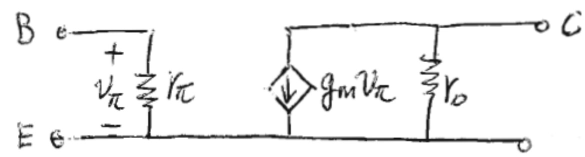
# Recitation 19: Common Emitter Amplifier

## Review: Small signal model of BJT

### Low Frequency

Voltage/Current Controlled Current Source




$v_\pi$: (or $v_{be}$)

$$
\begin{aligned}
g_{\mathrm{m}} &= \frac{I_{\mathrm{c}}}{V_{\mathrm{th}}} = \frac{I_{\mathrm{c}}}{kT/q} \quad \text{transconductance} \\
\gamma_\pi &= \frac{1}{g_\pi} = \frac{\beta_{\mathrm{F}}}{g_{\mathrm{m}}} \\
\gamma_{\mathrm{o}} &= \frac{1}{g_{\mathrm{o}}} = \frac{1}{\frac{\delta i_{\mathrm{c}}}{\delta V_{\mathrm{CE}}}} \simeq \frac{V_{\mathrm{A}}}{I_{\mathrm{C}}} \quad \text{base-width modulation}
\end{aligned}
$$

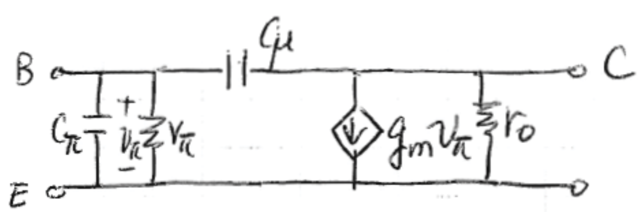
### High Frequency

Adding capacitances: between base-emitter, a forward-biased p-n junction

$$C_\pi = \text{depletion cap.} + \text{diffusion cap.}$$

Between base-collector, reverse biased p-n junction

$$C_\mu = \text{depletion cap.}$$

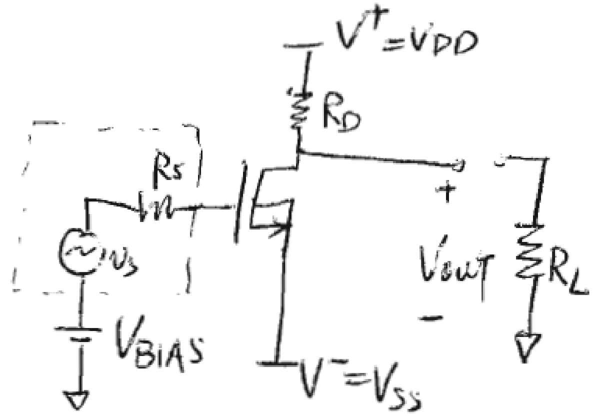


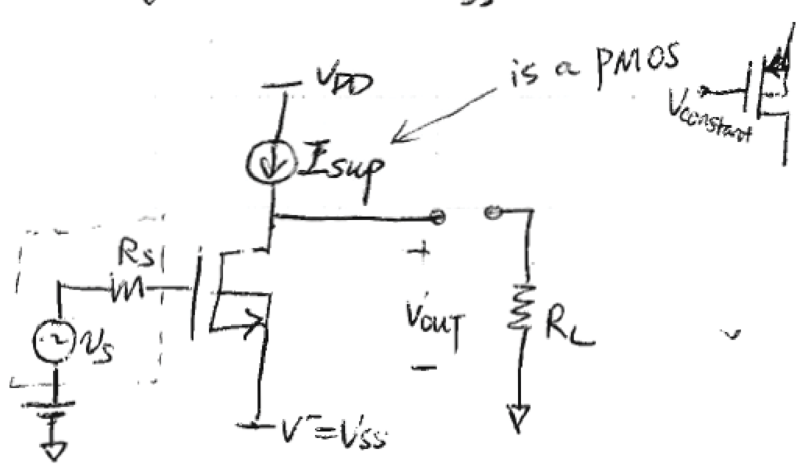
## Transistor Amplifiers

Yesterday we started our discussion on transistor amplifiers. For amplifiers, we have:

| Type | Input | Output |
|---|---|---|
| Voltage Amplifier | V | V |
| Current Amplifier | I | I |
| Transconductance Amplifier | V | I |
| Transresistance Amplifier | I | V |

