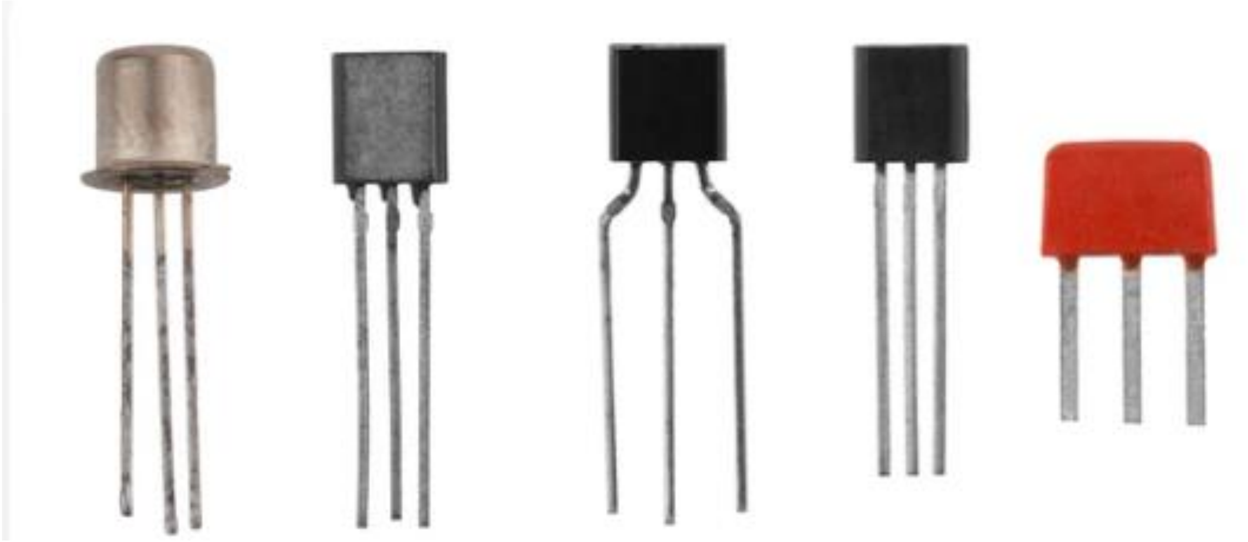
Electronic Circuits (1) EEC2103

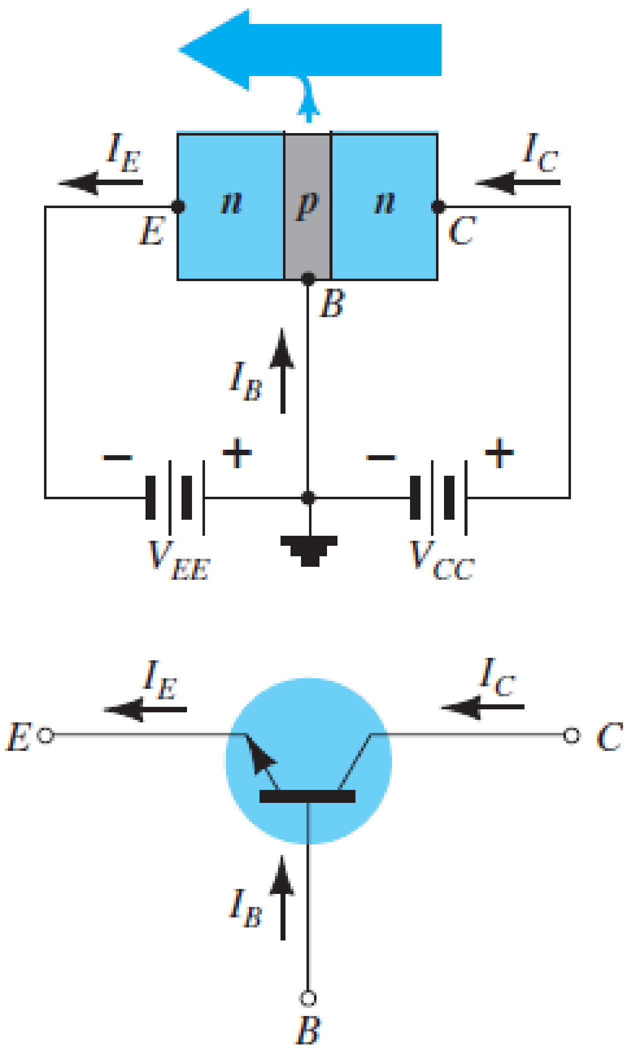


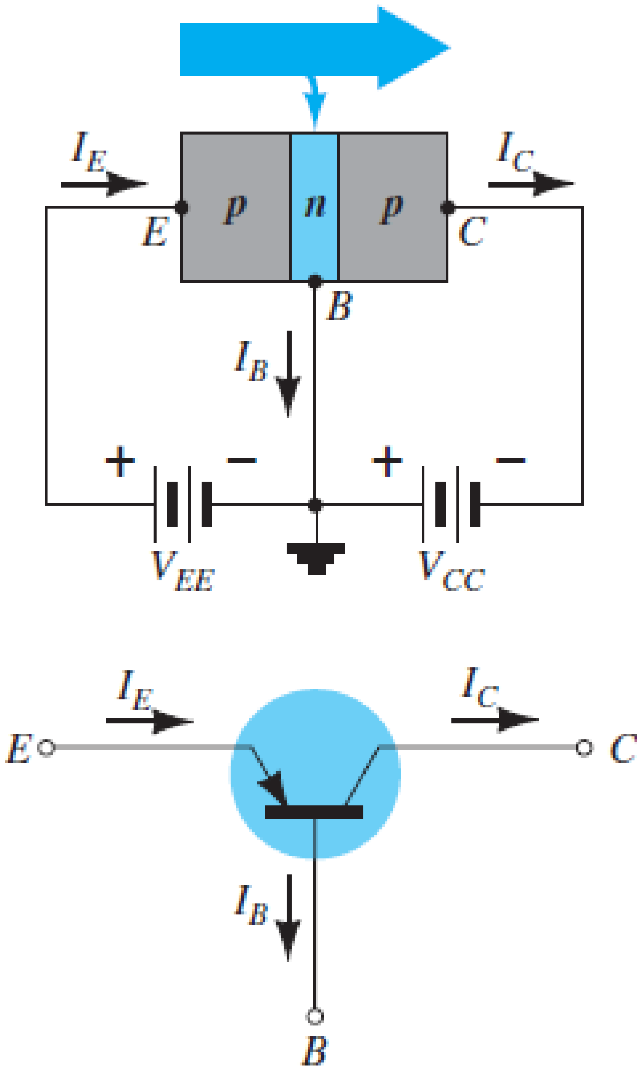
LEC (2) BJT Part 2

DC Bias – AC analysis

Dr. Nancy Alshaer

Characteristic Curves \ CB configuration



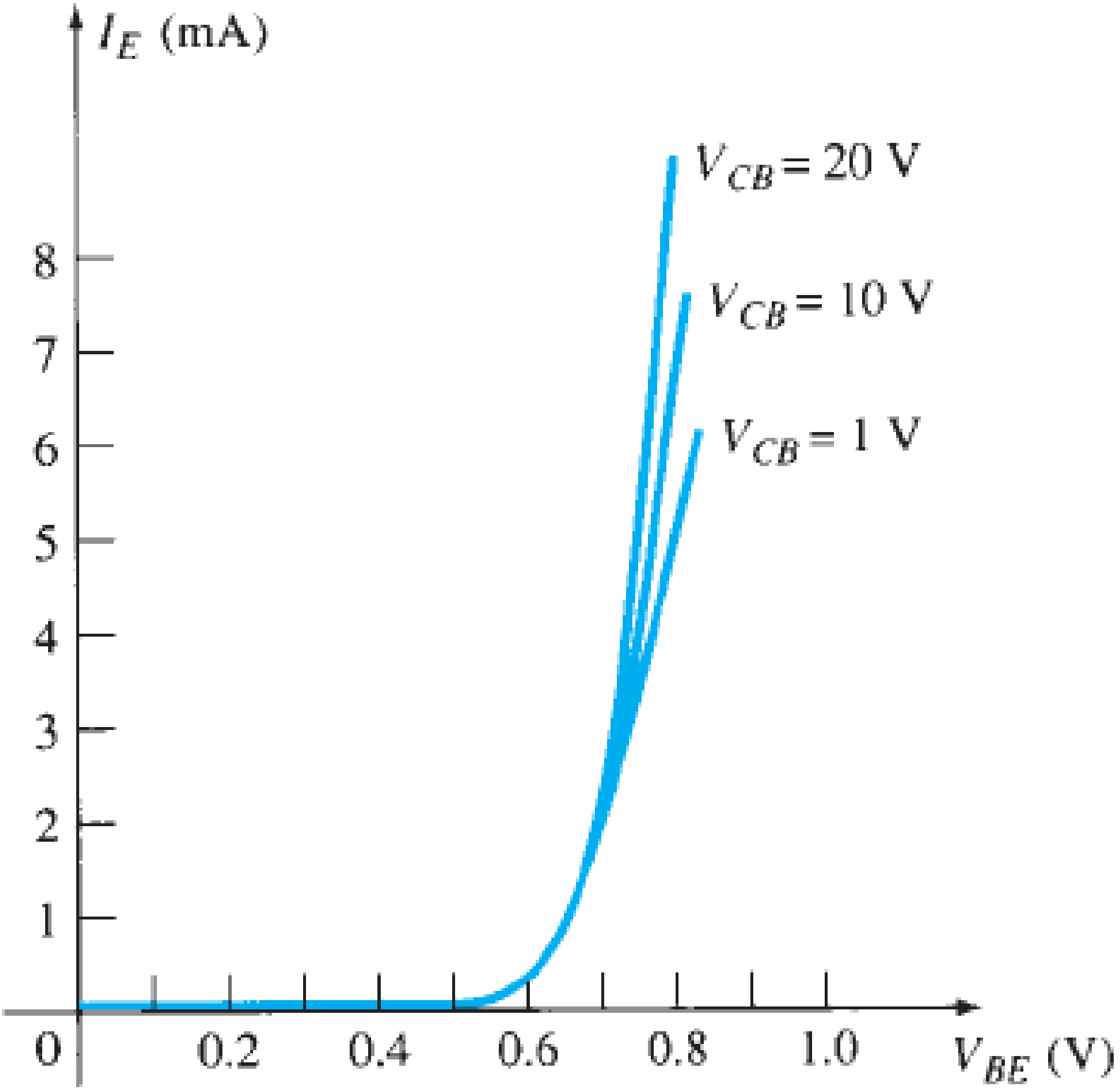


Characteristic Curves \ CB configuration \ Input

- Emitter-base junction is forward bias eand the input is applied to the emitter . So, there is an exponential relation between VBE and IE

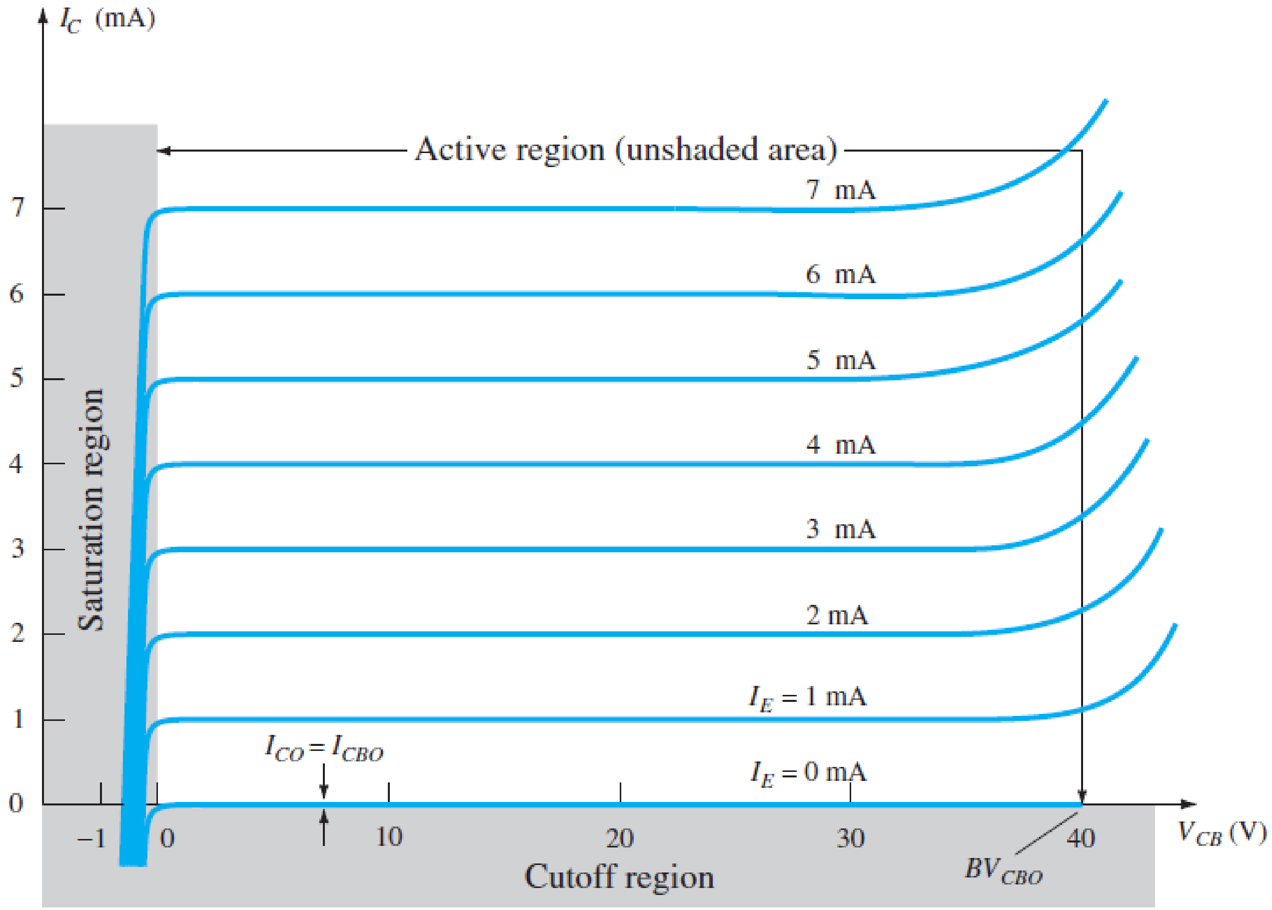
How the increase in V_{CB} affects I_E?

- Constant VBE, VCB ↑ (reverse bias) => Early effect => effective- width of the base ↓ => recombination ↓ => IE ↑



Characteristic Curves \ CB configuration \ Output

- **Early Effect:** The curves exhibit a slight upward slope in the active region (ideal curve it appears straight). This is due to the Early Effect, which causes a slight increase in IC as VCB increases.
- **Current Source Effect**: This means that the collector current (IC) remains relatively constant for a given emitter current (IE), regardless of changes in VCB within the active region.
- Compare the performance of the CB configuration with that of CE configuration.



$$I_C \cong I_E$$

Characteristic Curves \ CB configuration \ Output

Alpha (α)

DC Mode In the dc mode the levels of I_C and I_E due to the majority carriers are related by a quantity called *alpha* and defined by the following equation:

$$\boxed{\alpha_{dc} = \frac{I_C}{I_E}} \qquad (3.5)$$

Ideally, $\alpha_{dc} \cong 1$,. Practically $\alpha_{dc} = 0.9$ or0.998

AC Mode For ac situations where the point of operation moves on the characteristic curve, an ac alpha is defined by

$$\boxed{\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB=\text{constant}}}} \qquad (3.7)$$

The ac alpha is formally called the *common-base, short-circuit, amplification factor*.

Characteristic of CB transistor amplifier

- Low input resistance
- Very high output resistance.
- High voltage gain
- Current gain less than unity (ideally=1)
- Input and output signals are in phase

- It is used for impedance matching in circuits with very low output resistances to those with a high input resistance.

