Electrical, Electronic and Digital Principles (EEDP)

Lecture 5

CE Amplifier, Coupling, and Multistage Amplifiers

د. باسم ممدوح الحلوانى

6–3 THE COMMON-EMITTER AMPLIFIER

Total Output Resistance

- The output resistance of any system is defined as the resistance Ro (Zo) determined when Vi = 0.

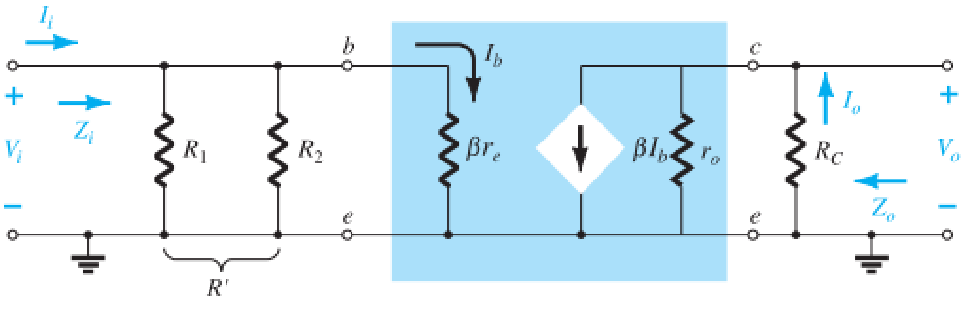
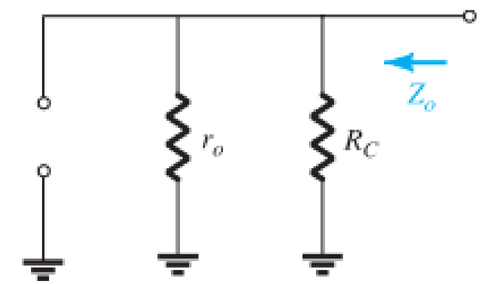


FIG. 5.27
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.26.

when Vi =0, Ii = Ib = 0, resulting in an open-circuit equivalence for the current source.



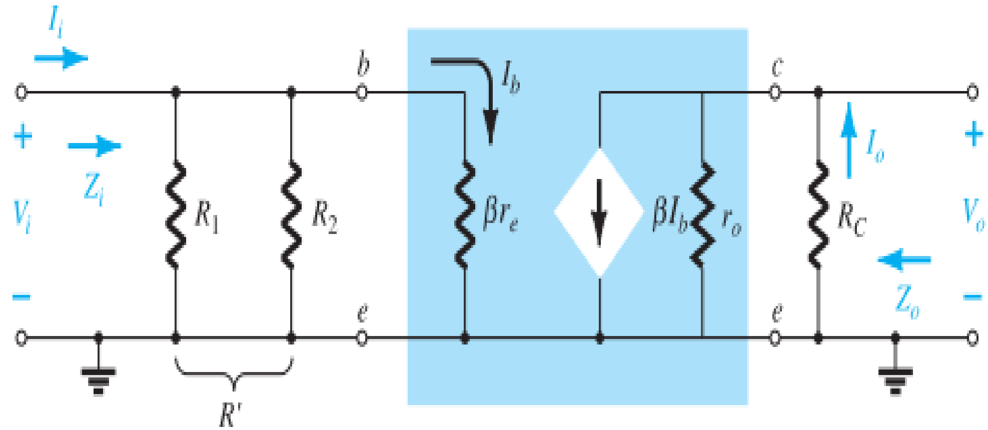
$$Z_o = R_C \| r_o$$

If $r_o \geq 10R_C$, the approximation $R_C \| r_o \cong R_C$ is frequently applied, and

$$Z_o \cong R_C \qquad r_o \geq 10R_C$$

Voltage Gain

The gain is the ratio of ac output voltage at the collector (Vc) to ac input voltage at the base (Vb).



$$V_o = -(\beta I_b)(R_C \| r_o)$$

$$I_b = \frac{V_i}{\beta r_e}$$

$$\frac{V_c}{V_b}$$

the voltage gain from base to collector.

$$V_o = -\beta\left(\frac{V_i}{\beta r_e}\right)(R_C \| r_o)$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_C \| r_o}{r_e}$$

Phase Relationship The negative sign of Eq. (5.15) reveals a 180° phase shift between V_0 and V_i.

