EE 330
Lecture 31

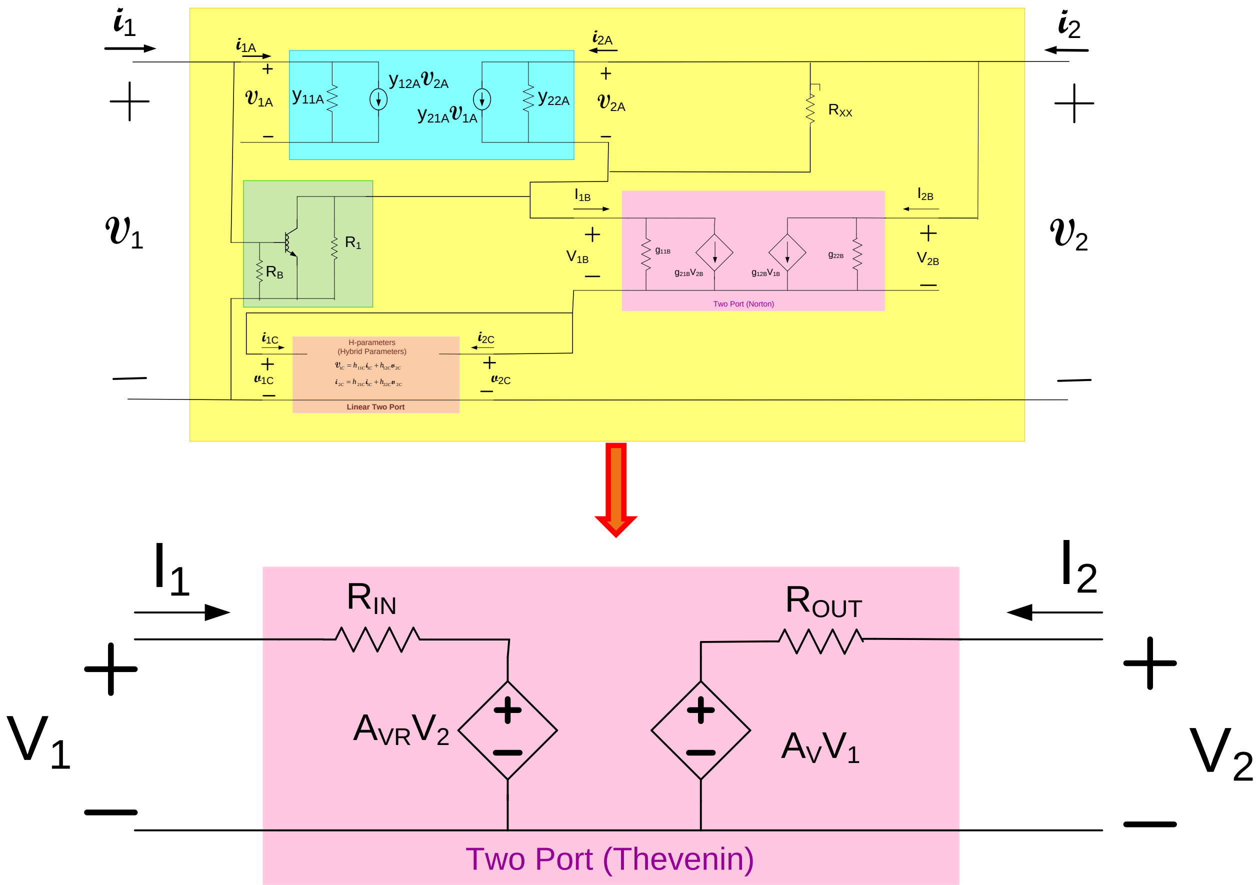
Basic amplifier architectures

- Common Emitter/Source
- Common Collector/Drain
- Common Base/Gate
- Common Emitter/Source with R_E/R_S

Basic Amplifiers

- Analysis, Operation, and Design

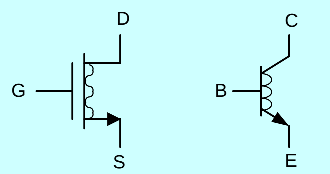
Two-Port Equivalents of Interconnected Two-ports



Apply V_1, open V_2 to get A_V but short V_2 to get R_{IN}

Apply V_2, open V_1 to get A_{VR} but short V_1 to get R_{OUT}

Basic Amplifier Structures



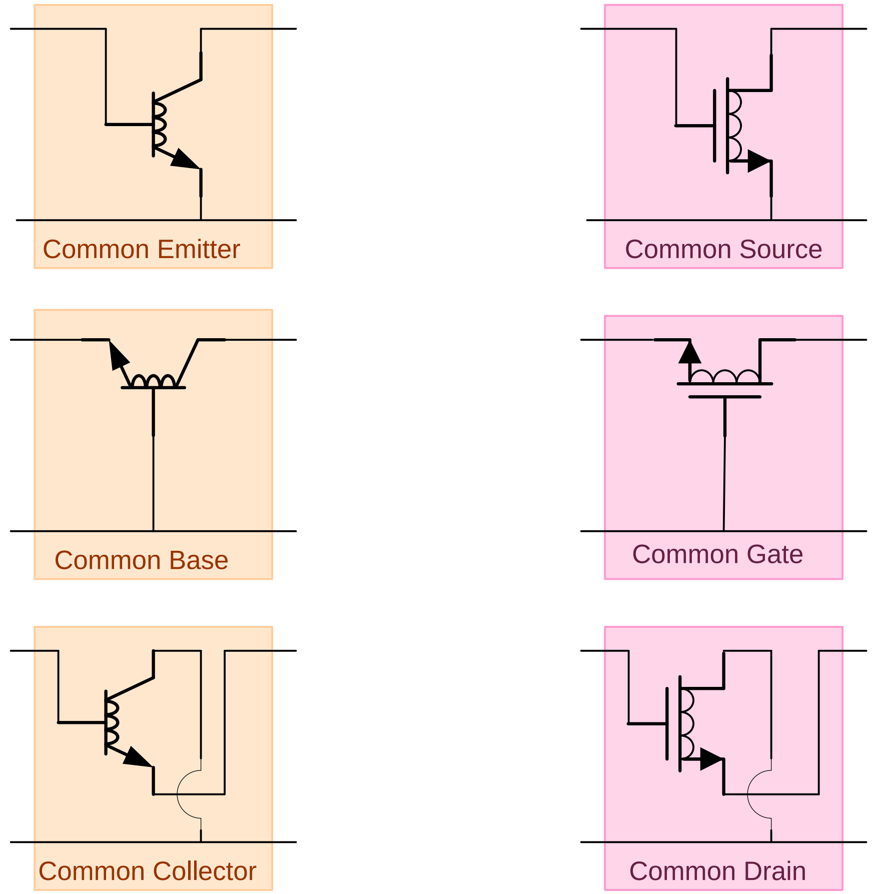
Small Signal Transistor Models
as 3-terminal Devices

	MOS			BJT		
	Common	Input	Output	Common	Input	Output
Common Source or Common Emitter	S	G	D	E	B	C
Common Gate or Common Base	G	S	D	B	E	C
Common Drain or Common Collector	D	G	S	C	B	E

Objectives in Study of Basic Amplifier Structures

1. Obtain key properties of each basic amplifier
2. Develop method of designing amplifiers with specific characteristics using basic amplifier structures

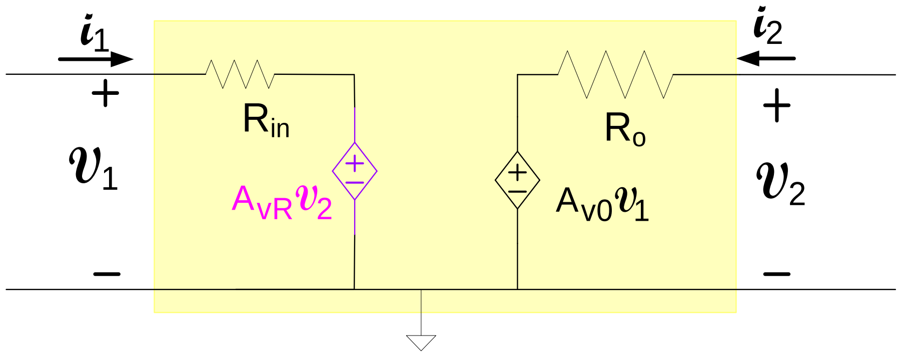
The three basic amplifier types for both MOS and bipolar processes



Will focus on the performance of the bipolar structures and then obtain performance of the MOS structures by observation

Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network



1. v_{TEST} : i_{TEST} Method (considered in last lecture)

2. Write v_1 : v_2 equations in standard form

$$v_1 = i_1 R_{IN} + A_{VR} v_2$$

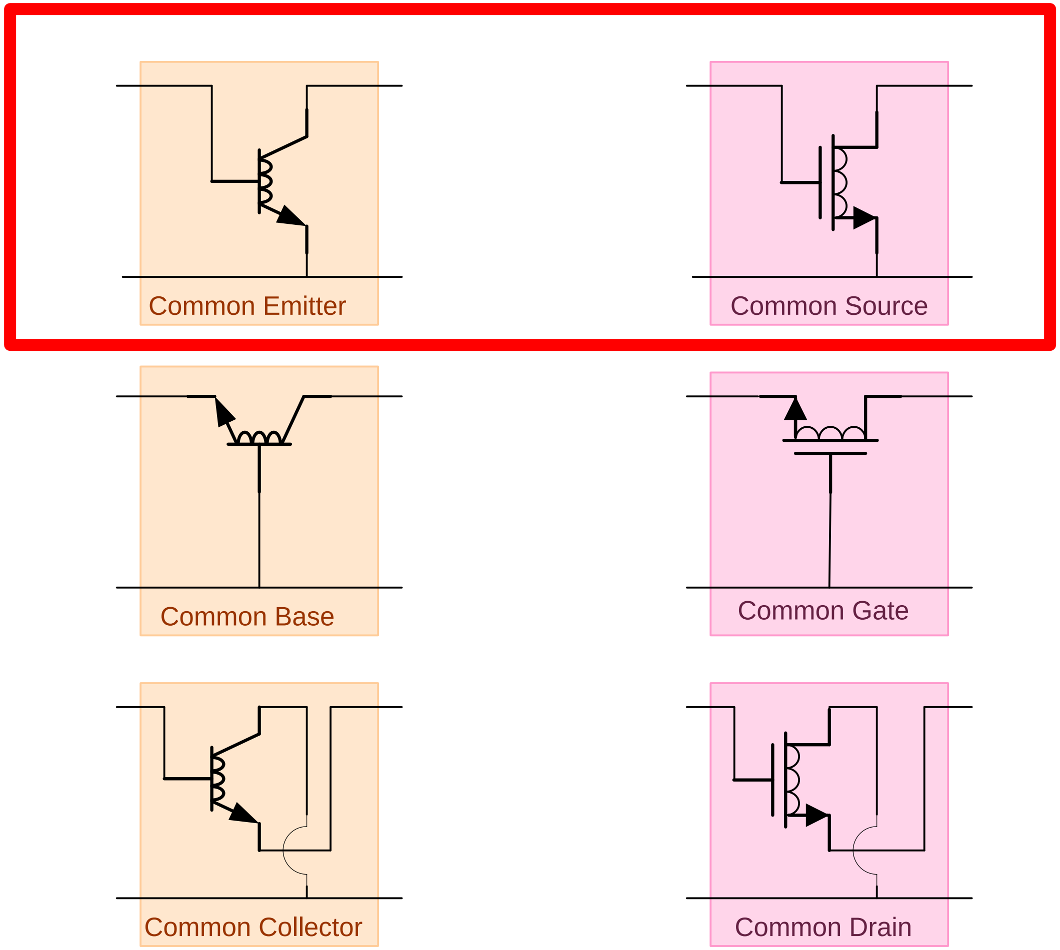
$$v_2 = i_2 R_O + A_{V0} v_1$$

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

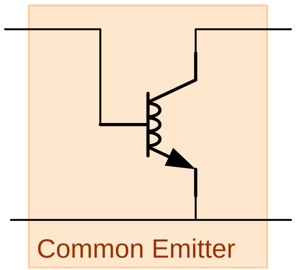
Any of these methods can be used to obtain the two-port model

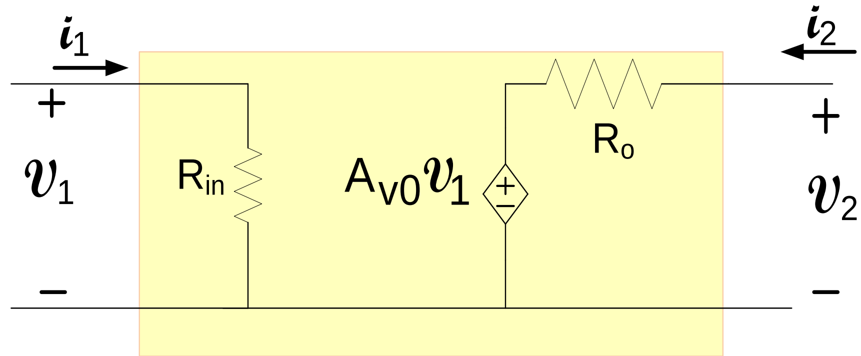
Consider Common Emitter/Common Source Two-port Models



Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting $g_{\pi}=0$

Two-port model for Common Emitter Configuration





In terms of small signal model parameters:

$$R_{in} = \frac{1}{g_\pi} \qquad A_{V0} = -\frac{g_m}{g_0} \qquad R_0 = \frac{1}{g_0} \qquad A_{VR} = 0$$

In terms of operating point and model parameters:

$$R_i = \frac{\beta V_t}{I_{CQ}} \qquad A_{V0} = -\frac{V_{AF}}{V_t} \qquad R_0 = \frac{V_{AF}}{I_{CQ}} \qquad A_{VR} = 0$$

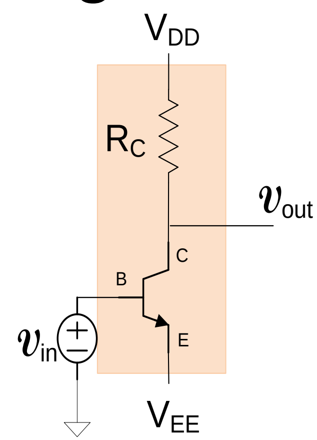
Characteristics:

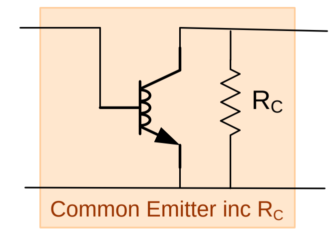
- Input impedance is mid-range
- Voltage Gain is Large and Inverting
- Output impedance is large
- Unilateral
- Widely used to build voltage amplifiers

