EE 330
Lecture 31

Basic amplifier architectures

- Common Emitter/Source
- Common Collector/Drain
- Common Base/Gate

Exam Schedule

Exam 1	Friday Sept 24
Exam 2	Friday Oct 22
Exam 3	Friday Nov 19
Final	Tues Dec 14 12:00 p.m.

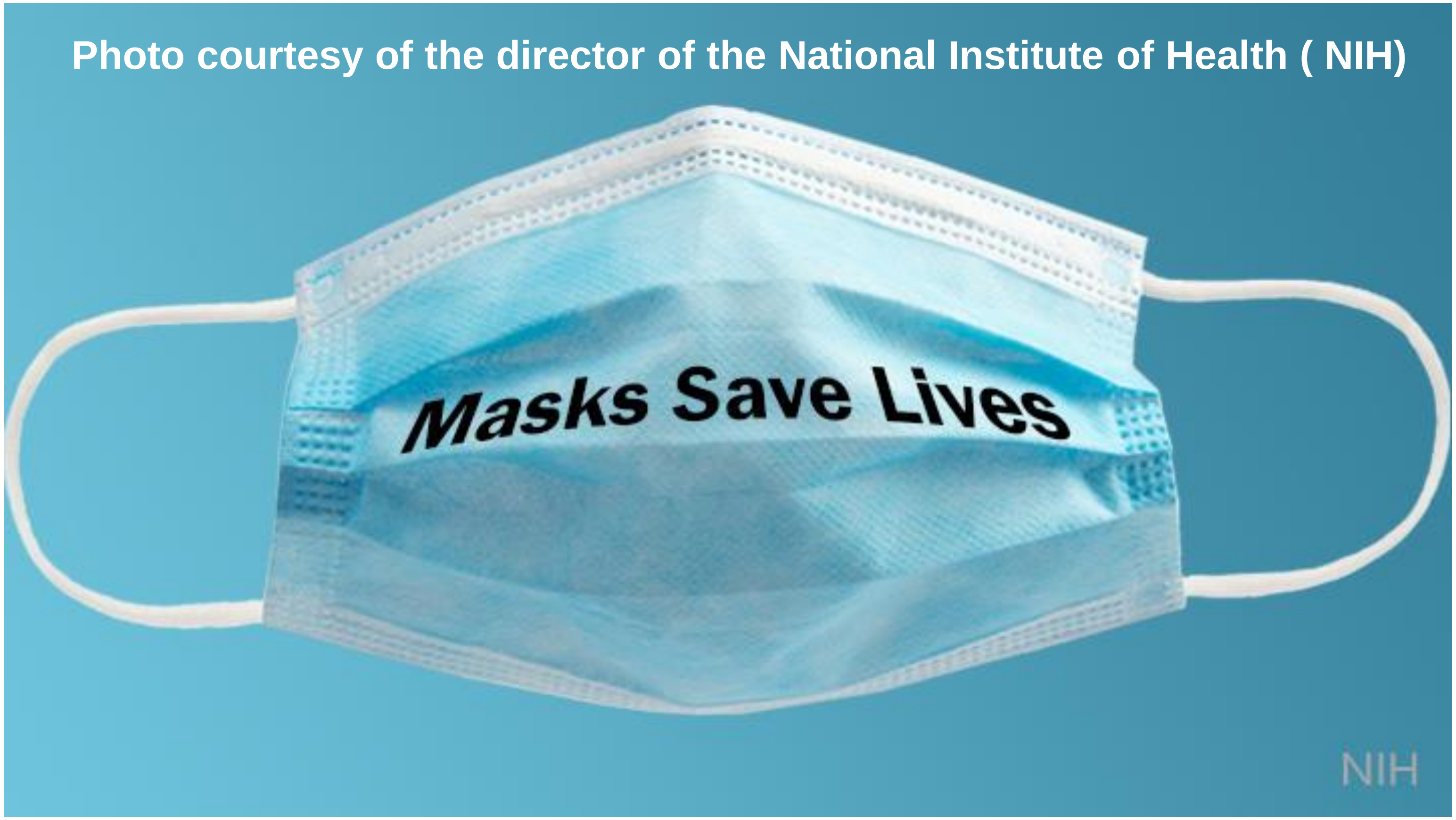


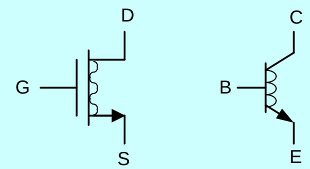
Photo courtesy of the director of the National Institute of Health (NIH)

As a courtesy to fellow classmates, TAs, and the instructor

Wearing of masks during lectures and in the laboratories for this course would be appreciated irrespective of vaccination status

Review From Previous Lecture

Basic Amplifier Structures



Small Signal Transistor Models as 3-terminal Devices

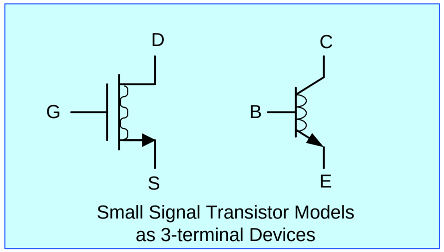
	MOS Common	MOS Input	MOS Output	BJT Common	BJT Input	BJT Output
Common Source or Common Emitter	S	G	D	E	B	C
Common Gate or Common Base	G	S	D	B	E	C
Common Drain or Common Collector	D	G	S	C	B	E

Identification of Input and Output Terminals is not arbitrary

It will be shown that all 3 of the basic amplifiers are useful !

Review From Previous Lecture

Basic Amplifier Structures



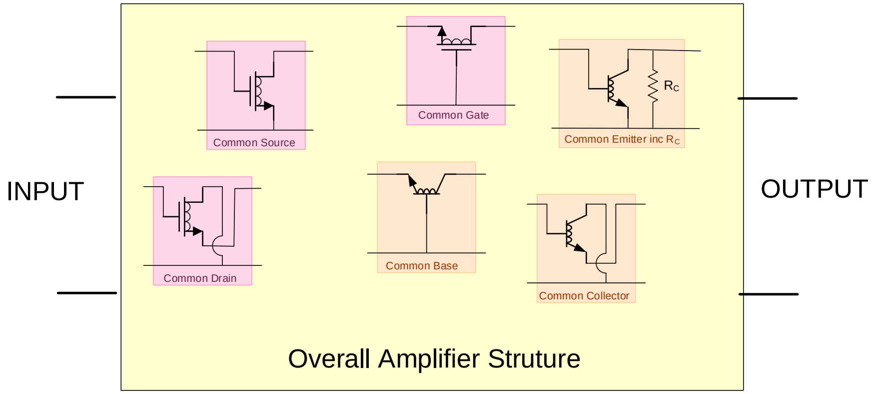
Common Source or Common Emitter

Common Gate or Common Base

Common Drain or Common Collector

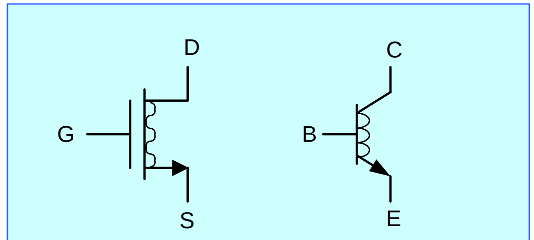
Objectives in Study of Basic Amplifier Structures

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



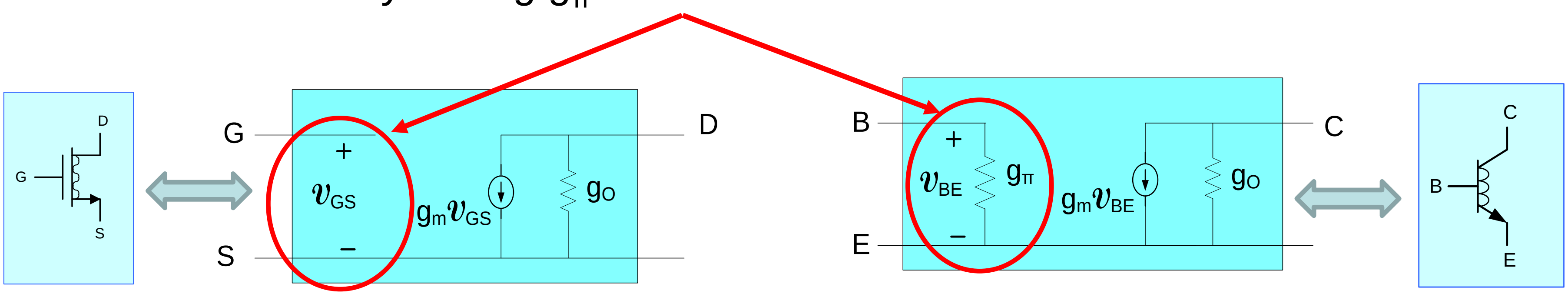
Review From Previous Lecture

Characterization of Basic Amplifier Structures

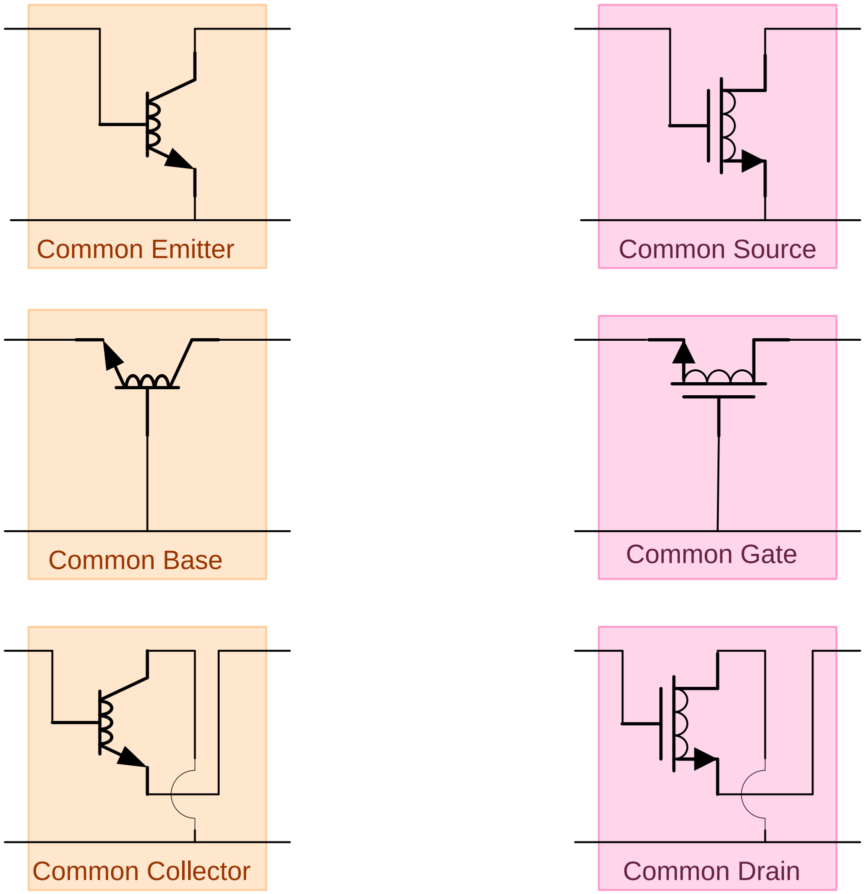


Small Signal Transistor Models
as 3-terminal Devices

- Observe that the small-signal equivalent of any 3-terminal network is a two-port
- Thus to characterize any of the 3 basic amplifier structures, it suffices to determine the two-port equivalent network
- Since small signal model when expressed in terms of small-signal parameters of BJT and MOSFET differ only in the presence/absence of g_π term, can analyze the BJT structures and then obtain characteristics of corresponding MOS structure by setting g_π=0



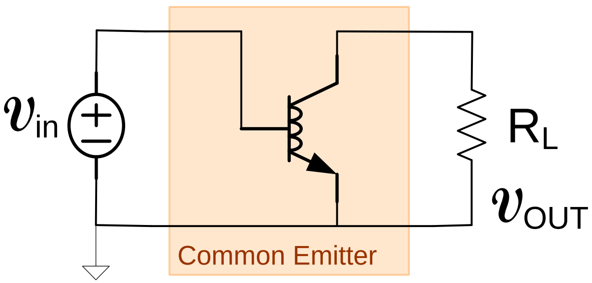
The three basic amplifier types for both MOS and bipolar processes

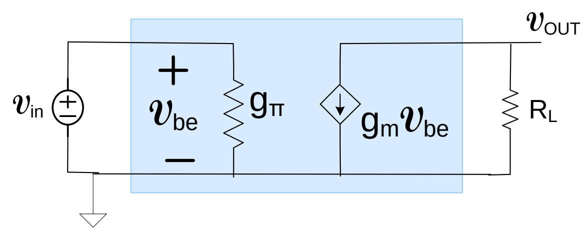


Will focus on the performance of the bipolar structures and then obtain performance of the MOS structures by observation

Review From Previous Lecture

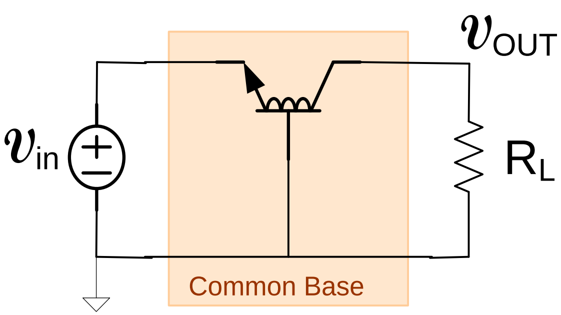
The three basic amplifier types for both MOS and bipolar processes

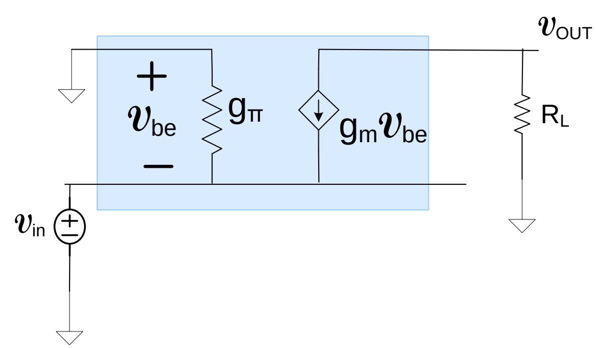




$$\left.\begin{aligned} v_{OUT} &= -g_m R_L v_{be} \\ v_{IN} &= v_{be} \end{aligned}\right\}$$

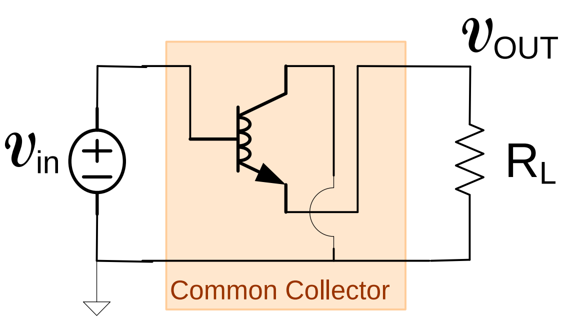
$$A_V = \frac{v_{OUT}}{v_{IN}} = -g_m R_L$$

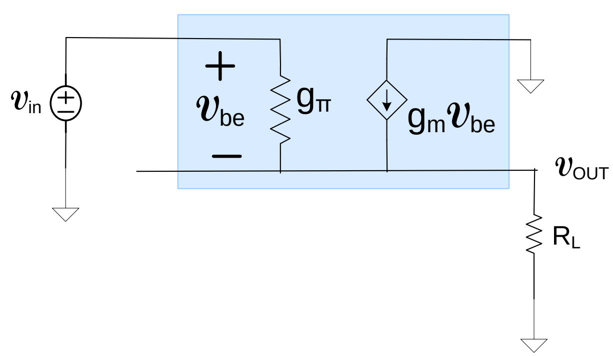




$$\left.\begin{aligned} v_{OUT} &= -g_m R_L v_{be} \\ v_{IN} &= -v_{be} \end{aligned}\right\}$$

$$A_V = \frac{v_{OUT}}{v_{IN}} = g_m R_L$$



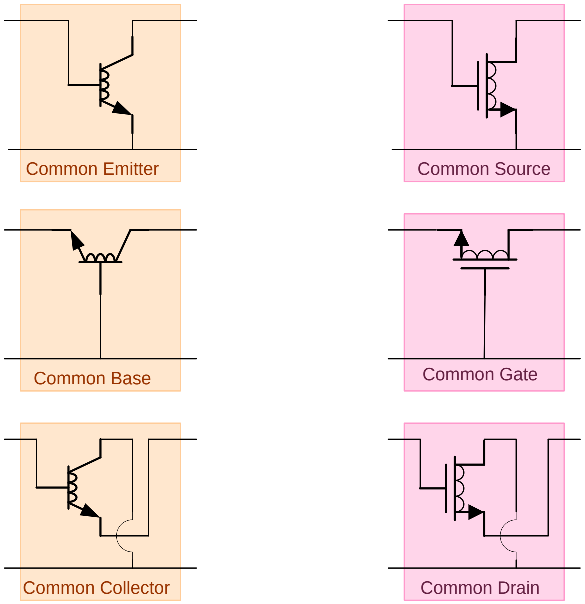


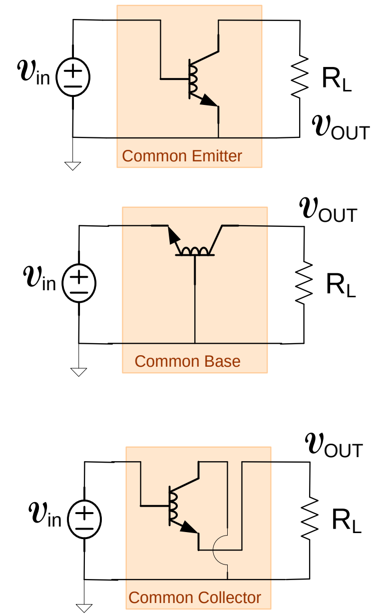
$$\left.\begin{aligned} v_{OUT} &= (g_m + g_\pi) v_{be} R_L \\ v_{IN} &= v_{be} + (g_m + g_\pi) v_{be} R_L \end{aligned}\right\}$$

$$A_V = \frac{v_{OUT}}{v_{IN}} = \frac{(g_m + g_\pi) R_L}{1 + (g_m + g_\pi) R_L} \cong 1$$

- Significantly different gain characteristics for the three basic amplifiers
- There are other significant differences too (R_{IN}, R_{OUT}, …) as well

The three basic amplifier types for both MOS and bipolar processes





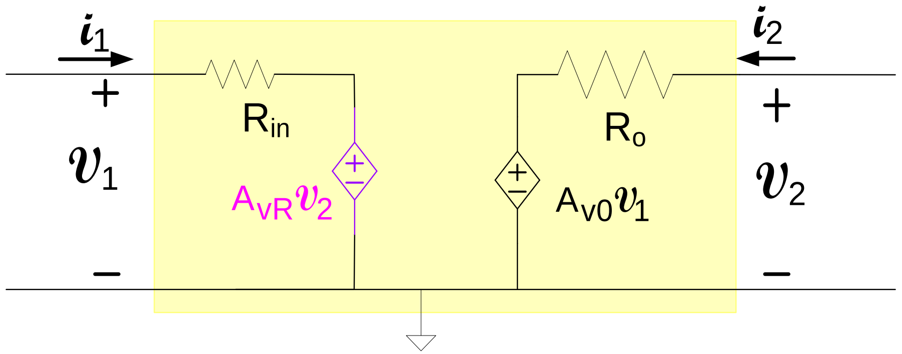
More general models are needed to accommodate biasing, understand performance capabilities, and include effects of loading of the basic structures

Two-port models are useful for characterizing the basic amplifier structures

How can the two-port parameters be obtained for these or any other linear two-port networks?

