{GS}) is zero.

Figure 9.4

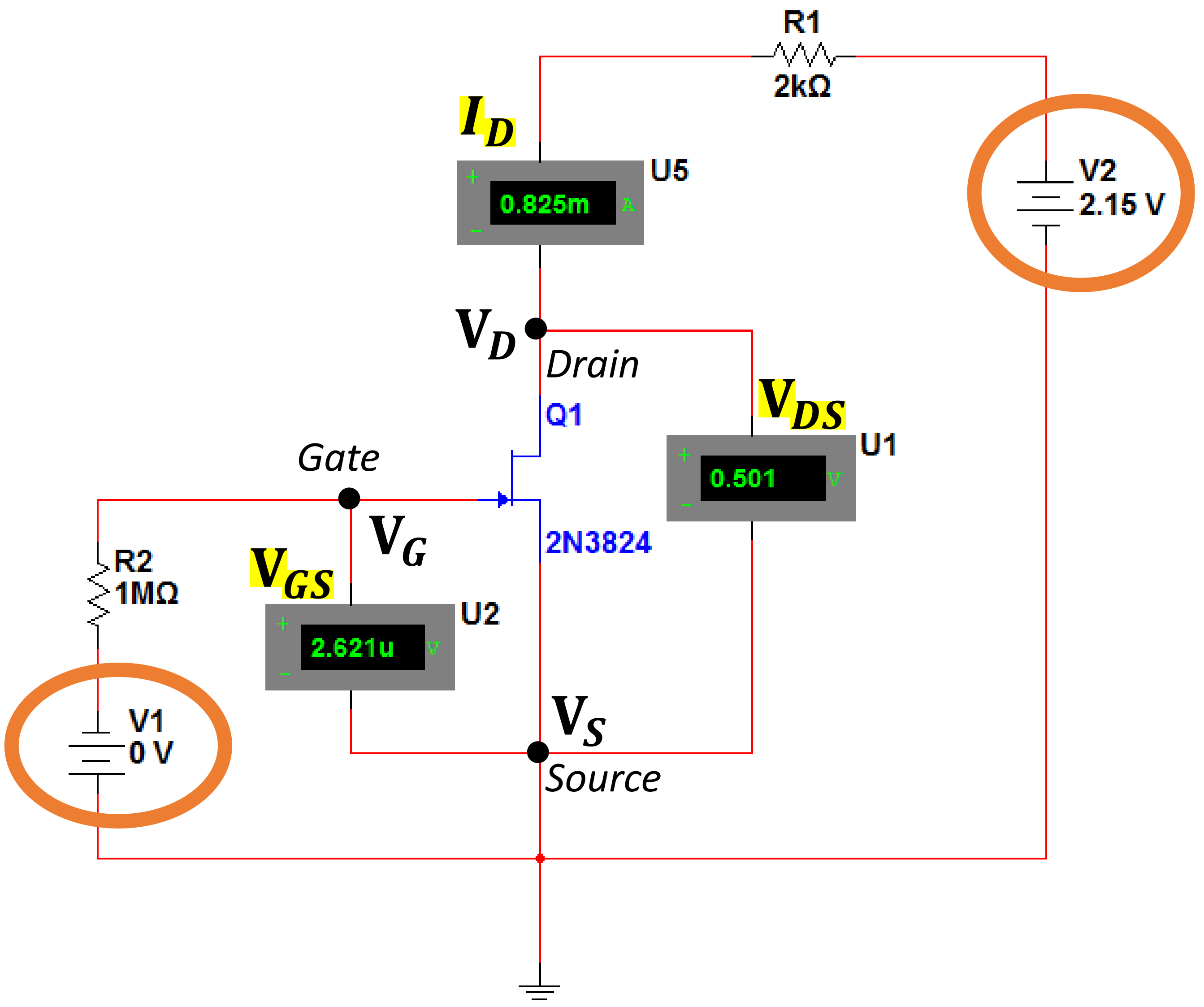
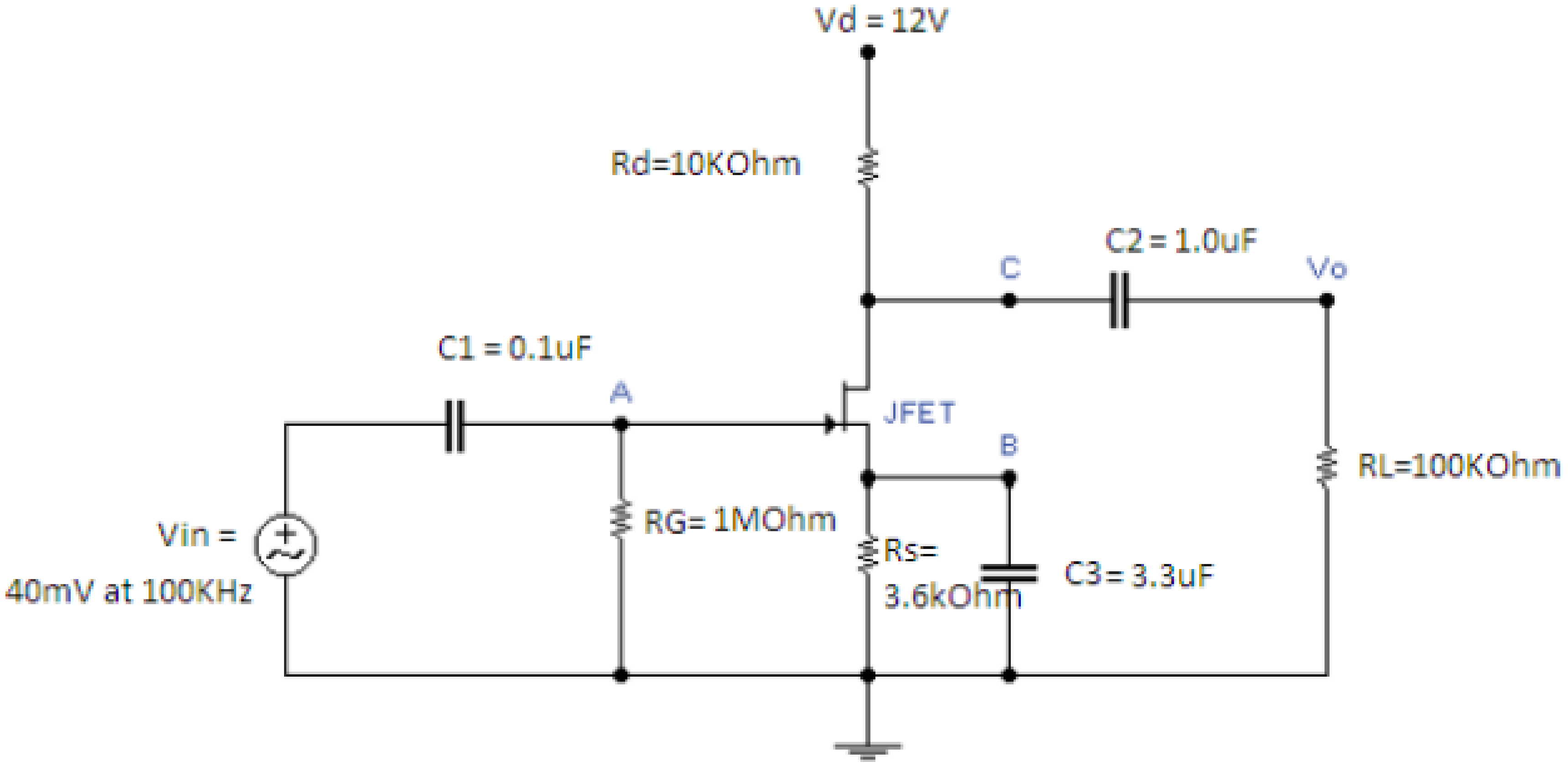
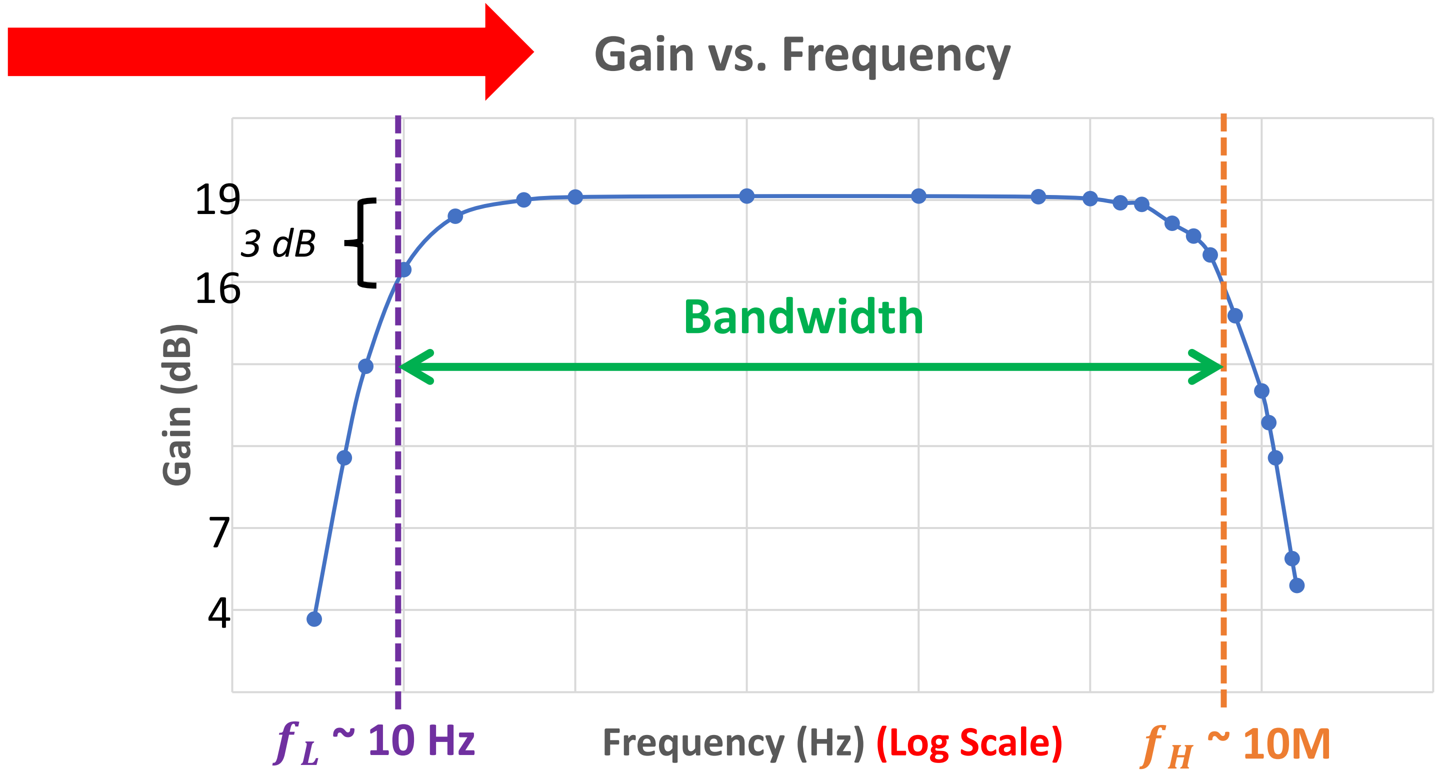

