Solution Bonus Exercises on Optical Sources and Detectors

July 17th 2012

Problem 1: Noise properties of photodetectors

The signal-to-noise ratio (SNR) is a measure of the quality of the detected signal. For a given detector bandwidth Δf the SNR can be calculated by relating the mean electrical signal power to the electrical noise power, which consists of shot noise and thermal noise from the load resistor R_L. For a PIN diode this results in:

$$SNR = \frac{\overline{i^2}}{\overline{\delta i^2}} = \frac{\left(SP_e\right)^2}{2eSP_e\Delta f + \frac{4kT\Delta f}{R_L}}.$$

The quantity S denotes the responsivity for the detector, P_e the external optical power, kT the thermal energy, and Δf the electrical detection bandwidth. In the following we consider a photodiode which is specified with a responsivity of $S = 0.95\,\mathrm{A/W}$. Perform the subsequent calculations for two different load resistors, $R_L = 50\,\Omega$ and $R_L = 100\,\mathrm{k}\Omega$.

a) Shot-noise-limited operation is obtained when the shot noise exceeds the thermal noise. Calculate the signal power that is necessary to obtain shot noise limited operation at room temperature.

➔ $$2e\left(SP_e\right) > \frac{4kT}{R_L}$$

From this inequality follows that for 50 ohm load impedance the receiver operates shot-noise limited for optical powers above 1.09mW or 0.34dBm whereas for $100\,\mathrm{k}\Omega$ the optical power needs to be above 544nW or -32.6dBm.

b) The bandwidth f_{BW} of a photodiode can be approximated by its RC time constant

$$f_{\mathrm{BW}} = \frac{1}{2\pi R_L C}.$$

Calculate f_{BW} for a parasitic capacitance of C = 1 pF. Which load resistance would you choose for highly sensitive and which one for high-speed detection?

➔ $50\Omega \rightarrow$ 3.2GHz
$100\mathrm{k}\Omega \rightarrow$ 1.6MHz

For high-speed applications a 50 ohm load would be beneficial whereas the receiver is much more sensitive when using a high load resistance and can operate in the shot noise limit for lower optical powers.

c) How does the SNR increase with P_e above and below the shot-noise limit. Sketch the SNR [dB] as a function of P_e [dBm].

➔ Below the shot noise limit the SNR increases proportional to P_e^2, the thermal noise dominates which is independent of P_e, by increasing P_e in first approximation only the signal power increases with P_e^2 and so does the SNR. Above the shot noise limit the shot noise dominates, the signal power increases with P_e^2, while the noise power increases with P_e, therefore the SNR increases only proportional to P_e.

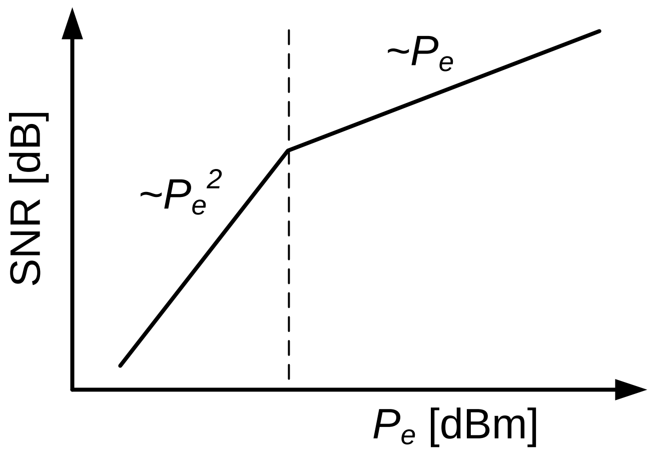

Figure 1: SNR of a photo diode below and above the shot noise limit

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