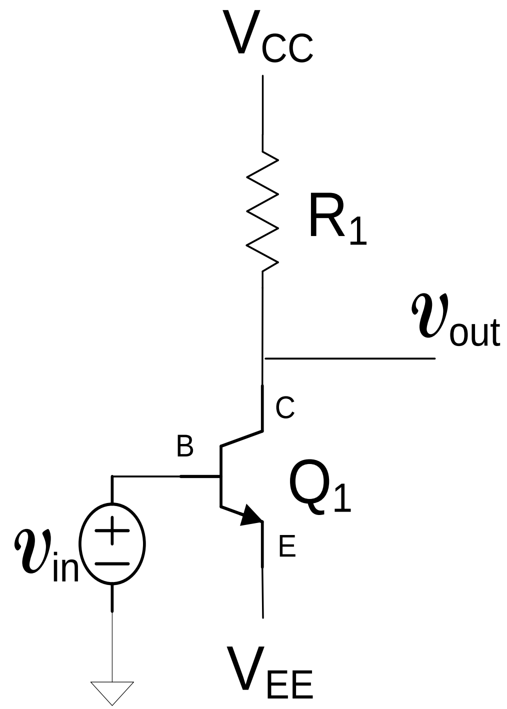
EE 330
Lecture 29

Amplifier Biasing (a precursor)

Amplifier Characterization

- Amplifier parameters
- Two-port amplifier models
- Dependent Sources

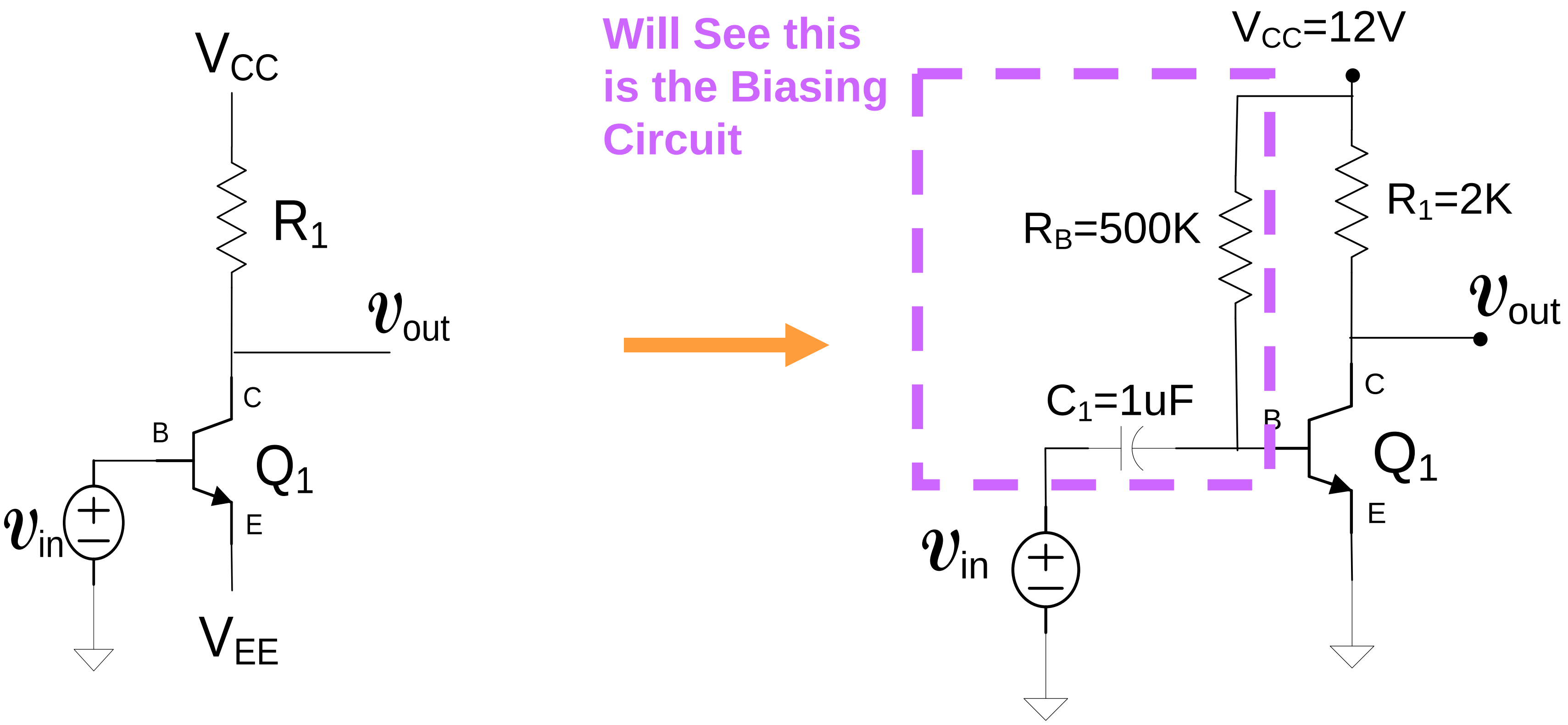
Amplifier Biasing (precursor)



- Voltage sources V_{EE} and V_{CC} used for biasing
- Not convenient to have multiple dc power supplies
- V_{OUTQ} very sensitive to V_{EE}

- Biasing is used to obtain the desired operating point of a circuit
- Ideally the biasing circuit should not distract significantly from the basic operation of the circuit

Amplifier Biasing (precursor)

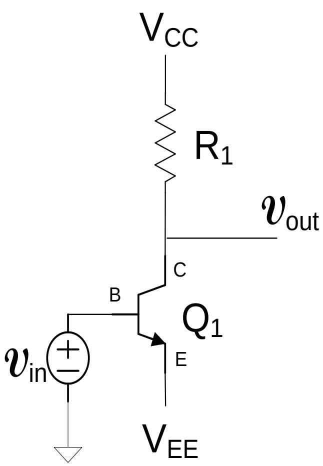


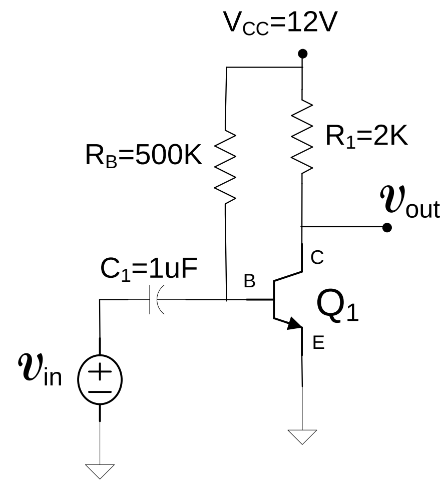
Not convenient to have multiple dc power supplies
V_{OUTQ} very sensitive to V_{EE}

Single power supply
Additional resistor and capacitor

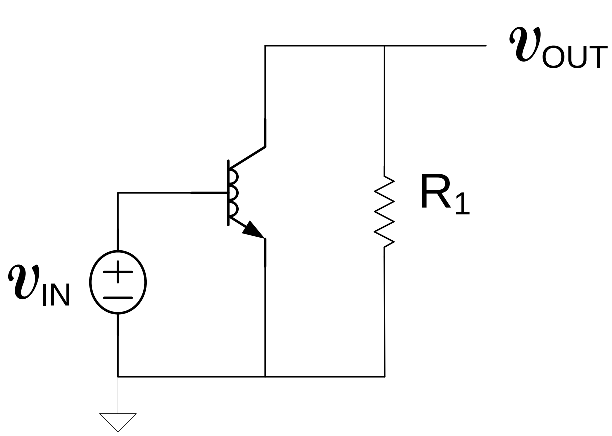
Compare the small-signal equivalent circuits of these two structures
Compare the small-signal voltage gain of these two structures

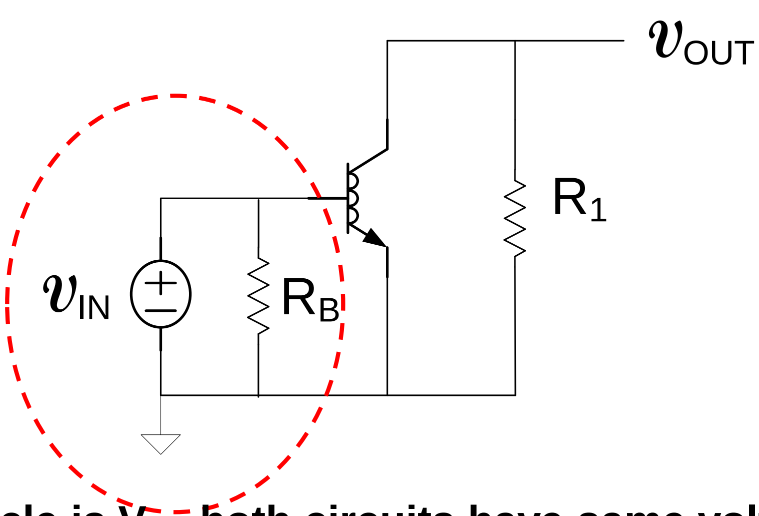
Amplifier Biasing (precursor)





Compare the small-signal equivalent circuits of these two structures





Since Thevenin equivalent circuit in red circle is V_{IN}, both circuits have same voltage gain

But the load placed on V_{IN} is different

Method of characterizing the amplifiers is needed to assess impact of difference

Amplifier Biasing (a precursor)

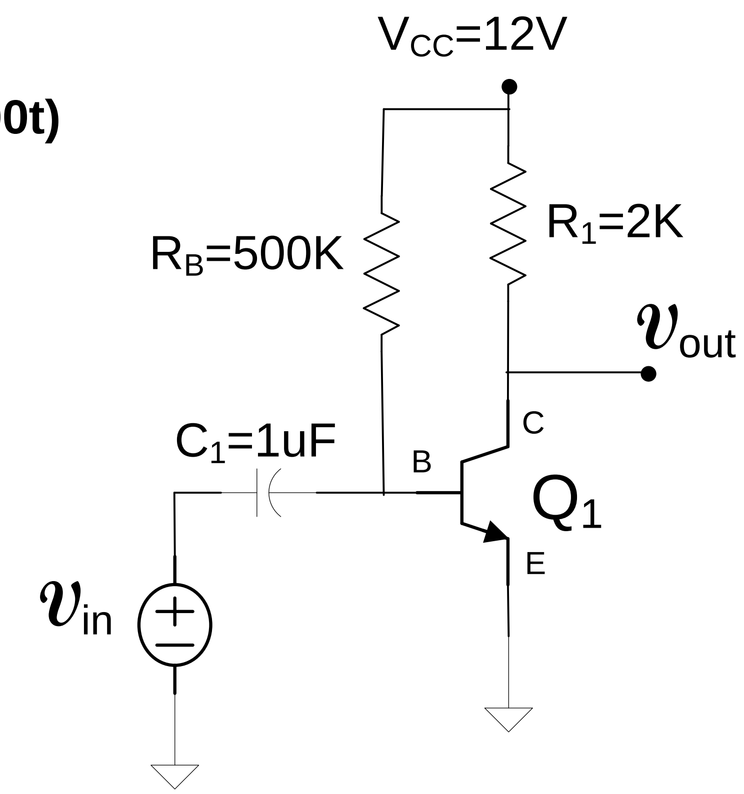
Amplifier Characterization

- Amplifier parameters
- Two-port amplifier models
- Dependent Sources

Amplifier Characterization (an example)

