# VE311 RC1

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# Overview

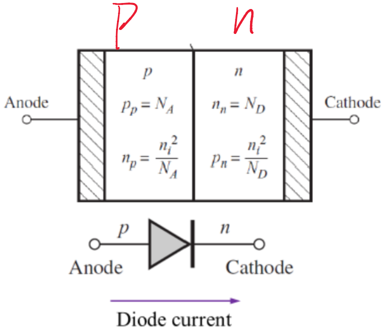
1. Diode and Diode Circuit
2. BJT
3. BJT Common-Emitter Amplifier

mid

1. diode
2. op-amp
3. BJT
4. MOSFET Big Signal

MOSFET SS X

# PN Junction Diode




$N_A, N_D$: doping densities
$n_i$: intrinsic carrier concentration

hole in p: majority

$$p_p = N_A \tag{1}$$

electron in p: minority

$$n_p = \frac{n_i^2}{N_A} \tag{2}$$

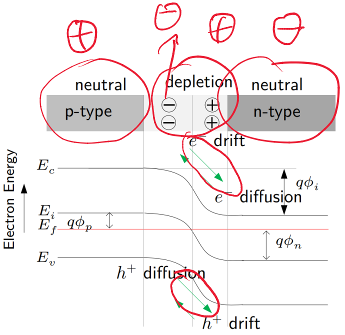
electron in n: majority

$$n_n = N_D \tag{3}$$

hole in n: minority

$$p_n = \frac{n_i^2}{N_D} \tag{4}$$

# PN Junction Diode




built-in potential:

$$V_{bi} = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) \quad (5)$$

- Some electrons/holes in the neutral regions with sufficient energy continuously diffuse to the opposite sides. $\rightarrow$ Formation of diffusion high concentration $\rightarrow$ low
- Some electrons/holes wandering into the in the depletion region get swept by the built-in electric field. $\rightarrow$ Formation of drift current
- Diffusion current cancels drift current. **No net current flowing.** at equilibrium

# Diode Equation

$\xleftarrow{I_S}$ $I_D$

p $\longrightarrow$ n

$V_D > 0$

- Forward Bias: Diode is on. Current flows from p to n.
- Reverse Bias: Diode is off. Current doesn't flow, but saturation current exists.

$V_T = \frac{kT}{q}$

can be ignored

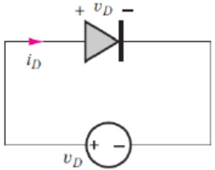
$$I_D = I_S\left(e^{\frac{qV_D}{KT}} - 1\right) = I_S\left(e^{\frac{V_D}{V_T}} - 1\right) \quad (6)$$

$\longrightarrow I_D$

$\longleftarrow I_S$

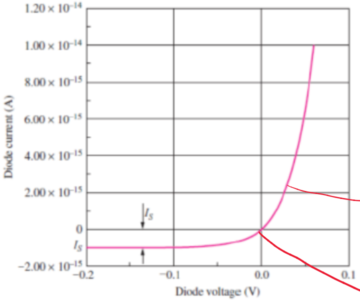
**Note**:

- k = Boltzmann's constant, 8.62 × 105 eV/K
- $\frac{kT}{q}$ = 0.026(0.025875)V at 300K when calculation.



# IV Characteristics of Diode

ideal condition




Non-linear, or rectifying, behavior

- **Non-linear** behavior
- turn-on voltage> $V_{bi}$

$$I_D = I_S\left(e^{\frac{V_D}{V_T}} - 1\right)$$

rectifying behavior

let current flow in one direction, but prevent it flowing to the opposite direction

Von : 0.5V ~ 0.7V

due to the Vbi

Von > Vbi

# Exercise 1

(23FA Mid/1) Choose one description that is not right. (5)

(1) At equilibrium, a PN diode current is zero. drift and diffusion cancel out

(2) Under a forward bias, a PN diode current increases exponentially. $I_D = I_S(e^{\frac{V_D}{V_T}} - 1)$

(3) Under a forward bias, a PN diode current is from P to N. P —▷|— N $\xrightarrow{I_D}$

(4) Under a moderate reverse bias (before the breakdown), a PN diode current is almost zero.

(5) A PN diode shows a rectifying behavior, i.e. nonlinear I-V curve, because a drift current is dominant over a diffusion current under a forward bias.

off

internal structure

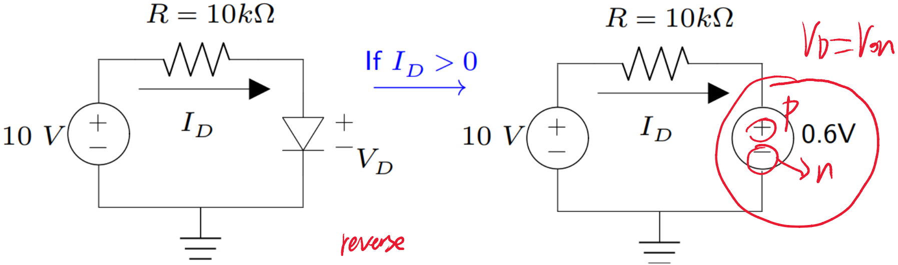
# Diode Simplification

Forward bias $I_D > 0$

reverse $I_D = 0$

$V_D = e$

- Ideal Diode Model: **Short circuit** for Forward Bias and **Open Circuit** for Reverse Bias
- Constant Voltage Drop Model: **Replace Diode with a voltage source** for Forward Bias and **Open Circuit** for Reverse Bias.




reverse

# Diode Simplification more than 1 diode

1. Identify the model for simplification. ideal or CVD
2. Assume the voltage applied on the diode Assume diode is on
3. Transform the diode to source and resistor according to the assumption.
4. Validate that the assumption is correct or not.

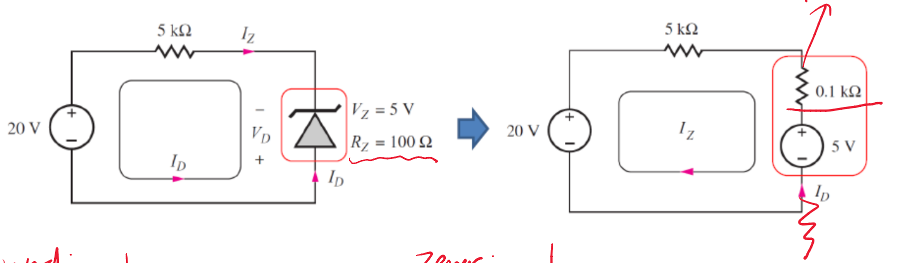
judge $I_D > 0 \Rightarrow$ assumption is right

