OPERATIONAL AMPLIFIERS

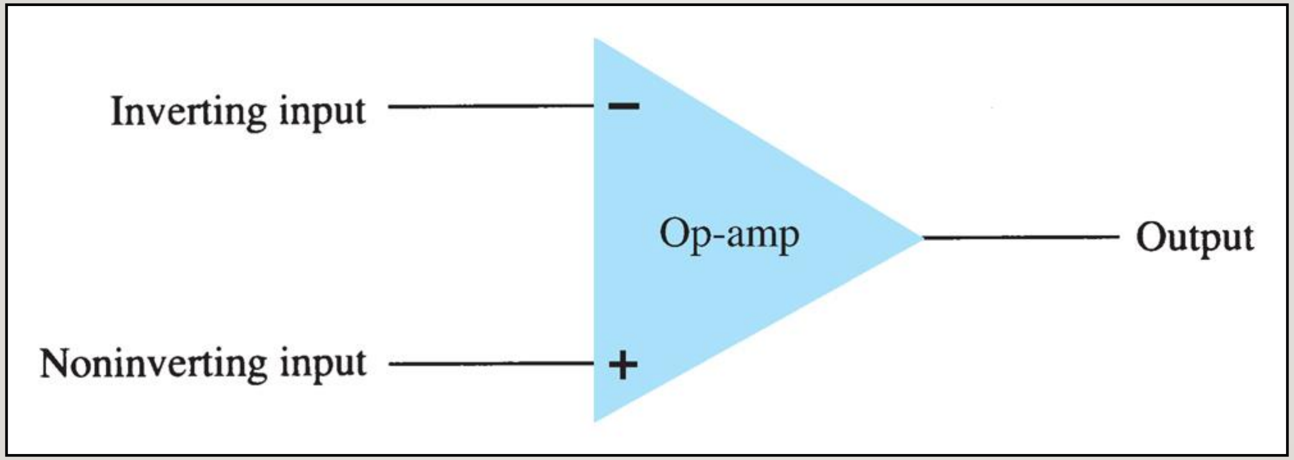
CHAPTER 10 OF " *ELECTRONIC DEVICES AND CIRCUIT THEORY*" BY BOYLESTAD, ROBERT L.; NASHELSKY, L.

RESOURCE PERSONS:

DR. JEHANGIR ARSHAD

WAJEEHA KHAN

The Basic Op-Amp



Operational amplifier (Op-amp): A high gain differential amplifier with a high input impedance (typically in MΩ) and low output impedance (less than 100Ω).

Note the op-amp has two inputs and one output.

Op-Amp Gain

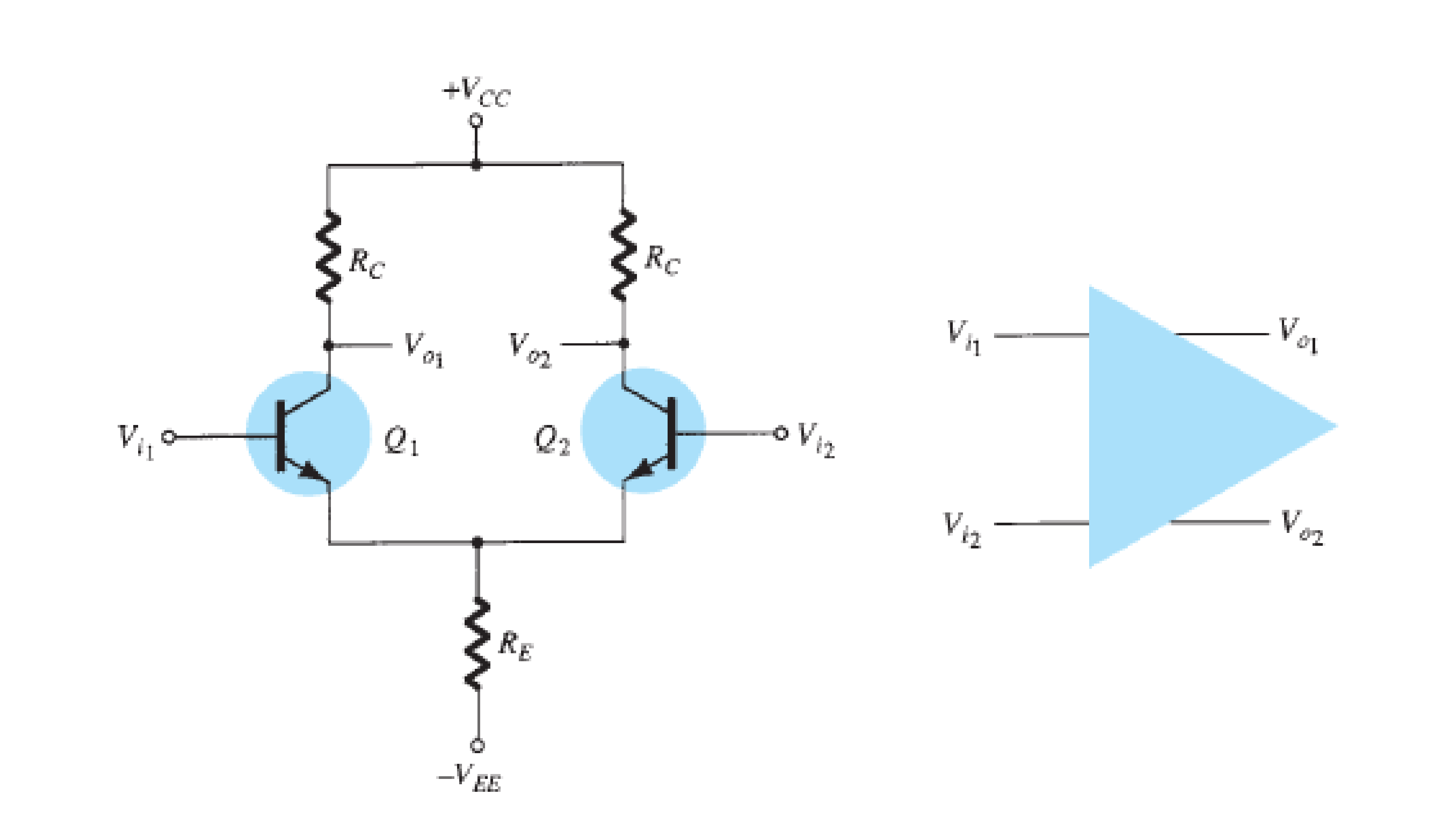
Op-Amps can be connected in *open-loop* or *closed-loop* configurations.

