Preamplifiers for IR Photodetectors

Preamplifiers are used to amplify weak signals from low noise photodetectors and provide optimal conditions for detector operation. In addition, preamplifiers protect detectors against overbias and make the detector/preamplifier system immune to electromagnetic interferences.
We offer a variety of transimpedance preamplifiers, AC and DC coupled, with narrow and wide bandwidths, standing alone or integrated with detector in common packages called **Detection Modules**. The transimpedance preamplifiers are preferable in most of applications due to inherent linearity and good frequency response.

Transimpedance Preamplifiers

The current readout of infrared detectors is typically achieved in transimpedance (TI) preamplifiers. Important advantage of the TI amp is the ability to maintain the detector at constant bias voltage, equal to voltage applied to the non-inverting input of the op-amp.
Simple description of the detector/TI preamplifier system, schematically shown in Figure 1. The detector is modeled by a photocurrent source $\mathbf{I_{ph}}$, shunt resistance $\mathbf{R_d}$ and capacitance $\mathbf{C_d}$. The photocurrent is proportional to the input optical power **P** and detector current responsivity $\mathbf{R_i}$.

$$I_{ph}=R_i \cdot P \tag{1}$$

Transimpedance preamplifier is an operational amplifier with feedback resistance $\mathbf{R_f}$. Feedback capacitance $\mathbf{C_f}$ is used to set system bandwidth and eliminate gain peaking at high frequencies.

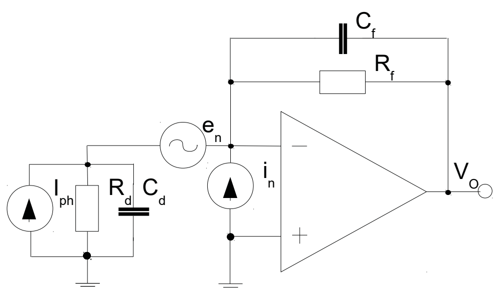

Figure 1. Transimpedance circuit for infrared photodetector

The output voltage of the transimpedance preamplifier is:

$$V_0=Z_f \cdot I_{ph} \tag{2}$$

The transimpedance gain Z_f can be approximated by one-pole filter characteristics:

$$Z_f=\frac{R_f}{\sqrt{1+(2\pi f)^2 \cdot C_f^2 \cdot R_f^2}} \tag{3}$$

with cut-off frequency:

$$f_\infty=\frac{1}{2\pi f \cdot C_f \cdot R_f} \tag{4}$$

It should be noted that the cut-off frequency is typically greater compared with the voltage preamplifier when bandwidth is limited by the detector $\mathbf{R_d \cdot C_d}$ time constant. For frequencies less than the 3dB cut-off frequency $\mathbf{f_\infty}$, transimpedance is equal to $\mathbf{R_f}$. In consequence, the circuit converts linearly optical input power **P** into output voltage:

$$V_0=R_i \cdot R_f \cdot P \tag{5}$$

with resulting voltage responsivity $R_v=R_i \cdot R_f$ independent on frequency, detector resistance and capacitance.
Unfortunately, the above considerations are limited to maximal frequencies dependent on detector capacitance and resistance, op-amp gain-bandwidth product and other factors.

Noise

As follows from the transimpedance circuit (Figure 1), the preamplifier noise current can be approximated as:

$$i_{PA}^2=\frac{4kT}{R_f}+i_n^2+\frac{e_n^2}{Z_d^2} \tag{6}$$

where $\mathbf{i_n}$ and $\mathbf{e_n}$ are the op-amp open input noise current and short input noise voltage, respectively. Z_d is the detector impedance:

$$Z_d=\frac{R_d}{\sqrt{1+(2\pi f \cdot C_d \cdot R_d)^2}} \tag{7}$$

At low frequencies preamplifier noise (frequently called „floor noise level") is not dependent on frequency:

$$i_{PA}^2=\frac{4kT}{R_f}+i_n^2+\frac{e_n^2}{R_d^2} \tag{8}$$

At large frequencies the noise current increases due to decreasing detector impedance:

$$i_{PA}=2\pi f \cdot C_d \cdot e_n \tag{9}$$

Incorrect frequency compensation of transimpedance amplifier may cause remarkable increase of the noise level near the top cut-off frequency (as shown in Figure 2).

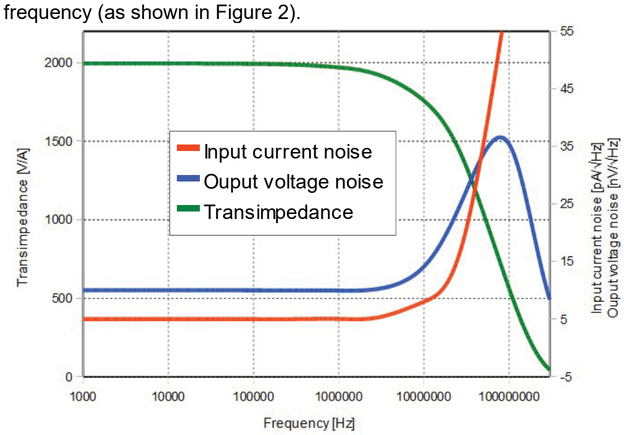

Figure 2. Output noise density and frequency response of the transimpedance amplifier.

How Preamplifier Affects System Performance

Total input current noise of a detection module is:

$$i_n^2=i_{PA}^2+i_d^2 \tag{10}$$

This results in degradation of the overall detectivity of the detector/preamplifier system by i_n/i_d factor.
The degradation may be significant for low impedance detectors-having low resistance <50 Ω) or, at high frequencies, having large capacitance.
The design of preamplifiers is dependent on required bandwidth, gain, detector resistance, capacitance and other factors. The crucial step is the selection of suitable op-amps or discrete transistors. Bipolar op-amps are characterized by large $\mathbf{i_n} \approx 2\frac{pA}{\sqrt{Hz}}$ and low $\mathbf{e_n} \approx 1\frac{nV}{\sqrt{Hz}}$, in contrast to FET-based preamplifiers where $\mathbf{i_n}$ is low $\approx 1\frac{fA}{\sqrt{Hz}}$ and $\mathbf{e_n}$ is large $\approx 5\frac{nV}{\sqrt{Hz}}$. Therefore, the low e_n-bipolar op-amps suits well to low Z_d detectors (which means low resistance, large capacitance and high frequencies). FET-based op-amps are useful for high Z_d detectors operating at low frequencies.