ELL100: INTRODUCTION TO ELECTRICAL ENGG.

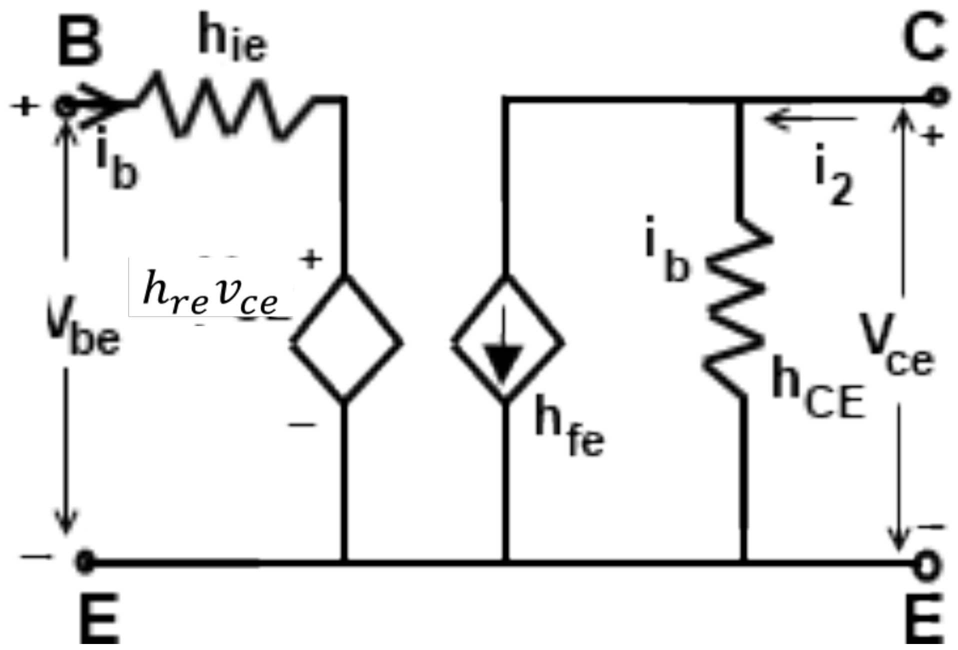
Bipolar Junction Transistors - Amplifiers

Reference: Donald Neamen's 'Electronic Circuits Analysis' Chapter 4 (Basic BJT amplifiers)

BJT as Two Port Network:

The model for CE configuration is

$$
\begin{aligned}
v_{be} &= h_{ie} i_b + h_{re} v_{ce} \\
i_c &= h_{fe} i_b + h_{oe} v_{ce}
\end{aligned}
$$



h-parameters are not constant for a transistor they depend on base current and temperature.

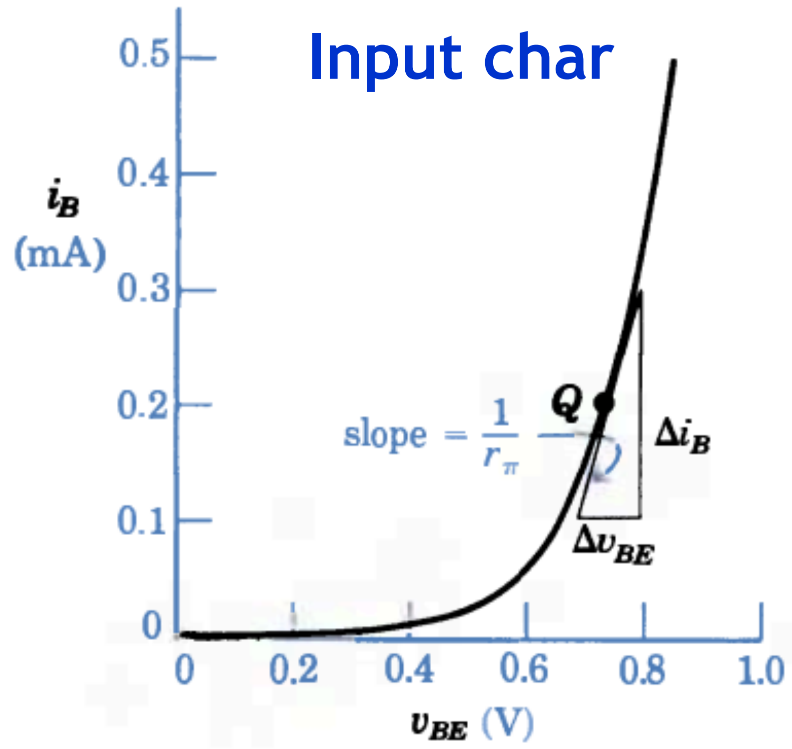
They give the incremental effects of small changes in base current and collector voltage.

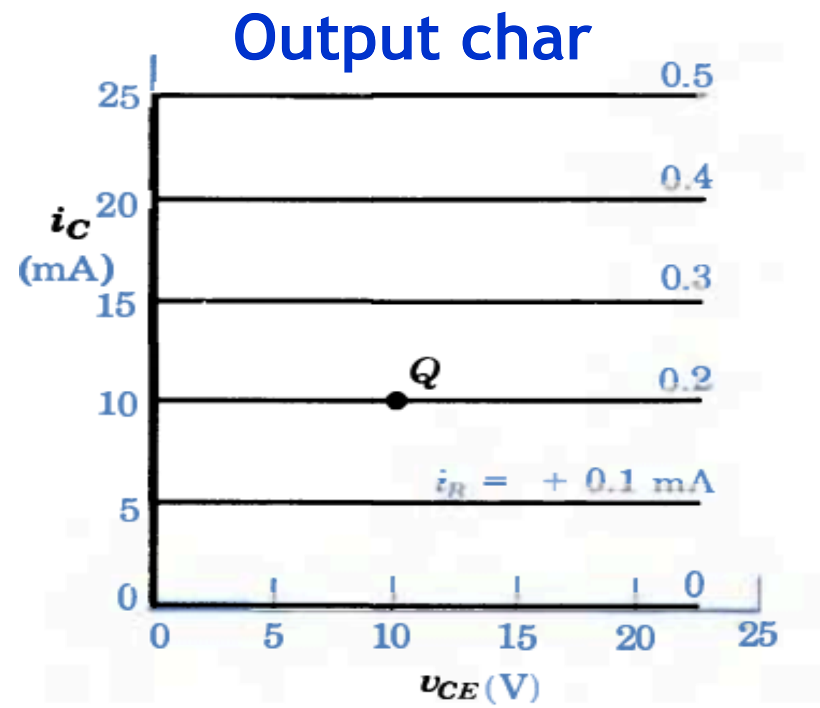
R_π Model (CE configuration):

We know using h-parameters,

$$\begin{cases} v_{BE} = f_1(i_B,\ v_{CE}) \\ i_C = f_2(i_B,\ v_{CE}) \end{cases}$$

If we limit operation to the region where v_{BE} and i_C are independent of v_{CE}. The base-emitter characteristic is that of a theoretical diode and the collector characteristics indicate a constant β and I_{CEO}.



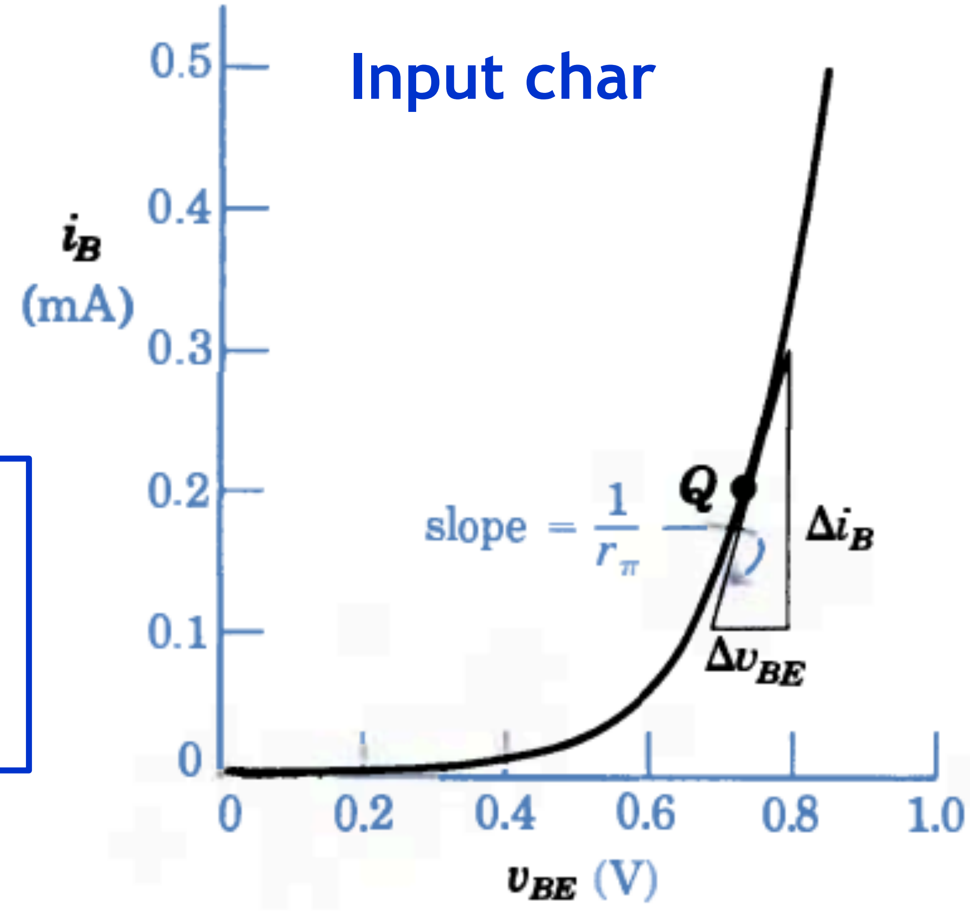


R_π Model (CE configuration):