Open-loop: A configuration with no feedback from the op-amp output back to its input. Op-amp open-loop gain typically exceeds 10,000.

Closed-loop: A configuration that has a negative feedback path from the op-amp output back to its input. **Negative feedback** reduces the gain and improves many characteristics of the op-amp.

- Closed-loop gain is always lower than open-loop gain.

DC BIAS

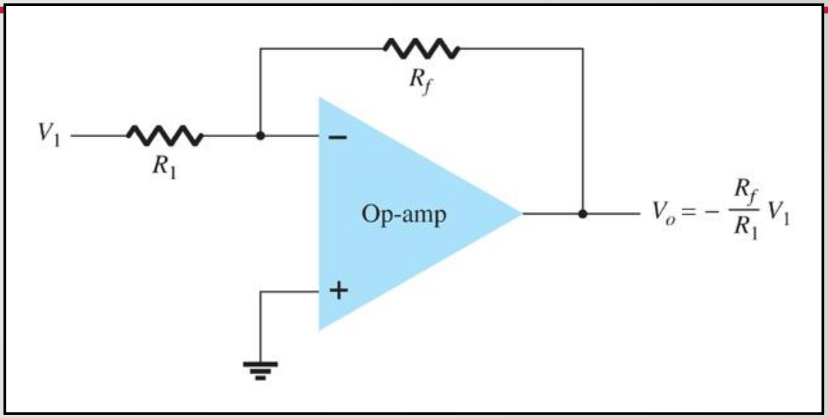


DC-Offset Parameters

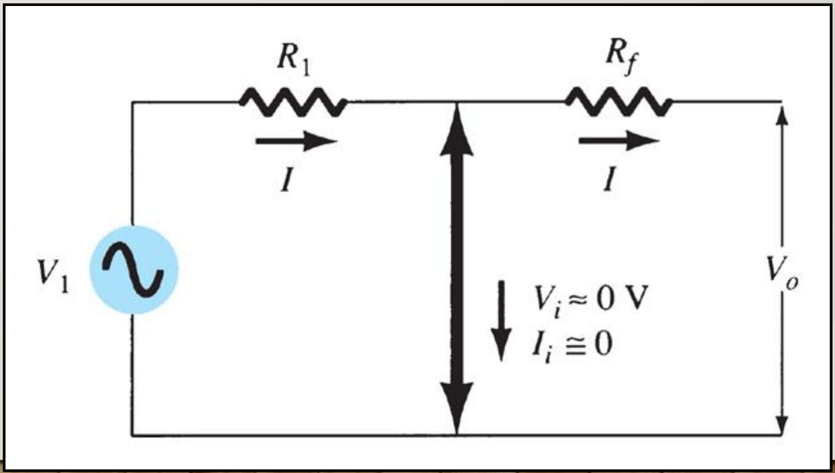
Even when the input voltage is zero, an op-amp can have an output **offset**. The following can cause this offset:

Input offset voltage
Input offset current
Input offset voltage *and* input offset current
Input bias current

Virtual Ground



Virtual ground: A term used to describe the condition where $V_i \cong 0$ V (at the inverting input) when the noninverting input is grounded.