$I_D < 0 \Rightarrow$ wrong, calculate again assuming diode is off

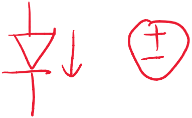
# Diodes (Zener) in Breakdown Region

**Method:** Replace the Diode with a "Reverse" voltage source and a resistance.

Sequence X

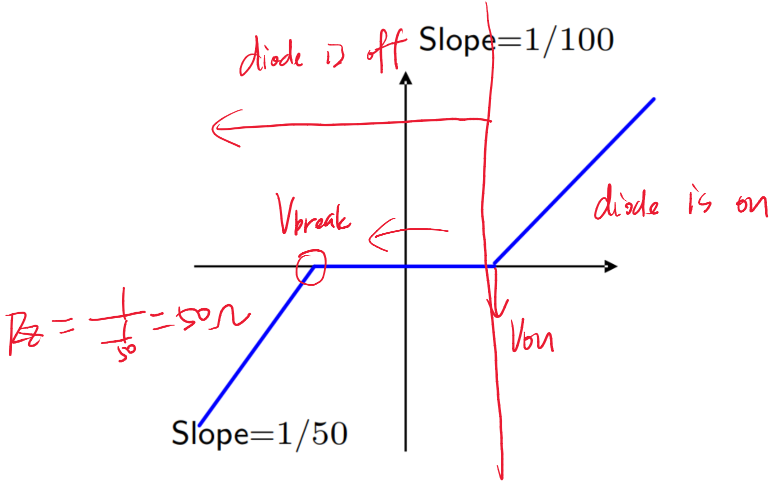



forward:



Zener:

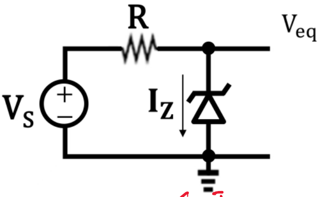
When $V_D < V_{break}$, voltage source is $V_{break}$, slope is $\frac{1}{R_Z}$.

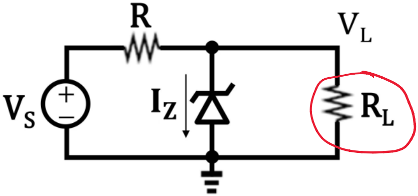


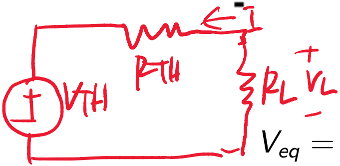
# Voltage Regulator

maintain a constant voltage of the load resistor

Assume the zener diode operates in reverse breakdown region.

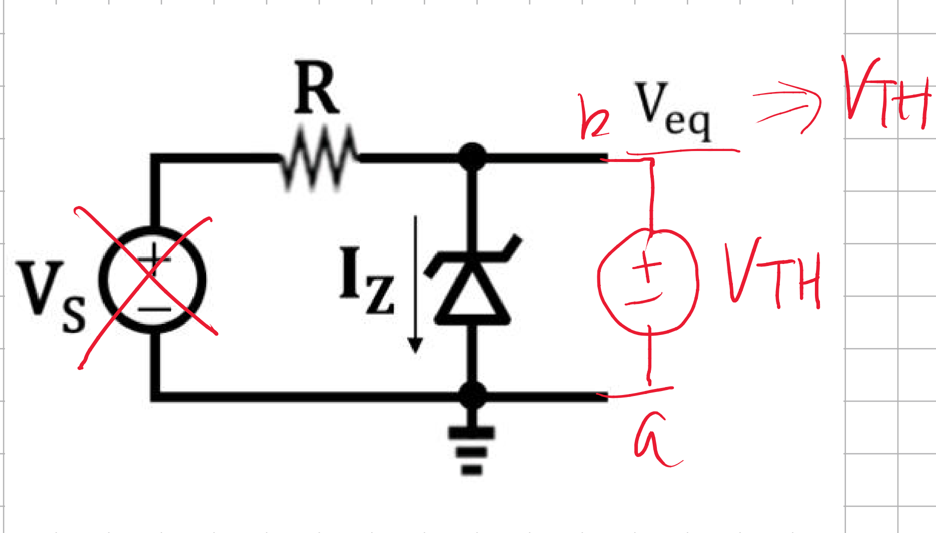


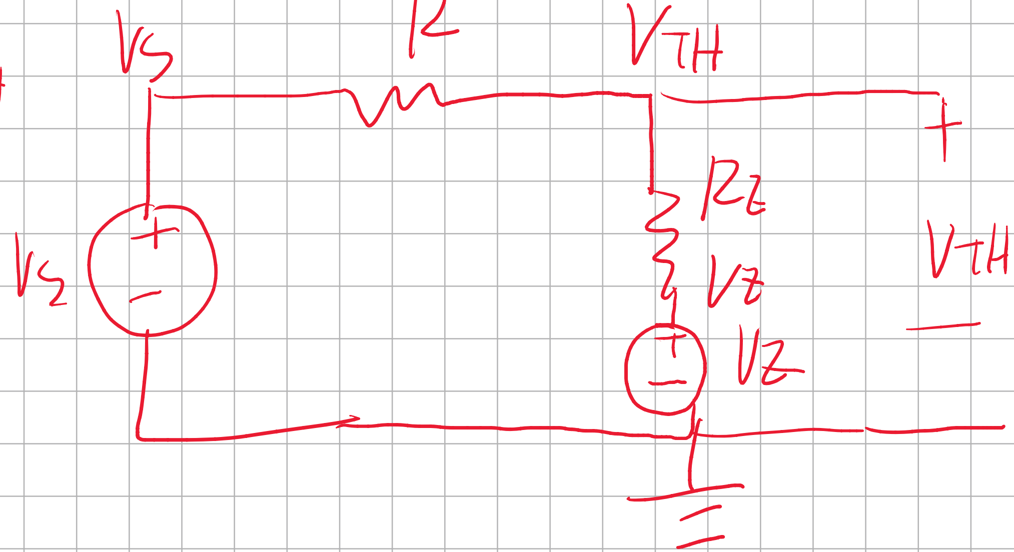




$$V_{eq} = V_{break} + \frac{V_s - V_{break}}{R + R_Z} R_Z \tag{7}$$

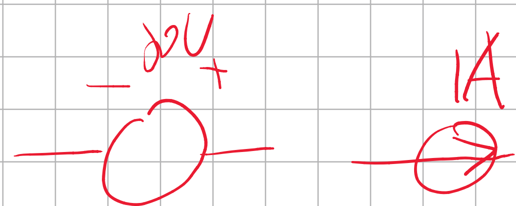
$$V_L = V_{eq} \frac{R_L}{(R||R_Z) + R_L} \tag{8}$$

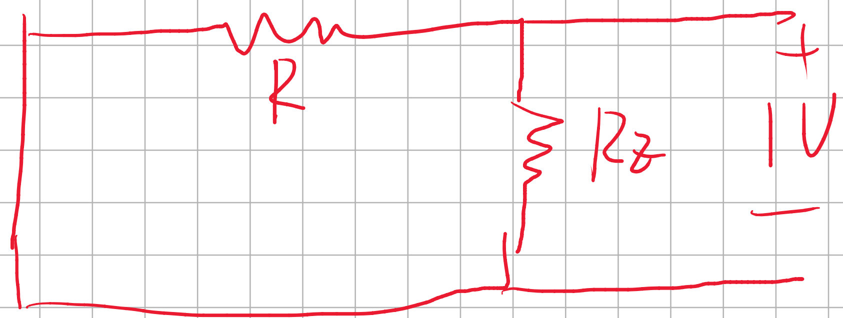


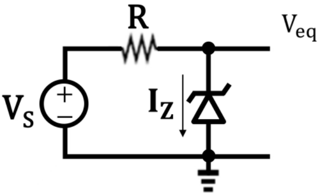

① $V_{TH}$

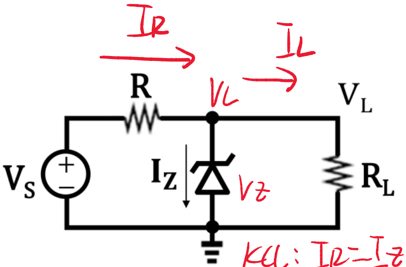
② $R_{TH}$: add a voltage source of 1V on a-b
and turn off the independent sources




