# Electronic Circuits for Mechatronics (ELCT 609)

## Spring 2021

## Lecture 5: BJT Amplifiers Theory

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# Objective

- We want to implement an analog voltage amplifier using BJT



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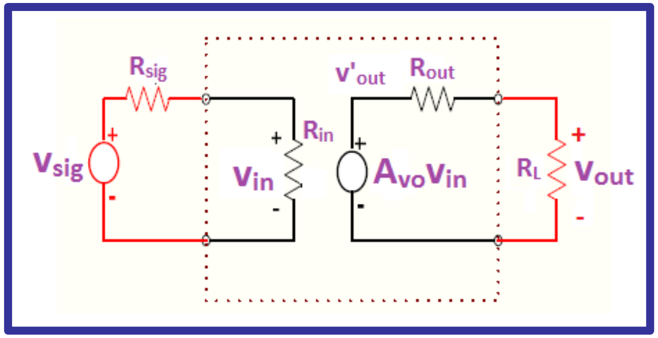
# Objective

- **What are the Specifications of an Ideal Voltage Amp.?**
  - Infinite Input Resistance: $R_{in}$ **(Thevinen at the Input Port)**
  - Infinite Voltage Gain: $A_{vo}$
  - Finite Output Resistance (Short Circuit): $R_{out}$ **(Thevinen at the Output Port)**




$$A_v = \frac{v_{out}}{v_{sig}}$$

$$A_v = A_{vo}\frac{R_{in}}{R_{sig}+R_{in}}\frac{R_L}{R_{out}+R_L}$$

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# Important Notes

- BJT Amplifiers deals with DC, AC and instantaneous signals, Thus we need to have different symbols to distinguish between them

| Type of Signal | Signal Symbol | Example |
|---|---|---|
| DC Signals | Capital Letter and Subscript | $V_{BE}$, $V_{CE}$, $I_C$ |
| AC Signals (Small Signals) | Small Letter and Subscript | $v_{be}$ ,$v_{ce}$, $i_c$ |
| Instantaneous (Large Signals) | Small Letter and Capital Subscript | $v_{BE}$, $v_{CE}$, $i_C$ |



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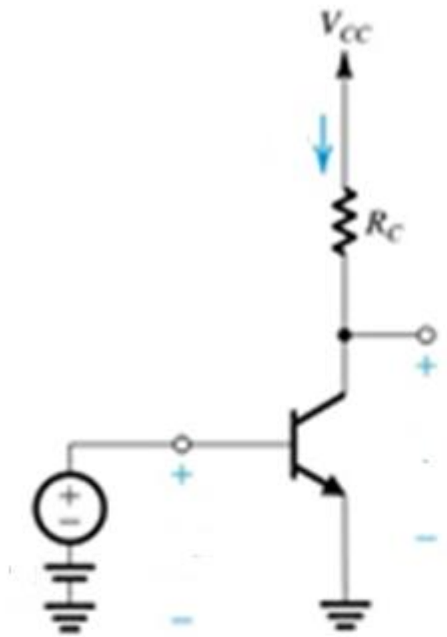
# BJT Amplifier Large Signal Analysis

- **Voltage Amplifier using BJT**
  - Assume that we have instantaneous input and output voltage signal '$v_I$' and '$v_O$'

$$v_{BE} = v_I$$

$$v_O = V_{CC} - i_C R_C$$



# BJT Amplifier Large Signal Analysis

- **Voltage Amplifier using BJT (cont.)**

$v_{BE} = v_I$ $\quad$ $v_O = V_{CC} - i_C R_C$

# BJT Amplifier Large Signal Analysis

- **<u>Voltage Amplifier using BJT (cont.)</u>**

$$v_{BE} = v_I$$

$$v_O = V_{CC} - i_C R_C$$

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# BJT Amplifier Large Signal Analysis