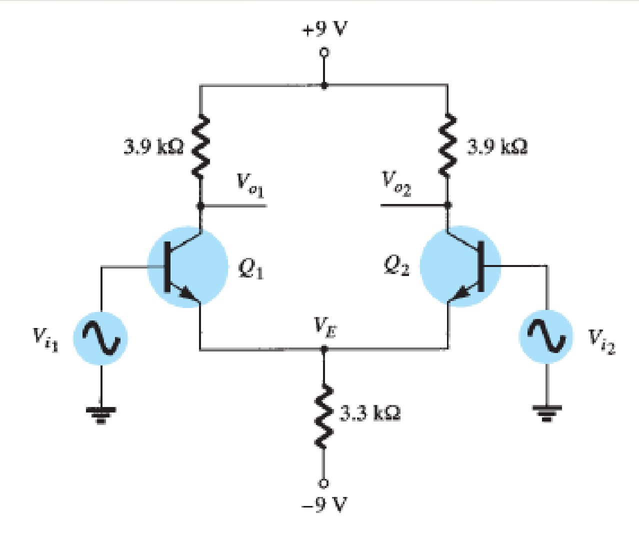


The op-amp has such high input impedance that even with a high gain there is no current through the inverting input pin, therefore all of the input current passes through R_f.

$$V_i = \frac{-V_o}{A_v} = \frac{10\text{ V}}{20{,}000} = 0.5\text{ mV}$$

DC BIAS EXAMPLE

- Example 10.1: Calculate the DC voltages and currents in the given circuit



DC BIAS

- Example 10.1 Solution:

$$I_E = \frac{V_{EE} - 0.7\text{ V}}{R_E} = \frac{9\text{ V} - 0.7\text{ V}}{3.3\text{ k}\Omega} \approx \mathbf{2.5\text{ mA}}$$

The collector current is then

$$I_C = \frac{I_E}{2} = \frac{2.5\text{ mA}}{2} = \mathbf{1.25\text{ mA}}$$

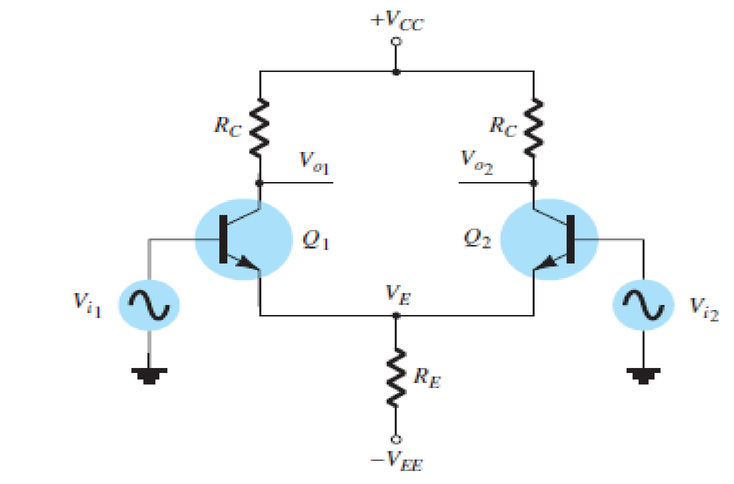
resulting in a collector voltage of

$$V_C = V_{CC} - I_C R_C = 9\text{ V} - (1.25\text{ mA})(3.9\text{ k}\Omega) \approx \mathbf{4.1\text{ V}}$$