$R_{TH} = R \parallel R_Z$




KCL: $I_R = I_Z + I_L$

$$\frac{V_S - V_L}{R} = \frac{V_L - V_Z}{R_Z} + \underbrace{\frac{V_L}{R_L}}_{I_L}$$

how sensitive $V_L$ is to $V_S$ when $R_L \to \infty$

$$\text{Line Regulation} = \frac{dV_L}{dV_S} = \frac{R_Z}{R + R_Z} \; (R_L = \infty) \tag{9}$$

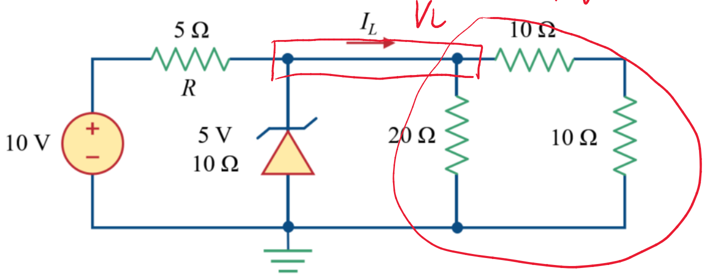
$$\underbrace{\text{Load Regulation}}_{R_{TH}} = \frac{dV_L}{dI_L} = R \parallel R_Z \tag{10}$$

# Exercise 2

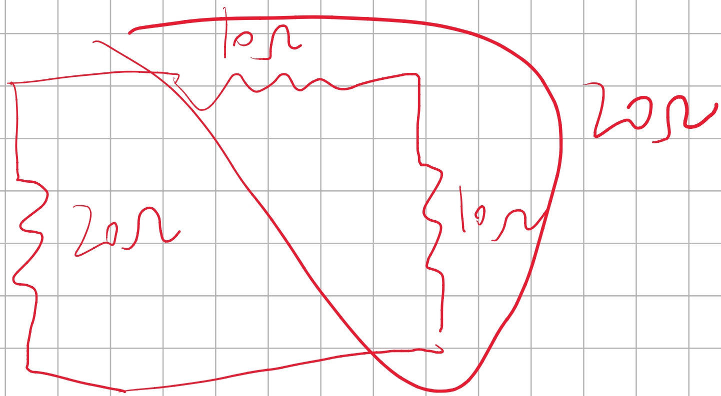
(23FA Mid/6) For the diode circuit below:
(1) Calculate the value $I_L$. [10 points]
(2) Find the maximum value of R required for reverse breakdown to happen. [5 points]

extreme condition: $I_Z > 0$

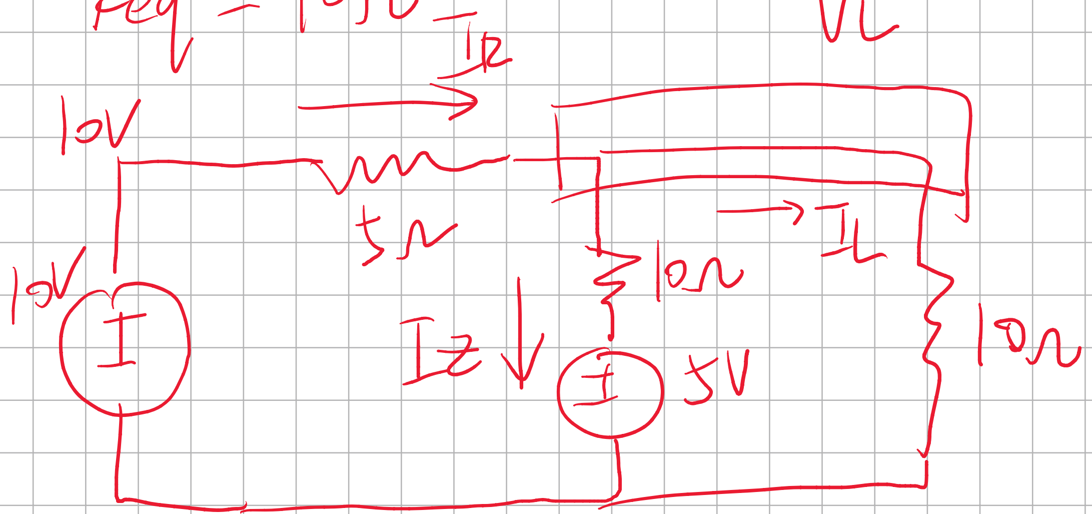
$I_L = \frac{V_L}{R_{eq}}$



(1)




$R_{eq} = 10\Omega$




KCL: $I_R = I_Z + I_L$

$$\frac{10 - V_L}{5} = \frac{V_L - 5}{10} + \frac{V_L - 0}{10}$$

$$\Rightarrow V_L = \frac{25}{4} V$$

$$I_L = \frac{V_L - 0}{R_{eq}} = \frac{\frac{25}{4}}{10} = \frac{5}{8} A$$

(2) $I_Z = \dfrac{V_L - 5}{10} > 0$

$$\frac{10 - V_L}{R} = \frac{V_L - 5}{10} + \frac{V_L - 0}{10}$$

$$\Rightarrow V_L = \frac{5R + 100}{2R + 10}$$

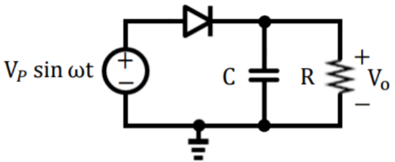
$$V_L - 5 = \frac{50 - 5R}{2R + 10} > 0$$

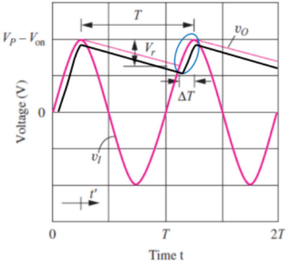
$$\Rightarrow R < 10$$

$\max = 10\Omega$

# Half-Wave Rectifier

The basic rectifier circuit converts an AC voltage to a pulsating DC voltage.




$V_p \sin \omega t > V_O$
Diode ON

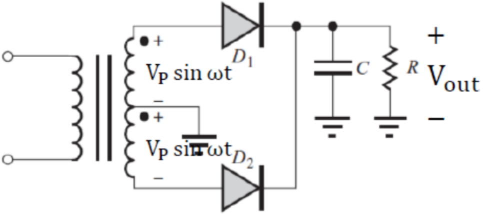
# Half-Wave Rectifier

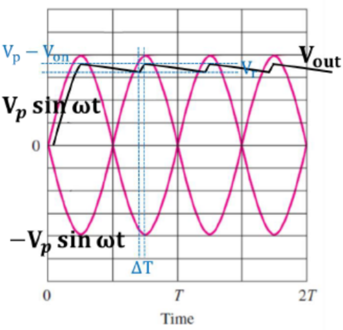
CTPP Time!