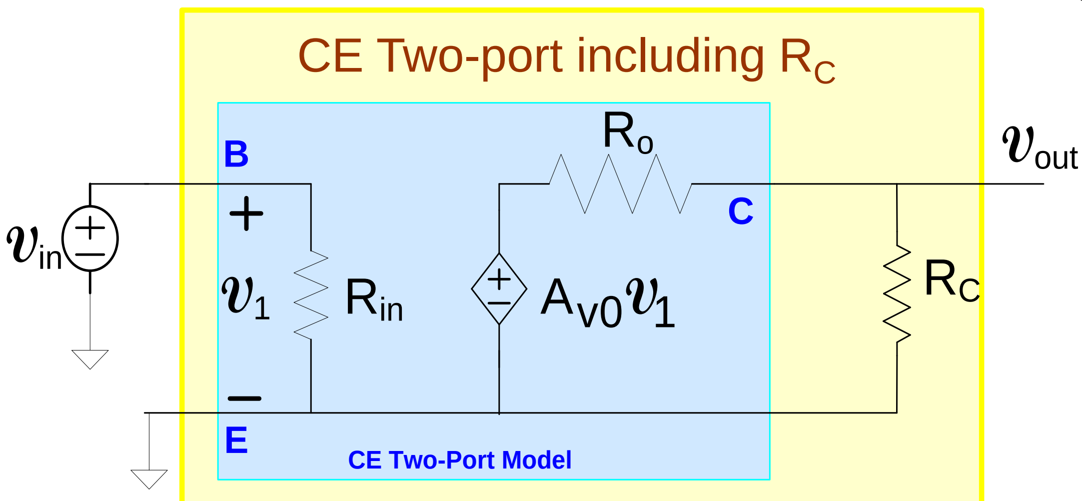
Common Emitter Configuration

Consider the following CE application

(this will also generate a two-port model for this CE application)







$A_{VR} = 0$

$$v_{out}\left(g_C + g_0\right) = g_0 A_{V0} v_{in} \rightarrow A_{VC} = \frac{v_{out}}{v_{in}} = \frac{g_0 A_{V0}}{g_0 + g_C} = \frac{-g_m}{g_0 + g_C} \overset{g_0 << g_C}{\cong} -g_m R_C$$

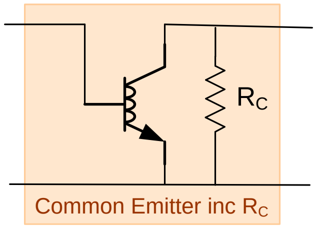
$$R_{inC} = R_{in} = r_\pi$$

$$R_{outC} = R_o // R_C \rightarrow R_{outC} = R_o // R_C = \frac{1}{g_0 + g_C} \overset{g_0 << g_C}{\cong} R_C$$

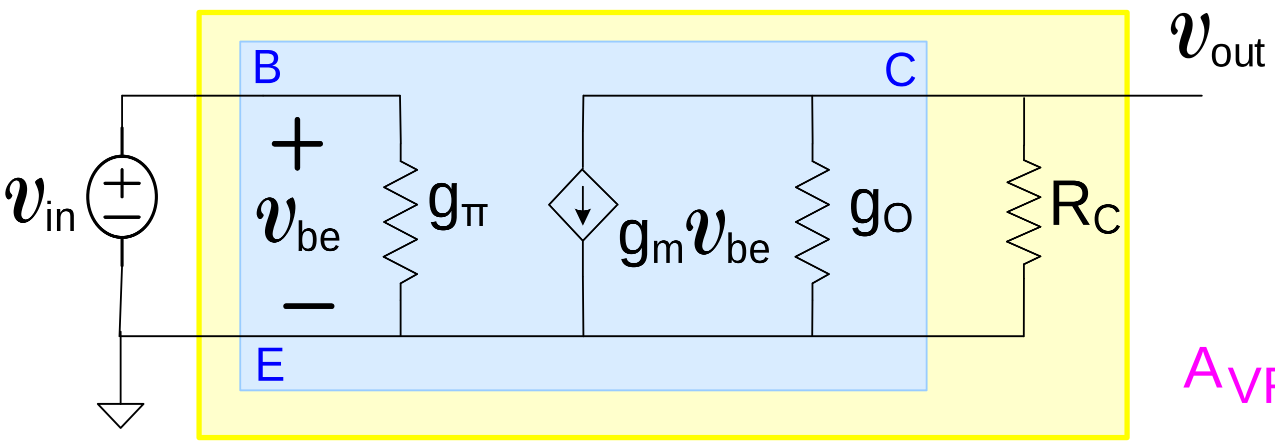
Common Emitter Configuration

Consider the following CE application

(this will also generate a two-port model for this CE application)



This circuit can also be analyzed directly without using 2-port model for CE configuration



$A_{VR} = 0$

$$v_{out} = -g_m v_{in}\left(\frac{1}{g_0 + g_C}\right)$$

$$A_v = \frac{v_{out}}{v_{in}} = -\left(\frac{g_m}{g_0 + g_C}\right) \overset{g_0 << g_C}{\cong} -g_m R_C$$

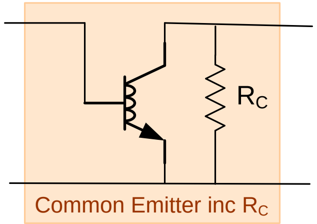
$$R_{in} = r_\pi$$

$$R_{out} = \frac{1}{g_0 + g_C} \overset{g_0 << g_C}{\cong} R_C$$

Common Emitter Configuration

Consider the following CE application

(this is also a two-port model for this CE application)



Small signal parameter domain

$$A_v \overset{g_0 << g_C}{\cong} -g_m R_C$$

$$R_{out} = \frac{1}{g_0 + g_C} \overset{g_0 << g_C}{\cong} R_C$$

$$R_{in} = r_\pi$$

Operating point and model parameter domain

$$A_v \overset{g_0 << g_C}{\cong} -\frac{I_{CQ} R_C}{V_t}$$

$$R_{out} \overset{g_0 << g_C}{\cong} R_C$$

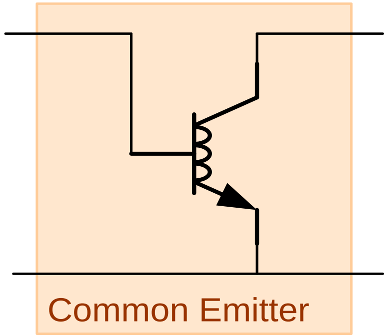
$$R_{in} = \frac{\beta V_t}{I_{CQ}}$$

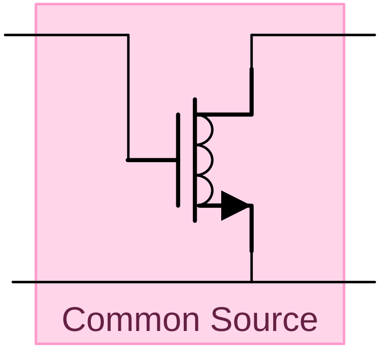
$$A_{VR} = 0$$

Characteristics:

- Input impedance is mid-range
- Voltage Gain is large and Inverting
- Output impedance is mid-range
- Unilateral
- Widely used as a voltage amplifier

Common Source/ Common Emitter Configurations





$$A_{VR} = 0 \qquad A_{VR} = 0$$

$$R_{in} = \frac{1}{g_\pi} \qquad A_{V0} = -\frac{g_m}{g_0} \qquad R_0 = \frac{1}{g_0}$$

$$R_{in} = \infty \qquad A_{V0} = -\frac{g_m}{g_0} \qquad R_0 = \frac{1}{g_0}$$

In terms of operating point and model parameters:

$$R_{in} = \frac{\beta V_t}{I_{CQ}} \qquad A_{V0} = -\frac{V_{AF}}{V_t} \qquad R_0 = \frac{V_{AF}}{I_{CQ}}$$

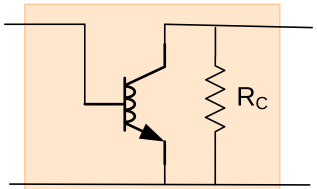
$$R_{in} = \infty \qquad R_0 = \frac{1}{\lambda I_{DQ}} = \frac{V_{AF}}{I_{DQ}}$$

$$A_{V0} = -\frac{2}{\lambda V_{EBQ}} = -2\frac{V_{AF}}{V_{EBQ}}$$

Characteristics:

- Input impedance is mid-range (infinite for MOS)
- Voltage Gain is Large and Inverting
- Output impedance is large
- Unilateral
- Widely used to build voltage amplifiers

Common Source/Common Emitter Configuration



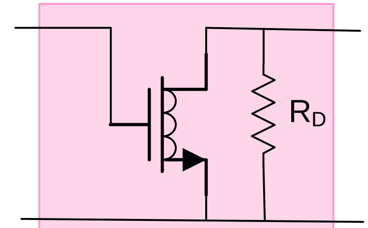
Common Emitter inc R_C

$$R_{out} = \frac{1}{g_0 + g_C} \overset{g_0 << g_C}{\cong} R_C$$

$$A_v \overset{g_0 << g_C}{\cong} -g_m R_C$$

$$R_{in} = r_\pi$$

$$A_{VR} = 0$$



Common Source inc R_D

$$R_{out} = \frac{1}{g_0 + g_D} \overset{g_0 << g_D}{\cong} R_D$$

$$A_v \overset{g_0 << g_D}{\cong} -g_m R_D$$

$$A_{VR} = 0$$

$$R_{in} = \infty$$

In terms of operating point and model parameters:

$$A_v \overset{g_0 << g_C}{\cong} -\frac{I_{CQ} R_C}{V_t}$$

$$R_{out} \overset{g_0 << g_C}{\cong} R_C$$

$$R_{in} = \frac{\beta V_t}{I_{CQ}}$$

$$A_v \overset{g_0 << g_D}{\cong} -\frac{2 I_{DQ} R_D}{V_{EBQ}}$$

$$R_{in} = \infty$$

$$R_{out} \overset{g_0 << g_D}{\cong} R_D$$

Characteristics:

- Input impedance is mid-range (infinite for MOS)
- Voltage Gain is Large and Inverting
- Output impedance is mid-range
- Unilateral
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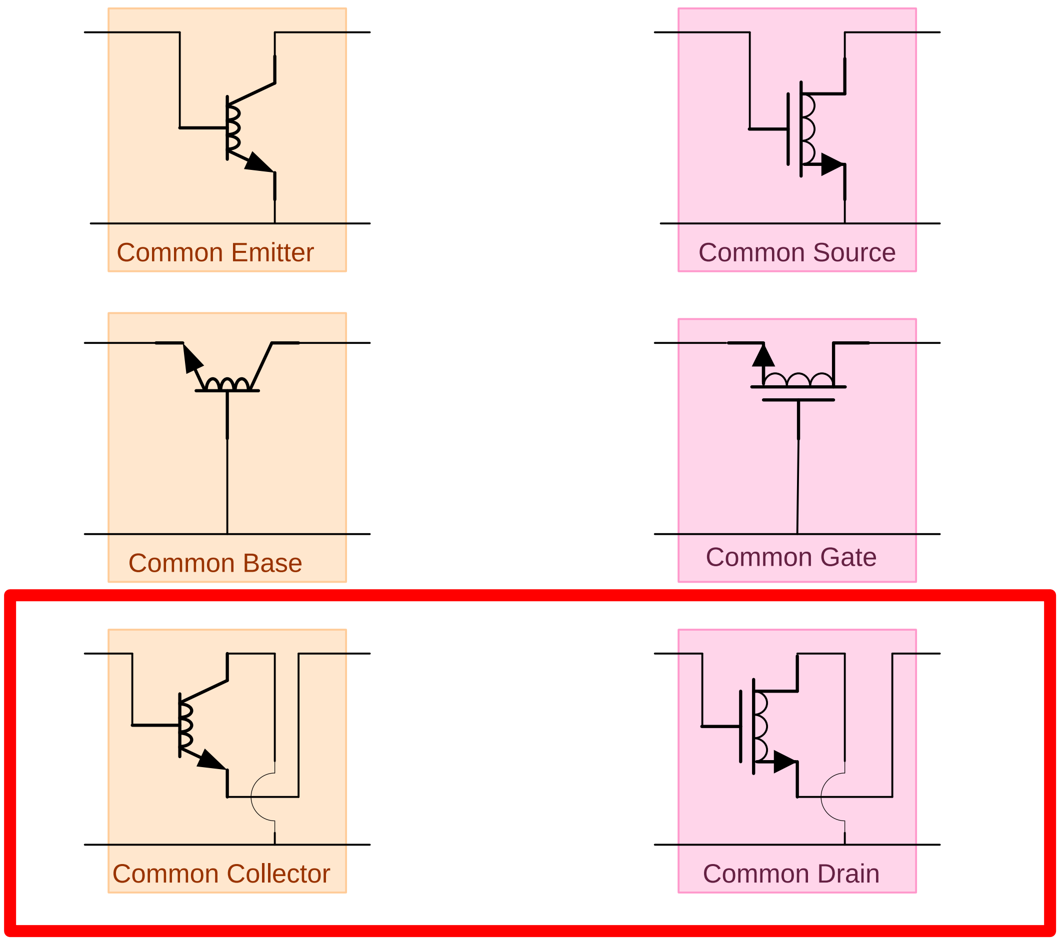
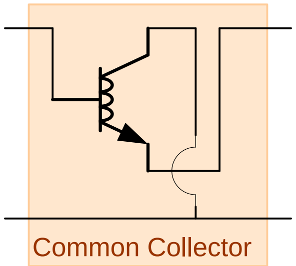
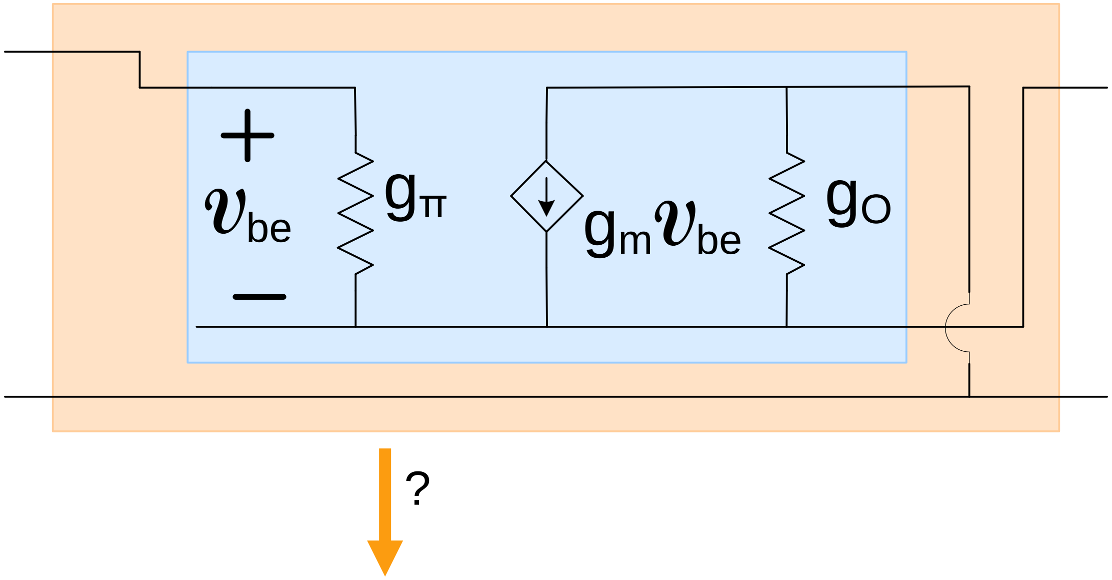
Consider Common Collector/Common Drain Two-port Models