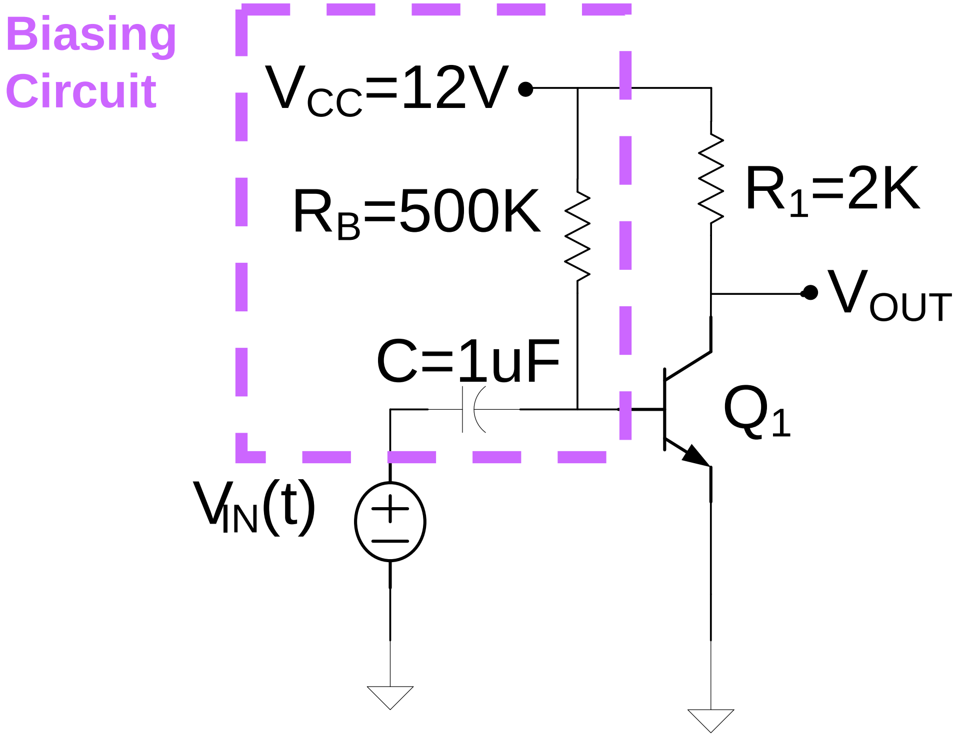
Determine V_{OUTQ}, A_V, R_{IN} Assume β=100

Determine v_{OUT} and $V_{OUT}(t)$ if v_{IN}=.002sin(400t)



In the following slides we will analyze this circuit

Amplifier Characterization (an example)

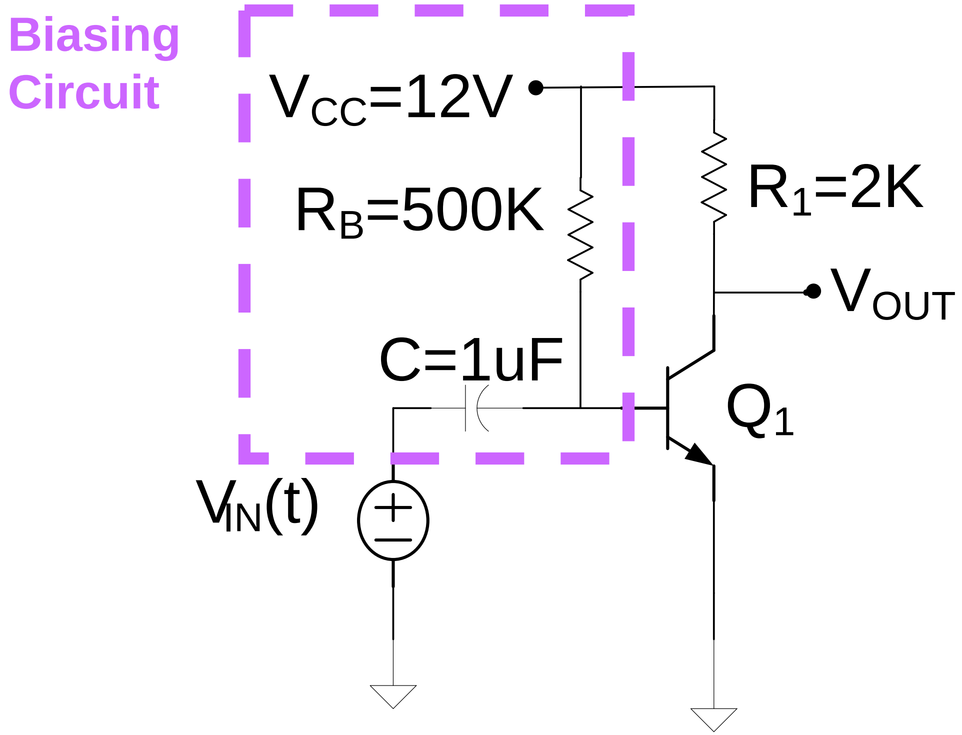


(biasing components: C, R_B, V_{CC} in this case, all disappear in small-signal gain circuit)

Several different biasing circuits can be used

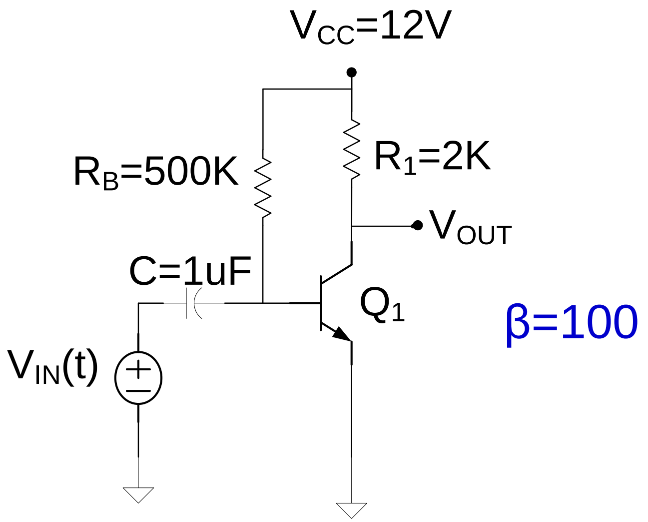
Amplifier Characterization (an example)

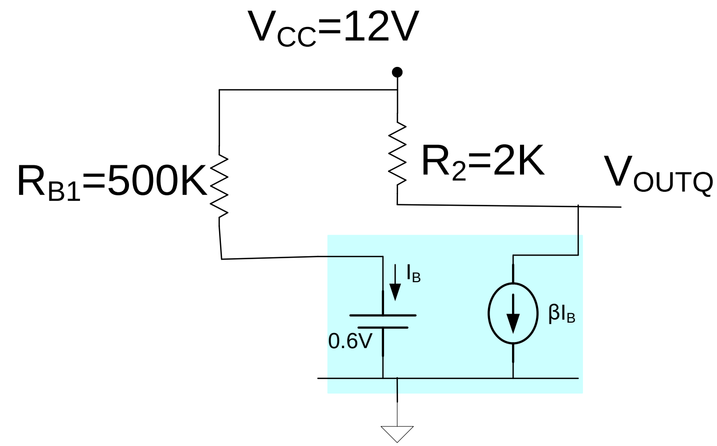
Determine V_{OUTQ}, A_V, R_{IN}



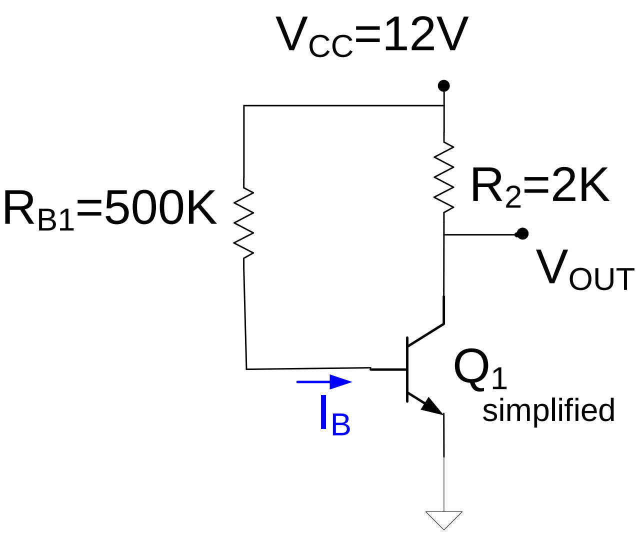
Amplifier Characterization (an example)

Determine V_{OUTQ}





dc equivalent circuit



dc equivalent circuit

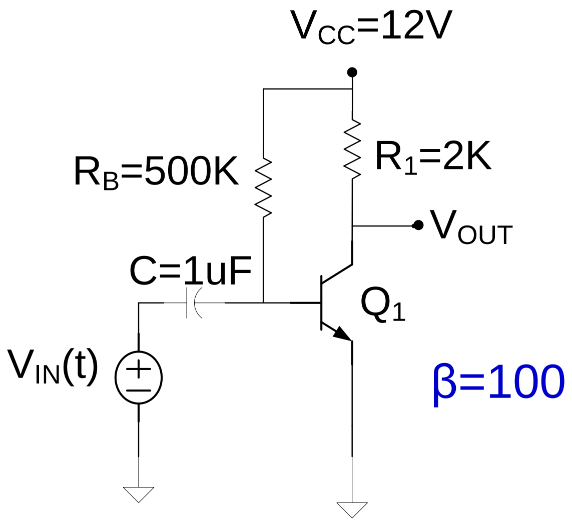
$$I_{CQ} = \beta I_{BQ} = 100\left(\frac{12V\text{-}0.6V}{500K}\right) = 2.3mA$$

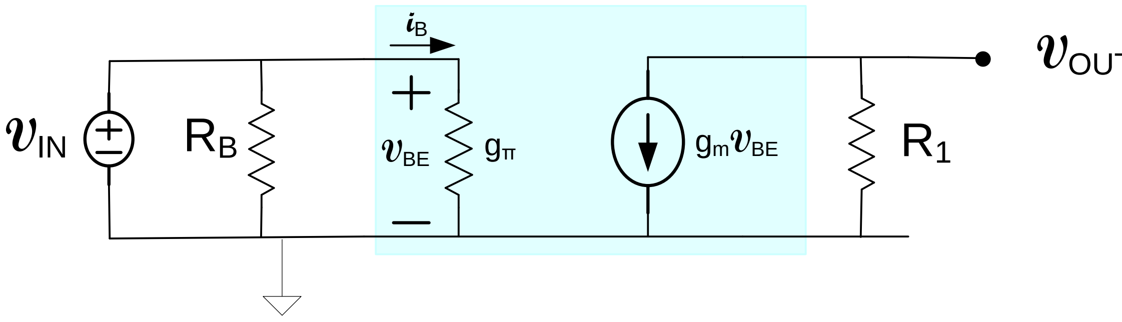
$$V_{OUTQ} = 12V\text{-}I_{CQ}R_1 = 12V - 2.3mA \bullet 2K = 7.4V$$

Check: $V_{CE} = V_{OUTQ} = 7.4V > 0.4V$ in F.A.

