EE285 Electronics I

Amplifiers

Dr. Lasith Yasakethu

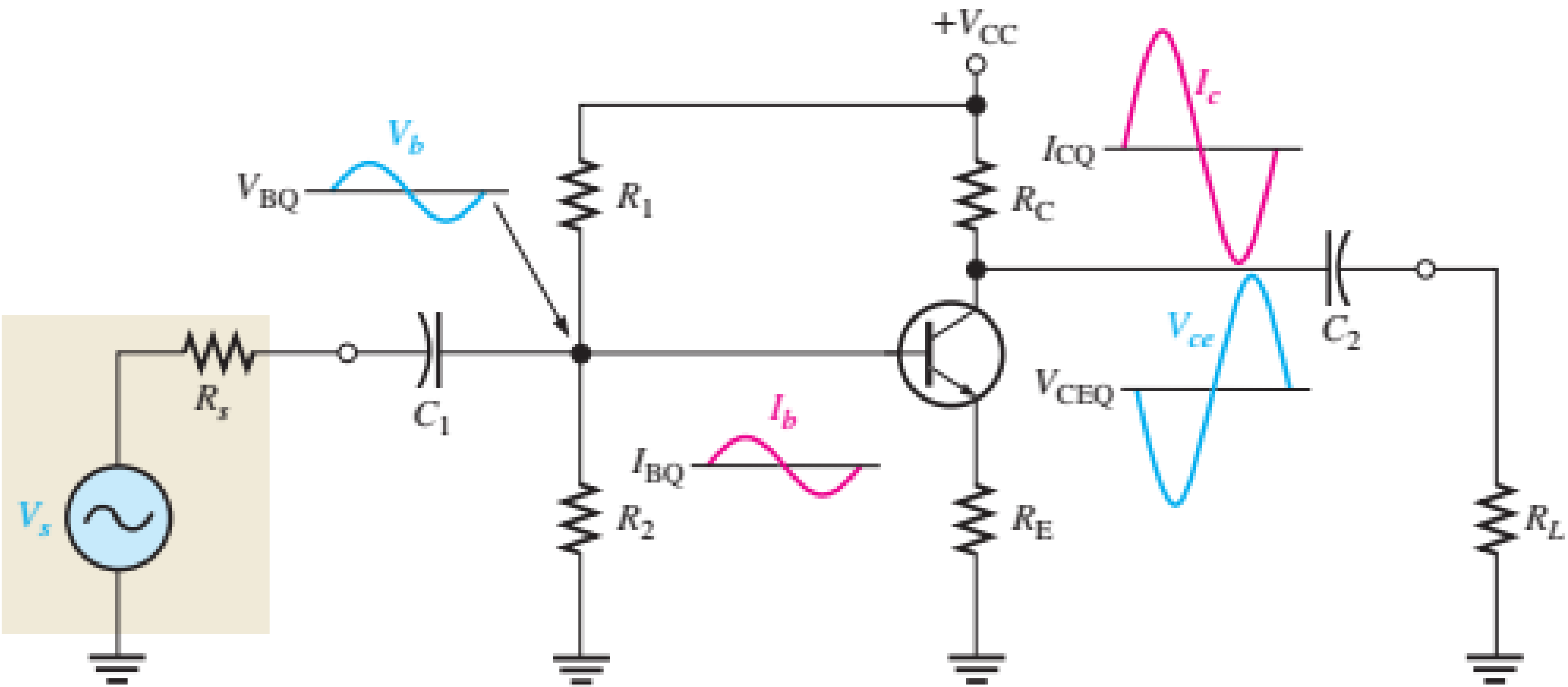
Amplifier Operation

- Notations
  - DC quantities are identified by nonitalic uppercase (capital) subscripts such as I_C, I_E, V_C, and V_{CE}
  - Lowercase italic subscripts are used to indicate ac quantities: for example, I_c , I_e , I_b , V_c , and V_{ce} (rms values are assumed unless otherwise stated)
  - Instantaneous quantities are represented by both lowercase letters and subscripts such as i_c , i_e , i_b , and v_{ce}
  - Lowercase subscripts are used to identify ac resistance values. For example, R_c is the ac collector resistance, and R_C is the dc collector resistance
  - Resistance values *internal* to the transistor use a lowercase *r'* to show it is an ac resistance. An example is the internal ac emitter resistance, r_e'.

Amplifier Operation

- The Linear Amplifier
  - A linear amplifier provides amplification of a signal without any distortion so that the output signal is an exact amplified replica of the input signal
  - A voltage-divider biased transistor with a sinusoidal ac source capacitively coupled to the base through C_1 and a load capacitively coupled to the collector through C_2 is shown in Figure
  - The capacitors ideally appear as shorts to the signal voltage
  - The sinusoidal source voltage causes the base voltage to vary sinusoidally above and below its dc bias level, V_{BQ}. The resulting variation in base current produces a larger variation in collector current because of the current gain of the transistor

Amplifier Operation



Amplifier Operation

- As the sinusoidal collector current increases, the collector voltage decreases.
- The collector current varies above and below its Q-point value, I_{CQ}, in phase with the base current.
- The sinusoidal collector-to-emitter voltage varies above and below its Q-point value, V_{CEQ}, out of phase with the base voltage
- A transistor always produces a **phase inversion** between the base voltage and the collector voltage

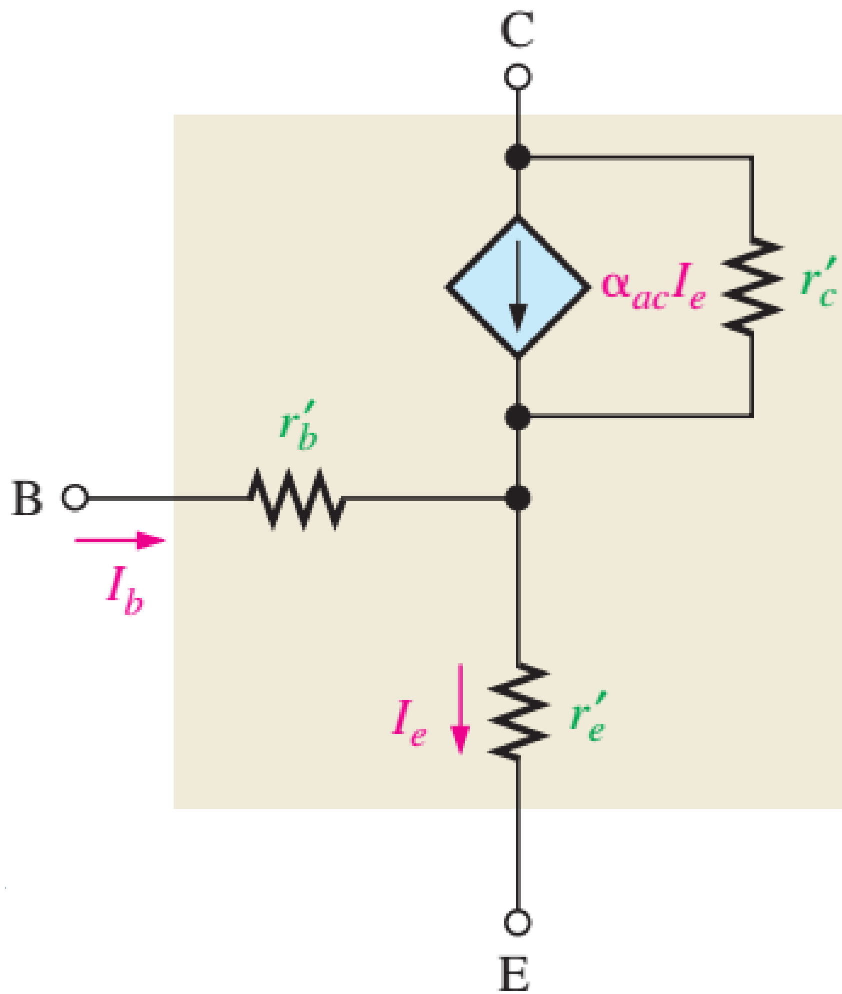
Transistor AC Models

- ***r* Parameters**
  - The five *r* parameters commonly used for BJTs are given in Table. The italic lowercase letter *r* with a prime denotes resistances internal to the transistor.

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

Transistor AC Models

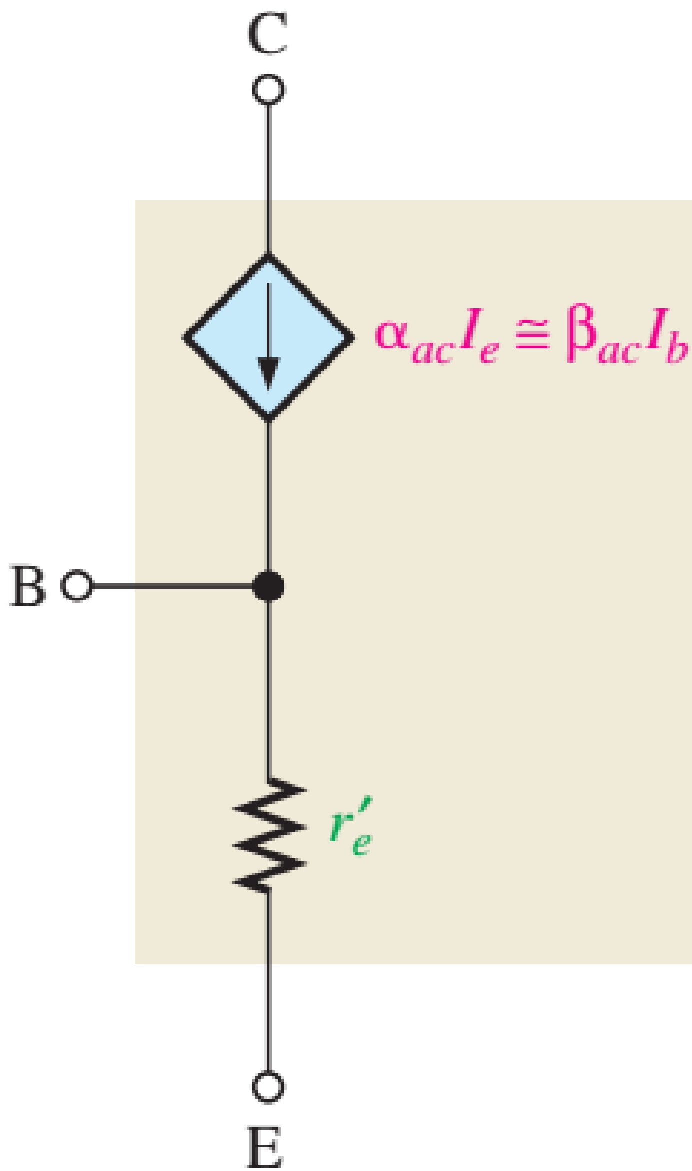
- ***r*-Parameter Transistor Model**
  - An ***r*-parameter** model for a BJT is shown in Figure



Transistor AC Models

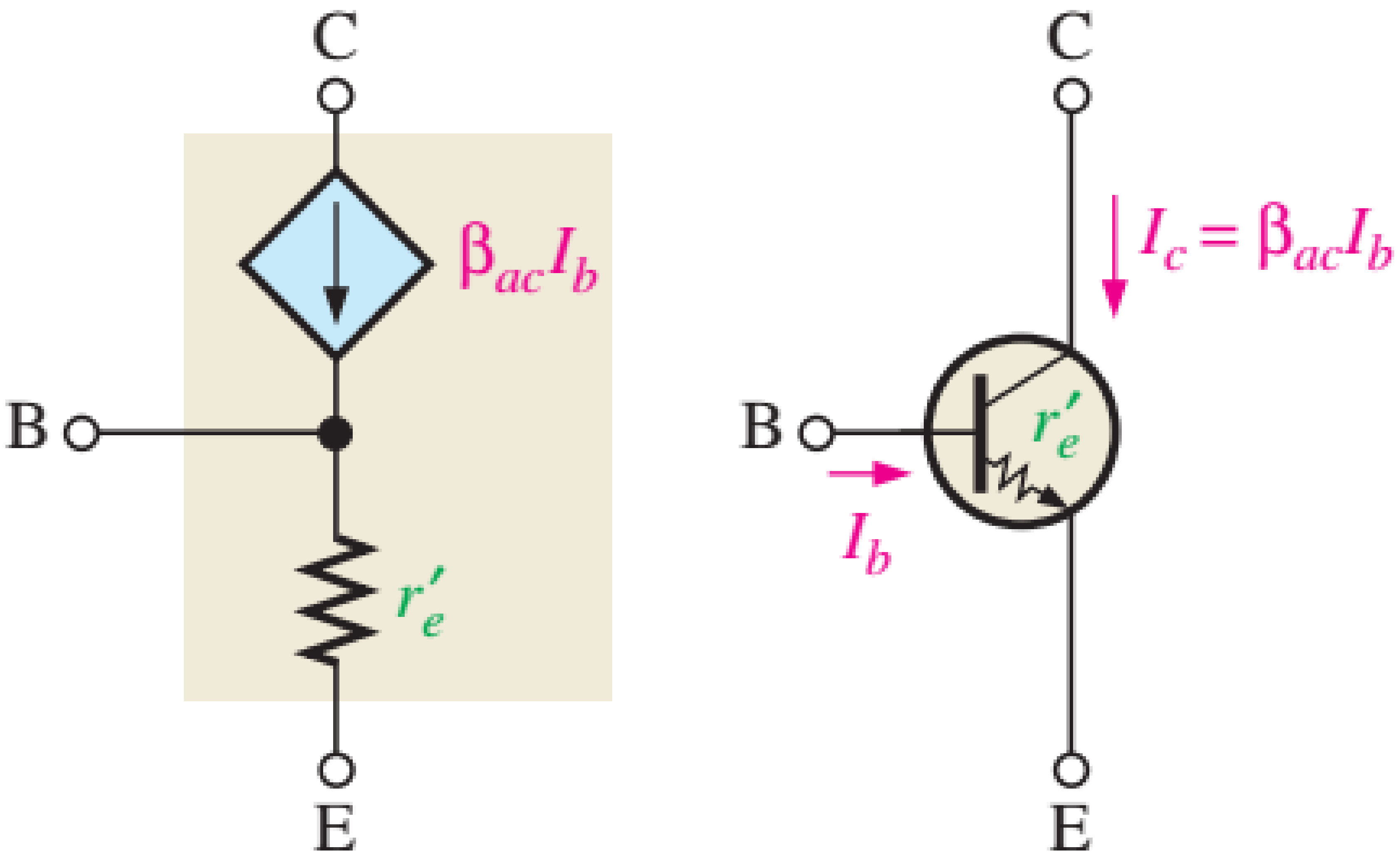
- For most general analysis work, it can be simplified as follows:
  - The effect of the ac base resistance (r_b') is usually small enough to neglect, so it can be replaced by a short
  - The ac collector resistance (r_c') is usually several hundred kilohms and can be replaced by an open
  - The resulting simplified *r*-parameter equivalent circuit is shown in Figure