To calculate r_π from the input characteristics (resembles with diode char),

$$\boxed{i_B = I_s\,(e^{e v_{BE}/kT} - 1)}$$

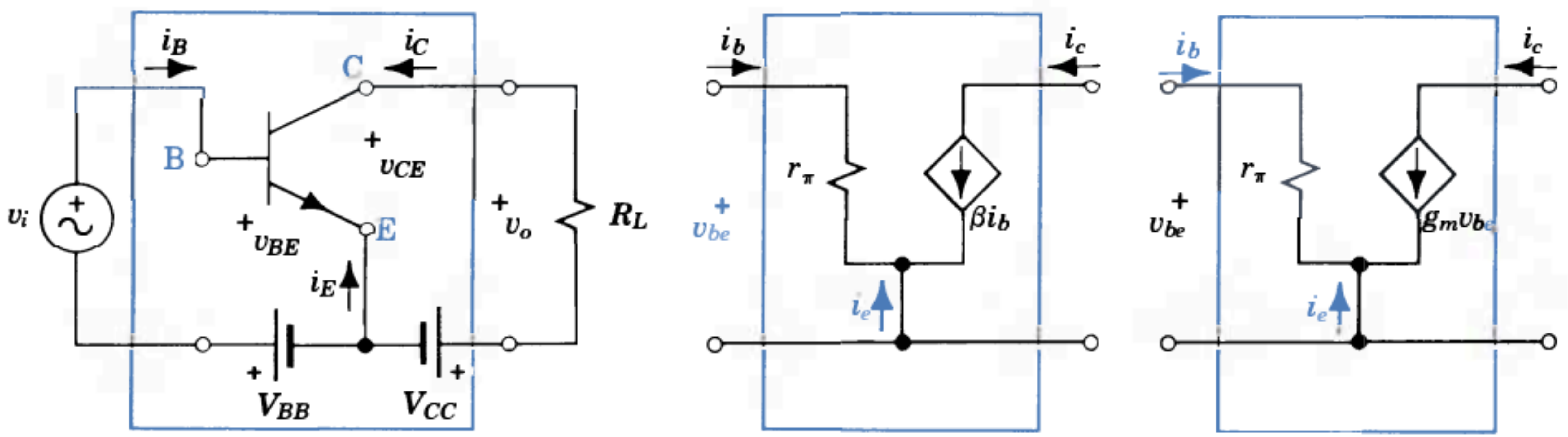
r_π is the dynamic resistance and is directly proportional to absolute temperature T and inversely proportional to the dc current I_B.



At room temperature, $kT/e \cong 0.025$ V and

$$r_\pi = \frac{0.025}{I_B} = \beta\,\frac{25}{I_C(\text{in mA})}\ \Omega$$

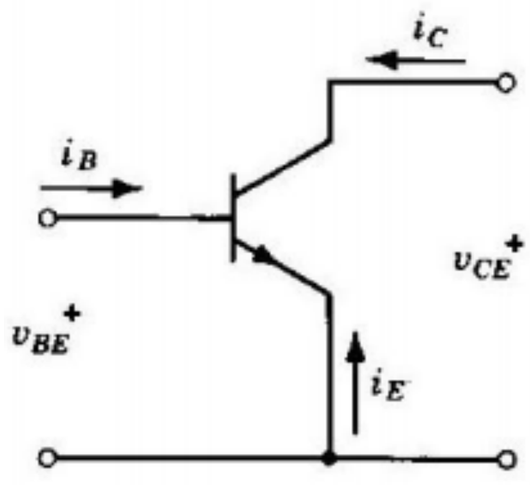
R_π Model (CE configuration):

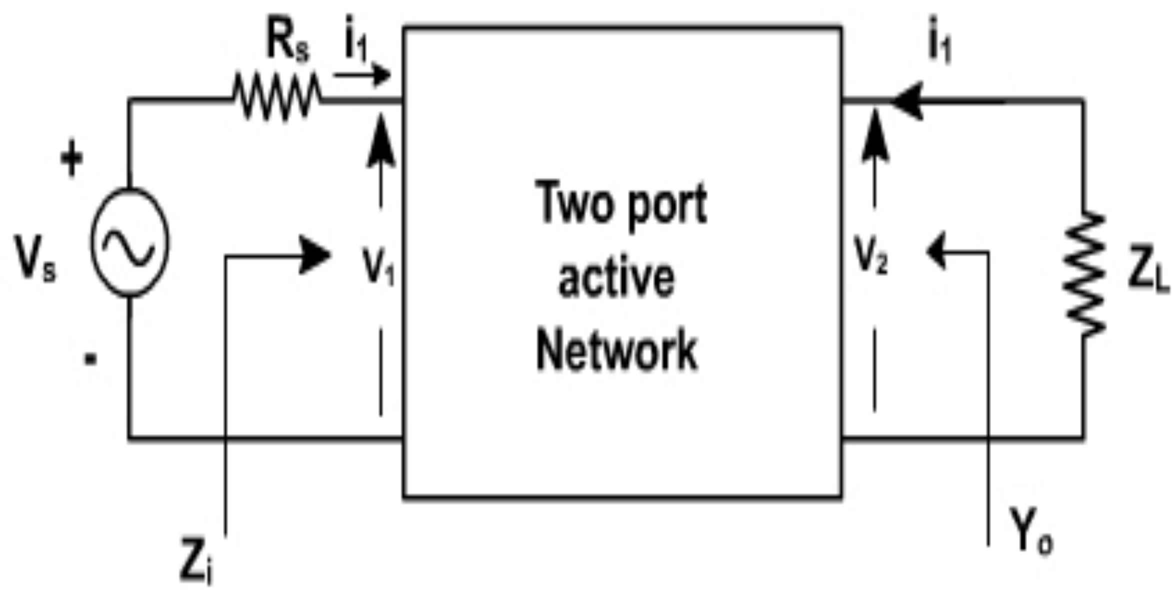


(a) Elementary amplifier (b) Small-signal r_π-β model (c) Alternative r_π- g_m model

h-parameter analysis for CE transistor:

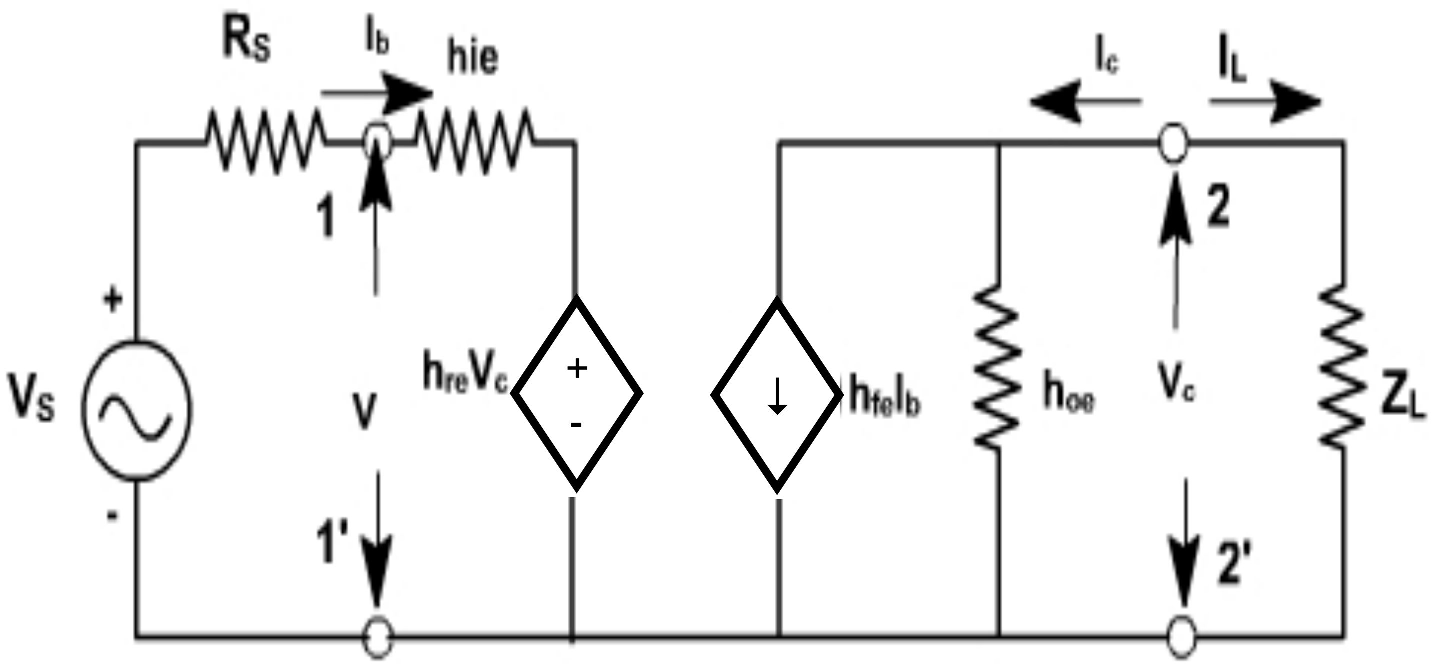
To form a transistor amplifier it is necessary to connect an external load and signal source and to bias the transistor properly (shown below).





h-parameter analysis for CE transistor:

Consider the two-port network of CE amplifier. R_S is the source resistance and Z_L is the load impedance. The ac equivalent circuit is shown below. Calculate current gain, input impedance, voltage gain, and output admittance.