Amplifier Characterization (an example)

Determine the SS voltage gain (A_V)





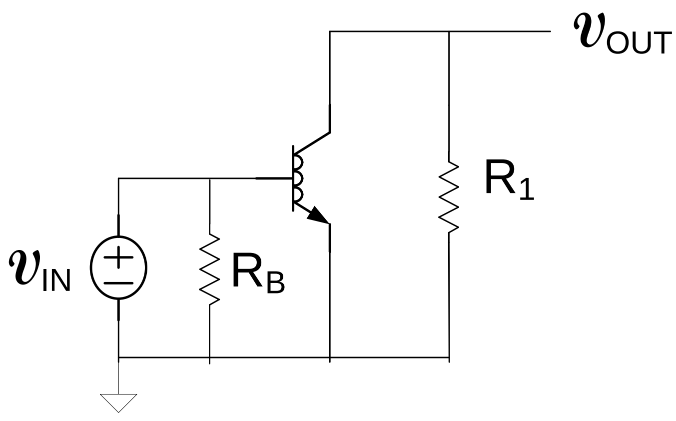
ss equivalent circuit

$$\left.\begin{array}{l} v_{OUT} = -g_m v_{BE} R_1 \\ v_{IN} = v_{BE} \end{array}\right\}$$

$$A_V = -R_1 g_m$$

$$A_V \cong -\frac{I_{CQ} R_1}{V_t}$$

$$A_V \cong -\frac{2.3\text{mA} \bullet 2\text{K}}{26\text{mV}} \cong -177$$

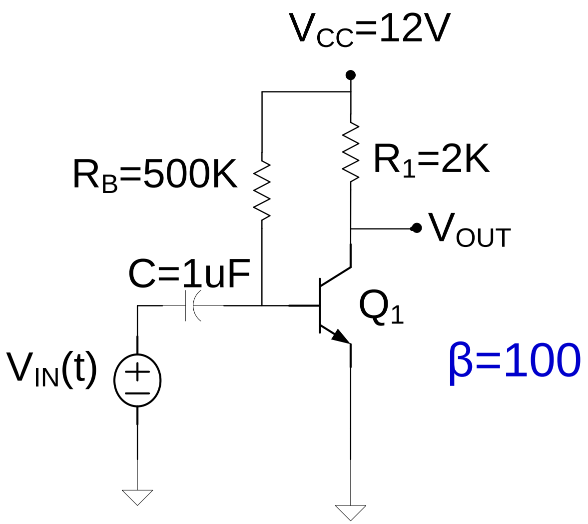


ss equivalent circuit

This basic amplifier structure is widely used and repeated analysis serves no useful purpose

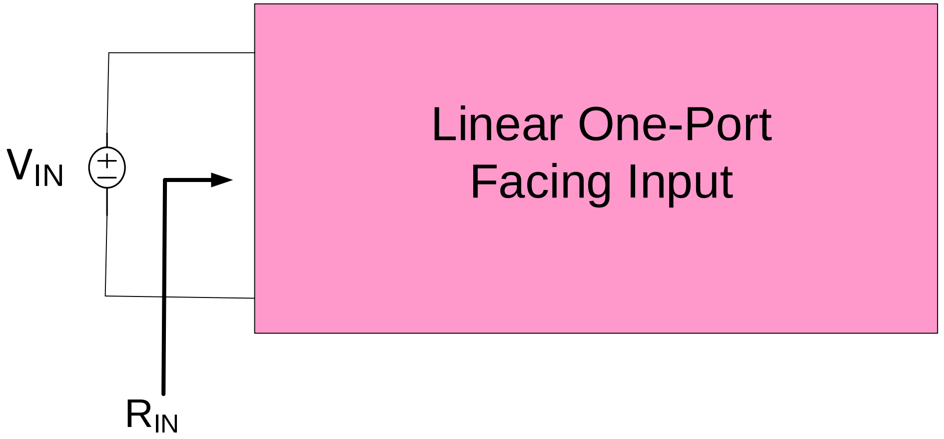
Have seen this circuit before but will repeat for review purposes

Amplifier Characterization (an example)



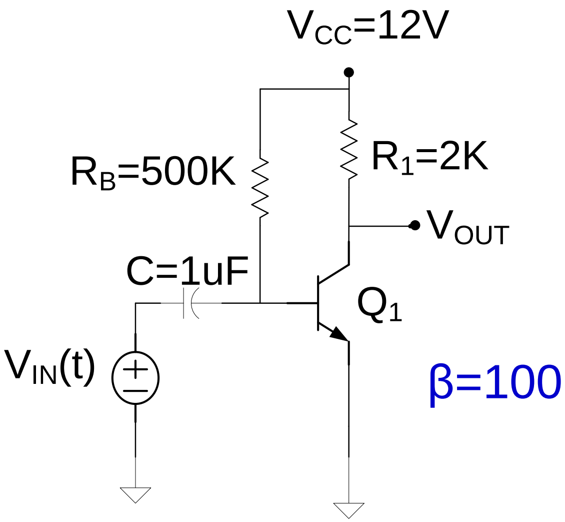
Determine V_{OUTQ}, A_V, R_{IN}

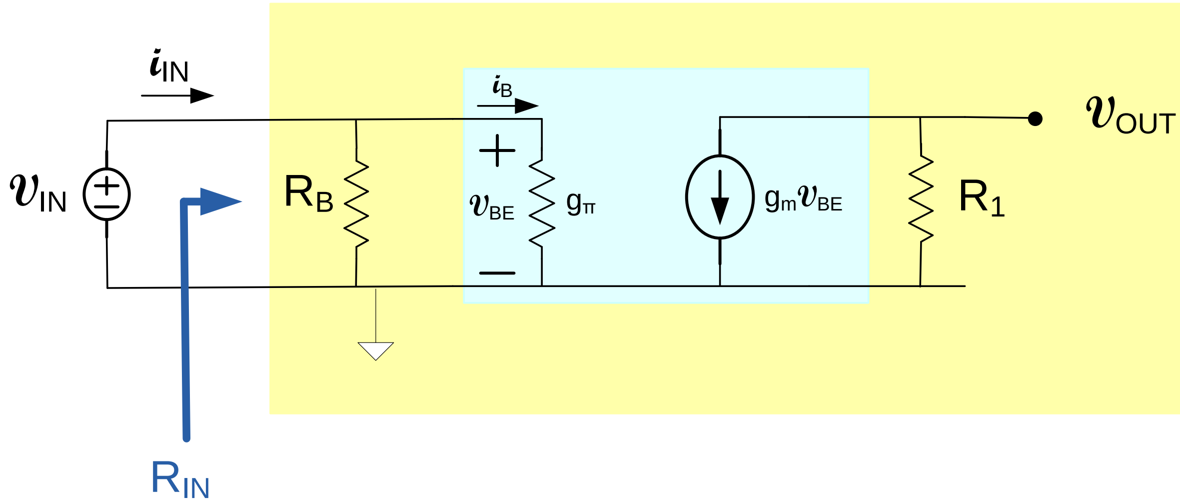
- Here R_{IN} is defined to be the impedance facing V_{IN}
- Here any load is assumed to be absorbed into the one-port
- Later will consider how load is connected in defining R_{IN}

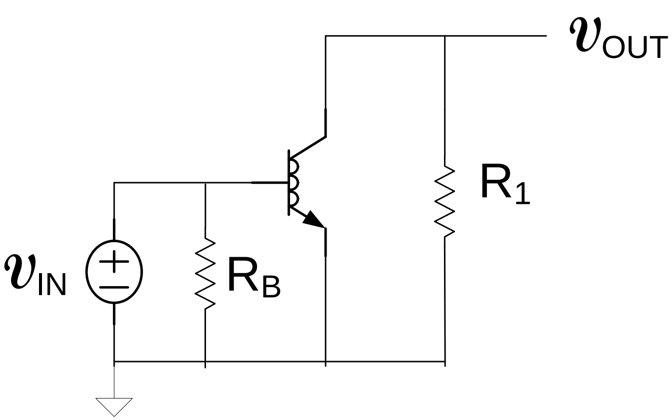


Amplifier Characterization (an example)

Determine R_{IN}







ss equivalent circuit

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

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

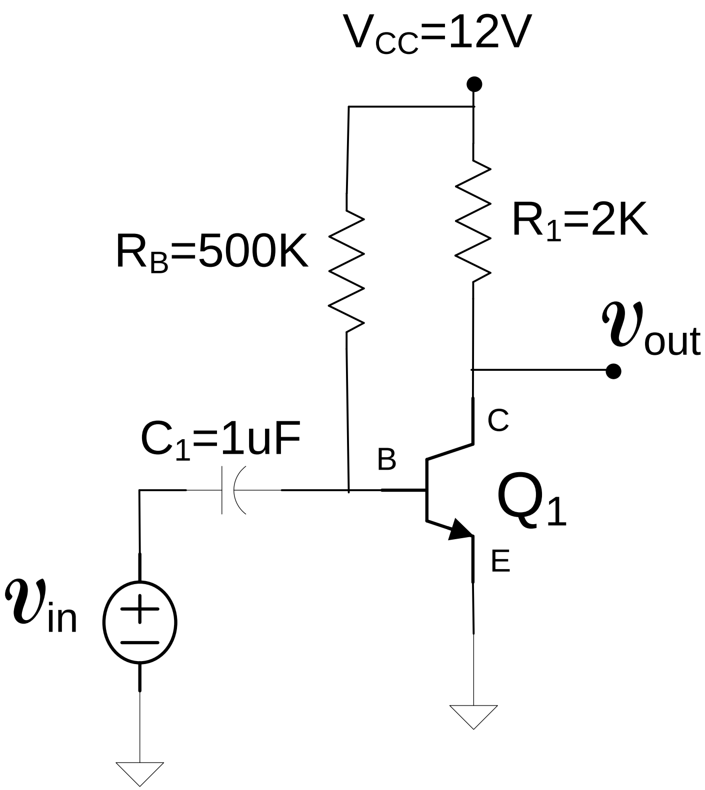
Usually $R_B >> r_\pi$

$$R_{in} = R_B // r_\pi \cong r_\pi$$

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

Examples

Determine v_{OUT} and $V_{OUT}(t)$ if v_{IN}=.002sin(400t)



$$v_{OUT} = A_V v_{IN}$$

$$v_{OUT} = -177 \bullet .002\sin(400t) = -0.354\sin(400t)$$

$$V_{OUT}(t) \cong V_{OUTQ} + A_V v_{IN}$$

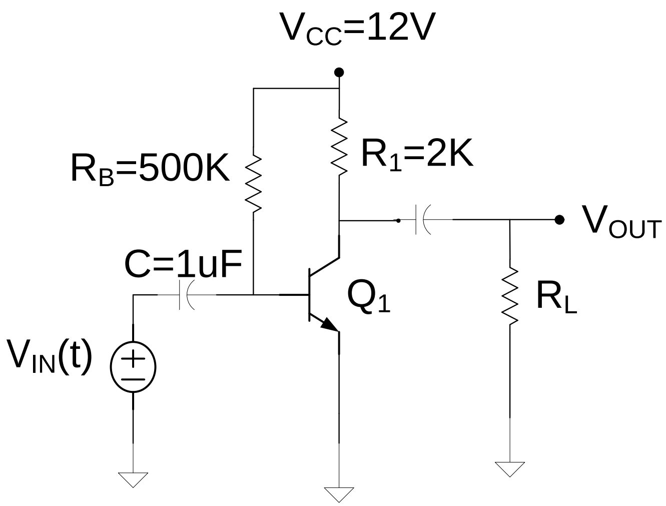
$$V_{OUT} \cong 7.4V - 0.35 \bullet \sin(400t)$$