1. $V_{dc} = V_s - V_{on}$
2. $I_{dc} = \frac{V_{dc}}{R}$
3. Ripple Voltage: $V_r = V_{dc}(1 - e^{\frac{T-\Delta T}{RC}}) \approx V_{dc}\frac{T}{RC}$
4. Conduction Angle: $\theta_c = \sqrt{\frac{2V_r}{V_S}}$
5. Conduction Interval: $\Delta T = \frac{\theta_c}{\omega}$
6. Diode Current: $I_{peak} = \frac{2I_{dc}T}{\Delta T}$
7. Surge Current: $I_{surge} = C\frac{dV}{dt} = \omega CV_S(t=0)$
8. Peak Inverse Voltage (PIV): $PIV = 2V_s - V_{on}$

# Full-Wave Rectifier

Full-wave rectifier circuits cut the capacitor discharge time in half and offer the advantage of requiring only one-half the filter capacitance to achieve a given ripple voltage



# Full-Wave Rectifier

CTPP Time!

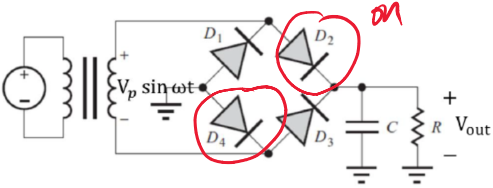
$T \mapsto \frac{T}{2}$

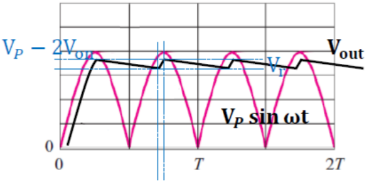
Just replace $T$ with $\frac{T}{2}$ in the Half-Wave rectifier.

1. $V_{dc} = V_s - V_{on}$
2. $I_{dc} = \frac{V_{dc}}{R}$
3. Ripple Voltage: $V_r = V_{dc}(1 - e^{\frac{T/2 - \Delta T}{RC}}) \approx V_{dc}\frac{T}{2RC}$
4. Conduction Angle: $\theta_c = \sqrt{\frac{2V_r}{V_S}}$
5. Conduction Interval: $\Delta T = \frac{\theta_c}{\omega}$
6. Diode Current: $I_{peak} = \frac{I_{dc}T}{\Delta T}$
7. Surge Current: $I_{surge} = C\frac{dV}{dt} = \omega C V_S(t = 0)$
8. Peak Inverse Voltage (PIV): $PIV = 2V_s - V_{on}$

# Full-Wave Bridge Rectifier

- For $v_I > 0$, $D_2$ and $D_4$ will be on and $D_1$ and $D_3$ will be off.
- For $v_I < 0$, $D_2$ and $D_4$ will be off and $D_1$ and $D_3$ will be on.



CTPP Time!

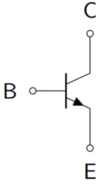
Just replace $V_{on}$ with $2V_{on}$ in the Full-Wave rectifier and change PIV.

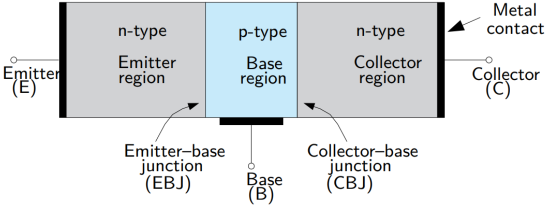
1. $V_{dc} = V_s - 2V_{on}$
2. $I_{dc} = \frac{V_{dc}}{R}$
3. Ripple Voltage: $V_r = V_{dc}(1 - e^{\frac{T/2-\Delta T}{RC}}) \approx V_{dc}\frac{T}{2RC}$
4. Conduction Angle: $\theta_c = \sqrt{\frac{2V_r}{V_S}}$
5. Conduction Interval: $\Delta T = \frac{\theta_c}{\omega}$
6. Diode Current: $I_{peak} = \frac{I_{dc}T}{\Delta T}$
7. Surge Current: $I_{surge} = C\frac{dV}{dt} = \omega C V_S(t=0)$
8. Peak Inverse Voltage (PIV): $PIV = \boxed{V_s - V_{on}}$

# Overview

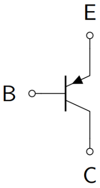
# npn and pnp

npn

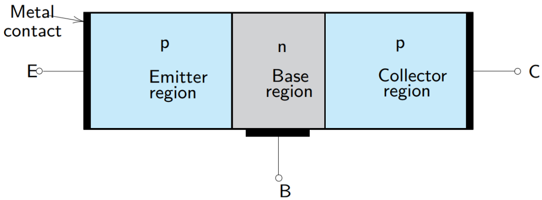



B doesn't change, C->E

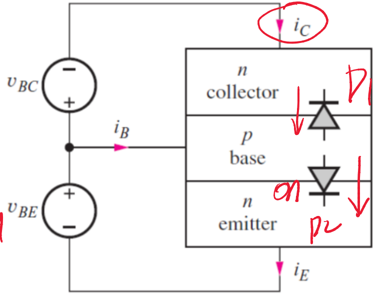



pnp



$V_{BE} > 0$

$V_{BC} < 0$




reverse biased

$I_D$ forward biased

saturation:

$V_{BC} > 0$, $D_1$ forward

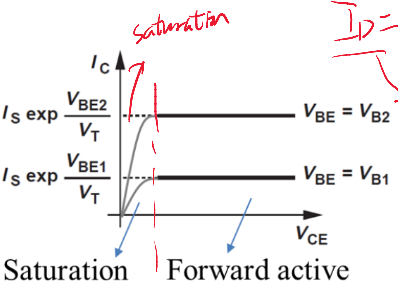
$V_{BE} > 0$, $D_2$ forward

- EB diode is forward biased ($V_{BE} > 0$ or $V_{EB} < 0$)
- BC diode is reversed biased ($V_{BC} < 0$ or $V_{CB} > 0$)

# Saturation v.s. Forward Active

$$I_D = I_s e^{\frac{V_{BE}}{V_T}}$$

has no relation with $V_{CE}$



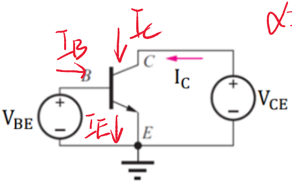

- $V_{CE} < V_{BE}$, then $V_{CB} < 0$ or $V_{BC} > 0$, meaning that BC diode is forward biased. Both diodes are on, which is called as saturation.
- $V_{CE} > V_{BE}$, then $V_{CB} > 0$ or $V_{BC} < 0$, meaning that BC diode is reverse biased. $\rightarrow$ Forward Active

# BJT

Summary:

$I_B + I_C = I_E$

$\alpha = \frac{I_C}{I_E}$, $\beta = \frac{I_C}{I_B}$ $\Rightarrow \beta = \frac{\alpha}{1-\alpha}$




$V_{CE} \geq V_{BE}$
$\Rightarrow$ Forward – Active

Ideal case

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)$$
$$\alpha = \frac{I_C}{I_E} \cong 1$$
$$\beta = \frac{I_C}{I_B} = \frac{\alpha}{1-\alpha}$$

$$I_C = I_S\left(e^{\frac{qV_{BE}}{kT}} - 1\right)$$
$$\alpha = \frac{I_C}{I_E} = 1$$
$$\beta = \frac{I_C}{I_B} = \infty$$

Don't forget this: $I_E = I_C + I_B$

# Early effect

Early effect: $V_A$ is called the Early voltage

limit the gain of BJT amplifier

$$I_C = I_S \left( e^{\frac{qV_{BE}}{kT}} - 1 \right) \left( 1 + \frac{V_{CE}}{V_A} \right) \tag{11}$$

or

$$I_C = I_S \left( e^{\frac{qV_{BE}}{kT}} \right) \left( 1 + \frac{V_{CE}}{V_A} \right) \tag{12}$$

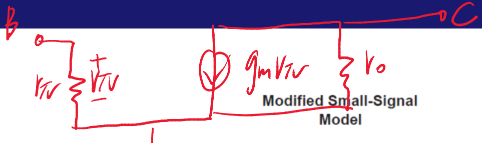
$V_{out} = V_{OUT} + v_{out}$
$V_{out}$: DC+AC, $V_{OUT}$ : DC, $v_{out}$: AC
It is important to bear in mind that small-signal analysis deals with only (small) changes in voltages and currents in a circuit around their quiescent values. Thus, all constant sources, i.e., **voltage and current sources that do not vary with time (independent sources), must be set to zero** for small-signal analysis.