Transistor AC Models



Transistor AC Models

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



Transistor AC Models

- **Determining r_e' by a Formula**
  - For amplifier analysis, the ac emitter resistance, r_e' is the most important of the *r* parameters
  - To calculate the approximate value of r_e' you can use the below equation

$$r'_e \cong \frac{25\ \mathrm{mV}}{I_{\mathrm{E}}}$$

  - This is temperature dependent and above formula is based on an ambient temperature of 20°C

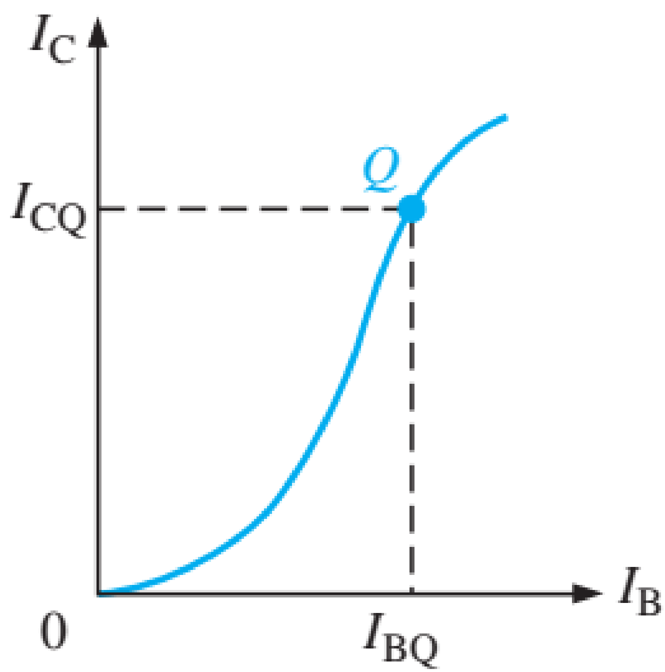
Transistor AC Models

Determine the r'_e of a transistor that is operating with a dc emitter current of 2 mA.

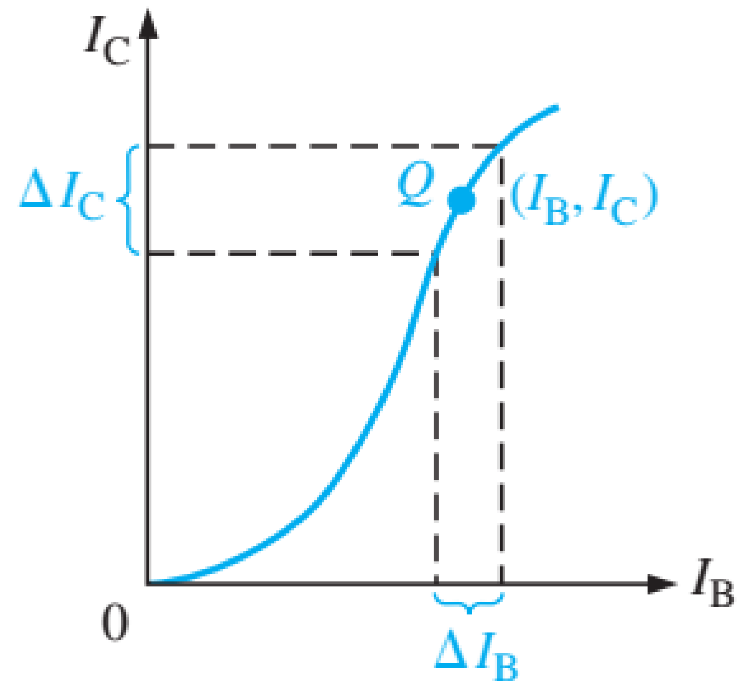
$$r'_e \cong \frac{25\ \text{mV}}{I_E} = \frac{25\ \text{mV}}{2\ \text{mA}} = \mathbf{12.5\ \Omega}$$

Transistor AC Models

- **Comparison of the AC Beta (β_{ac}) to the DC Beta (β_{DC})**
  - For a typical transistor, a graph of I_C versus I_B is nonlinear, as shown in Figure



(a) $\beta_{DC} = I_C/I_B$ at Q-point



(b) $\beta_{ac} = \Delta I_C/\Delta I_B$

Transistor AC Models

- If you pick a Q-point on the curve and cause the base current to vary an amount ΔI_B then the collector current will vary an amount ΔI_C as shown in part (b)

- At different points on the nonlinear curve, the ratio $\Delta I_C/\Delta I_B$ will be different, and it may also differ from the I_C/I_B ratio at the Q-point

- Since $\beta_{DC}=I_C/I_B$ and $\beta_{AC}=\Delta I_C/\Delta I_B$ the values of these two quantities can differ slightly

Transistor AC Models

- ***h* Parameters**
  - A manufacturer's datasheet typically specifies *h* (hybrid) parameters (h_i, h_r, h_f, and h_o) because they are relatively easy to measure
  - The four basic ac *h* parameters and their descriptions are given in Table

h PARAMETER	DESCRIPTION	CONDITION
h_i	Input impedance (resistance)	Output shorted
h_r	Voltage feedback ratio	Input open
h_f	Forward current gain	Output shorted
h_o	Output admittance (conductance)	Input open

Transistor AC Models

- Each of the four *h* parameters carries a second subscript letter to designate the common-emitter (*e*), common-base (*b*), or common-collector (*c*) amplifier configuration, as listed in Table
- The term *common* refers to one of the three terminals (E, B, or C) that is referenced to ac ground for both input and output signals.

CONFIGURATION	*h* PARAMETERS
Common-Emitter	h_{ie}, h_{re}, h_{fe}, h_{oe}
Common-Base	h_{ib}, h_{rb}, h_{fb}, h_{ob}
Common-Collector	h_{ic}, h_{rc}, h_{fc}, h_{oc}

Transistor AC Models

- **Relationships of *h* Parameters and *r* Parameters**
  - The ac current ratios, α_{ac} and β_{ac} convert directly from *h* parameters as follows:

$$\alpha_{ac} = h_{fb}$$

$$\beta_{ac} = h_{fe}$$

  - The following formulas show how to convert to *r* parameters

$$r'_e = \frac{h_{re}}{h_{oe}}$$

$$r'_c = \frac{h_{re} + 1}{h_{oe}}$$

$$r'_b = h_{ie} - \frac{h_{re}}{h_{oe}}(1 + h_{fe})$$

The Common Emitter Amplifier

- Figure shows a **common-emitter** amplifier

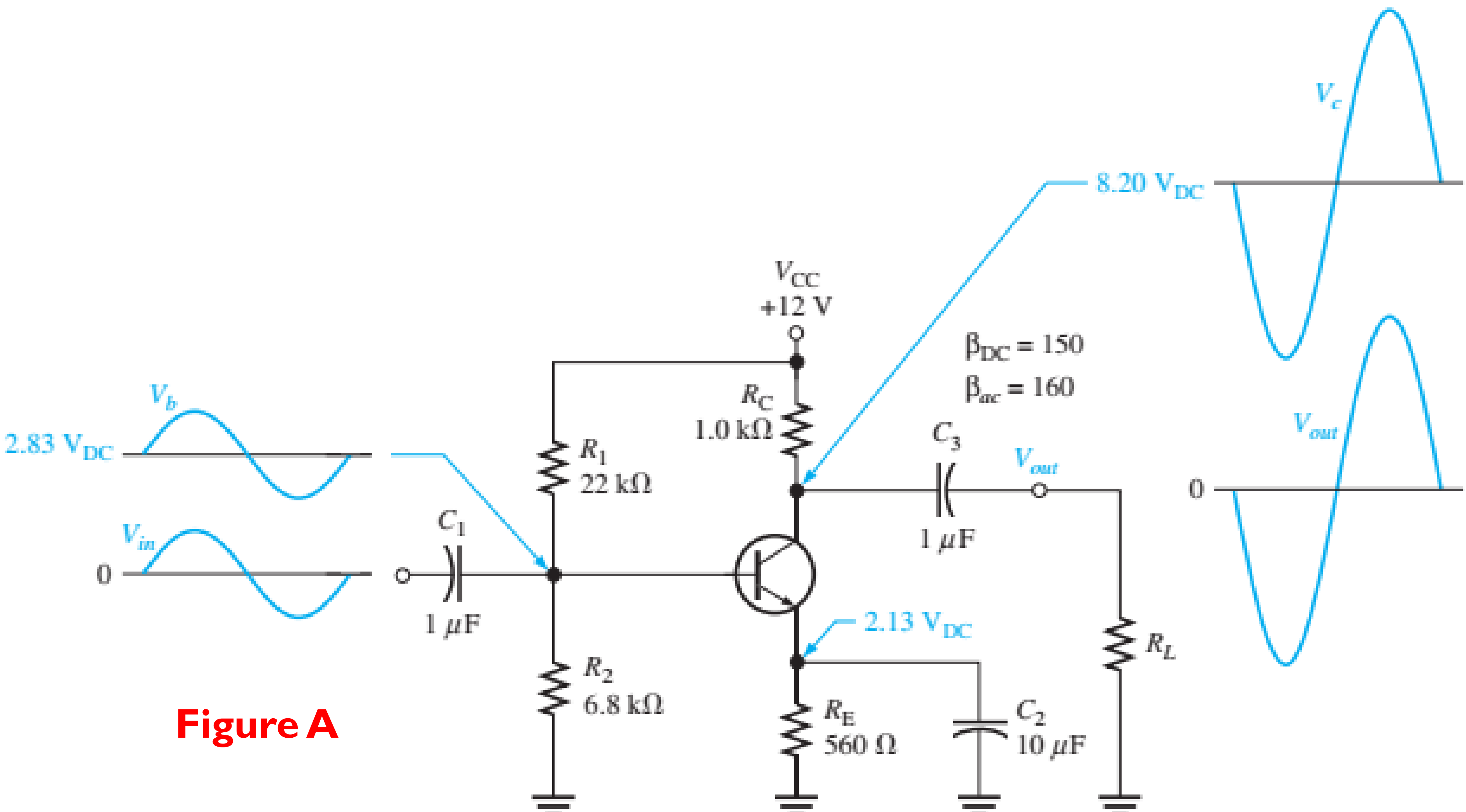


Figure A

The Common Emitter Amplifier

- The input signal, V_{in}, is capacitively coupled to the base terminal, the output signal, V_{out}, is capacitively coupled from the collector to the load

- Because the ac signal is applied to the base terminal as the input and taken from the collector terminal as the output, the emitter is common to both the input and output signals

- There is no signal at the emitter because the bypass capacitor effectively shorts the emitter to ground at the signal frequency

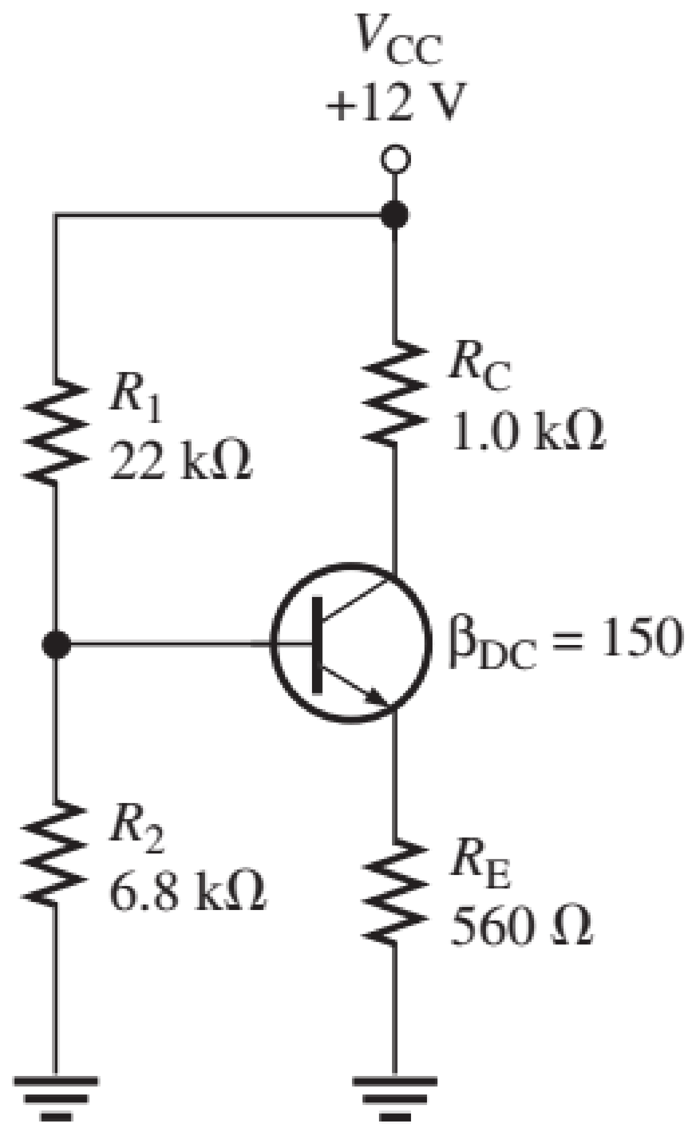
- The output signal is 180°out of phase with the input signal

The Common Emitter Amplifier

- **DC Analysis**
  - To analyze the amplifier in Figure A, the dc bias values must first be determined
  - To do this, 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.
  - The dc equivalent circuit is shown in Figure B