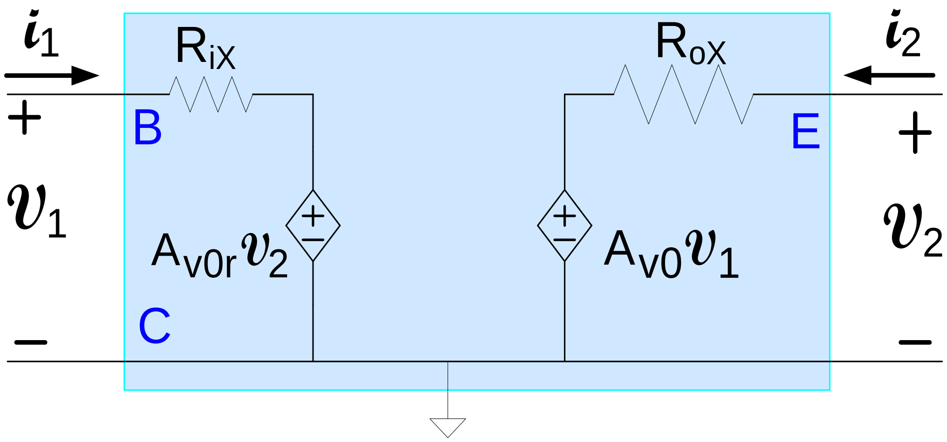


Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting g_π=0

Two-port model for Common Collector Configuration



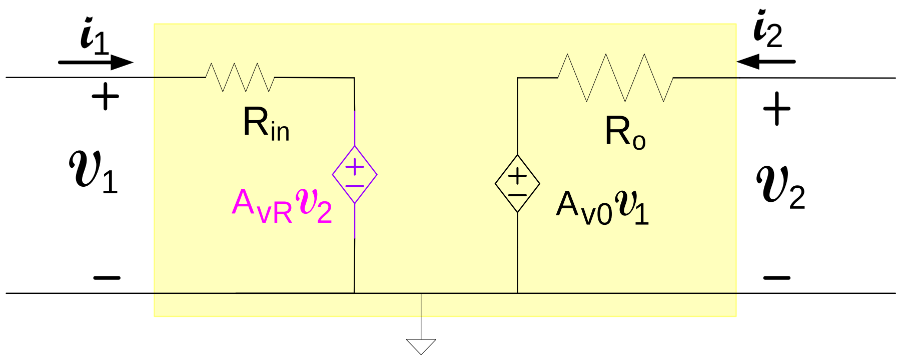




$\{R_{iX}, A_{V0}, A_{V0r}$ and $R_{0X}\}$

Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network



1. v_{TEST} : i_{TEST} Method

2. Write v_1 : v_2 equations in standard form

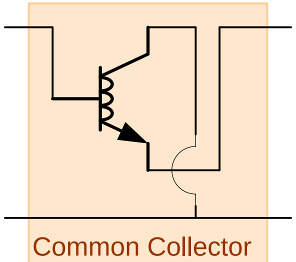
$$v_1 = i_1 R_{IN} + A_{VR} v_2$$

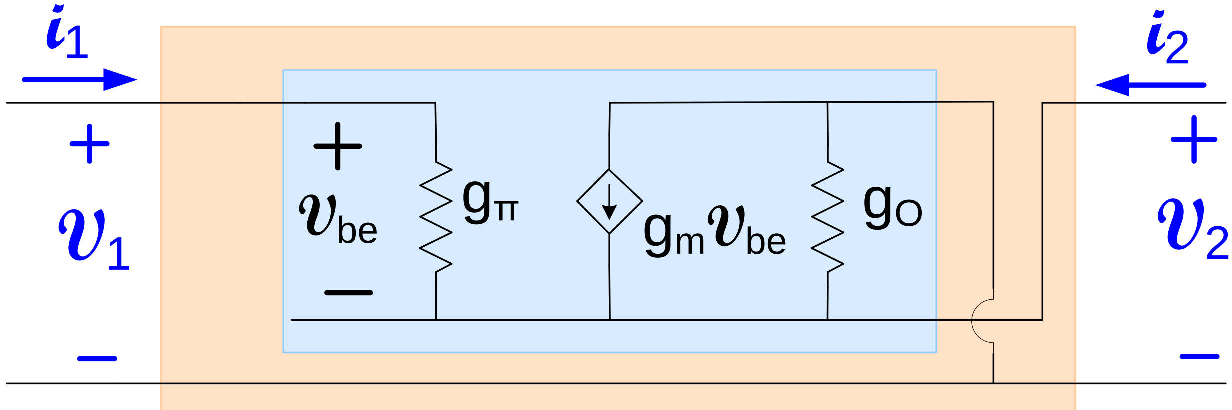
$$v_2 = i_2 R_O + A_{V0} v_1$$

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

Two-port model for Common Collector Configuration





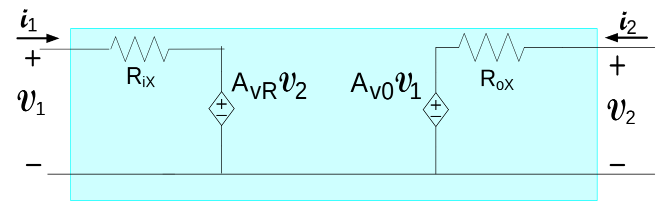
Applying KCL at the input and output node, obtain

$$\left.\begin{aligned} i_1 &= (v_1 - v_2)\, g_\pi \\ i_2 &= (g_m + g_\pi + g_o)\, v_2 - (g_m + g_\pi)\, v_1 \end{aligned}\right\}$$

These can be rewritten as

$$\left.\begin{aligned} v_1 &= i_1 r_\pi + v_2 \\ v_2 &= \left(\frac{1}{g_m + g_\pi + g_o}\right) i_2 + \left(\frac{g_m + g_\pi}{g_m + g_\pi + g_o}\right) v_1 \end{aligned}\right\}$$

Standard Two-Port Amplifier Representation



$$v_1 = i_1 R_{iX} + A_{VR} v_2$$

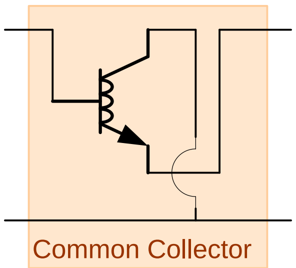
$$v_2 = i_2 R_{oX} + A_V v_1$$

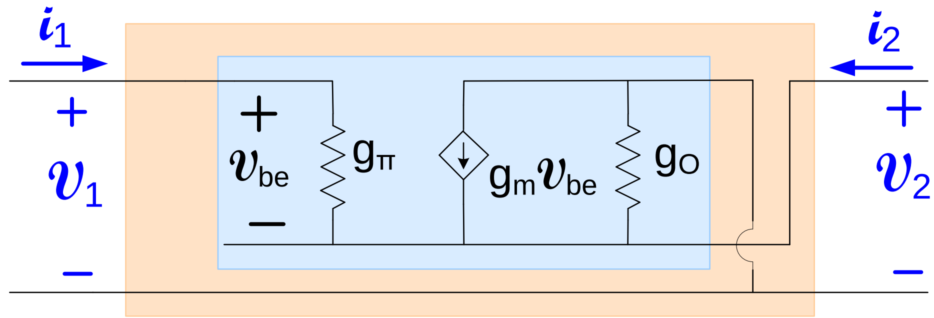
$v_1 : v_2$ equations in standard form

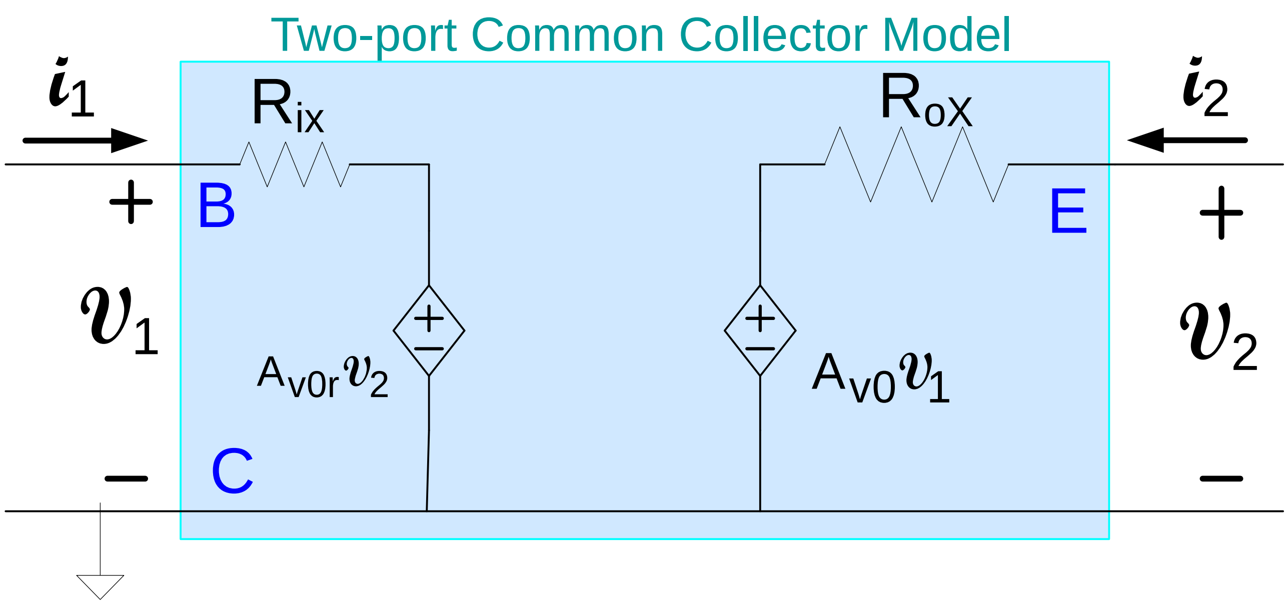
It thus follows that

$R_{iX} = r_\pi$ $\quad A_{Vr} = 1$ $\quad R_{0X} = \left(\dfrac{1}{g_m + g_\pi + g_o}\right)$ $\quad A_{V0} = \left(\dfrac{g_m + g_\pi}{g_m + g_\pi + g_o}\right)$

Two-port model for Common Collector Configuration







$R_{iX} = r_\pi$

$A_{VOr} = 1$

$$R_{0X} = \left(\frac{1}{g_m + g_\pi + g_o} \right) \cong \frac{1}{g_m}$$

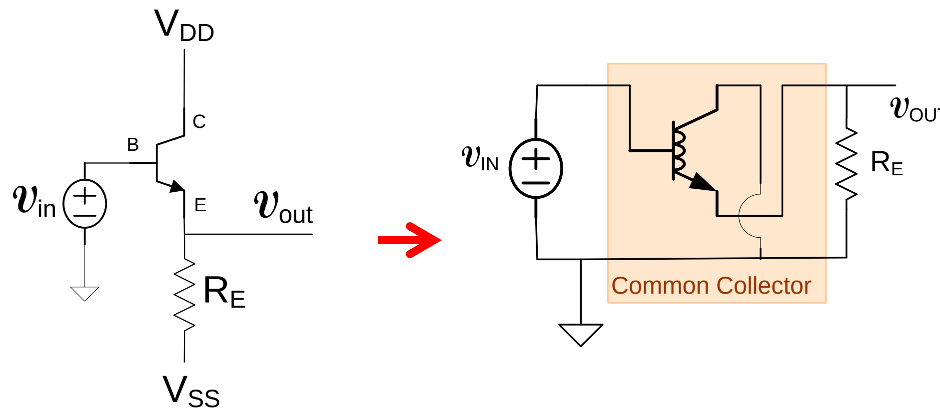
$$A_{V0} = \left(\frac{g_m + g_\pi}{g_m + g_\pi + g_o} \right) \cong 1$$

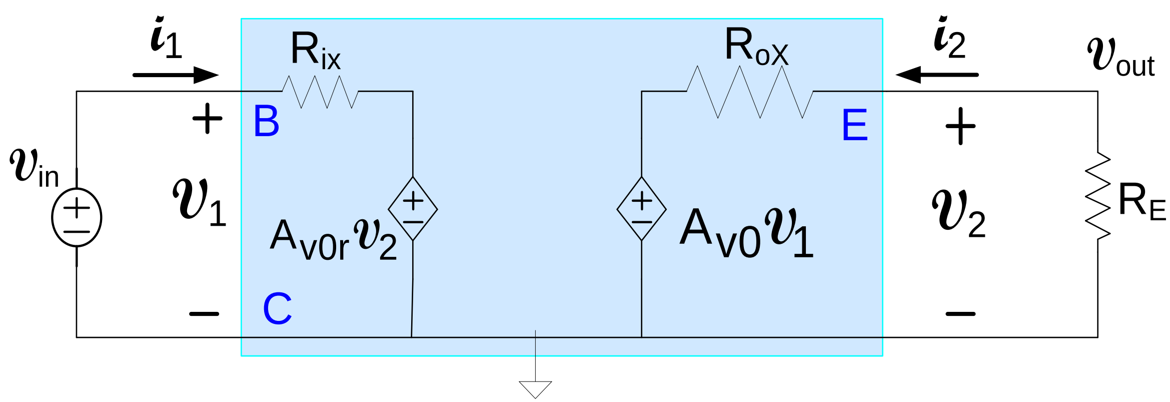
Common Collector Configuration

Consider the following CC application

Determine R_{in}, R_0, and A_V

(this is not asking for a two-port model for the CC application – R_{in} and A_V defined for no additional load on output, R_o defined for short-circuit input)





$$A_V = A_{V0}\frac{g_{ox}}{g_{ox}+g_E} = \frac{g_m+g_\pi}{g_m+g_\pi+g_o}\left(\frac{g_m+g_\pi+g_o}{g_m+g_\pi+g_o+g_E}\right) = \frac{g_m+g_\pi}{g_m+g_\pi+g_o+g_E} \cong \frac{g_m}{g_m+g_E} \overset{if\ g_m>>g_E}{\cong} 1$$