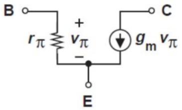
# Small Signal

How to get a small signal circuit:

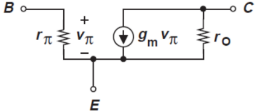
- DC voltage source: short circuit
- DC current source: open circuit
- Capacitor: short circuit (short in AC, open in DC)

# Small Signal




Without Early Effect



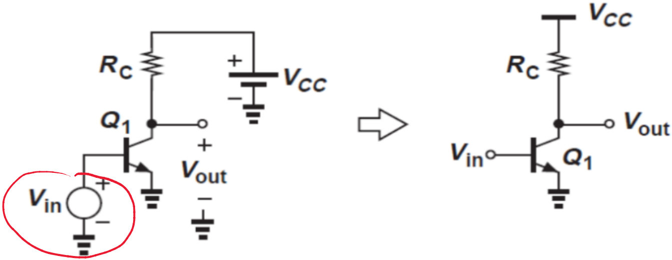

With Early Effect

$$r_\pi = \frac{dV_{BE}}{dI_B} = \frac{1}{\frac{dI_C}{\beta dV_{BE}}} = \frac{1}{\frac{g_m}{\beta}} = \frac{\beta}{g_m} \tag{13}$$

$$g_m = \frac{dI_C}{dV_{BE}} \cong \frac{I_C}{kT/q} \tag{14}$$

$$r_o = \frac{1}{\frac{dI_C}{dV_{CE}}} \cong \frac{V_A}{I_C} \tag{15}$$

# Small Signal




**Attention:**

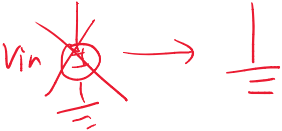
- $V_{out}$ is not connected in the circuit! There is no current to it.
- $V_{in}$ is connected. There is current from it.

Tips: See $V_{out}$ as a voltmeter, $V_{in}$ as a voltage source.

# $R_{out}$

How to calculate $R_{out}$?

1. Draw small signal model.
2. Connect port with $V_{in}$ to ground. Connect a test voltage $v_t$ on port with $V_{out}$.
3. Derive $i_t$.
4. Calculate $R_{out} = \frac{v_t}{i_t}$

How to calcaulate $R_{in}$?

1. Draw small signal model.
2. Connect a test voltage $v_t$ on port with $V_{in}$. Do nothing on output port.
3. Derive $i_t$.
4. Calculate $R_{in} = \frac{v_t}{i_t}$

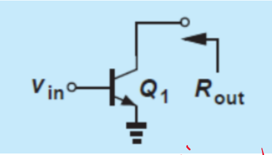
# Exercise 3

Assuming that the BJT operates in the forward active region, determine the impedance seen into the collector of Q1. Please **consider the Early effect.** $\Rightarrow V_A$ is finite

$R_{out}$

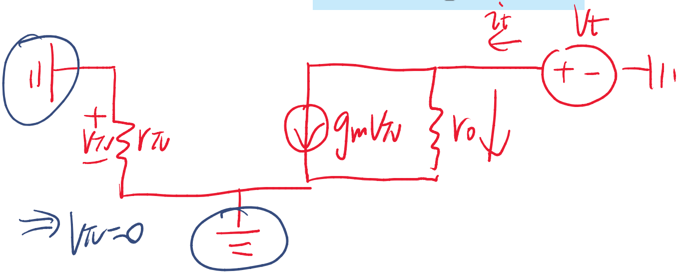
① $V_{in} \to$ ground

② $V_{out} \to V_t$




KCL: $i_t = \frac{V_t}{r_o} + g_m V_\pi$

$= \frac{V_t}{r_o}$

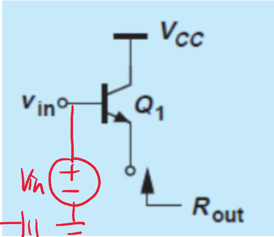



$\Rightarrow R_{out} = r_o$

$\Rightarrow V_\pi = 0$

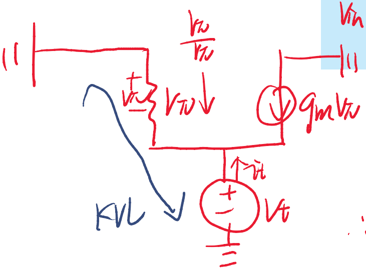
Assuming that the BJT operates in the forward active region, determine the impedance seen at the emitter. Please **neglect the Early effect** for simplicity.

$V_A$ is infinite




KCL: $i_t + \frac{v_\pi}{r_\pi} + g_m v_\pi = 0$

$\Rightarrow i_t = -\frac{v_\pi}{r_\pi} - g_m v_\pi$




KVL: $v_\pi + v_t = 0$

$\Rightarrow v_\pi = -v_t$

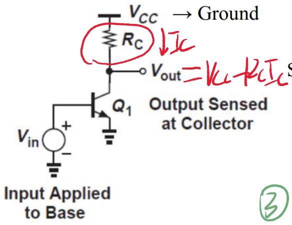
$$\therefore R_{out} = \frac{v_t}{i_t} = \frac{v_t}{\frac{v_t}{r_\pi} + g_m v_t} = \frac{1}{\frac{1}{r_\pi} + g_m} = r_\pi \,\|\, \frac{1}{g_m}$$

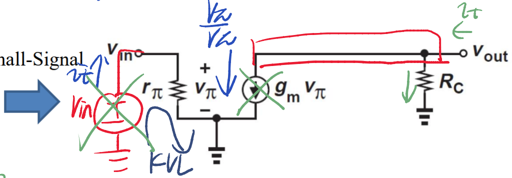
# Overview

# CE Amplifier (Without Early Effect)

② $R_{in}$ $\quad i_t = \frac{V_\pi}{r_\pi}$ $\quad \Rightarrow R_{in} = \frac{V_{in}}{i_t} = r_\pi$

$V_{in} = V_\pi$




③ $R_{out}$

$V_\pi = 0$

$i_t = \frac{V_{out}}{R_C}$

$\Rightarrow R_{out} = R_C$

① $A_V$

KVL: $-V_{in} + V_\pi = 0$

$\Rightarrow V_{in} = V_\pi$

KCL: $\frac{V_{out}}{R_C} + g_m V_\pi = 0$

$\Rightarrow V_{out} = -g_m V_\pi R_C$

$\Rightarrow A_V = \frac{V_{out}}{V_{in}} = -g_m R_C$

$$A_v = \frac{V_{out}}{V_{in}} = -g_m R_C \tag{16}$$

$$R_{in} = r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_C} \tag{17}$$

$$R_{out} = R_C \tag{18}$$

# CE Amplifier (Without Early Effect)

$\uparrow V_{BE}$

$A_V = -g_m R_C$ $\quad \uparrow I_C = I_S e^{\frac{V_{BE}}{V_T}}$

Important properties of the CE stage:

$\downarrow V_{out} = V_{CC} - R_C I_C \uparrow$

1. The small-signal gain is negative, i.e. $V_{BE} \uparrow$ and $I_C \uparrow$ lower $V_{out}$.
2. The voltage gain of the stage is limited by the supply voltage.