The Common Emitter Amplifier

Figure B



The Common Emitter Amplifier

- Theveninizing the bias circuit and applying Kirchhoff's voltage law to the base-emitter circuit,

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

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

- $V_{TH} - I_B R_{TH} - V_{BE} - I_E R_E = 0$

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

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

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

The Common Emitter Amplifier

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

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

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

The Common Emitter Amplifier

- **AC Analysis**
  - To analyze the ac signal operation of an amplifier, an ac equivalent circuit is developed as follows:
    - 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 0Ω
    - The dc source is replaced by ground
  - The ac equivalent circuit for the common-emitter amplifier in Figure A is shown in Figure C
  - Notice that both R_C and R_1 have one end connected to ac ground (red) because, in the actual circuit, they are connected to V_{CC} which is, in effect, ac ground

The Common Emitter Amplifier

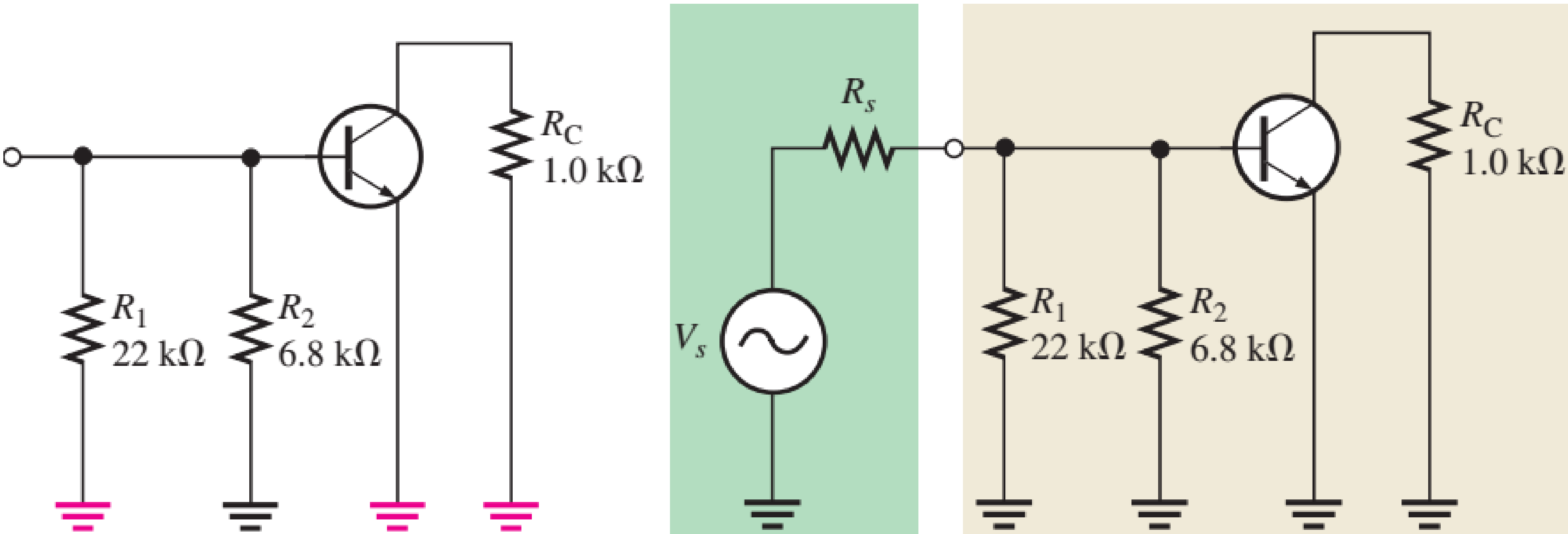


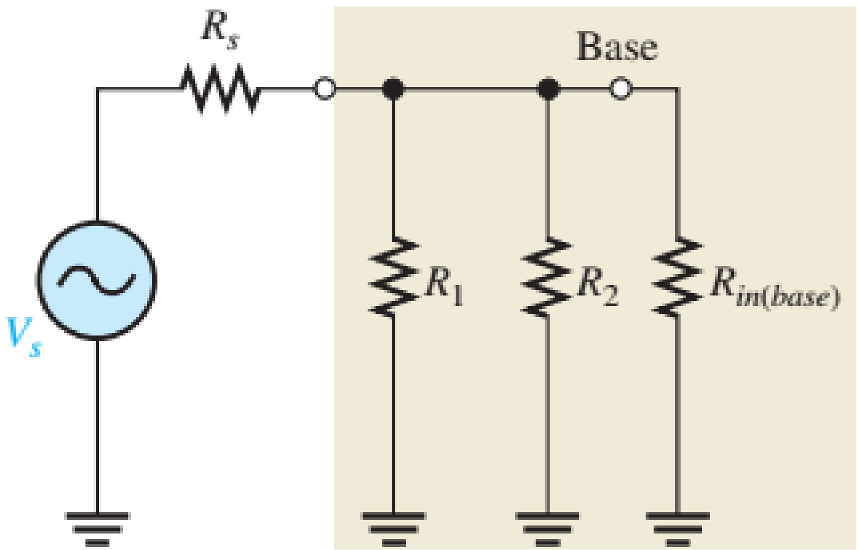
Figure C

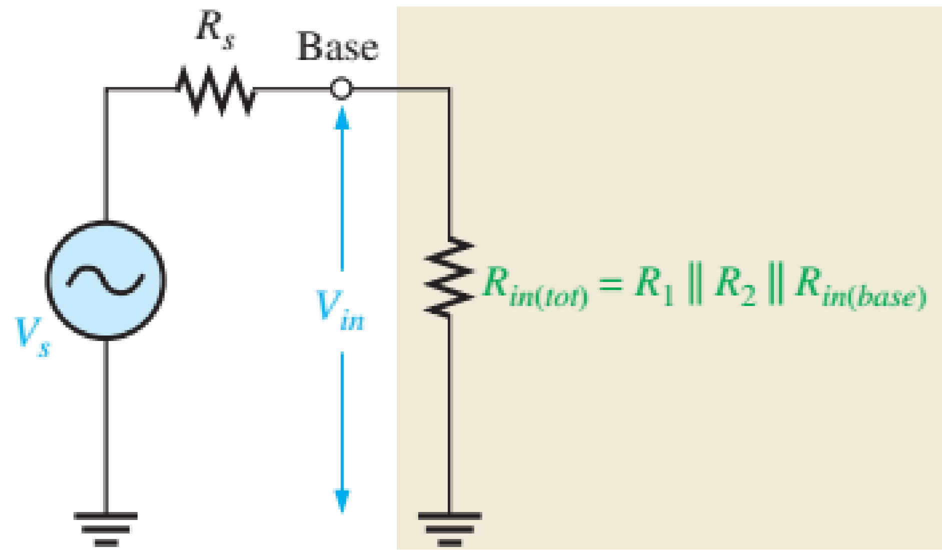
- In ac analysis, the ac ground and the actual ground are treated as the same point electrically. The amplifier in Figure A is called a common-emitter amplifier because the bypass capacitor C_2 keeps the emitter at ac ground. Ground is the common point in the circuit.

The Common Emitter Amplifier

- ***Signal (AC) Voltage at the Base***
  - An ac voltage source, V_s, is shown connected to the input in Figure C
  - If the internal resistance of the ac source is 0Ω then all of the source voltage appears at the base terminal
  - If, however, the ac source has a nonzero internal resistance, then three factors must be taken into account in determining the actual signal voltage at the base. These are
    - the *source resistance* (R_s),
    - the *bias resistance* ($R_1 \parallel R_2$) and
    - the *ac input resistance* at the base of the transistor ($R_{in(base)}$)

The Common Emitter Amplifier





- R_1, R_2, and $R_{in(base)}$ are combined in parallel to get the total **input resistance**, $R_{in(tot)}$, which is the resistance "seen" by an ac source connected to the input

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

The Common Emitter Amplifier

- Signal voltage at the base of the transistor is found by the voltage-divider formula as follows:

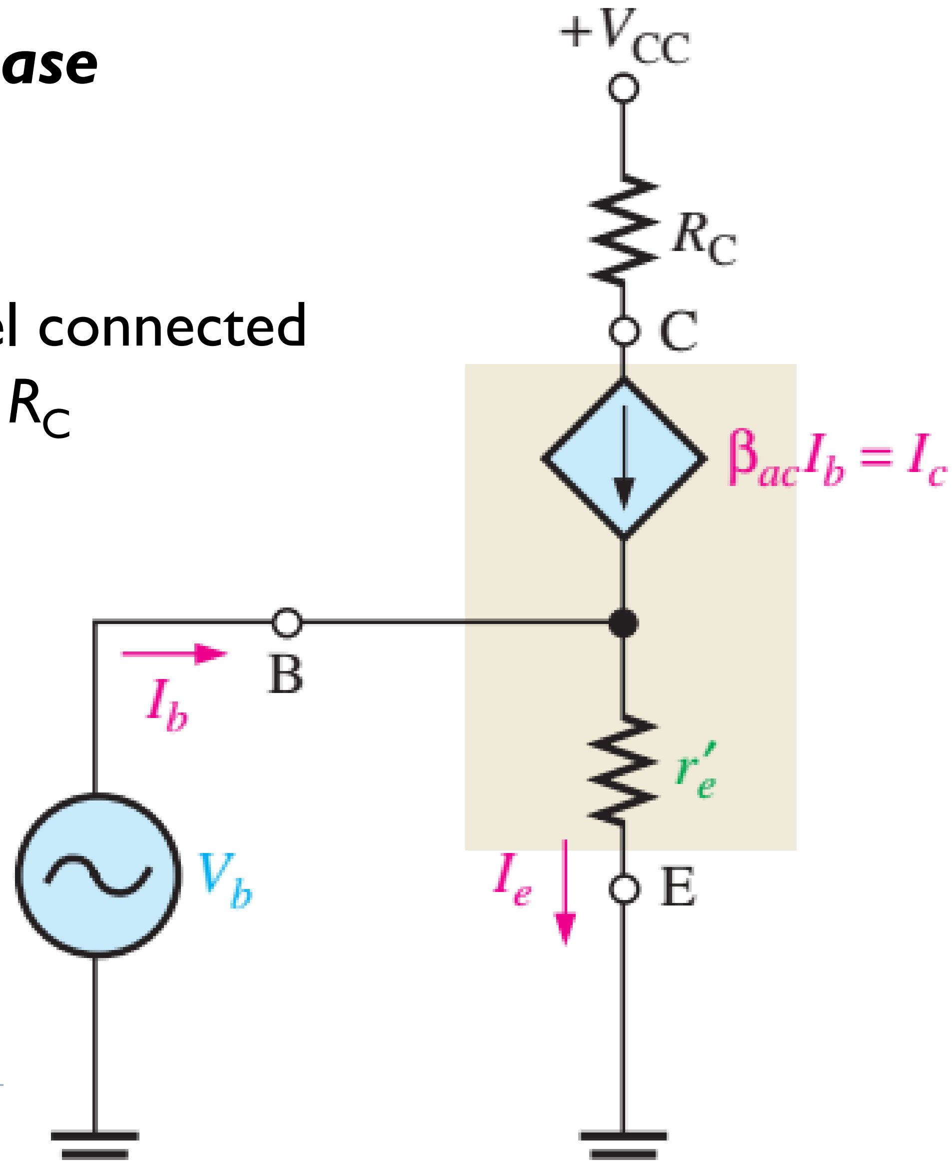
$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}}\right)V_s$$

- If $R_s << R_{in(tot)}$ then $V_b \approx V_s$ where V_b is the input voltage, V_{in}, to the amplifier

The Common Emitter Amplifier

- ***Input Resistance at the Base***

Figure shows the transistor model connected to the external collector resistor, R_C



The Common Emitter Amplifier

- The input resistance looking in at the base is
- $R_{in(base)} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_b}$
- The base voltage is: $V_b = I_e r_e'$
- and since $I_e \approx I_c$: $I_b \approx {}^{I_e}/_{\beta_{ac}}$
- Substituting for V_b and I_b
- $R_{in(base)} = \frac{V_b}{I_b} = \frac{I_e r_e'}{{}^{I_e}/_{\beta_{ac}}}$
- $\boldsymbol{R_{in(base)} = \beta_{ac} r_e'}$