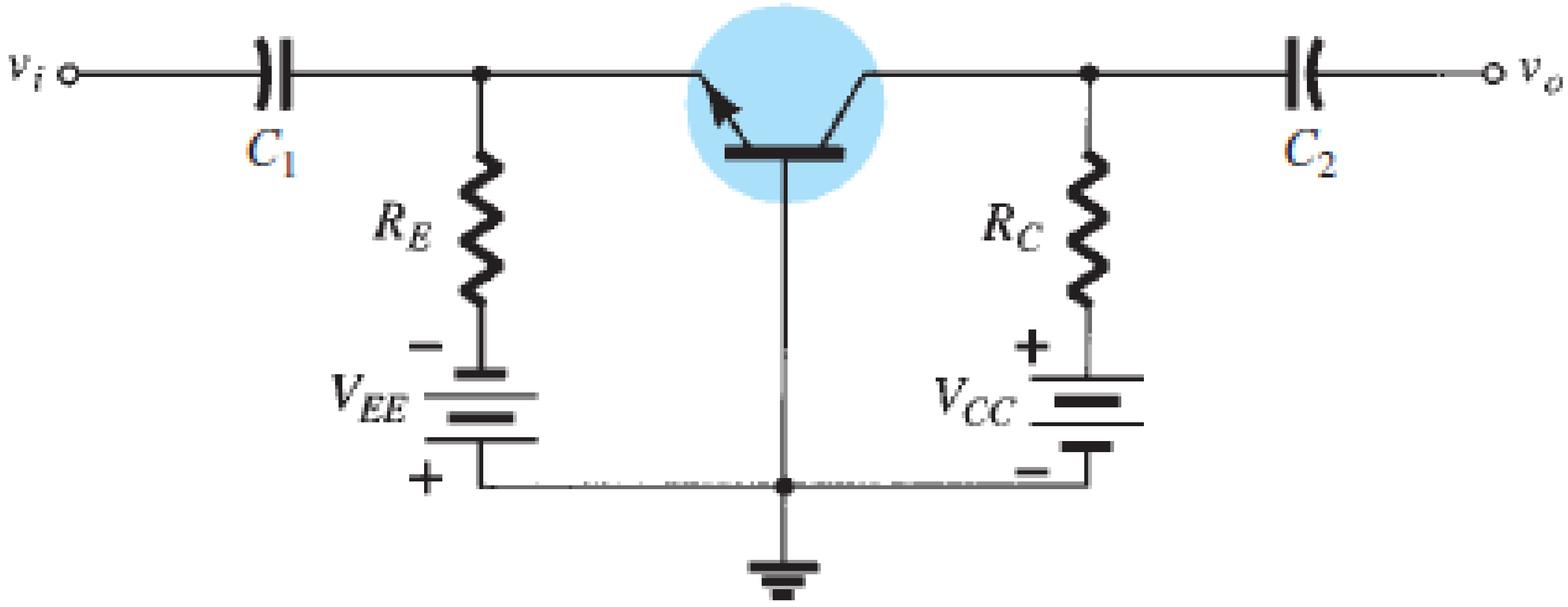
Circuit 1
Low output Ro

CB
Low Rin, high Ro

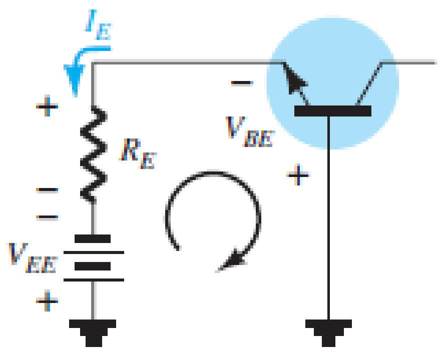
Circuit 2
High input Rin

DC Biasing of CB configuration

Common Base Bias Circuit:



DC Biasing of CB configuration : Common Base Bias Circuit



Input dc equivalent of
of figure in previous slide

Applying Kirchhoff's voltage law will result in

$$-V_{EE} + I_E R_E + V_{BE} = 0$$

$$\boxed{I_E = \frac{V_{EE} - V_{BE}}{R_E}}$$

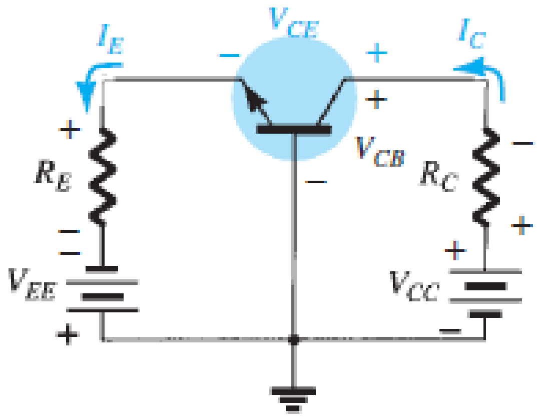
Applying Kirchhoff's voltage law to the entire outside perimeter of the network of Fig. below will result in

$$-V_{EE} + I_E R_E + V_{CE} + I_C R_C - V_{CC} = 0$$

and solving for V_{CE}: $\quad V_{CE} = V_{EE} + V_{CC} - I_E R_E - I_C R_C$

Because $\quad I_E \cong I_C$

$$\boxed{V_{CE} = V_{EE} + V_{CC} - I_E(R_C + R_E)}$$



Determining V_{CE} and V_{CB}.

The voltage V_{CB} can be found by applying Kirchhoff's voltage law to the output loop of Fig 4.51 to obtain:

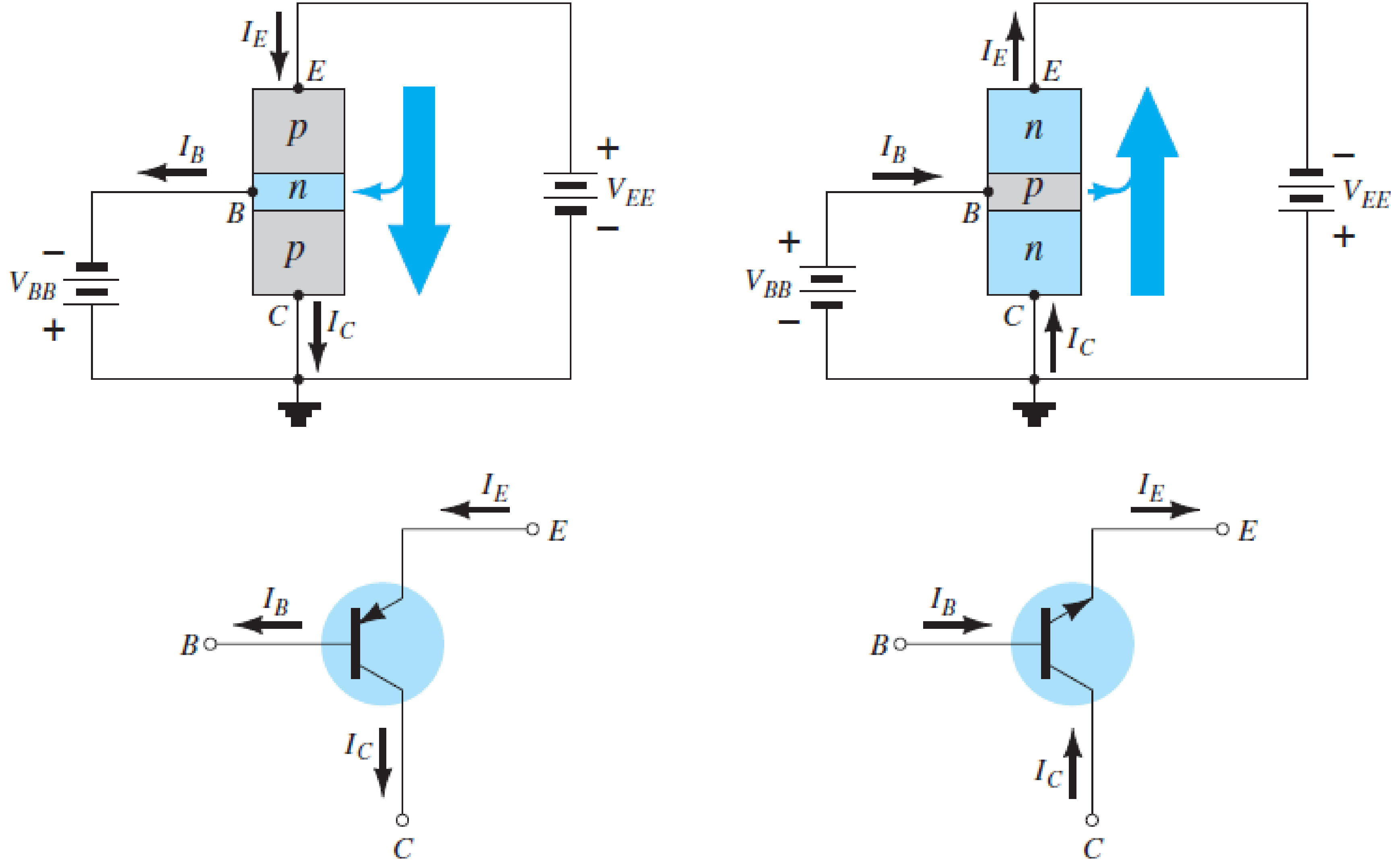
$$V_{CB} + I_C R_C - V_{CC} = 0$$

or $\quad V_{CB} = V_{CC} - I_C R_C$

Using $\quad I_C \cong I_E$

we have $\quad \boxed{V_{CB} = V_{CC} - I_C R_C}$

CC transistor amplifier



Characteristic of CC transistor amplifier

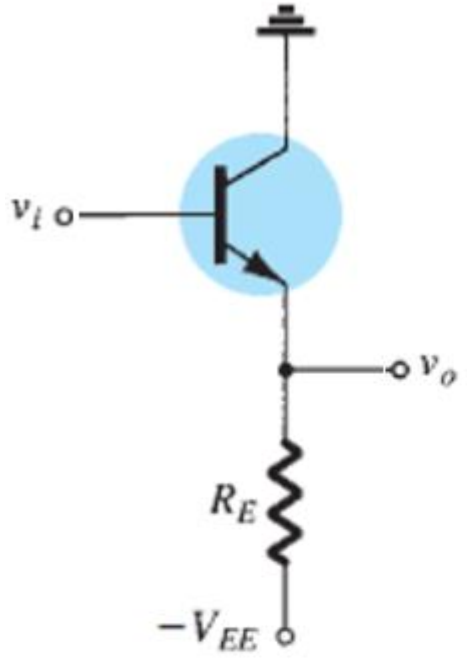
The input is connected to ------

The base

- The output is connected to -------

The emitter

- Why is CC amplifier called emitter follower amplifier?



Because the output voltage signal at the emitter is approximately equal to the voltage signal input on the base

Characteristic of CC transistor amplifier

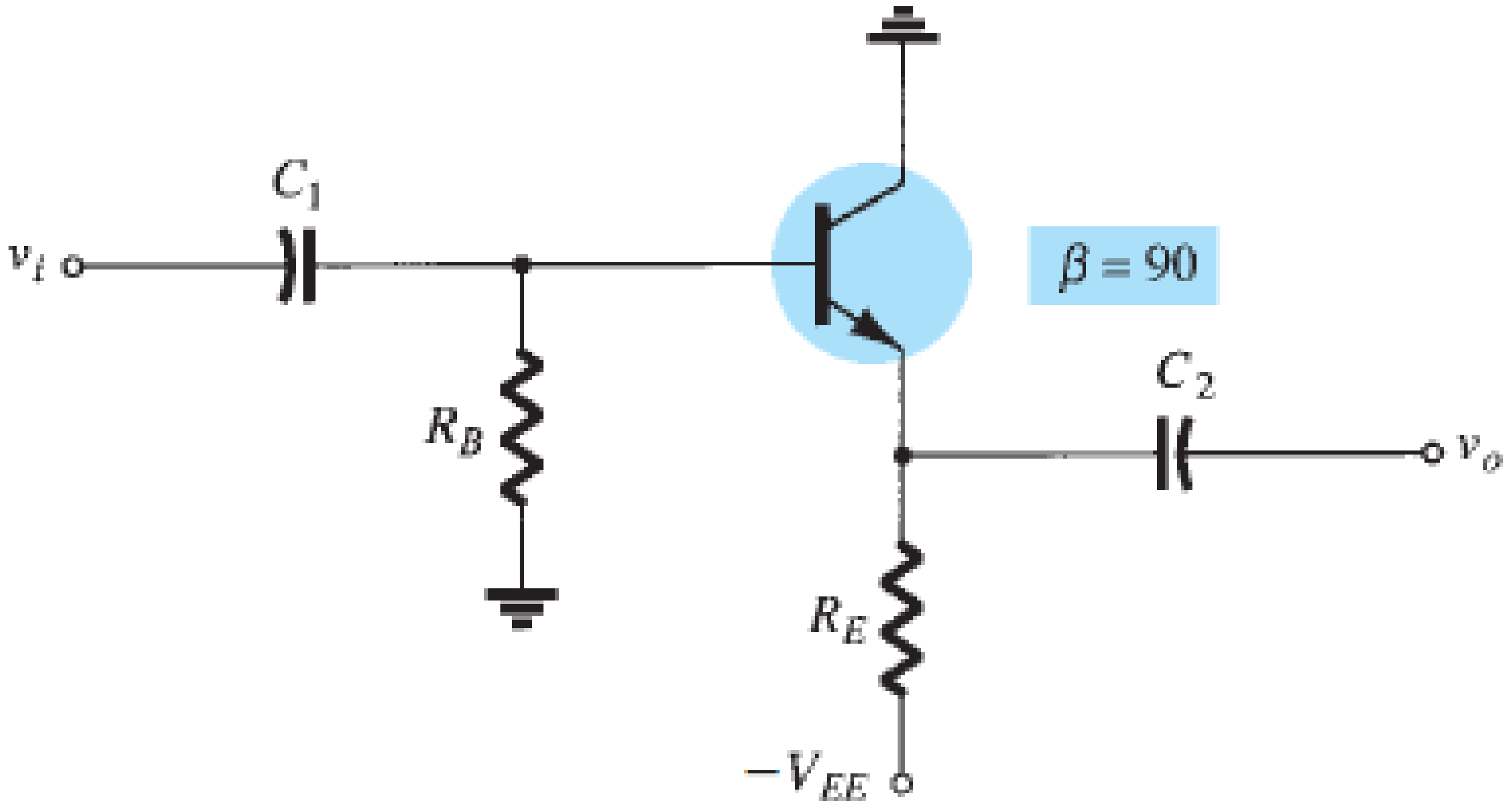
Parameter	Characteristics
Voltage gain	unity
Current gain	High
Input or output phase relationship	Zero degree
Input resistance	High
Output resistance	Low

- This amplifier is used as an impedance matching circuit.
- The high current gain combined with near-unity voltage gain makes this circuit a great voltage buffer
- It is also used for circuit isolation.

By providing a high input impedance, the CC amplifier can isolate the driving stage from the load, preventing loading effects.

DC Biasing of CC configuration

Common Collector Bias Circuit:



DC Biasing of CC configuration: Common Collector Bias Circuit

$$-I_B R_B - V_{BE} - I_E R_E + V_{EE} = 0$$

and using $I_E = (\beta + 1)I_B$

$$I_B R_B + (\beta + 1)I_B R_E = V_{EE} - V_{BE}$$

so that

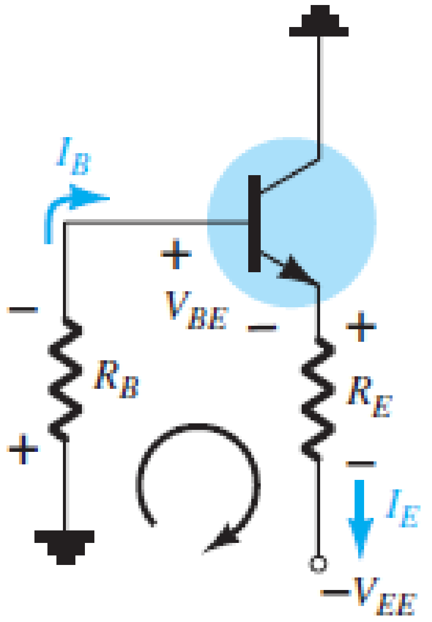
$$\boxed{I_B = \frac{V_{EE} - V_{BE}}{R_B + (\beta + 1)R_E}}$$

For the output network, an application of Kirchhoff's voltage law will result in

$$-V_{CE} - I_E R_E + V_{EE} = 0$$

and

$$\boxed{V_{CE} = V_{EE} - I_E R_E}$$



dc equivalent of
fig. in previous slide

Note: $I_E = I_C + I_B = \beta\ I_B + I_B = (\beta+1)\ I_B$

Comparison of the 3 BJT Configurations

Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Shift	0^o	180^o	0^o
Voltage Gain	High	Medium	Unity
Current Gain	Unity	Medium	High

BJT AC Analysis

Amplification in the AC Domain

- It was demonstrated in the previous lecture that the transistor can be employed as an amplifying device.
- That is, the output sinusoidal signal is greater than the input sinusoidal signal, or stated another way, the output ac power is greater than the input ac power.
- The question then arises as: how the ac power output can be greater than the input ac power?!
- Conservation of energy dictates that over time the total power output, P_o , of a system cannot be greater than its power input, P_i , and that the efficiency defined by $\eta = Po/Pi$ cannot be greater than 1.

