NOISE AND CIRCUIT ANALYSIS FOR THE UNBIASED PHOTODIODE RADIATION DETECTOR

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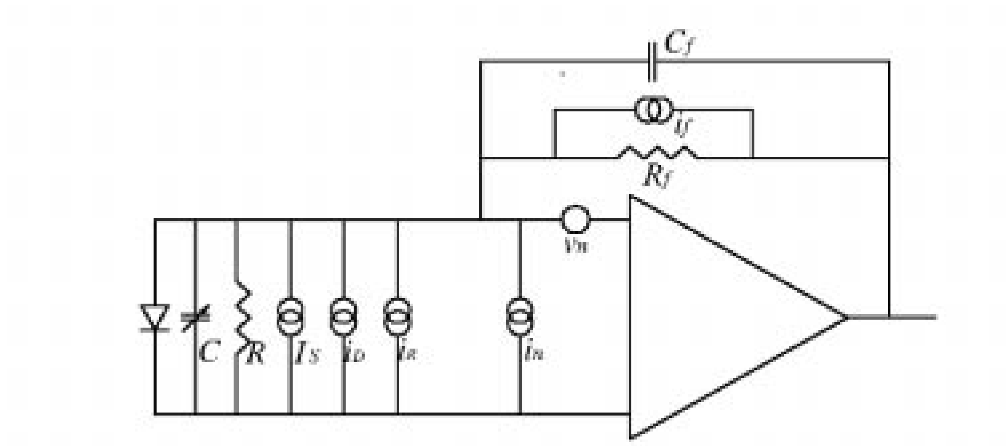
Presented here is a detailed noise analysis for an unbiased photodiode radiation detector. The analysis accounts for all of the intrinsic noise sources in the device and demonstrates how the signal to noise ratio (SNR) depends upon the bandwidth of the detection system and the feedback capacitance. The detector is identical to that presented by Zeisler (1) except for the choice of feedback capacitance and the fact that it is not biased. The photodiode is not biased because biasing does not improve the detector's dc response to 511 KeV gamma radiation, it adds additional dark noise current and fast detector response (which improves with reverse biasing) is not required for our particular application. Luckau and Hartung (2) have demonstrated improved performance with unbiased operation and some modification to Zeisler's circuit. This note should aid in the design or modification of similar detectors since it quantifies the relative importance of the various noise sources.

Shown below in figure 1 is the equivalent detector circuit with its noise sources. These include resistor thermal noise, diode dark current noise, and op-amp voltage and current noise. if represents the current noise generator associated with Rf. i_R represents the current noise generator associated with the photodiode's shunt resistance R. i_D represents shot noise due to the photodiode dark current. in represents the amplifier's current noise and v_n represents the amplifier's voltage noise. I_S represents the combined signal current and its associated radioactive decay noise.



The transfer function relating the signal and the various noise sources to the output voltage v_o can be derived and is given below. It is assumed in the derivation that the amplifier's output resistance is less than R_f and R. The second stage voltage amplifier used in Zeisler's circuit is not included since it does not affect the SNR if properly designed.

$$v_0 = \left\{ v_n^2 \left[1 + \frac{R_f\left(1+\omega^2 C^2 R^2\right)^{1/2}}{R\left(1+\omega^2 C_f^2 R_f^2\right)^{1/2}} \right]^2 + \left(i_f^2 + i_D^2 + i_R^2 + i_n^2 + i_s^2\right) \left[\frac{\dfrac{R_f}{\left(1+\omega^2 C_f^2 R_f^2\right)^{1/2}}}{1 + \dfrac{R_f\left(1+\omega^2 C^2 R^2\right)^{1/2}}{R\left(1+\omega^2 C_f^2 R_f^2\right)^{1/2}}} \right]^2 \right\}^{1/2}$$

The expression for v_0 shows that $1/(R_f C_f)$ controls the corner frequency at which the current sources roll off, C/C_f determines the high frequency gain of the voltage noise source and Rf sets the dc current to voltage transfer function. It should be noted that throughout this paper the use of the term frequency refers to a bandwidth frequency, f, and not a counting rate frequency; also $\alpha=2\pi f$.