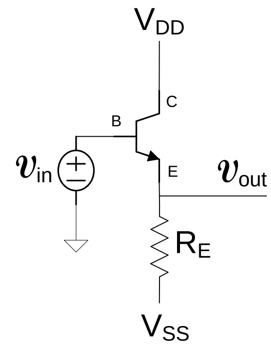
$$v_{in} = i_1 R_{ix} + A_{v0r}A_{v0}\frac{g_{0X}}{g_{0X}+g_E}v_{in} \rightarrow R_{in} = \frac{r_\pi}{1-\dfrac{g_m+g_\pi}{g_m+g_\pi+g_o+g_E}} = r_\pi\frac{g_m+g_\pi+g_o+g_E}{g_o+g_E} \overset{g_E>>g_o}{\cong} r_\pi+\beta R_E$$

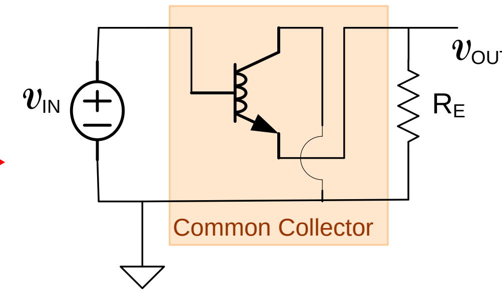
$$R_0 \cong \frac{1}{g_m+g_E+g_0+g_\pi} = \frac{1}{g_m+g_E} = \frac{R_E}{1+g_mR_E} \overset{g_m>>g_E}{\cong} \frac{1}{g_m}$$

Common Collector Configuration

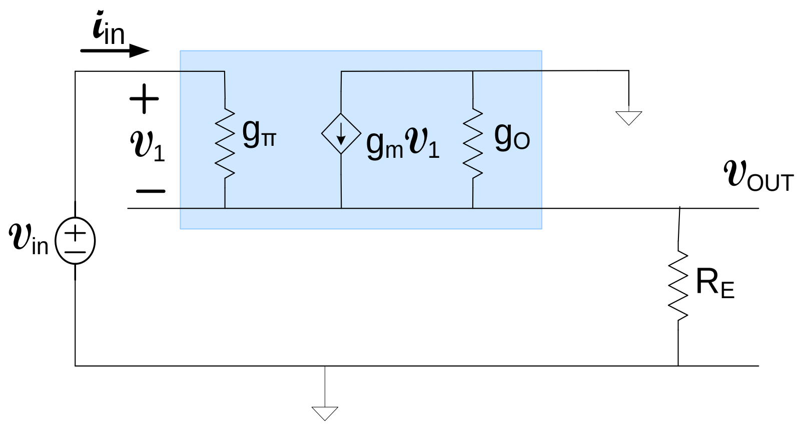
Consider the following CC application

(this is not asking for a two-port model for the CC application, – R_{in} and A_V defined for no additional load on output, R_o defined for short-circuit input -)





Alternately, this circuit can also be analyzed directly



$$\left.\begin{aligned} v_{out}\left(g_E+g_0+g_\pi\right) &= v_{in}g_\pi + g_m v_1 \\ v_{in} &= v_1 + v_{out} \end{aligned}\right\}$$

$$v_{out}\left(g_m+g_E+g_0+g_\pi\right) = v_{in}\left(g_\pi+g_m\right)$$

$$A_V = \frac{g_\pi+g_m}{g_m+g_E+g_0+g_\pi} \cong \frac{g_m}{g_m+g_E} = \frac{I_{CQ}R_E}{I_{CQ}R_E+V_t}$$

$$\left.\begin{aligned} i_{in} &= g_\pi\left(v_{in}-v_{out}\right) \\ v_{out}\left(g_m+g_E+g_0+g_\pi\right) &= v_{in}\left(g_\pi+g_m\right) \end{aligned}\right\}$$

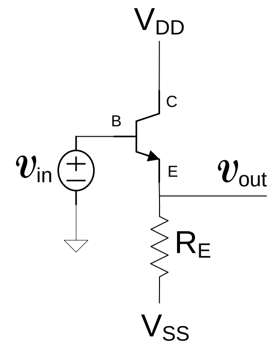
$$i_{in}\left(g_m+g_\pi+g_E+g_0\right) = g_\pi v_{in}\left(g_E+g_0\right)$$

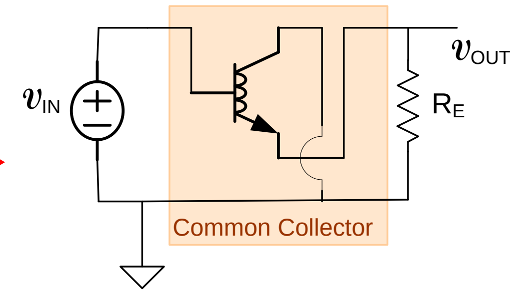
$$R_{in} = r_\pi \frac{g_m+g_\pi+g_o+g_E}{g_o+g_E} \overset{g_E >> g_o}{\cong} r_\pi + \beta R_E$$

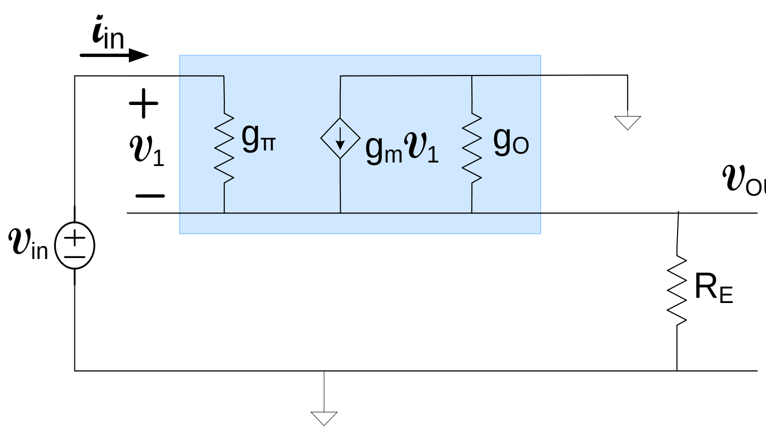
Common Collector Configuration

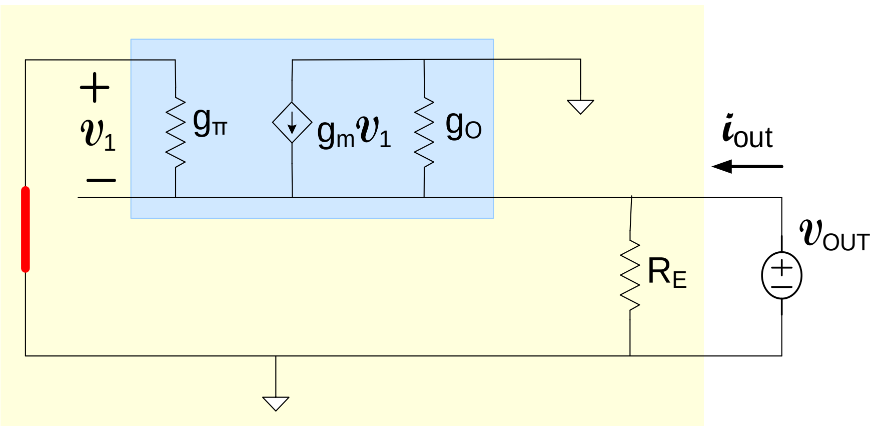
Consider the following CC application

(this is not asking for a two-port model for the CC application, – R_{in} and A_V defined for no additional load on output, R_o defined for short-circuit input -)









To obtain R_0, set $v_{in} = 0$

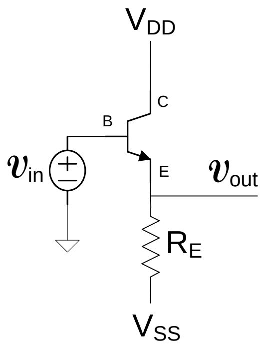
$$i_{out} = v_{out}\left(g_E + g_0 + g_\pi\right) - g_m\left(-v_{out}\right)$$

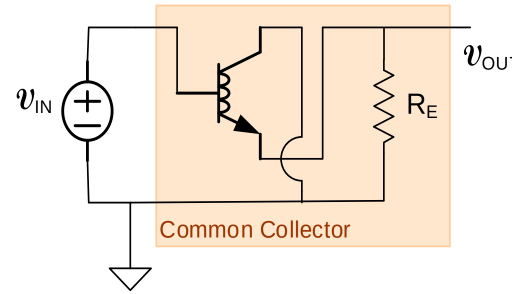
$$R_{out} = \frac{1}{g_m + g_\pi + g_o + g_E} \overset{g_E \ll g_o}{\cong} \frac{1}{g_m}$$

Common Collector Configuration

Consider the following CC application

(this is not asking for a two-port model for the CC application, – R_{in} and A_V defined for no additional load on output, R_o defined for short-circuit input -)





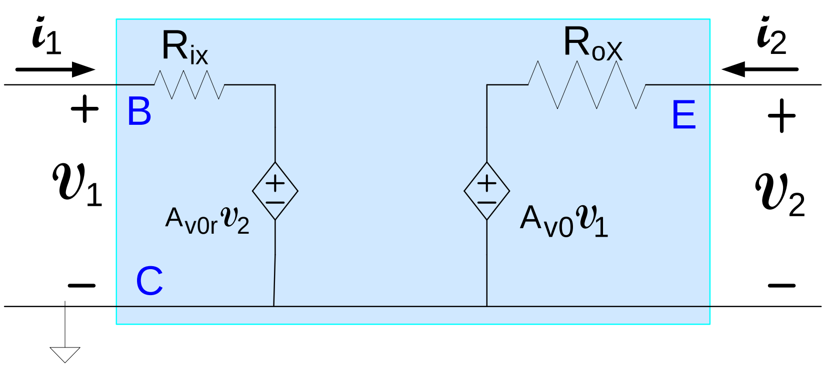
$$A_V = \frac{g_\pi + g_m}{g_m + g_E + g_0 + g_\pi} \cong \frac{g_m}{g_m + g_E} = \frac{I_{CQ}R_E}{I_{CQ}R_E + V_t} \cong 1$$

$$R_{in} = r_\pi \frac{g_m + g_\pi + g_o + g_E}{g_o + g_E} \overset{g_E >> g_o}{\cong} r_\pi + \beta R_E$$

$$R_{out} = \frac{1}{g_m + g_\pi + g_o + g_E} \overset{g_E << g_o}{\cong} \frac{1}{g_m}$$

Question: Why are these not the two-port parameters of this circuit?

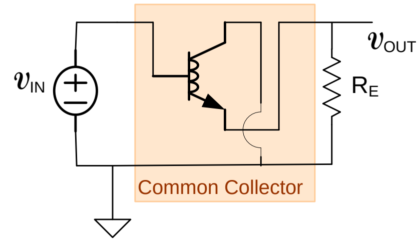
- R_{in} defined for open-circuit on output instead of short-circuit (see previous slide : -2 slides)
- $A_{V0r} \neq 0$

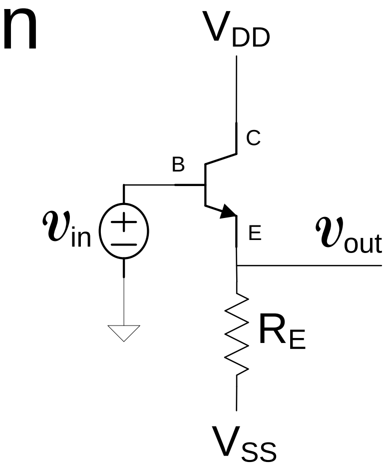


Common Collector Configuration

For this CC application

(this is not a two-port model for this CC application)





Small signal parameter domain

$$A_V = \frac{g_\pi + g_m}{g_m + g_E + g_0 + g_\pi} \overset{if\ g_m >> g_E}{\cong} 1$$

$$R_{in} \overset{g_E >> g_o}{\cong} r_\pi + \beta R_E$$

$$R_0 \cong \frac{R_E}{1 + g_m R_E} \overset{g_m R_E >> 1}{\cong} \frac{1}{g_m}$$

Operating point and model parameter domain

$$A_V \cong \frac{I_{CQ} R_E}{I_{CQ} R_E + V_t} \overset{I_{CQ} R_E >> V_t}{\cong} 1$$

$$R_{in} \overset{I_{CQ} R_E >> V_t}{\cong} \beta R_E$$

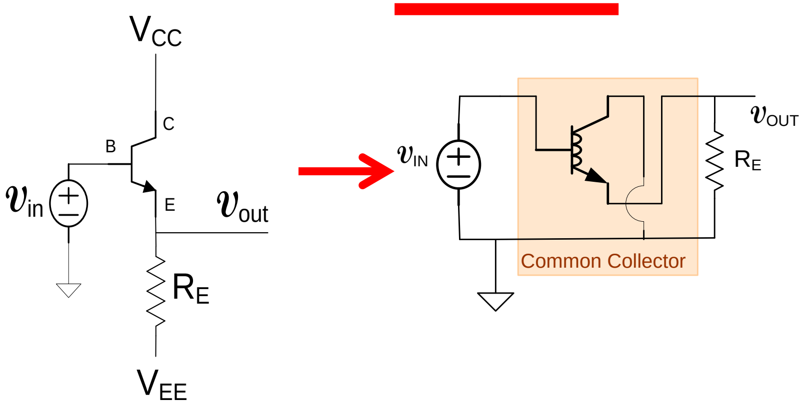
$$R_0 \overset{I_{CQ} R_E >> V_t}{\cong} \frac{V_t}{I_{CQ}}$$