Amplification in the AC Domain

- The factor missing from the discussion above that permits an ac power output greater than the input ac power is the applied dc power.
- It is the principal contributor to the total output power even though part of it is dissipated by the device and resistive elements.
- In other words, there is an "exchange" of dc power to the ac domain that permits establishing a higher output ac power.
- In fact, a conversion efficiency is defined by $\eta = P_{o(ac)}/P_{i(dc)}$, where $P_{o(ac)}$ is the ac power to the load and $P_{i(dc)}$ is the dc power supplied.

DC and AC Analysis

- ***The superposition theorem is applicable for the analysis and design of the dc and ac components of a BJT network, permitting the separation of the analysis of the dc and ac responses of the system.***
- In other words, one can make a complete dc analysis of a system before considering the ac response. Once the dc analysis is complete, the ac response can be determined using a completely ac analysis.
- It happens, however, that one of the components appearing in the ac analysis of BJT networks will be determined by the dc conditions, so there is still an important link between the two types of analysis.

DC and AC Analysis

- The peak value of the oscillation in the output circuit is controlled by the established dc level.
- Any attempt to exceed the limit set by the dc level will result in a "clipping" (flattening) of the peak region at the high and low end of the output signal.
- In general, therefore, proper amplification design requires that the dc and ac components be sensitive to each other's requirements and limitations.

Transistor Modeling

- Why do we need a model for the transistor? (Hint: what about the diode model)

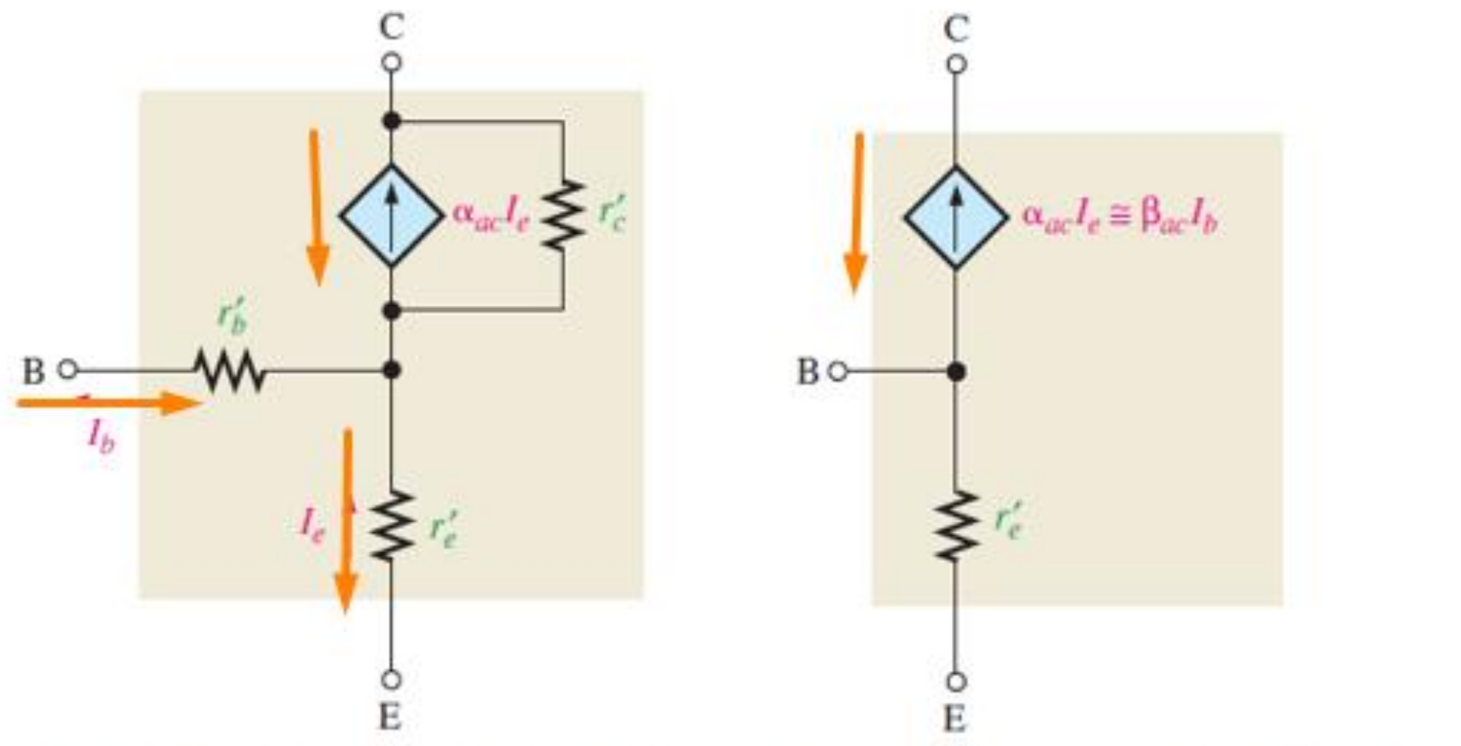
Transistor Modeling

- ***A model is a combination of circuit elements, properly chosen, that best approximates the actual behavior of a semiconductor device under specific operating conditions.***
- The key to transistor small-signal analysis is the use of the equivalent circuits (models) .
- The equivalent model is used to find the important ac parameters for an amplifier (A_v, A_i, R_i, R_o).

Transistor AC Models

- A transistor model circuit uses various internal transistor parameters to represent its operation.
- Transistor models are described in this course based on **resistance or r parameters**.
- Another system of parameters, called **h parameters**, is briefly described.

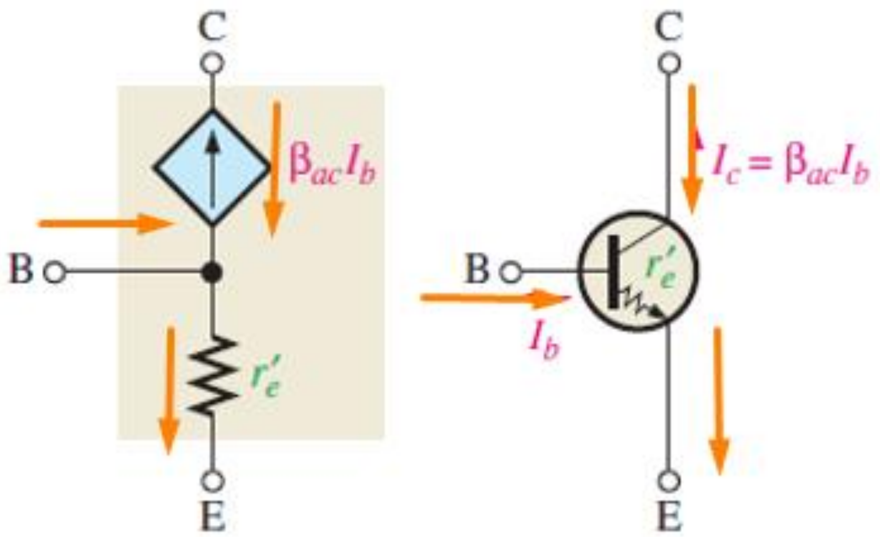
r-Parameter Transistor Model



(a) Generalized *r*-parameter model for a BJT (b) Simplified *r*-parameter model for a BJT

r PARAMETER	DESCRIPTION
α_{ac}	ac alpha (I_c/I_e)
β_{ac}	ac beta (I_c/I_b)
r'_e	ac emitter resistance
r'_b	ac base resistance
r'_c	ac collector resistance