R1
2kΩ
I_D
U5
0.825m
V2
2.15 V
V_D
Drain
V_{DS}
Q1
U1
0.501
Gate
V_G
2N3824
R2
1MΩ
V_{GS}
U2
2.621u
V1
0 V
V_S
Source

Figure 10.1


Vd = 12V
Rd=10KOhm
C2 = 1.0uF
C
Vo
C1 = 0.1uF
A
JFET
B
RL=100KOhm
Vin =
RG= 1MOhm
Rs=
3.6kOhm
C3= 3.3uF
40mV at 100KHz

Gain, Low and High Cutoff Frequencies, and Bandwidth

Frequency (Hz)	Vout (mV)	Gain
30		
45		
60		
100		
200		
500		
1000		
10000 (10 kHz)		
100000 (100 kHz)		
500000		
1000000 (1MHz)		
1500000		
2000000		
3000000		
4000000		
5000000		
7000000		
10000000 (10MHz)		
11000000		
12000000		
15000000		
16000000		



Therefore, Bandwidth = f_H - f_L

Summary

- Lab 9 and 10 Report is due Tuesday 6th April 2021 by midnight.
- Prelab 11 and 12 is due Tuesday 13th April 2021 by midnight.

- Fill out Table 9.1, 9.2 and 10.1 with results from…
  - Simulation
  - ~~Experimental results~~

Reference

- Electronic Devices and Circuit Theory, 7th Ed. by Robert Boylestad and Louis Nashelsky.

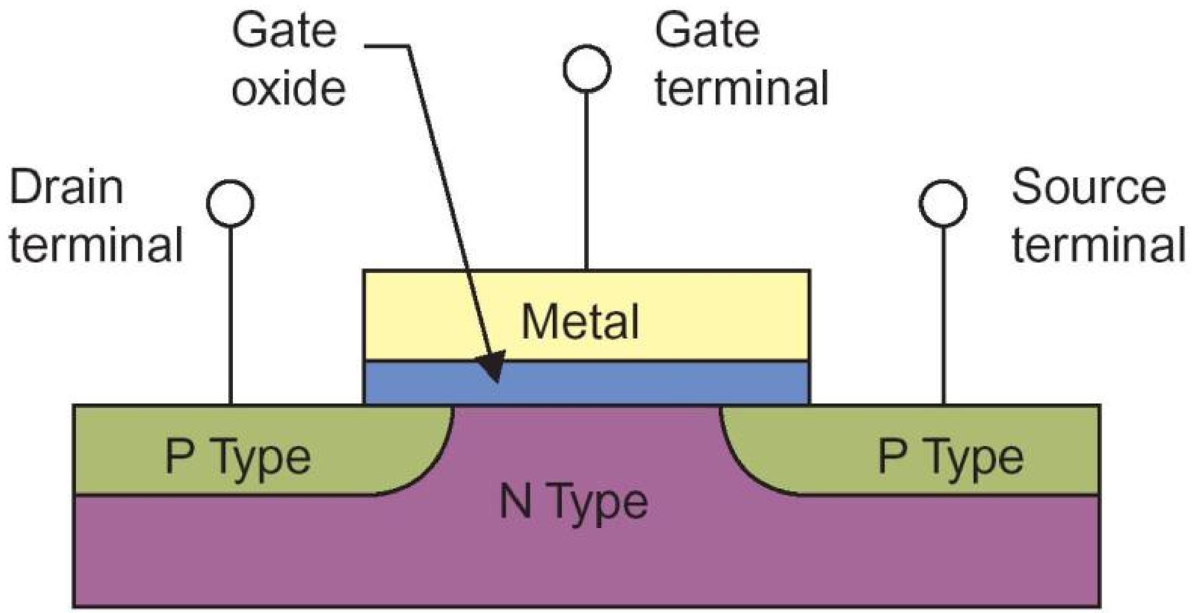
Lab 11 and 12: MOSFETs

EE316-08 Spring 2021

- **Purpose:** The concept and characteristics of **Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)** are introduced. Both **N-channel** and **P-channel MOSFETs** will be considered.