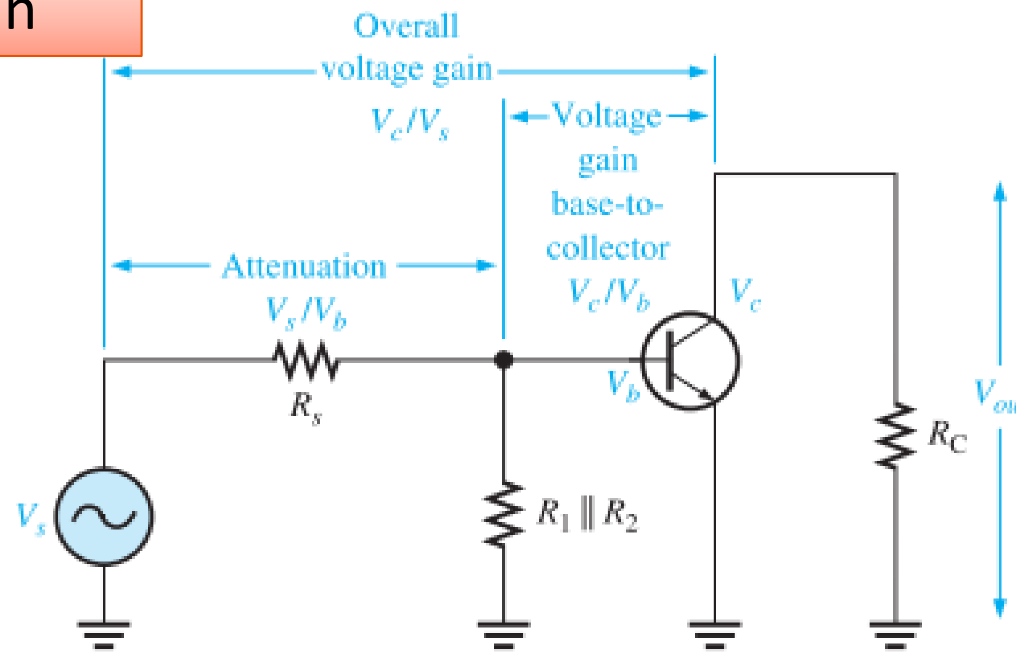
For $r_o \geq 10R_C$,

$$A_v = \frac{V_o}{V_i} \cong -\frac{R_C}{r_e} \qquad r_o \geq 10R_C$$

To get the overall gain of the amplifier from the source voltage to collector, the attenuation of the input circuit must be included

Attenuation and the Overall Gain

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

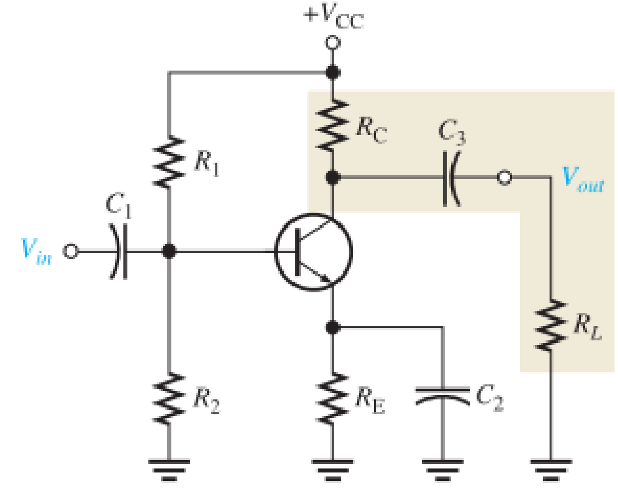


Overall Voltage Gain

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

Effect of a Load on the Voltage Gain

When a resistor, RL, is connected to the output through the coupling capacitor C3, as shown in Figure 6–17(a), it creates a load on the circuit.