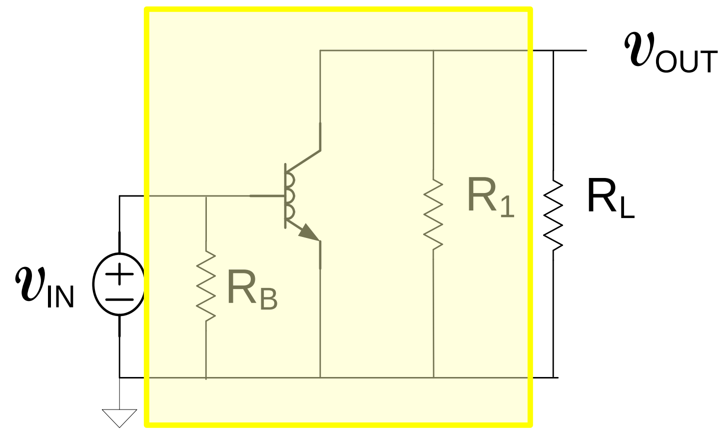
Amplifier Biasing (a precursor)

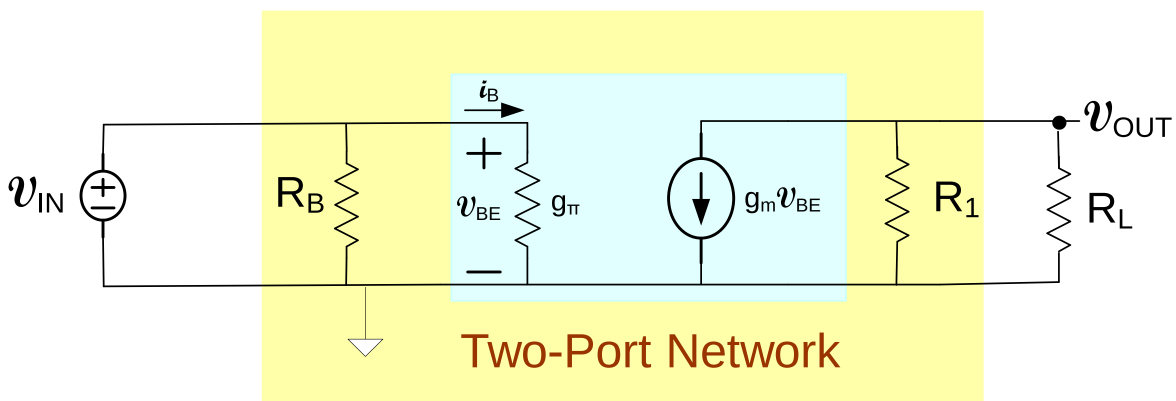
Amplifier Characterization

- Amplifier parameters
- Two-port amplifier models
- Dependent Sources

Two-Port Representation of Amplifiers



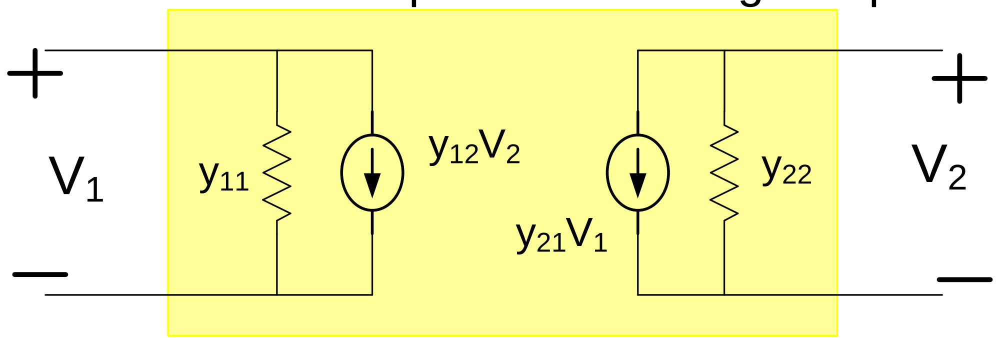




- Two-port model representation of amplifiers useful for insight into operation and analysis
- Internal components to the two-port can be quite complicated but equivalent two-port model is quite simple

Two-port representation of amplifiers

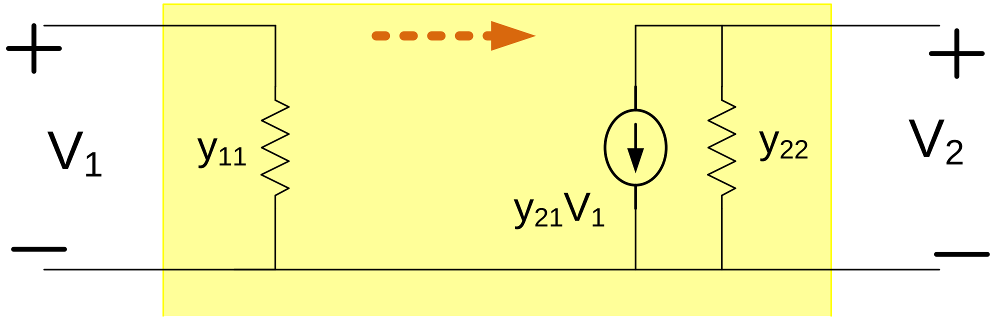
Amplifiers can be modeled as a two-port for small-signal operation



In terms of y-parameters

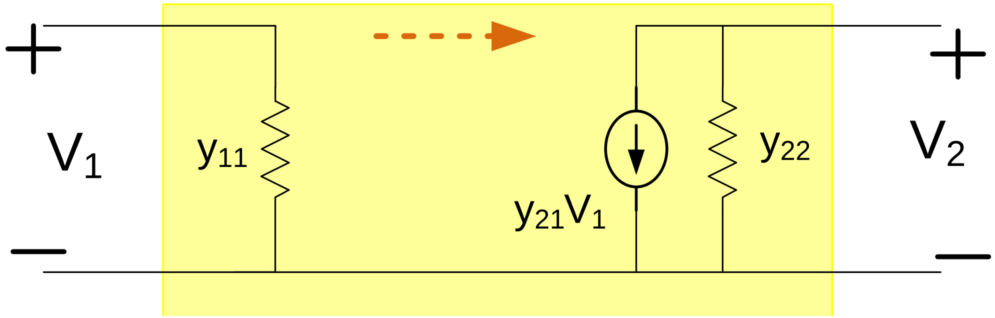
Other parameter sets could be used

- Amplifier often **unilateral** (signal propagates in only one direction: wlog y_{12}=0)
- One terminal is often common

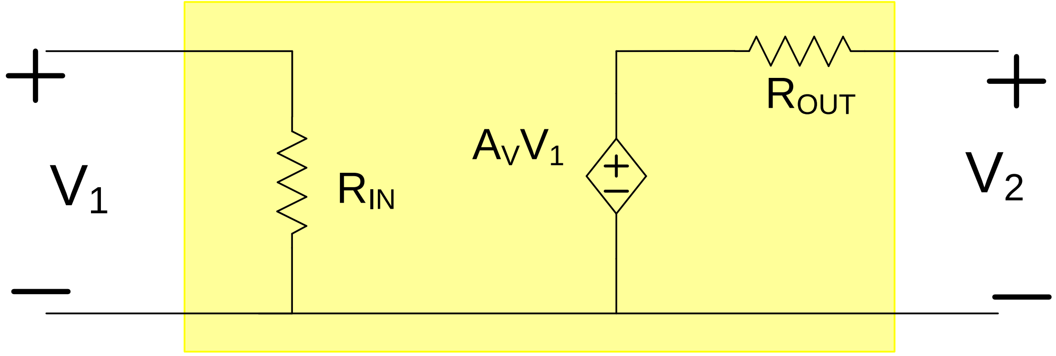


Two-port representation of amplifiers

Unilateral amplifiers:



- Thevenin equivalent output port often more standard
- R_{IN}, A_V, and R_{OUT} often used to characterize the two-port of amplifiers



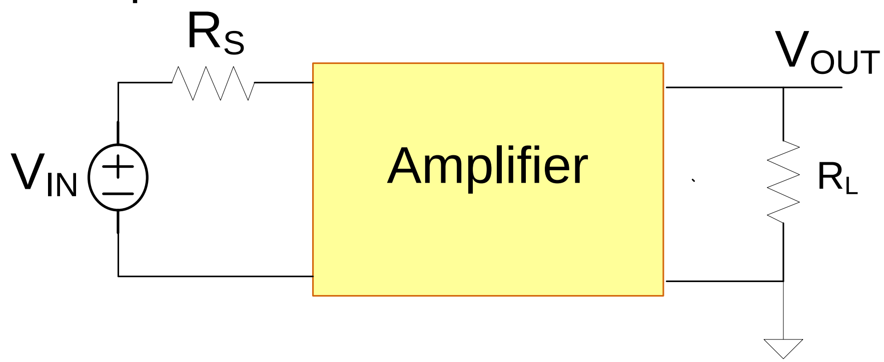
Unilateral amplifier in terms of “amplifier” parameters

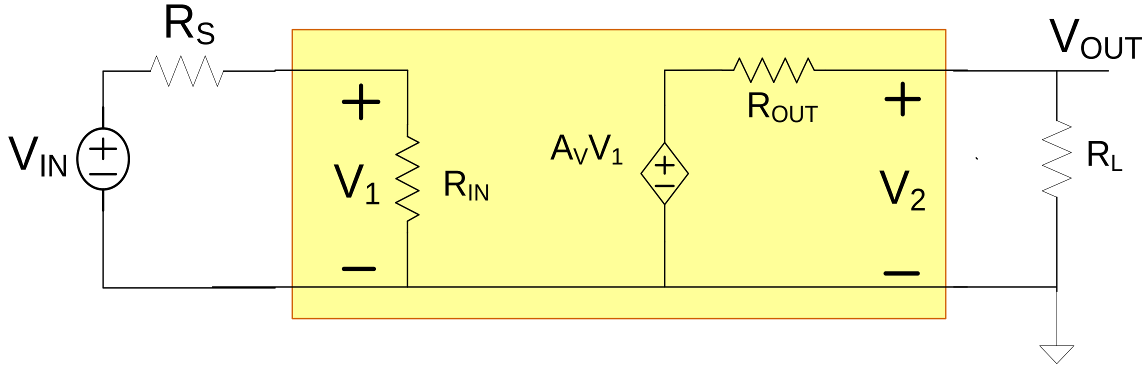
$$R_{IN} = \frac{1}{y_{11}} \qquad A_V = -\frac{y_{21}}{y_{22}} \qquad R_{OUT} = \frac{1}{y_{22}}$$

Amplifier input impedance, output impedance and gain are usually of interest

Why?