Background

- **Metal Oxide Semiconductor Field Effect Transistor (MOSFET)** is the most common type of insulated gate FET that designed for switching or amplifying voltages in the circuits.
- In other word, MOSFET is **a voltage-controlled field effect transistor**.

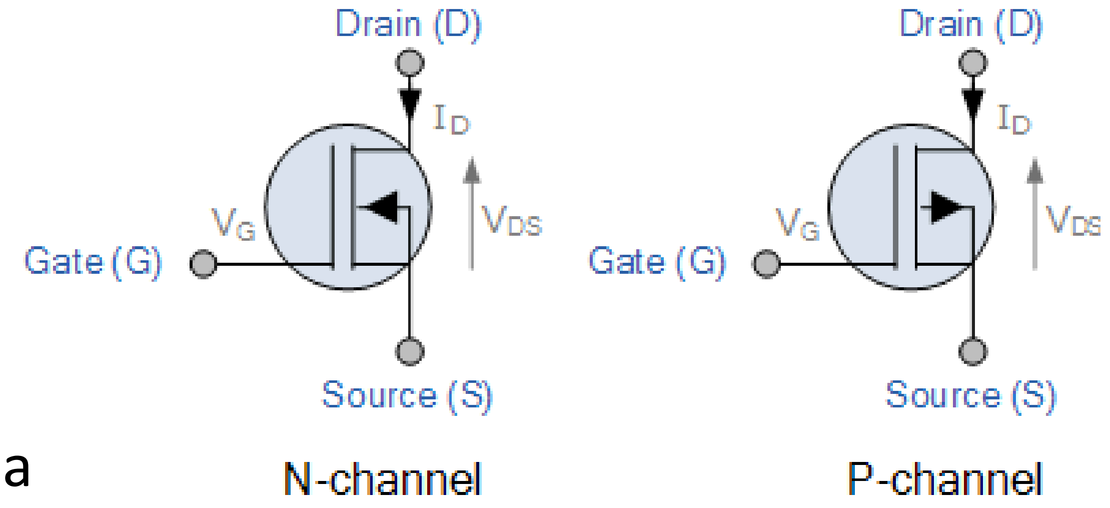


Structural diagram of N-channel MOSFET

- MOSFET has a **metal oxide gate electrode** which is electrically insulated from the main semiconductor N-channel or P-channel by **a thin layer of insulating material**.
- Therefore, the gate terminal is isolated from the main current carrying channel, and **no current flows into the gate**.

Background

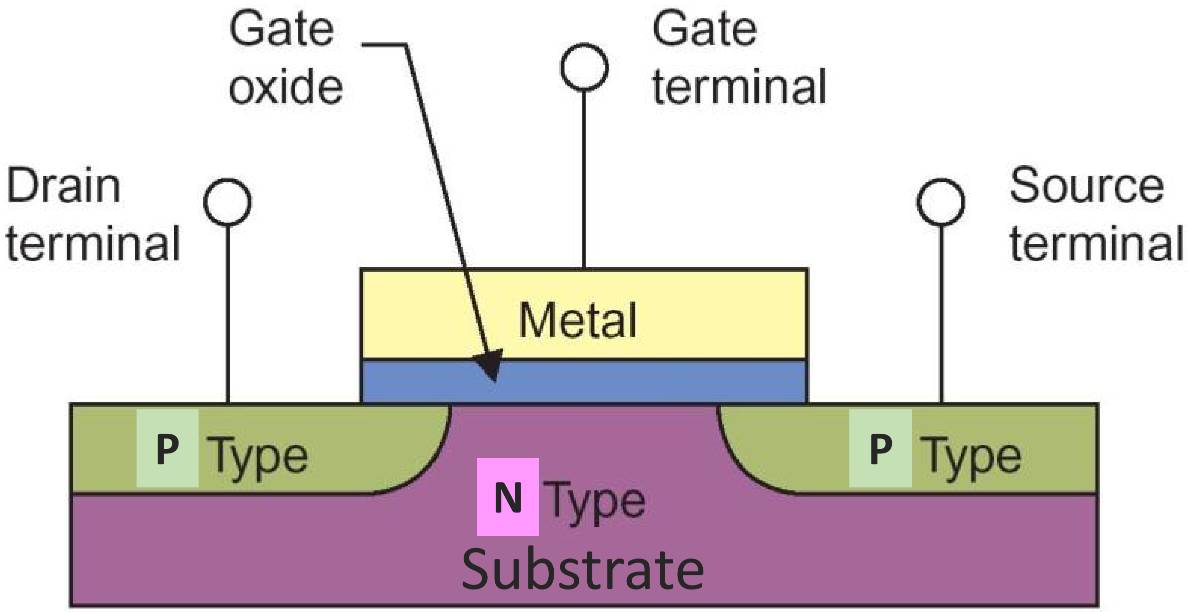
- MOSFETs are **three terminal devices** with a **Gate**, **Drain**, and **Source**.
- The current flowing through the main channel between the drain and source **is proportional to** the input voltage.
- MOSFETs can be made extremely small, can draw very little input current, and consume small power.
- MOSFETs operate in **two different modes.**
  1. **Depletion Mode**: the transistor requires the Gate-Source voltage (V_{GS}) **to switch the device OFF**. The depletion mode MOSFET is equivalent to a **normally closed** switch.
  2. **Enhancement Mode**: the transistor requires a gate-source voltage, (V_{GS}) **to switch the device ON**. The enhancement mode MOSFET is equivalent to a **normally open** switch.