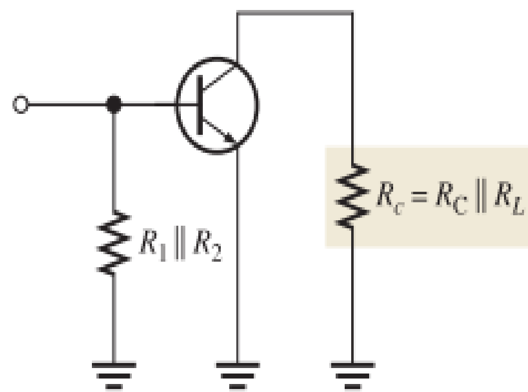


(a) Complete amplifier

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

Replacing R_C with R_c in the voltage gain expression gives

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



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

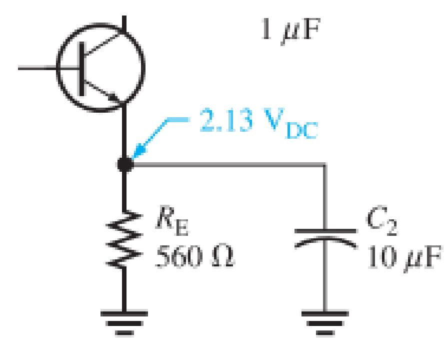
When $R_c < R_C$ because of R_L, the voltage gain is reduced.

However, if RL>> RC then:

$$R_c \cong R_C$$

and the load has very little effect on the gain.

Effect of the Emitter Bypass Capacitor on Voltage Gain



- ✓ The emitter bypass capacitor, which is C2 in Figure , provides an effective short to the ac signal around the emitter resistor, thus **keeping the emitter at ac ground**

- 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 ohms) 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

EXAMPLE 6–4

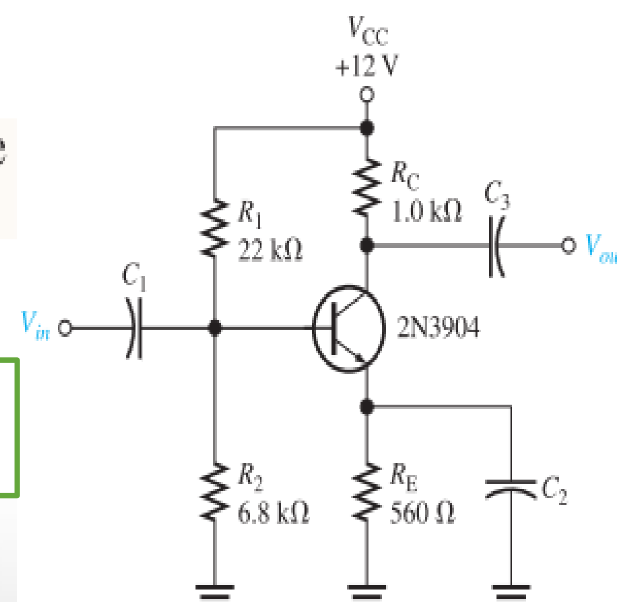
$$10X_C \leq R_E$$

Select a minimum value for the emitter bypass capacitor, C_2, in Figure 6–16 if the amplifier must operate over a frequency range from 200 Hz to 10 kHz.