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 a previous lecture)

2. Write v_1 : v_2 equations in standard form

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

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

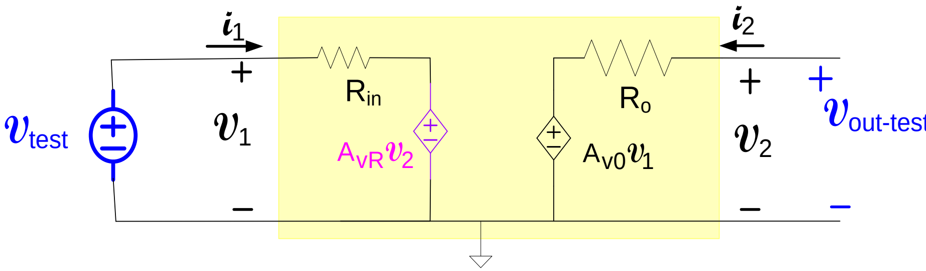
3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

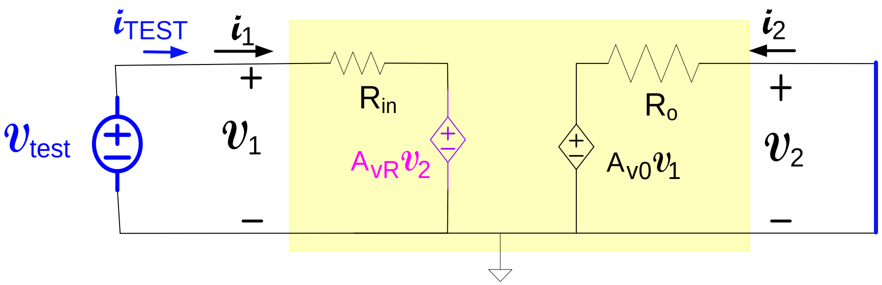
Any of these methods can be used to obtain the two-port model

$v_{\text{test}} : i_{\text{test}}$ Method for Obtaining Two-Port Amplifier Parameters

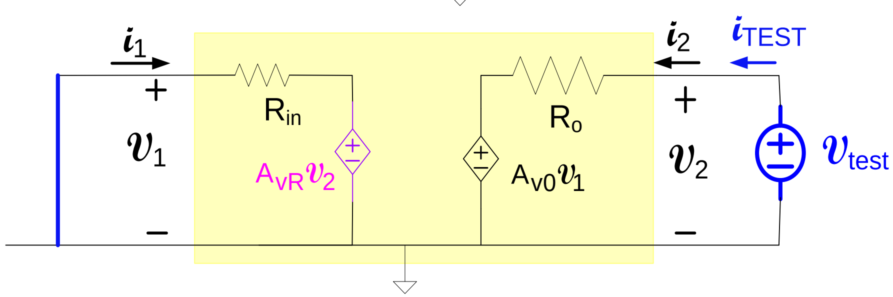
SUMMARY from PREVIOUS LECTURE



$$A_{V0} = \frac{v_{\text{out-test}}}{v_{\text{test}}}$$

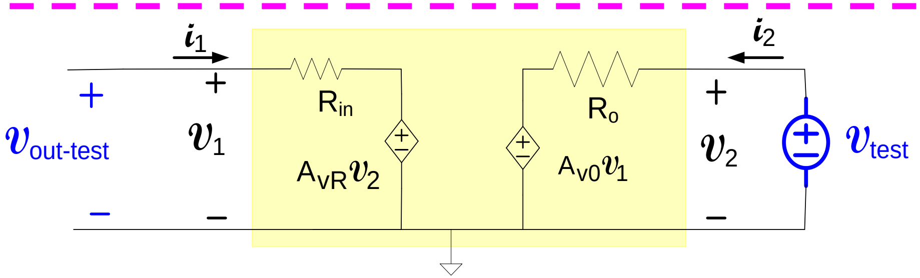


$$R_{in} = \frac{v_{\text{test}}}{i_{\text{test}}}$$



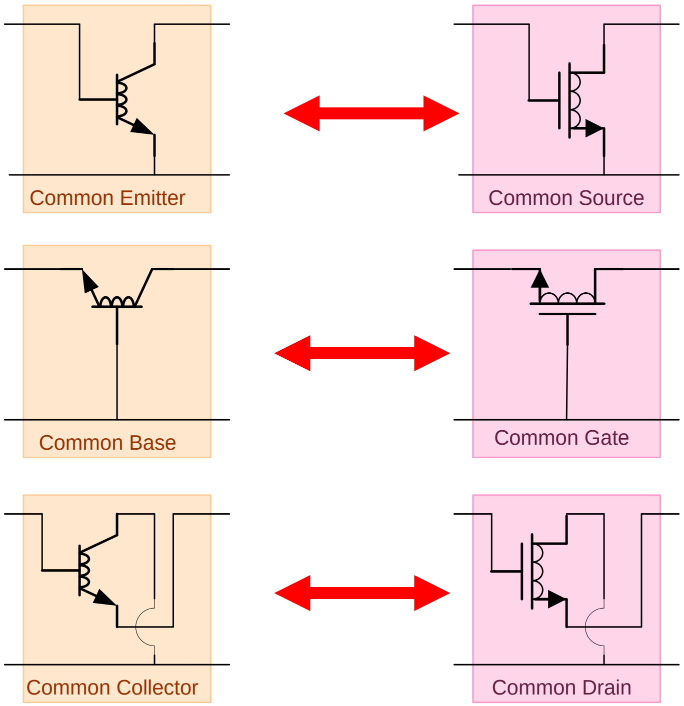
$$R_0 = \frac{v_{\text{test}}}{i_{\text{test}}}$$

If Unilateral $A_{VR}=0$

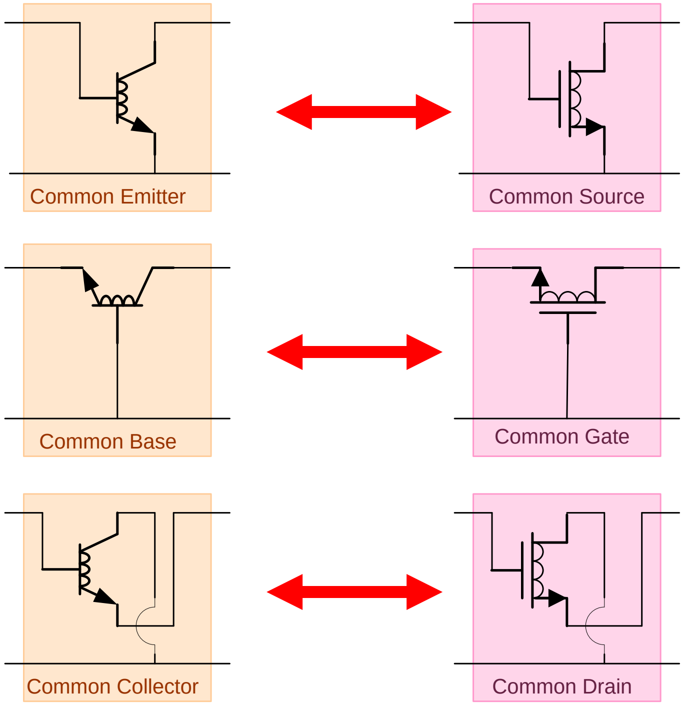


$$A_{VR} = \frac{v_{\text{out-test}}}{v_{\text{test}}}$$

Will now develop two-port model for each of the three basic amplifiers and look at one widely used application of each



Parameter Domains for Small-Signal Models for Any Devices



- Small-signal parameter domain

  Y-parameters, g-parameters, amplifier parameters, …

- Model Parameters and Operating Point (MPOP)

– Small-signal analysis naturally results in small-signal parameter domain
– More insight often in MPOP domain
– Mixed-parameter domains possible but often difficult to obtain insight

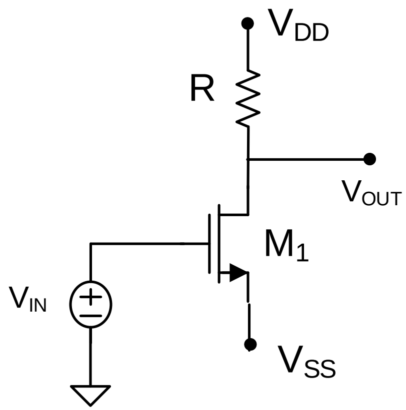
Parameter Domains for Small-Signal Models for Any Devices

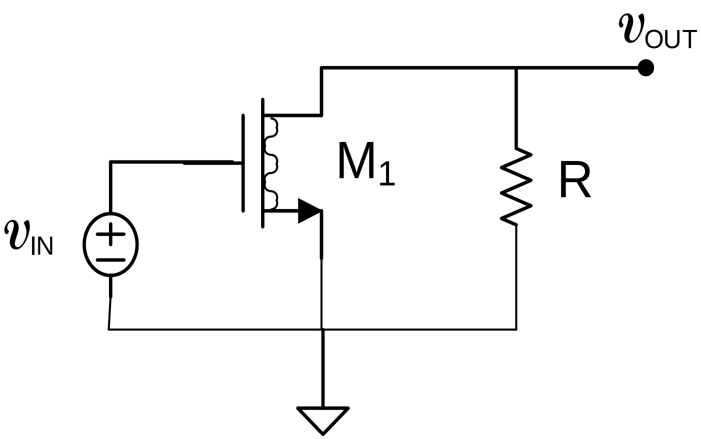
- Small-signal parameter domain

  Y-parameters, g-parameters, amplifier parameters, …

- Model Parameters and Operating Point (MPOP)

Example: Give A_V for basic amplifier in ss parameter domain and MPOP domain





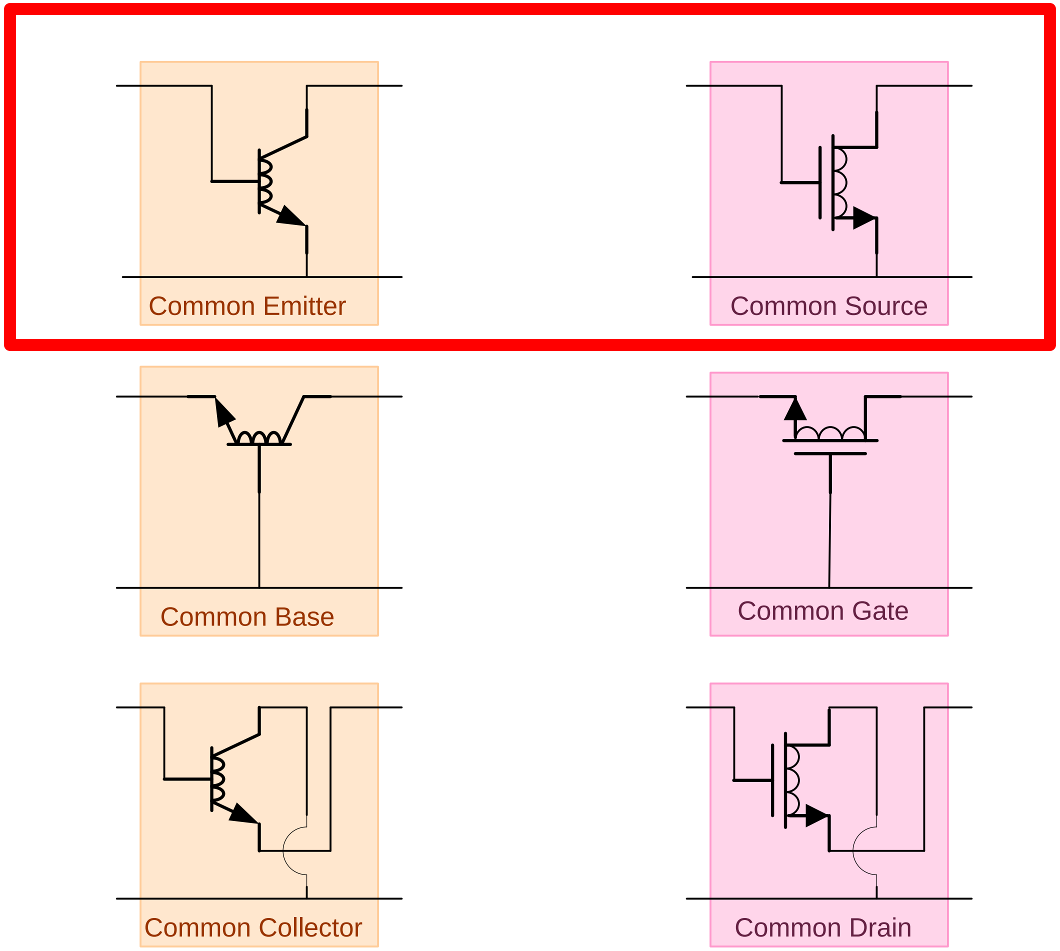
Small-Signal parameter domain

$$A_V = \frac{v_{OUT}}{v_{IN}} = -g_m R$$

MPOP domain

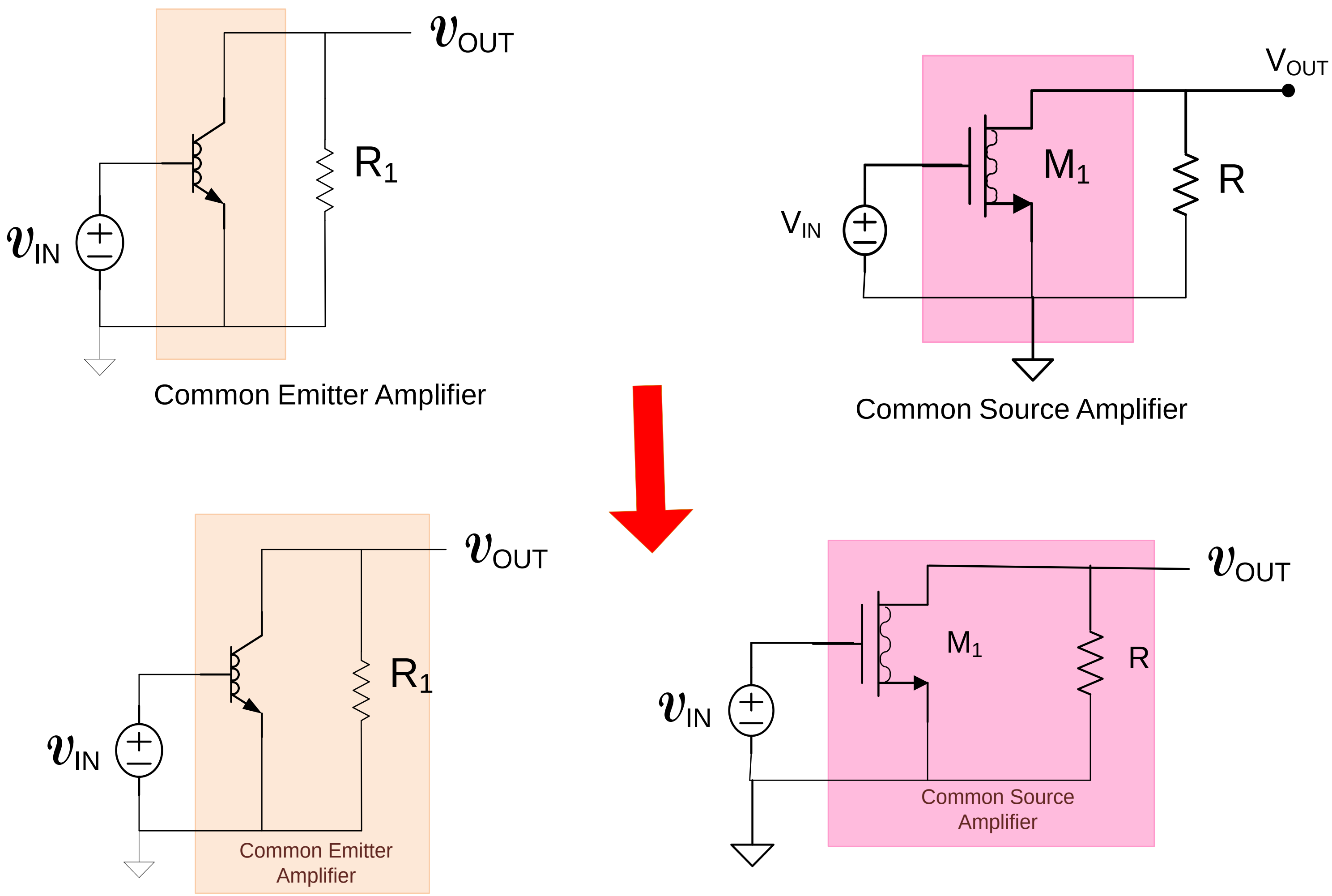
$$A_V = \frac{v_{OUT}}{v_{IN}} = -2\frac{I_{DQ}R}{V_{EB}}$$