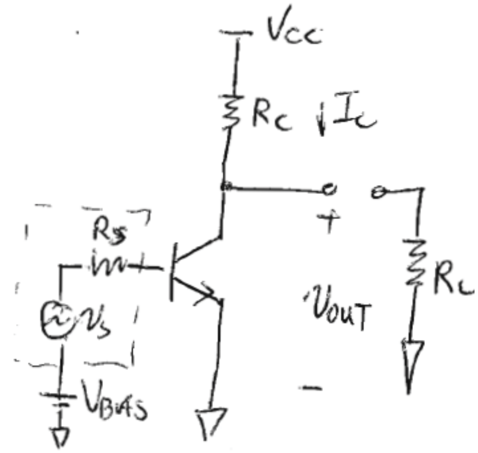
Voltage and transconductance amplifiers are most common. Yesterday, we discussed the common-source amplifier shown below:



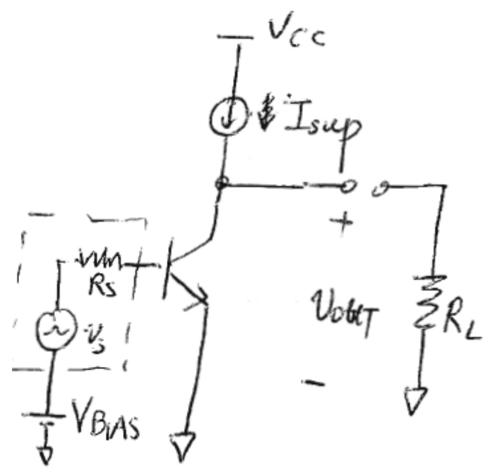



Today, we will discuss common-emitter amplifier (for the BJT version)

Resistor Bias
At Collector




Current Source
At Collector




For amplifier circuits, what we are interested in are:

- What is the operating point? (Bias point)
- Signal Swing?
- Small signal gain; input resistance; output resistance
- Frequency Response

Among these, first two are *large signal* analysis, while the last two are related to *small signal* circuits.

## DC Bias Point

For large signal analysis, $V_s$ & $R_s$ will be gone. Also make $R_L$ $\infty$. See figure 4,

$$\begin{aligned}
V_{out} &= V_{cc} - I_c \cdot R_c \\
\text{If we choose } V_{out} &= \frac{V_{cc}}{2} = 2.5\,\mathrm{V}\ (\mathrm{V_{cc}} = 5\,\mathrm{V}),\ \mathrm{R_c} = 10\,\mathrm{k}\Omega \\
I_c &= \frac{V_{cc} - V_{out}}{R_c} = \frac{5\,\mathrm{V} \cdot 2.5\,\mathrm{V}}{10\,\mathrm{k}\Omega} = 250\,\mu\mathrm{A} \\
I_c &= I_s e^{\mathrm{qV_{BIAS}/kT}} \implies \mathrm{V_{BIAS}} = \frac{\mathrm{kT}}{\mathrm{q}} \ln \frac{\mathrm{I_c}}{\mathrm{I_s}} = 0.682\,\mathrm{V}
\end{aligned}$$

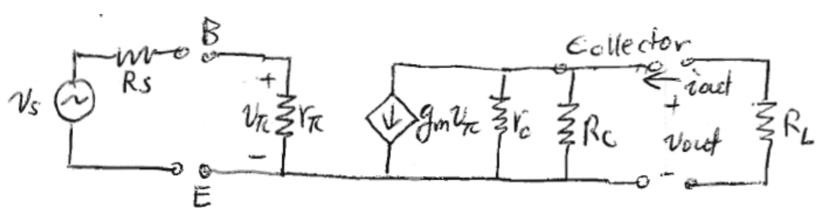
## Signal Swing

- Upswing limited by BJT going into cutoff: Total signal $V_{out,max} = V_{cc}$
- Down swing limited by BJT going out of FAR into saturation $V_{out,min} = V_{CE,SAT}$