The Common Emitter Amplifier

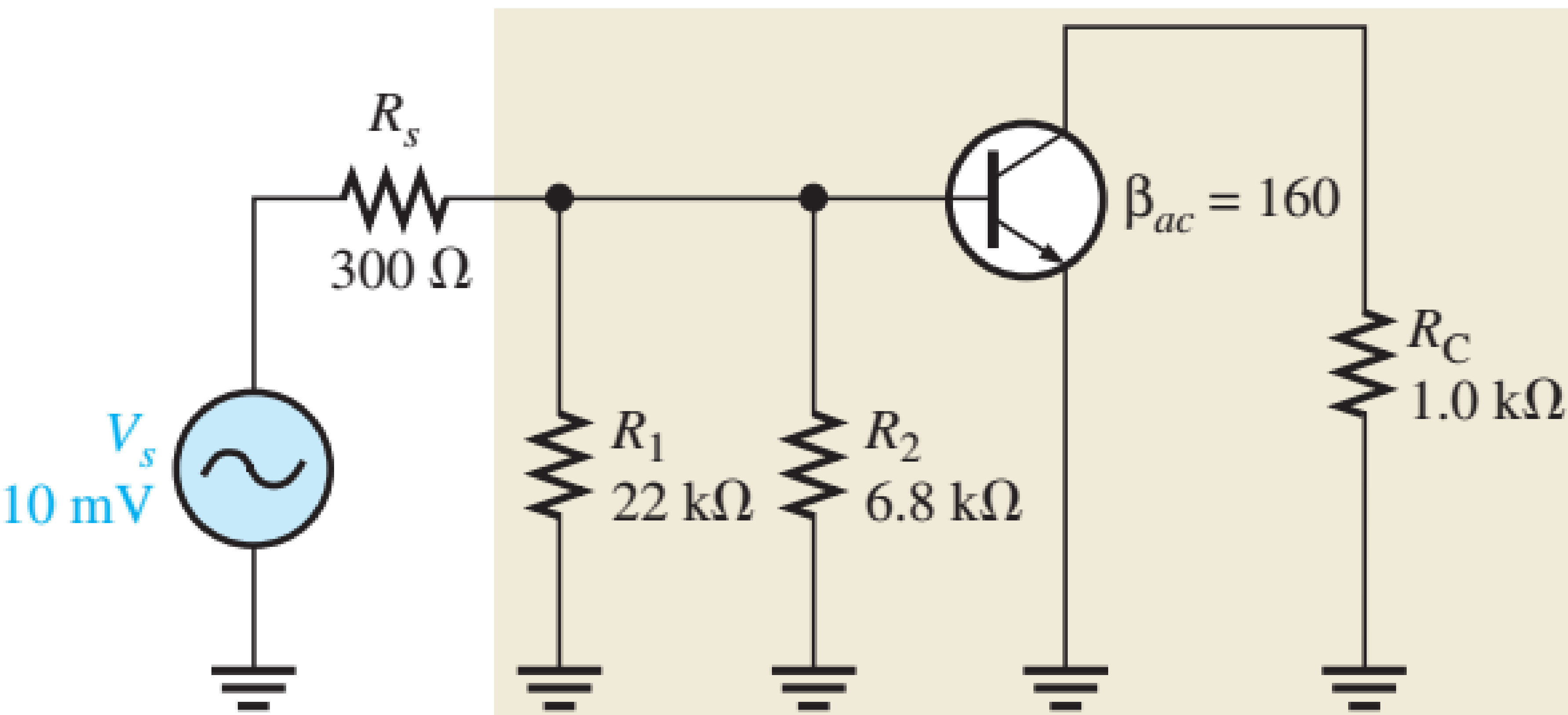
- ***Output Resistance***
  - The **output resistance** of the common-emitter amplifier is the resistance looking in at the collector and is approximately equal to the collector resistor

$$R_{out} \cong R_C$$

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

The Common Emitter Amplifier

- Determine the signal voltage at the base of the transistor in Figure. This circuit is the ac equivalent of the amplifier in Figure A with a 10 mV rms, 300 Ω signal source. I_E was previously found to be 3.80 mA.



First, determine the ac emitter resistance.

$$r'_e \cong \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{3.80\text{ mA}} = 6.58\ \Omega$$

Then,

$$R_{in(base)} = \beta_{ac} r'_e = 160(6.58\ \Omega) = 1.05\text{ k}\Omega$$

Next, determine the total input resistance viewed from the source.

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)} = \frac{1}{\frac{1}{22\text{ k}\Omega} + \frac{1}{6.8\text{ k}\Omega} + \frac{1}{1.05\text{ k}\Omega}} = 873\ \Omega$$

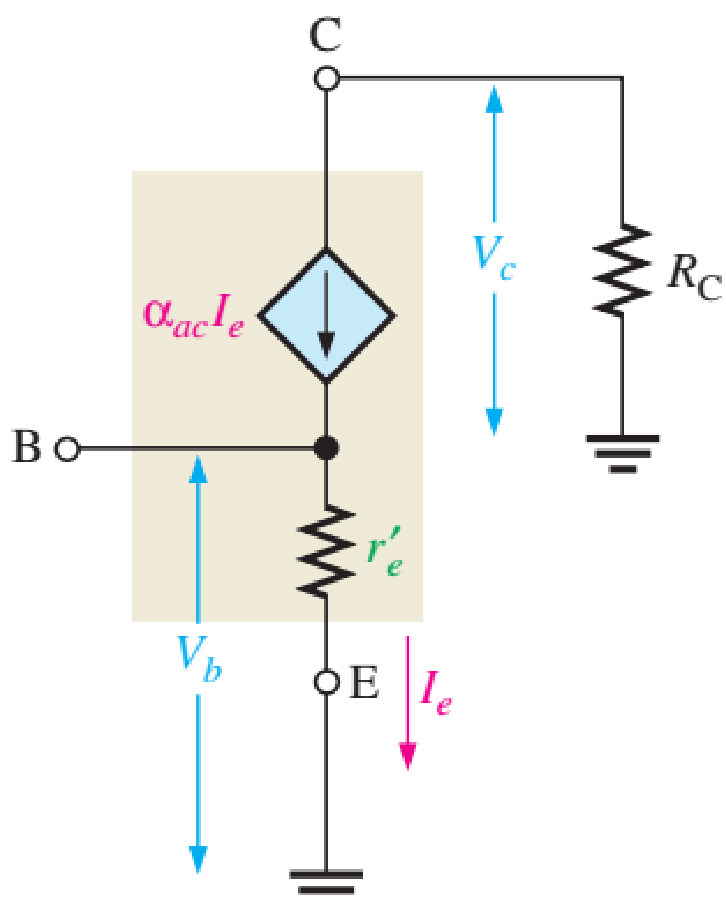
The source voltage is divided down by R_s and $R_{in(tot)}$, so the signal voltage at the base is the voltage across $R_{in(tot)}$.

$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}}\right)V_s = \left(\frac{873\ \Omega}{1173\ \Omega}\right)10\text{ mV} = \mathbf{7.44\text{ mV}}$$

As you can see, there is significant attenuation (reduction) of the source voltage due to the source resistance and amplifier's input resistance combining to act as a voltage divider.

The Common Emitter Amplifier

- **Voltage Gain**
  - The ac voltage gain expression for the common-emitter amplifier is developed using the below model circuit



The Common Emitter Amplifier

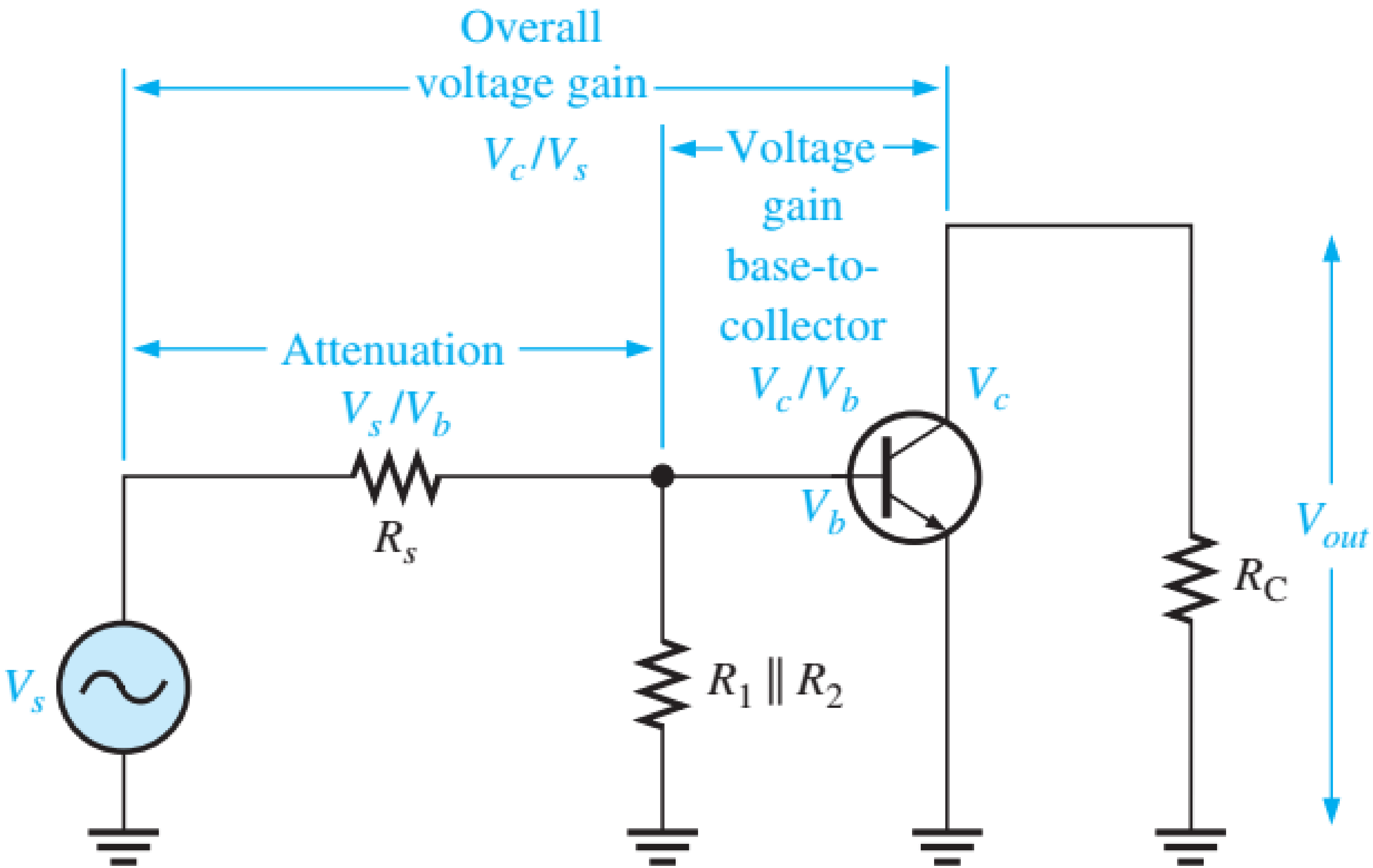
- The gain is the ratio of ac output voltage at the collector (V_c) to ac input voltage at the base (V_b)
- $A_V = \frac{V_{out}}{V_{in}} = \frac{V_c}{V_b}$
- Notice in the figure that: $V_c = \alpha_{ac} I_e R_C \approx I_e R_C$ and $V_b = I_e r_e'$
- Therefore, $A_V = \frac{I_e R_C}{I_e r_e'}$
- $\boldsymbol{A_V = \frac{R_C}{r_e'}}$
- Equation gives the voltage gain from base to collector. To get the overall gain of the amplifier from the source voltage to collector, the attenuation of the input circuit must be included

The Common Emitter Amplifier

- **Attenuation**
  - Attenuation is the reduction in signal voltage as it passes through a circuit and corresponds to a gain of less than 1.
  - For example, if the signal amplitude is reduced by half, the attenuation is 2, which can be expressed as a gain of 0.5 because gain is the reciprocal of attenuation.
  - Assume that the amplifier in Figure has a voltage gain from base to collector of A_v and the attenuation from the source to the base is V_s/V_b. This attenuation is produced by the source resistance and total input resistance of the amplifier acting as a voltage divider and can be expressed as

$$\text{Attenuation} = \frac{V_s}{V_b} = \frac{R_s + R_{in(tot)}}{R_{in(tot)}}$$

The Common Emitter Amplifier



The Common Emitter Amplifier

- The overall voltage gain of the amplifier, is the voltage gain from base to collector, V_c/V_b, times the reciprocal of the attenuation, V_b/V_s

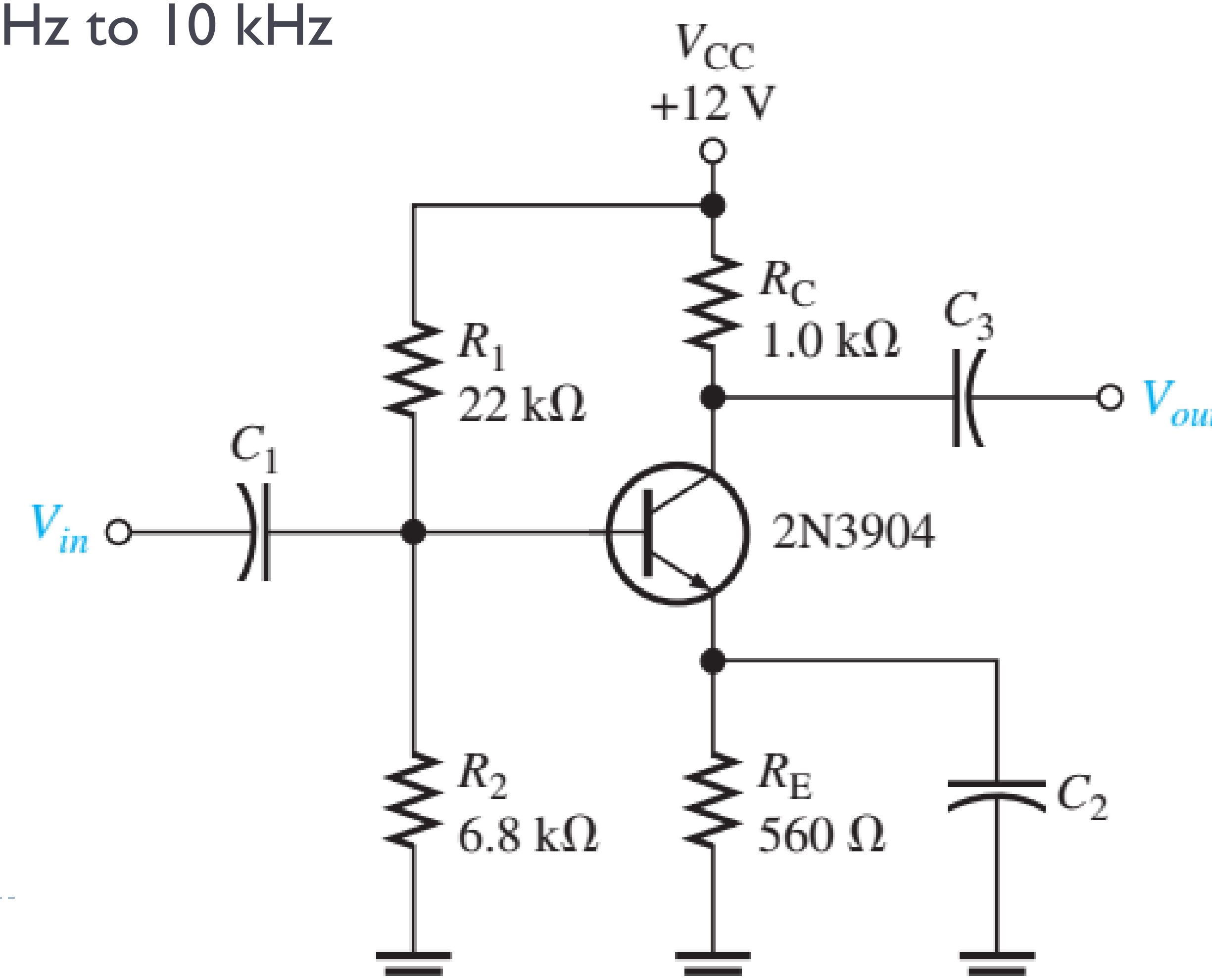
$$A_v' = \left(\frac{V_c}{V_b}\right)\left(\frac{V_b}{V_s}\right) = \frac{V_c}{V_s}$$

The Common Emitter Amplifier

- ***Effect of the Emitter Bypass Capacitor***
  - The emitter bypass capacitor, which is C_2 in Figure A, provides an effective short to the ac signal around the emitter resistor, thus keeping the emitter at ac ground. With the bypass capacitor, the gain of a given amplifier is maximum and equal to $\boldsymbol{A_V = \frac{R_C}{r'_e}}$
  - 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
  - $$X_C \leq \frac{R_E}{10}$$

The Common Emitter Amplifier

- Select a minimum value for the emitter bypass capacitor, C_2, in Figure if the amplifier must operate over a frequency range from 200 Hz to 10 kHz



The Common Emitter Amplifier

The X_C of the bypass capacitor, C_2, should be at least ten times less than R_E.

$$X_{C2} = \frac{R_E}{10} = \frac{560\ \Omega}{10} = 56\ \Omega$$

Determine the capacitance value at the minimum frequency of 200 Hz as follows:

$$C_2 = \frac{1}{2\pi f X_{C2}} = \frac{1}{2\pi(200\ \text{Hz})(56\ \Omega)} = \mathbf{14.2\ \mu F}$$

This is the minimum value for the bypass capacitor for this circuit. You can always use a larger value, although cost and physical size may impose limitations.