Consider Common Emitter/Common Source Two-port Models



- Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting g_π=0
- Will consider both two-port model and a widely used application

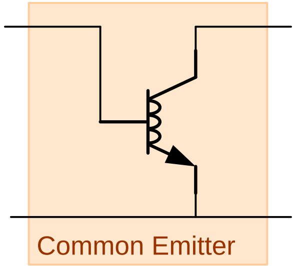
Basic CE/CS Amplifier Structures

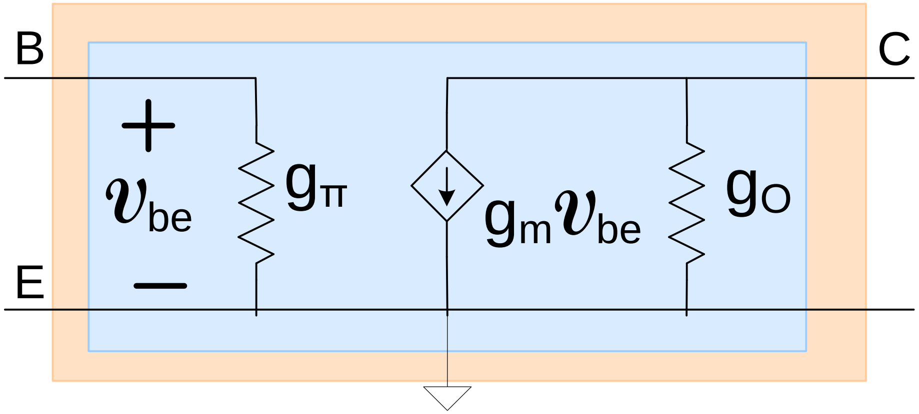


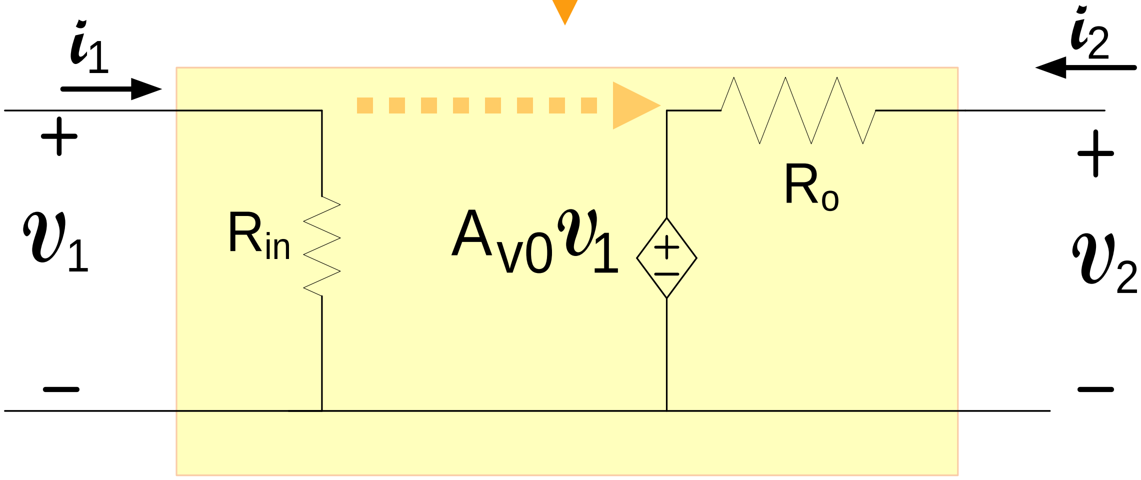
Can include or exclude R and R_1 in two-port models (of course they are different circuits)

The CE and CS amplifiers are themselves two-ports !

Two-port model for Common Emitter Configuration



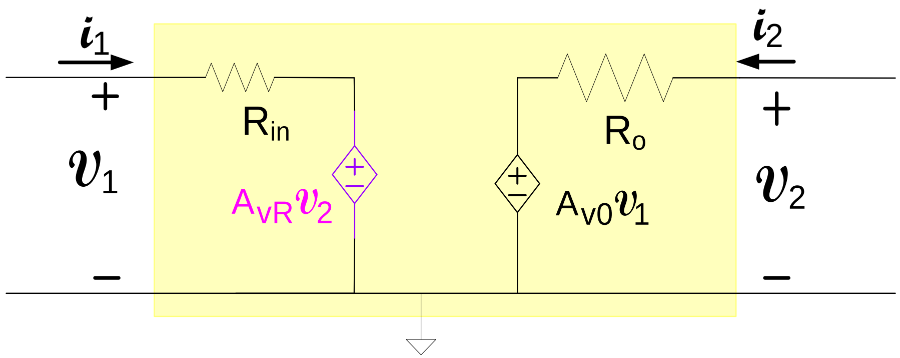




{R_i, A_{V0} and R_0}

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

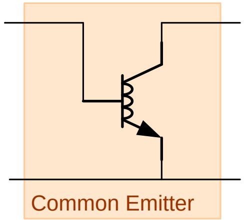
$$v_1 = i_1 R_{IN} + A_{VR} v_2$$

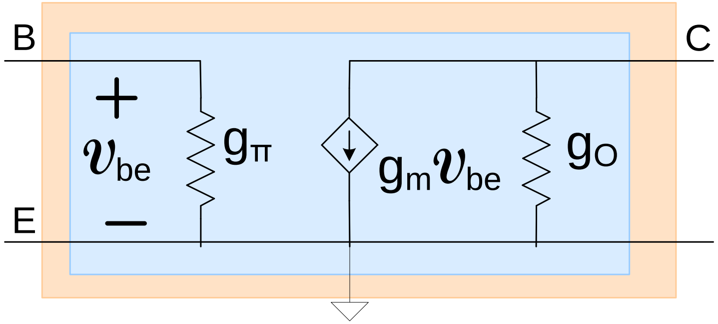
$$v_2 = i_2 R_O + A_{V0} v_1$$

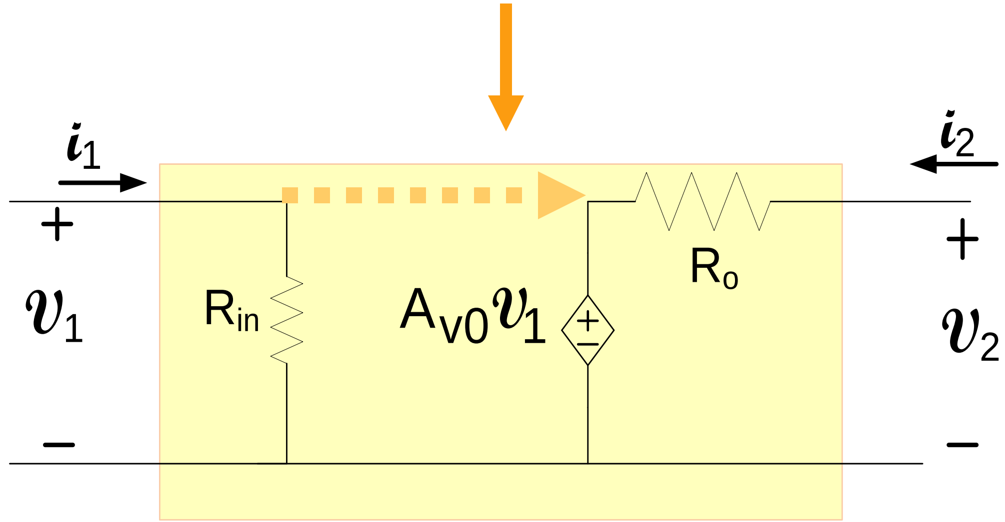
3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

Two-port model for Common Emitter Configuration





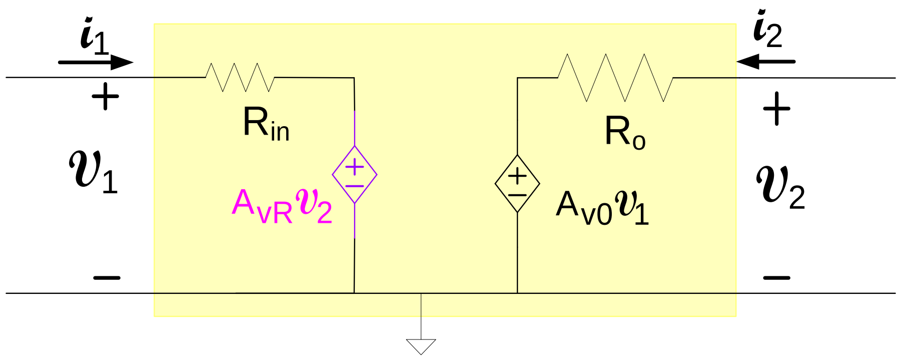


By Thevenin : Norton Transformations

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

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

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

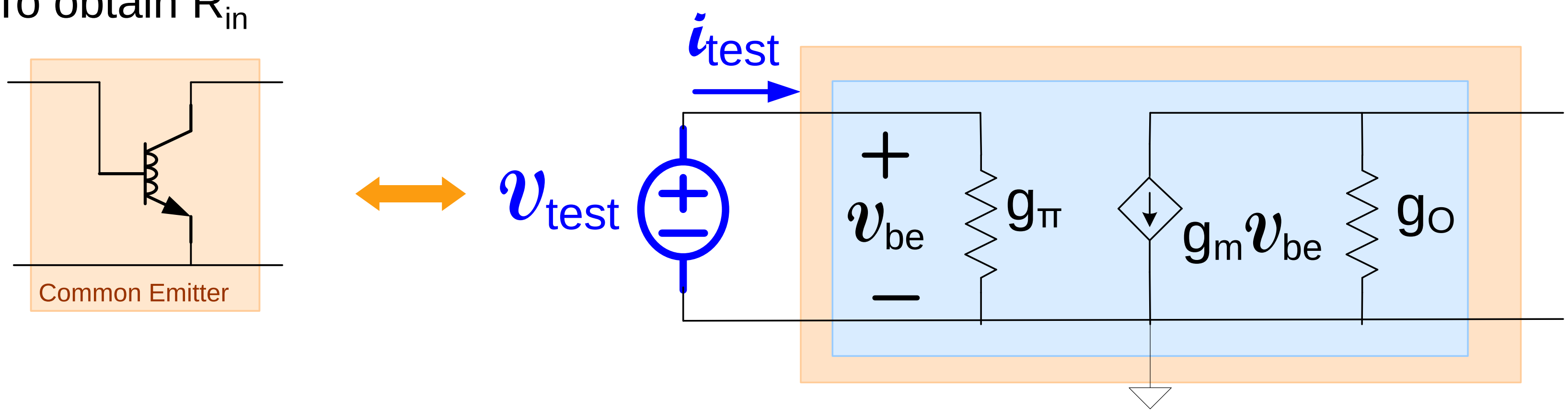
$$v_2 = i_2 R_O + A_{V0} v_1$$

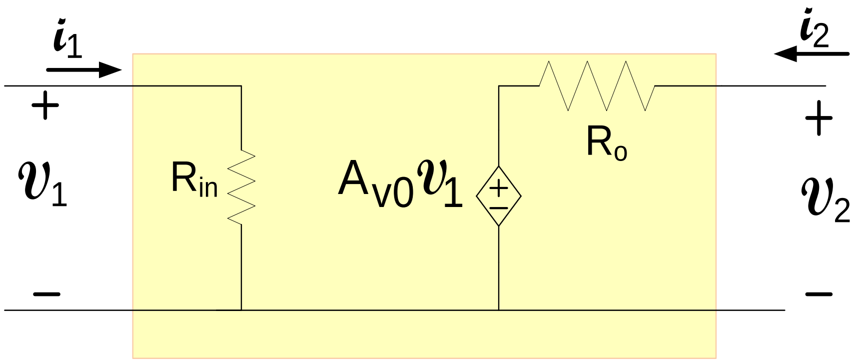
3. Thevenin-Norton Transformations
4. Ad Hoc Approaches