The h-parameters here are of the circuit without the source or load being connected.

Biasing done.

h-parameter analysis for CE Amplifier

Current gain:

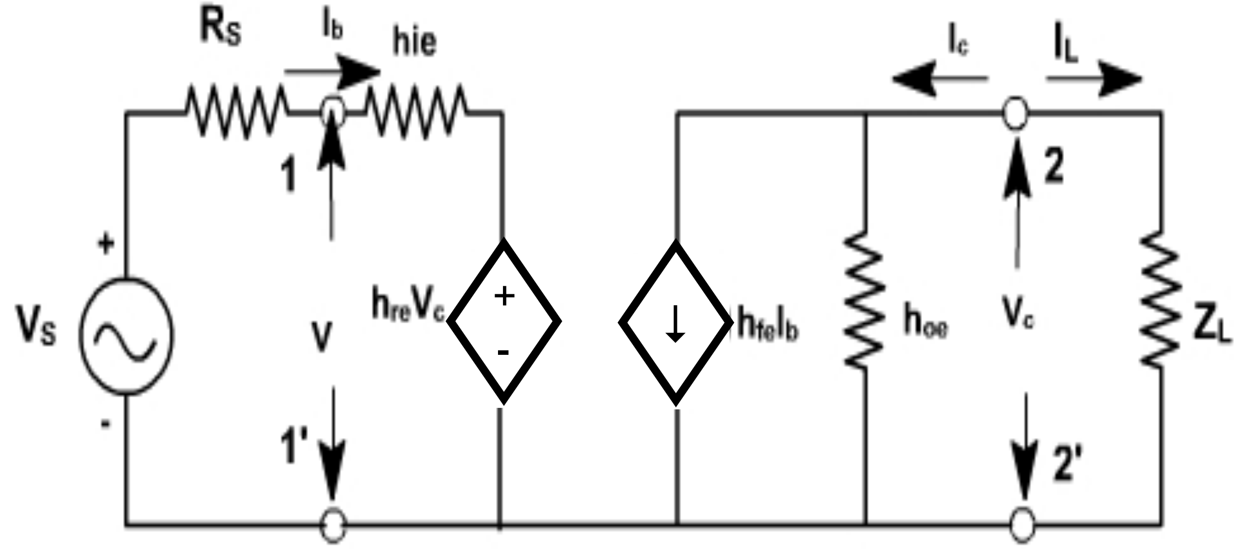
For the transistor amplifier stage, A_i is defined as the ratio of output to input currents.

$$A_i = \frac{i_L}{i_b} = -\frac{i_c}{i_b}$$

$$i_c = h_{fe} i_b + h_{oe} v_c$$
$$v_c = i_L Z_L = -i_c Z_L$$

$$i_c = h_{fe} i_b - h_{oe} i_c Z_L$$

$$A_i = \frac{i_L}{i_b} = -\frac{i_c}{i_b} = -\frac{h_{fe}}{1 + h_{oe} Z_L}$$



h-parameter analysis for CE Amplifier

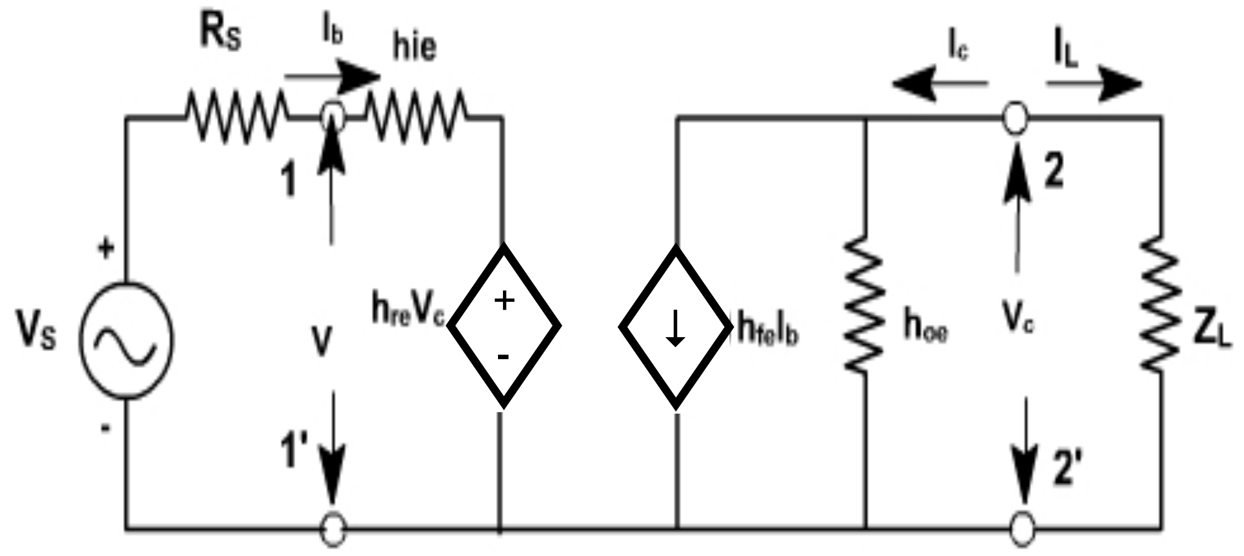
Current gain:

For the transistor amplifier stage, A_i is defined as the ratio of output to input currents.

$$A_i = \frac{i_L}{i_b} = -\frac{i_c}{i_b}$$

$$i_c = h_{fe} i_b + h_{oe} v_c$$
$$v_c = i_L Z_L = -i_c Z_L$$

$$i_c = h_{fe} i_b - h_{oe} i_c Z_L$$



$$A_i = \frac{i_L}{i_b} = -\frac{i_c}{i_b} = -\frac{h_{fe}}{1+h_{oe} Z_L}$$

h_{fe} → 20-200

h_{oe} → 1- 30 mu mhos

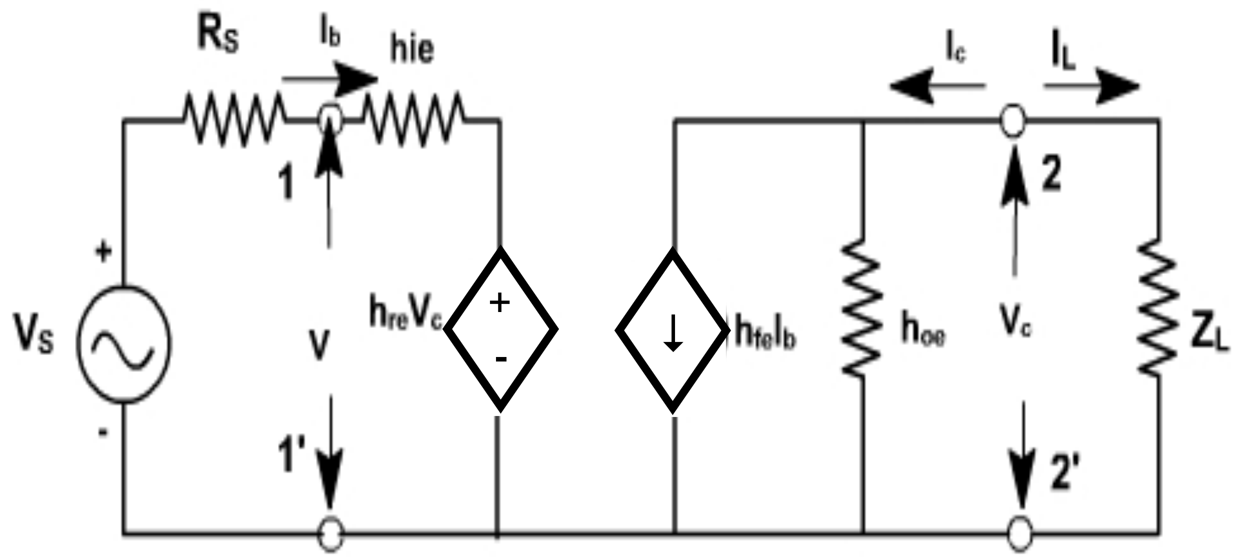
Z_L → few K ohms

A_i → same as h_{fe}.

h-parameter analysis for CE Amplifier

Input Impedance:

The impedance looking into the amplifier in terminals (1,1') is the input impedance Z_i



$$Z_i = \frac{v_b}{i_b}$$

$$v_b = h_{ie} i_b + h_{re} v_c$$

$$\frac{v_b}{i_b} = h_{ie} + h_{re}\frac{v_c}{i_b} = h_{ie} + h_{re} Z_L \frac{i_L}{i_b}$$

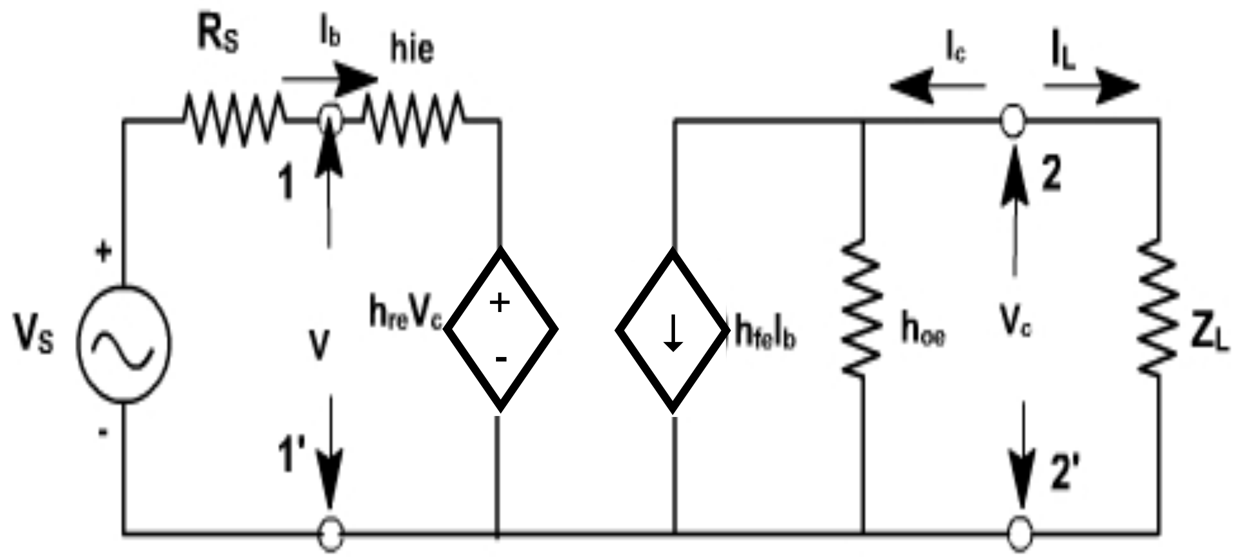
$$Z_i = h_{ie} + h_{re} A_i Z_L = h_{ie} - \frac{h_{re} h_{fe} Z_L}{1 + h_{oe} Z_L}$$

$$Z_i = h_{ie} - \frac{h_{re} h_{fe}}{Y_L + h_{oe}} \text{ with } Y_L = \frac{1}{Z_L}$$

h-parameter analysis for CE Amplifier

Input Impedance:

The impedance looking into the amplifier in terminals (1,1') is the input impedance Z_i



$$Z_i = \frac{v_b}{i_b}$$

$$v_b = h_{ie} i_b + h_{re} v_c$$
$$\frac{v_b}{i_b} = h_{ie} + h_{re}\frac{v_c}{i_b} = h_{ie} + h_{re} Z_L \frac{i_L}{i_b}$$

$$Z_i = h_{ie} + h_{re} A_i Z_L = h_{ie} - \frac{h_{re} h_{fe} Z_L}{1 + h_{oe} Z_L}$$

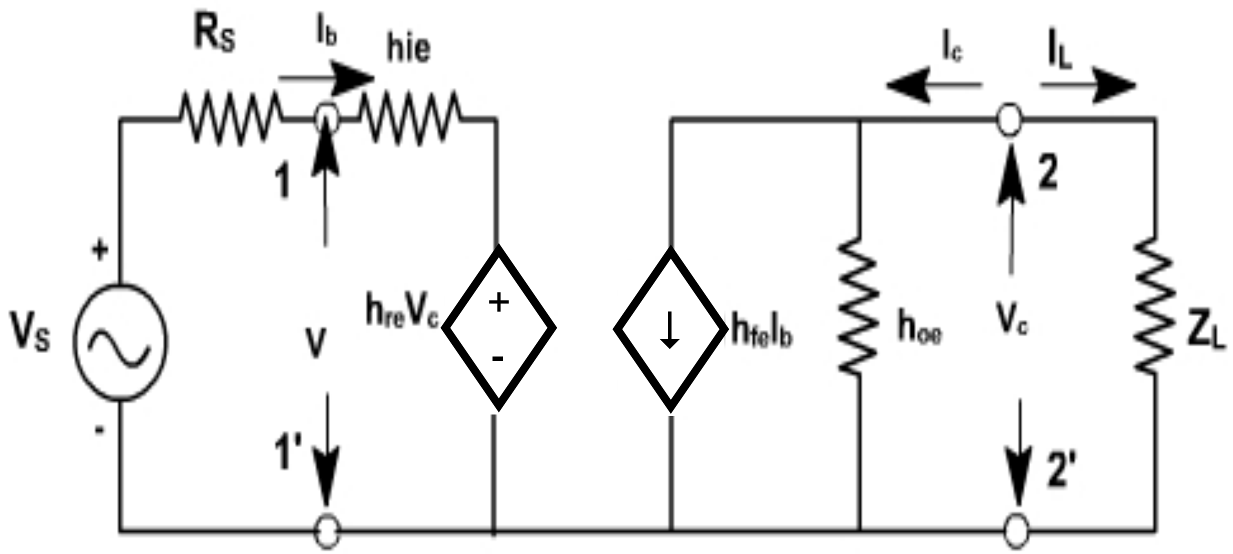
$$Z_i = h_{ie} - \frac{h_{re} h_{fe}}{Y_L + h_{oe}} \text{ with } Y_L = \frac{1}{Z_L}$$

h_{ie} → 1-10 k ohms
h_{re} → <10^{-3}
h_{fe} → 20-200
h_{oe} → 1- 30 mu mhos
Z_L → few K ohms
Z_i → same as h_{ie} for low Z_L. But, i_b vs v_b will have –ve relation for large Z_L.

h-parameter analysis for CE Amplifier

Voltage gain:

The ratio of output voltage to input voltage gives the gain of the transistors.



$$A_v = \frac{v_c}{v_b} = \frac{i_L}{i_b}\frac{Z_L}{Z_i}$$

$$A_v = \frac{A_i Z_L}{Z_i}$$

If Z_L is more than few tens of ohms, Z_i is negative. A_v is negative. 180 degree phase shift between input and output voltages.

h-parameter analysis for CE Amplifier

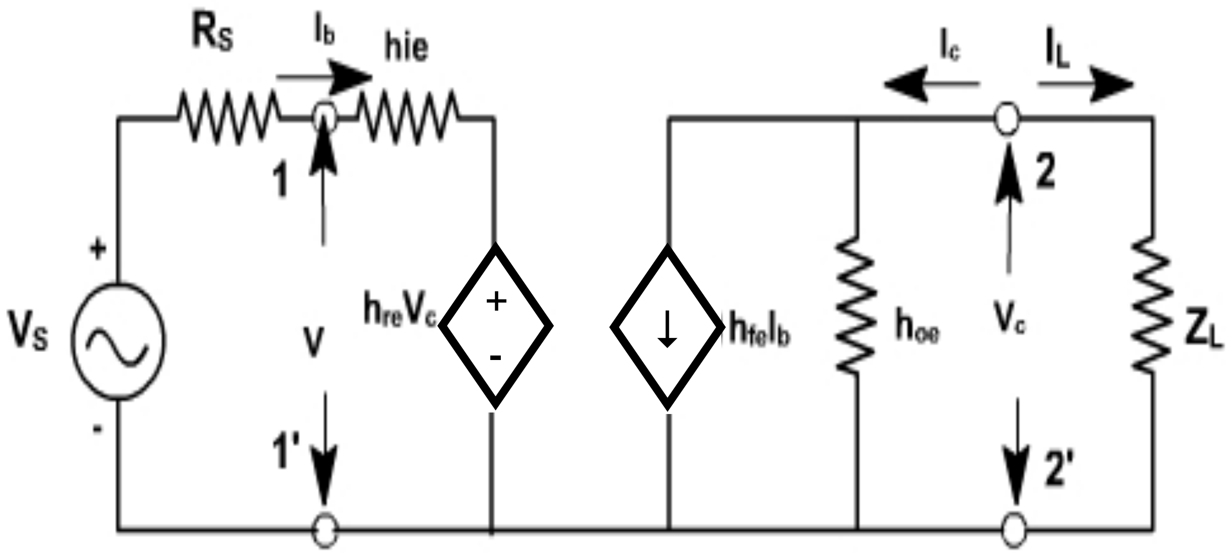
Output Admittance:

$$Y_O = \left. \frac{i_c}{v_c} \right|_{v_s=0}$$

$$i_c = h_{fe} i_b + h_{oe} v_c$$
$$\frac{i_c}{v_c} = h_{fe} \frac{i_b}{v_c} + h_{oe}$$