- **<u>Voltage Amplifier using BJT (cont.)</u>**

$$v_{BE} = v_I$$

$$v_O = V_{CC} - i_C R_C$$

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# BJT Amplifier Large Signal Analysis

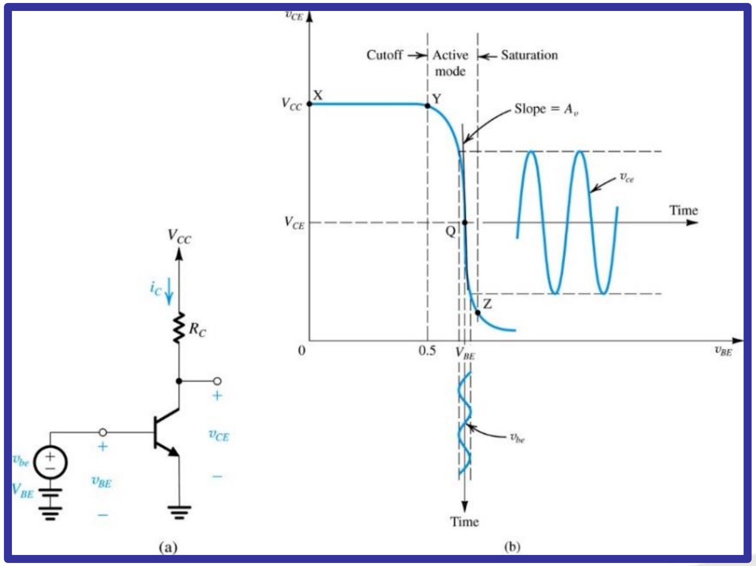
- **Voltage Amplifier using BJT (Cont.)**