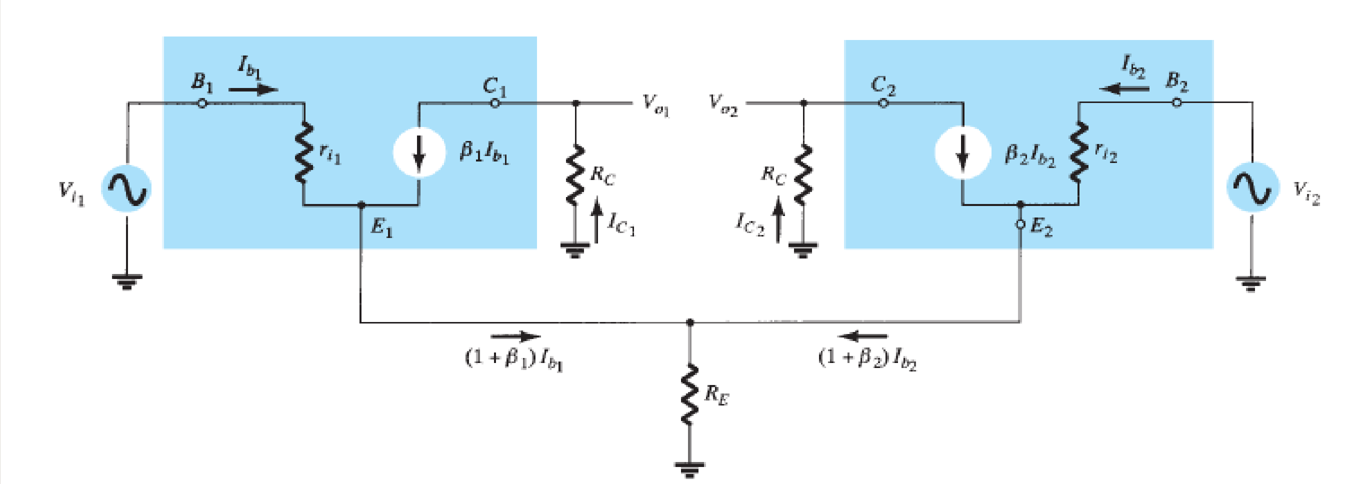
The common-emitter voltage is thus –0.7 V, whereas the collector bias voltage is near 4.1 V for both outputs.

AC Operation

An ac connection of a differential amplifier is shown in figure below. Separate input signals are applied as V_{i1} and V_{i2}, with separate outputs resulting as V_{o1} and V_{o2}. To carry out ac analysis, we redraw the circuit. Each transistor is replaced by its ac equivalent.



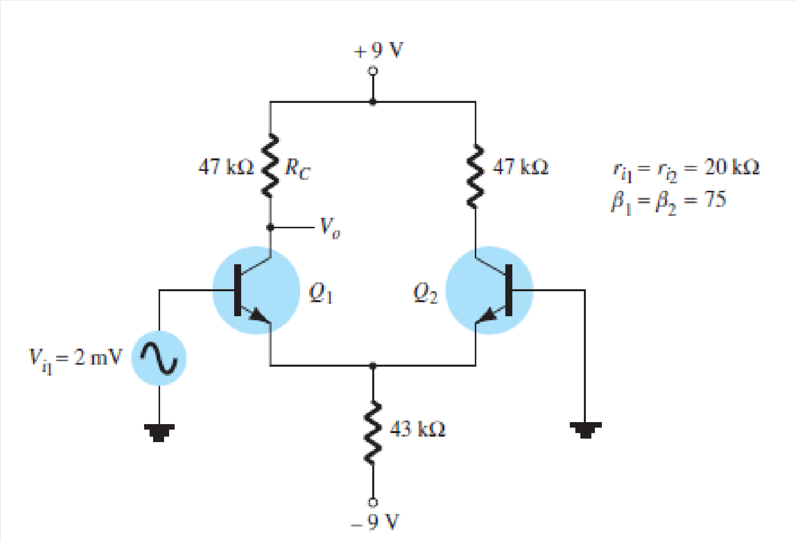
(a) AC connection of differential amplifier



(b) AC equivalent of differential amplifier

AC OPERATION EXAMPLE

- Example 10.2: Calculate the single-ended output voltage in the given circuit



Solution: The dc bias calculations provide

$$I_E = \frac{V_{EE} - 0.7\text{ V}}{R_E} = \frac{9\text{ V} - 0.7\text{ V}}{43\text{ k}\Omega} = 193\ \mu\text{A}$$

The collector dc current is then

$$I_C = \frac{I_E}{2} = 96.5\ \mu\text{A}$$

so that $V_C = V_{CC} - I_C R_C = 9\text{ V} - (96.5\ \mu\text{A})(47\text{ k}\Omega) = 4.5\text{ V}$

The value of r_e is then

$$r_e = \frac{26}{0.0965} \cong 269\ \Omega$$

The ac voltage gain magnitude can be calculated using Eq. (10.31):

$$A_v = \frac{R_C}{2r_e} = \frac{(47\text{ k}\Omega)}{2(269\ \Omega)} = 87.4$$

providing an output ac voltage of magnitude

$$V_o = A_v V_i = (87.4)(2\text{ mV}) = 174.8\text{ mV} = \mathbf{0.175\ V}$$

CMRR

One rating that is unique to op-amps is **CMRR** or **common-mode rejection ratio**.

Because the op-amp has two inputs that are opposite in phase (inverting input and the non-inverting input) any signal that is common to both inputs will be cancelled.

Op-amp CMRR is a measure of the ability to cancel out common-mode signals.