Symbolic representation of MOSFETs Under the Depletion Mode

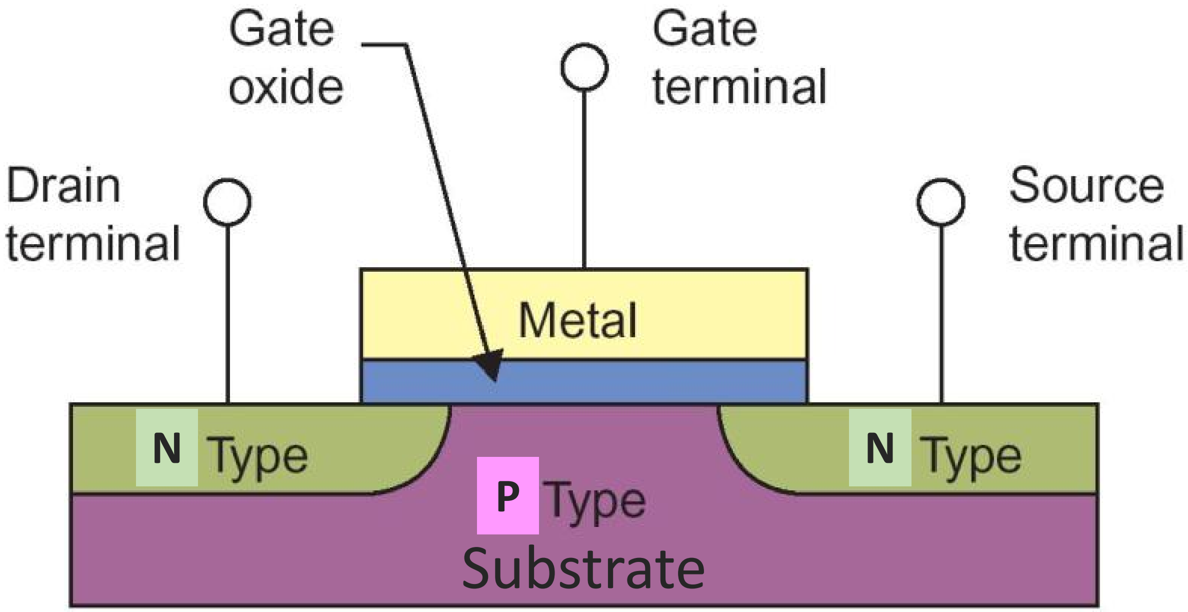
Structural Diagram of MOSFETs

- Two **P-type semiconductors** fixed at Drain and Source terminals in the channel region.
- The channel between Drain and Source is **N-type**.



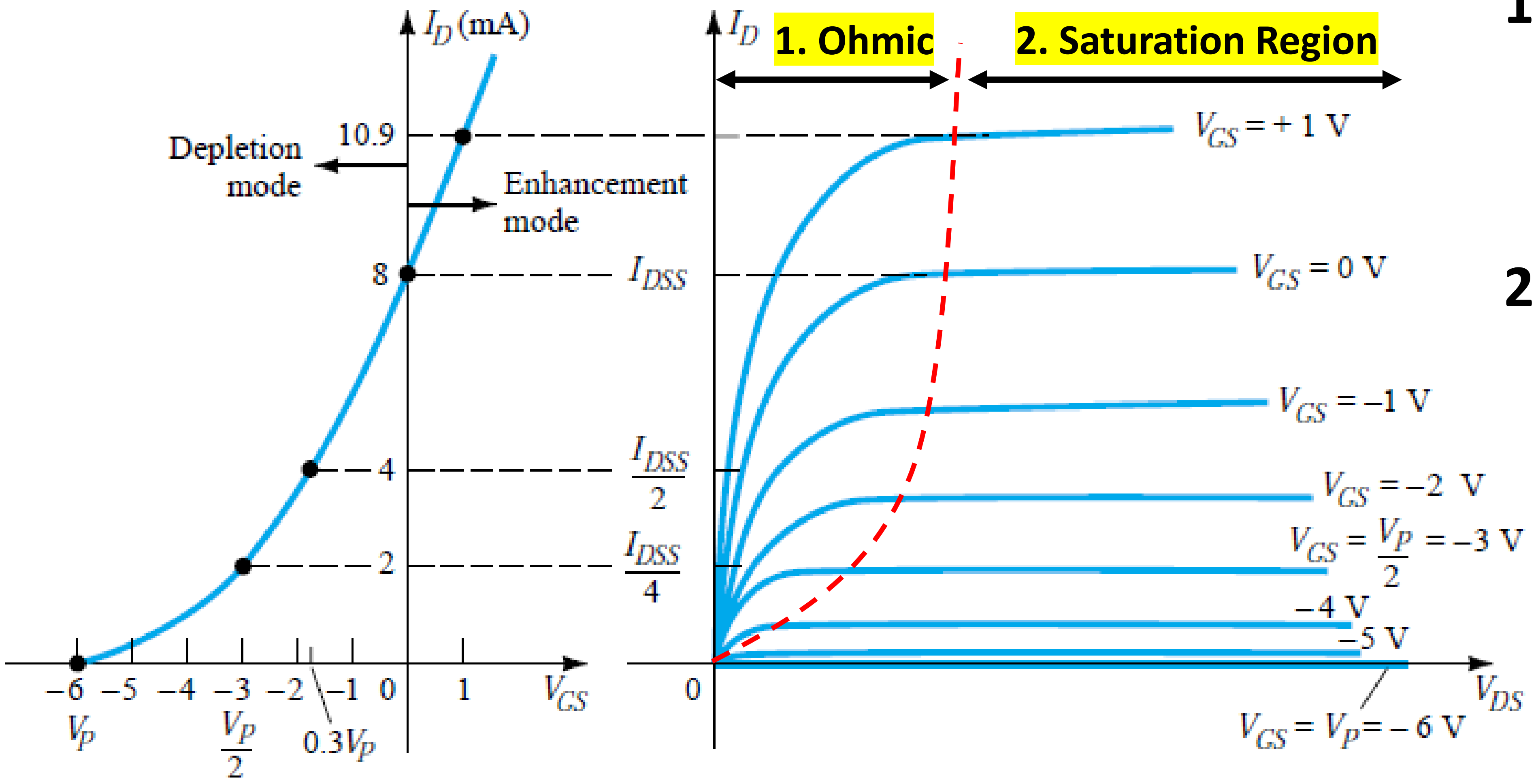
N-channel MOSFET

- Two **N-type semiconductors** fixed at Drain and Source terminals in the channel region.
- The channel between Drain and Source is **P-type**.