The Common Emitter Amplifier

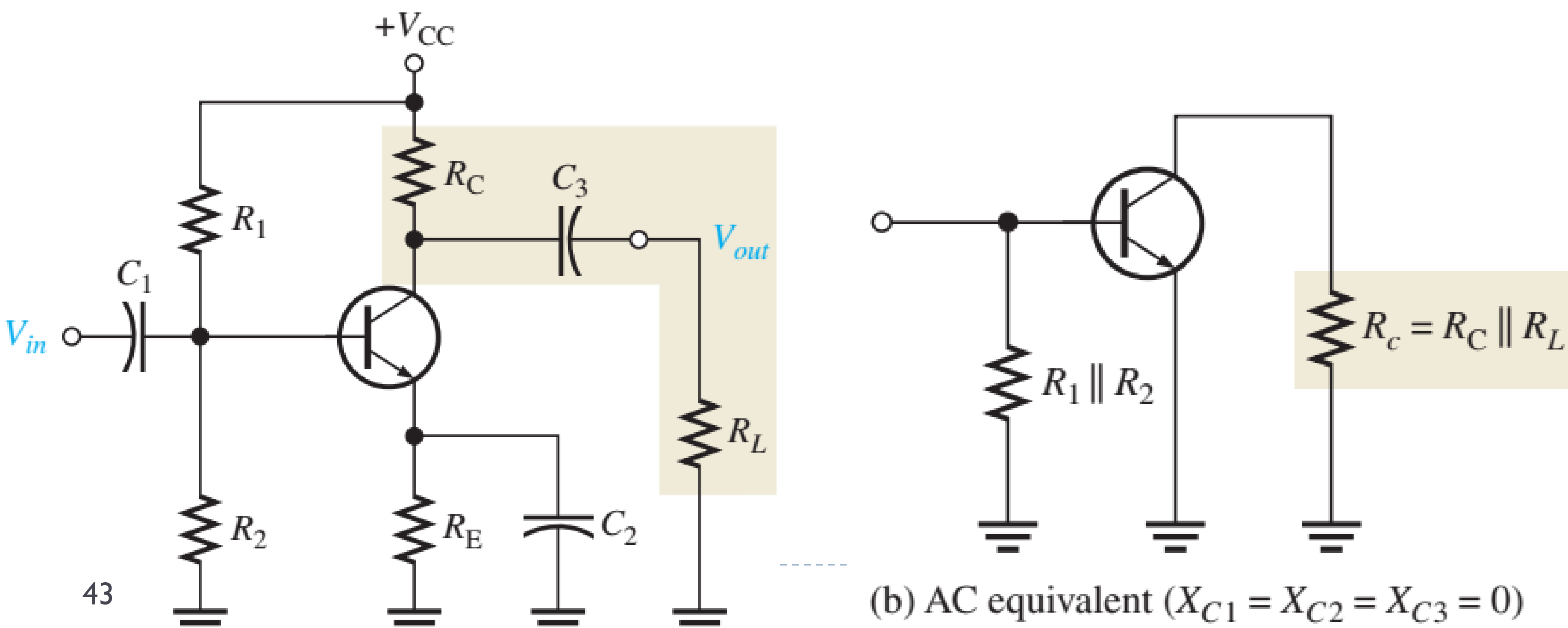
- ***Voltage Gain Without the Emitter Bypass Capacitor***
  - Without the bypass capacitor, the emitter is no longer at ac ground. Instead, R_E is seen by the ac signal between the emitter and ground and effectively adds to in the voltage gain formula *(refer model circuit used to derive volt. gain with bypass capacitor)*

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

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

The Common Emitter Amplifier

- ***Effect of a Load on the Voltage Gain***
  - When a resistor, R_L, is connected to the output through the coupling capacitor C_3, as shown in Figure, it creates a load on the circuit. The collector resistance at the signal frequency is effectively R_C in parallel with R_L.



(b) AC equivalent ($X_{C1} = X_{C2} = X_{C3} = 0$)

The Common Emitter Amplifier

- The total ac collector resistance is

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

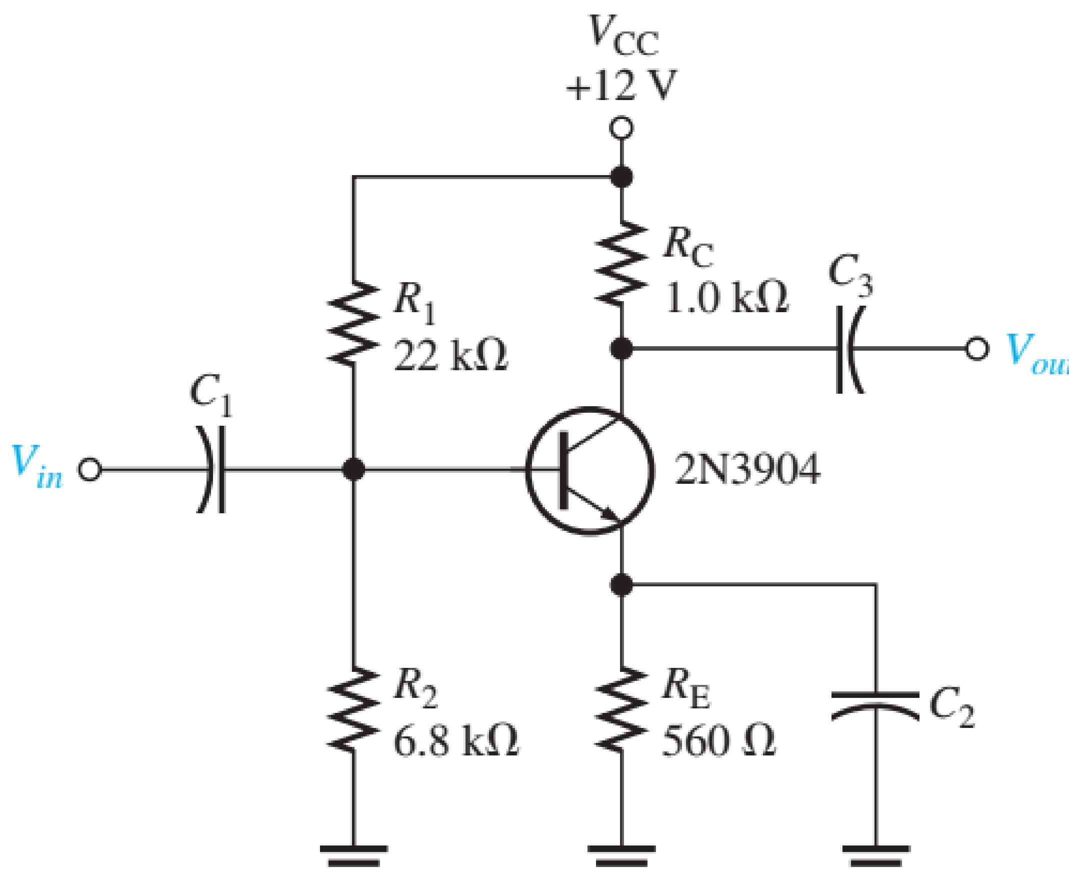
- Replacing R_C with R_c in the voltage gain expression gives

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

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

The Common Emitter Amplifier

- Calculate the base-to-collector voltage gain of the amplifier in Figure when a load resistance of 5 kΩ is connected to the output. The emitter is effectively bypassed and $r'_e = 6.58\ \Omega$



The Common Emitter Amplifier

The ac collector resistance is

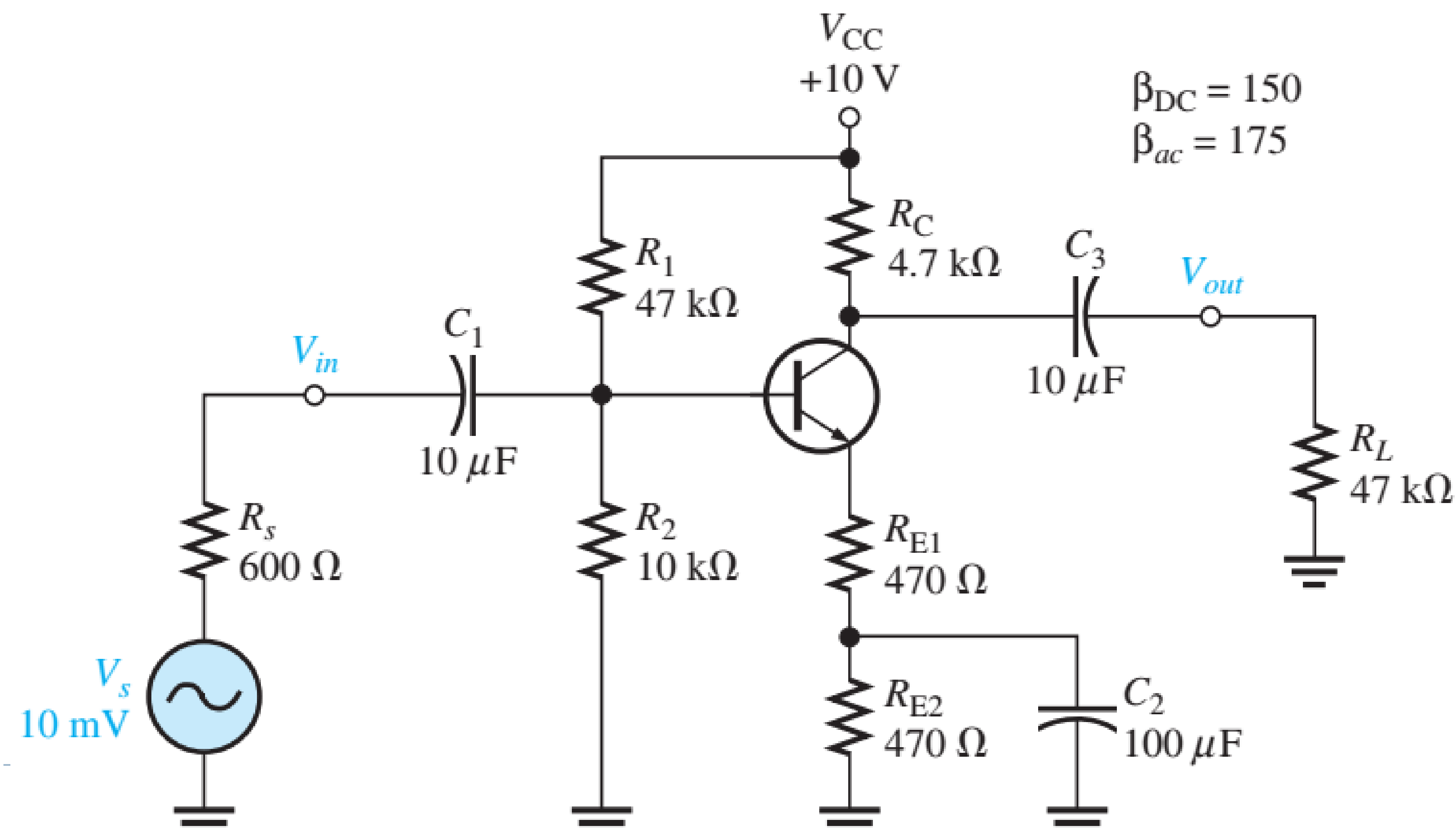
$$R_c = \frac{R_C R_L}{R_C + R_L} = \frac{(1.0\ \text{k}\Omega)(5\ \text{k}\Omega)}{6\ \text{k}\Omega} = 833\ \Omega$$