$g_m = \frac{I_C}{V_T}$   voltage drop across $R_C$

$$|A_v| = g_m R_C = \frac{I_C R_C}{V_T} \tag{19}$$

$I_C R_C < V_{CC}$

$I_C R_C$ indicates the voltage drops at the collector resistor $R_C$. Because $I_C R_C < V_{CC}$, $|A_v| < \frac{V_{CC}}{V_T}$. Finally, as the BJT is in the active region, we can say that, $|A_v| < \frac{V_{CC} - V_{BE}}{V_T}$.

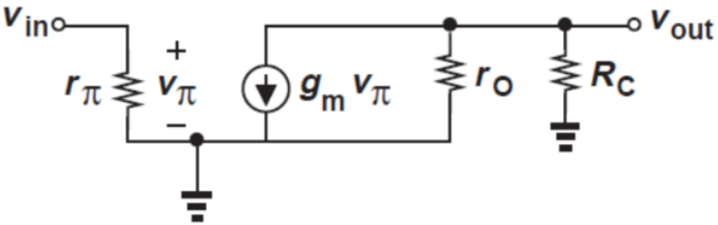
$|A_v| < \frac{V_{CC}}{V_T}$ finite value

However, when $R_C \to \infty$, $|A_v| \to \infty$. Contradiction!

$R_C \to \infty$, $|A_v| = g_m R_C \to \infty$

Contradiction

$\Rightarrow$ early effect




$$A_v = \frac{V_{out}}{V_{in}} = -g_m(R_C \parallel r_O) \quad (20)$$

$$R_{in} = r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_C} \quad (21)$$

$$R_{out} = R_C \parallel r_O \quad (22)$$

# CE Amplifier (With Early Effect)

$R_{out} = R_C \| r_o \to r_o \quad A_v = -g_m (R_C \| r_o) \to -g_m r_o$

If $R_C \to \infty$, $A_v = -g_m r_O \to$intrinsic gain

Because

$$g_m = \frac{I_C}{V_T} \tag{23}$$

and

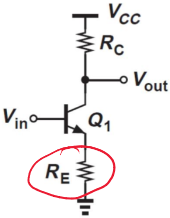
$$r_O = \frac{V_A}{I_C}, \tag{24}$$

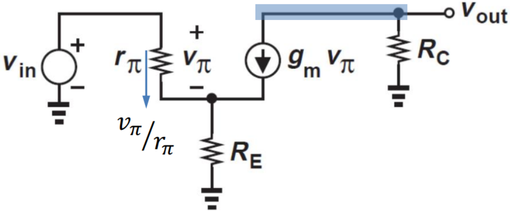
we can get

$$A_v = -\frac{V_A}{V_T} \quad \text{finite} \tag{25}$$

The Early effect limits the voltage gain even if $R_C$ approaches infinity.

# CE Stage With Emitter Degeneration (Without Early Effect)

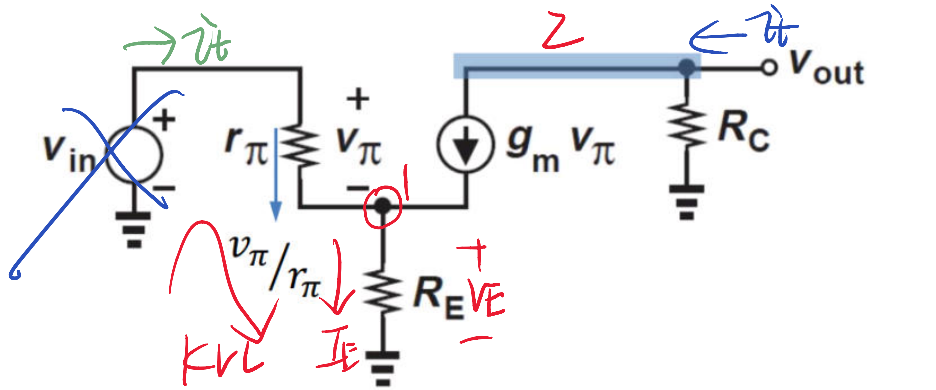



$$A_v = \frac{V_{out}}{V_{in}} = \frac{-g_m R_C}{1 + (\frac{1}{r_\pi} + g_m) R_E} \tag{26}$$

$$R_{in} = r_\pi + (\beta + 1) R_E \tag{27}$$

$$R_{out} = R_C \tag{28}$$




① $A_v$

KVL: $-V_{in}+V_\pi+\underbrace{V_E}_{=R_E I_E}=0$ ✓

KCL1: $\frac{V_\pi}{r_\pi}+g_mV_\pi=I_E$ ✓

KCL2: $\frac{V_{out}}{R_C}+g_mV_\pi=0 \Rightarrow V_{out}=-g_mR_CV_\pi$

$$V_{in}=V_\pi+R_E\left(\frac{V_\pi}{r_\pi}+g_mV_\pi\right)$$

$$=V_\pi\left[1+R_E\left(\frac{1}{r_\pi}+g_m\right)\right]$$

$$V_{out}=-g_mR_C\frac{V_{in}}{1+R_E\left(\frac{1}{r_\pi}+g_m\right)}$$

$$\Rightarrow A_v=-\frac{g_mR_C}{1+R_E\left(\frac{1}{r_\pi}+g_m\right)}$$

② $R_{in}$

$$i_t=\frac{V_\pi}{r_\pi}$$

KVL: $-V_{in}+V_\pi+V_E=0$

KCL: $\frac{V_\pi}{r_\pi}+g_mV_\pi=I_E$

$$\Rightarrow V_{in}=V_\pi+V_E \quad (=R_E I_E)$$

$$=V_\pi\left[1+R_E\left(\frac{1}{r_\pi}+g_m\right)\right]$$

$$\Rightarrow R_{in}=\frac{V_{in}}{i_t}=r_\pi\left[1+R_E\left(\frac{1}{r_\pi}+g_m\right)\right]$$

$$=r_\pi+R_E(1+\underbrace{r_\pi g_m}_{=\beta})$$

$$=r_\pi+R_E(1+\beta)$$

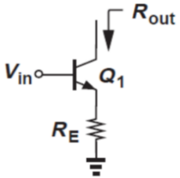
③ $R_{out}$

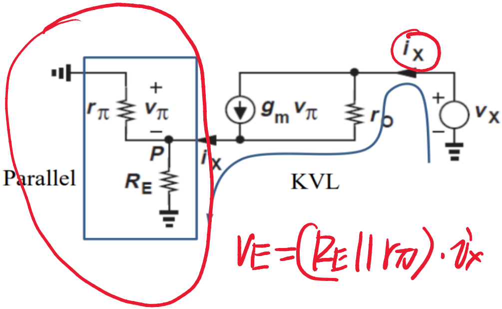
$$i_t=\cancel{g_mV_\pi}+\frac{V_{out}}{R_C}$$