Two-port model for Common Emitter Configuration

Alternately, by v_{TEST} : i_{TEST} Method

To obtain R_{in}





$$R_{in} = \frac{v_{test}}{i_{test}}$$

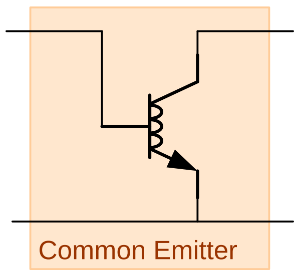
$$R_{in} = \frac{1}{g_\pi}$$

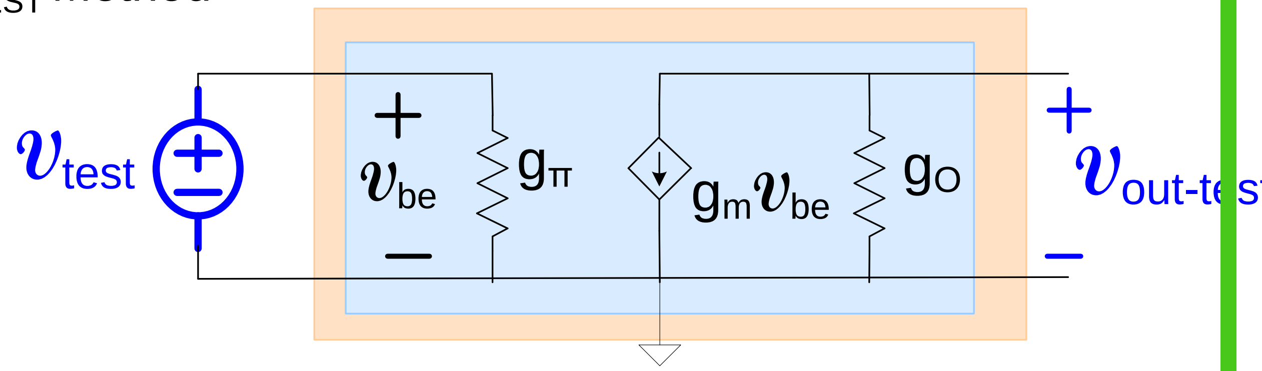
{R_{in}, A_{V0} and R_0}

Two-port model for Common Emitter Configuration

Alternately, by v_{TEST} : i_{TEST} Method

To obtain A_{V0}

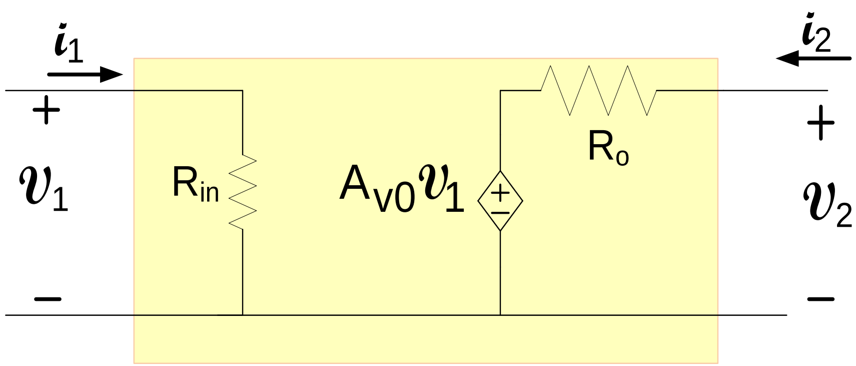




$$A_{V0} = \frac{v_{out\text{-}test}}{v_{test}}$$

$$v_{out-test} = v_{test}\left(-\frac{g_m}{g_0}\right)$$

$$A_{V0} = -\frac{g_m}{g_O}$$

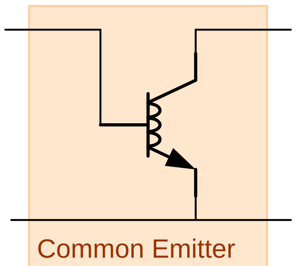


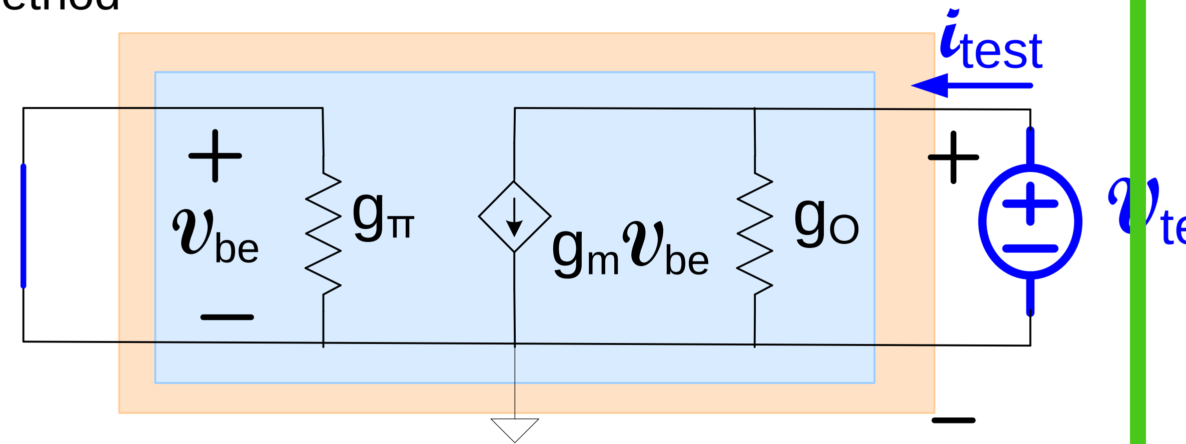
{R_{in}, A_{V0} and R_0}

Two-port model for Common Emitter Configuration

Alternately, by v_{TEST} : i_{TEST} Method

To obtain g_0

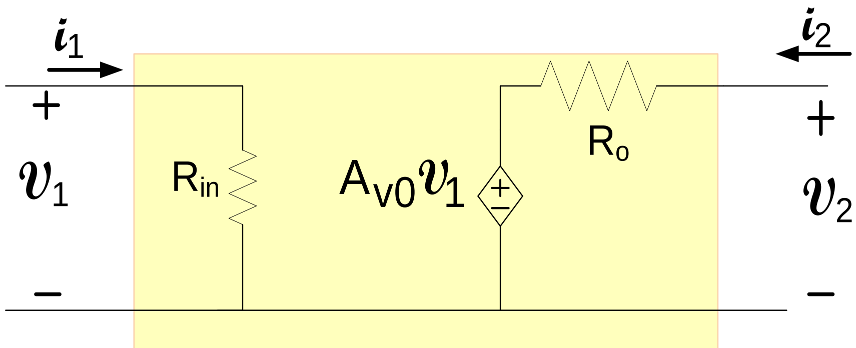




$$R_0 = \frac{v_{test}}{i_{test}}$$

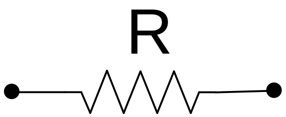
$$v_{test} = i_{test}\left(g_0\right)$$

$$R_0 = \frac{1}{g_0}$$



$\{R_{in}, A_{V0}$ and $R_0\}$

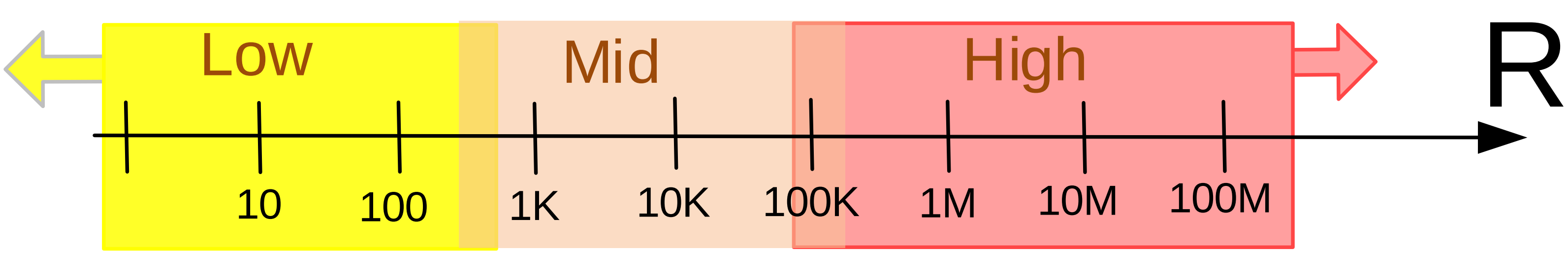
Impedance Range and Classification



The terms “High Impedance” and “ Low Impedance” are often used

Whether an impedance is considered high or low or mid-range is a relative assessment

When building MOS or BJT amplifiers, the following relative notation of impedance levels is often useful (though there may be some extreme applications where even this notation is not standard)

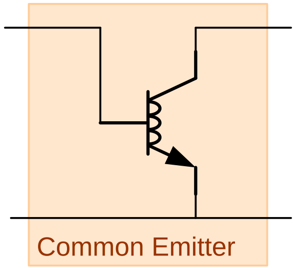


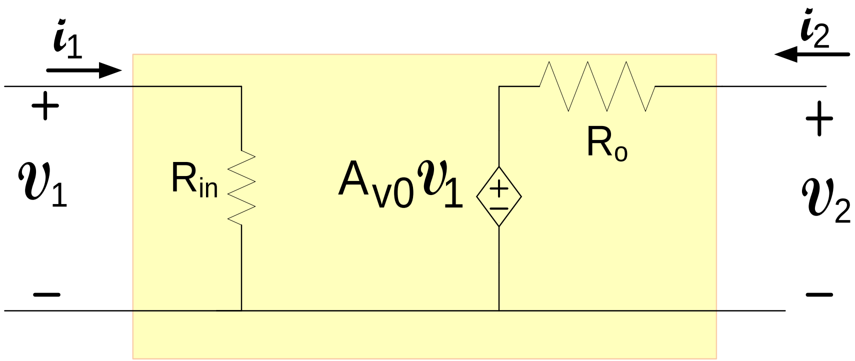
Impedance Range and Classification

Ideal Port Impedance of the four basic amplifiers

Amplifier Type	R_{IN}	R_{OUT}
Voltage	∞	0
Current	0	∞
Transconductance	∞	∞
Transresistance	0	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:

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

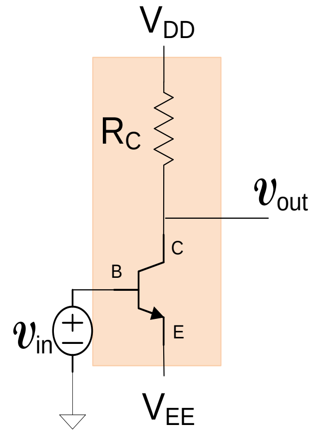
Characteristics:

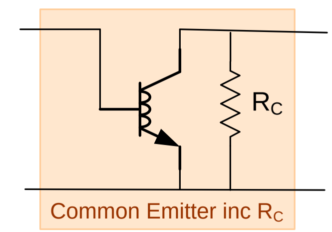
- Input impedance is mid-range
- Voltage Gain is Large and Inverting
- Output impedance is large
- Unilateral
- Widely used to build voltage amplifiers

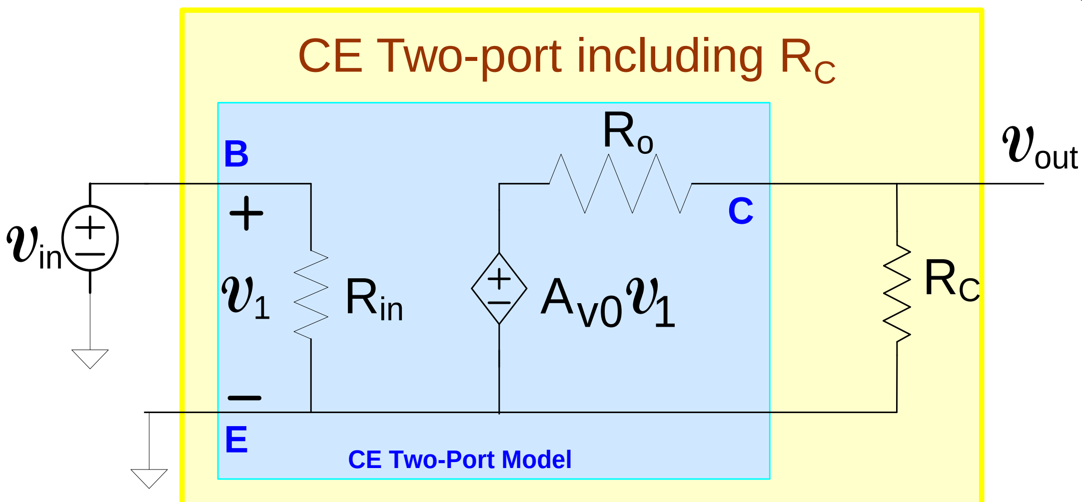
Common Emitter Configuration

Consider the following CE application

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







$$g_C \underset{def}{=} \frac{1}{R_C}$$

$$\frac{g_o}{g_C} = \frac{I_{CQ}R_C}{V_{AF}} << 1$$

$$A_{VR} = 0$$

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

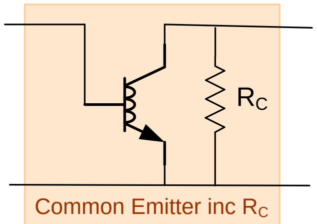
$$R_{inC} = R_{in} = r_\pi$$

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

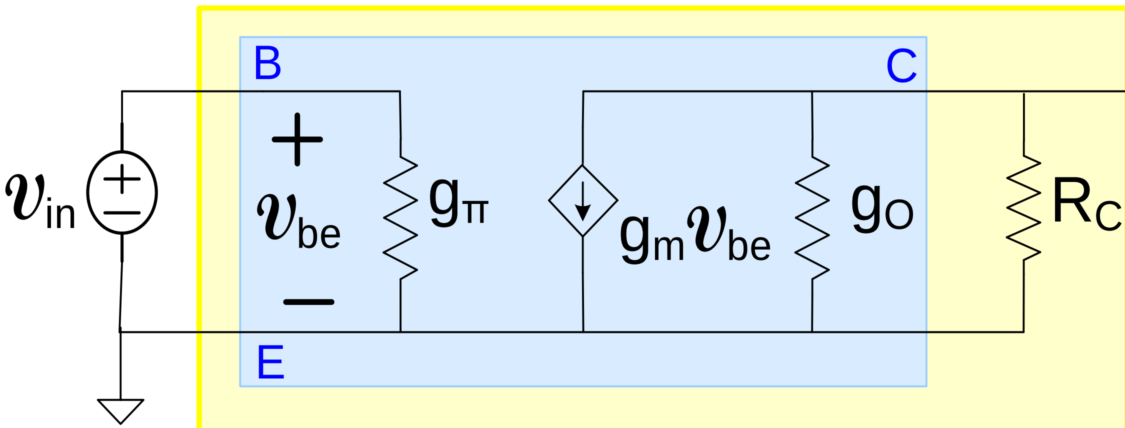
Common Emitter Configuration

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 (use standard 2-port transistor model instead)



v_{out}

$$g_C \underset{def}{=} \frac{1}{R_C}$$

$$\frac{g_O}{g_C} = \frac{I_{CQ} R_C}{V_{AF}} << 1$$

$$A_{VR} = 0$$

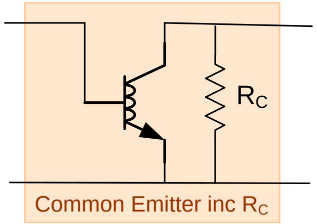
$$v_{out} = -g_m v_{in} \left(\frac{1}{g_0 + g_C} \right) \rightarrow A_v = \frac{v_{out}}{v_{in}} = -\left(\frac{g_m}{g_0 + g_C} \right) \overset{g_0 << g_C}{\cong} -g_m R_C$$

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

Common Emitter Configuration

Consider the following CE application

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



Small-signal parameter domain

Operating point and model parameter domain

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

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

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

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

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

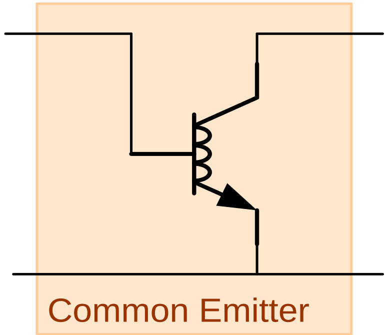
$$R_{in} = \frac{\beta V_t}{I_{CQ}}$$

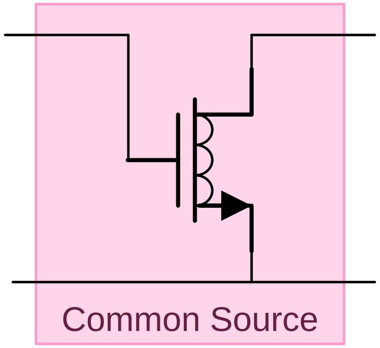
$$A_{VR} = 0$$

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:

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

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

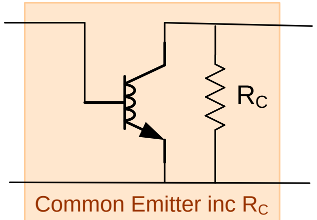
$$A_{V0} = -\frac{2}{\lambda V_{EBQ}} = -2\frac{V_{AF}}{V_{EBQ}}$$

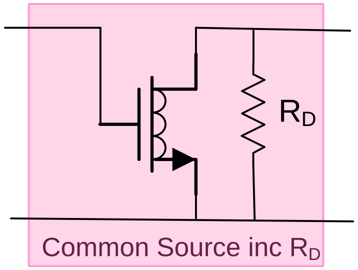
Characteristics:

- 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

Widely used CE application (but also a two-port)





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

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

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

$$A_{VR} = 0$$

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

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

$$R_{in} = \infty$$

$$A_{VR} = 0$$

In terms of operating point and model parameters:

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

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

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

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

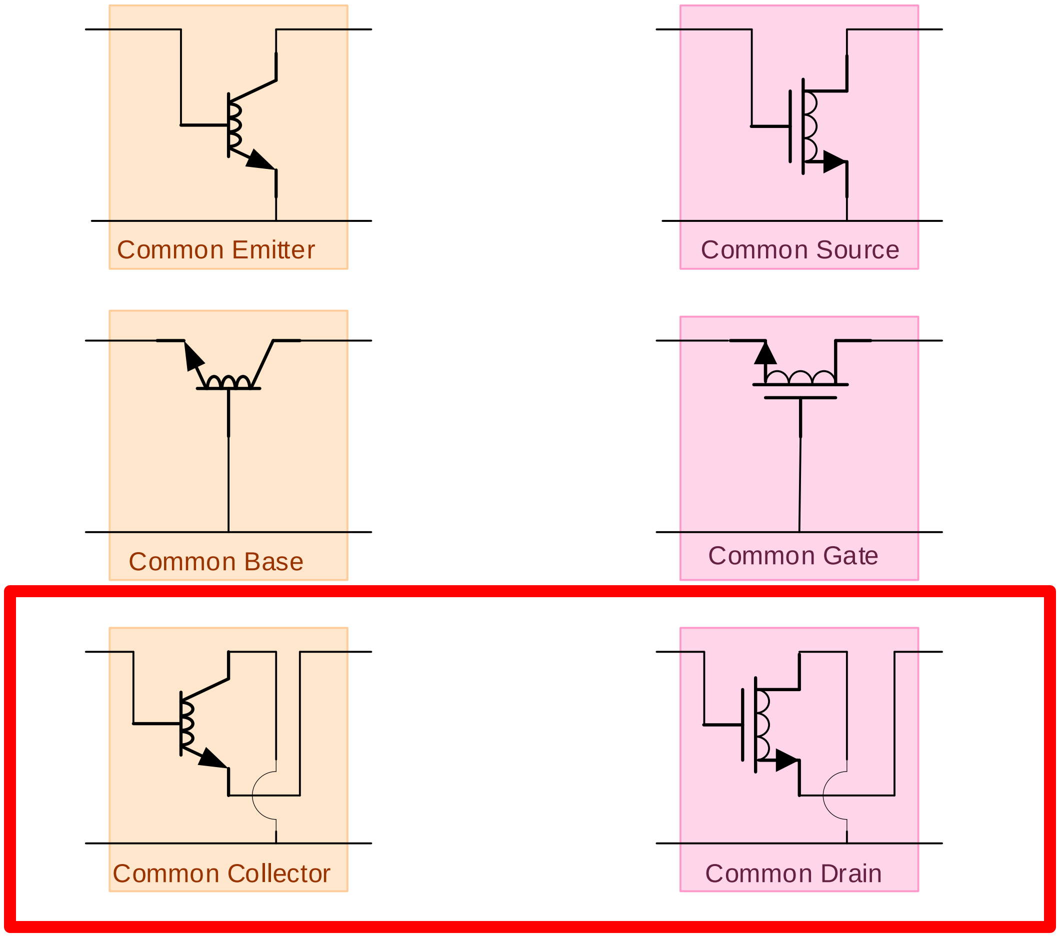
$$R_{in} = \infty$$

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

Characteristics:

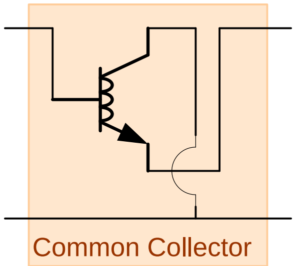
- Input impedance is mid-range (infinite for MOS)
- Voltage Gain is Large and Inverting
- Output impedance is mid-range
- Unilateral
- Widely used as a voltage amplifier

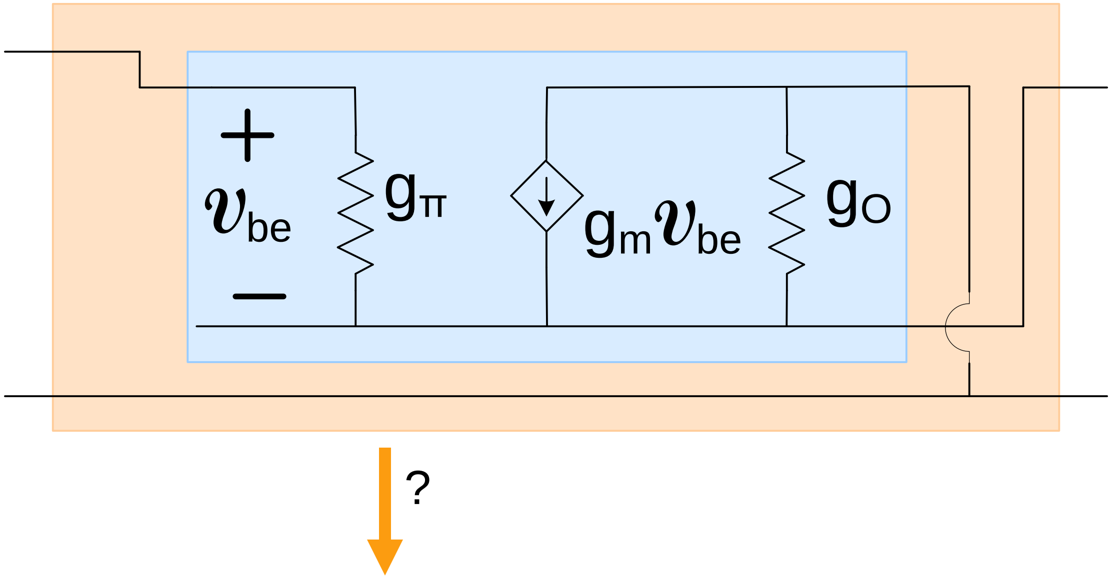
Consider Common Collector/Common Drain Two-port Models

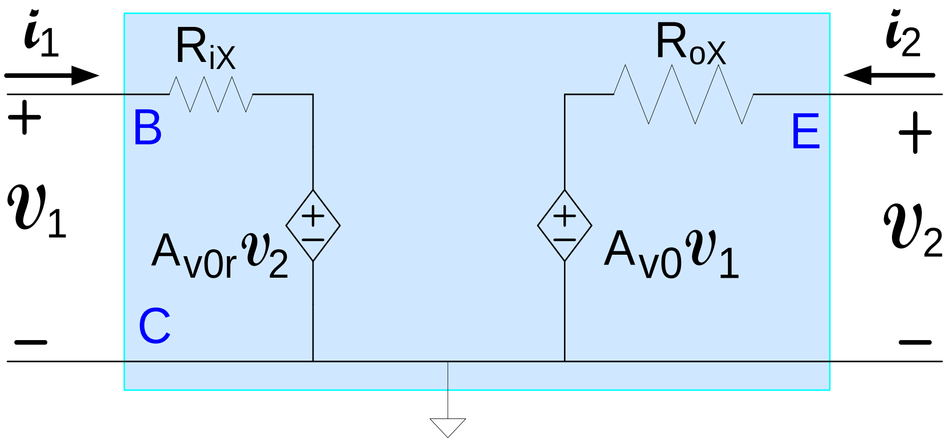


- Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting $g_{\pi}=0$
- Will consider both two-port model and a widely used application

Two-port model for Common Collector Configuration



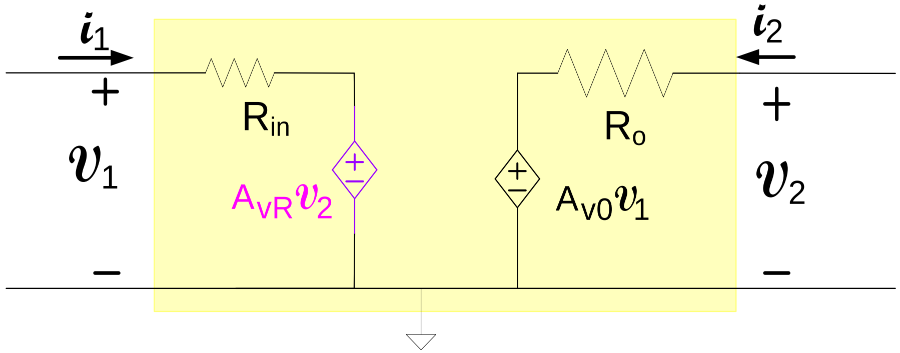




{R_{iX}, A_{V0}, A_{V0r} and R_{0X}}

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

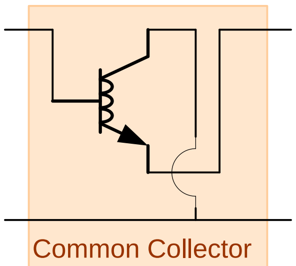
$$v_1 = i_1 R_{IN} + A_{VR} v_2$$

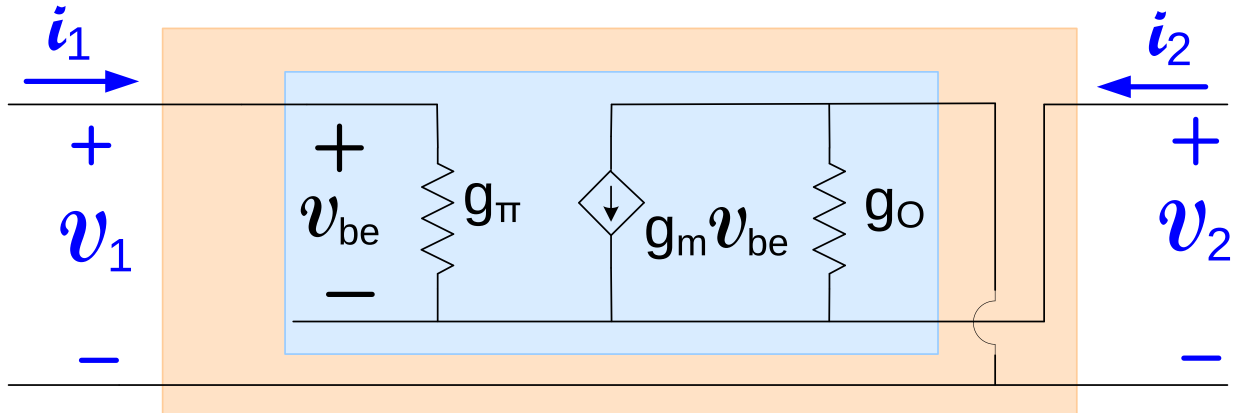
$$v_2 = i_2 R_O + A_{V0} v_1$$

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

Two-port model for Common Collector Configuration





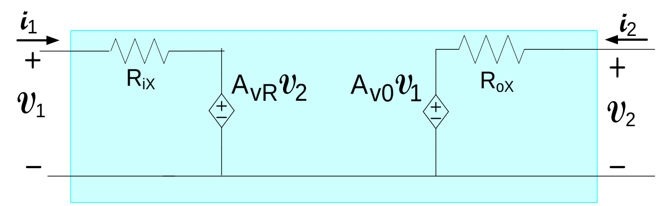
Applying KCL at the input and output node, obtain

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

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



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

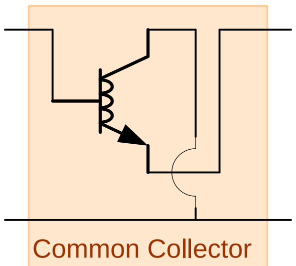
$$v_2 = i_2 R_{oX} + A_V v_1$$

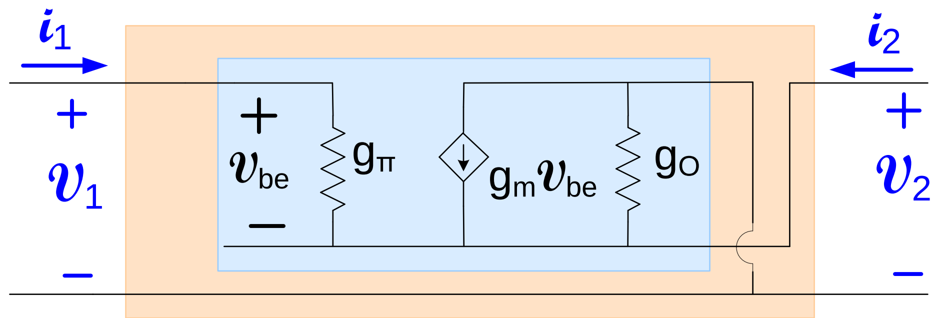
v_1 : v_2 equations in standard form

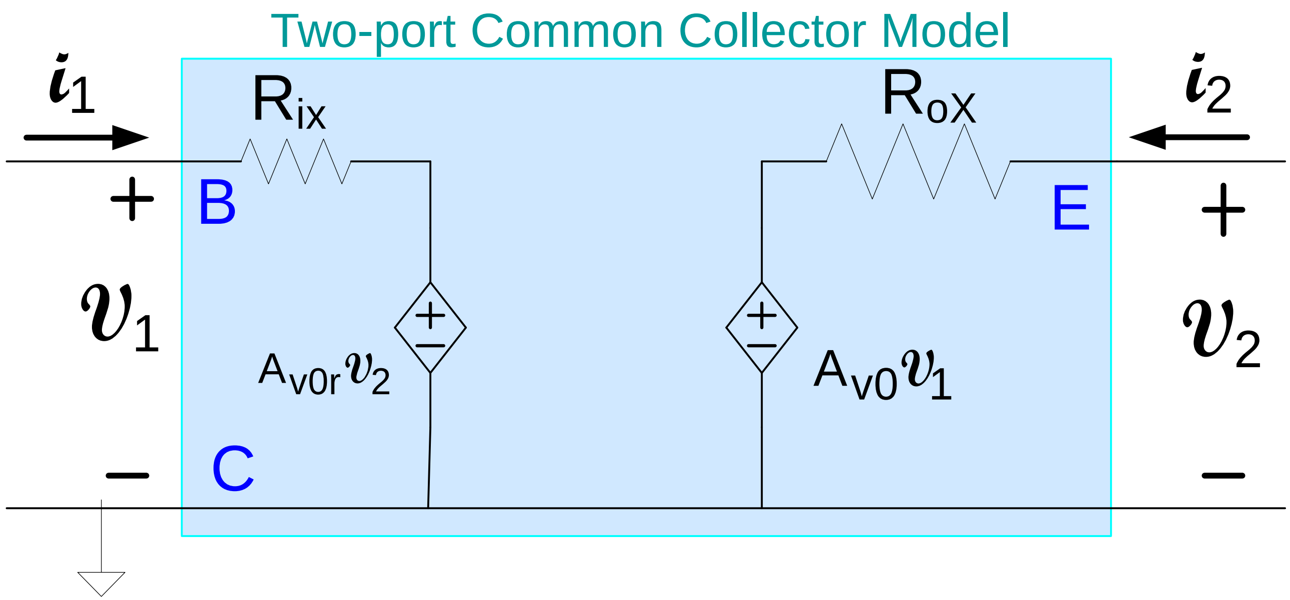
It thus follows that

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

Two-port model for Common Collector Configuration







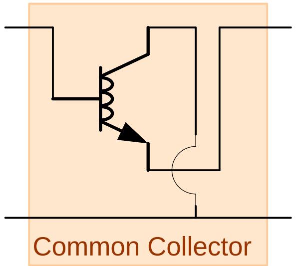
$R_{iX} = r_\pi$

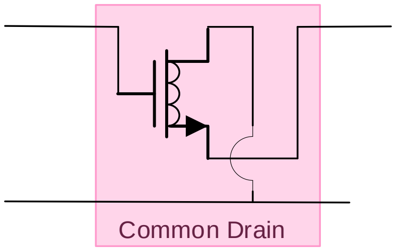
$A_{VOr} = 1$

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

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

Two-port model for Common Collector Configuration





$A_{VR} = 1$ $A_{VR} = 1$

$R_{in} = r_{\pi}$ $A_{V0} = 1$ $R_0 = \frac{1}{g_m}$ $R_{in} = \infty$ $A_{V0} = 1$ $R_0 = \frac{1}{g_m}$

In terms of operating point and model parameters:

$R_{in} = \frac{\beta V_t}{I_{CQ}}$ $A_{V0} = 1$ $R_0 = \frac{V_t}{I_{CQ}}$ $R_{in} = \infty$ $A_{V0} = 1$ $R_0 = \frac{V_{EB}}{2I_{DQ}}$

Characteristics:

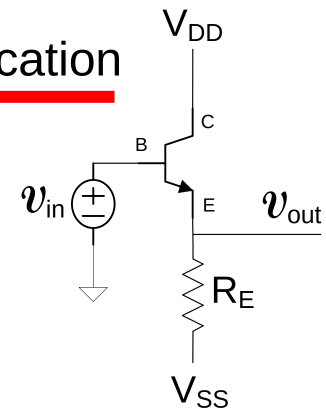
- Input impedance is mid-range (infinite for MOS)
- Voltage Gain is nearly 1
- Output impedance is very low
- Slightly non-unilateral (critical though in increasing input impedance when R_E added)
- Widely used as a buffer

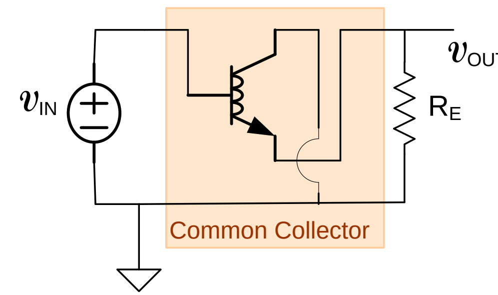
Common Collector Configuration

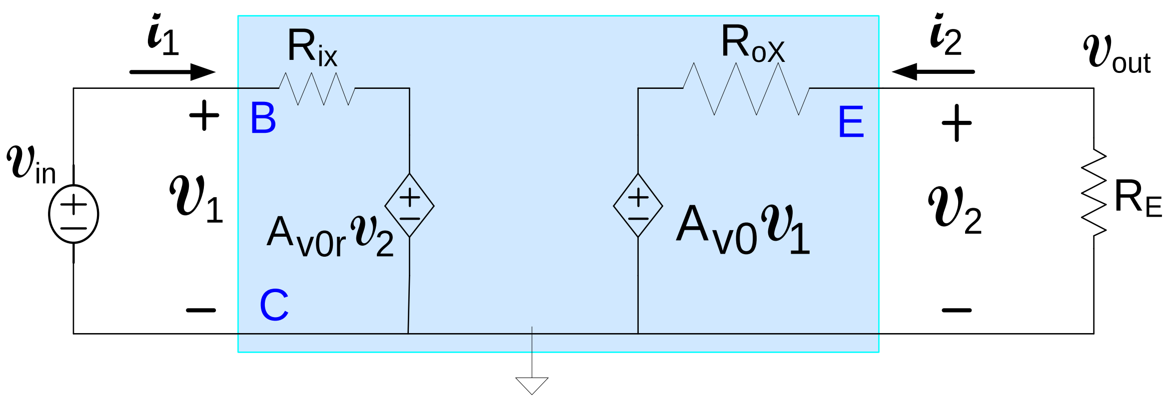
Consider the following popular CC application

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)







$$\frac{g_m}{g_{RE}} = \frac{I_{CQ}R_E}{V_t} >> 1$$

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

$$v_{in} = i_1 R_{ix} + A_{v0r}A_{v0}\frac{g_{0X}}{g_{0X}+g_{RE}}v_{in}$$

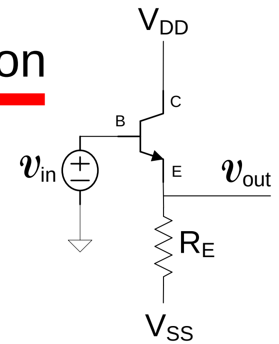
$$R_{in} = \frac{r_\pi}{1-\frac{g_m+g_\pi}{g_m+g_\pi+g_o+g_{RE}}} = r_\pi\frac{g_m+g_\pi+g_o+g_{RE}}{g_o+g_{RE}} \overset{g_{RE}>>g_o}{\cong} r_\pi+\beta R_E$$

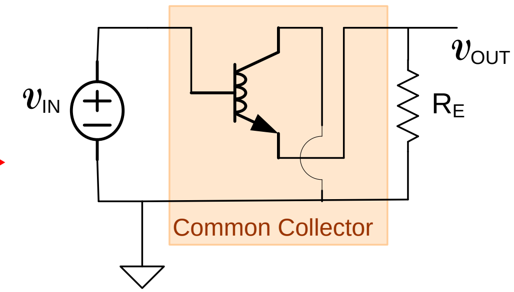
$$R_0 \cong \frac{1}{g_m+g_{RE}+g_0+g_\pi} = \frac{1}{g_m+g_{RE}} = \frac{R_E}{1+g_mR_E} \overset{g_m>>g_{RE}}{\cong} \frac{1}{g_m}$$