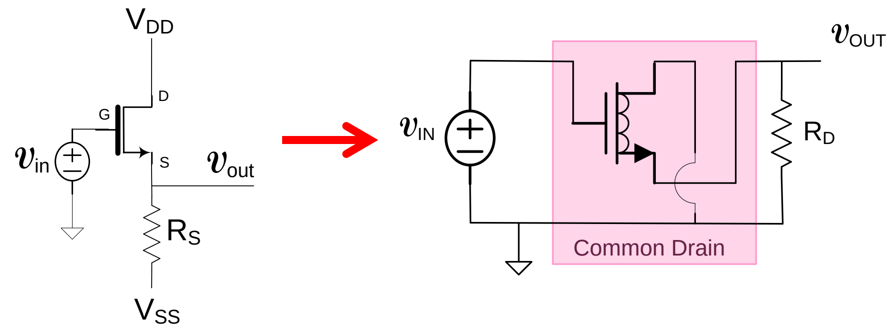
Characteristics:

- Output impedance is low
- A_{V0} is positive and near 1
- Input impedance is very large
- Widely used as a buffer
- Not completely unilateral but output-input transconductance (or A_{Vr}) is small and effects are generally negligible though magnitude same as A_V

Common Collector/Common Drain Configurations

For these CC/CD applications (not two-port models for these applications)





$$A_V = \frac{g_\pi + g_m}{g_m + g_E + g_0 + g_\pi} \overset{if\ g_m >> g_E}{\cong} 1$$

$$R_{in} \overset{g_E >> g_o}{\cong} r_\pi + \beta R_E$$

$$R_0 \cong \frac{R_E}{1+g_m R_E} \overset{g_m R_E >> 1}{\cong} \frac{1}{g_m}$$

$$A_V = \frac{g_m}{g_m + g_S + g_0} \overset{if\ g_m >> g_s}{\cong} 1$$

$$R_{in} = \infty$$

$$R_0 \cong \frac{R_S}{1+g_m R_S} \overset{g_m R_S >> 1}{\cong} \frac{1}{g_m}$$

In terms of operating point and model parameters:

$$A_V \cong \frac{I_{CQ} R_E}{I_{CQ} R_E + V_t} \overset{I_{CQ} R_E >> V_t}{\cong} 1 \qquad R_0 \overset{I_{CQ} R_E >> V_t}{\cong} \frac{V_t}{I_{CQ}}$$

$$R_{in} \overset{I_{CQ} R_E >> V_t}{\cong} \beta R_E$$

$$A_V \cong \frac{2 I_{DQ} R_S}{2 I_{DQ} R_S + V_{EBQ}} \overset{if\ 2 I_{DQ} R_S >> V_{EBQ}}{\cong} 1$$

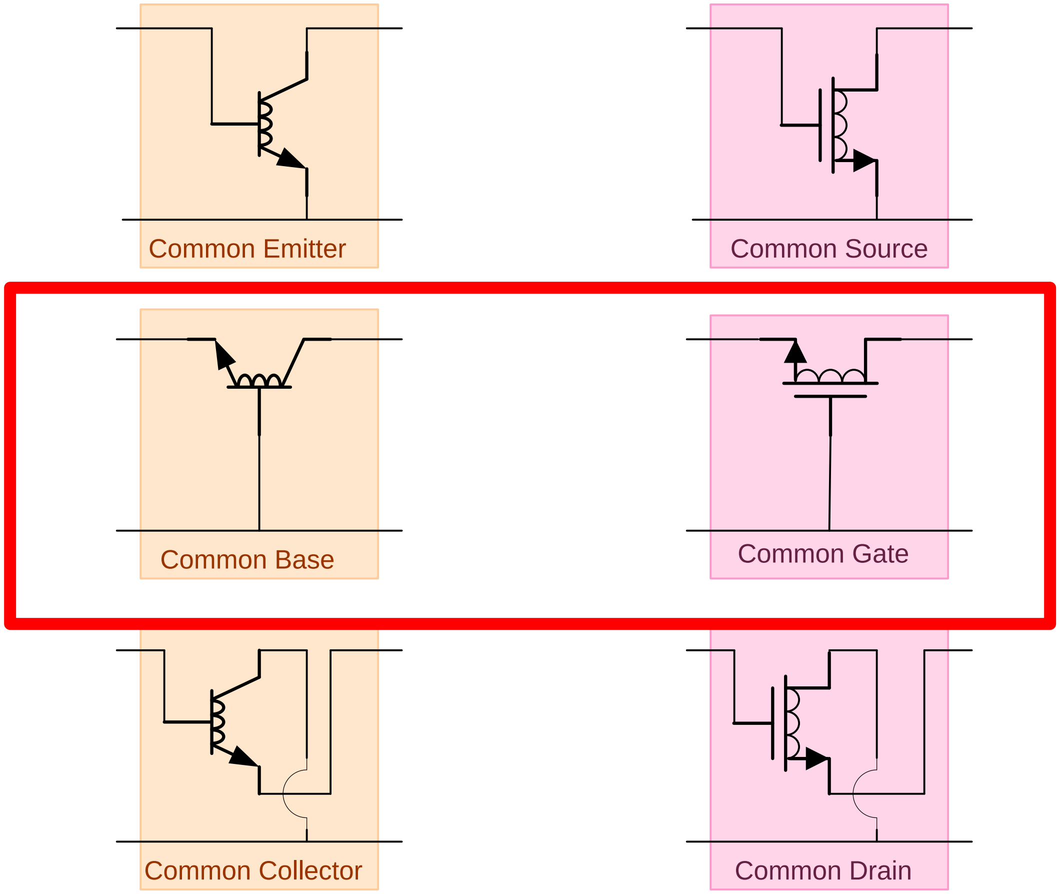
$$R_0 \cong \frac{V_{EBQ} R_S}{V_{EBQ} + 2 I_{DQ} R_S} \overset{2 I_{DQ} R_S >> V_{EBQ}}{\cong} \frac{V_{EBQ}}{2 I_{DQ}}$$

$$R_{in} = \infty$$

- Output impedance is low
- A_{V0} is positive and near 1
- Input impedance is very large

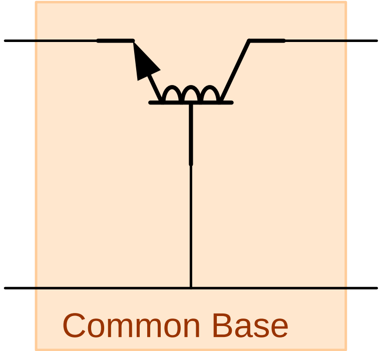
- Widely used as a buffer
- Not completely unilateral but output-input transconductance is small

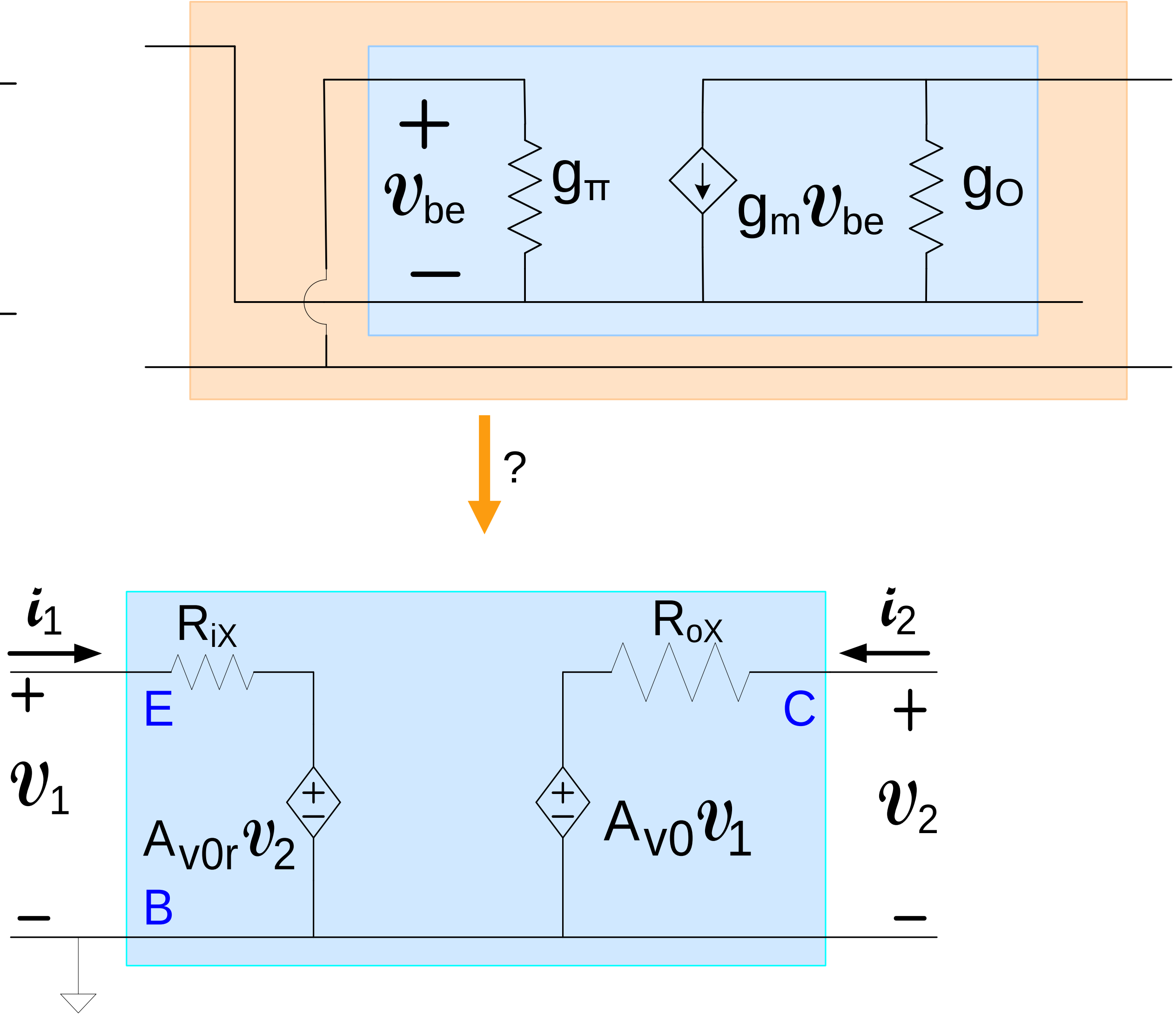
Consider Common Base/Common Gate Two-port Models



Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting $g_{\pi}=0$

Two-port model for Common Base Configuration

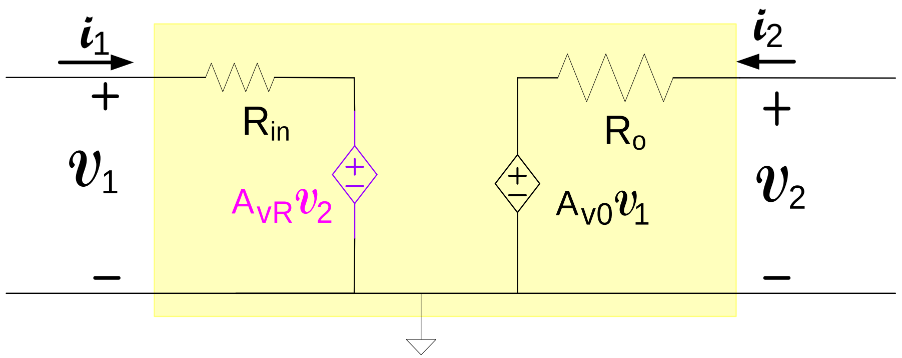




{R_{iX}, A_{V0}, A_{V0r} and R_{0X}}

Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network



1. v_{TEST} : i_{TEST} Method

2. Write $v_1 : v_2$ equations in standard form

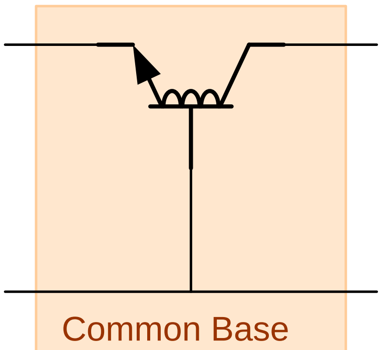
$$v_1 = i_1 R_{IN} + A_{VR} v_2$$

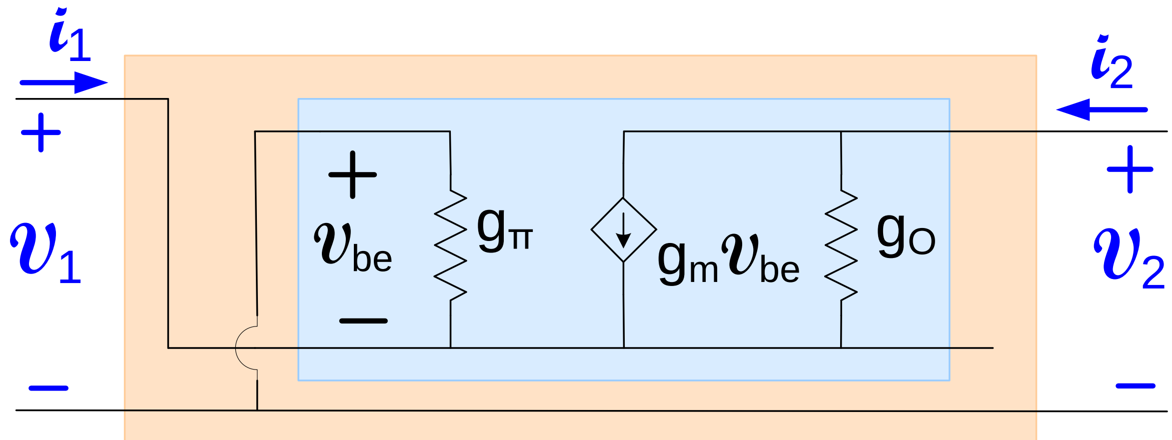
$$v_2 = i_2 R_O + A_{V0} v_1$$

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

Two-port model for Common Base Configuration





From KCL

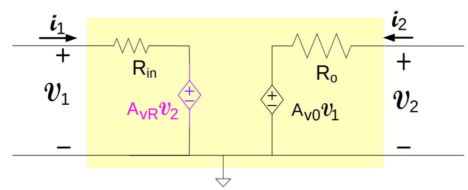
$$\left.\begin{aligned} i_1 &= v_1 g_\pi + (v_1 - v_2) g_0 + g_m v_1 \\ i_2 &= (v_2 - v_1) g_0 - g_m v_1 \end{aligned}\right\}$$

These can be rewritten as

$$\left.\begin{aligned} v_1 &= \left(\frac{1}{g_m + g_\pi + g_0}\right) i_1 + \left(\frac{g_0}{g_m + g_\pi + g_0}\right) v_2 \\ v_2 &= \left(\frac{1}{g_0}\right) i_2 + \left(1 + \frac{g_m}{g_0}\right) v_1 \end{aligned}\right\}$$