r-Parameter Transistor Model



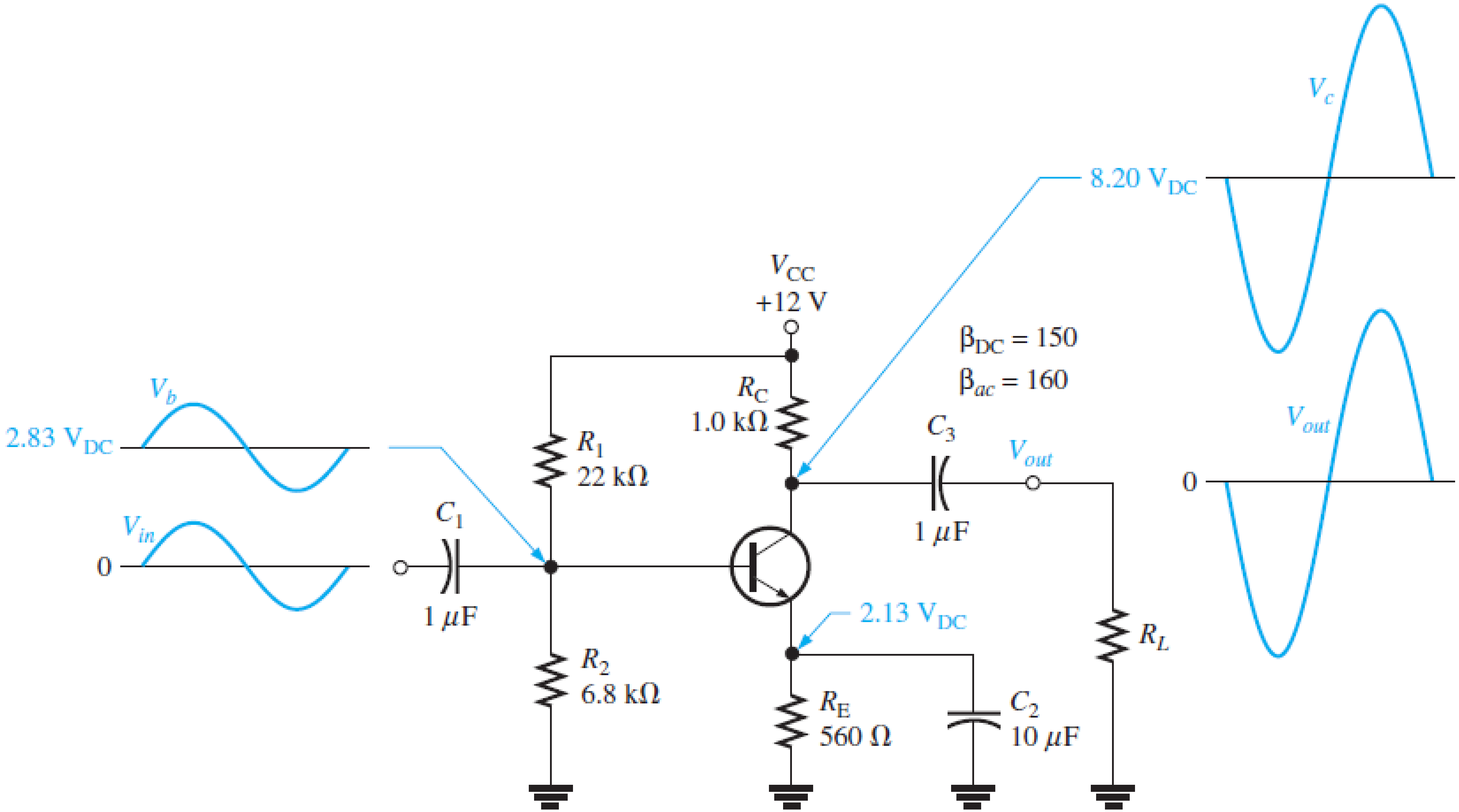
Relation of transistor symbol to *r*-parameter model.

based on an ambient temperature of 20°C.

$$r'_e \cong \frac{25\text{ mV}}{I_E}$$

Analysis of CE Amplifier

Common Emitter Amplifier



Common Emitter Amplifier

- DC analysis (determine Q point, i.e., $I_C \cong I_E$ and V_{CE})
- AC analysis
- Input resistance
- Input voltage
- Output resistance
- Voltage gain
- Overall voltage gain
- Voltage gain without the bypass capacitor
- Voltage gain with load resistance
- Current gain
- Floyd page 279-291

Report: deduce all the above relations

Common Emitter Amplifier / DC analysis

A dc equivalent circuit is developed by:

- Removing the coupling and bypass capacitors

  Because they appear **open** as far as the dc bias is concerned.

  This also removes the **load resistor** and **signal source.**

Common Emitter Amplifier / DC analysis

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(6.8\text{ k}\Omega)(22\text{ k}\Omega)}{6.8\text{ k}\Omega + 22\text{ k}\Omega} = 5.19\text{ k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{6.8\text{ k}\Omega}{6.8\text{ k}\Omega + 22\text{ k}\Omega}\right)12\text{ V} = 2.83\text{ V}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}} = \frac{2.83\text{ V} - 0.7\text{ V}}{560\ \Omega + 34.6\ \Omega} = 3.58\text{ mA}$$

$$I_C \cong I_E = 3.58\text{ mA}$$

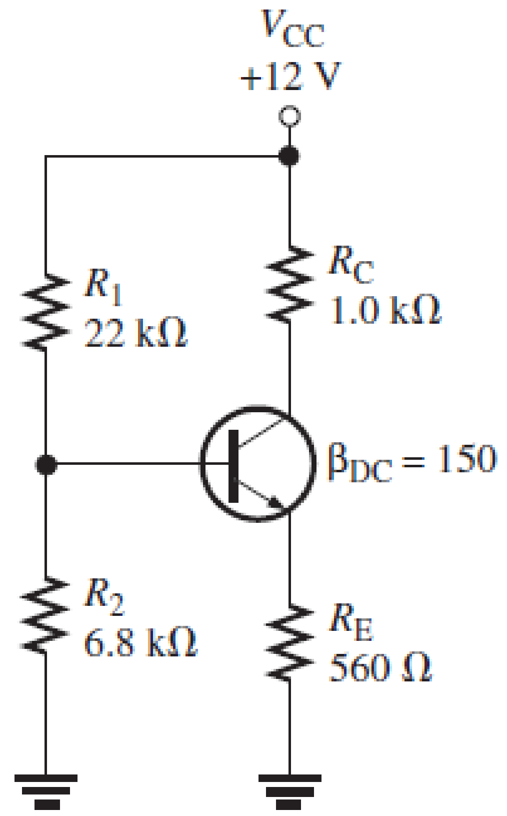
$$V_E = I_E R_E = (3.58\text{ mA})(560\ \Omega) = 2\text{ V}$$

$$V_B = V_E + 0.7\text{ V} = 2.7\text{ V}$$

$$V_C = V_{CC} - I_C R_C = 12\text{ V} - (3.58\text{ mA})(1.0\text{ k}\Omega) = 8.42\text{ V}$$

$$V_{CE} = V_C - V_E = 8.42\text{ V} - 2\text{ V} = 6.42\text{ V}$$

VCE=VCC-ICRC



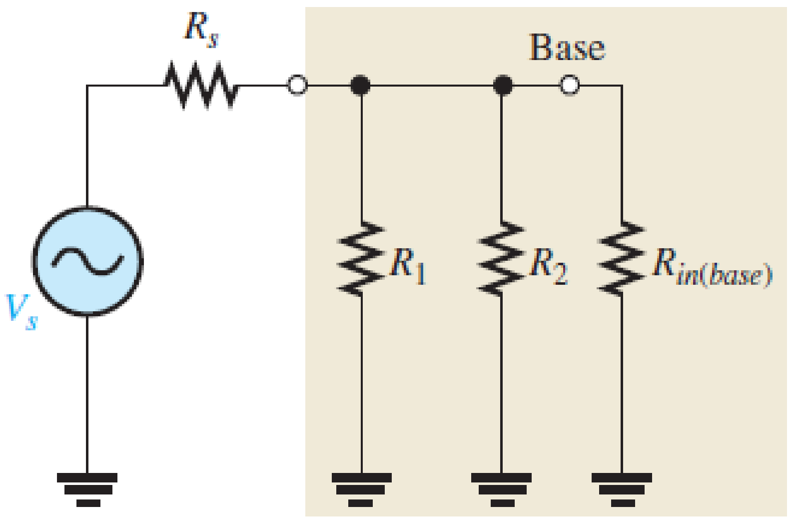
Common Emitter Amplifier / AC analysis

To analyze the ac signal operation of an amplifier, an ac equivalent circuit is developed as follows:

1. The capacitors C_1, C_2, and C_3 are replaced by effective shorts because their values are selected so that X_C is negligible at the signal frequency and can be considered to be 0 Ω.