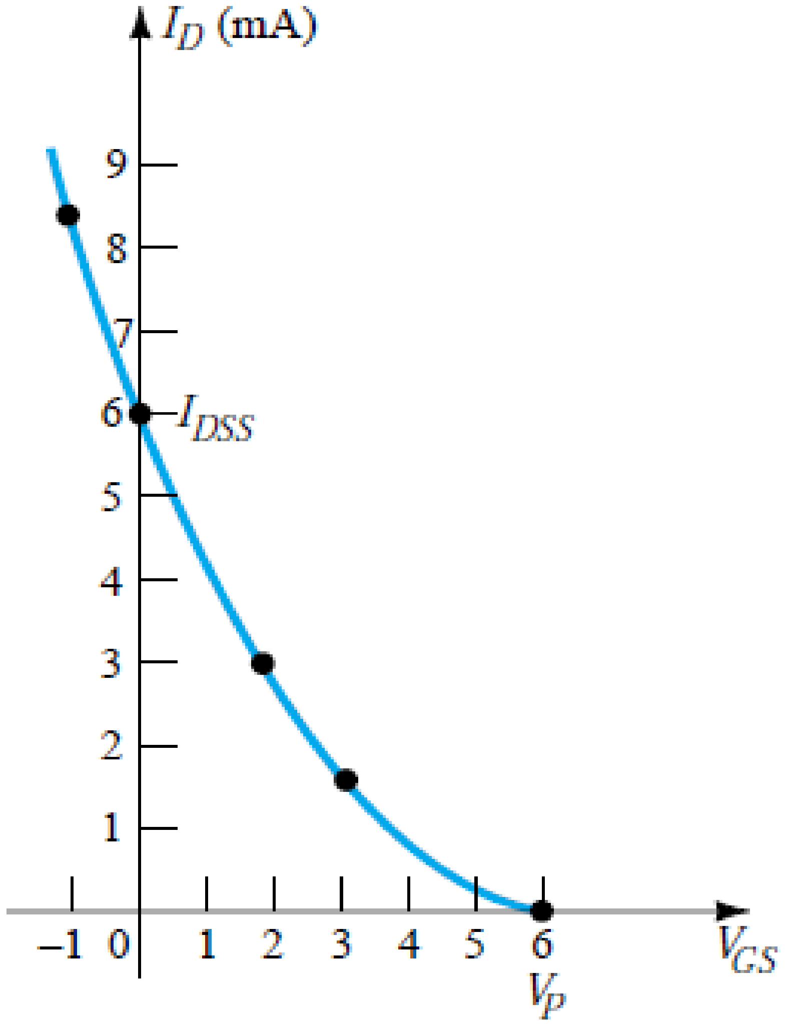
P-channel MOSFET

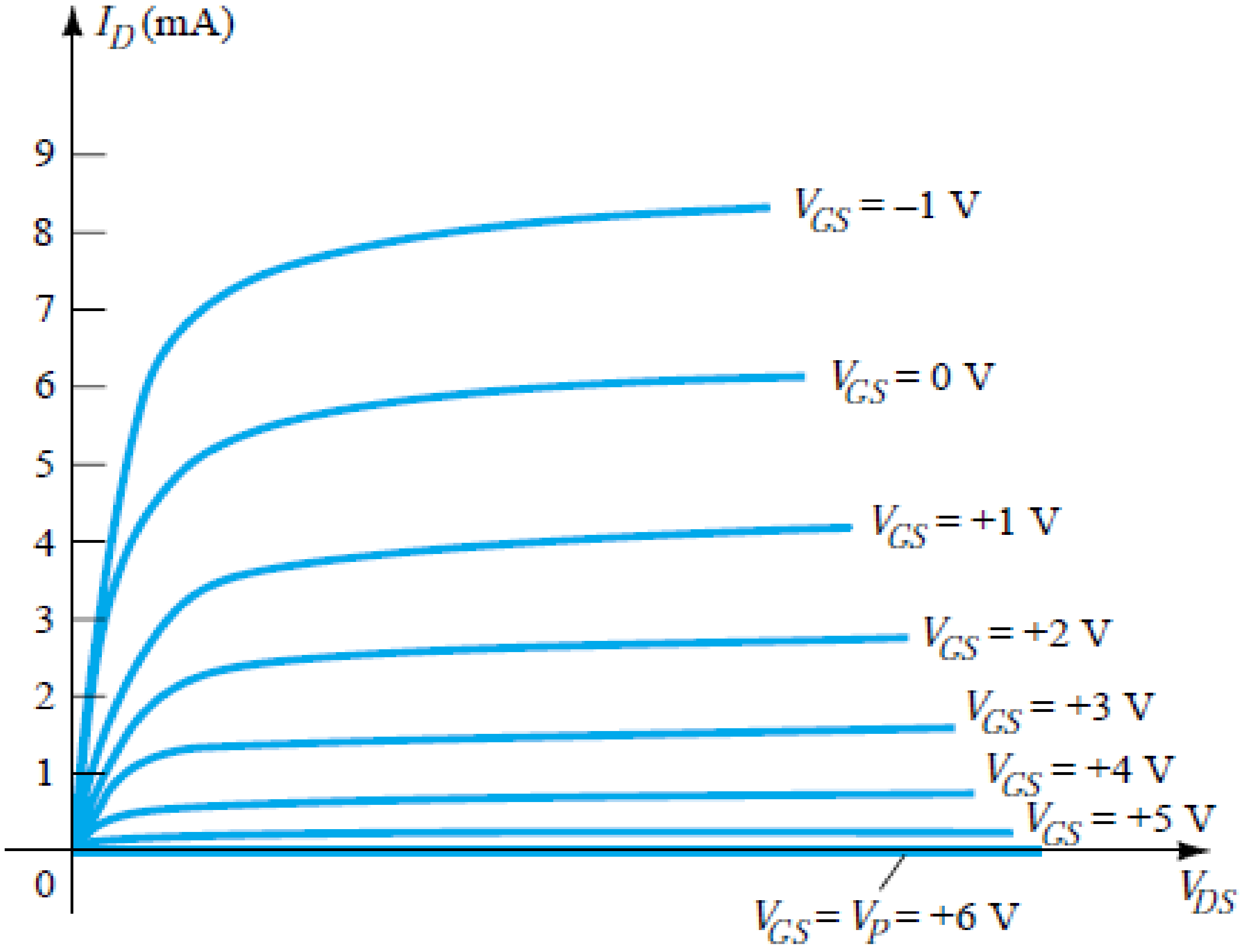
Depletion Mode N-Channel MOSFET



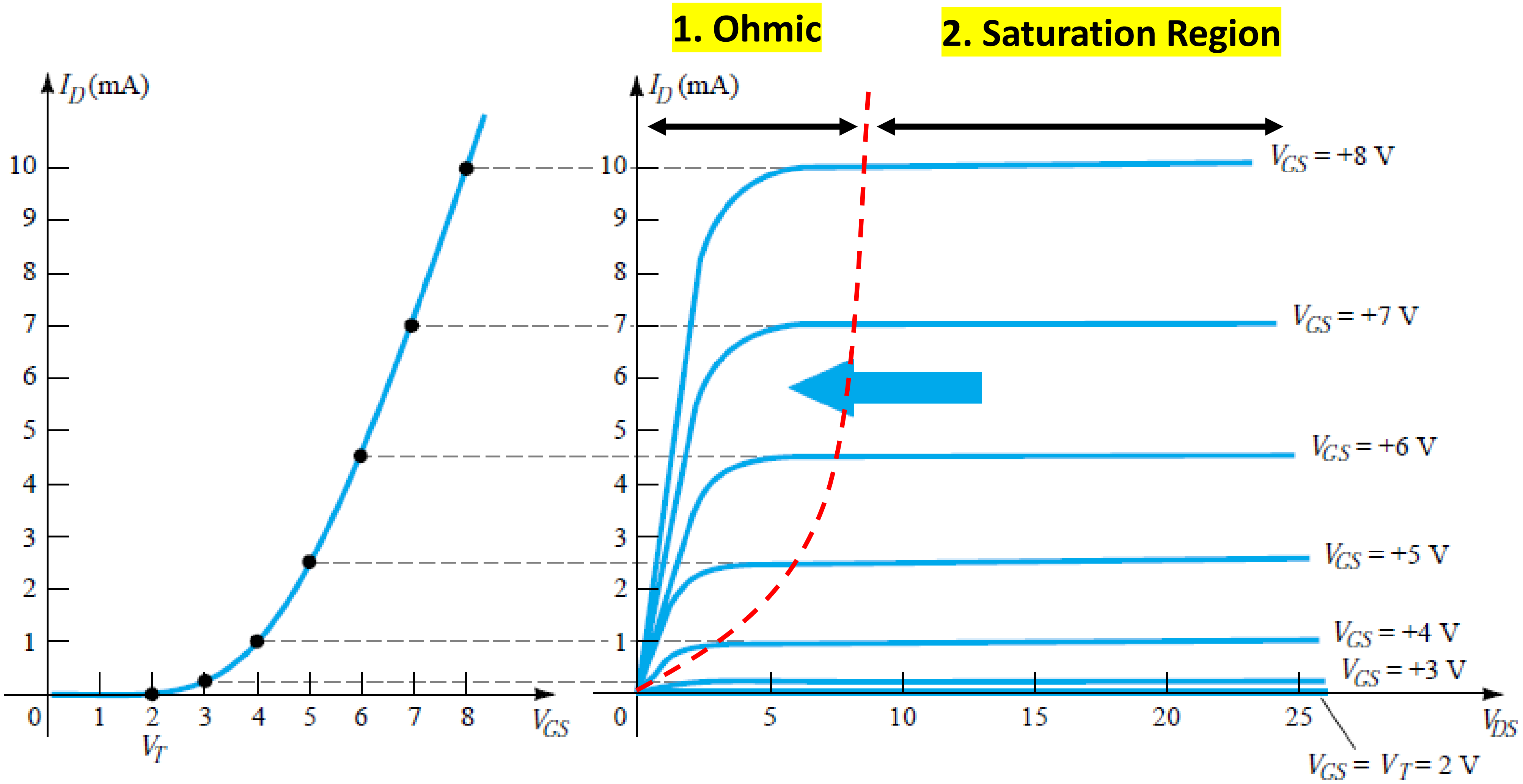
1. **Ohmic Region:** MOSFET acts like a variable resistor.
2. **Saturation Region or Linear Region:** MOSFET is strongly influenced by V_{GS}. MOSFET is ON.