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

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

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



Effect of the Emitter Bypass Capacitor on Voltage Gain

Voltage Gain Without the Bypass Capacitor

- ✓ **Without** the bypass capacitor, the emitter is no longer at ac ground.
- ✓ Instead, RE is seen by the ac signal between the emitter and ground and effectively adds to r_e' in the voltage gain formula and reduces the gain:

$$A_v = \frac{R_C}{r_e' + R_E}$$

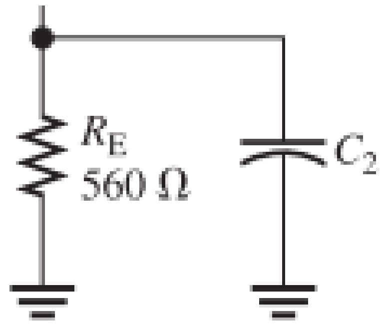
Proof (Page 288- Boylstad)

EXAMPLE 6–5 Calculate the base-to-collector voltage gain of the amplifier in Figure 6–16 both without and with an emitter bypass capacitor if there is no load resistor.

$r_e' = 6.58\ \Omega$

Without C2, the gain is

$$A_v = \frac{R_C}{r_e' + R_E} = \frac{1.0\,\text{k}\Omega}{567\ \Omega} = 1.76$$



With C2, the gain is

$$A_v = \frac{R_C}{r_e'} = \frac{1.0\,\text{k}\Omega}{6.58\ \Omega} = 152$$

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 B.
- ✓ Although bypassing RE does produce the maximum voltage gain, there is a stability problem because the ac voltage gain is dependent on r_e

$$A_v = R_C / r'_e.$$

- ✓ Since r_e depends on I_E and on temperature, the gain is unstable over changes in temperature
- ✓ With no bypass capacitor, the gain is decreased because R_E is now in the ac circuit and the gain became:

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

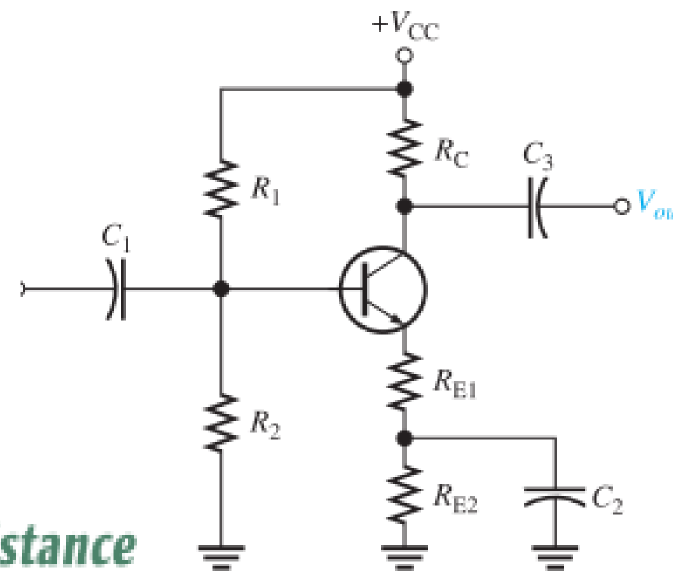
- ➢ **How to minimize the effect of r_e without reducing the voltage gain to its minimum value.**

Swamping

Swamping R_E effect on the Gain

- Swamping is a compromise between having a bypass capacitor across RE 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 re on the gain is greatly reduced or eliminated.

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



- 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:

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

The Effect of Swamping on the Amplifier's Input Resistance

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

MULTISTAGE AMPLIFIERS

- Two or more amplifiers can be connected in a cascaded arrangement with the output of one amplifier driving the input of the next.
- The basic purpose of using multistage is to increase the overall voltage gain.