$$v_{BE} = v_I$$

$$v_O = V_{CC} - i_C R_C$$

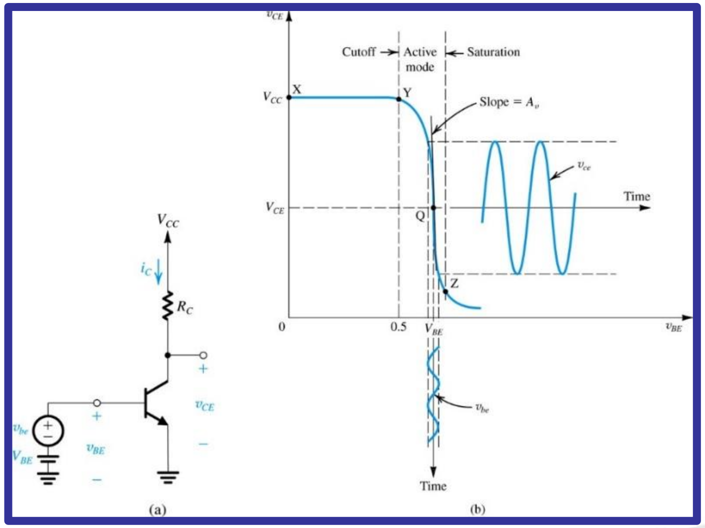
For Active Mode ONLY

$$i_C = I_S \exp\left(\frac{v_I}{V_T}\right)$$



# BJT Amplifier Large Signal Analysis

- **Voltage Amplifier using BJT (cont.)**

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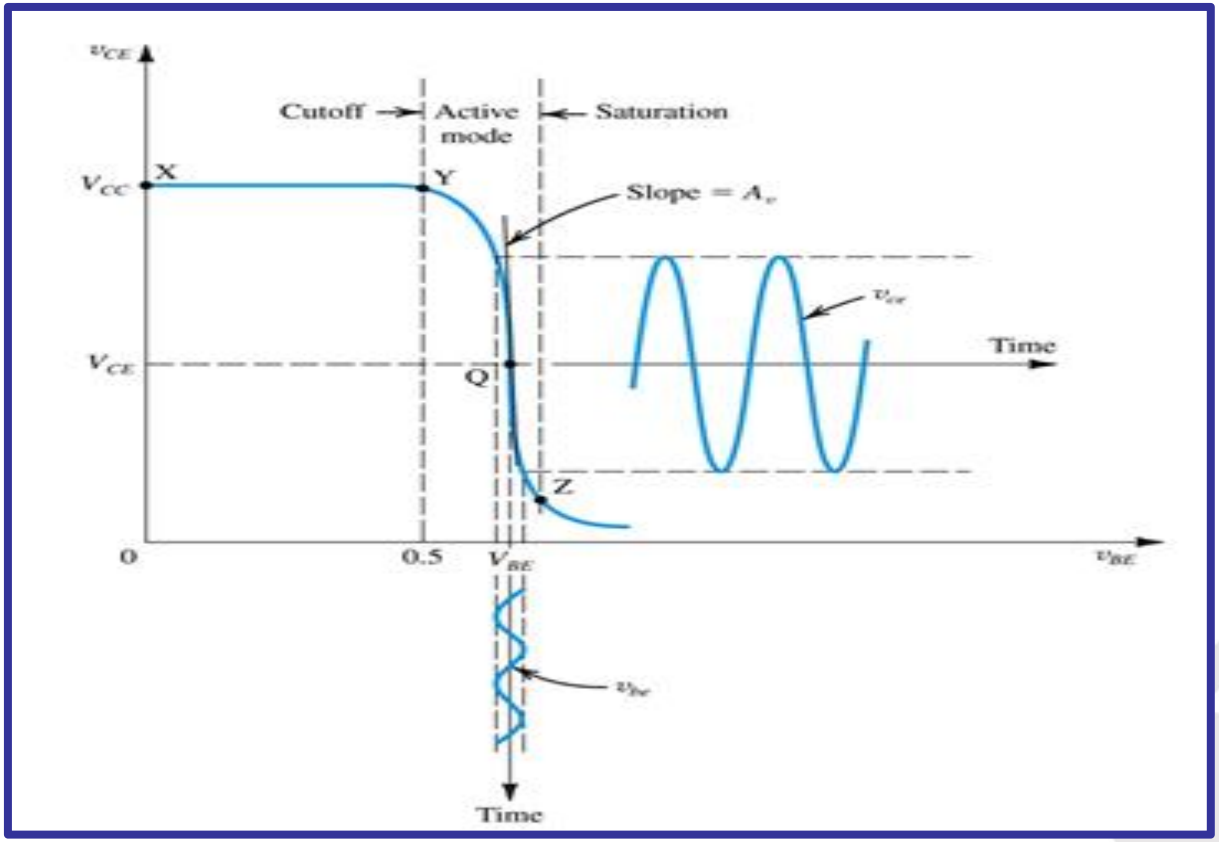
# BJT Amplifier Large Signal Analysis

- **Voltage Amplifier using BJT (cont.)**

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# BJT Amplifier Large Signal Analysis