Common Collector Configuration

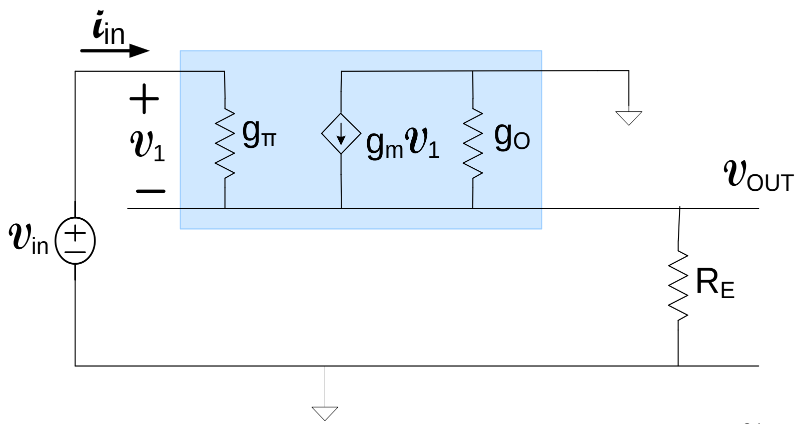
Consider the following popular CC application

(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



$$\frac{g_m}{g_{RE}} = \frac{I_{CQ}R_E}{V_t} >> 1$$

$$v_{out}\left(g_{RE}+g_0+g_\pi\right) = v_{in}g_\pi + g_m v_1$$

$$v_{in} = v_1 + v_{out}$$

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

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

$$i_{in} = g_\pi\left(v_{in}-v_{out}\right)$$

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

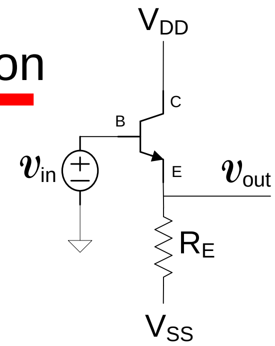
$$i_{in}\left(g_m+g_\pi+g_{RE}+g_0\right) = g_\pi v_{in}\left(g_{RE}+g_0\right)$$

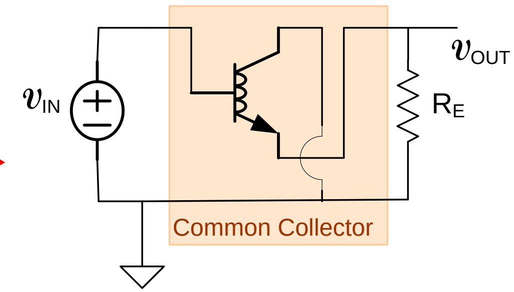
$$R_{in} = r_\pi\frac{g_m+g_\pi+g_o+g_{RE}}{g_o+g_{RE}} \overset{\frac{g_{RE}>>g_o}{\beta>>1}}{\cong} r_\pi + \beta R_E$$

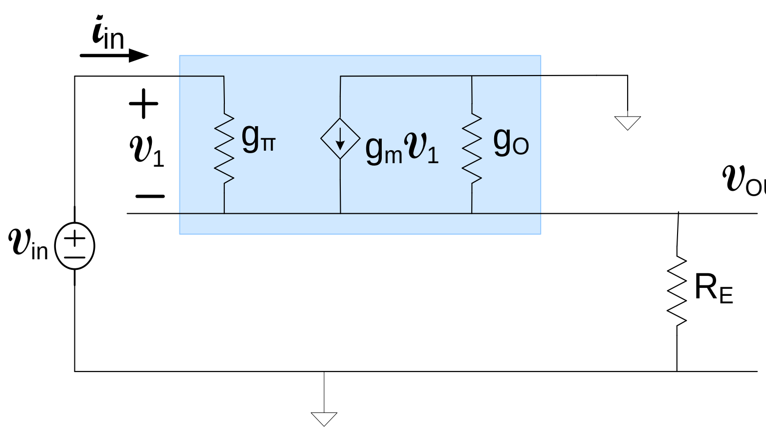
Common Collector Configuration

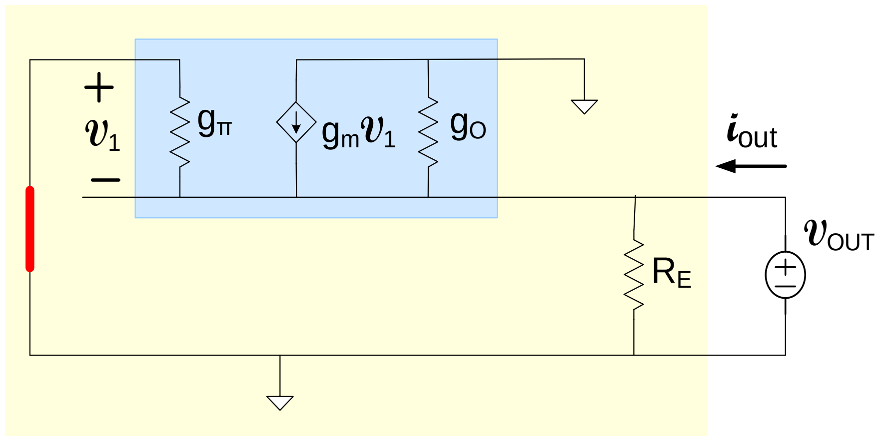
Consider the following popular CC application

(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 $v_{in} = 0$

$$\frac{g_m}{g_{RE}} = \frac{I_{CQ} R_E}{V_t} >> 1$$

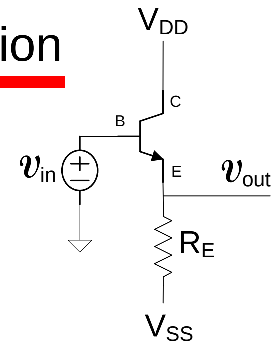
$$i_{out} = v_{out}\left(g_{RE} + g_0 + g_\pi\right) - g_m\left(-v_{out}\right)$$

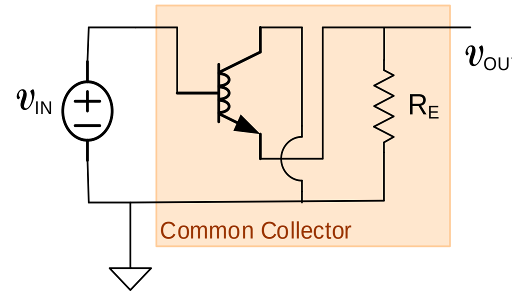
$$R_{out} = \frac{1}{g_m + g_\pi + g_o + g_{RE}} \overset{g_E << g_m}{\cong} \frac{1}{g_m}$$

Common Collector Configuration

Consider the following popular 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 -)





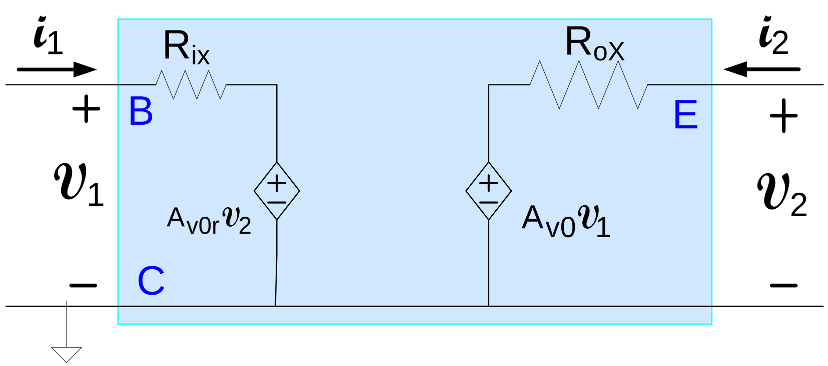
$$A_V = \frac{g_\pi + g_m}{g_m + g_{RE} + g_0 + g_\pi} \cong \frac{g_m}{g_m + g_{RE}} = \frac{I_{CQ}R_E}{I_{CQ}R_E + V_t} \cong 1$$

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

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

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

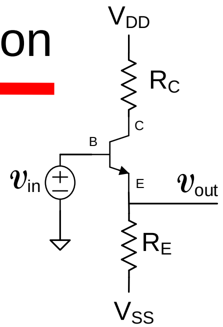
- R_{in} defined for open-circuit on output instead of short-circuit (see previous slide : -2 slides)
- $A_{V0r} \neq 0$

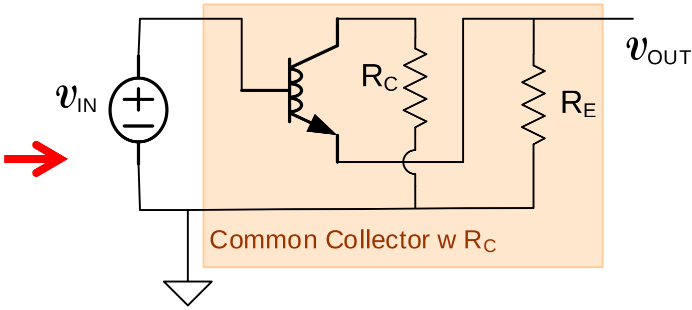


Common Collector Configuration with R_C

Consider the following popular CC application

(though not real common, sometimes a resistor is included in the collector)





It can be readily shown that unless R_C is very large, it has little effect on the performance and have same expressions for A_V, R_{IN}, and R_{OUT}

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

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

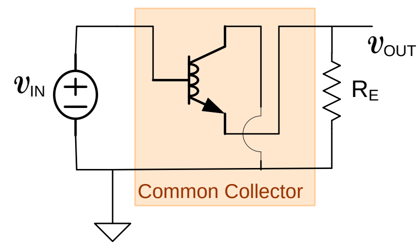
$$R_{out} \cong \frac{1}{g_m}$$

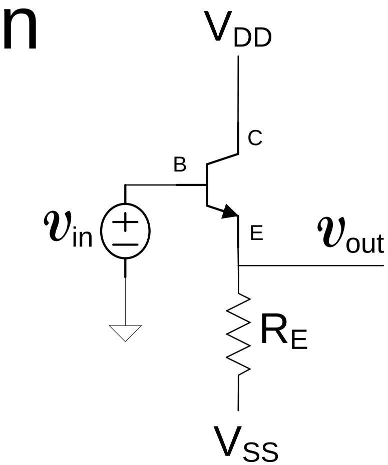
Intuitively this can be expected since if g_0 is neglected, R_C is in series with a current source in the ss BJT model

Common Collector Configuration

For this popular CC application

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





Small signal parameter domain

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

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

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

Operating point and model parameter domain

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

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

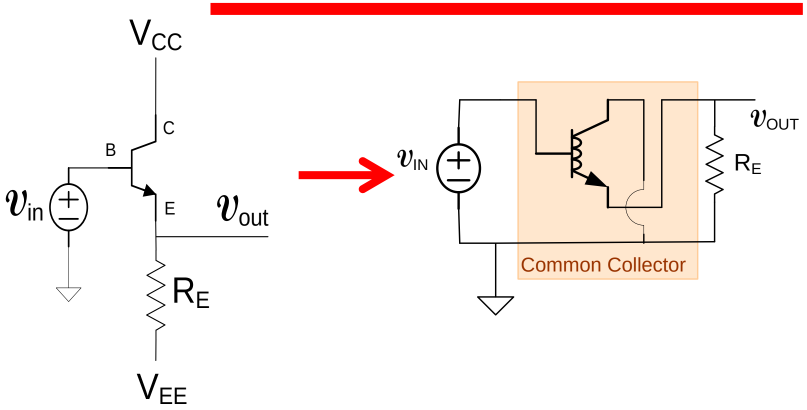
$$R_0 \overset{I_{CQ} R_E >> V_t}{\cong} \frac{V_t}{I_{CQ}}$$

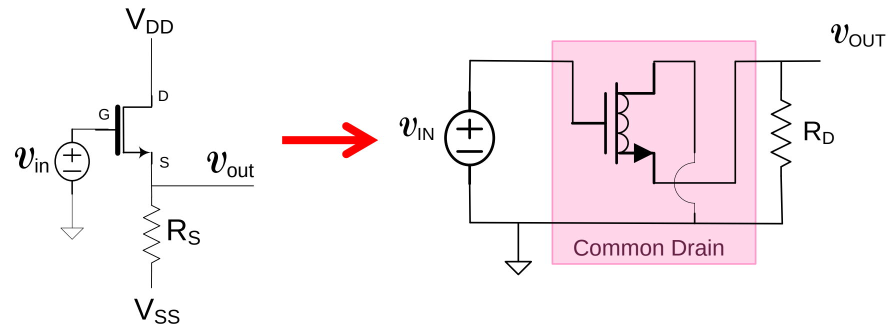
Characteristics:

- 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 popular 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:

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

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

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

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

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

$$R_{in} = \infty$$

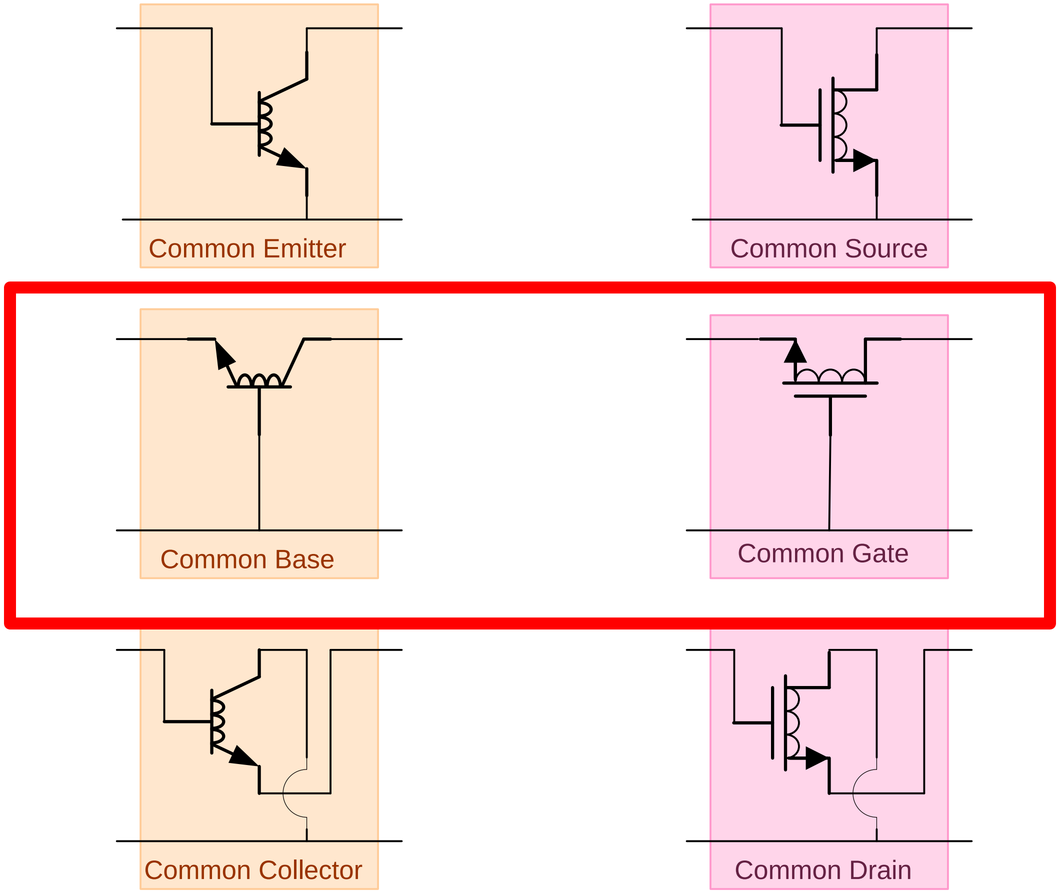
- Output impedance is low
- A_{V0} is positive and near 1
- Input impedance is very large

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

Stay Safe and Stay Healthy !