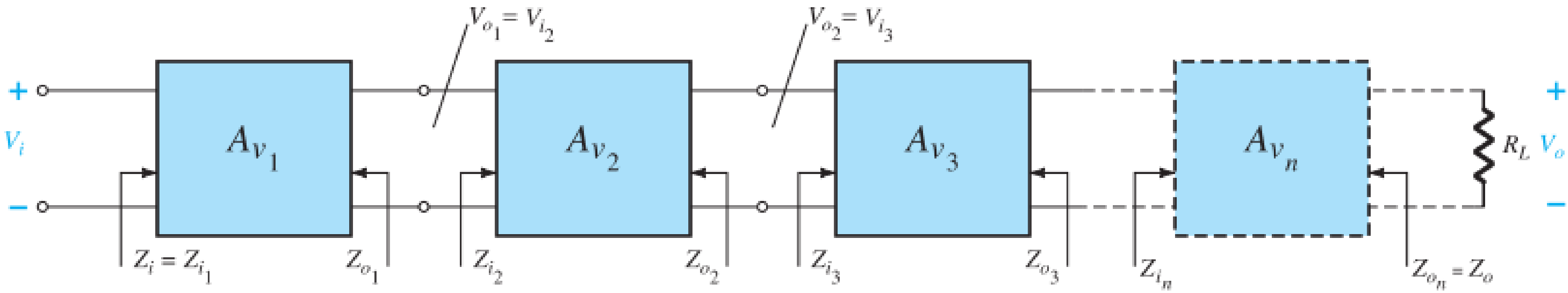


FIG. 5.67

Cascaded system.

$$A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots$$

- Amplifier voltage gain is often expressed in decibels (dB) as follows:

$$A_{v(\mathrm{dB})} = 20 \log A_v$$

- Total gain in dB is given by:

$$A'_{v(\mathrm{dB})} = A_{v1(\mathrm{dB})} + A_{v2(\mathrm{dB})} + \cdots + A_{vn(\mathrm{dB})}$$

Amplifiers Coupling

1. RC-Coupling
2. Transformer Coupling
3. Direct Coupling

The purpose of coupling device (*e.g.* a capacitor, transformer etc.) is

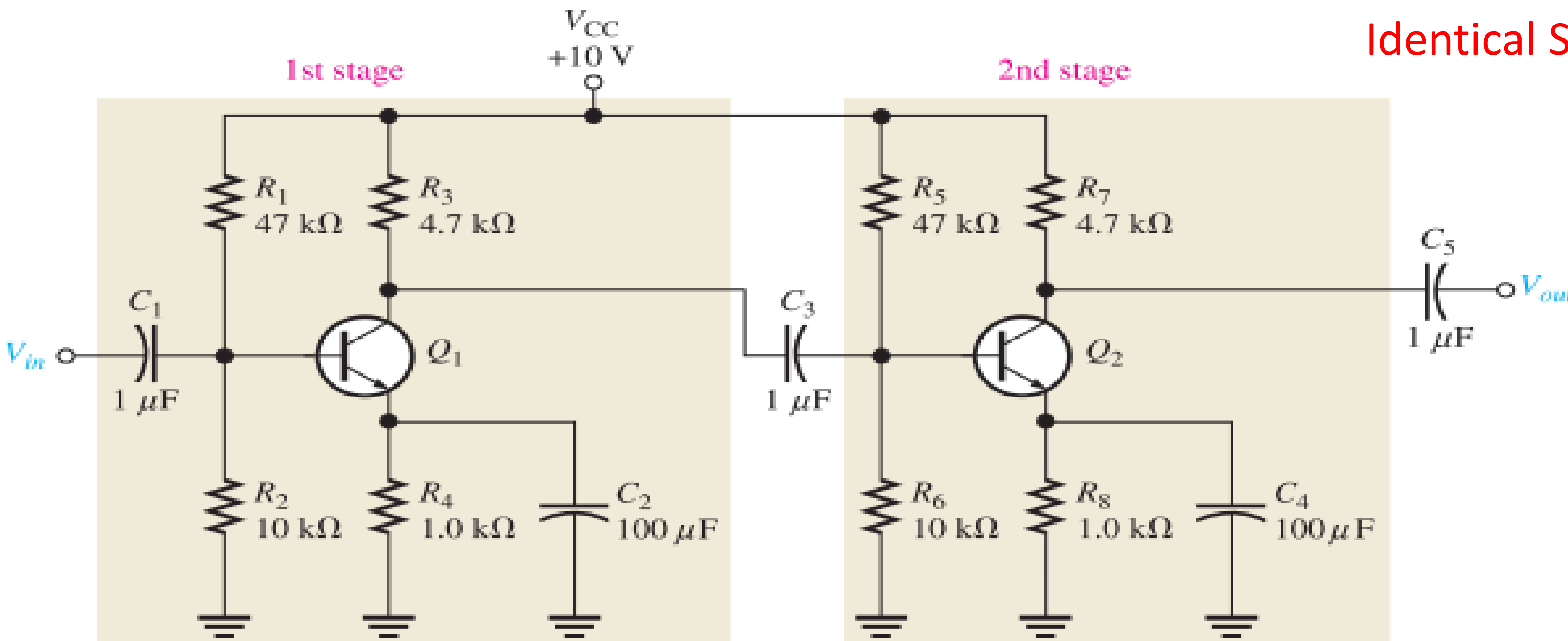
(*i*) to transfer a.c. output of one stage to the input of the next stage