Example 1:   Assume amplifier is unilateral





$$V_{OUT} = \left(\frac{R_L}{R_L + R_{OUT}}\right) A_V \left(\frac{R_{IN}}{R_S + R_{IN}}\right) V_{IN}$$

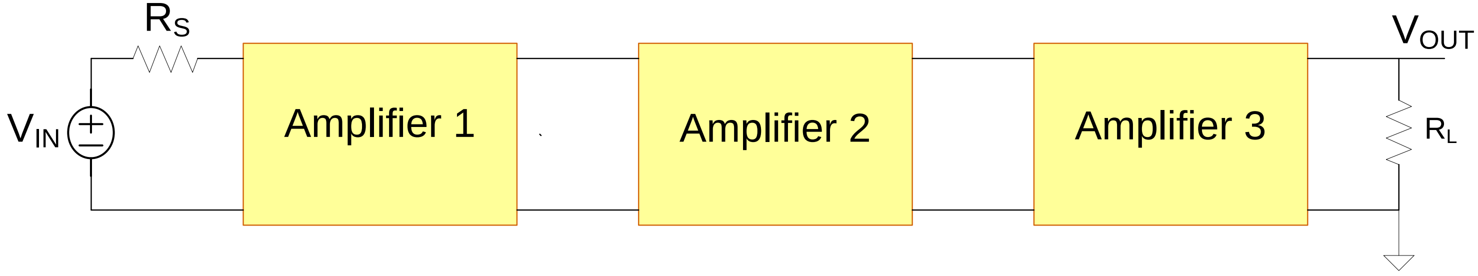
$$A_{VAMP} = \frac{V_{OUT}}{V_{IN}} = \left(\frac{R_L}{R_L + R_{OUT}}\right)\left(\frac{R_{IN}}{R_S + R_{IN}}\right) A_V$$

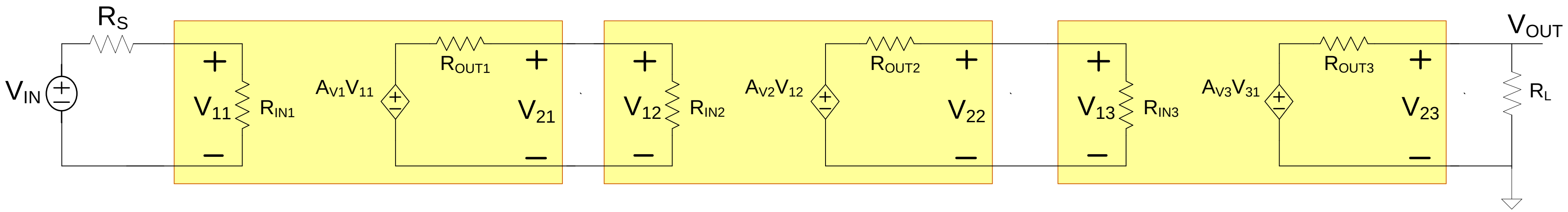
- Can get gain without reconsidering details about components internal to the Amplifier !!!
  - Analysis more involved when not unilateral

Amplifier input impedance, output impedance and gain are usually of interest

Why?

Example 2: Assume amplifiers are unilateral





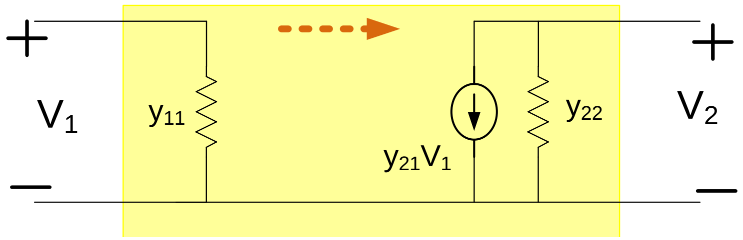
$$V_{OUT} = \left(\frac{R_L}{R_L + R_{OUT3}}\right) A_{V3} \left(\frac{R_{IN3}}{R_{OUT2} + R_{IN3}}\right) A_{V2} \left(\frac{R_{IN2}}{R_{OUT1} + R_{IN2}}\right) A_{V1} \left(\frac{R_{IN1}}{R_S + R_{IN1}}\right) V_{IN}$$

$$A_{VAMP} = \frac{V_{OUT}}{V_{IN}} = \left(\frac{R_L}{R_L + R_{OUT3}}\right) A_{V3} \left(\frac{R_{IN3}}{R_{OUT2} + R_{IN3}}\right) A_{V2} \left(\frac{R_{IN2}}{R_{OUT1} + R_{IN2}}\right) A_{V1} \left(\frac{R_{IN1}}{R_S + R_{IN1}}\right)$$

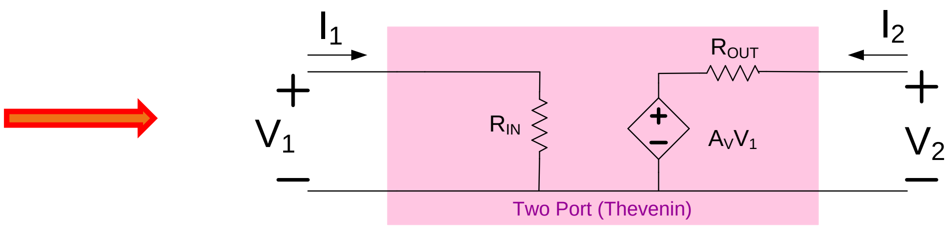
- Can get gain without reconsidering details about components internal to the Amplifier !!!
- Analysis more involved when not unilateral

Two-port representation of amplifiers

- Amplifier usually **unilateral** (signal propagates in only one direction: wlog y_{12}=0)
- One terminal is often common
- "Amplifier" parameters often used

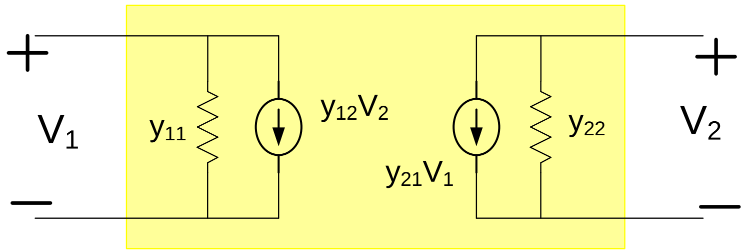


y parameters

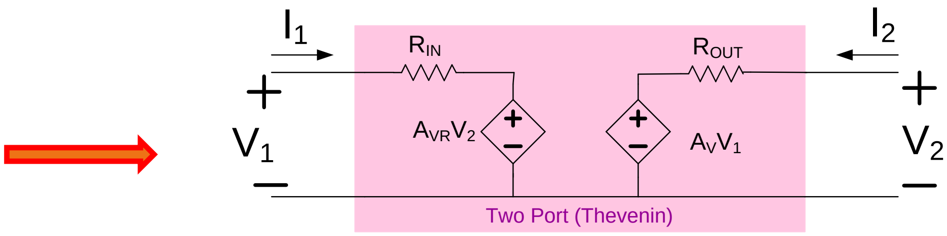


Amplifier parameters

- Amplifier parameters can also be used if not **unilateral**
- One terminal is often common

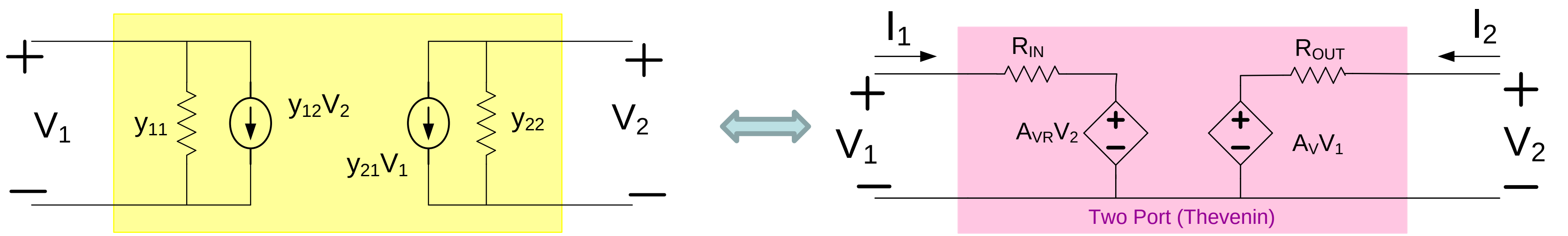


y parameters



Amplifier parameters

Determination of small-signal model parameters:



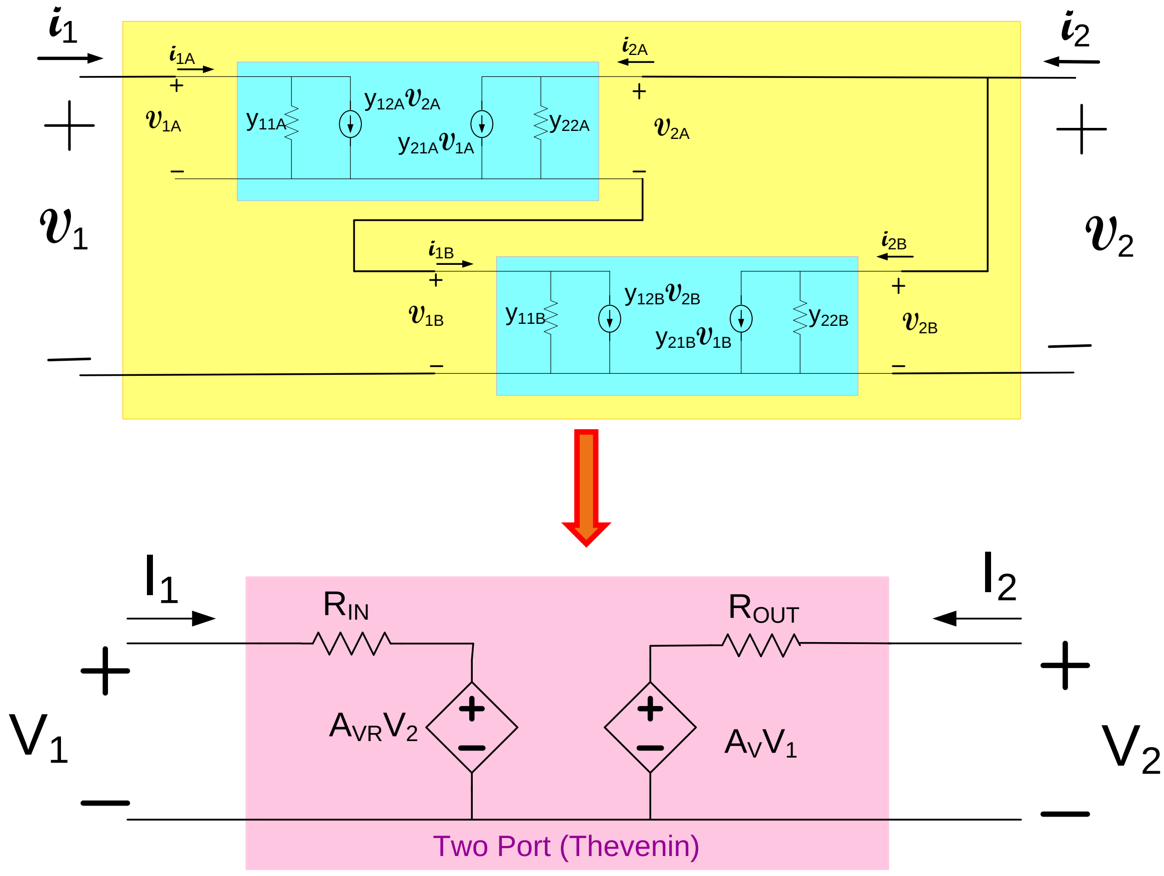
In the past, we have determined small-signal model parameters of electronic devices from the nonlinear port characteristics

$$\left.\begin{aligned} \mathbf{I_1} &= \mathbf{f_1(V_1,V_2)} \\ \mathbf{I_2} &= \mathbf{f_2(V_1,V_2)} \end{aligned}\right\} \qquad \mathbf{y_{ij}} = \left.\frac{\partial \mathbf{f_i(V_1,V_2)}}{\partial \mathbf{V_j}}\right|_{\vec{\mathbf{V}}=\vec{\mathbf{V}}_\mathbf{Q}}$$

