

Calculation of the differential amplifier output offset voltage

Part 1. Internal resistances of sources are not taken into analysis.

Calculations for inverting input network:

Step 1: current source is excluded from circuit

$$U_1 = 0, U_a = U_{out} \frac{R_1}{R_1 + R_2}; (1)$$

$$U_{out} = 0, U_a = U_1 \frac{R_2}{R_1 + R_2} (2).$$

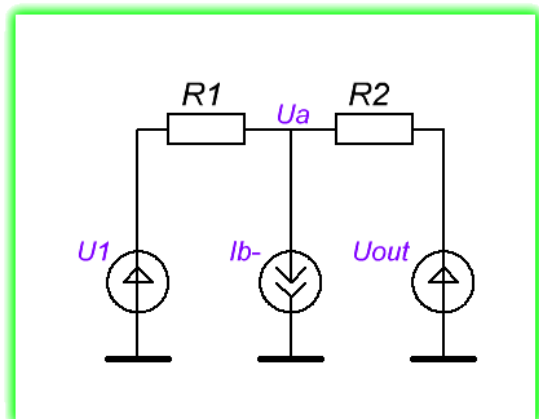
$$U_a = U_1 \frac{R_2}{R_1 + R_2} + U_{out} \frac{R_1}{R_1 + R_2} (3).$$

Step 2: voltage source is excluded from circuit

$$U_a = -I_{b-} \frac{R_1 R_2}{R_1 + R_2} (4)$$

The final equation for U_a :

$$U_a = U_1 \frac{R_2}{R_1 + R_2} + U_{out} \frac{R_1}{R_1 + R_2} - I_{b-} \frac{R_1 R_2}{R_1 + R_2} (5)$$



Equivalent circuit for bias current of inverting input

Calculations for non-inverting input network:

Step 1: current source is excluded from circuit

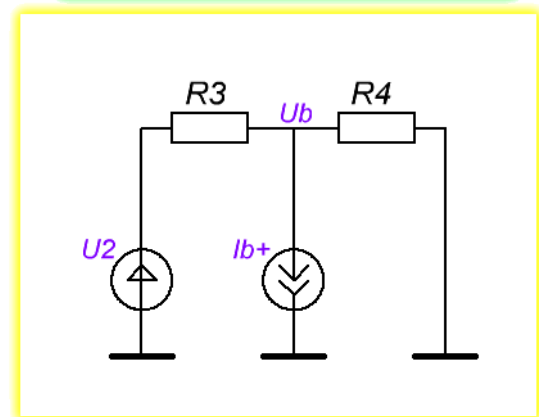
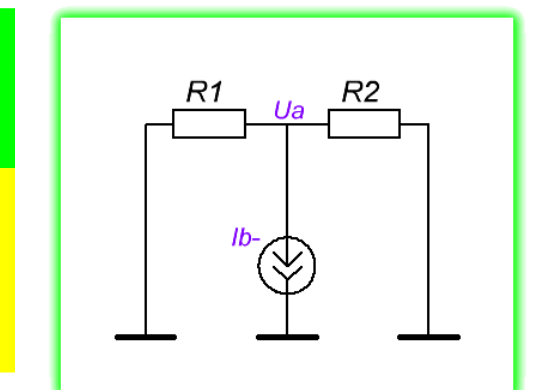
$$I_{b+} = 0, U_b = U_2 \frac{R_4}{R_3 + R_4}; (6)$$

Step 2: voltage source is excluded from circuit

$$U_2 = 0, U_b = -I_{b+} \frac{R_3 R_4}{R_3 + R_4}. (7)$$

The final equation for U_b :