$$R_{out}=\frac{V_{out}}{i_t}=R_C$$

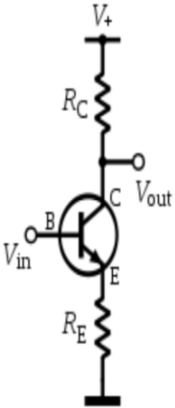
KVL: $V_\pi+V_E=0 \Rightarrow V_\pi=0$

# CE Stage With Emitter Degeneration (With Early Effect)




$$R_{out} = r_o + (g_m r_o + 1)(R_E \parallel r_\pi) \approx r_o[1 + g_m(R_E \parallel r_\pi)] \tag{29}$$




| | Definition | Expression | |
|---|---|---|---|
| | | With emitter degeneration | Without emitter degeneration; i.e., $R_E = 0$ |
| Current gain | $A_i \triangleq \frac{i_{out}}{i_{in}}$ | $\beta$ | $\beta$ |
| Voltage gain | $A_v \triangleq \frac{v_{out}}{v_{in}}$ | $-\frac{\beta R_C}{r_\pi + (\beta+1)R_E}$ | $-g_m R_C$ |
| Input impedance | $r_{in} \triangleq \frac{v_{in}}{i_{in}}$ | $r_\pi + (\beta+1)R_E$ | $r_\pi$ |
| Output impedance | $r_{out} \triangleq \frac{v_{out}}{i_{out}}$ | $R_C$ | $R_C$ |

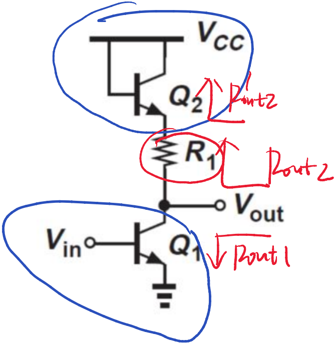
**Suggestion:**

- Remember the general case
- First identify B, C, E port
- Know how to analyze small signal model
- Understand all the exercise in lecture slides
- Don't ignore some small values too easily! Be careful!

$r_o$

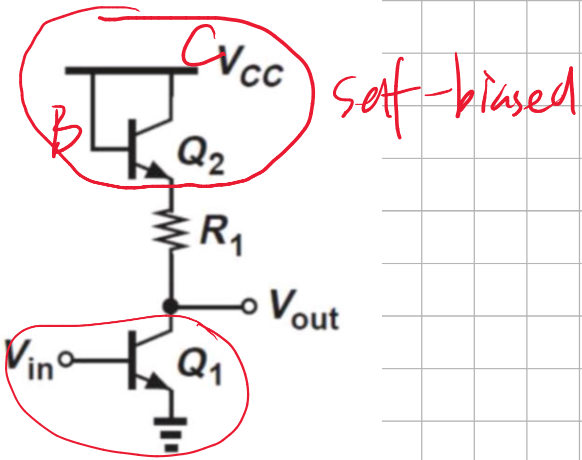
# Exercise 5

(23FA Mid/5) Using a small-signal model, determine output impedance of the circuit shown below with and without Early effect. [10 points]

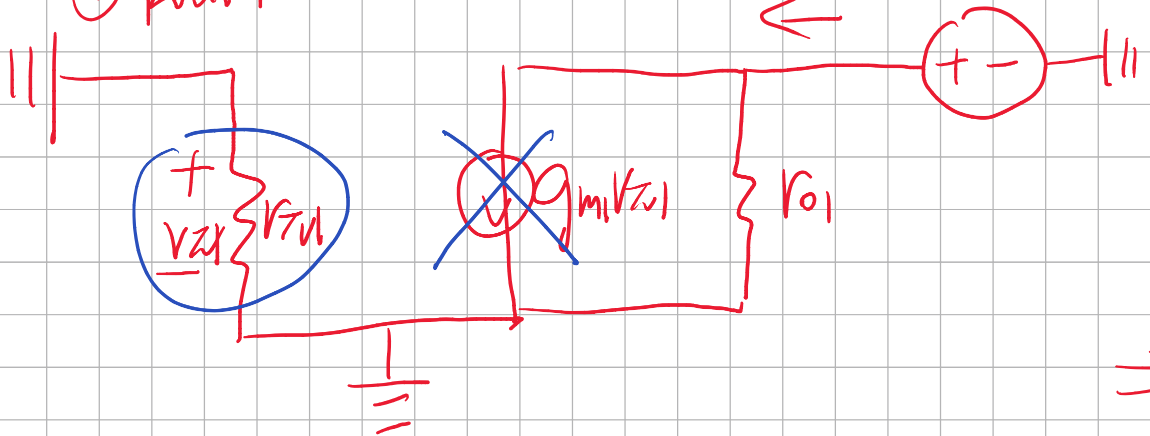



$R_{out} = R_{out1} \| R_{out2}$

$R_{out2} = R_1 + R_{out2}$




① Rout1

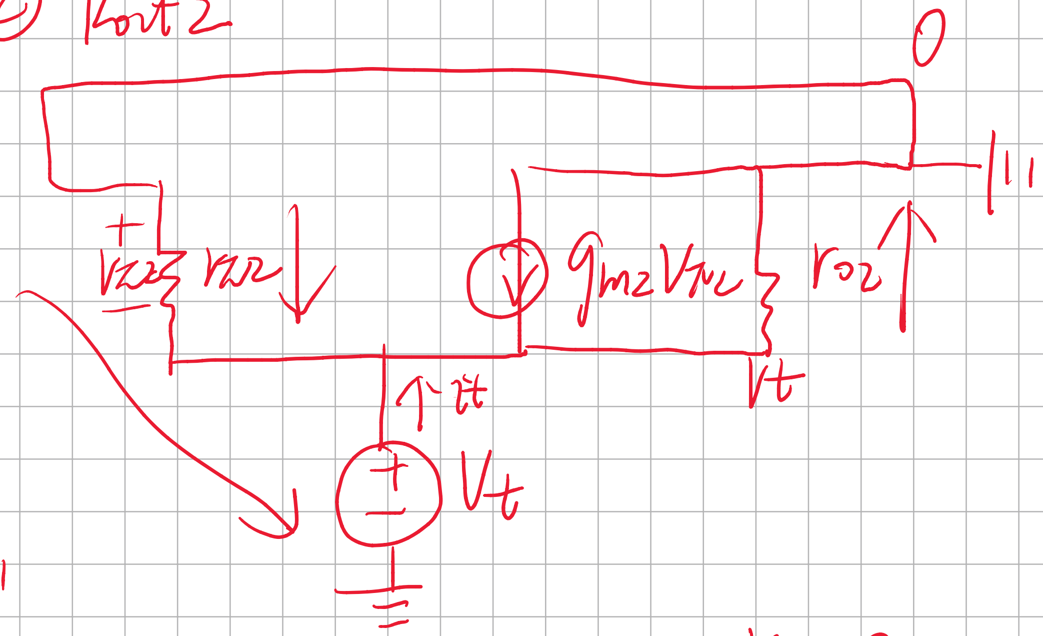



$V_{\pi 1} = 0$

$$i_t = \frac{V_t}{r_{o1}}$$

$$\Rightarrow R_{out1} = \frac{V_t}{i_t} = r_{o1}$$

② Rout2




$$i_t + \frac{V_{\pi 2}}{r_{\pi 2}} + g_{m2} V_{\pi 2} = \frac{V_t - 0}{r_{o2}}$$

$$\Rightarrow i_t = \frac{V_t}{r_{o2}} - \frac{V_{\pi 2}}{r_{\pi 2}} - g_{m2} V_{\pi 2}$$