- Will now determine small-signal model parameters for two-port comprised of linear networks (instead of just electronic devices)
- Could go back to the nonlinear models and analyze as we did for electronic devices
- Will follow a different approach (results are identical) that is often much easier

Two-Port Equivalents of Interconnected Two-ports

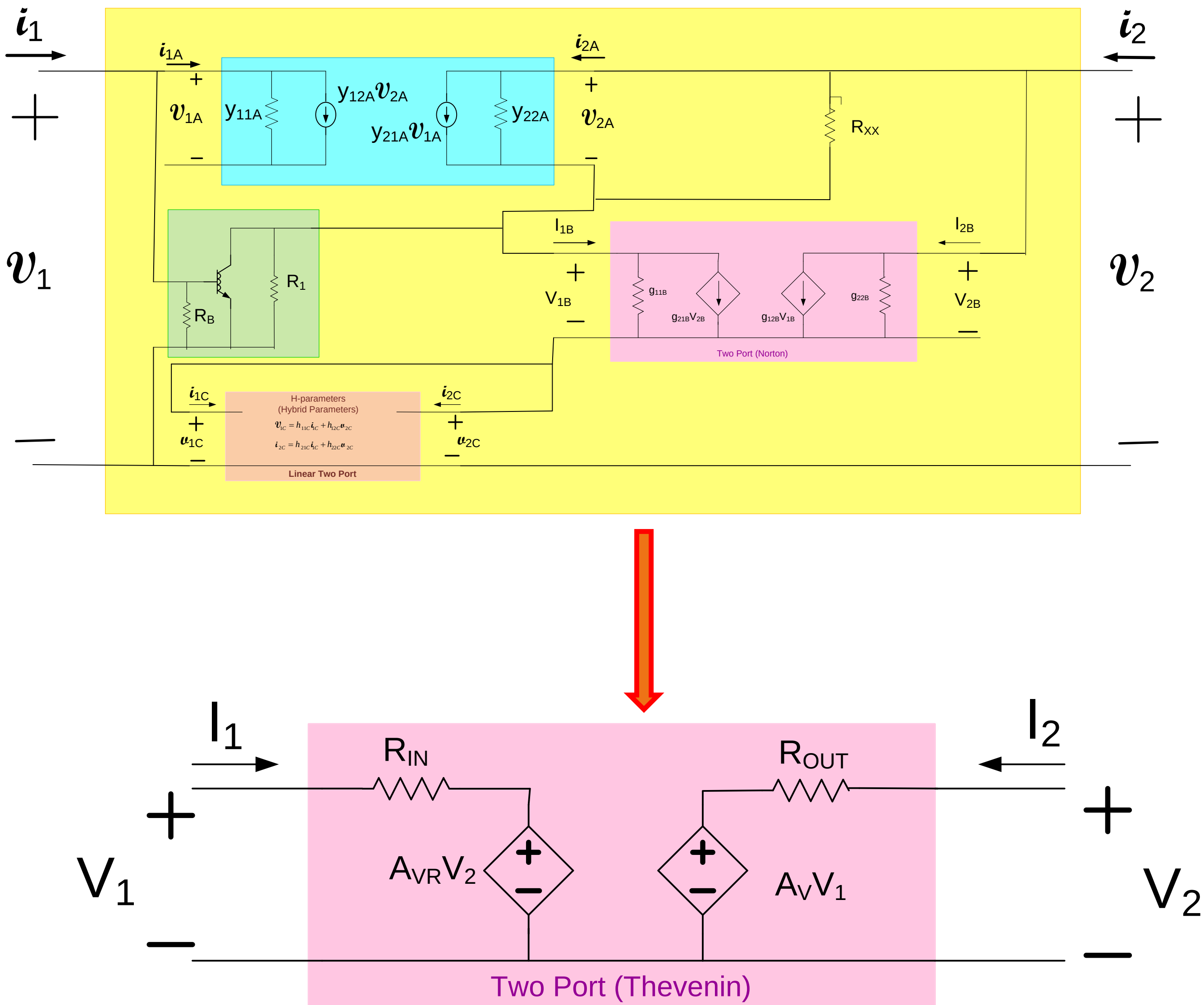
Example:



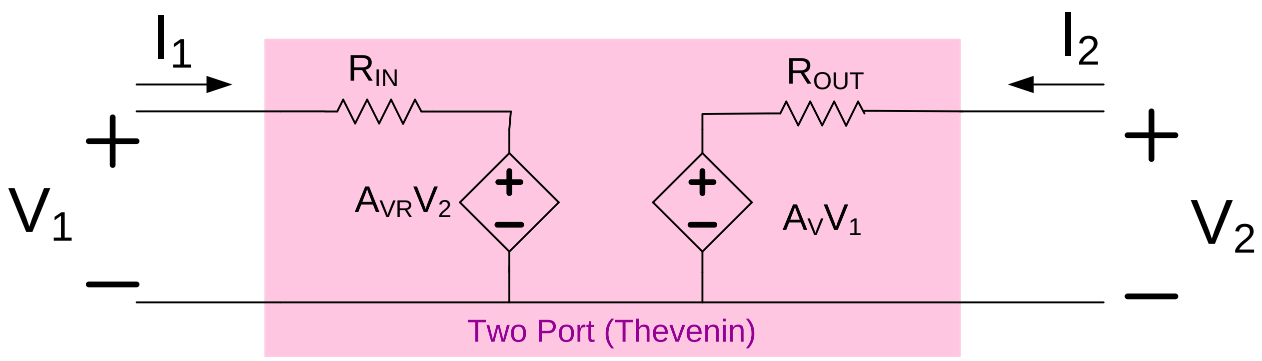
- could obtain two-port in any form
- often obtain equivalent circuit w/o identifying independent variables
- Unilateral iff A_{VR}=0
- Thevenin-Norton transformations can be made on either or both ports

Two-Port Equivalents of Interconnected Two-ports

Example:



Two-Port Equivalents of Interconnected Two-ports



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

$$v_2 = i_2 R_0 + A_{V0} v_1$$

Or equivalently

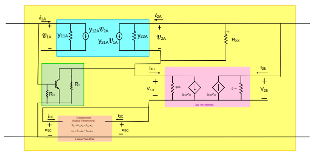
$$i_1 = v_1 \left(\frac{1}{R_{in}} \right) + v_2 \left(\frac{-A_{VR}}{R_{in}} \right)$$

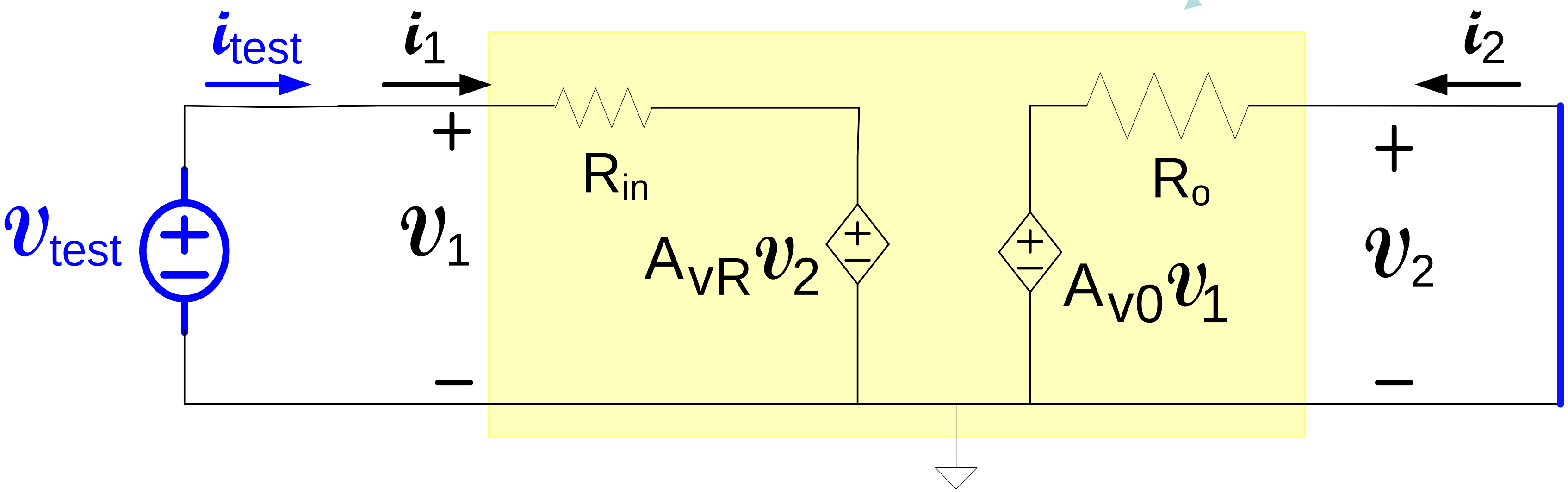
$$i_2 = v_1 \left(\frac{-A_{V0}}{R_0} \right) + v_2 \left(\frac{1}{R_0} \right)$$

Determination of two-port model parameters

(One method will be discussed here)

A method of obtaining R_{in}





Terminate the output in a short-circuit

$$\left.\begin{aligned} i_1 &= v_1\left(\frac{1}{R_{in}}\right) + v_2\left(\frac{-A_{VR}}{R_{in}}\right) \\ i_2 &= v_1\left(\frac{-A_{V0}}{R_0}\right) + v_2\left(\frac{1}{R_0}\right) \end{aligned}\right\}$$