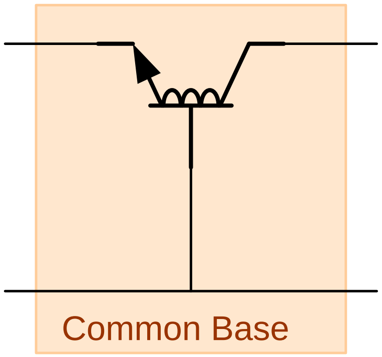
End of Lecture 31

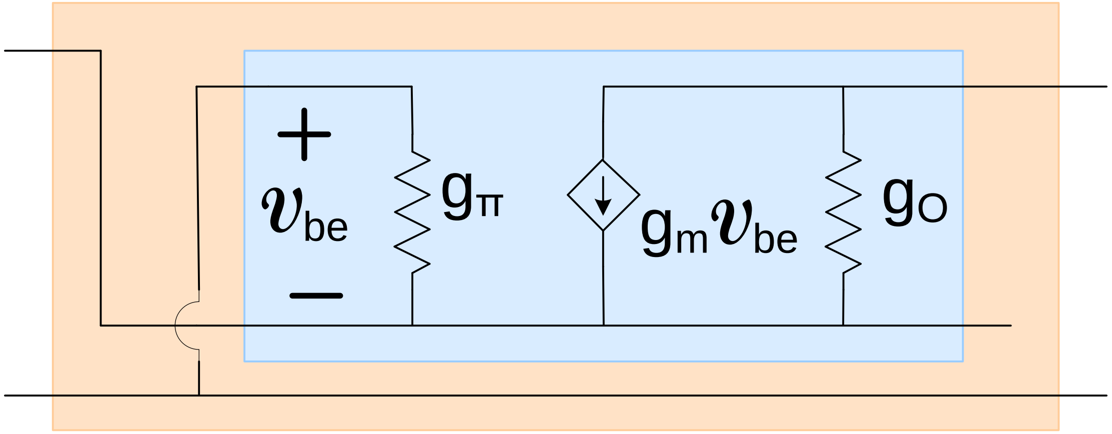
Consider Common Base/Common Gate Two-port Models



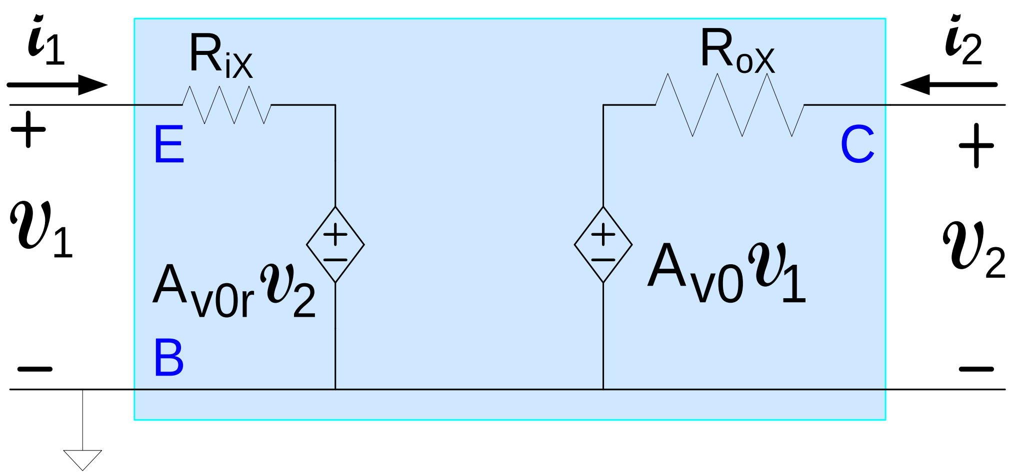
- Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting $g_{\pi}=0$
- Will consider both two-port model and a widely used application

Two-port model for Common Base Configuration





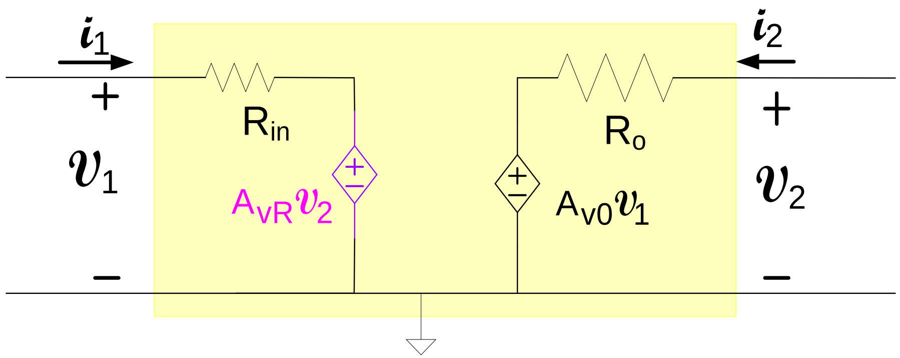
?



{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



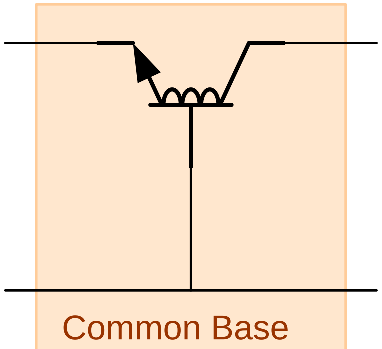
1. v_{TEST} : i_{TEST} Method
2. Write $v_1 : v_2$ equations in standard form

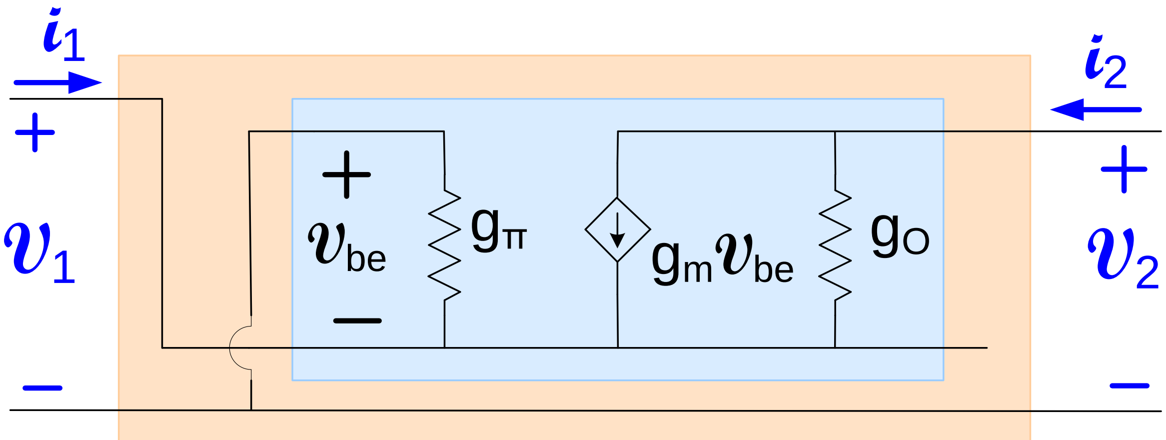
$$v_1 = i_1 R_{IN} + A_{VR} v_2$$

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

3. Thevenin-Norton Transformations
4. Ad Hoc Approaches

Two-port model for Common Base Configuration





From KCL

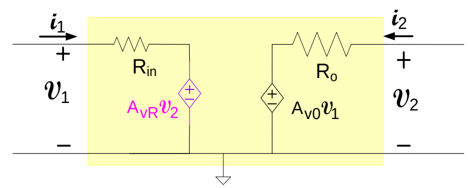
$$\left.\begin{aligned} i_1 &= v_1 g_\pi + (v_1 - v_2) g_0 + g_m v_1 \\ i_2 &= (v_2 - v_1) g_0 - g_m v_1 \end{aligned}\right\}$$

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

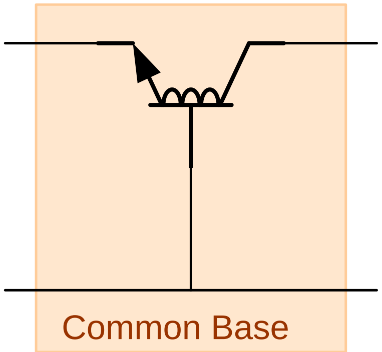


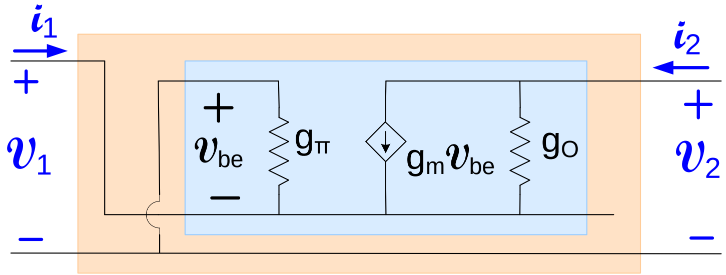
$$\Leftrightarrow \quad \begin{aligned} v_1 &= i_1 R_{IN} + A_{VR} v_2 \\ v_2 &= i_2 R_O + A_{V0} v_1 \end{aligned}$$

It thus follows that:

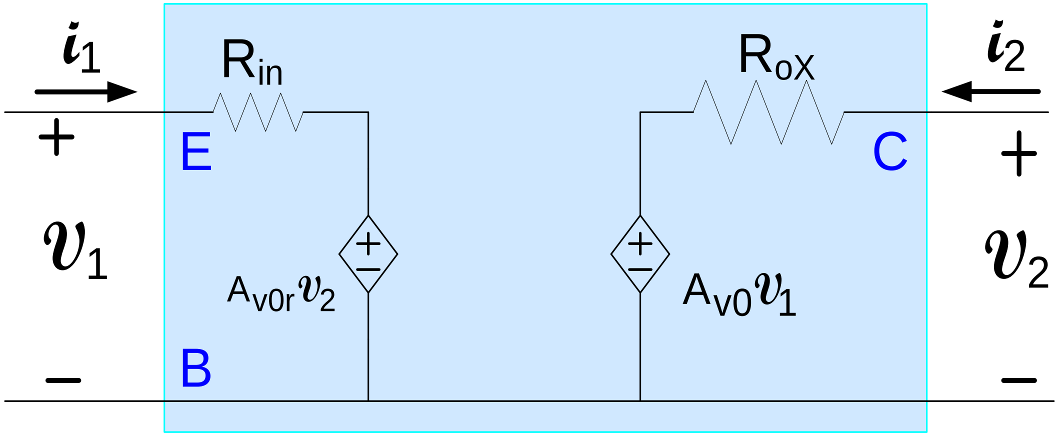
$$R_{iX} = \frac{1}{g_m + g_\pi + g_0} \cong \frac{1}{g_m} \qquad A_{VOr} = \frac{g_0}{g_m + g_\pi + g_0} \qquad A_{V0} = 1 + \frac{g_m}{g_0} \cong \frac{g_m}{g_0} \qquad R_{oX} = \frac{1}{g_0}$$

Two-port model for Common Base Configuration





Two-port Common Base Model



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

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

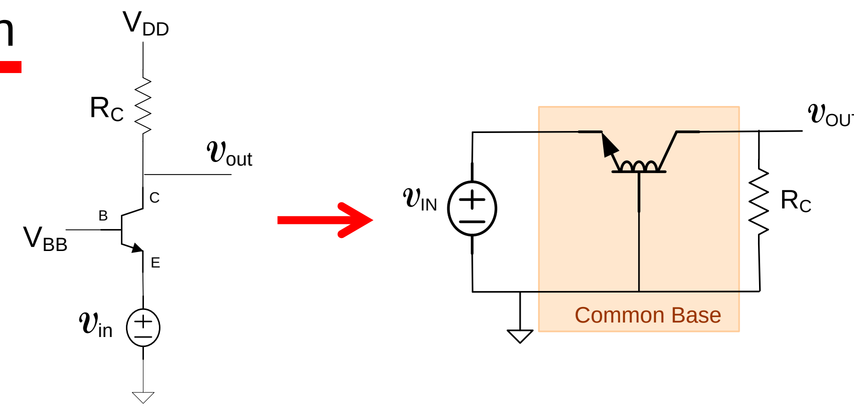
$$A_{VOr} = \frac{g_0}{g_m + g_\pi + g_0} \cong \frac{g_0}{g_m}$$

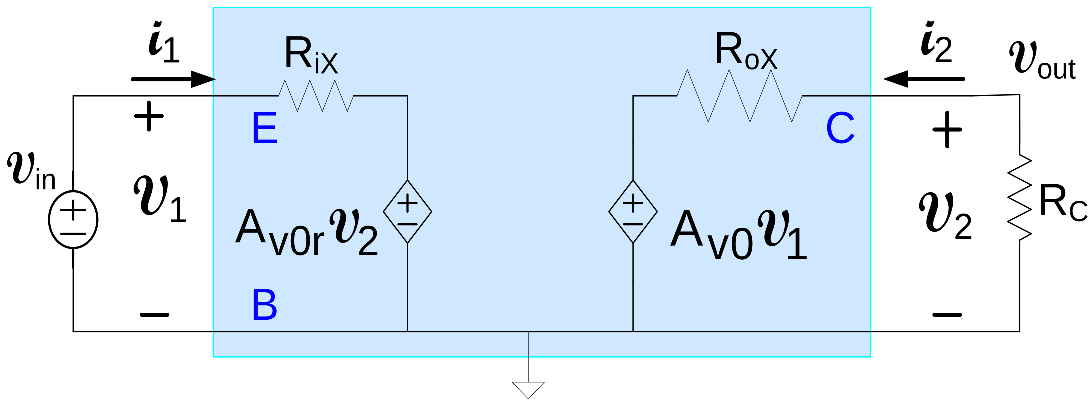
$$R_{oX} = \frac{1}{g_0}$$

Common Base Configuration

Consider the following popular 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)





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

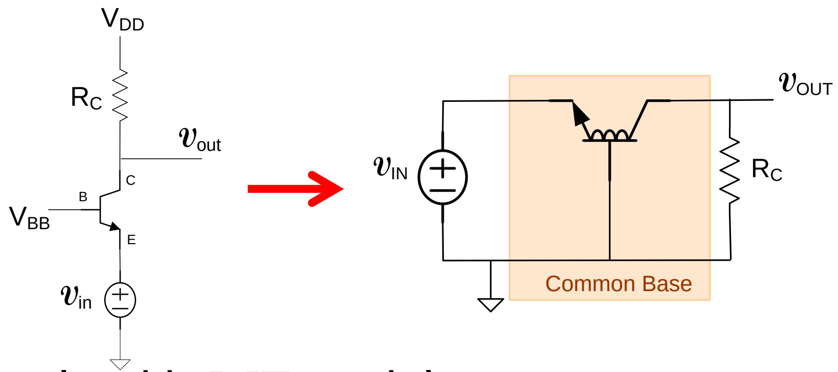
$$R_{in} = \frac{v_{in}}{i_1} = \frac{i_1 R_{iX} + A_{V0r} v_{out}}{i_1} \rightarrow R_{in} = \frac{R_{iX}}{1-A_{V0r}A_V} = \frac{g_0+g_C}{g_C\left(g_m+g_\pi+g_0\right)+g_\pi g_0} \cong \frac{1}{g_m}$$

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

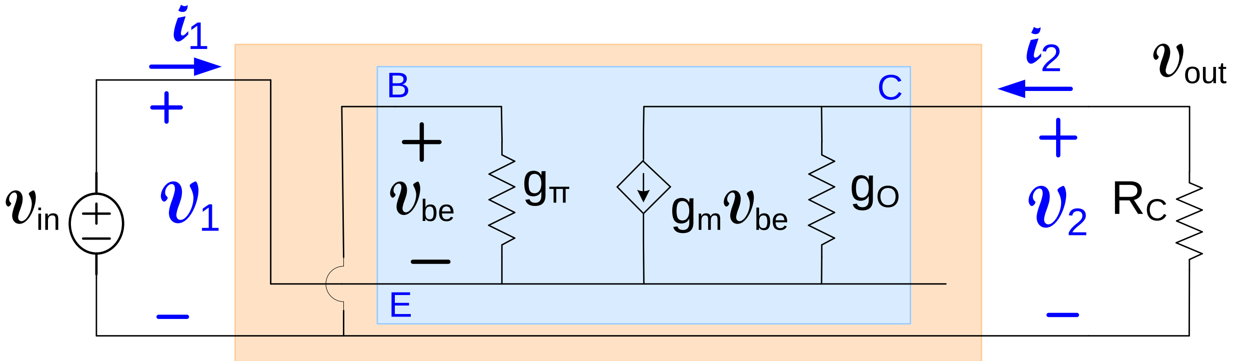
Common Base Configuration

Consider the following popular 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 with BJT model



$$g_c = \frac{1}{R_c}$$

By KCL at the output node, obtain

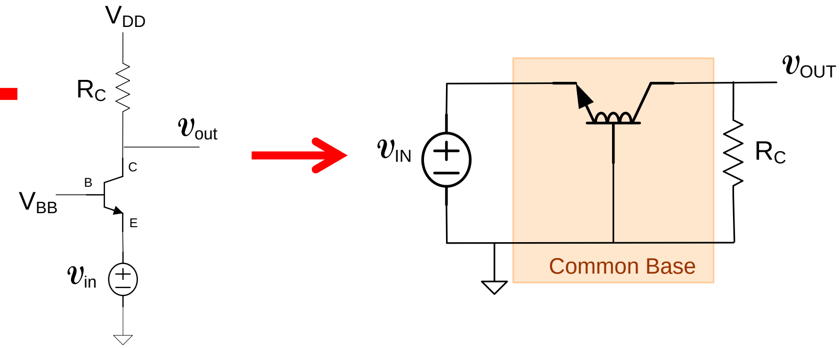
$$(g_C+g_0)v_0=(g_m+g_0)v_{in} \longrightarrow A_V = \frac{g_m+g_0}{g_C+g_0} \cong g_m R_C$$

By KCL at the emitter node, obtain

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

$$R_{out} = R_C // r_0 \longrightarrow R_{out} = \frac{R_C}{1+g_0 R_C} \cong R_C$$

Popular Common Base Application



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

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

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

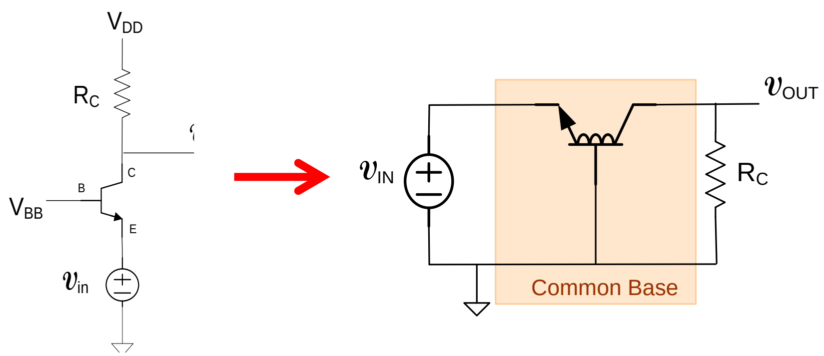
$$R_{out} \overset{R_C \ll r_0}{\cong} R_C \qquad R_{out} \overset{R_C \ll r_0}{\cong} R_C$$

