Position-sensitive device

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April 6, 2019

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[1]

Parameter	Symbol	Values		Unit
		Typical	Maximum	
Dark current	I_d	0.5	10	nA
Interelectrode resistance	R_e	7	15	kΩ
Terminal capacitance	C_t	150	300	pF

Table 1: Important parameters of the S5990 extracted from the datasheet [2].

3 Preamplifier

The photocurrents created by our detector are in the range of microampere where they are vulnerable to noise. Using a preamplifier, we can increase the amplitude of the signal for an improved signal-to-noise ratio. The typical photocurrent preamplifier is based on the transimpedance (current-to-voltage) amplifier design using a voltage-feedback operational amplifier. Converting the current to a voltage signal has the benefit that the voltage signal can be easily visualized with an oscilloscope. Furthermore, the voltage-feedback operational amplifier design appears to be more common than the current-feedback operational amplifier, as manufacturers offer much more choice and they are more prominent in the literature. That said, current-feedback operational amplifiers are reported to be a viable solution for high-speed and high-bandwidth applications, see Ref. [3, p. 110] for an overview of the benefits of current-feedback amplifiers and Ref. [4, Ch. 9] for a comparison with voltage-feedback amplifiers.

In the following, we will always refer to the voltage-feedback operational amplifier if not noted otherwise. Moreover, we expect the reader to be familiar with the foundations of the operational amplifier. Well-written introductions to this topic can be found in [3, Ch. 1] and [4, Ch. 3].

3.1 Basic design

The basic design of a transimpedance amplifier is illustrated in Figure 1. Ignoring imperfections of the photodiode, we can represent the photodiode as a current source. The non-inverting input of the operational amplifier is connected to ground. The inverting input is coupled with the output of the operational amplifier via a feedback impedance Z_f.

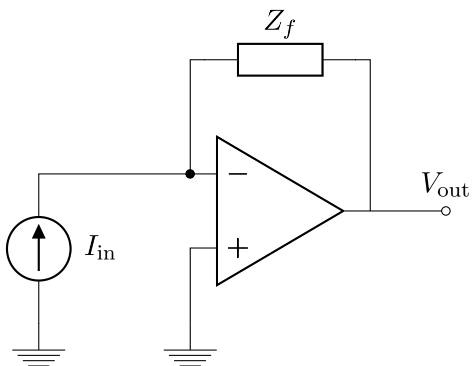


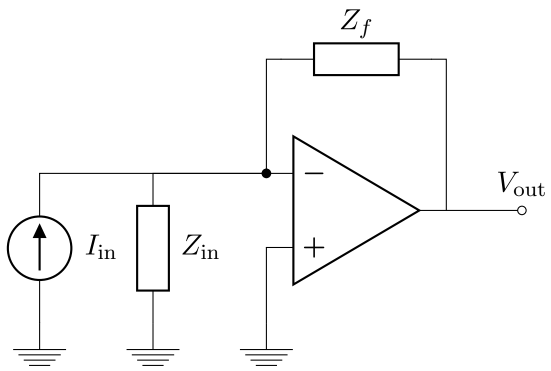
Figure 1: Basic transimpedance amplifier using voltage feedback operational amplifier.

The ideal operation amplifier has zero input current, thus, in the node of the inverting input of the operational amplifier Kirchhoff's law states that the current going through the feedback impedance has to cancel the current of the current source I_{in}. The current through the feedback impedance Z_f can be expressed in terms of the feedback impedance Z_f and the output voltage V_{out} of the operational amplifier through the use of Ohm's law, yielding,

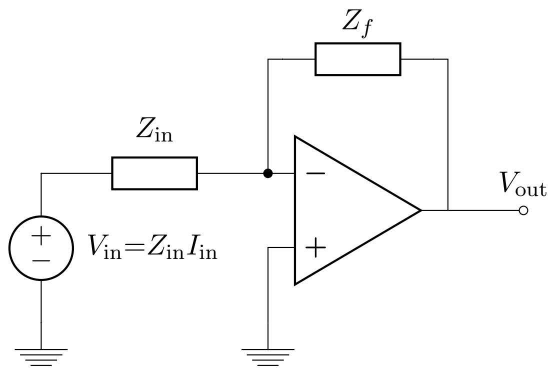
$$V_{\text{out}} = -Z_f I_{\text{in}}. \tag{1}$$

