Transimpedance-amplifier-noise issues

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How much noise is too much noise in a photodiode-preamplifier circuit? You can derive the noise performance of a transimpedance amplifier (Figure 1a) with calculations or by using a Spice simulation (Reference 1). When calculating the noise performance of the circuit, consider six regions in the frequency spectrum (Figure 1b) and add each region with a root-sum-square equation or the following equation (Reference 2):

\[ V_{\text{OUT}} \left( \text{NOISE}_{\text{RMS}} \right) = \sqrt{e_1^2 + e_2^2 + e_3^2 + e_4^2 + e_5^2 + e_6^2} \]

The first five regions are equal to the multiple of the areas under the closed-loop-gain and amplifier-noise-density curves. The area under the noise-density curve in the e₁, flicker-noise (1/f), region is

\[ V_{\text{1/f dB}} = A_N \sqrt{\ln \left( \frac{f_B}{f_A} \right)} \]

where \( A_N \) is the amplifier’s input-noise-density at 1 Hz and \( f_B \) is the corner frequency where the flicker noise tapers off. For many CMOS or FET amplifiers, the flicker-noise region usually ranges from dc to 100 or 1000 Hz. A calculation proves that the contribution to noise in this low-frequency region is relatively low:

\[ e_1 = \left( 1 + \frac{R_F}{R_{PD}} \right) \times A_N \times \sqrt{\ln \left( \frac{f_B}{f_A} \right)} \]

where \( R_F \) is the feedback resistor and \( R_{PD} \) is the device’s parallel resistance.

In the e₂ region, multiply the broadband noise of the amplifier, the closed-loop dc-noise gain \( (1+R_F/R_{PD}) \), and the square root of the region’s bandwidth. Again, the contributed noise in this region is usually relatively low because of its location in the lower frequency range.

\[ e_2 = \left( 1 + \frac{R_F}{R_{PD}} \right) \times e_N \times \sqrt{f_Z - f_B} \]

Calculate the noise contribution and the e₃ region in the same manner with \( f_Z = 1/[2\pi (R_{PD}||R_{RF}) (C_{PD}+C_{CM}+C_{DIFF}+C_F+C_{RF})] \) and \( f_B = 1/[2\pi (R_F) (C_F+C_{RF})] \).

\[ e_3 = \left( 1 + \frac{R_F}{R_{PD}} \right) \times e_N \times \left( 1 + \frac{f_Z}{f_B} \times \frac{1}{\sqrt{3}} \times \sqrt{f_B / f_Z} \right) \times \frac{1}{\sqrt{3}} \]

where \( C_{PD} \) is the device’s capacitance and \( C_{DIFF} \) is the differential amplifier’s capacitance.

The noise in regions e₁ and e₂ uses the higher-frequency gain of the closed-loop-gain curve with the value of \( C_F \) being the parallel combination of the input capacitors, or \( [C_{P-R}||2C_{CM}]||C_{DIFF} \), and \( C_{RF} \) is the parallel combination of \( C_F \) and \( C_{RF} \).
\[ e_4 = \left(1 + \frac{C_1}{C_2}\right) \times e_N \times \sqrt{\frac{f_{AOL}}{f_p}}. \]

\[ e_5 = \left(1 + \frac{C_1}{C_2}\right) \times e_N \times \sqrt{\frac{f_f - f_{AOL}}{2}}. \]

The sixth part of the noise equation, \( e_6 \), represents the noise contribution of the feedback resistor. The amplifier does not gain the contribution of noise from the feedback resistor:

\[ e_6 = \sqrt{4 \times K \times T \times R_f \times BW}, \]

where \( K \) is Boltzmann’s constant, which is \( 1.38 \times 10^{-23} \); \( T \) is temperature in Kelvin; \( R_f \) is the feedback resistor in ohms; and \( BW \) is the bandwidth of interest.

When asking how much noise is too much noise in this photodiode-preamp circuit, consider that a 12-bit system operating with a 5V input range has an LSB of 1.22 mV. The LSB for a 16-bit system with the same input-voltage range is 76.29 µV. Both LSBs are peak-to-peak numbers, and the values in this column are root-mean-square values (Reference 3).

**References**