Depletion Mode P-Channel MOSFET





Enhancement Mode N-Channel MOSFET



Enhancement Mode P-Channel MOSFET

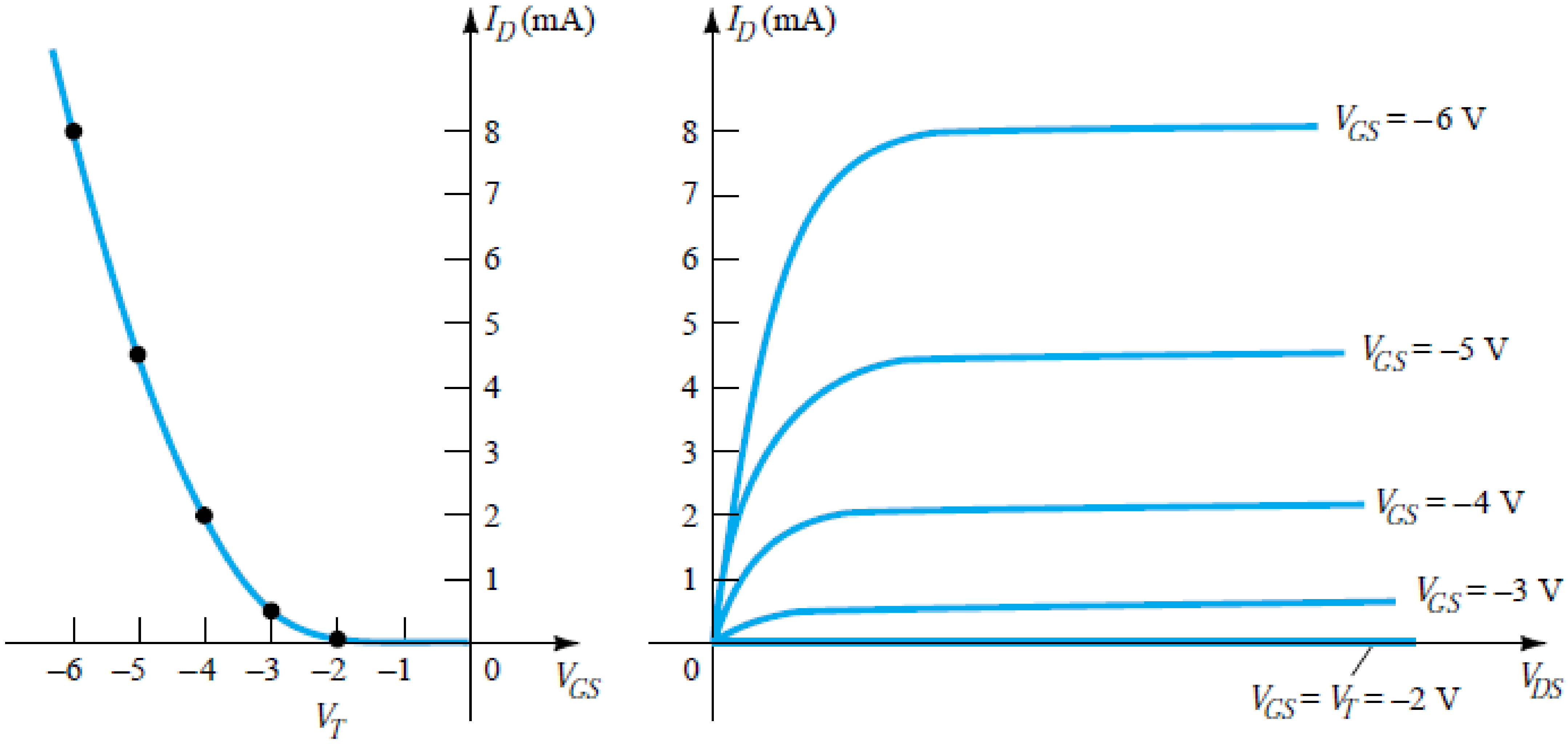
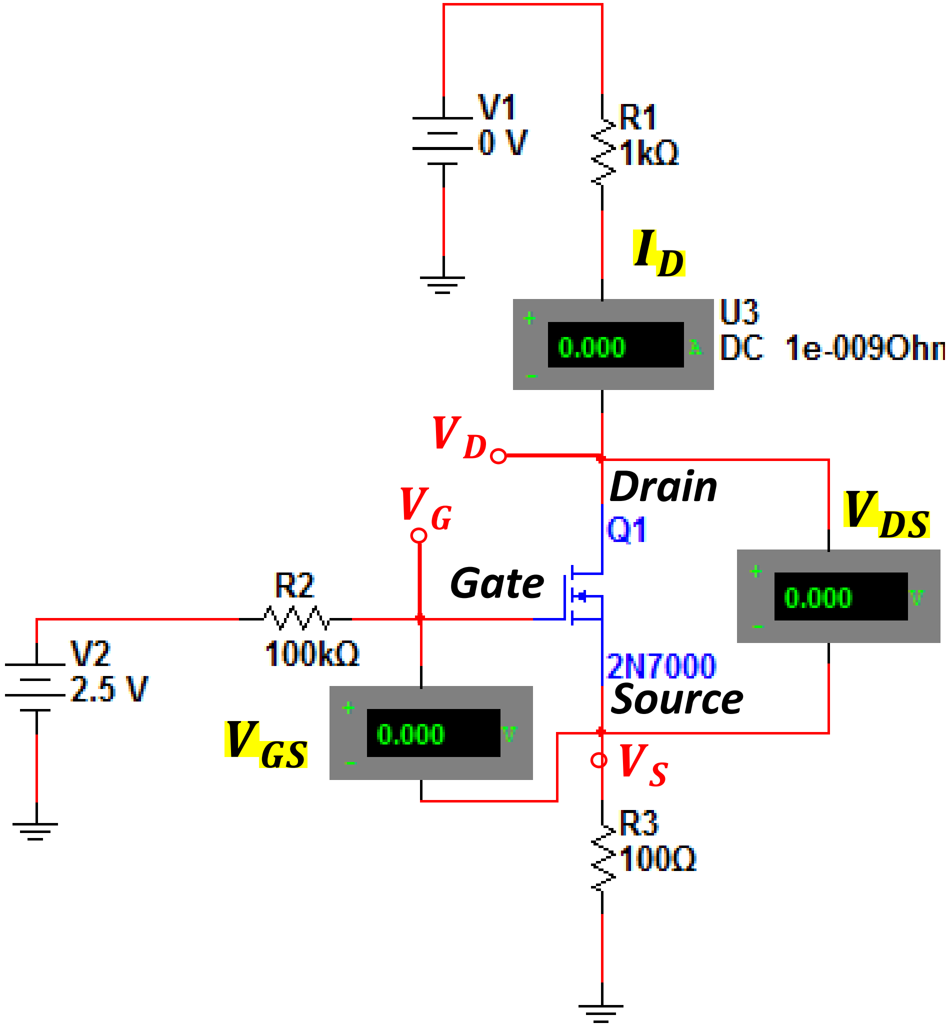