Given a maximum current I_{in} and a desired maximum output voltage V_{out}, Equation (1) determines the feedback resistance. Limitations arise for real operational amplifiers where the output voltage is limited to be below the supply voltage of the operational amplifier.

Aside from photodiode applications, it is more common to find the inverting (voltage-to-voltage) operational amplifier in the literature. By using the source transformation on the current source with a parallel impedance in the transimpedance amplifier circuit, we can recover the inverting operational amplifier circuit, and thereby easily use results obtained for this design.



(a) Transimpedance amplifier.



(b) Inverting amplifier.

Figure 2: Equivalence between transimpedance and inverting amplifier using source transformation.

Figure 2 shows the source transformation applied to transimpedance and inverting amplifier circuits. Given a current source I_{in} with parallel impedance Z_{in} the equivalent voltage source has value $V_{\text{in}} = Z_{\text{in}} I_{\text{in}}$ with impedance Z_{in} in series.

3.2 Offset

So far we have assumed ideal properties of the operational amplifier. In this section, we are going to start with the discussion of operational amplifier imperfections that contribute to a constant offset voltage at the output.

3.2.1 Input offset voltage

Real operational amplifiers only reduce the voltage difference between the inverting and non-inverting input to a non-zero input offset voltage. For high-precision operational amplifiers, the input offset voltage is in the range of microvolts. We can model the input offset voltage as a voltage source at the non-inverting input of an ideal operational amplifier in our transimpedance circuit, as can be seen from Figure 3.

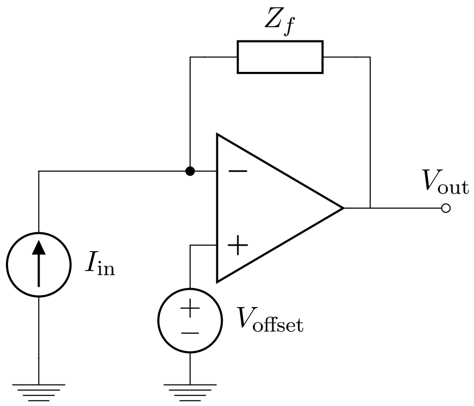


Figure 3: Input offset voltage in the transimpedance amplifier.

[3, p. 54]

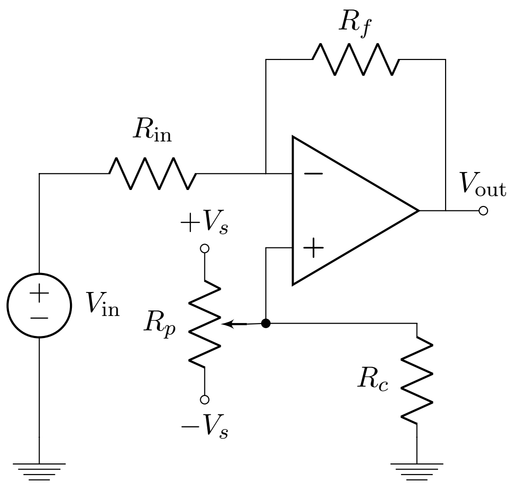
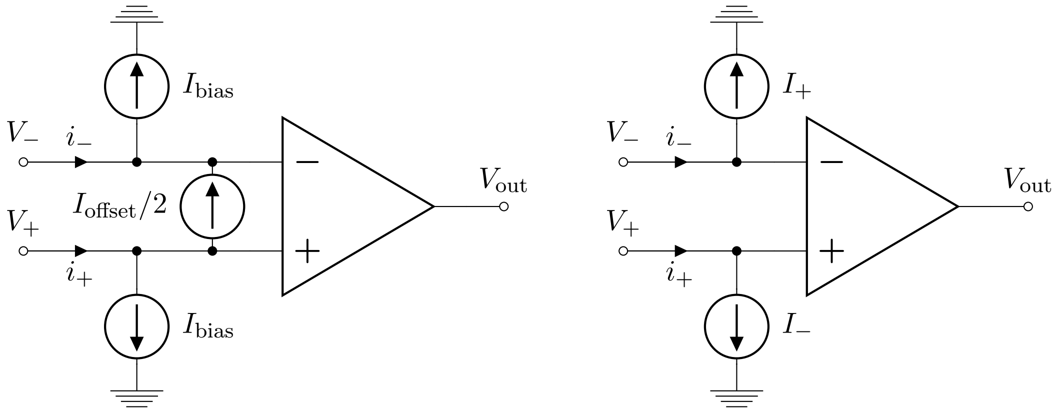