- **Voltage Amplifier using BJT (cont.)**

$$v_O = V_{CC} - i_C R_C$$

1. **Cutoff Mode**

$$0 \le v_I \le 0.5 \qquad v_O = V_{CC}$$

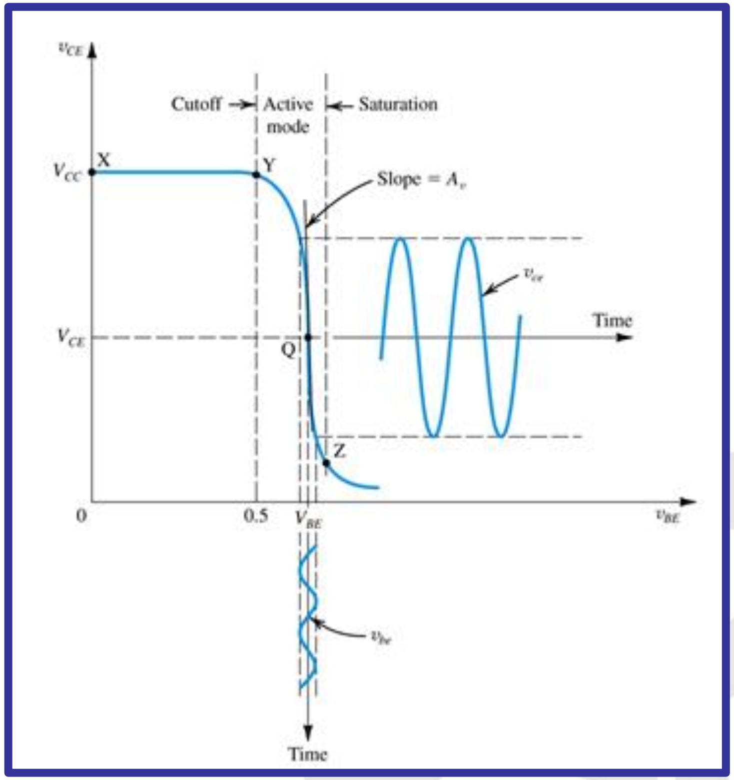
2. **Active Mode**

$$0.5 \le v_I \le v_{BE,sat} \qquad v_O > v_{CE,sat}$$

$$v_O = V_{CC} - I_S R_C \exp\left(\frac{v_I}{V_T}\right)$$

3. **Saturation Mode**

$$v_I \ge v_{BE,sat} \qquad v_O = V_{CE,sat}$$



# BJT Amplifier Large Signal Analysis

- We can easily separate DC and AC Signals (Superposition)
  - Under the assumption that the AC signal amplitude is very small, such that the transistor's mode will remain the same for the complete cycle
- BJT must work in **Active Mode** to avoid signal distortion
- DC Sources are used to set the DC Operating point to Active mode
- Input terminals of the amplifier are Base/Emitter
- Output terminals of the amplifier are Collector/Emitter
- Equivalent Circuit for Small Signal Analysis can be derived

$$v_{BE} = V_{BE} + v_{be}$$

$$i_C = I_S \exp\left(\frac{V_{BE}+v_{be}}{V_T}\right)$$

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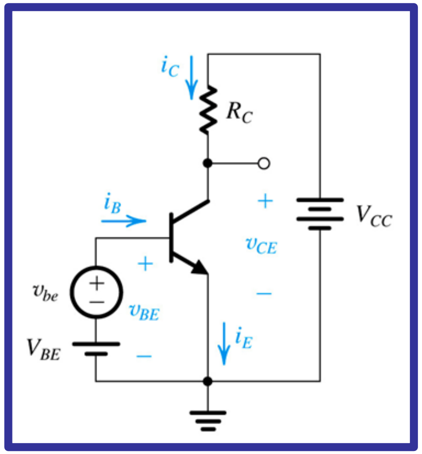
# BJT Small Signal Model Derivation

- Assume BJT is in active mode & $v_{be} << V_T$

$$i_C = I_S \exp\left(\frac{V_{BE} + v_{be}}{V_T}\right)$$

$$i_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \exp\left(\frac{v_{be}}{V_T}\right)$$