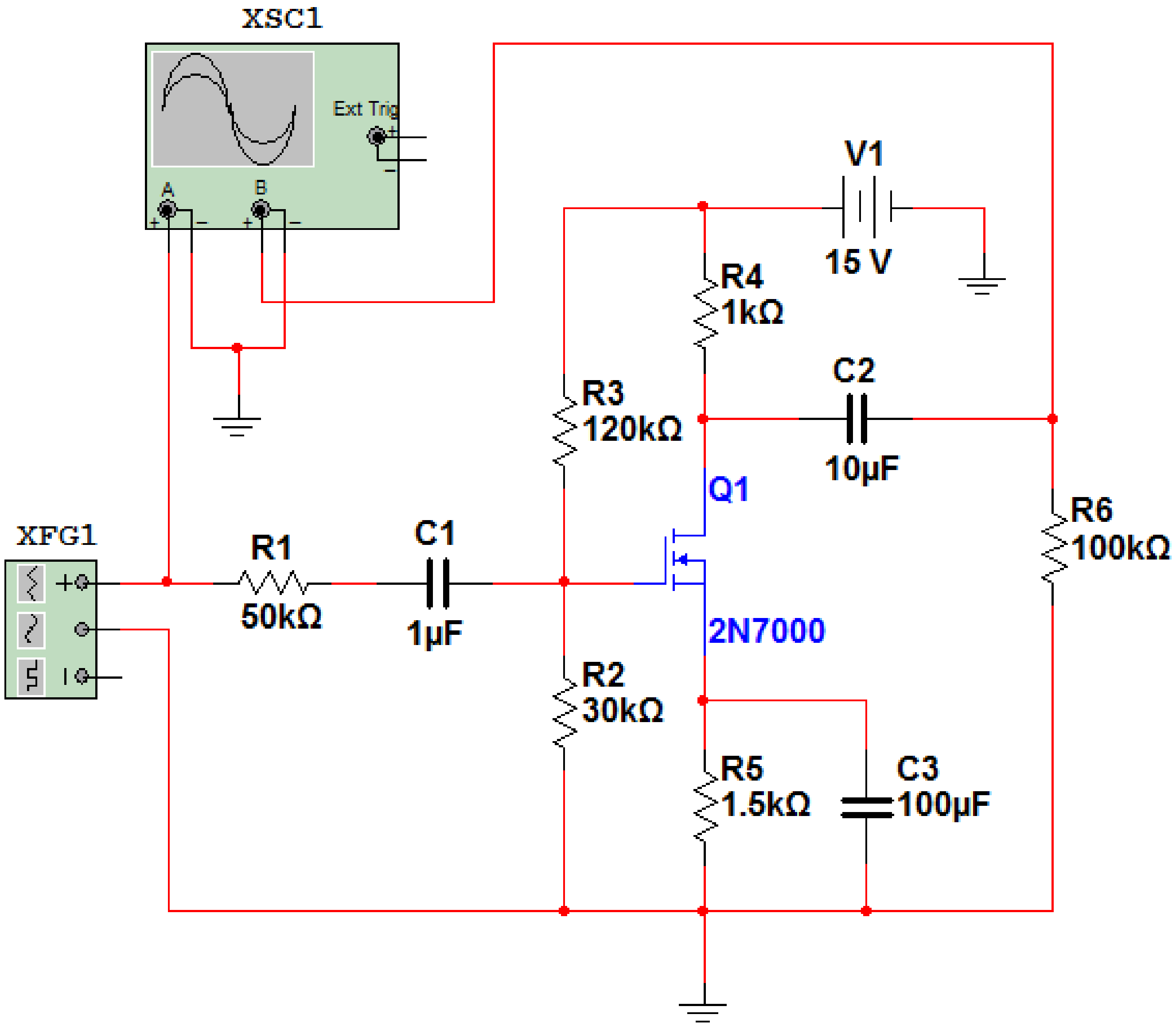
Figure 11.5: Main Idea



- An unknown MOSFET (***2N7000***) is given
- Measure V_{GS} (V), V_{DS} (V), I_D (mA)
- Plot...
  - *V_{DS} (V) vs. I_D (mA)*
  - *V_{GS} (V) vs. I_D (mA)*
- Find out...
  - Type of the given MOSFET (N or P)
  - Mode of the given MOSFET (Depletion or Enhancement)

Note: This is just the main point for lab 11. There will be sub-questions such as identify threshold voltage, and the minimum V_{DS} values. Please make sure you answer all questions in the lab manual.