Therefore,

$$A_v = \frac{R_c}{r'_e} = \frac{833\ \Omega}{6.58\ \Omega} = \mathbf{127}$$

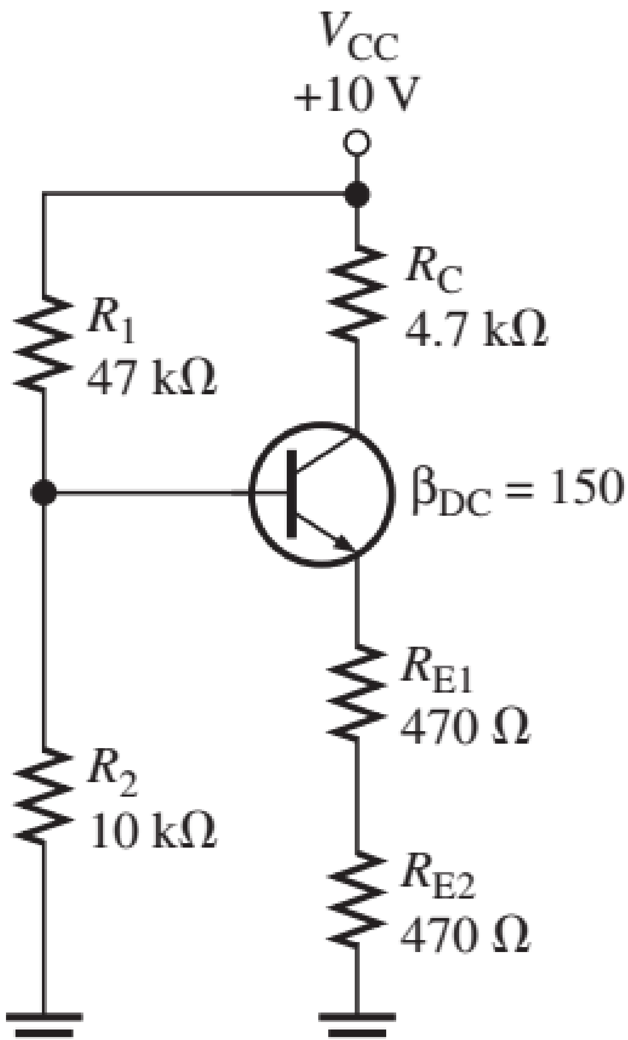
The Common Emitter Amplifier

- For the amplifier in Figure a) Determine the dc collector voltage b) Determine the ac collector voltage



The Common Emitter Amplifier

- Determine the dc bias values using the dc equivalent circuit in below Figure



The Common Emitter Amplifier

Apply Thevenin's theorem and Kirchhoff's voltage law to the base-emitter circuit in Figure .

$$R_{TH} = \frac{R_1R_2}{R_1 + R_2} = \frac{(47\,\text{k}\Omega)(10\,\text{k}\Omega)}{47\,\text{k}\Omega + 10\,\text{k}\Omega} = 8.25\,\text{k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{10\,\text{k}\Omega}{47\,\text{k}\Omega + 10\,\text{k}\Omega}\right)10\,\text{V} = 1.75\,\text{V}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}} = \frac{1.75\,\text{V} - 0.7\,\text{V}}{940\,\Omega + 55\,\Omega} = 1.06\,\text{mA}$$

$$I_C \cong I_E = 1.06\,\text{mA}$$

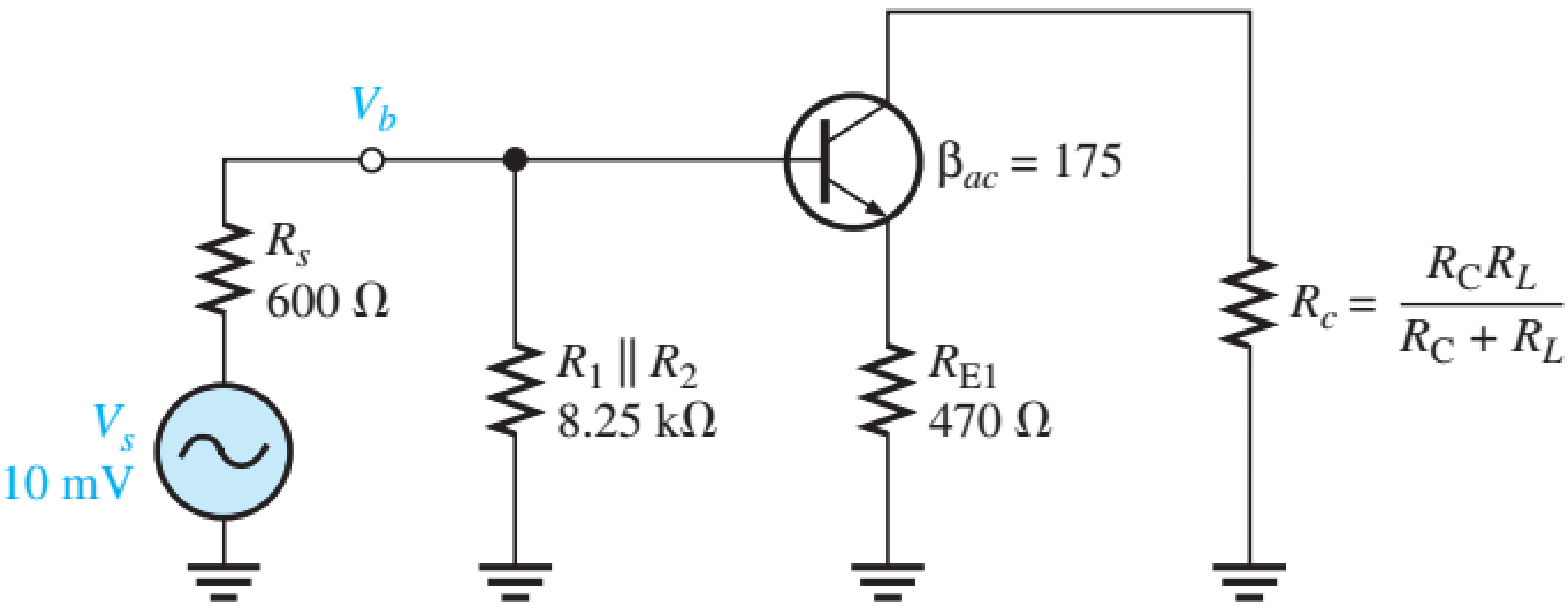
$$V_E = I_E(R_{E1} + R_{E2}) = (1.06\,\text{mA})(940\,\Omega) = 1\,\text{V}$$

$$V_B = V_E + 0.7\,\text{V} = 1\,\text{V} - 0.7\,\text{V} = 0.3\,\text{V}$$

$$V_C = V_{CC} - I_CR_C = 10\,\text{V} - (1.06\,\text{mA})(4.7\,\text{k}\Omega) = \mathbf{5.02\,V}$$

The Common Emitter Amplifier

- The ac analysis is based on the ac equivalent circuit in below Figure



The Common Emitter Amplifier

The first thing to do in the ac analysis is calculate r'_e.

$$r'_e \cong \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{1.06\text{ mA}} = 23.6\ \Omega$$

Next, determine the attenuation in the base circuit. Looking from the 600 Ω source, the total R_{in} is

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)}$$
$$R_{in(base)} = \beta_{ac}(r'_e + R_{E1}) = 175(494\ \Omega) = 86.5\text{ k}\Omega$$

Therefore,

$$R_{in(tot)} = 47\text{ k}\Omega \parallel 10\text{ k}\Omega \parallel 86.5\text{ k}\Omega = 7.53\text{ k}\Omega$$

The attenuation from source to base is

$$\text{Attenuation} = \frac{V_s}{V_b} = \frac{R_s + R_{in(tot)}}{R_{in(tot)}} = \frac{600\ \Omega + 7.53\text{ k}\Omega}{7.53\text{ k}\Omega} = 1.08$$

The Common Emitter Amplifier

Before A_v can be determined, you must know the ac collector resistance R_c.

$$R_c = \frac{R_C R_L}{R_C + R_L} = \frac{(4.7\ \text{k}\Omega)(47\ \text{k}\Omega)}{4.7\ \text{k}\Omega + 47\ \text{k}\Omega} = 4.27\ \text{k}\Omega$$

The voltage gain from base to collector is

$$A_v \cong \frac{R_c}{R_{E1}} = \frac{4.27\ \text{k}\Omega}{470\ \Omega} = 9.09$$

The overall voltage gain is the reciprocal of the attenuation times the amplifier voltage gain.

$$A'_v = \left(\frac{V_b}{V_s}\right)A_v = (0.93)(9.09) = 8.45$$

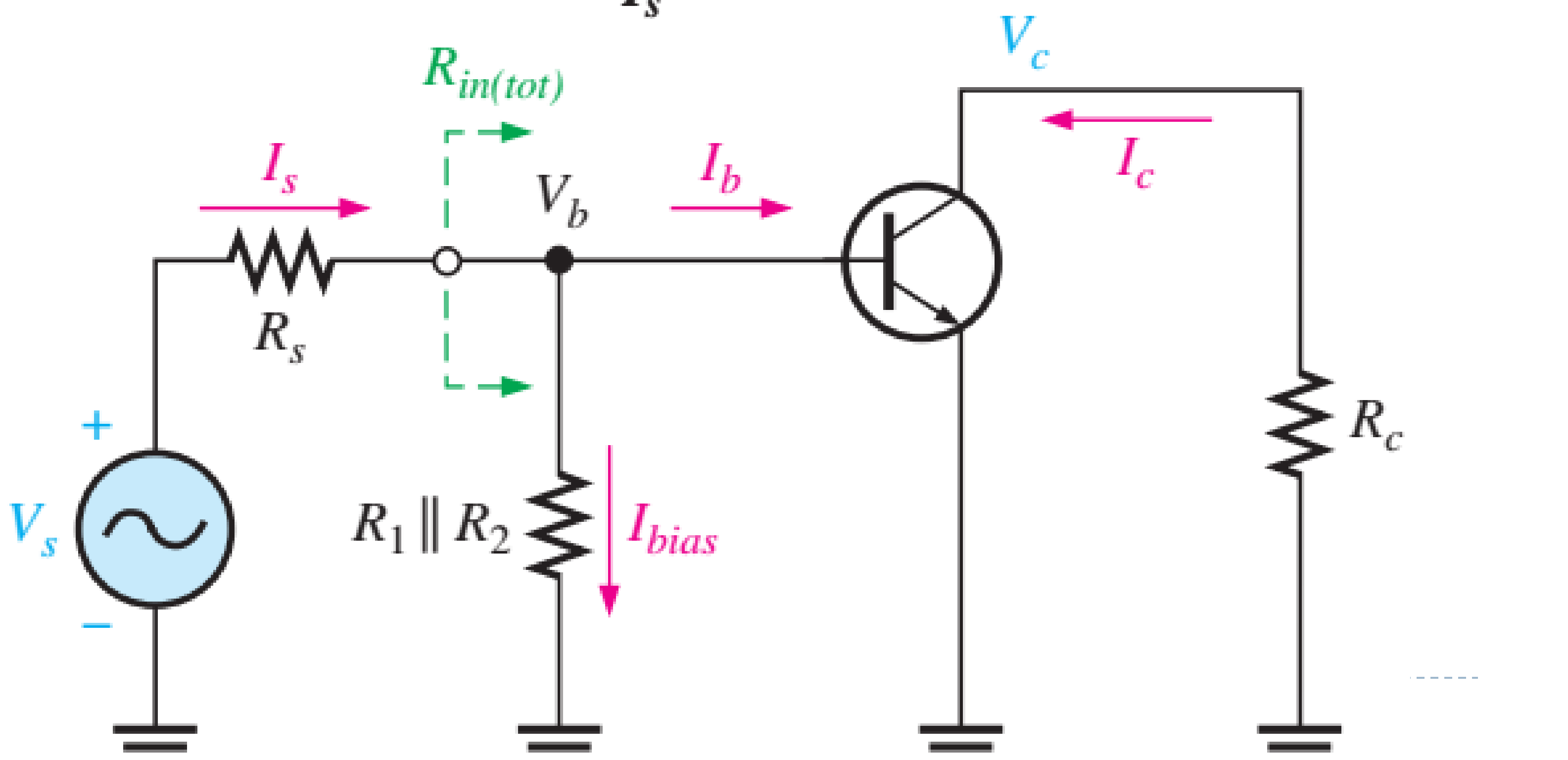
The source produces 10 mV rms, so the rms voltage at the collector is

$$V_c = A'_v V_s = (8.45)(10\ \text{mV}) = \mathbf{84.5\ mV}$$

The Common Emitter Amplifier

- **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

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



The Common Emitter Amplifier

- 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. The source "sees" a total resistance of $R_s + R_{in(tot)}$. The total current produced by the source is

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

The Common Emitter Amplifier

- **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 $A'_v = V_c/V_s$

The Common Collector Amplifier

- The **common-collector** (CC) amplifier is usually referred to as an emitter-follower (EF). An **emitter-follower** circuit with voltage-divider bias is shown in Figure.