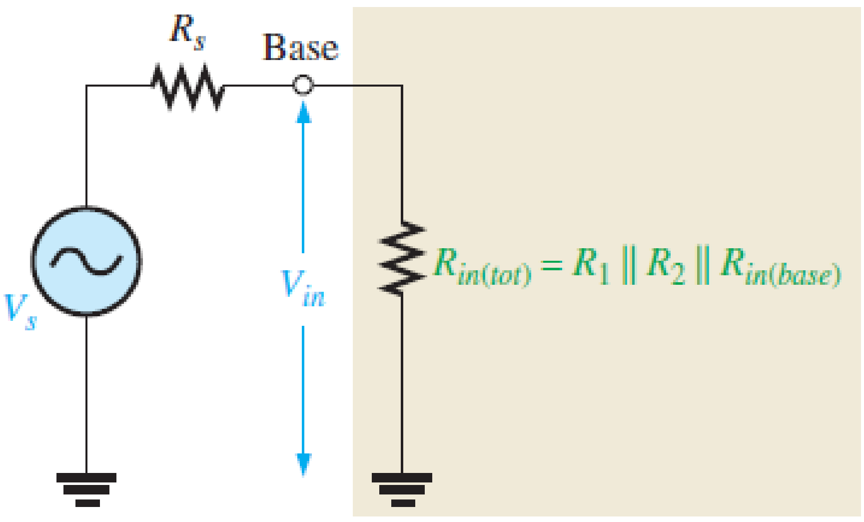
2. The dc source is replaced by ground.

Common Emitter Amplifier / input voltage



(a)

AC equivalent of the base circuit



(b)

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)}$$

Input voltage

$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}}\right) V_s$$

If $R_s \ll R_{in(tot)}$, then $V_b \cong V_s$ where V_b is the input voltage, V_{in}, to the amplifier.

Common Emitter Amplifier / input resistance at the base

$$R_{in(base)} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_b}$$

The base voltage is

$$V_b = I_e r'_e$$

and since $I_e \cong I_c$,

$$I_b \cong \frac{I_e}{\beta_{ac}}$$

Substituting for V_b and I_b,

$$R_{in(base)} = \frac{V_b}{I_b} = \frac{I_e r'_e}{I_e/\beta_{ac}}$$

Cancelling I_e,

$$\boldsymbol{R_{in(base)} = \beta_{ac} r'_e}$$

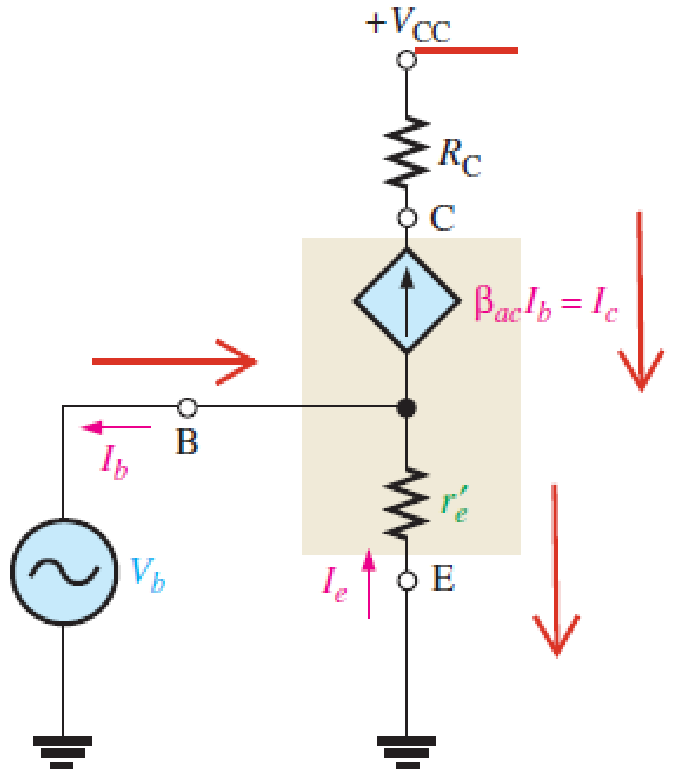


FIGURE 6–12

r-parameter transistor model (inside shaded block) connected to external circuit.

Common Emitter Amplifier / output Resistance

Output Resistance The **output resistance** of the common-emitter amplifier is the resistance looking in at the collector and is approximately equal to the collector resistor.

$$R_{out} \cong R_C \quad // R_L$$

Actually, $R_{out} = R_C \parallel r'_c$, but since the internal ac collector resistance of the transistor, r'_c, is typically much larger than R_C, the approximation is usually valid.

Common Emitter Amplifier / AC analysis

$$R_{in(tot)} = R_1 \| R_2 \| R_{in(base)}$$

$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}}\right)V_s$$

$$R_{in(base)} = \beta_{ac} r'_e$$

$$R_{out} \cong R_C \quad // R_L$$

Study Example 6-3 page 282

What is the relation between $R_{in(tot)}$ and R_s in this example?

Common Emitter Amplifier / AC analysis

- Voltage gain

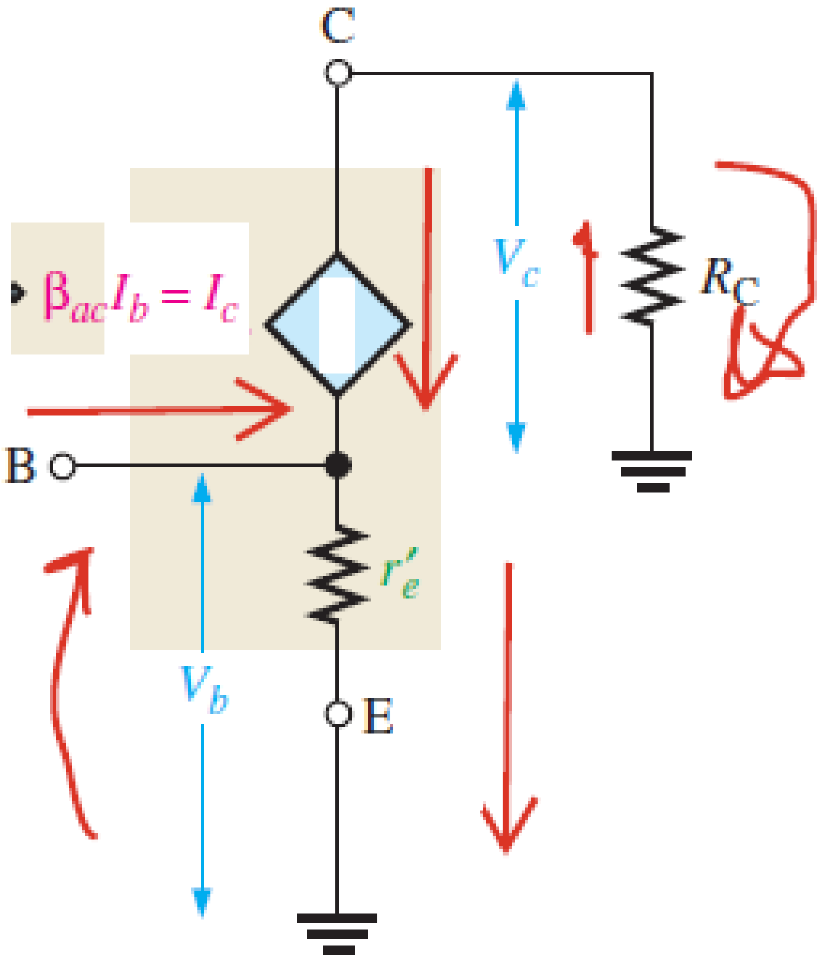
$Av=V_o/V_{in}=V_c/V_b=-I_c\ R_C/I_er_e=-I_eR_C/I_er_e$

$Av=-R_C/r_e$

The negative sign refers to --------

- The Overall Voltage Gain

$$A'_v = \left(\frac{V_c}{V_b}\right)\left(\frac{V_b}{V_s}\right) = \frac{V_c}{V_s}$$



Note: Rc=RC// RL

Common Emitter Amplifier / AC analysis

Effect of the Emitter Bypass Capacitor on Voltage Gain The emitter **bypass capacitor**, which is C_2 in Figure 6–8, provides an effective short to the ac signal around the emitter resistor, thus keeping the emitter at ac ground, as you have seen. With the bypass capacitor, the gain of a given amplifier is maximum and equal to R_C/r'_e.