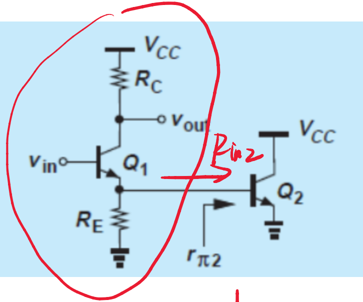
$$\text{KVL: } V_{\pi 2} + V_t = 0 \Rightarrow V_{\pi 2} = -V_t$$

$$\Rightarrow i_t = V_t \left( \frac{1}{r_{o2}} + \frac{1}{r_{\pi 2}} + g_{m2} \right)$$

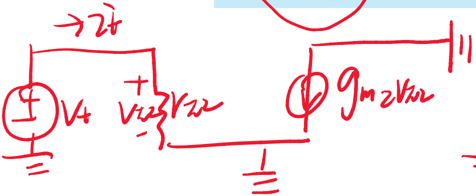
$$\Rightarrow R_{out2} = \frac{1}{\frac{1}{r_{o2}} + \frac{1}{r_{\pi 2}} + g_{m2}} = r_{o2} \parallel r_{\pi 2} \parallel \frac{1}{g_{m2}}$$

# Exercise 6

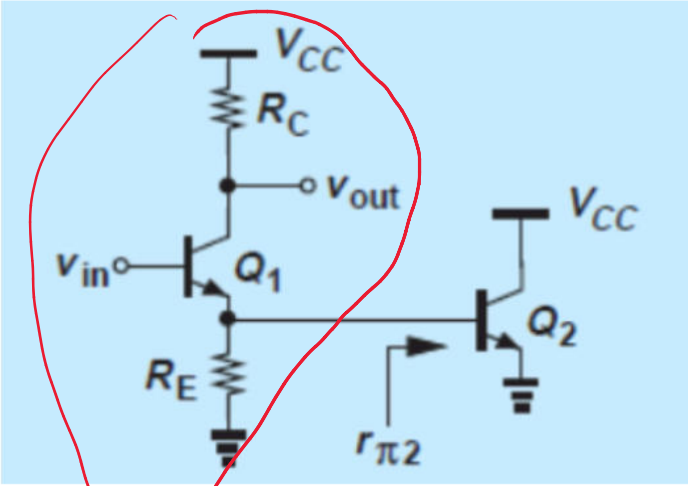
Determine the voltage gain of the stage shown below. No Early effect




$$R_E' = R_E \parallel R_{in2}$$
$$= R_E \parallel r_{\pi 2}$$

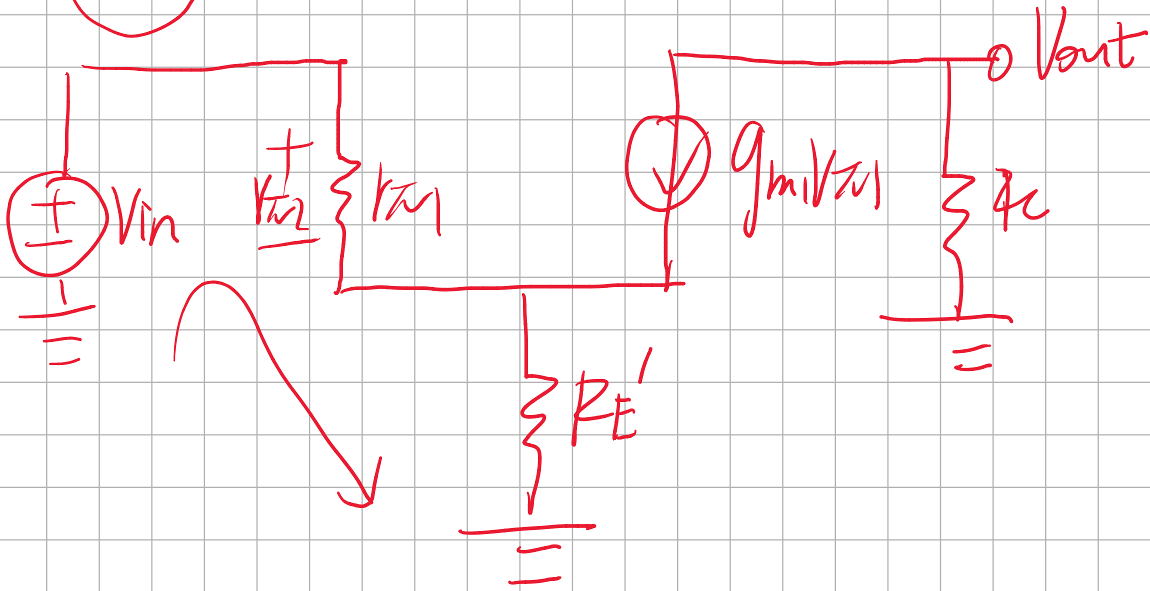



$$i_t = \frac{v_{\pi 2}}{r_{\pi 2}}$$
$$\Rightarrow R_{in2} = r_{\pi 2}$$




$$KCL: \frac{V_{out}}{R_C} + g_m V_{\pi 1} = 0$$

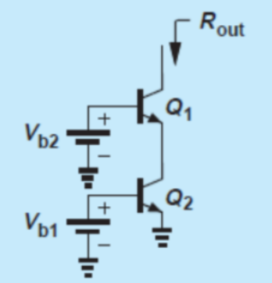
$$\Rightarrow \frac{V_{out}}{V_{in}} = -\frac{g_{m1} R_C}{1+(R_E \| r_{\pi 2})(\frac{1}{r_{\pi 1}}+g_{m1})}$$



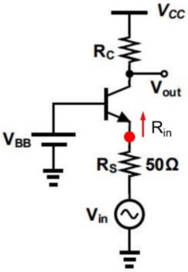

$$KVL: -V_{in} + V_{\pi 2} + I_E \cdot R_E' = 0$$

$$KCL: \frac{V_{\pi 1}}{r_{\pi 1}} + g_{m1} V_{\pi 1} = I_E$$

Determine the output resistance of the circuit below. With Early Effect.



(23FA Mid/9) The figure below shows a BJT amplifier. Assume $V_{BE} = 0.7$ V, $V_T = 25$ mV, $\beta$ is very large (to be infinity). No Early effect. [15 points]




(a) Draw the small signal model and derive the gain for the amplifier. [5 points]

(b) Find values of $V_{BB}$ and $R_C$ to have a gain of 20 and a matched resistance of 100 $\Omega$ at the input, i.e. $R_{in} = 100\ \Omega$ from the point above $R_S$. [5 points]
(c) By cascading another BJT circuit to the circuit in part b as shown below, find the total parametric gain of the amplifier. [5 points]