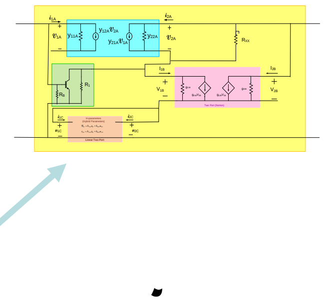
$$\xrightarrow{v_2 = 0}$$

$$v_1 = v_{test}$$

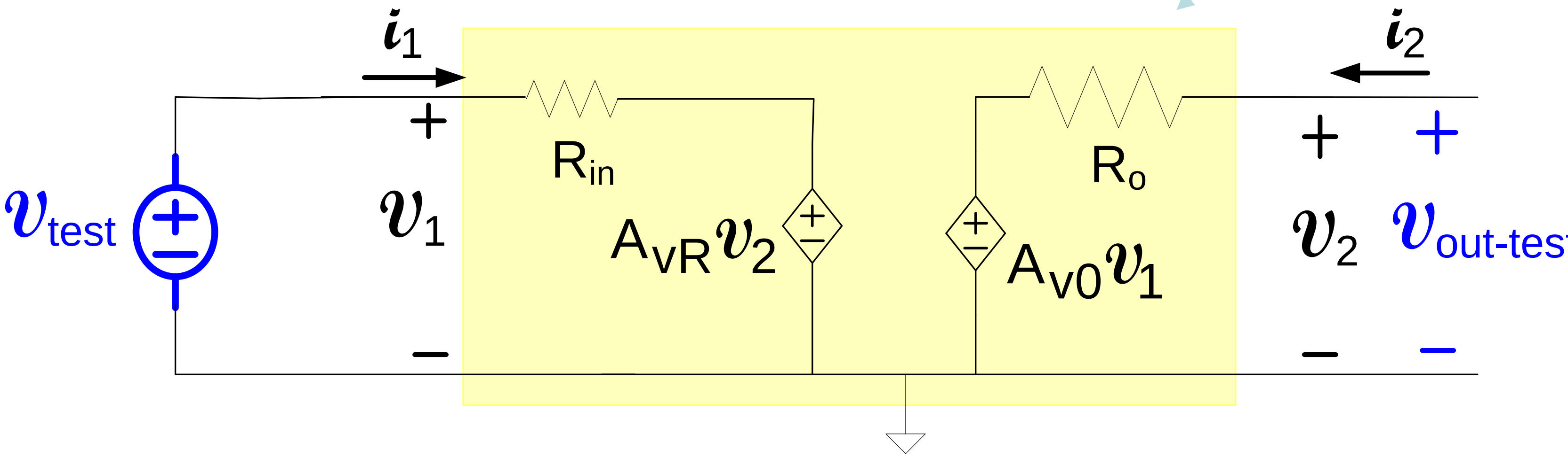
$$i_1 = i_{test}$$

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

Determination of two-port model parameters



A method of obtaining A_{V0}



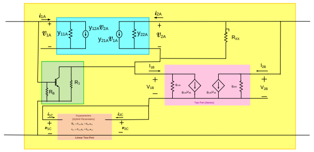
Terminate the output in an open-circuit

$$\left.\begin{aligned} i_1 &= v_1\left(\frac{1}{R_{in}}\right) + v_2\left(\frac{-A_{VR}}{R_{in}}\right) \\ i_2 &= v_1\left(\frac{-A_{V0}}{R_0}\right) + v_2\left(\frac{1}{R_0}\right) \end{aligned}\right\} \xrightarrow{i_2 = 0} \qquad A_{V0} = \frac{v_{\text{out-test}}}{v_{\text{test}}}$$

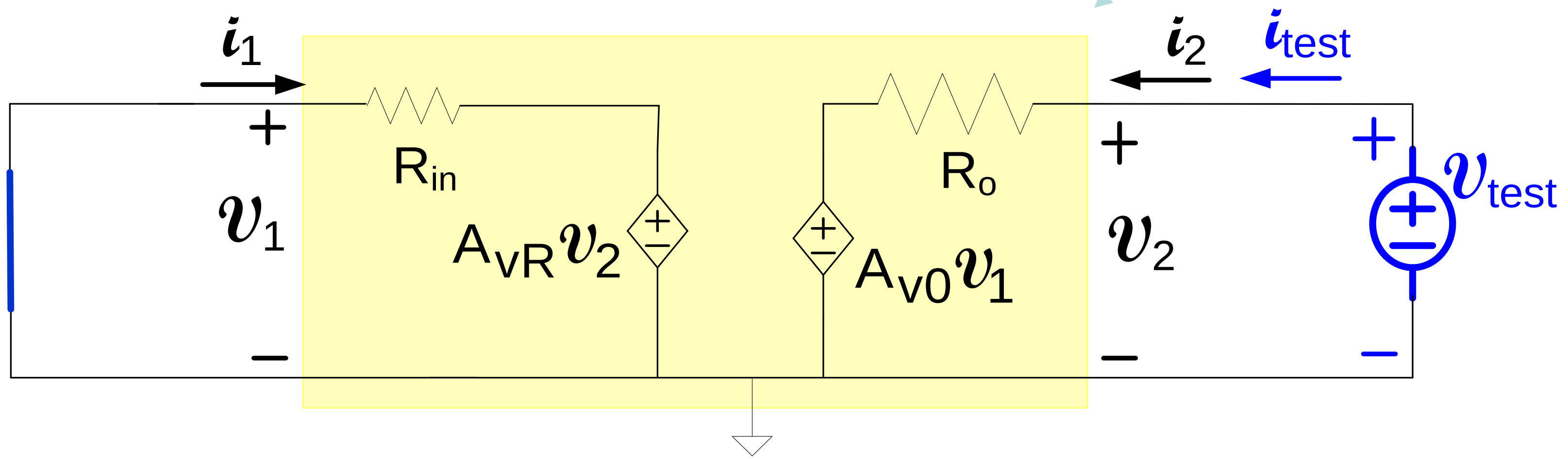
$v_1 = v_{\text{test}}$

$v_2 = v_{\text{out-test}}$

Determination of two-port model parameters



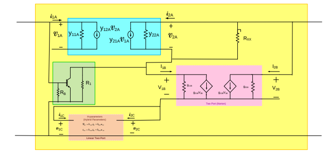
A method of obtaining R_0



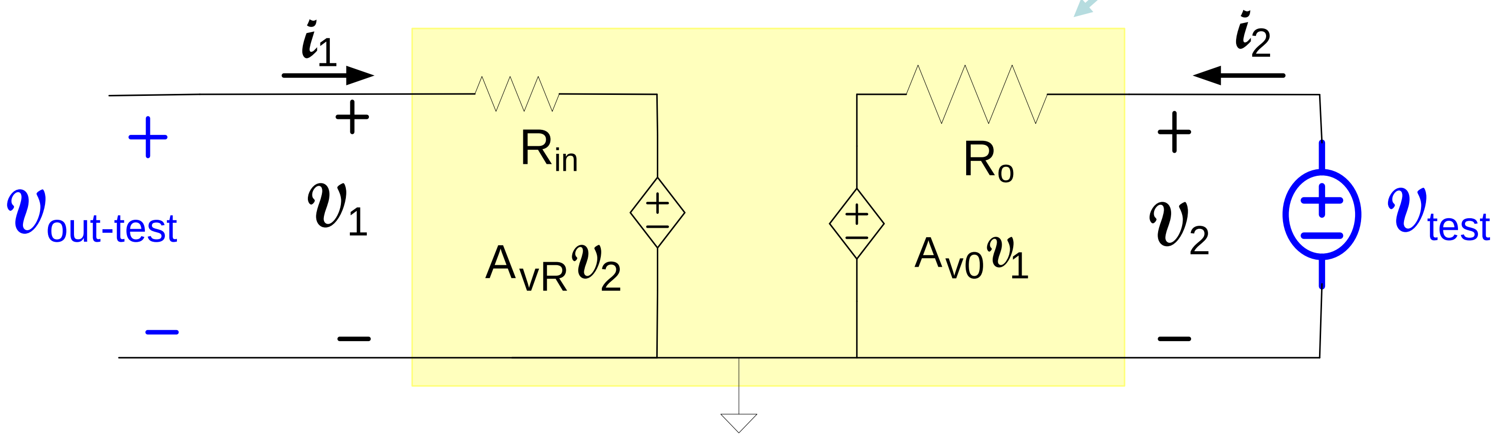
Terminate the input in a short-circuit

$$\left.\begin{aligned} i_1 &= v_1\left(\frac{1}{R_{in}}\right) + v_2\left(\frac{-A_{VR}}{R_{in}}\right) \\ i_2 &= v_1\left(\frac{-A_{V0}}{R_0}\right) + v_2\left(\frac{1}{R_0}\right) \end{aligned}\right\} \xrightarrow{v_1 = 0} \quad R_0 = \frac{v_{test}}{i_{test}}$$

Determination of two-port model parameters



A method of obtaining A_{VR}



Terminate the <u>input</u> in an open-circuit

$$\left.\begin{aligned} i_1 &= v_1\left(\frac{1}{R_{in}}\right) - v_2\left(\frac{A_{VR}}{R_{in}}\right) \\ i_2 &= v_1\left(\frac{-A_{V0}}{R_0}\right) + v_2\left(\frac{1}{R_0}\right) \end{aligned}\right\} \xrightarrow{i_1 = 0} A_{VR} = \frac{v_{out\text{-}test}}{v_{test}}$$

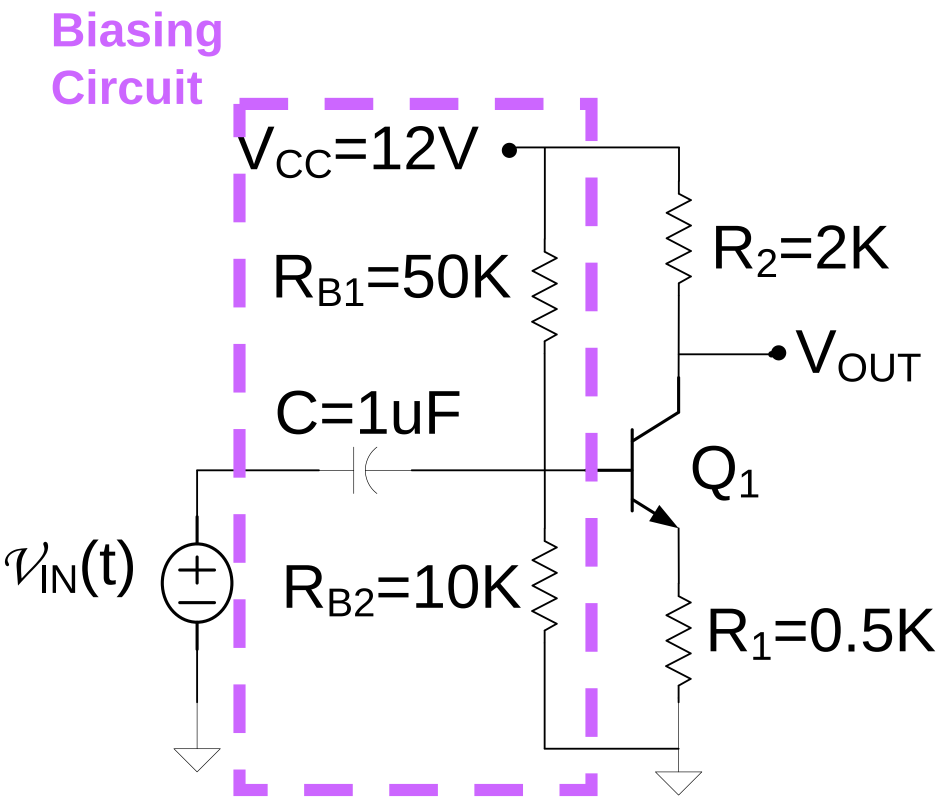
Determination of Amplifier Two-Port Parameters

- Input and output parameters are obtained in exactly the same way, only distinction is in the notation used for the ports.

- Methods given for obtaining amplifier parameters R_{in}, R_{OUT} and A_V for unilateral networks are a special case of the non-unilateral analysis by observing that $A_{VR}=0$.