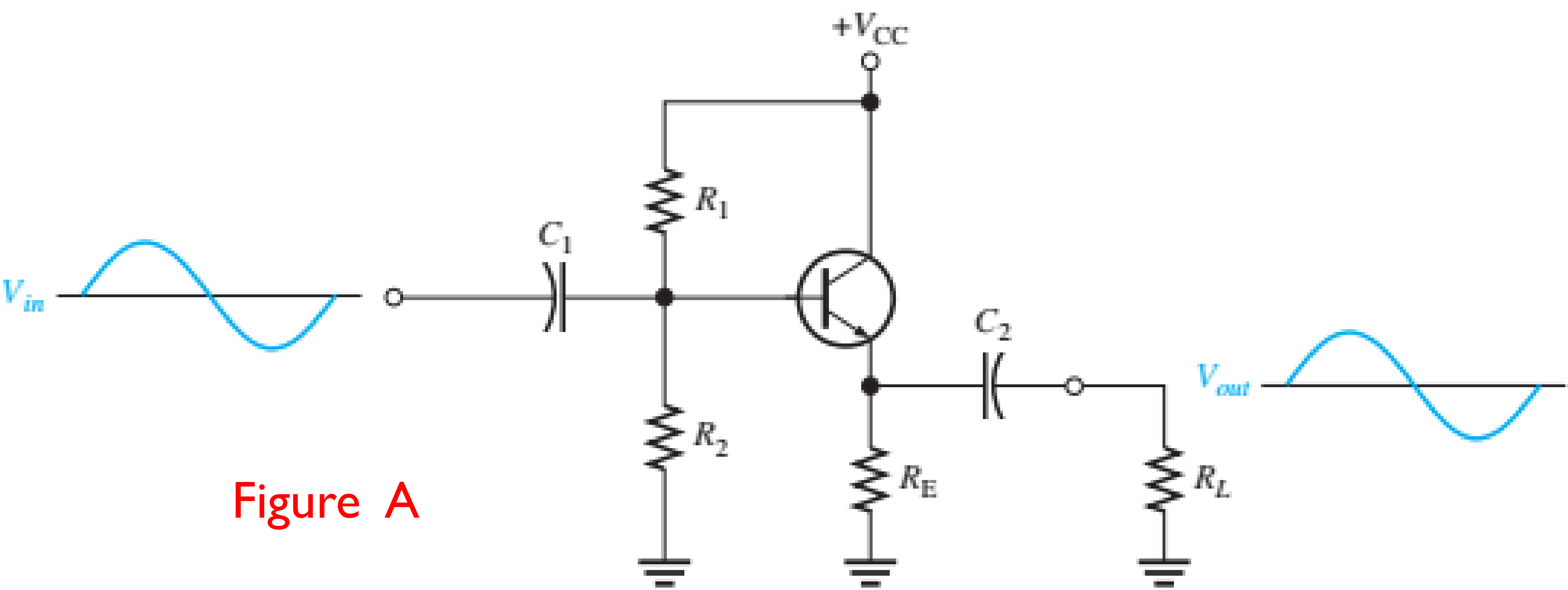


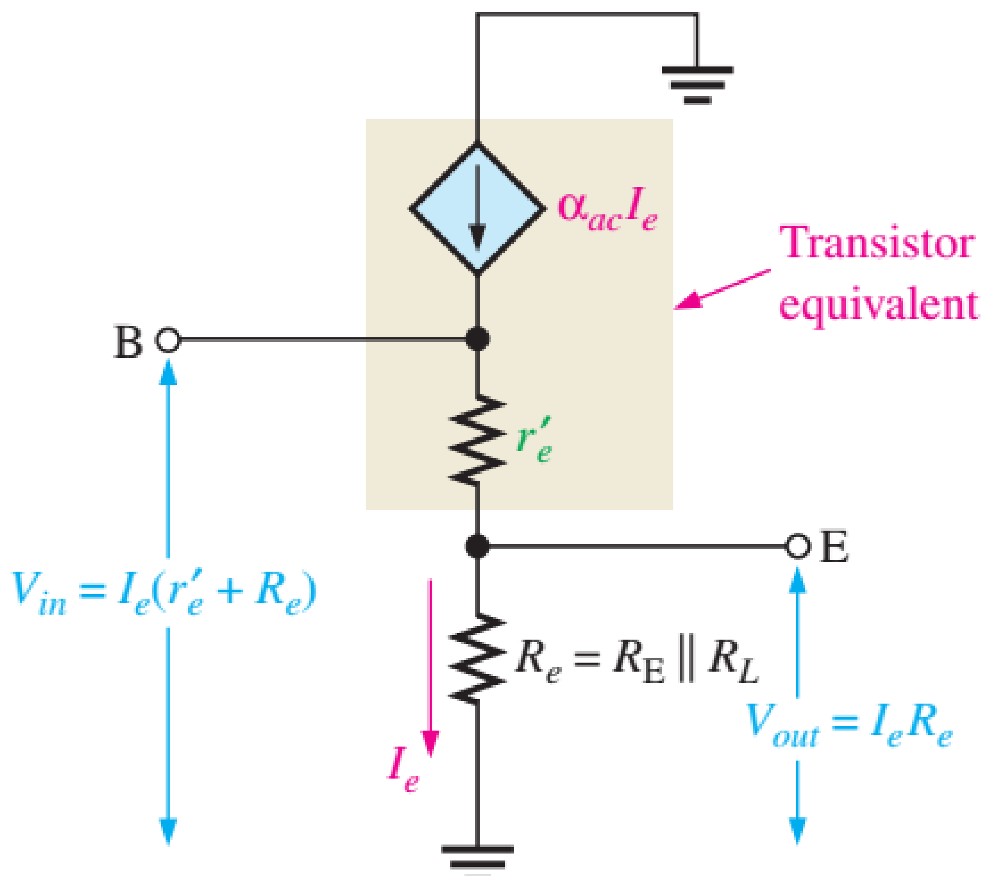
Figure A

The Common Collector Amplifier

- Notice that the input signal is capacitively coupled to the base, the output signal is capacitively coupled from the emitter, and the collector is at ac ground.
- There is no phase inversion, and the output is approximately the same amplitude as the input.

The Common Collector Amplifier

- **Voltage Gain**
  - As in all amplifiers, the voltage gain is $A_v = V_{out}/V_{in}$. The ac model for the emitter follower is shown in Figure



The Common Collector Amplifier

$$V_{out} = I_e R_e$$

$$V_{in} = I_e(r'_e + R_e)$$

- Therefore, the voltage gain is

$$A_v = \frac{I_e R_e}{I_e(r'_e + R_e)}$$

$$A_v = \frac{R_e}{r'_e + R_e}$$

- where R_e is the parallel combination of R_E and R_L

The Common Collector Amplifier

$$A_v = \frac{R_e}{r'_e + R_e}$$

- If there is no load, then $R_e = R_E$.
- Notice that the gain is always less than 1. If $R_E >> r'_e$ then a good approximation is

$$A_v \cong 1$$

- Since the output voltage is at the emitter, it is in phase with the base voltage, so there is no inversion from input to output. Because there is no inversion and because the voltage gain is approximately 1, the output voltage closely follows the input voltage in both phase and amplitude; thus the term *emitter-follower*

The Common Collector Amplifier

- **Input Resistance**
  - The emitter-follower is characterized by a high input resistance; this is what makes it a useful circuit. Because of the high input resistance, it can be used as a buffer to minimize loading effects when a circuit is driving a low-resistance load
  - The derivation of the input resistance, looking in at the base of the common-collector amplifier, is similar to that for the common-emitter amplifier. In a common-collector circuit, however, the emitter resistor is *never* bypassed because the output is taken across R_e, which is R_E in parallel with R_L

The Common Collector Amplifier

$$R_{in(base)} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_b} = \frac{I_e(r'_e + R_e)}{I_b}$$

Since $I_e \cong I_c = \beta_{ac} I_b$,

$$R_{in(base)} \cong \frac{\beta_{ac} I_b (r'_e + R_e)}{I_b}$$

$$R_{in(base)} \cong \beta_{ac}(r'_e + R_e)$$

If $R_e \gg r'_e$, then the input resistance at the base is simplified to

$$\boldsymbol{R_{in(base)} \cong \beta_{ac} R_e}$$

The Common Collector Amplifier

- The bias resistors in Figure A appear in parallel with $R_{in(base)}$, looking from the input source; and just as in the common-emitter circuit, the total input resistance is

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

The Common Collector Amplifier

- **Output Resistance**
  - With the load removed, the output resistance, looking into the emitter of the emitter-follower is approximated as follows:

$$R_{out} \cong \left(\frac{R_s}{\beta_{ac}}\right) \| R_{\mathrm{E}}$$

  - R_s is the resistance of the input source

The Common Collector Amplifier

- **Current Gain**
  - The current gain for the emitter-follower in Figure A is

$$A_i = \frac{I_e}{I_{in}}$$

  - where $I_{in} = V_{in}/R_{in(tot)}$

The Common Collector Amplifier

- **Power Gain**
  - The common-collector power gain is the product of the voltage gain and the current gain. For the emitter-follower, the power gain is approximately equal to the current gain because the voltage gain is approximately 1

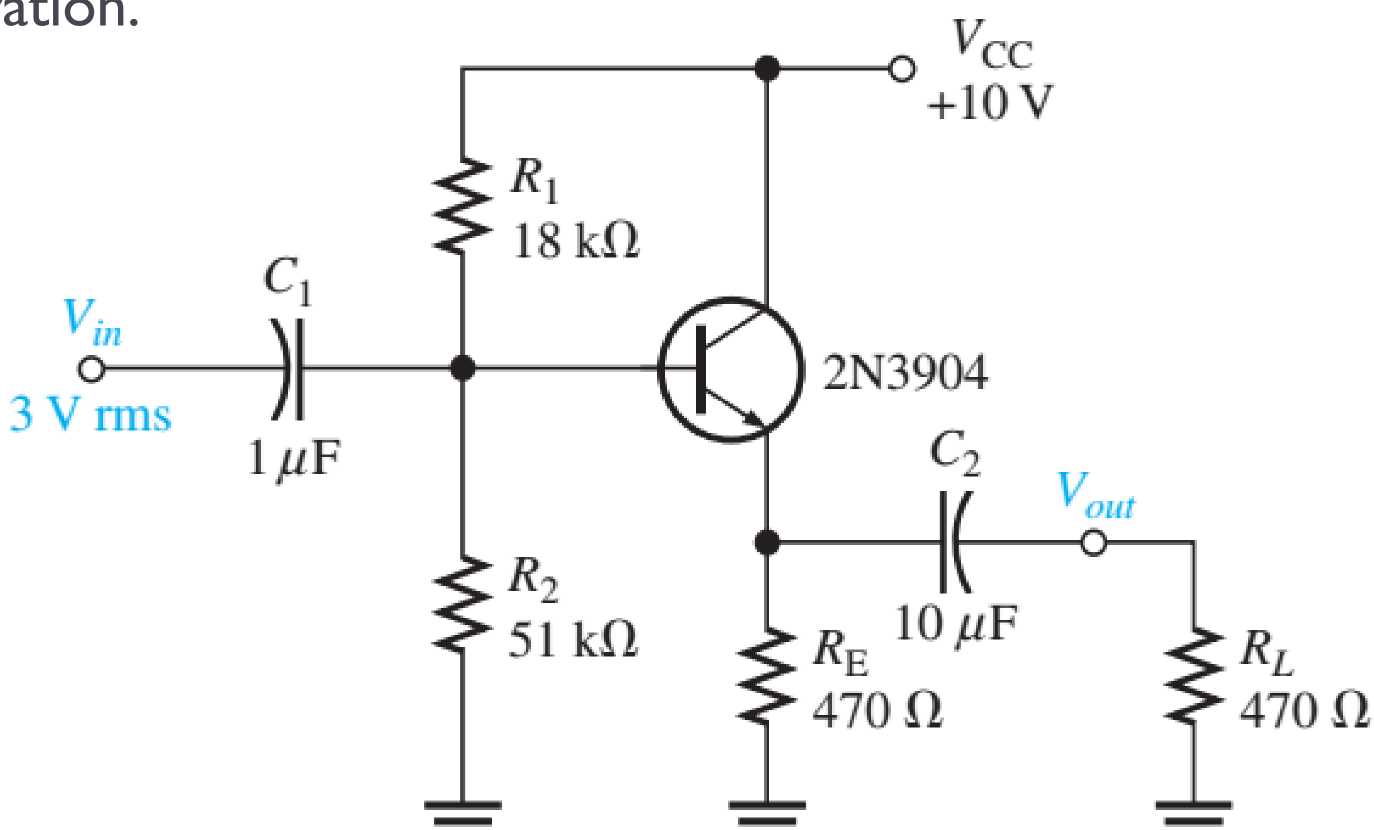
$$A_p = A_v A_i$$

Since $A_v \cong 1$, the power gain is

$$A_p \cong A_i$$

The Common Collector Amplifier

- Determine the total input resistance of the emitter-follower in Figure. Also find the voltage gain, current gain, and power gain in terms of power delivered to the load, R_L. Assume β_{ac} = 175 and that the capacitive reactances are negligible at the frequency of operation.



The Common Collector Amplifier

The ac emitter resistance external to the transistor is

$$R_e = R_E \| R_L = 470\ \Omega \| 470\ \Omega = 235\ \Omega$$

The approximate resistance, looking in at the base, is

$$R_{in(base)} \cong \beta_{ac} R_e = (175)(235\ \Omega) = 41.1\ \text{k}\Omega$$

The total input resistance is

$$R_{in(tot)} = R_1 \| R_2 \| R_{in(base)} = 18\ \text{k}\Omega \| 51\ \text{k}\Omega \| 41.1\ \text{k}\Omega = \mathbf{10.1\ k\Omega}$$

The voltage gain is $A_v \cong 1$. By using r'_e, you can determine a more precise value of A_v if necessary.

$$V_E = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} - V_{BE} = \left(\frac{51\ \text{k}\Omega}{18\ \text{k}\Omega + 51\ \text{k}\Omega}\right)10\ \text{V} - 0.7\ \text{V}$$

$$= (0.739)(10\ \text{V}) - 0.7\ \text{V} = 6.69\ \text{V}$$

The Common Collector Amplifier

Therefore,

$$I_E = \frac{V_E}{R_E} = \frac{6.69\ \text{V}}{470\ \Omega} = 14.2\ \text{mA}$$

and

$$r'_e \cong \frac{25\ \text{mV}}{I_E} = \frac{25\ \text{mV}}{14.2\ \text{mA}} = 1.76\ \Omega$$

So,

$$A_v = \frac{R_e}{r'_e + R_e} = \frac{235\ \Omega}{237\ \Omega} = \mathbf{0.992}$$

The small difference in A_v as a result of considering r'_e is insignificant in most cases.