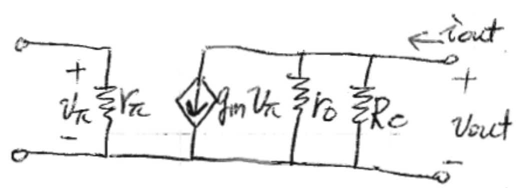
## Small Signal Analysis of CE Amplifier

First obtain the small signal circuit of the circuit in Figure 4

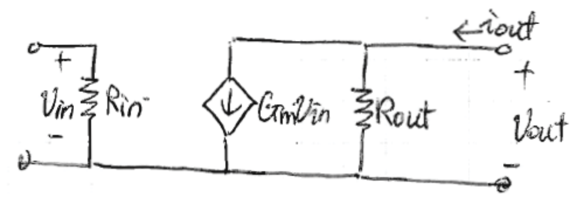
- Short DC voltage bias
- Open DC circuit bias




Intrinsic will be (without $R_s$ and $R_L$)




This is a transconductance amplifier, it turns out its small signal circuit is very similar to the topography of our “two port model”



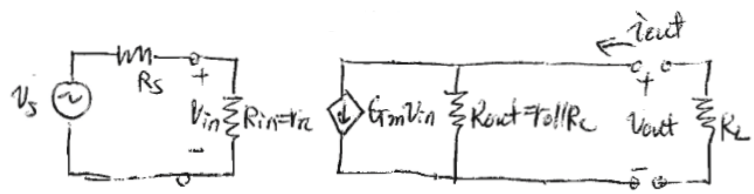

In comparison, we see

$$\begin{aligned} R_{\text{in}} &= \gamma_\pi \\ G_{\text{m}} &= g_{\text{m}} = \frac{I_{\text{c}}}{kT/q} \\ R_{\text{out}} &= \gamma_{\text{o}}||R_{\text{c}} \end{aligned}$$

Intrinsic or unloaded gain (short circuit output)

$$\frac{i_{\text{out}}}{V_{\text{in}}} = \frac{G_{\text{m}} V_{\text{in}}}{V_{\text{in}}} = G_{\text{m}}$$

And the loaded transconductance gain:




$$\begin{aligned} \frac{i_{\text{out}}}{V_{\text{s}}} &= G_{\text{m}} V_{\text{in}} \cdot \left( \frac{R_{\text{out}}}{R_{\text{out}} + R_{\text{L}}} \right) \frac{1}{V_{\text{s}}} \\ &= G_{\text{m}} \left( \frac{R_{\text{out}}}{R_{\text{out+R_L}}} \right) \cdot \frac{\frac{R_{\text{in}}}{R_{\text{in}} + R_{\text{s}}} V_{\text{s}}}{V_{\text{s}}} = g_{\text{m}} \left( \frac{\gamma_{\text{o}}||R_{\text{c}}}{\gamma_{\text{o}}||R_{\text{c}} + R_{\text{L}}} \right) \left( \frac{\gamma_\pi}{\gamma_\pi + R} \right) \end{aligned}$$

## Replacing $R_{\text{c}}$ with a Current Source

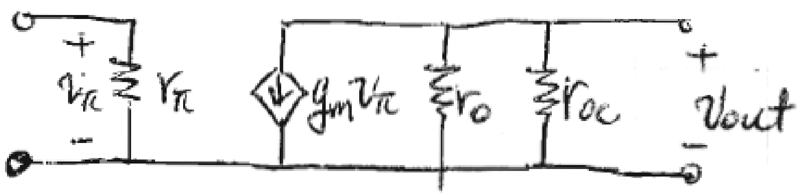
From the discussions in the above subsection, in general:

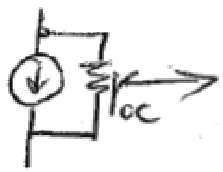
$$\begin{aligned} r_{\text{o}} &\gg R_{\text{c}} \implies r_{\text{o}}||R_{\text{c}} = R_{\text{c}} \\ \text{and } \frac{i_{\text{out}}}{v_{\text{s}}} &= g_{\text{m}} \left( \frac{R_{\text{c}}}{R_{\text{c}} + R_{\text{L}}} \right) \cdot \left( \frac{r_\pi}{r_\pi + R_{\text{s}}} \right) \end{aligned}$$

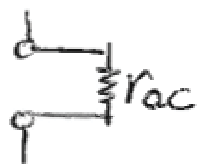
If $R_{\text{c}} \simeq R_{\text{L}}$ or $R_{\text{c}} < R_{\text{L}}$, transconductance gain is degraded.

So we need a large $R_{\text{out}}$ (output is a current)

$\Longrightarrow$ use a current source at the collector $\Longrightarrow$ Figure 5 can be a p-MOSFET, $R_c \rightarrow r_{oc}$ (in small signal circuit, DC current is open)

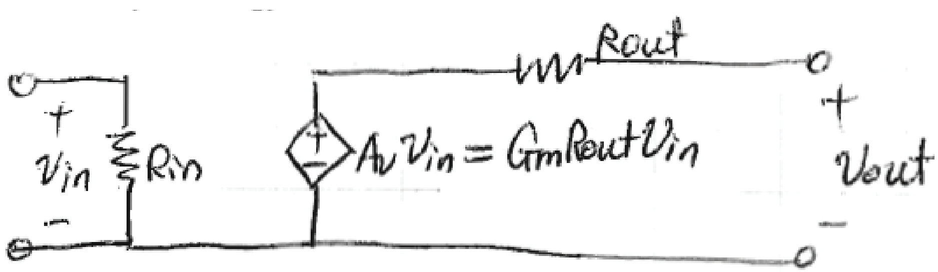



**On the CE Amp.**

We consider the CE Amp. to be a transconductance amplifier. In fact, it can also be just a voltage amplifier. In that case, the two port model becomes:




(a norton Eq circuit
change to a Thevenin Eq
circuit)

## CS vs. CE Amp

In comparison with the CS Amp we discussed yesterday:

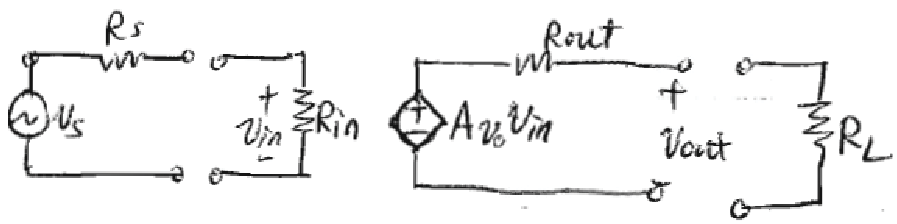
- $V_{\text{BIAS}} = \sqrt{\dfrac{2I_{\text{D}}}{\frac{w}{L}\mu_{\text{n}}C_{\text{ox}}}} + V_{\text{SS}} + V_{\text{T}}$

  (by letting $V_{\text{OUT}} = 0$, & $I_{\text{R}} = I_{\text{D}} = \dfrac{w}{2L}\mu_{\text{n}}C_{\text{ox}}(V_{\text{BIAS}} - V_{\text{SS}} - V_{\text{T}})^2 = \dfrac{V_{\text{DD}}}{R_{\text{D}}}$)

- $V_{\text{OUT,MAX}} = V_{\text{DD}}$ (MOS into cutoff)

  $V_{\text{OUT,MIN}} = V_{\text{BIAS}} - V_{\text{T}}$ (MOSFET leave saturation)

- $R_{\text{in}} = \infty$, $R_{\text{out}} = r_{\text{o}}||R_{\text{D}}$




$$\begin{aligned} A_{\text{VD}} &= \frac{V_{\text{out}}}{V_{\text{in}}} = -g_{\text{m}}(r_{\text{o}}||R_{\text{D}}) \\ \frac{V_{\text{out}}}{V_{\text{s}}} &= -g_{\text{m}}(r_{\text{o}}||R_{\text{D}}||R_{\text{L}}) \end{aligned}$$