$$U_b = U_2 \frac{R_4}{R_3 + R_4} - I_{b+} \frac{R_3 R_4}{R_3 + R_4}. (8)$$



Equivalent circuit for bias current of non-inverting input

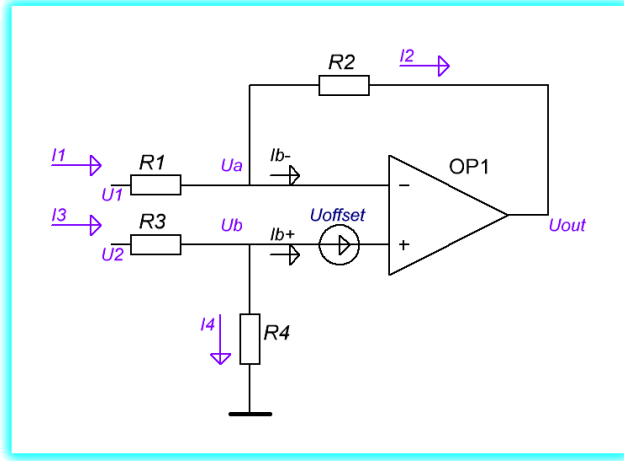
Note 1: Introduce the transfer factors of input resistors networks:

$$\frac{R_2}{R_1 + R_2} = \beta_-; \frac{R_4}{R_3 + R_4} = \beta_+; (9)$$

Note 2: Resistances of input networks related to an op-amp inputs:

$$\frac{R_1 R_2}{R_1 + R_2} = \gamma_-; \frac{R_3 R_4}{R_3 + R_4} = \gamma_+. (10)$$

Note 3: If an op-amp is ideal, $U_a = U_b$; in reality : $U_b - U_a = -U_{offset}$. (11)



Equivalent circuit including bias voltage

Note 4: Usually, $R_1 = R_3$; $R_2 = R_4$

$$U_2 \frac{R_4}{R_3 + R_4} - U_1 \frac{R_2}{R_1 + R_2} + I_{b-} \frac{R_1 R_2}{R_1 + R_2} - I_{b+} \frac{R_3 R_4}{R_3 + R_4} + U_{offset} = U_{out} \frac{R_1}{R_1 + R_2}. (12)$$

Note that $\frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$ is noise gain; also note that according to **Note 4**: $\beta_- = \beta_+$; $\gamma_- = \gamma_+$

$$[U_2 \beta_+ - U_1 \beta_-] NG + [\gamma_- I_{b-} - \gamma_+ I_{b+}] NG + U_{offset} \cdot NG = U_{out}. (13)$$

Also note that $\beta_+ \cdot NG = \frac{R_4}{R_1}$; $\beta_- \cdot NG = \frac{R_2}{R_1}$ and $\gamma_+ \cdot NG = R_4$; $\gamma_- \cdot NG = R_2$

If **Note 4** is true:

$$(U_2 - U_1) \frac{R_2}{R_1} + R_2 (I_{b-} - I_{b+}) + U_{offset} \cdot NG = U_{out}. (14)$$

In addition, input bias currents flowing through input resistance network cause voltages that are applied to op-amp inputs. If **Note 4** isn't true, this voltages are different, even if bias currents are equal, that cause output offset voltage.

If $I_{b-} = I_{b+} = I_b$, we can rewrite expression 13:

$$(U_2 \beta_+ - U_1 \beta_-) NG + I_b [\gamma_- - \gamma_+] NG + U_{offset} \cdot NG = U_{out}. (15)$$

$$I_b [\gamma_- - \gamma_+] NG = I_b \left[R_2 - \frac{R_3 R_4}{R_1} \frac{R_1 + R_2}{R_3 + R_4} \right] = R_2 I_b \left[1 - \frac{R_3 R_4}{R_1 R_2} \frac{R_1 + R_2}{R_3 + R_4} \right]. (16)$$

$$(U_2 \beta_+ - U_1 \beta_-) NG + R_2 I_b \left[1 - \frac{R_3 R_4}{R_3 + R_4} \frac{R_1 + R_2}{R_1 R_2} \right] + U_{offset} \cdot NG = U_{out}. (17)$$

$$(U_2 \beta_+ - U_1 \beta_-) NG + R_2 I_b \left[1 - \frac{R_p}{R_n} \right] + U_{offset} \cdot NG = U_{out}. (18) , \text{ here } R_p \text{ is total resistance at non-inv. input; } R_n$$

is total resistance at inv. input of op-amp.

The disadvantage of the above formulas is that it is necessary to know the magnitude of the bias currents and their actual directions. Worst case value of the output offset voltage can be estimated using this expression:

$$R_2 I_{offset} + R_2 I_b \left[1 - \frac{R_p}{R_n} \right] + U_{offset} \cdot NG = U_{out}. (19)$$