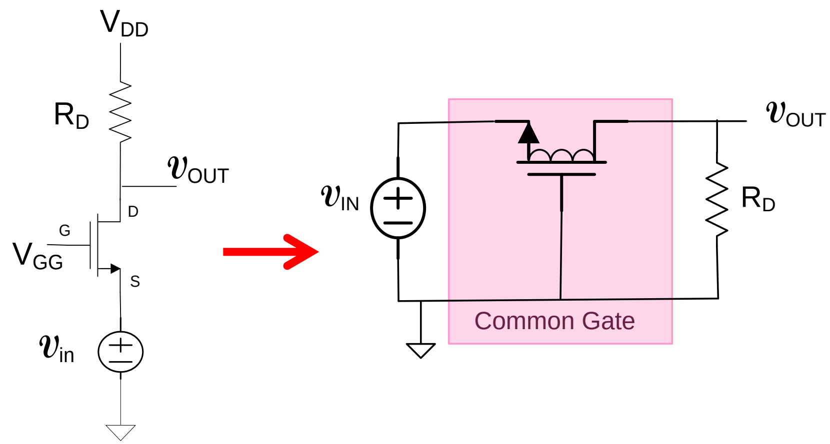
Characteristics:

- 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)





$A_V \cong g_m R_C$ $\quad R_{in} \cong \dfrac{1}{g_m}$ $\quad R_{out} \overset{R_C \ll r_0}{\cong} R_C$

$A_V \cong g_m R_D$ $\quad R_{in} \cong \dfrac{1}{g_m}$ $\quad R_{out} \overset{R_D \ll r_0}{\cong} R_D$

In terms of operating point and model parameters:

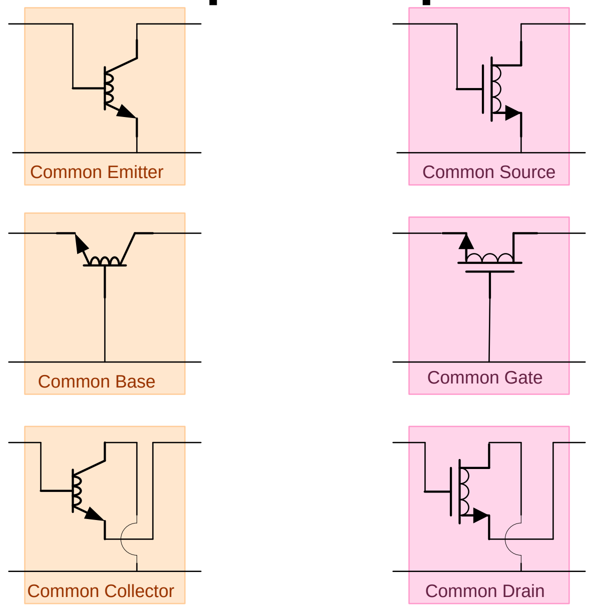
$A_V \cong \dfrac{I_{CQ} R_C}{V_t}$ $\quad R_{in} \cong \dfrac{V_t}{I_{CQ}}$ $\quad R_{out} \overset{I_{CQ} R_C \ll V_{AF}}{\cong} R_C$

$A_V \cong \dfrac{2 I_{DQ} R_D}{V_{EBQ}}$ $\quad R_{in} \cong \dfrac{V_{EBQ}}{2 I_{DQ}}$ $\quad R_{out} \overset{I_{DQ} R_D \ll 1/\lambda}{\cong} R_D$

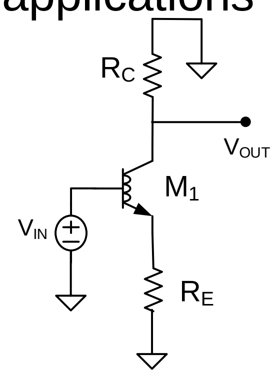
Characteristics:

- 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

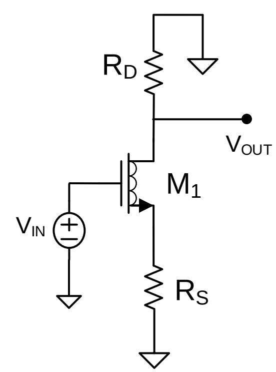
The three basic amplifier types for both MOS and bipolar processes



- 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



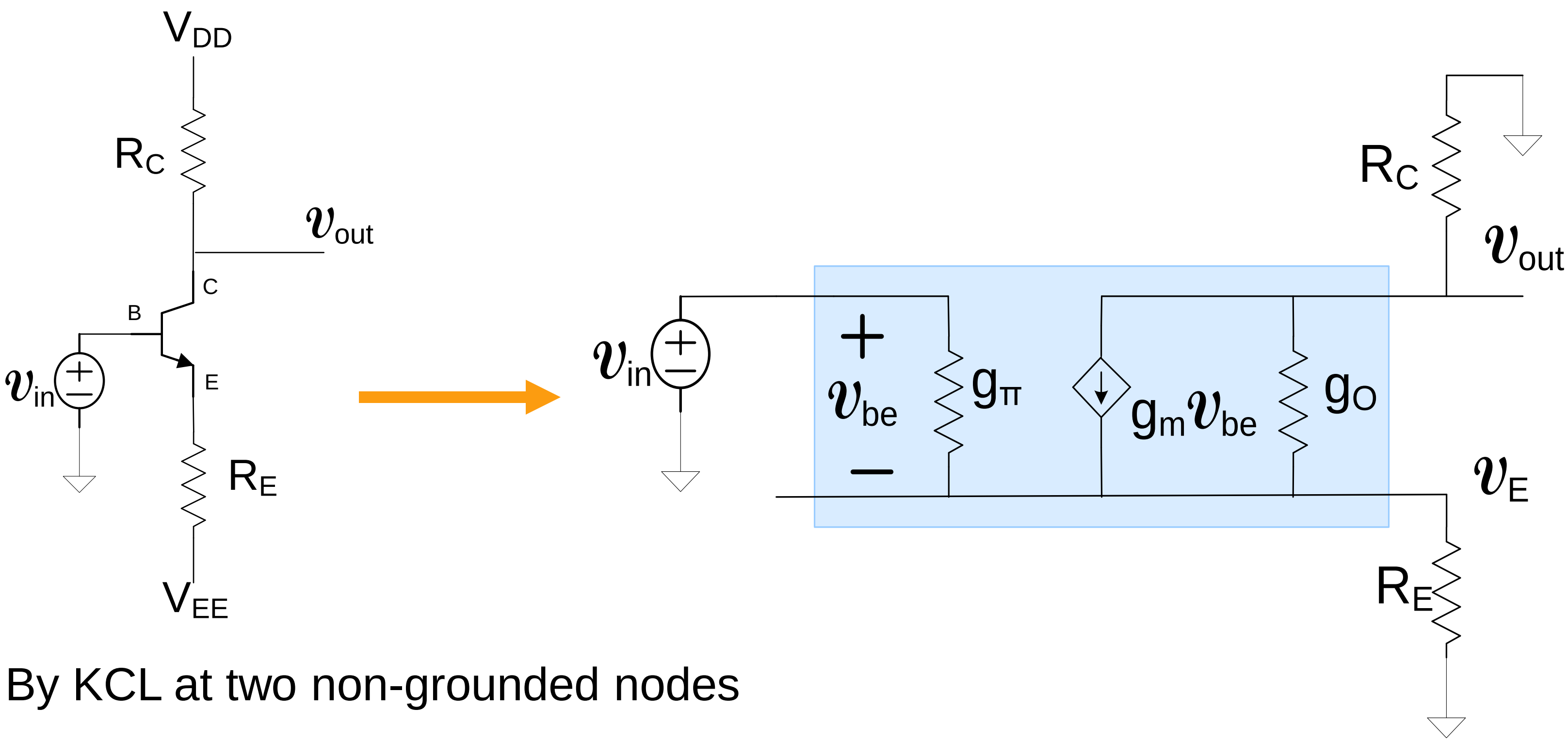
CE with R_E



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)



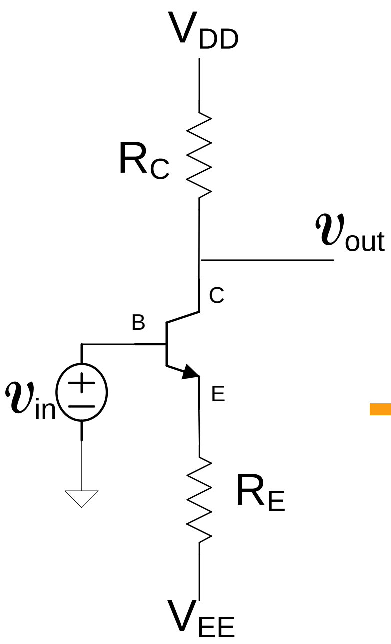
By KCL at two non-grounded nodes

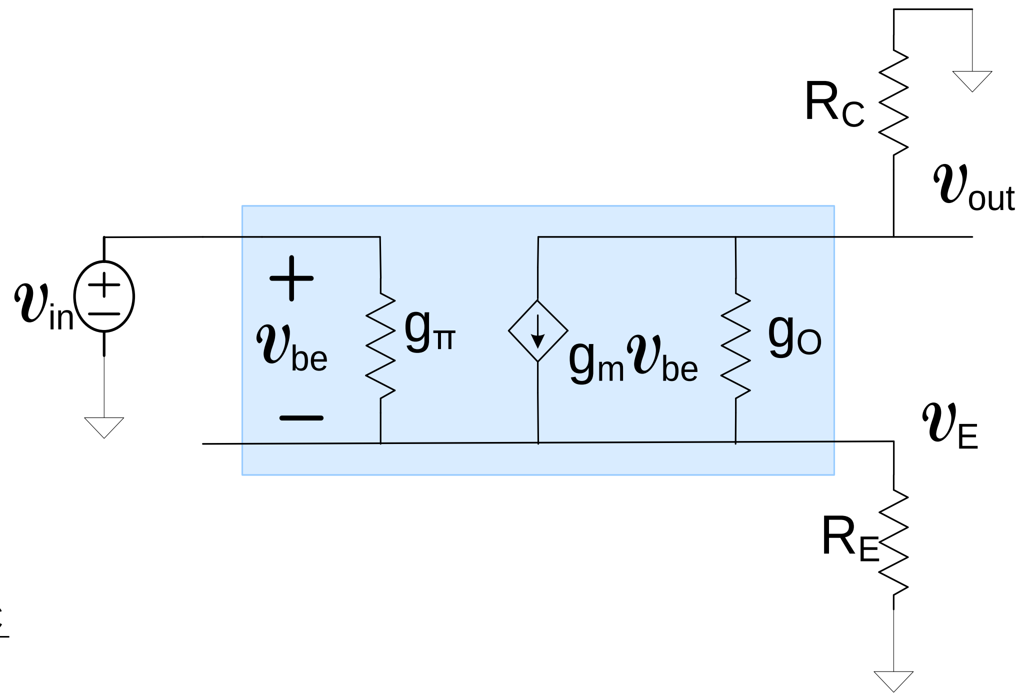
$$\left.\begin{aligned} v_{out}\left(g_C + g_0\right) + \left(v_{in} - v_E\right) g_m &= g_0 v_E \\ v_E\left(g_E + g_0 + g_\pi\right) - \left(v_{in} - v_E\right) g_m &= g_0 v_{out} + g_\pi v_{in} \end{aligned}\right\}$$

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

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

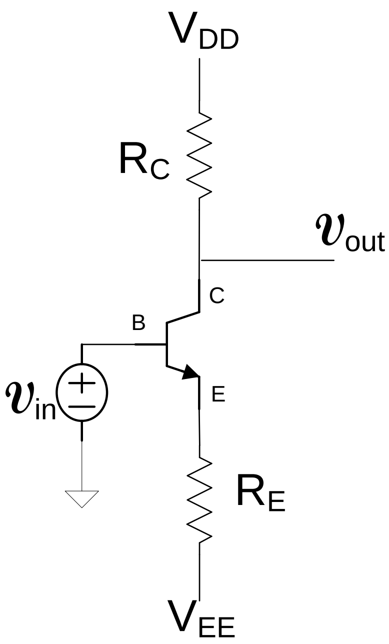
$$R_{in} \cong r_\pi + \beta R_E$$

$$R_{out} \cong R_C$$

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)



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

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

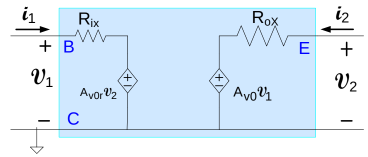
$$R_{out} \cong R_C$$

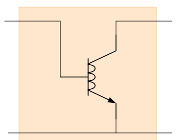
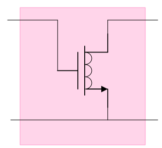
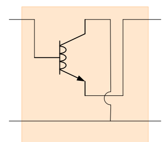
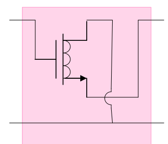
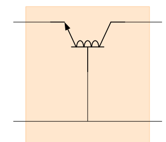
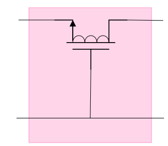
(this is not a two-port model)

Characteristics:

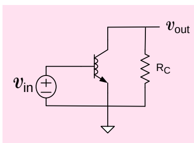
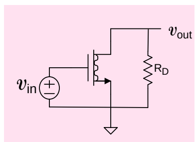
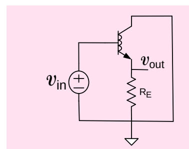
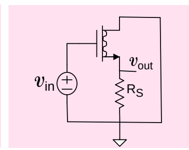
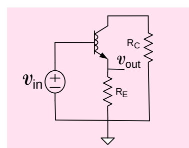
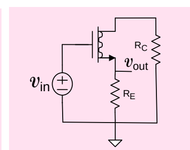
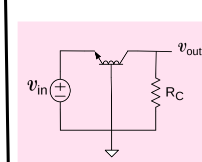
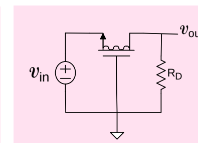
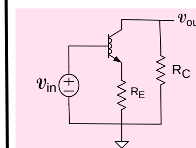
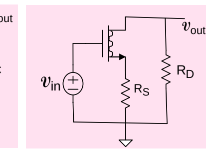
- Analysis would simplify if g_0 were set to 0 in model
- Gain can be accurately controlled with resistor ratios
- Useful for reasonably accurate low gains
- Input impedance is high

Basic Two-Port Amplifier Gain Table



	CE/CS BJT	CE/CS MOS	CC/CD BJT	CC/CD MOS	CB/CG BJT	CB/CG MOS
						
A_V	$-\frac{g_m}{g_o}$		$\frac{g_m+g_\pi}{g_m+g_\pi+g_o}\simeq 1$	$\frac{g_m}{g_m+g_o}\simeq 1$	$1+\frac{g_m}{g_o}\simeq\frac{g_m}{g_o}$	
	$-\frac{I_{CQ}R_C}{V_t}$	$-\frac{2I_{DQ}R_D}{V_{EB}}$	1	1	$\frac{V_{AF}}{V_t}$	$\frac{2}{\lambda V_{EB}}$
R_{in}	r_π	∞	r_π	∞	$\frac{1}{g_m+g_\pi+g_o}\simeq g_m^{-1}$	$\frac{1}{g_m+g_o}\simeq g_m^{-1}$
	$\frac{\beta V_t}{I_{CQ}}$	∞	$\beta\left(\frac{V_t}{I_{CQ}}\right)$	∞	$\frac{V_t}{I_{CQ}}$	$\frac{V_{EB}}{2I_{DQ}}$
R_{out}	$\frac{1}{g_o}$		$\frac{1}{g_m+g_\pi+g_o}\simeq g_m^{-1}$	$\frac{1}{g_m+g_o}\simeq g_m^{-1}$	$\frac{1}{g_o}$	
			$\frac{V_t}{I_{CQ}}$	$\frac{V_{EB}}{2I_{DQ}}$	$\frac{V_{AF}}{I_{CQ}}$	$\frac{1}{\lambda I_{DQ}}$
A_{VR}	0		1		$\frac{g_o}{g_m+g_\pi+g_o}\simeq\frac{g_o}{g_m}$	$\frac{g_o}{g_m+g_o}\simeq\frac{g_o}{g_m}$
	0	0	1	1	$\frac{V_t}{V_{AF}}$	$\frac{\lambda V_{EB}}{2}$

Basic Amplifier Application Gain Table

	CE/CS	CC/CD	CB/CG	CEwRE/CSwRS
	BJT / MOS	BJT / MOS	BJT / MOS	BJT / MOS
	 	   	 	 
A_V	$-g_m R_C$ 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: $\frac{2I_{DQ} R_E}{2I_{DQ} R_E + V_{EB}}$	$g_m R_C$ 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: $r_\pi + \beta R_E$ 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)

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

Stay Safe and Stay Healthy !

End of Lecture 31