The Common Collector Amplifier

The current gain is $A_i = I_e/I_{in}$. The calculations are as follows:

$$I_e = \frac{V_e}{R_e} = \frac{A_v V_b}{R_e} \cong \frac{(0.992)(3\ \text{V})}{235\ \Omega} = \frac{2.98\ \text{V}}{235\ \Omega} = 12.7\ \text{mA}$$

$$I_{in} = \frac{V_{in}}{R_{in(tot)}} = \frac{3\ \text{V}}{10.1\ \text{k}\Omega} = 297\ \mu\text{A}$$

$$A_i = \frac{I_e}{I_{in}} = \frac{12.7\ \text{mA}}{297\ \mu\text{A}} = \mathbf{42.8}$$

The Common Collector Amplifier

The power gain is

$$A_p \cong A_i = 42.8$$

Since $R_L = R_E$, one-half of the power is dissipated in R_E and one-half in R_L. Therefore, in terms of power to the load, the power gain is

$$A_{p(load)} = \frac{A_p}{2} = \frac{42.8}{2} = \mathbf{21.4}$$

The Common Base Amplifier

- A typical **common-base** amplifier is shown in Figure A

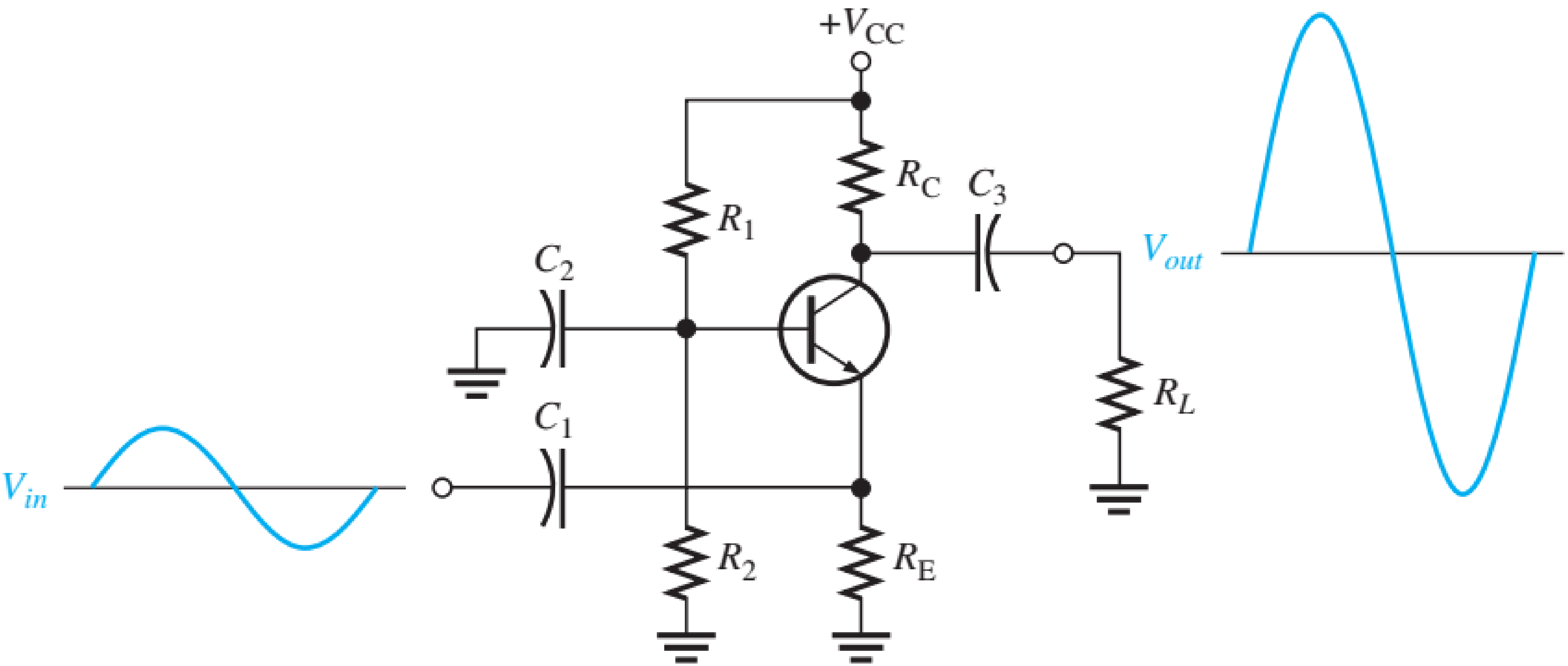


Figure A

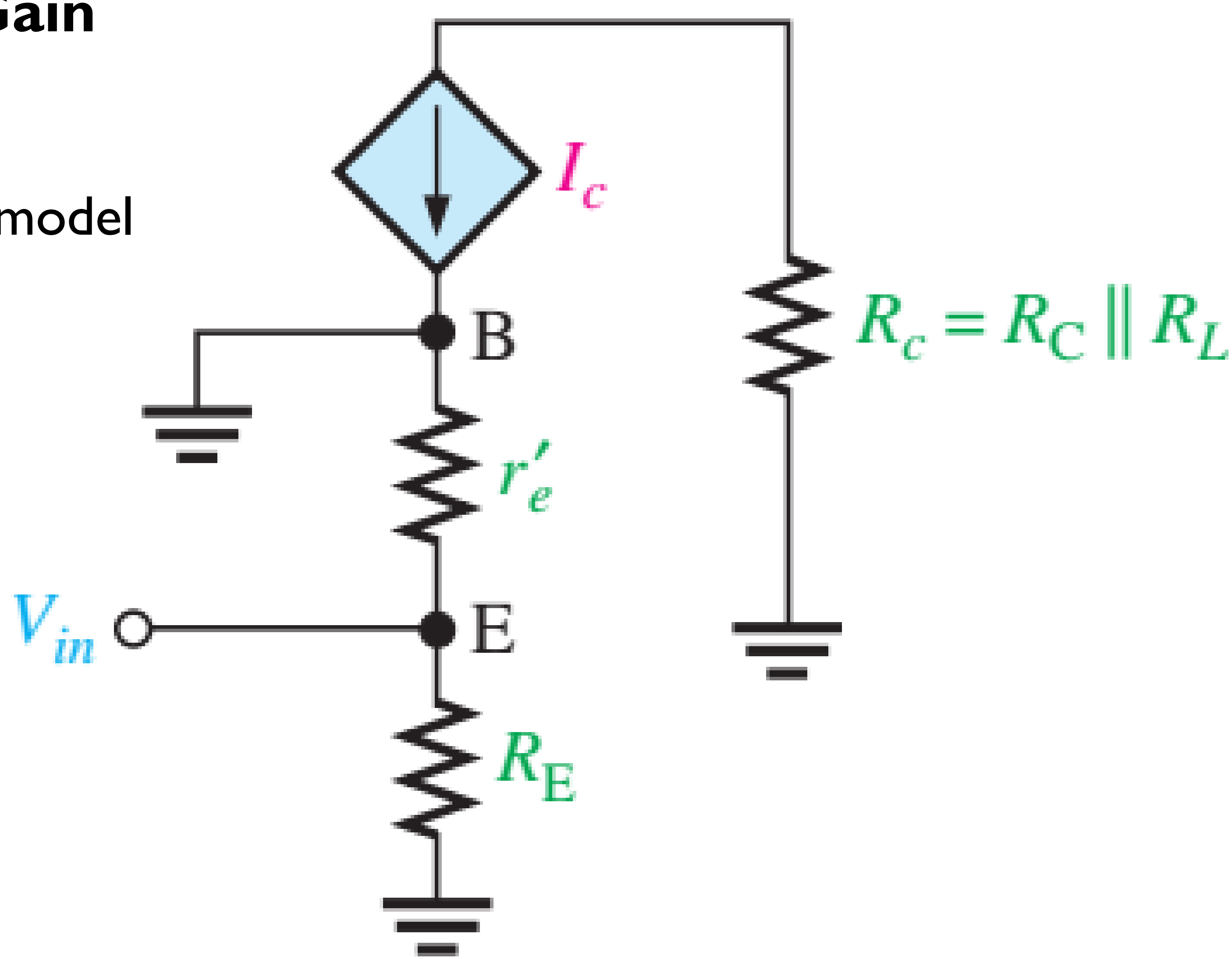
The Common Base Amplifier

- The base is the common terminal and is at ac ground because of capacitor C_2.
- The input signal is capacitively coupled to the emitter
- The output is capacitively coupled from the collector to a load resistor

The Common Base Amplifier

- **Voltage Gain**

AC equivalent model



The Common Base Amplifier

- The voltage gain from emitter to collector is developed as follows ($V_{in} = V_e$, $V_{out} = V_c$)

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_c}{V_e} = \frac{I_c R_c}{I_e(r'_e \parallel R_E)} \cong \frac{I_e R_c}{I_e(r'_e \parallel R_E)}$$

If $R_E \gg r'_e$, then

$$\mathbf{A_v \cong \frac{R_c}{r'_e}}$$

- where $R_c = R_C \parallel R_L$. Notice that the gain expression is the same as for the common-emitter amplifier. However, there is no phase inversion from emitter to collector

The Common Base Amplifier

- **Input Resistance**
  - The resistance, looking in at the emitter, is

$$R_{in(emitter)} = \frac{V_{in}}{I_{in}} = \frac{V_e}{I_e} = \frac{I_e(r'_e \parallel R_E)}{I_e}$$

If $R_E \gg r'_e$, then

$$\boldsymbol{R_{in(emitter)} \cong r'_e}$$

  - R_E is typically much greater than r'_e so the assumption that $r'_e \parallel R_E \approx r'_e$ is usually valid

The Common Base Amplifier

- **Output Resistance**
  - Looking into the collector, the ac collector resistance, r'_c appears in parallel with R_C. As you have previously seen in connection with the CE amplifier, r'_c, is typically much larger than R_C, so a good approximation for the output resistance is

$$R_{out} \cong R_C$$

- **Current Gain**
  - The current gain is the output current divided by the input current. I_c is the ac output current, and I_e is the ac input current. Since $I_c \approx I_e$ the current gain is approximately 1

$$A_i \cong 1$$

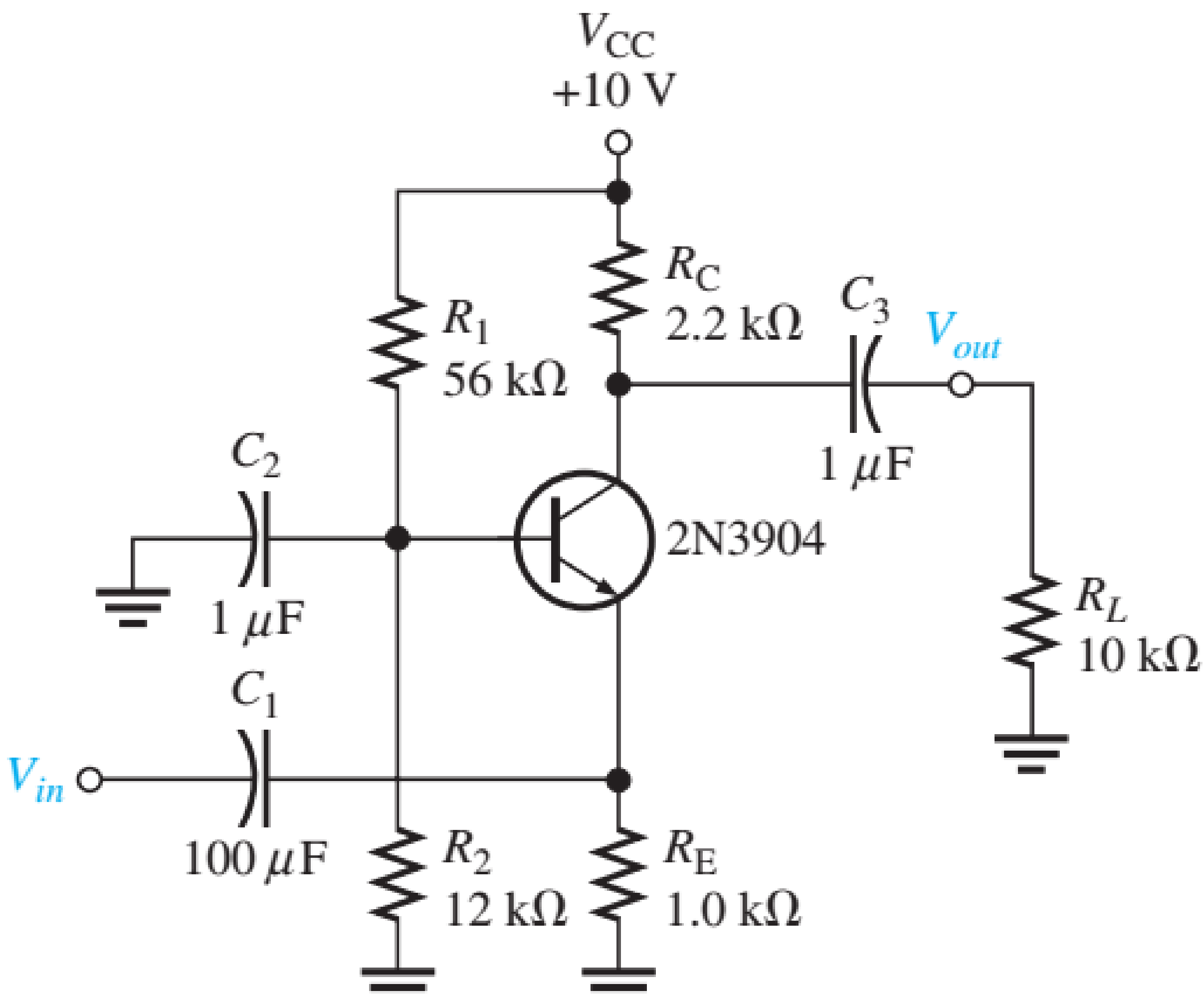
The Common Base Amplifier

- **Power Gain**
  - Since the current gain is approximately 1 for the common-base amplifier and $A_p = A_v A_i$ the power gain is approximately equal to the voltage gain.

$$A_P \cong A_v$$

The Common Base Amplifier

- Find the input resistance, voltage gain, current gain, and power gain for the amplifier in Figure. $\beta_{DC} = 250$.



First, find I_E so that you can determine r'_e. Then $R_{in} \cong r'_e$.

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(56\,\text{k}\Omega)(12\,\text{k}\Omega)}{56\,\text{k}\Omega + 12\,\text{k}\Omega} = 9.88\,\text{k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{12\,\text{k}\Omega}{56\,\text{k}\Omega + 12\,\text{k}\Omega}\right)10\,\text{V} = 1.76\,\text{V}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}} = \frac{1.76\,\text{V} - 0.7\,\text{V}}{1.0\,\text{k}\Omega + 39.5\,\Omega} = 1.02\,\text{mA}$$

Therefore,

$$R_{in} \cong r'_e = \frac{25\,\text{mV}}{I_E} = \frac{25\,\text{mV}}{1.02\,\text{mA}} = \mathbf{24.5\,\Omega}$$

Calculate the voltage gain as follows:

$$R_c = R_C \| R_L = 2.2\,\text{k}\Omega \| 10\,\text{k}\Omega = 1.8\,\text{k}\Omega$$

$$A_v = \frac{R_c}{r'_e} = \frac{1.8\,\text{k}\Omega}{24.5\,\Omega} = \mathbf{73.5}$$

Also, $A_i \cong \mathbf{1}$ and $A_p \cong A_v =$ 73.5