(*ii*) to isolate the d.c. conditions of one stage from the next stage.

Capacitively-Coupled (R-C Coupling)

- The output of the first stage capacitively *coupled* to the input of the 2nd stage.
- Capacitive coupling prevents the dc bias of one stage from affecting that of the other but allows the ac signal to pass without attenuation

Identical Stages



$\beta_{DC} = \beta_{ac} = 150$ for Q_1 and Q_2

- The first stage introduces a loading effect to the second stage.
- Because the coupling capacitor C3 effectively appears as a short at the signal frequency, the total input resistance of the second stage presents an ac load to the first stage.

Capacitively-Coupled (R-C Coupling)

DC Analysis of each stage (Identical and capacitively coupled)

Since $\beta_{DC}R_4 \gg R_2$ and $\beta_{DC}R_8 \gg R_6$

the dc base voltage for Q_1 and Q_2 is

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{10\text{ k}\Omega}{57\text{ k}\Omega}\right)10\text{ V} = 1.75\text{ V}$$

The dc emitter and collector voltages are as follows:

$$V_E = V_B - 0.7\text{ V} = 1.05\text{ V}$$

$$I_E = \frac{V_E}{R_4} = \frac{1.05\text{ V}}{1.0\text{ k}\Omega} = 1.05\text{ mA}$$

$$I_C \cong I_E = 1.05\text{ mA}$$

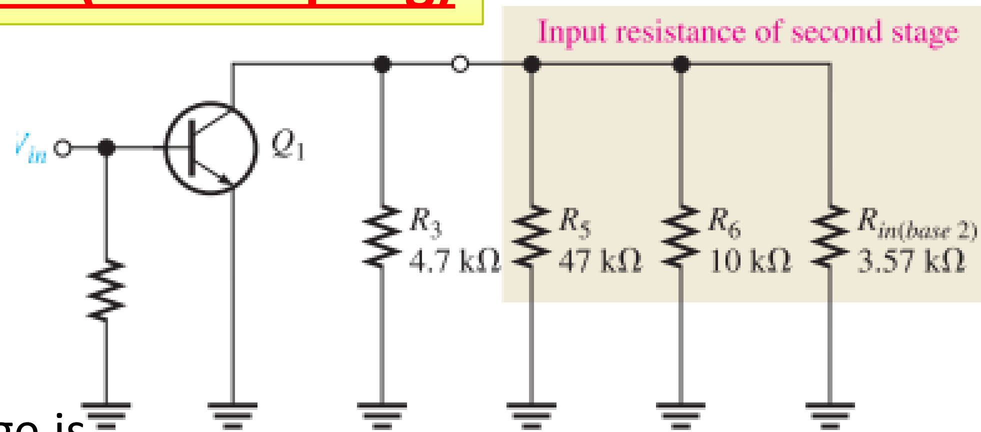
$$V_C = V_{CC} - I_C R_3 = 10\text{ V} - (1.05\text{ mA})(4.7\text{ k}\Omega) = 5.07\text{ V}$$