- In some cases, other methods for obtaining the amplifier paramaters are easier than what was just discussed

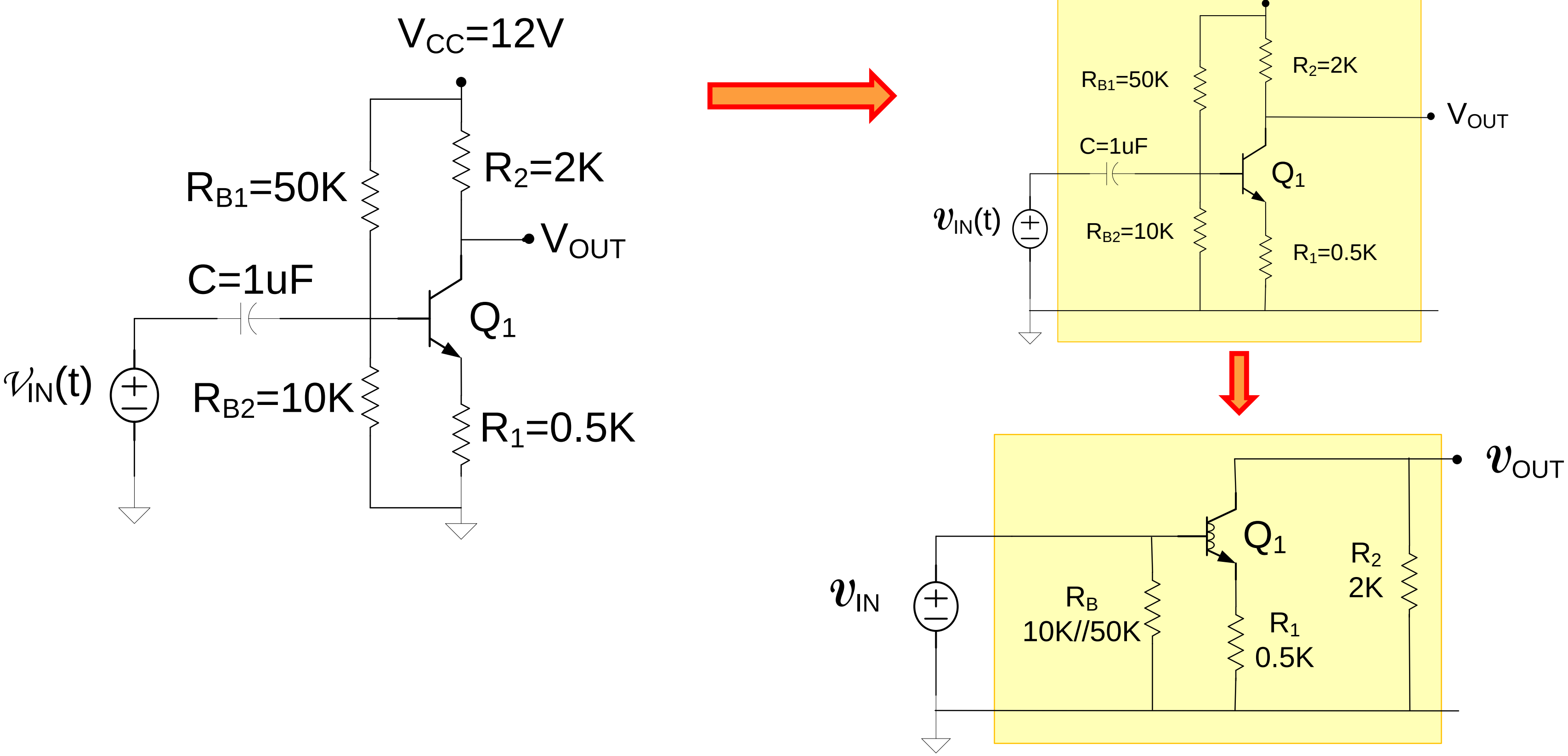
Examples



Determine V_{OUTQ} and the SS voltage gain (A_V), assume β=100

(A_V is one of the small-signal model parameters for this circuit)

Examples



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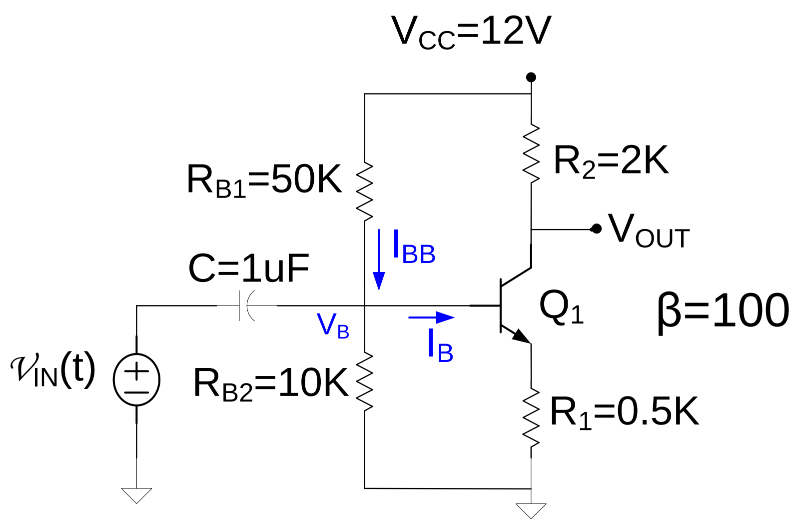
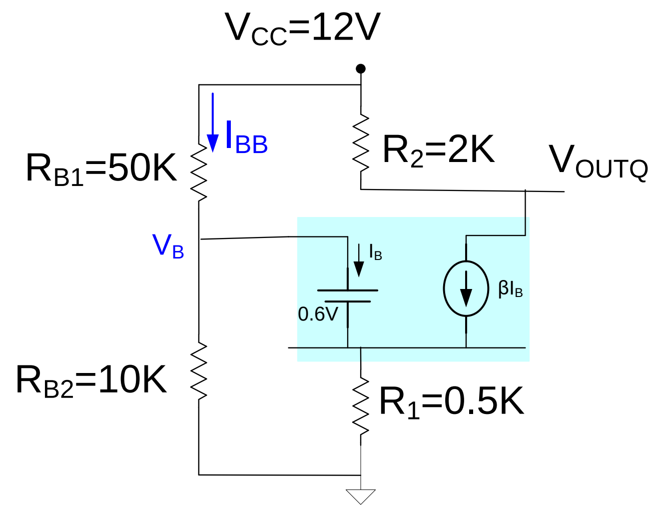
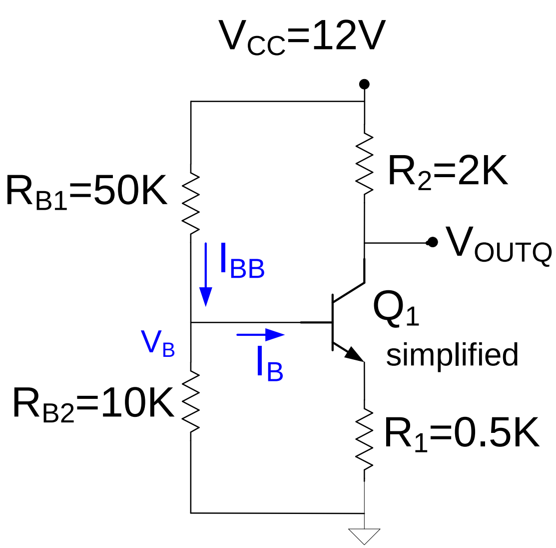


Determine V_{OUTQ}



dc equivalent circuit



dc equivalent circuit

This circuit is most practical when $I_B << I_{BB}$

With this assumption,

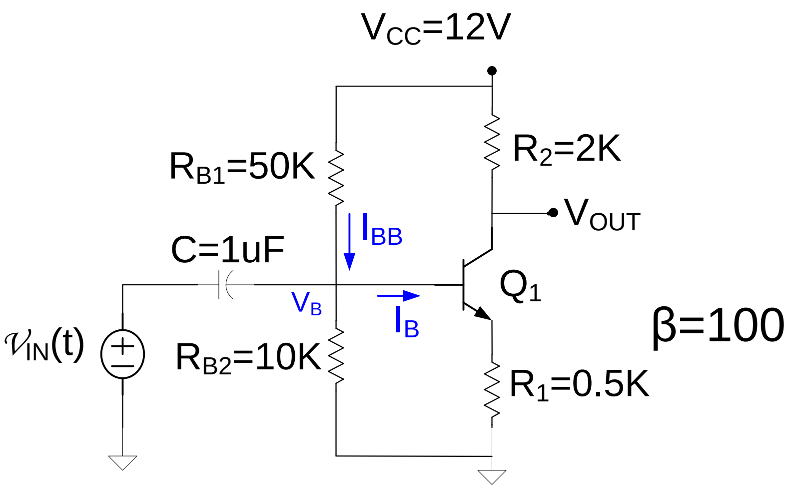
$$V_B = \left(\frac{R_{B2}}{R_{B1}+R_{B2}}\right)12V$$

$$I_{CQ} = I_{EQ} = \left(\frac{V_B - 0.6V}{R_1}\right) = \frac{1.4V}{.5K} = 2.8mA$$

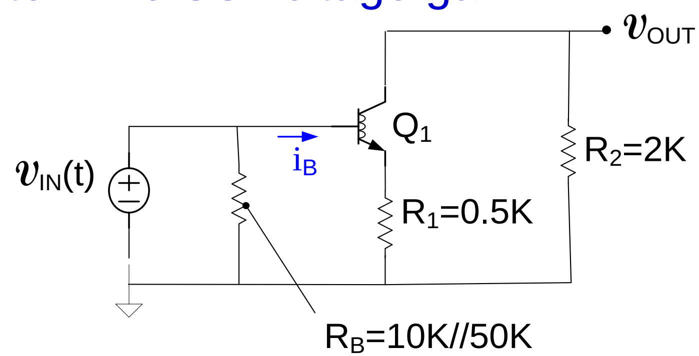
$$V_{OUTQ} = 12V - I_{CQ}R_1 = 6.4V$$

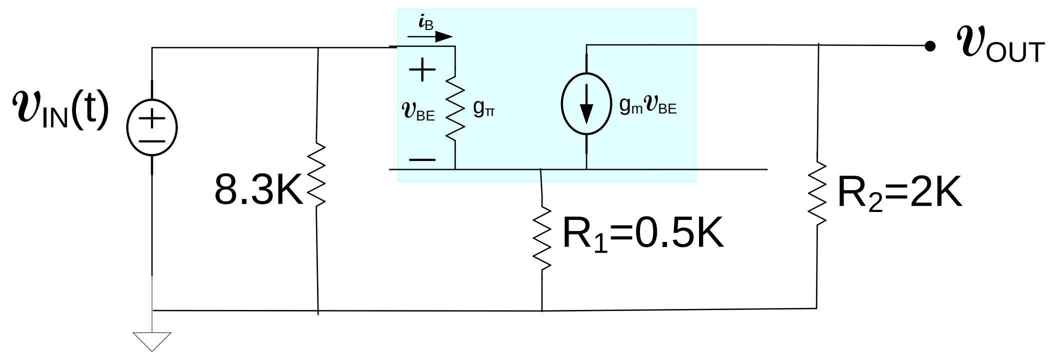
Note: This Q-point is nearly independent of the characteristics of the nonlinear BJT !

Examples



Determine SS voltage gain





This voltage gain is nearly independent of the characteristics of the nonlinear BJT !

This is a fundamentally different amplifier structure

It can be shown that this is slightly non-unilateral

$$\left.\begin{aligned} v_{OUT} &= -g_m v_{BE} R_2 \\ v_{IN} &= v_{BE} + R_1\left(v_{BE}\left[g_\pi + g_m\right]\right) \end{aligned}\right\}$$

$$A_V = \frac{-R_2 g_m v_{BE}}{v_{BE} + R_1\left(v_{BE}\left[g_\pi + g_m\right]\right)} = \frac{-R_2 g_m}{1 + R_1\left(\left[g_\pi + g_m\right]\right)}$$

$$A_V \cong \frac{-R_2 g_m}{R_1 g_m} = \frac{-R_2}{R_1} = -4$$

End of Lecture 29