The value of the bypass capacitor must be large enough so that its reactance over the frequency range of the amplifier is very small (ideally 0 Ω) compared to R_E. A good rule-of-thumb is that the capacitive reactance, X_C, of the bypass capacitor should be at least 10 times smaller than R_E at the minimum frequency for which the amplifier must operate.

$$10X_C \leq R_E$$

Study Example 6-4

Common Emitter Amplifier / AC analysis

Voltage Gain Without the Bypass Capacitor To see how the bypass capacitor affects ac voltage gain, let's remove it from the circuit in Figure 6–16 and compare voltage gains.

Without the bypass capacitor, the emitter is no longer at ac ground. Instead, R_E is seen by the ac signal between the emitter and ground and effectively adds to r'_e in the voltage gain formula.

$$\boxed{A_v = \frac{R_C}{r'_e + R_E}}$$

The effect of R_E is to decrease the ac voltage gain.

Add a resistance RE to the emitter in slid 31 and deduce the voltage gain relation without the bypass capacitor

Study Example 6-5

Common Emitter Amplifier / AC analysis

Effect of a Load on the Voltage Gain **A load** is the amount of current drawn from the output of an amplifier or other circuit through a load resistance. When a resistor, R_L, is connected to the output through the coupling capacitor C_3, as shown in Figure 6–17(a), it creates a load on the circuit. The collector resistance at the signal frequency is effectively R_C in parallel with R_L. Remember, the upper end of R_C is effectively at ac ground. The ac equivalent circuit is shown in Figure 6–17(b). The total ac collector resistance is

$$\boxed{R_c = \frac{R_C R_L}{R_C + R_L}}$$

Replacing R_C with R_c in the voltage gain expression gives

$$\boxed{A_v = \frac{R_c}{r'_e}}$$

When $R_c < R_C$ because of R_L, the voltage gain is reduced. However, if $R_L \gg R_C$, then $R_c \cong R_C$ and the load has very little effect on the gain.

Study Example 6-6

Common Emitter Amplifier / AC analysis

Stability of the Voltage Gain

Stability is a measure of how well an amplifier maintains its design values over changes in temperature or for a transistor with a different β. Although bypassing R_E does produce the maximum voltage gain, there is a stability problem because the ac voltage gain is dependent on r'_e since $A_v = R_C/r'_e$. Also, r'_e depends on I_E and on temperature. This causes the gain to be unstable over changes in temperature because when r'_e increases, the gain decreases and vice versa.

With no bypass capacitor, the gain is decreased because R_E is now in the ac circuit ($A_v = R_C/(r'_e + R_E)$). However, with R_E unbypassed, the gain is much less dependent on r'_e. If $R_E \gg r'_e$, the gain is essentially independent of r'_e because

$$A_v \cong \frac{R_C}{R_E}$$

Common Emitter Amplifier / AC analysis

Swamping r'_e to Stabilize the Voltage Gain *Swamping* is a method used to minimize the effect of r'_e without reducing the voltage gain to its minimum value. This method "swamps" out the effect of r'_e on the voltage gain. Swamping is, in effect, a compromise between having a bypass capacitor across R_E and having no bypass capacitor at all.

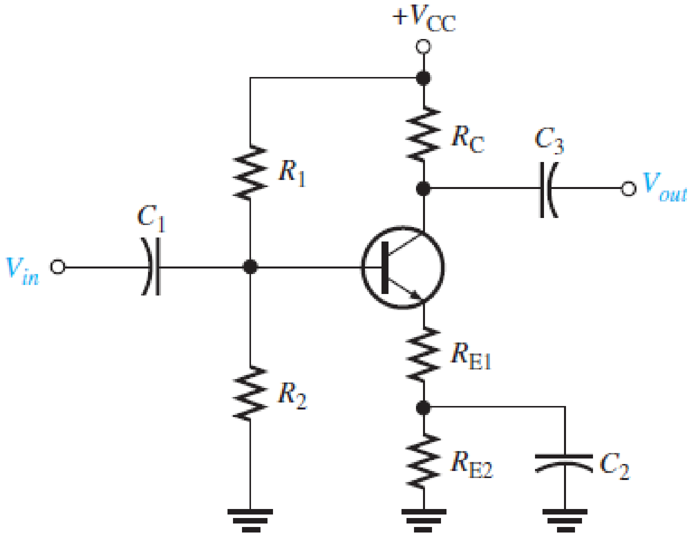
In a swamped amplifier, R_E is partially bypassed so that a reasonable gain can be achieved, and the effect of r'_e on the gain is greatly reduced or eliminated. The total external emitter resistance, R_E, is formed with two separate emitter resistors, R_{E1} and R_{E2}, as indicated in Figure 6–18. One of the resistors, R_{E2}, is bypassed and the other is not.

Both resistors ($R_{E1} + R_{E2}$) affect the dc bias while only R_{E1} affects the ac voltage gain.

$$A_v = \frac{R_C}{r'_e + R_{E1}}$$

If R_{E1} is at least ten times larger than r'_e, then the effect of r'_e is minimized and the approximate voltage gain for the swamped amplifier is

$$A_v \cong \frac{R_C}{R_{E1}}$$



Study Example 6-7

Common Emitter Amplifier / AC analysis

The Effect of Swamping on the Amplifier's Input Resistance The ac input resistance, looking in at the base of a common-emitter amplifier with R_E completely bypassed, is $R_{in} = \beta_{ac} r'_e$. When the emitter resistance is partially bypassed, the portion of the resistance that is unbypassed is seen by the ac signal and results in an increase in the ac input resistance by appearing in series with r'_e. The formula is

$$R_{in(base)} = \beta_{ac}(r'_e + R_{E1})$$

Study Example 6-8

Common Emitter Amplifier / Current gain

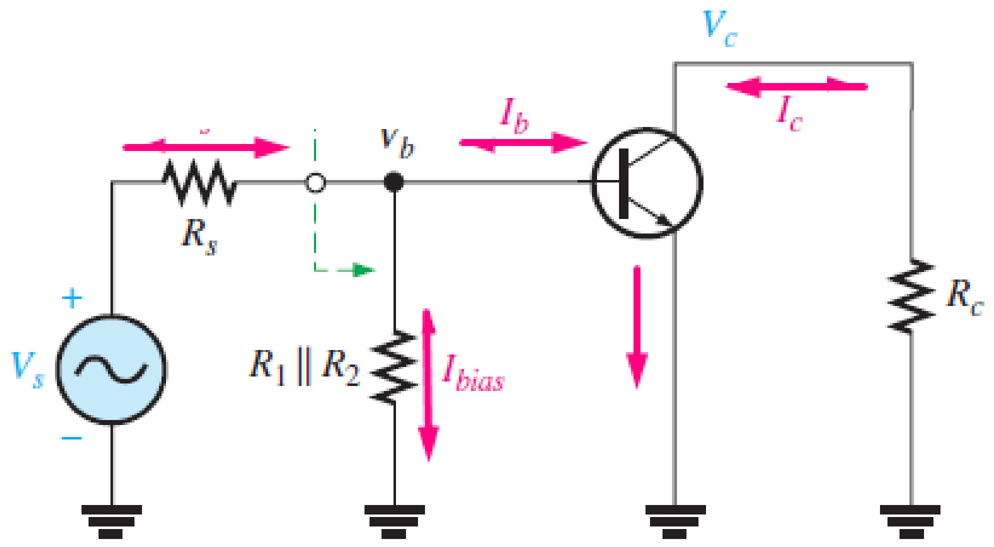
Current Gain

The current gain from base to collector is I_c/I_b or β_{ac}. However, the overall current gain of the common-emitter amplifier is

$$\boxed{A_i = \frac{I_c}{I_s}}$$

I_s is the total signal input current produced by the source, part of which (I_b) is base current and part of which (I_{bias}) goes through the bias circuit ($R_1 \parallel R_2$), as shown in Figure 6–24. The source "sees" a total resistance of $R_s + R_{in(tot)}$. The total current produced by the source is

$$\boxed{I_s = \frac{V_s}{R_s + R_{in(tot)}}}$$



Common Emitter Amplifier / Power gain

Power Gain

The overall power gain is the product of the overall voltage gain (A'_v) and the overall current gain (A_i).

$$A_p = A'_v A_i$$

where $A'_v = V_c/V_s$.