$$i_C \cong I_C\left(1 + \frac{v_{be}}{V_T}\right)$$

$$g_m = \frac{\partial i_C}{\partial v_{be}} = \frac{I_C}{V_T}$$

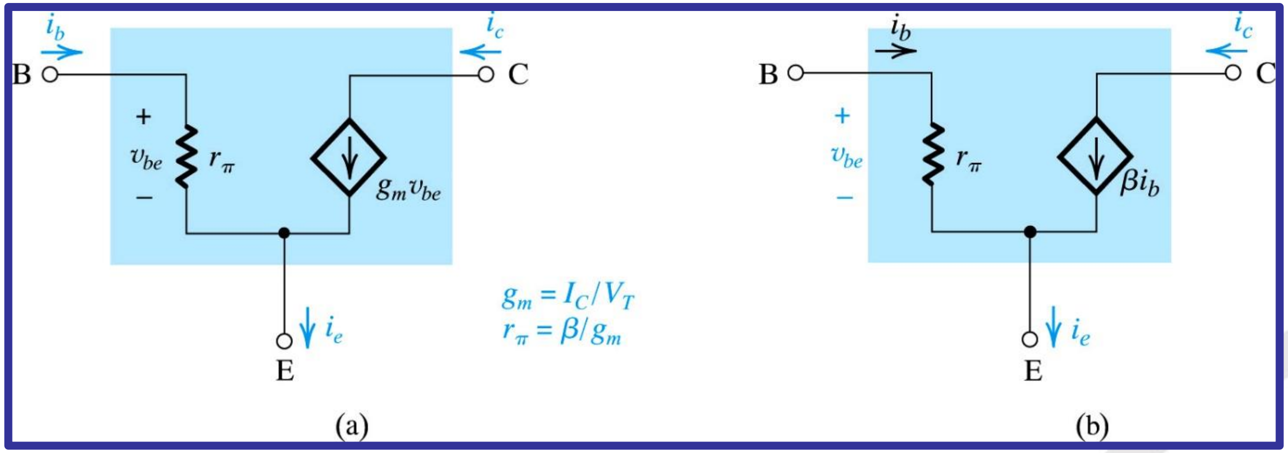
$$i_c = g_m v_{be} = \beta i_b$$

# BJT Small Signal Model Derivation

- We can place a resistance between Base and Emitter to have a path for the base current

$$i_c = g_m v_{be} = \beta i_b$$

$$r_\pi = \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \frac{V_T}{I_B}$$

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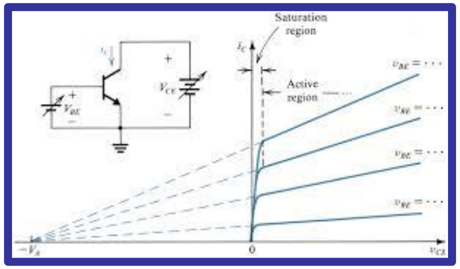
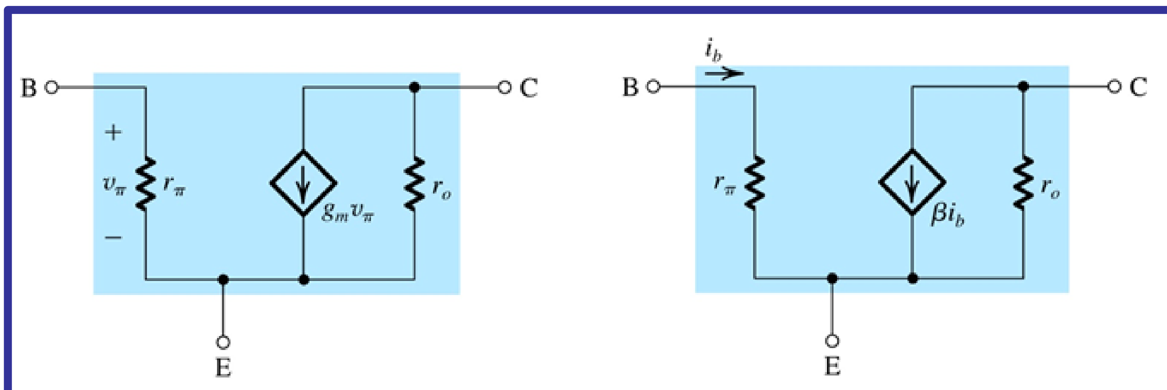
# BJT Small Signal Model Derivation

- **<u>Note</u>:** Early effect can be taken into consideration (if $V_A$ is given)




$$r_o = \frac{V_A}{I_C}$$



# Summary of Lecture

- Defined the Ideal voltage amplifier specs
- Defined Linear Amplifiers
- We learned the theory of small signal BJT-based voltage amplifiers

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