When $v_s = 0$, $i_b(R_s + h_{ie}) + h_{re} v_c = 0$
$$\frac{i_b}{v_c} = -\frac{h_{re}}{R_s + h_{ie}}$$

$$Y_O = h_{oe} - \frac{h_{re} h_{fe}}{R_s + h_{ie}}$$



h-parameter analysis for CE Amplifier

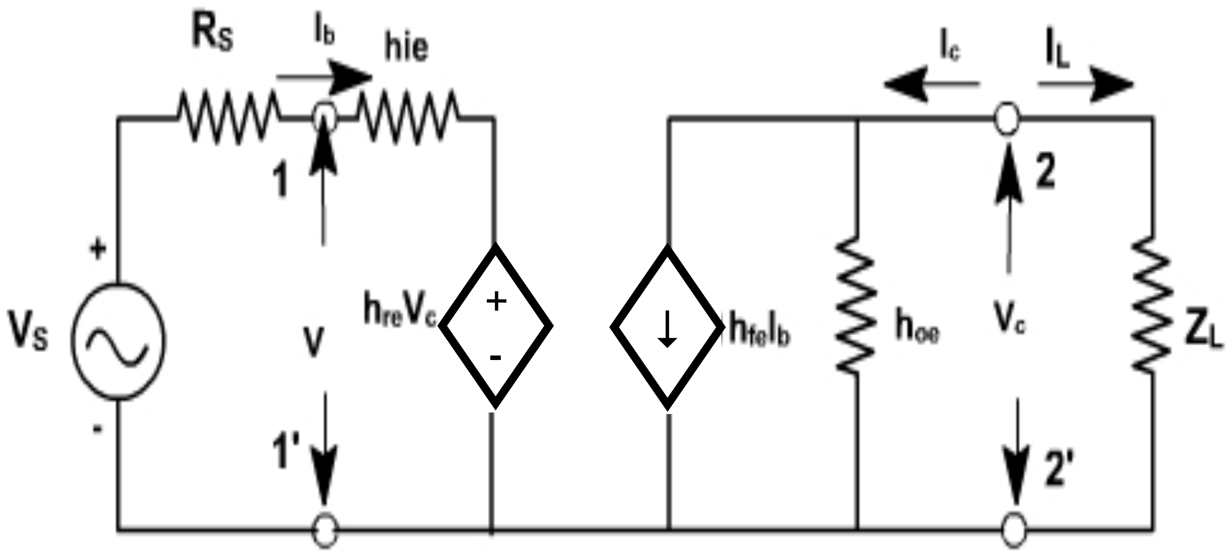
Output Admittance:

$$Y_O = \left.\frac{i_c}{v_c}\right|_{v_s=0}$$

$$i_c = h_{fe} i_b + h_{oe} v_c$$
$$\frac{i_c}{v_c} = h_{fe}\frac{i_b}{v_c} + h_{oe}$$

When $v_s = 0,\ i_b(R_s + h_{ie}) + h_{re} v_c = 0$
$$\frac{i_b}{v_c} = -\frac{h_{re}}{R_s+h_{ie}}$$

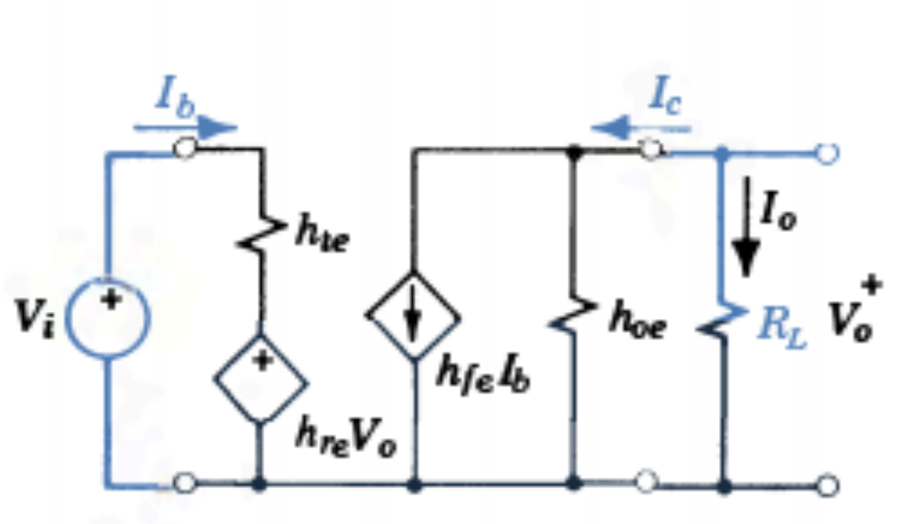
$$Y_O = h_{oe} - \frac{h_{re} h_{fe}}{R_s+h_{ie}}$$



R_s is typically much less than h_{ie}.
And Y_O is almost same as h_{oe}.

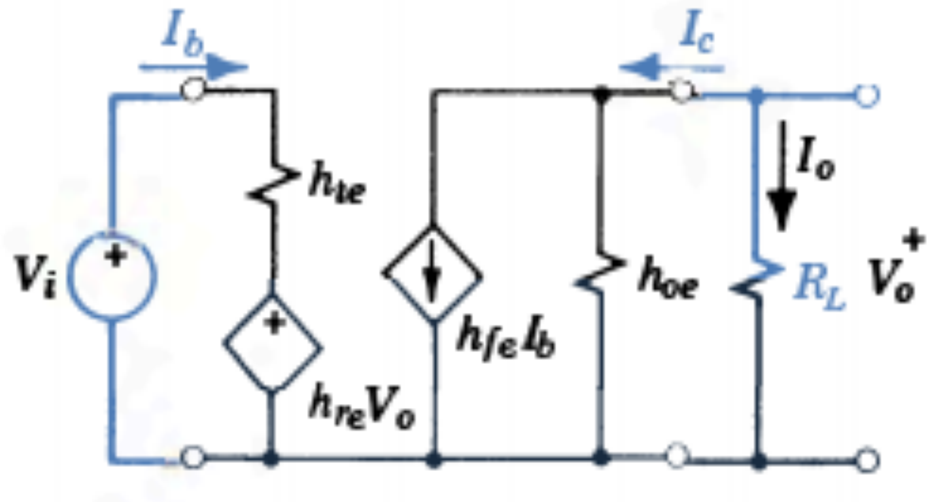
Example 1:

The transistor has the following common-emitter h-parameters: h_{ie} = 2500 Ω, h_{re} = 4*10^{-4}, h_{fe} = 50, and h_{oe} = 10 μS.
For R_L = 5 kΩ and I_o = 0.2 mA rms, estimate the current gain and voltage gain of the amplifier.



Example 1:

The transistor has the following common-emitter h-parameters: h_{ie} = 2500 Ω, h_{re} = $4*10^{-4}$, h_{fe} = 50, and h_{oe} = 10 μS.
For R_L = 5 kΩ and I_o = 0.2 mA rms, estimate the current gain and voltage gain of the amplifier.



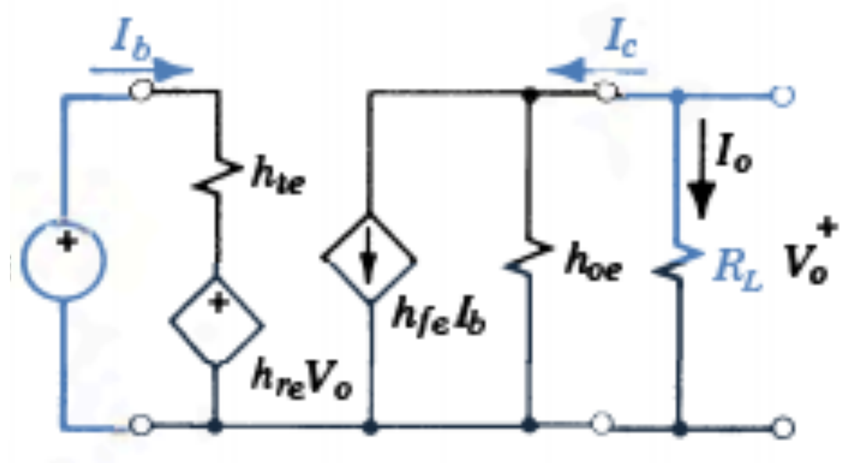
Applying the current-divider principle,

$$I_o = -I_c = -\frac{1/R_L}{h_{oe} + 1/R_L} h_{fe} I_b$$

The current gain is

$$\frac{I_o}{I_b} = -\frac{h_{fe}/R_L}{h_{oe} + 1/R_L} = -\frac{50/5000}{(10 + 200)10^{-6}} = -47.6$$

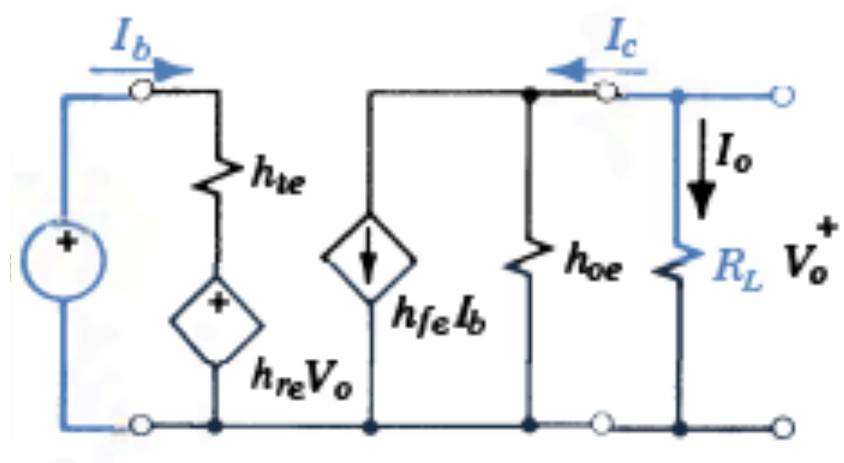
Example 1:



The required input signal is

$$I_b = I_o/(-47.6) = 200/(-47.6) = -4.2\ \mu\text{A}$$

Example 1:



The required input signal is

$$I_b = I_o/(-47.6) = 200/(-47.6) = -4.2\ \mu\text{A}$$

Since $V_o = I_o R_L = 0.2 \times 10^{-3} \times 5 \times 10^3 = 1$ V,

In the input loop,

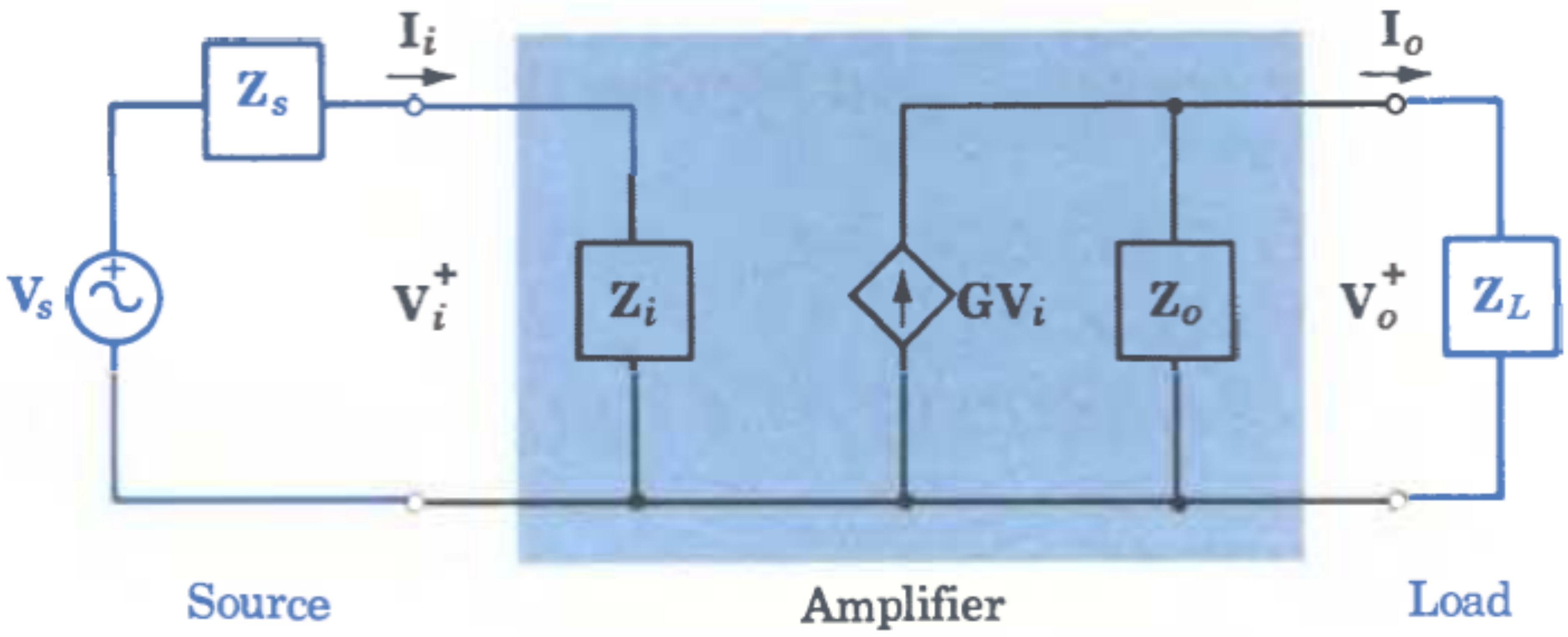
$$V_i = I_b h_{ie} + h_{re} V_o$$

$$= -4.2 \times 10^{-6} \times 2500 + 4 \times 10^{-4} \times 1$$

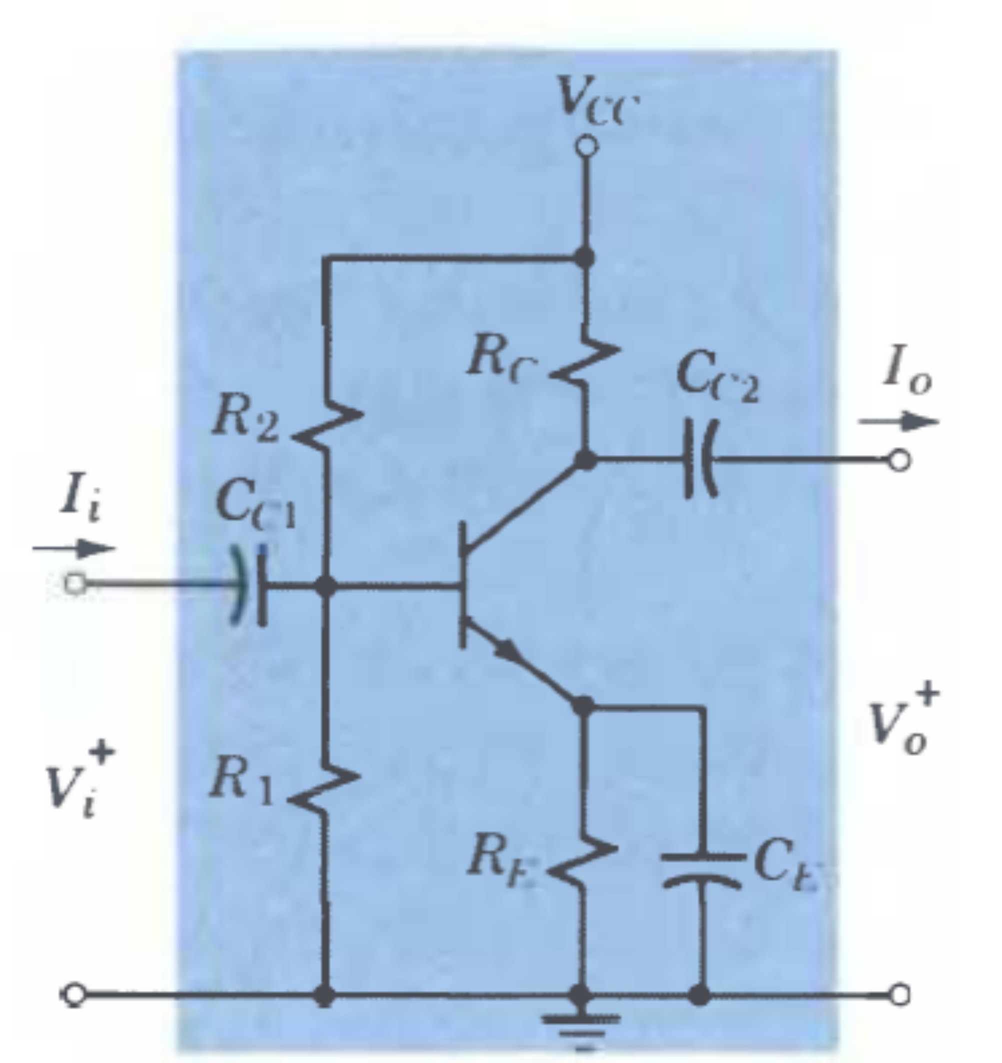
$$= (-10.5 + 0.4)10^{-3} = -10.1 \text{ mV}$$

