The current mirror inverts the right collector current and tries to pass it through the left transistor that produces the left collector current. In the middle point between the two left transistors, the two signal currents (current changes) are subtracted. In this case (differential input signal), they are equal and opposite. Thus, the difference is twice the individual signal currents ($\Delta I - (-\Delta I) = 2\Delta I$) and the differential to single ended conversion is completed without gain losses.

Interfacing considerations

Floating input source

It is possible to connect a floating source between the two bases, but it is necessary to ensure paths for the biasing base currents. In the case of galvanic source, only one resistor has to be connected between one of the bases and the ground. The biasing current will enter directly this base and indirectly (through the input source) the other one. If the source is capacitive, two resistors have to be connected between the two bases and the ground to ensure different paths for the base currents.

Input/output impedance

The input impedance of the differential pair highly depends on the input mode. At common mode, the two parts behave as common-collector stages with high emitter loads; so, the input impedances are extremely high. At differential mode, they behave as common-emitter stages with grounded emitters; so, the input impedances are low.

The output impedance of the differential pair is high (especially for the improved differential pair from Fig. 3).

Input/output range

The common-mode input voltage can vary between the two supply rails but cannot closely reach them since some voltage drops (minimum 1 volt) have to remain across the output transistors of the two current mirrors.

Operational amplifier as differential amplifier

An operational amplifier, or op-amp, is a differential amplifier with very high differential-mode gain, very high input impedance, and low output impedance. By applying negative feedback, an op-amp differential amplifier (Fig. 4) with predictable and stable gain can be built.[nb 5] Some kinds of differential amplifier usually include several simpler differential amplifiers. For example, an instrumentation amplifier, a fully differential amplifier, an instrument amplifier, or an isolation amplifier are often built from several op-amps.

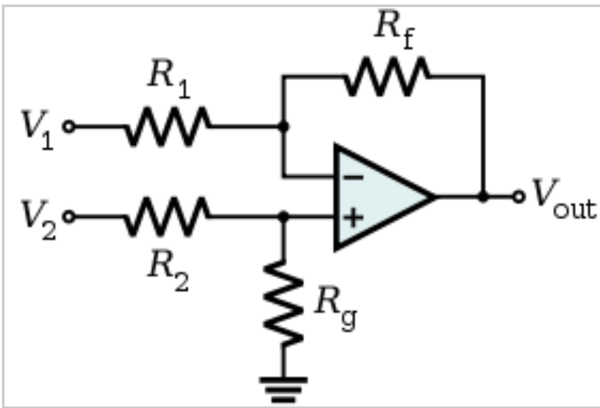

Figure 4: Op-amp differential amplifier

Applications

Differential amplifiers are found in many circuits that utilize series negative feedback (op-amp follower, non-inverting amplifier, etc.), where one input is used for the input signal, the other for the feedback signal (usually implemented by operational amplifiers). For comparison, the old-fashioned inverting single-ended op-amps from the early 1940s could realize only parallel negative feedback by connecting additional resistor networks (an op-amp inverting amplifier is the most popular example). A common application is for the control of motors or servos, as well as for signal amplification applications. In discrete electronics, a common arrangement for implementing a differential amplifier is the long-tailed pair, which is also usually found as the differential element in most op-amp integrated circuits. A long-tailed pair can be used as an analog multiplier with the differential voltage as one input and the biasing current as another.

A differential amplifier is used as the input stage emitter coupled logic gates and as switch. When used as a switch, the "left" base/grid is used as signal input and the "right" base/grid is grounded; output is taken from the right collector/plate. When the input is zero or negative, the output is close to zero (but can be not saturated); when the input is positive, the output is most-positive, dynamic operation being the same as the amplifier use described above.

Symmetrical feedback network eliminates common-mode gain and common-mode bias

In case the operational amplifier's (non-ideal) input bias current or differential input impedance are a significant effect, one can select a feedback network that ameliorates (improve) the effect of common-mode input signal and bias. In Figure 5, current generators model the input bias current at each terminal; I^+_b and I^-_b represent the input bias current at terminals V^+ and V^-, respectively.

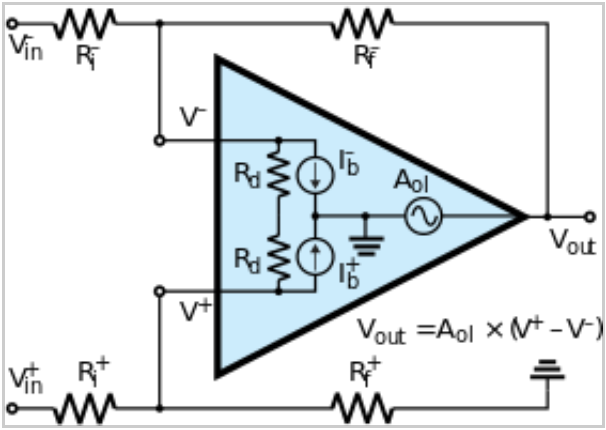

Figure 5: Differential amplifier with non-ideal op-amp: input bias current and differential input impedance

The Thévenin equivalent for the network driving the V^+ terminal has a voltage $V^{+'}$ and impedance $R^{+'}$:

$$V^{+\prime} = V^+_{\text{in}} * R^+_{/\!/} / R^+_{\text{i}} - I^+_{\text{b}} * R^+_{/\!/}; \quad R^{+\prime} = R^+_{/\!/} = R^+_{\text{i}} /\!/ R^+_{\text{f}}$$

while for the network driving the V^- terminal,

$$V^{-\prime} = V^-_{\text{in}} * R^-_{/\!/} / R^-_{\text{i}} + V_{\text{out}} * R^-_{/\!/} / R^-_{\text{f}} - I^-_{\text{b}} * R^-_{/\!/}; \quad R^{-\prime} = R^-_{/\!/} = R^-_{\text{i}} /\!/ R^-_{\text{f}}\,.$$

The output of the op amp is just the open-loop gain A_{ol} times the differential input current i times the differential input impedance $2R_d$, therefore

$$V_{\text{out}} = A_{\text{ol}} * 2R_{\text{d}} \frac{V^{+\prime} - V^{-\prime}}{2R_{/\!/} + 2R_{\text{d}}} = (V^{+\prime} - V^{-\prime}) * A_{\text{ol}} R_{/\!/} / (R_{/\!/} /\!/ R_{\text{d}})$$

where $R_{//}$ is the average of $R^+_{//}$ and $R^-_{//}$.

These equations undergo a great simplification if

$$R^+_{\text{i}} = R^-_{\text{i}} \quad \text{and} \quad R^+_{\text{f}} = R^-_{\text{f}}$$