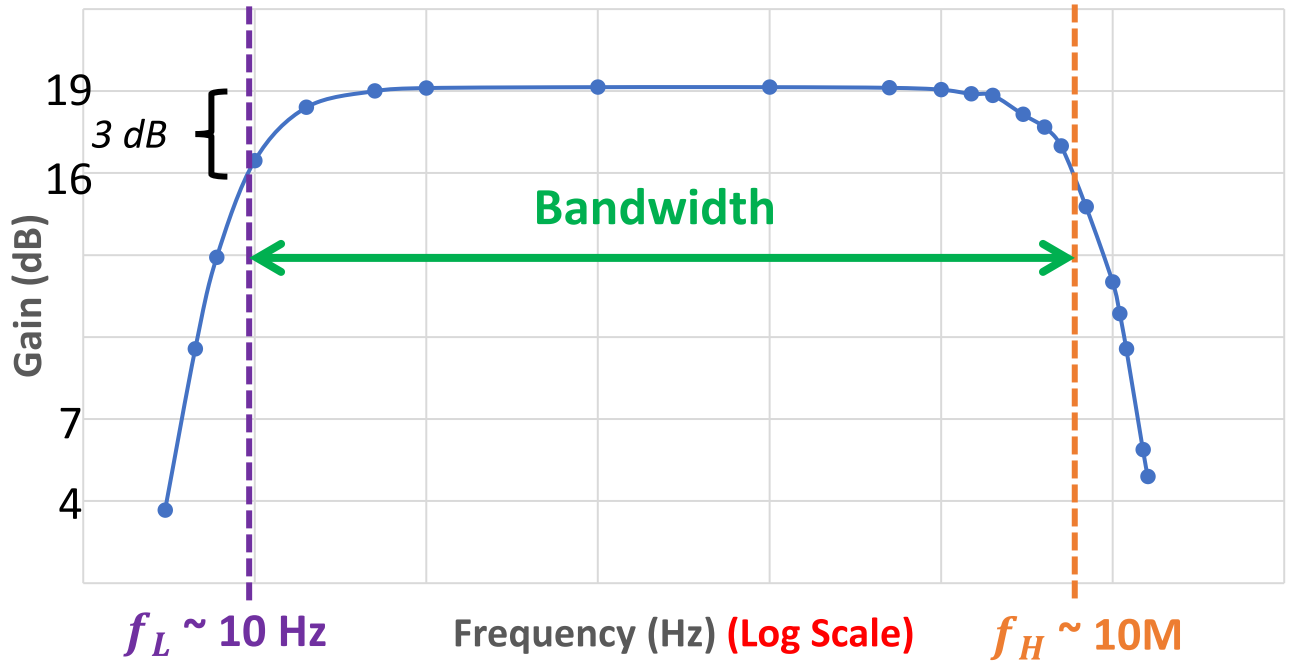
Figure 12.1



- Build the circuit in Fig. 12.1 with the input voltage $V_p = 100mV$
- Find V_{out} and Gain (dB)
- Plot Gain (dB) vs. Frequency (Hz)
  - Frequency-axis is in ***log*** scale
- Identify…
  - f_{low}
  - f_{high}
  - Bandwidth
- Comment on phase relationship

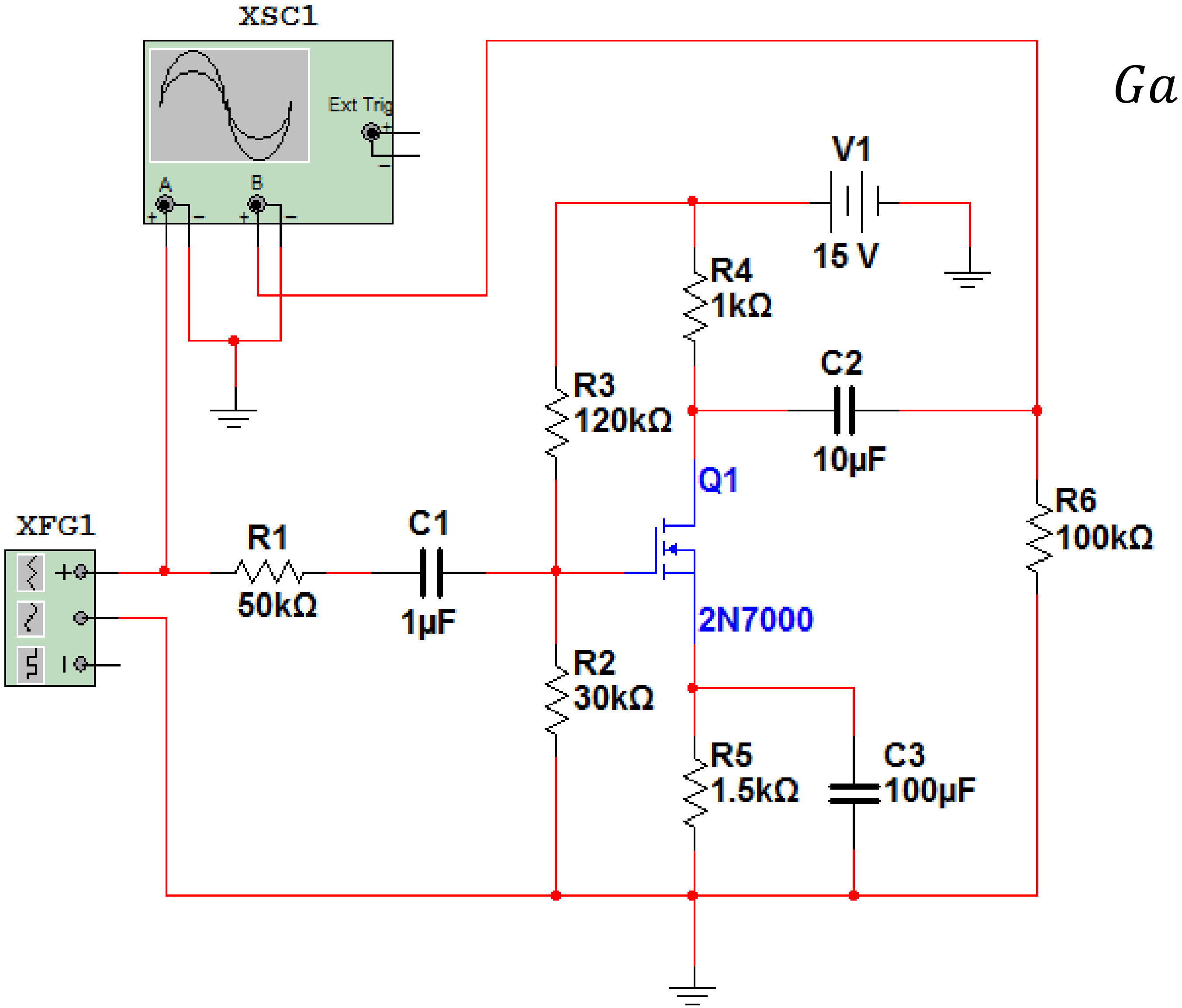
Gain, Low and High Cutoff Frequencies, and Bandwidth

Frequency	V_{out} $(\mathrm{m}V_p)$	Gain (dB)
10		
30		
60		
100		
200		
500		
1000		
2000		
5000		
10000		
15000		
20000		
50000		
75000		
100000		
150000		
200000		
500000		
750000		
1000000		
1500000		
2000000		
3000000		



Therefore, Bandwidth = f_H - f_L

Figure 12.1: Find V_{out} (Recall)



$$Gain(dB) = 20\log\left(Gain(ratio)\right)$$

$$Gain(ratio) = 10^{\frac{Gain(dB)}{20}}$$

$$Gain(ratio) = \frac{V_{out}}{V_{in}}$$

$$V_{out} = Gain(ratio) \times V_{in}$$

$$\boldsymbol{V_{out} = 10^{\frac{Gain(dB)}{20}} \times V_{in}}$$

Example: Find $\boldsymbol{V_{out}}$

Given $V_{in} = V_{peak} = 100mV$

Frequency (Hz)	Measured Vout (mVpeak)	Gain (dB)	Gain (ratio)	Calculated Vout (mVpeak)
10		4.32	1.6443	164.43

Step 1: Find Gain(ratio)

$$Gain(dB) = 20\log(Gain(ratio))$$

$$\boldsymbol{Gain(ratio) = 10^{\frac{Gain(dB)}{20}}}$$

$$Gain(ratio)_{at\ 10\ Hz} = 10^{\frac{4.32}{20}} = 1.6443$$

Step 2: Find Vout

$$\boldsymbol{V_{out} = Gain(ratio) \times V_{in}}$$

$$V_{out\ at\ 10\ Hz} = (1.6443) \times \left(100\ mV_{peak}\right) = 164.43\ mV_{peak}$$

Summary

- Lab 11 and 12 Report is due Tuesday 20th April 2021 by midnight.
- Final Exam will be available from Tuesday 20th April 2021 to Tuesday 27th April 2021.

- Fill out Table 11.1, 11.2 and 12.1 with results from…
  - Simulation
  - ~~Experimental results~~

Reference

Electronic Devices and Circuit Theory, 7th Ed. by Robert Boylestad and Louis Nashelsky.