$$\frac{V_o}{V_i} = \frac{1}{-0.0101} = -99$$

Generalized One Stage Amplifier



RC-Coupled CE BJT Amplifier

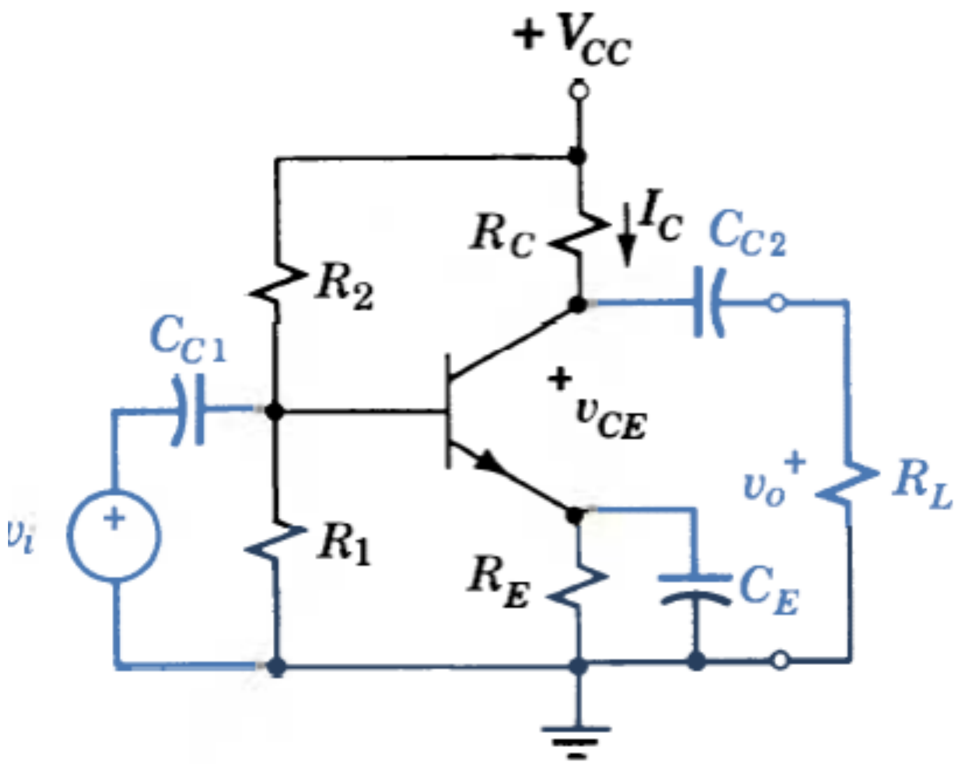


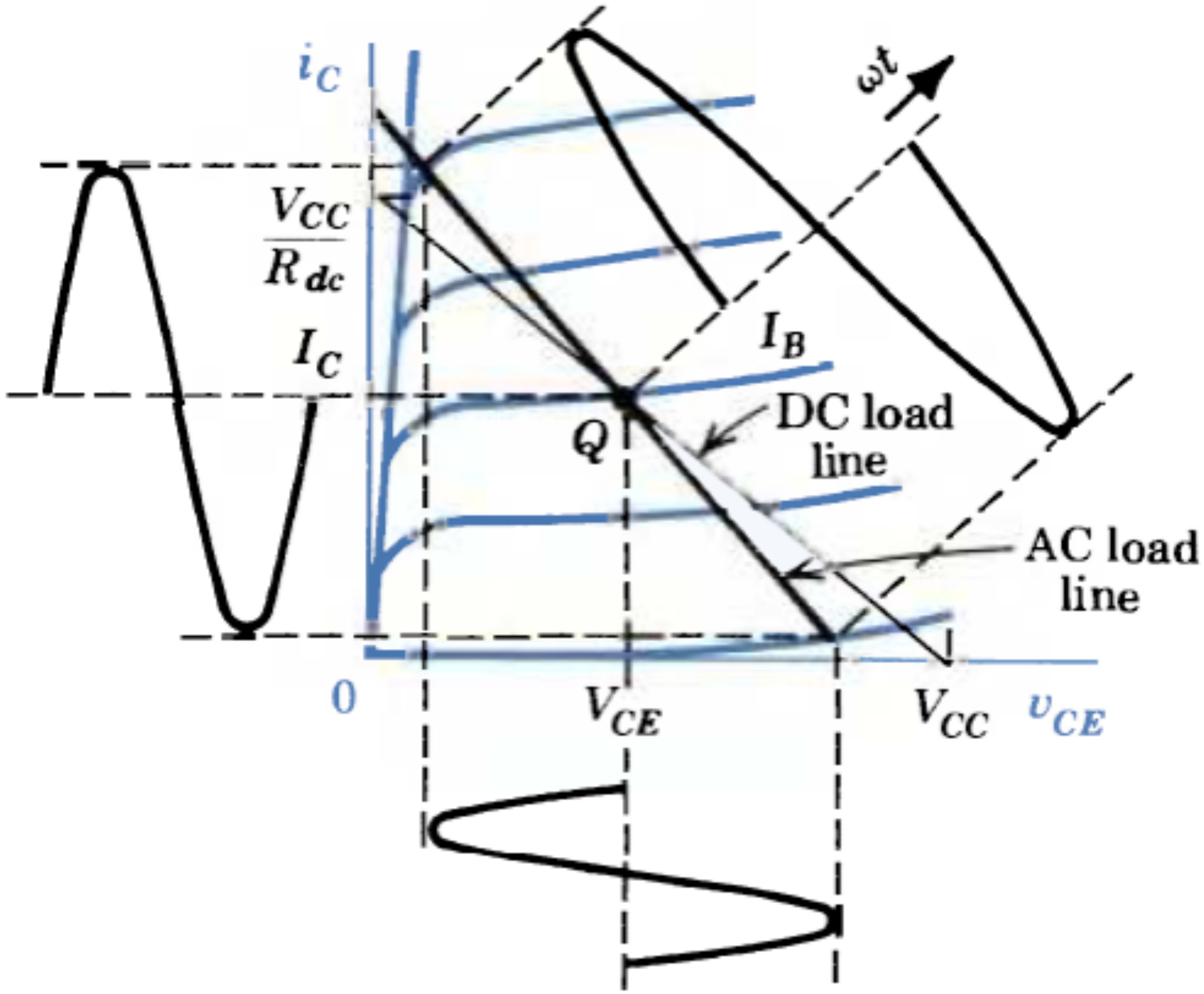
C_{C1} and C_{C2} isolate the DC bias currents from the AC signal source.
C_E offers low impedance to AC and prevents undesirable AC voltage across R_E

Assumption :
V_i does not make I_b change enough to move from away from active region.
The I_b lines on o/p characteristics, are evenly spaced.

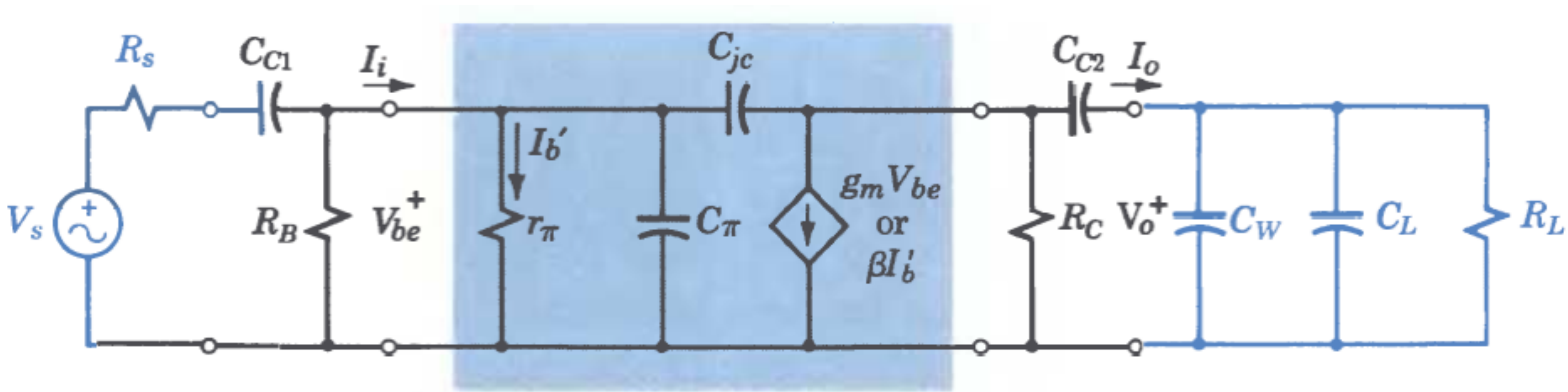
The total response is
Response to Vcc + Response to Vi.
Response to Vcc = Q point
Response to Vi = Variation about Q-point

CE Amplifier: The load line





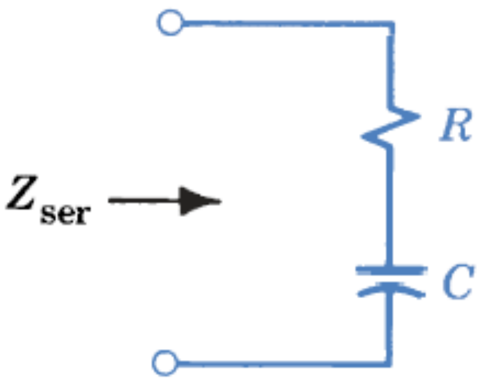
General Small Signal r-pi model of CE Amplifier



C_π – Diffusion capacitance of the forward biased base-emitter junction
C_{jc} – Junction capacitance of the reverse biased base-collector junction
C_W – Wiring Capacitance
C_L – Capacitance of the load