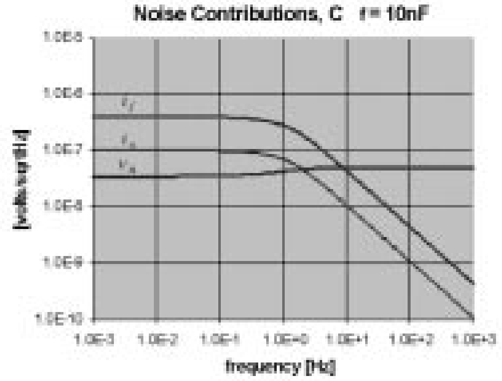
Listed below are typical values for the circuit parameters. A Hamamatsu S2386-8K silicon photodiode and a National Semiconductor LF-442 op-amp are used. In this case the dominant noise source is the thermal noise from R_f. Recall that the expression for a gaussian thermal noise current generator associated with a resistor R at absolute temperature T is

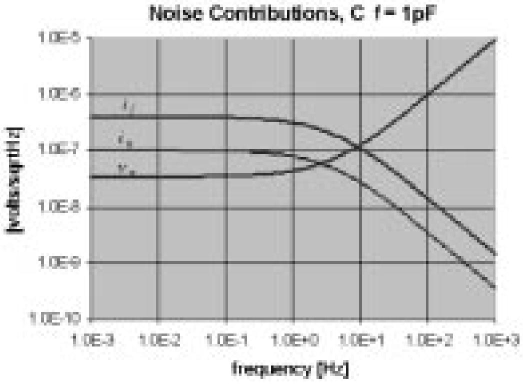
$i_R = \sqrt{4k_bT/R} \quad k_b=1.38x10^{-23}$ [W-sec/K].

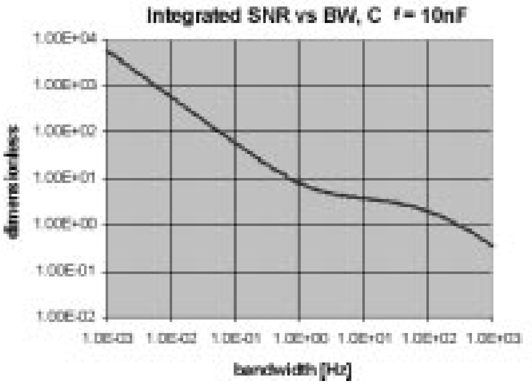
The SNR can be improved by increasing R_f until i_f equals i_n. However larger R_f values increase the effects of thermal drift. Setting R_f equal to 10^7 provides a convenient gain for the radioactive signals typically seen in our lab.

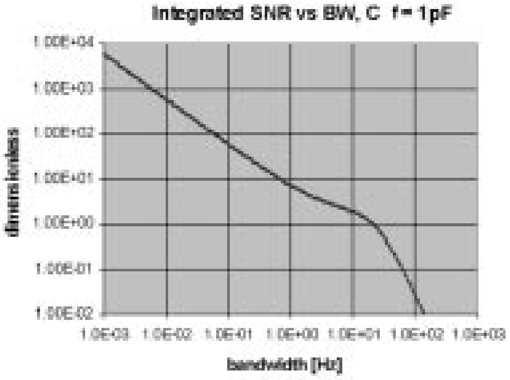
R_f Feedback resistance	~ 10^7 [Ω]
i_f Current noise associated with Rf	~ 40.7 [fA/√Hz]
C_f Feedback capacitance	~ 10^{-9} [nF]
C Photodiode capacitance at 10mV bias voltage	~ $4.3x10^{-9}$ [nF]
R Photodiode shunt resistance at 10mV bias voltage	~ 10^{10} [Ω]
i_R Current noise associated with R	~ 1.3 [fA/√Hz]
I_D Dark current at 10mV bias voltage	~ 1 [pA]
i_D Shot noise due to dark current	~ 0.6 [fA/√Hz]
v_n Amplifier voltage noise	~ 35 [nV/√Hz]
i_n Amplifier current noise	~ 10 [fA/√Hz]

The graphs below show how C_f affects the noise and the integrated SNR. The top two graphs refer the input noise sources i_f, i_n and v_n to the output of the detector. Noticeable above 10 Hz is the significant gain of v_n when C_f equals 1 pF. The bottom two graphs plot as a function of bandwidth the square of the signal divided by the noise power spectral density integrated from 0 Hz to the bandwidth frequency. The signal is arbitrarily assumed to be a dc signal current of 100 fA. For detection systems with bandwidths greater than 10Hz, larger values of C_f improve the performance. Clearly minimizing the detection bandwidth improves performance. However there is a limit to bandwidth reduction. The limit is determined by the time in which the baseline voltage drift becomes comparable to the signal of interest.









REFERENCES:

1. Zeisler S.K., Ruth T.J., Rector M.P., Appl. Radiat. Isot. 45: 377 (1994).

2. Luckau D. and Hartung T., Proceedings of the Sixth Workshop on Targetry and Target Chemistry, p. 234, 1995.