Figure 4: Input offset voltage compensation using adjustable potentiometer.

3.2.2 Input bias current



(a) Equivalent current sources as reported in the datasheet.

(b) Alternative equivalent current sources.

Figure 5: Non-zero input current from the operational amplifier.

$$I_+ = I_{\text{bias}} + \frac{1}{2} I_{\text{offset}} \qquad I_{\text{offset}} = I_+ - I_- \tag{2}$$

$$I_- = I_{\text{bias}} - \frac{1}{2} I_{\text{offset}} \qquad I_{\text{bias}} = \frac{I_+ + I_-}{2} \tag{3}$$

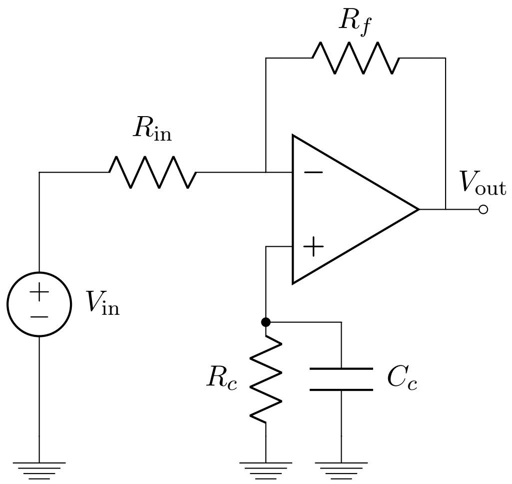


Figure 6: Input current offset compensation.

[3, p. 57] [5, p. 25]

$$R_c = \frac{R_{\text{in}} R_f}{R_{\text{in}} + R_f} \tag{4}$$

3.3 Noise

3.4 Stability

[6, p. 693] [7, p. 183] [4, Ch. 5] [5, Ch. 3]

Glossary

S5990 Hamamatsu two-dimensional PSD. 3

References

[1] Date Noorlag. "Lateral-photoeffect position-sensitive detectors". PhD thesis. Delft University of Technology, 1974.

[2] *S5990 2D PSD*. Hamamatsu. URL: `https://www.hamamatsu.com/resources/pdf/ssd/s5990-01_etc_kpsd1010e.pdf` (visited on 03/03/2019).

[3] Walt Jung. *Op Amp Applications Handbook*. Elsevier, 2005. ISBN: 9780750678445.

[4] Ron Mancini Bruce Carter. *Op Amps for Everyone*. Elsevier, 2002. ISBN: 9780750677011.

[5] Jerald Graeme. *Photodiode Amplifiers. Op Amp Solutions*. McGraw Hill Professional, 1996. ISBN: 9780070242470.

[6] Philip Hobbs. *Building Electro-Optical Systems. Making it all Work*. John Wiley & Sons, 2011. ISBN: 9781118211090.

[7] Art Kay. *Operational Amplifier Noise. Techniques and Tips for Analyzing and Reducing Noise*. Elsevier, 2012. ISBN: 9780750685252.