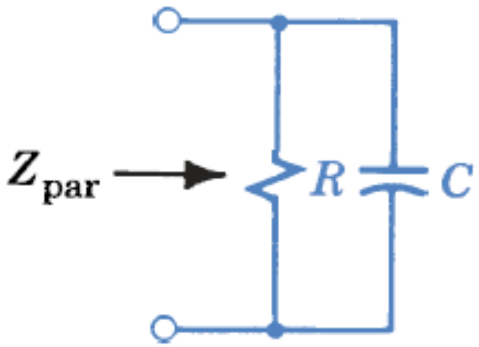
All of them have large C values

Refresher: Series RC and Parallel RC Impedance



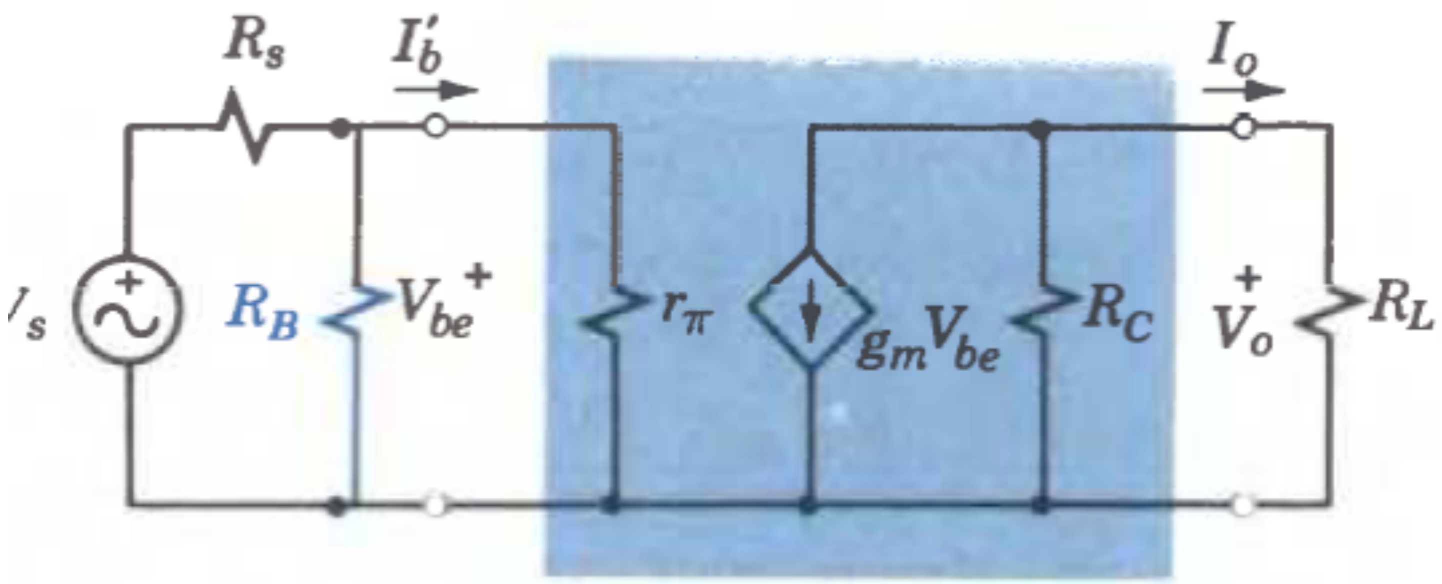
	Low freq.	Mid Freq.	High freq.
	ωCR<0.1		ωCR>10
Z_{ser}	High, f(R,C)	R	R
Z_{par}	R	R	Low f(R,C)

$$Z_{ser} = \sqrt{R^2 + (1/\omega C)^2} = R\sqrt{1 + (1/\omega CR)^2}$$



$$Z_{par} = \frac{1}{\sqrt{(1/R)^2 + (\omega C)^2}} = \frac{R}{\sqrt{1 + (\omega CR)^2}}$$

Small Signal r-pi model for Mid-frequency

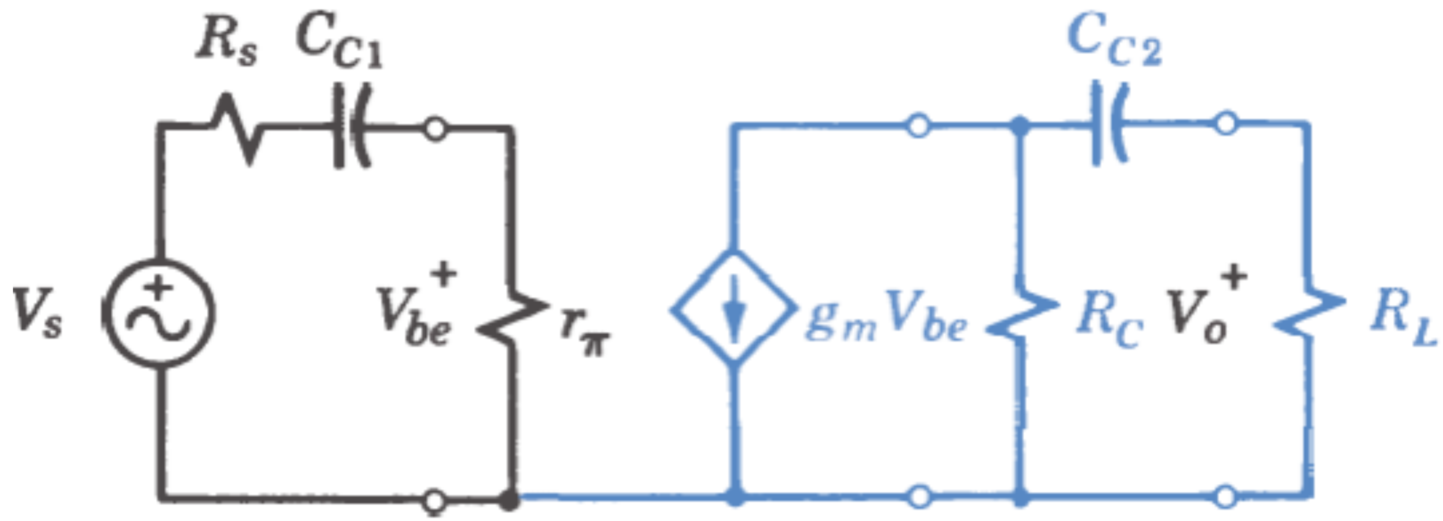


In mid frequencies, series capacitors are shorted.
Shunt capacitors are open.
Capacitances internal to the transistors have high impedance (low capacitance)
Assuming :

$$r_\pi \ll R_B \ll \beta R_E$$
$$I_b = \frac{V_s}{r_\pi + R_s}$$

$$V_o = -I_c(R_C||R_L) = -\beta I_b R_o = -\beta \frac{R_o}{r_\pi + R_s} V_s$$
$$A_{VO} = \frac{V_o}{V_s} = -\beta \frac{R_o}{r_\pi + R_s}$$

Small Signal r-pi model for Low frequency

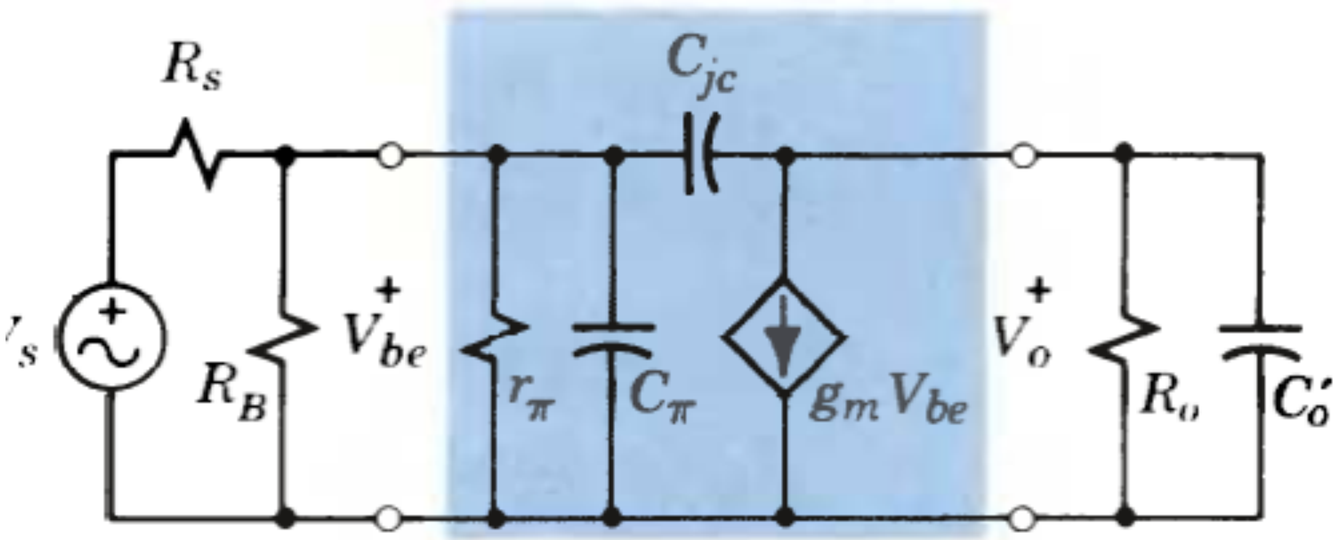


In low frequencies, series capacitors are NOT shorted.
Shunt capacitors are open.
Capacitances internal to the transistors have high impedance (low capacitance)

Acts like a high pass filter at both input and output ends.
Only small part of input enters into amplifier. Only small part of amplifier output appears across load.

In effect- Gain reduces as frequency is reduced.

Small Signal r-pi model for High frequency



In high frequencies, series capacitors are shorted.
Shunt capacitors are NOT open.
Capacitances internal to the transistors cannot be ignored.

Acts like a low pass filter at both input and output ends.
Only small part of input enters into amplifier. Only small part of amplifier output appears across load.

In effect- Gain reduces as frequency is increased.

Overall Frequency Response Characteristic of a CE Amplifier