$r'_e = 23.8\Omega$, **= 25 mv/I_E**

$R_{in(base2)} = 3.57\text{ k}\Omega$ **= B re**

Capacitively-Coupled (R-C Coupling)

- AC equivalent of first stage showing loading from second stage input resistance.



Voltage Gain of the First Stage

The ac collector resistance of the first stage is

$$R_{c1} = R_3 \| R_5 \| R_6 \| R_{in(base2)} \qquad R_{c1} = 4.7\ \text{k}\Omega \| 47\ \text{k}\Omega \| 10\ \text{k}\Omega \| 3.57\ \text{k}\Omega = 1.63\ \text{k}\Omega$$

$$A_{v1} = \frac{R_{c1}}{r'_e} = \frac{1.63\ \text{k}\Omega}{23.8\ \Omega} = 68.5$$

Voltage Gain of the Second Stage

- The second stage has no load resistor, so the ac collector resistance is R7, and the gain is

$$A_{v2} = \frac{R_7}{r'_e} = \frac{4.7\ \text{k}\Omega}{23.8\ \Omega} = 197$$

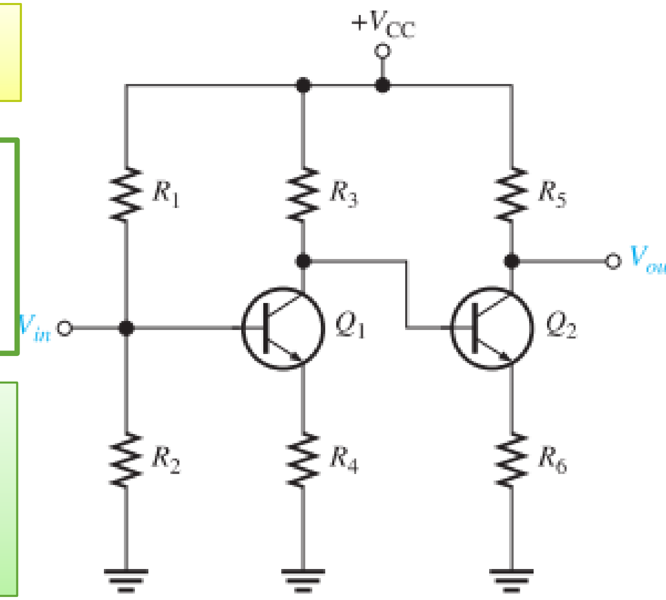
- Compare this to the gain of the first stage (Identical stages) , and
- Notice how much the loading from the second stage reduced the gain.

Overall Voltage Gain

$$A'_v = A_{v1}A_{v2} = (68.5)(197) \cong 13{,}495$$

Direct-Coupled Multistage Amplifiers

- There are no coupling or bypass capacitors
- The dc collector voltage of the first stage provides the base-bias voltage for the second stage.



- Because of the direct coupling, this type of amplifier has a better low-frequency response than the capacitively coupled type

- At Low Frequencies:
  - ✓ The reactance of coupling and bypass capacitors may become excessive.
  - ✓ The increased reactance of capacitors produces gain reduction in capacitively coupled amplifiers.

- Direct-coupled amplifiers can be used to amplify low frequencies all the way down to dc (0 Hz) without loss of voltage (no capacitors)

- The disadvantage of direct-coupled amplifiers, is that small changes in the dc bias voltages from temperature effects or power-supply variation are amplified by the succeeding stages, which can result in a significant drift in the dc levels throughout the circuit.

Next Lecture

- Amplifiers Classes (A, B, AB, and C