Noise analysis of OPAMPs

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OPAMPs have inherent voltage and current noise that must be accounted for in circuit design. We analyze noise in both non-inverting and inverting amplifier configurations by projecting noise sources into the input terminals and solving for the output noise voltage. The analysis reveals that noise currents flowing into high impedances create large equivalent input noise, which is particularly problematic for OPAMPs using BJTs in the input stages.

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OPAMP gain

Figure 1 shows two types of OPAMP amplification modes.

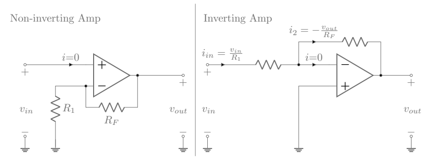

Figure 1: Two flavors of amplifications using OPAMP. An ideal OPAMP has infinite gain and draws no input current. The analysis is done by setting $v_- = v_+$ and $i = 0$ and using Kirchhoff's current and voltage laws.

The gain analysis is done by setting $v_- = v_+$ and $i = 0$ to get the input-output relations:

$$v_{out}^{non-inv} = v_{in}\frac{R_F + R_1}{R_1}, \text{ and } \quad v_{out}^{inv} = -v_{in}\frac{R_F}{R_1}, \tag{1}$$

A larger amplification can be achieved by selecting large $\frac{R_F}{R_1}$. An OPAMP has inherent voltage and current noise. The current noise couples to the input impedance. The output noise can be calculated by projecting the noise sources into the input terminals[1]. Consider the non-inverting amp in Figure 2 for noise analysis.

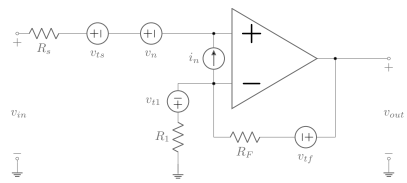

Figure 2: The circuit for noise analysis in non-inverting circuit. Resistors have thermal noise. OPAMP has noise in the input voltage and current. The input current noise passes through Z_{in}.

The voltages at the OPAMP inputs:

$$v_+ = v_s + v_{ts} + v_n + i_n R_S = v_- = (v_o + v_{tf})\frac{R_1}{R_1 + R_F} + v_{t1}\frac{R_F}{R_1 + R_F} - i_n\frac{R_1 R_F}{R_1 + R_F} \tag{2}$$

Solving for the output noise:

$$v_o = (1 + R_F/R_1)\left(v_s + v_{ts} + v_n + i_n\left[R_S + \frac{R_1 R_F}{R_1 + R_F}\right] - \frac{v_{tf}R_1 + v_{t1}R_F}{R_1 + R_F}\right) \tag{3}$$

OPAMPs typically use BJTs in the input stages, which generate much greater noise currents at the input. These noise currents, flowing into high impedances, the red term in Eq. 3 , create large equivalent input noise.

Let us now consider the inverting amp in Figure 3 which shows the circuit diagram for noise analysis.

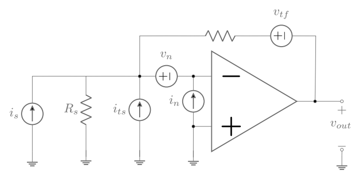

Figure 3: The circuit for noise analysis in inverting circuit. Resistors have thermal noise. OPAMP has noise in the input voltage and current. The input current noise passes through Z_{in}.

An alternative analysis method uses Norton equivalent elements. Thermal noise voltages can be converted to currents when convenient.

The voltages at the OPAMP inputs:

$$v_+ = v_n + (i_s + i_{ts} + i_n) R_S || R_F + (v_{tf} + v_o) \frac{R_S}{R_S + R_F} = v_- = 0. \tag{4}$$

Solve for the output noise:

$$v_o = -\frac{R_F}{R_S} \left(R_S \left[i_s + i_{ts} + \frac{v_{tf}}{R_F} \right] + v_n \frac{R_F + R_S}{R_F} + i_n R_S \right) \tag{5}$$

Again, we see the noise current, the red term in Eq. 5 , flowing into high impedances R_S, creating large equivalent noise.

[1] W. M. Leach, "Fundamentals of low-noise analog circuit design," *Proceedings of the IEEE*, vol. 82, no. 10, pp. 1515–1538, 1994, doi: 10.1109/5.326411.