$v_1 : v_2$ equations in standard form

Standard Form for Amplifier Two-Port

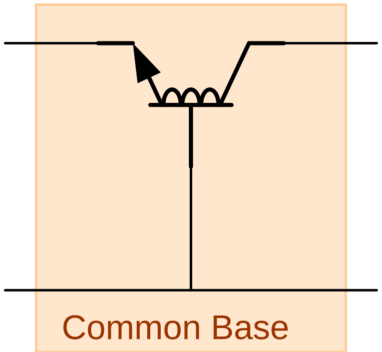


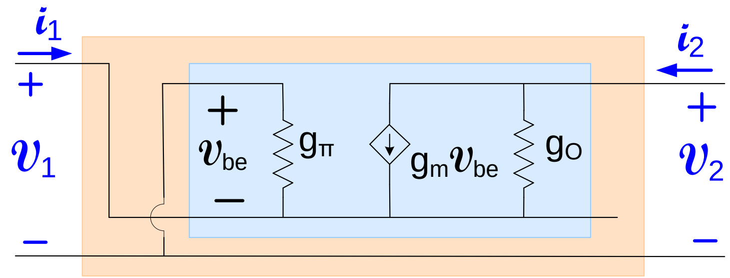
$$v_1 = i_1 R_{IN} + A_{VR} v_2$$
$$v_2 = i_2 R_O + A_{V0} v_1$$

It thus follows that:

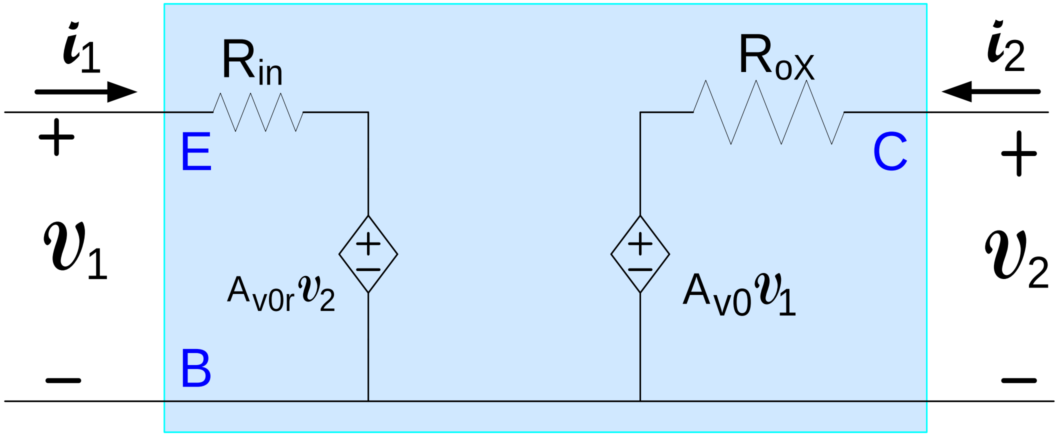
$$R_{iX} = \frac{1}{g_m + g_\pi + g_0} \cong \frac{1}{g_m} \qquad A_{VOr} = \frac{g_0}{g_m + g_\pi + g_0} \qquad A_{V0} = 1 + \frac{g_m}{g_0} \cong \frac{g_m}{g_0} \qquad R_{oX} = \frac{1}{g_0}$$

Two-port model for Common Base Configuration





Two-port Common Base Model



$$R_{iX} = \frac{1}{g_m + g_\pi + g_0} \cong \frac{1}{g_m}$$

$$A_{V0} = 1 + \frac{g_m}{g_0} \cong \frac{g_m}{g_0}$$

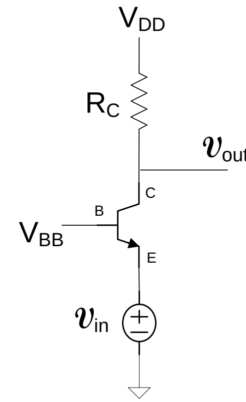
$$A_{VOr} = \frac{g_0}{g_m + g_\pi + g_0} \cong \frac{g_0}{g_m}$$

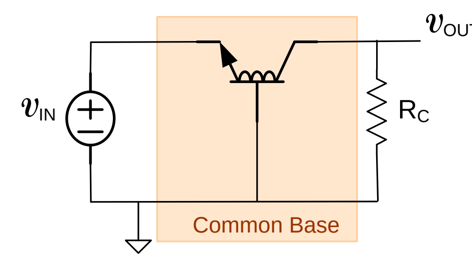
$$R_{oX} = \frac{1}{g_0}$$

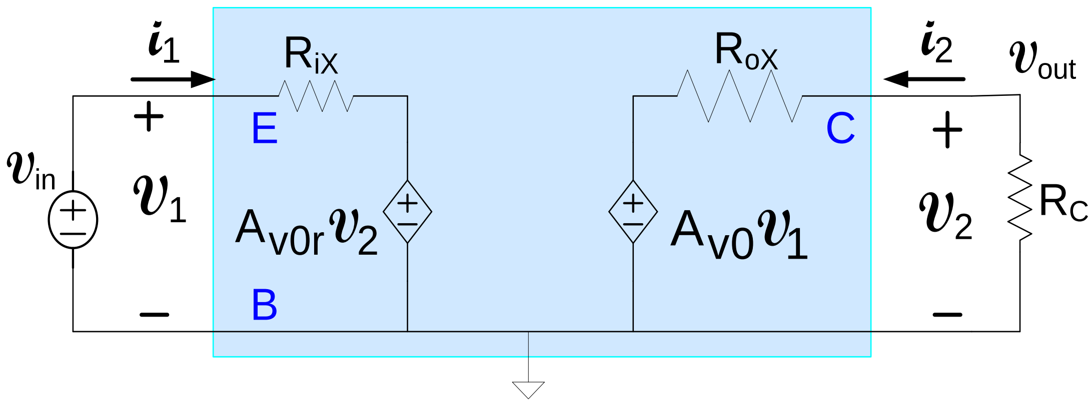
Common Base Configuration

Consider the following CB application

(this is not asking for a two-port model for this CB application - – R_{in} and A_V defined for no load on output, R_o defined for short-circuit input)







$$A_V = A_{V0}\frac{R_C}{R_C+R_{0X}} = \left(\frac{g_m+g_0}{g_0}\right)\left(\frac{g_0}{g_C+g_0}\right) = \frac{g_m+g_0}{g_C+g_0} \cong g_m R_C$$

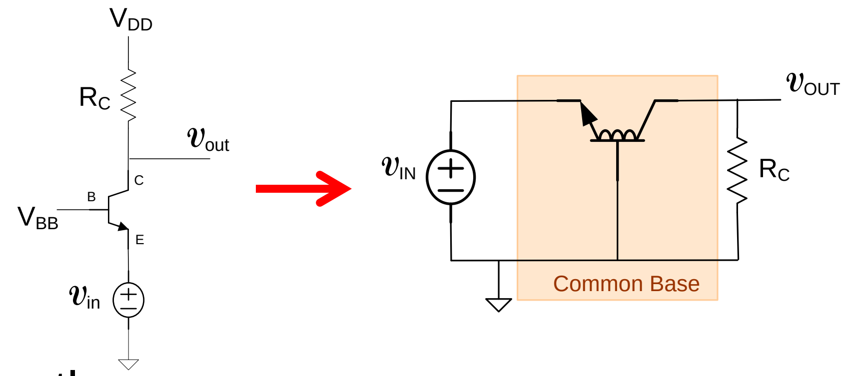
$$R_{in} = \frac{v_{in}}{i_1} = \frac{i_1 R_{iX} + A_{V0r} v_{out}}{i_1} \rightarrow R_{in} = \frac{R_{iX}}{1-A_{V0r}A_V} = \frac{g_0+g_C}{g_C\left(g_m+g_\pi+g_0\right)+g_\pi g_0} \cong \frac{1}{g_m}$$

$$R_{out} = R_C // R_{0X} \rightarrow R_{out} = \frac{R_C}{1+g_0 R_C}$$

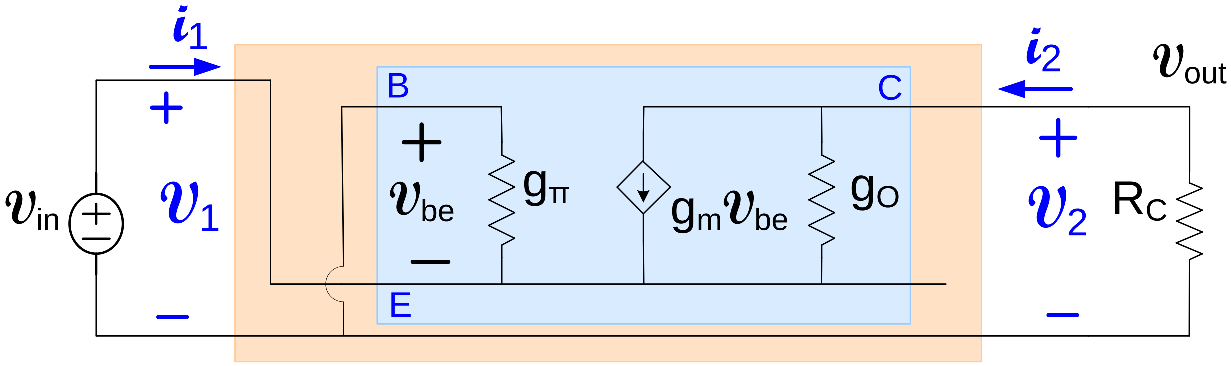
Common Base Configuration

Consider the following CB application

(this is not asking for a two-port model for this CB application – R_{in} and A_V defined for no load on output, R_o defined for short-circuit input)



Alternately, this circuit can also be analyzed directly



By KCL at the output node, obtain

$$(g_C+g_0)\,v_0=(g_m+g_0)\,v_{in} \longrightarrow A_V = \frac{g_m+g_0}{g_C+g_0} \cong g_m R_C$$

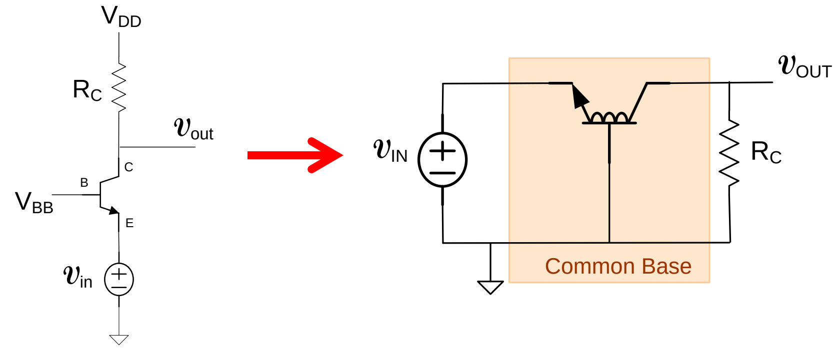
By KCL at the emitter node, obtain

$$i_1=(g_m+g_\pi+g_0)\,v_{in} - g_0 v_{out} \longrightarrow R_{in}=\frac{g_0+g_C}{g_C(g_m+g_\pi+g_0)+g_\pi g_0} \cong \frac{1}{g_m}$$

$$R_{out}=R_C//r_0 \longrightarrow R_{out}=\frac{R_C}{1+g_0R_C} \cong R_C$$

Common Base Application

(this is not a two-port model for this CB application)



$$A_V \cong g_m R_C \qquad A_V \cong \frac{I_{CQ}R_C}{V_t}$$

$$R_{in} \cong \frac{1}{g_m} \qquad R_{in} \cong \frac{V_t}{I_{CQ}}$$

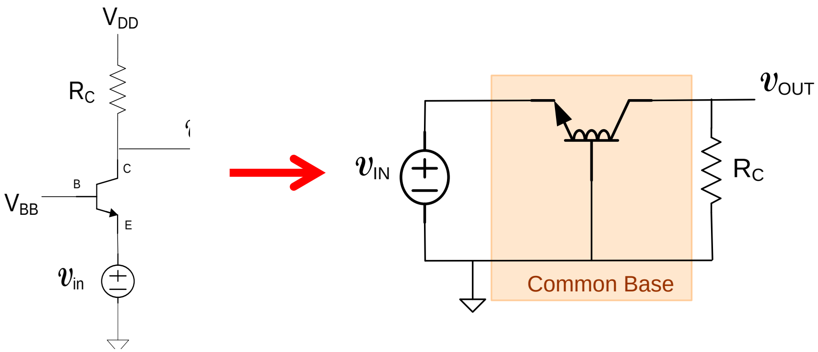
$$R_{out} \overset{R_C \ll r_0}{\cong} R_C \qquad R_{out} \overset{R_C \ll r_0}{\cong} R_C$$

Characteristics:

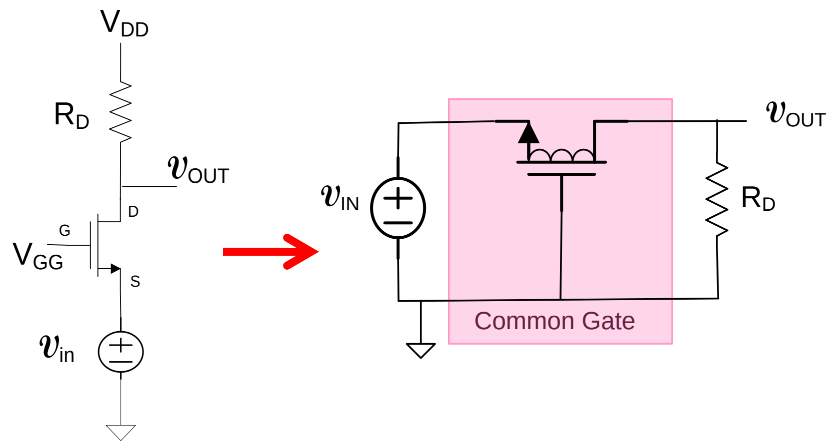
- Output impedance is mid-range
- A_{V0} is large and positive (equal in mag to that to CE)
- Input impedance is very low
- Not completely unilateral but output-input transconductance is small

Common Base/Common Gate Application

(these are not a two-port models)



$$A_V \cong g_m R_C \qquad R_{in} \cong \frac{1}{g_m} \qquad R_{out} \overset{R_C<<r_0}{\cong} R_C$$



$$A_V \cong g_m R_D \qquad R_{in} \cong \frac{1}{g_m} \qquad R_{out} \overset{R_D<<r_0}{\cong} R_D$$

In terms of operating point and model parameters:

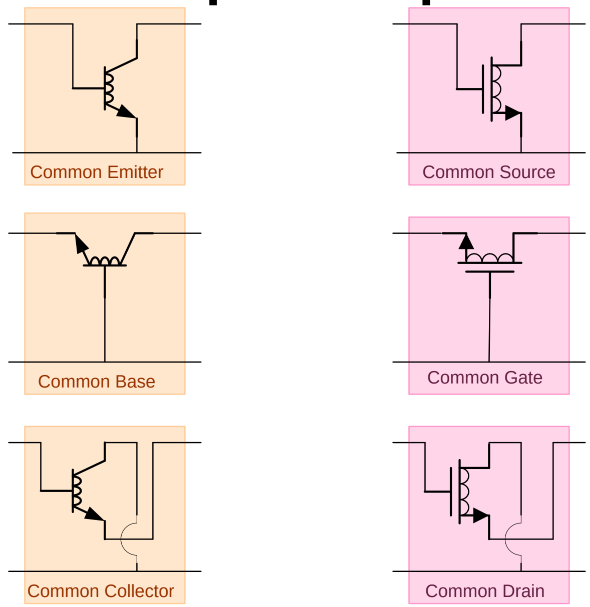
$$A_V \cong \frac{I_{CQ}R_C}{V_t} \qquad R_{in} \cong \frac{V_t}{I_{CQ}} \qquad R_{out} \overset{I_{CQ}R_C<<V_{AF}}{\cong} R_C$$

$$A_V \cong \frac{2I_{DQ}R_D}{V_{EBQ}} \qquad R_{in} \cong \frac{V_{EBQ}}{2I_{DQ}} \qquad R_{out} \overset{I_{DQ}R_D<<1/\lambda}{\cong} R_D$$

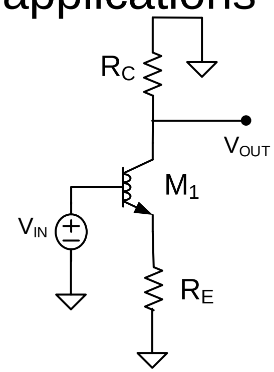
Characteristics:

- Output impedance is mid-range
- A_{V0} is large and positive (equal in mag to that to CE)
- Input impedance is very low
- Not completely unilateral but output-input transconductance is small

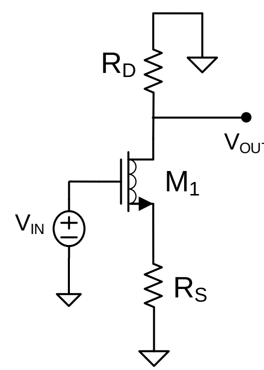
The three basic amplifier types for both MOS and bipolar processes



- Have developed both two-ports and a widely used application of all 6
- A fourth structure (two additional applications) is also quite common so will be added to list of basic applications



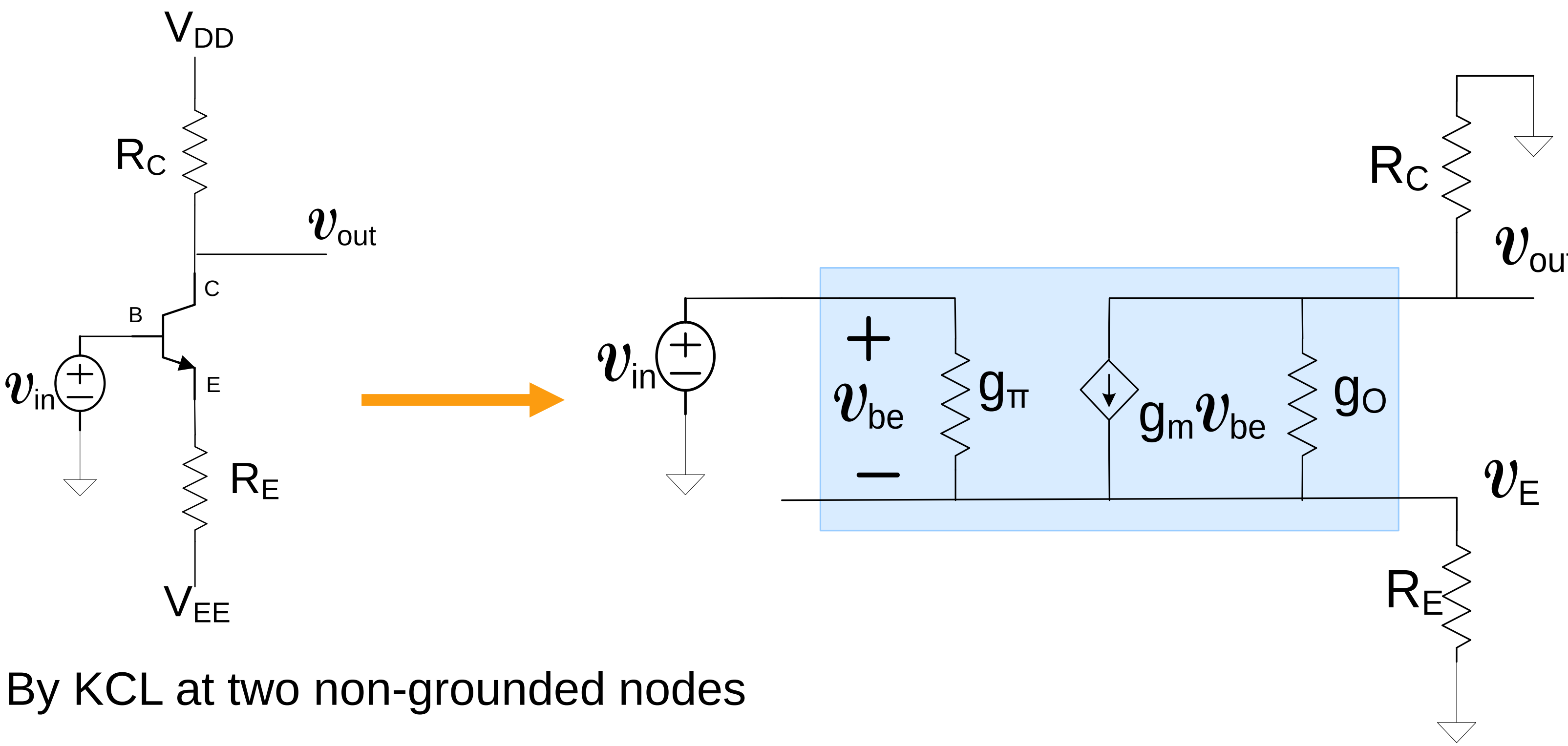
CE with R_E



CS with R_S

Common Emitter with Emitter Resistor Configuration Application

(this is not a two-port model for this CE with R_E application)



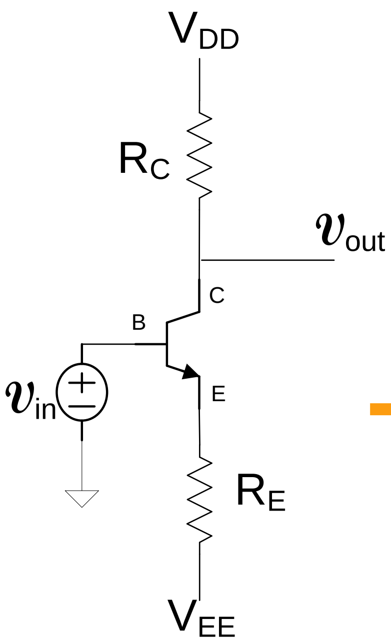
By KCL at two non-grounded nodes

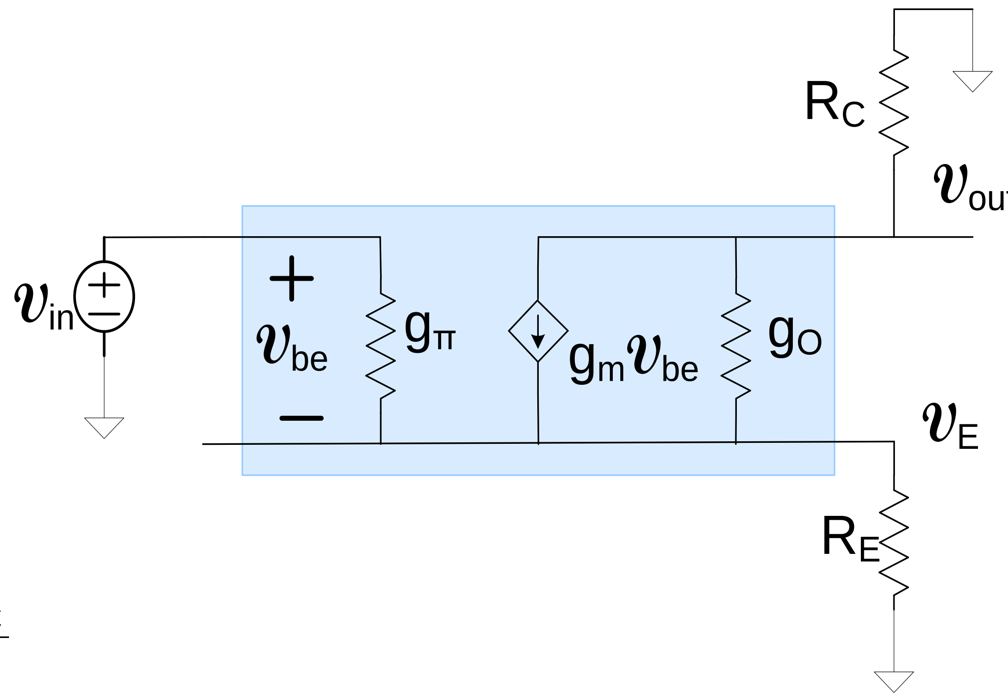
$$\left.\begin{aligned} v_{out}\left(g_C + g_0\right) + \left(v_{in} - v_E\right) g_m &= g_0 v_E \\ v_E\left(g_E + g_0 + g_\pi\right) - \left(v_{in} - v_E\right) g_m &= g_0 v_{out} + g_\pi v_{in} \end{aligned}\right\}$$

$$A_V = \frac{v_{out}}{v_{in}} = \frac{-g_m g_E + g_0 g_\pi}{g_C g_m + g_C\left(g_0 + g_\pi + g_E\right) + g_0\left(g_\pi + g_E\right)} \cong -\frac{R_C}{R_E}$$

Common Emitter with Emitter Resistor Configuration Application

(this is not a two-port model for this CE with R_E application)





$$A_V \cong -\frac{R_C}{R_E}$$

It can also be shown that

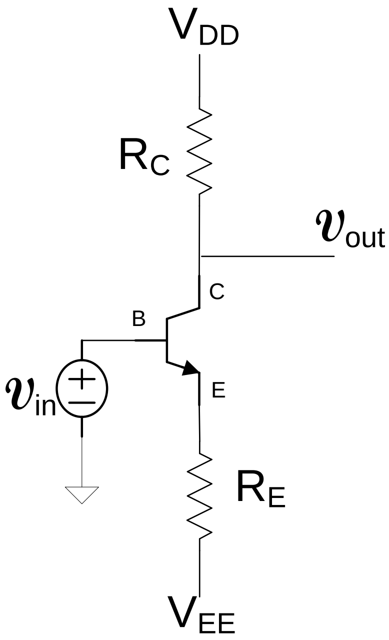
$$R_{in} \cong r_\pi + \beta R_E$$

$$R_{out} \cong R_C$$

Nearly unilateral (is unilateral if g_o=0)

Common Emitter with Emitter Resistor Configuration Application

(this is not a two-port model for this CE with R_E application)



$$A_V \cong -\frac{R_C}{R_E}$$

$$R_{in} \cong r_\pi + \beta R_E$$

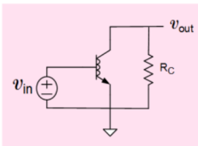
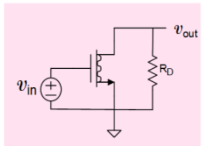
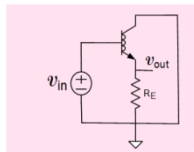
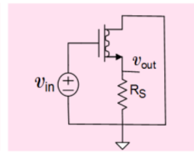
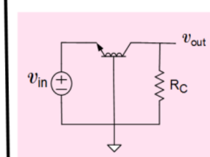
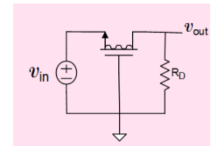
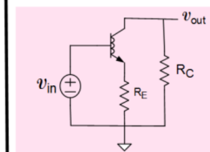
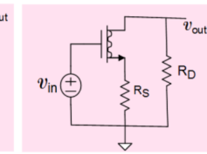
$$R_{out} \cong R_C$$

(this is not a two-port model)

Characteristics:

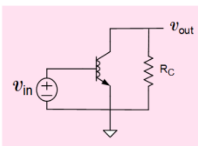
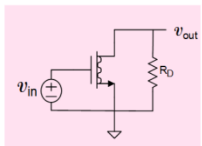
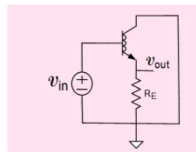
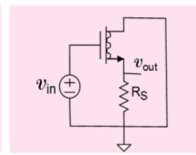
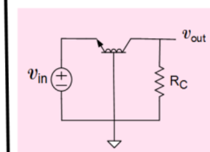
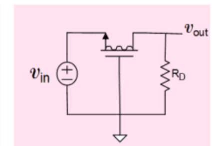
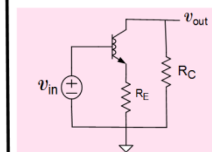
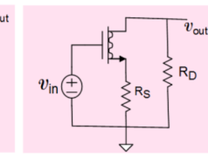
- Analysis would simplify if g_0 were set to 0 in model
- Gain can be accurately controlled with resistor ratios
- Useful for reasonably accurate low gains
- Input impedance is high

Basic Amplifier Gain Table

	CE/CS	CC/CD	CB/CG	CEwRE/CSwRS
	BJT  MOS 	BJT  MOS 	BJT  MOS 	BJT  MOS 
A_V	$-g_mR_C$ BJT: $-\frac{I_{CQ}R_C}{V_t}$ MOS: $-\frac{2I_{DQ}R_D}{V_{EB}}$	$\frac{g_m}{g_m+g_E}$ BJT: $\frac{I_{CQ}R_E}{I_{CQ}R_E+V_t}$ MOS: $\frac{2I_{DQ}R_E}{2I_{DQ}R_E+V_{EB}}$	g_mR_C BJT: $\frac{I_{CQ}R_C}{V_t}$ MOS: $\frac{2I_{DQ}R_C}{V_{EB}}$	$-\frac{R_C}{R_E}$
R_{in}	r_π BJT: $\frac{\beta V_t}{I_{CQ}}$ MOS: ∞	$r_\pi+\beta R_E$ BJT: $\beta\left(\frac{V_t}{I_{CQ}}+R_E\right)$ MOS: ∞	g_m^{-1} BJT: $\frac{V_t}{I_{CQ}}$ MOS: $\frac{V_{EB}}{2I_{DQ}}$	$r_\pi+\beta R_E$ BJT: $\beta\left(\frac{V_t}{I_{CQ}}+R_E\right)$ MOS: ∞
R_{out}	R_C	g_m^{-1} BJT: $\frac{V_t}{I_{CQ}}$ MOS: $\frac{V_{EB}}{2I_{DQ}}$	R_C	R_C

(not two-port models for the four structures)

Basic Amplifier Gain Table

	CE/CS		CC/CD		CB/CG		CEwRE/CSwRS	
	BJT	MOS	BJT	MOS	BJT	MOS	BJT	MOS
								
A_V (general)	$-g_mR_C$		$\frac{g_m}{g_m+g_E}$		g_mR_C		$-\frac{R_C}{R_E}$	
A_V	$-\frac{I_{CQ}R_C}{V_t}$	$-\frac{2I_{DQ}R_D}{V_{EB}}$	$\frac{I_{CQ}R_E}{I_{CQ}R_E+V_t}$	$\frac{2I_{DQ}R_E}{2I_{DQ}R_E+V_{EB}}$	$\frac{I_{CQ}R_C}{V_t}$	$\frac{2I_{DQ}R_C}{V_{EB}}$		
R_{in} (general)	r_π		$r_\pi+\beta R_E$		g_m^{-1}		$r_\pi+\beta R_E$	
R_{in}	$\frac{\beta V_t}{I_{CQ}}$	∞	$\beta\left(\frac{V_t}{I_{CQ}}+R_E\right)$	∞	$\frac{V_t}{I_{CQ}}$	$\frac{V_{EB}}{2I_{DQ}}$	$\beta\left(\frac{V_t}{I_{CQ}}+R_E\right)$	∞
R_{out} (general)	R_C		g_m^{-1}		R_C		R_C	
R_{out}			$\frac{V_t}{I_{CQ}}$	$\frac{V_{EB}}{2I_{DQ}}$				

Can use these equations only when small signal circuit is EXACTLY like that shown !!

Basic Amplifier Structures

1. Common Emitter/Common Source
2. Common Collector/Common Drain
3. Common Base/Common Gate
4. Common Emitter with R_E/ Common Source with R_S

5. Cascode (actually CE:CB or CS:CG cascade)
6. Darlington (special CC:CE or CD:CS cascade)

Will be discussed later

The first 4 are most popular

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The first 4 are most popular

Why are we focusing on these basic circuits?

1. So that we can develop analytical skills
2. So that we can design a circuit
3. So that we can get the insight needed to design a circuit

Which is the most important?

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Which is the most important?

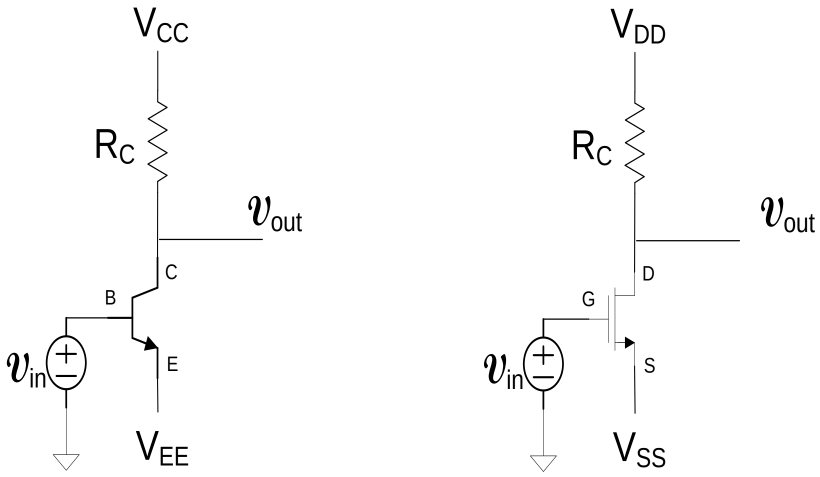
1. So that we can get the insight needed to design a circuit

2. So that we can design a circuit

3. So that we can develop analytical skills

Properties/Use of Basic Amplifiers

CE and CS



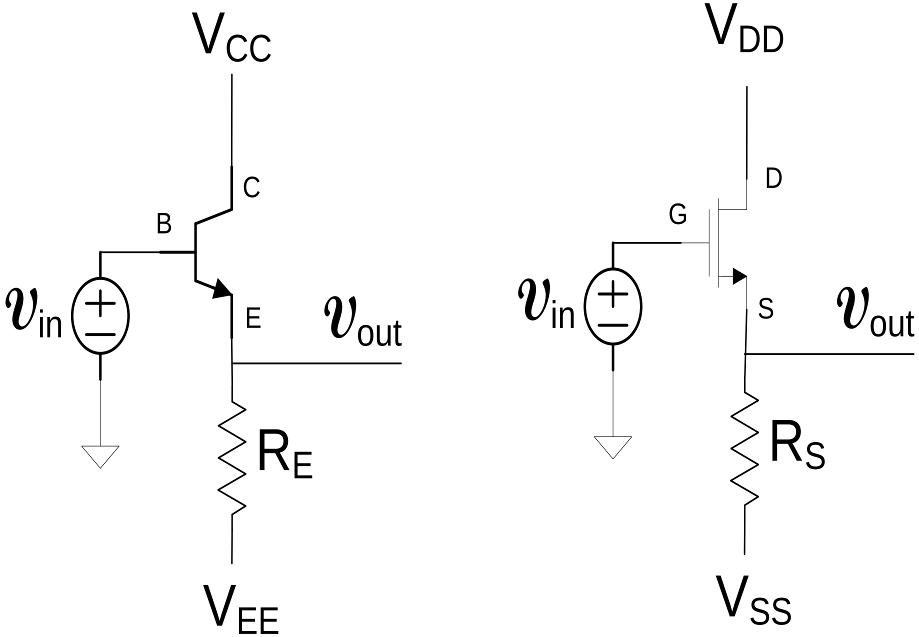
More practical biasing circuits usually used

R_C or R_D may (or may not) be load

- **Large inverting gain**
- **Moderate input impedance for BJT (high for MOS)**
- **Moderate output impedance**
- **Most widely used amplifier structure**

Properties/Use of Basic Amplifiers

CC and CD
(emitter follower or source follower)



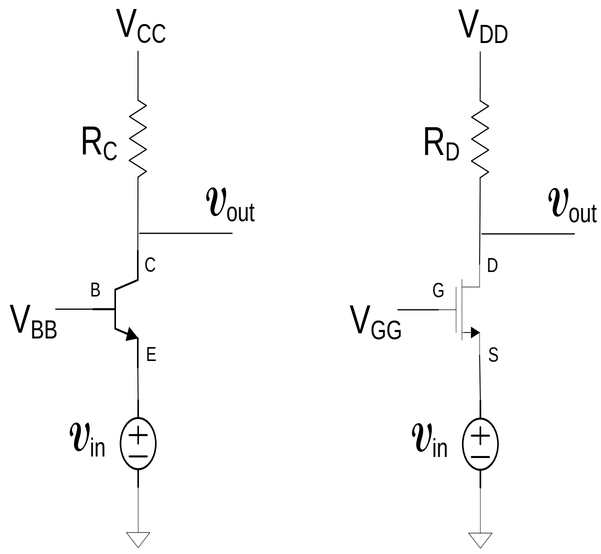
More practical biasing circuits usually used

R_E or R_S may (or may not) be load

- **Gain very close to +1 (little less)**
- **High input impedance for BJT (high for MOS)**
- **Low output impedance**
- **Widely used as a buffer**

Properties/Use of Basic Amplifiers

CB and CG



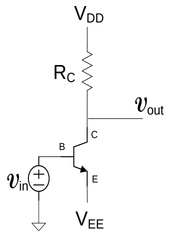
More practical biasing circuits usually used

R_C or R_D may (or may not) be load

- **Large noninverting gain**
- **Low input impedance**
- **Moderate (or high) output impedance**
- **Used more as current amplifier or, in conjunction with CD/CS to form two-stage cascode**

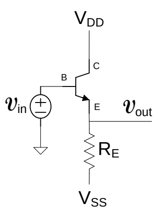
Basic Amplifier Characteristics Summary

CE/CS



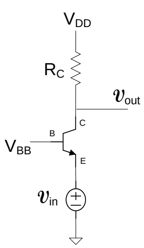
- **Large inverting gain**
- **Moderate input impedance**
- **Moderate (or high) output impedance**
- **Widely used as the basic high gain inverting amplifier**

CC/CD



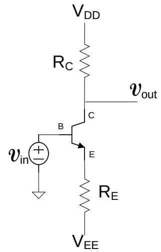
- **Gain very close to +1 (little less)**
- **High input impedance for BJT (high for MOS)**
- **Low output impedance**
- **Widely used as a buffer**

CB/CG



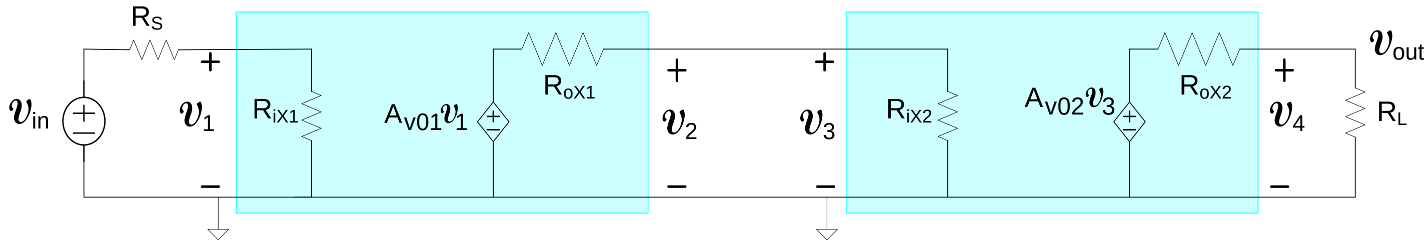
- **Large noninverting gain**
- **Low input impedance**
- **Moderate (or high) output impedance**
- **Used more as current amplifier or, in conjunction with CD/CS to form two-stage cascode**

CEwRE/
CSwRS



- **Reasonably accurate but somewhat small gain (resistor ratio)**
- **High input impedance**
- **Moderate output impedance**
- **Used when more accurate gain is required**

Cascaded Amplifiers



$$A_V = \frac{v_{out}}{v_{in}} = \left(\frac{R_{iX1}}{R_{iX1}+R_S}\right) A_{V01} \left(\frac{R_{iX2}}{R_{iX2}+R_{0X1}}\right) A_{V02} \left(\frac{R_L}{R_L+R_{0X2}}\right)$$

If $R_o << R_i$ $\quad R_S << R_i$ $\quad R_o << R_L$

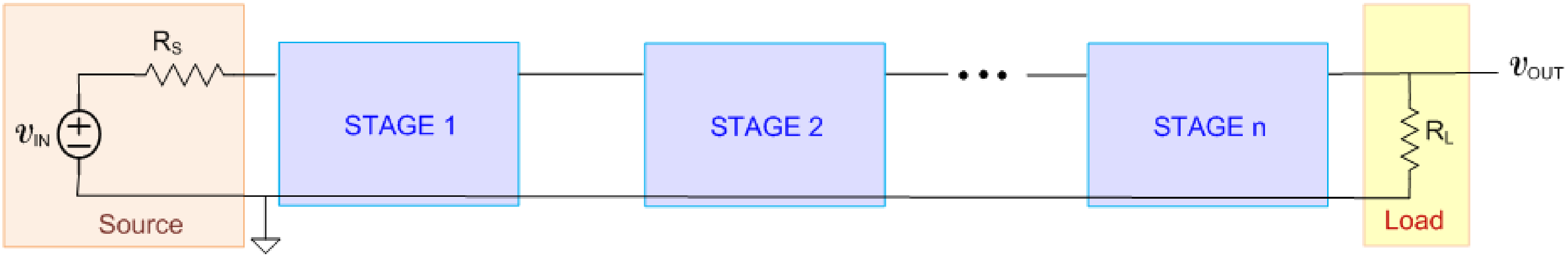
$$A_V \cong A_{V01} A_{V02}$$

- Amplifier cascading widely used to enhance gain
- Amplifier cascading widely used to enhance other characteristics and/or alter functionality as well

  e.g. (R_{IN}, BW, Power, R_O, Linearity, Impedance Conversion..)

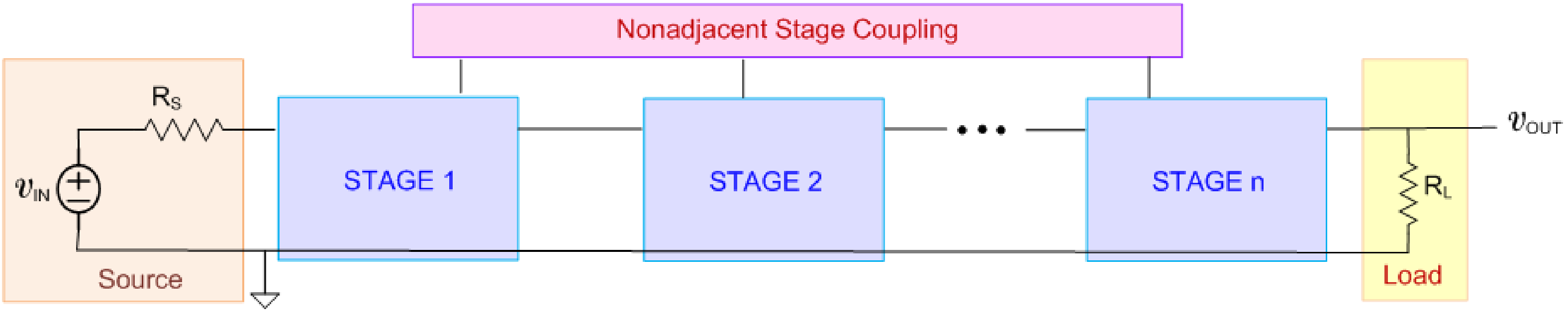
Cascaded Amplifier Analysis and Operation

Adjacent Stage Coupling Only



- Systematic Methods of Analysis/Design will be Developed

One or more couplings of nonadjacent stages



- Less Common
- Analysis Generally Much More Involved, Use Basic Circuit Analysis Methods

End of Lecture 31