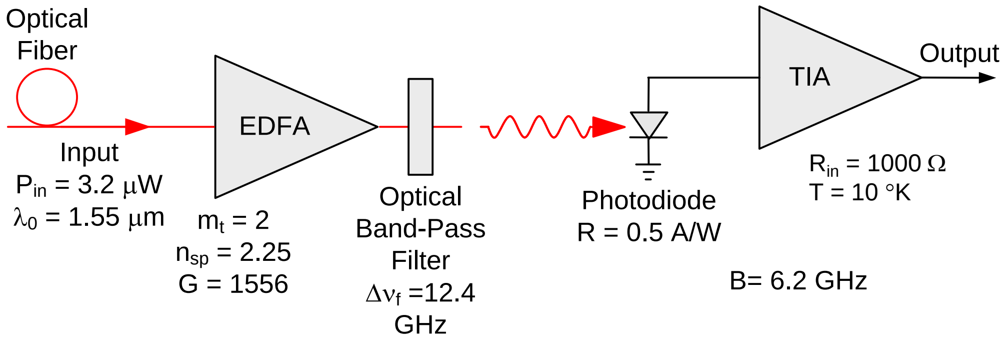
OPTI 500, Fall 2011

Homework #3

Solutions



Consider the calculations covered in class for the comparison of an optical receiver with and without an optical pre-amplifier. For this problem, take the input impedance of the transimpedance amplifier to be 1000 ohms and the temperature to be 10 K. Calculate the signal-to-noise ratio with and without the use of a pre-amplifier. Does the pre-amplifier improve the signal-to-noise ratio?

Note1 : Do not assume that you can neglect shot noise for the case where the receiver is used without a pre-amplifier.

Note 2: R is the photodiode responsivity. R_{in} is the input impedance of the transimpedance amplifier.

Signal to noise without a pre-amplifier

$$\langle i_{shot}^2 \rangle = 2eI_sB$$
$$= 2\left(1.6\times10^{-19}\right)\left(3.2\times10^{-6}\times0.5\right)6.2\times10^{9}A^2$$
$$= 3.174\times10^{-15}A^2$$

$$\langle i_{ther}^2 \rangle = \frac{4kTB}{R_L}$$
$$= \frac{4\left(1.38\times10^{-23}\right)(10)\left(6.2\times10^{9}\right)}{1000} = 3.422\times10^{-15}A^2$$

Shot noise and thermal noise are comparable and we must keep both of them.

$$\frac{S}{N} = \frac{\left(P_sR\right)^2}{\frac{4kTB}{R_L}} = \frac{\left(3.2\mu W\times0.5A/W\right)^2}{3.174\times10^{-15}A^2 + 3.422\times10^{-15}} = 388$$

Signal to noise with a pre-amplifier

Consider the signal-ASE beat noise, which is the largest ASE-related noise when an pre-amplifier is used.

$$P_{ASE} = m_t n_{sp} h\nu \Delta\nu_f$$
$$= (2)(2.25)\left(6.63\times10^{-34}\right)\left(1.94\times10^{14}\right)\left(1.24\times10^{10}\right)$$
$$= 7.18x10^{-9}W$$
$$I_{ASE} = \frac{\eta e}{h\nu}P_{ASE} = (0.5)\left(7.18\times10^{-9}\right) = 3.59\times10^{-9}A$$

$$\left\langle i_{sig-spon}^2 \right\rangle = 4GI_s GI_{ASE} \frac{B}{\Delta \nu_f}$$

$$= 4(1556)(3.2\times10^{-6}\times0.5)(1556)(3.59\times10^{-9})\frac{6.2\times10^9}{1.24\times10^{10}}$$

$$= 2.78\times10^{-8} A^2$$

This signal-ASE beat noise is much larger than the thermal noise in the receiver, so

$$\frac{S}{N} = \frac{(GP_sR)^2}{\left\langle i_{sig-spon}^2 \right\rangle}$$

$$= \frac{(1556\times3.2\mu W\times0.5A/W)^2}{2.78\times10^{-8}A^2} = 223.$$

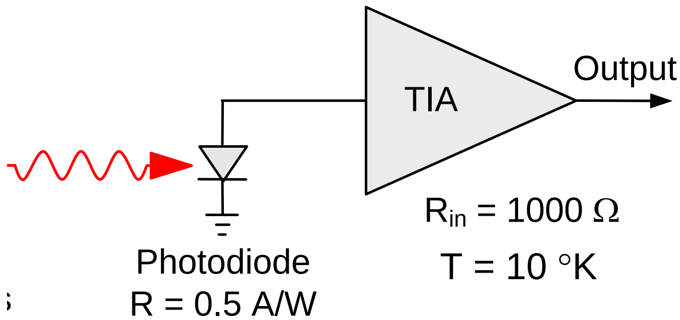
In this case, the pre-amplifier does not improve signal to noise ration.

Extra credit: What are possible disadvantages for the use of a high input impedance and low temperature?

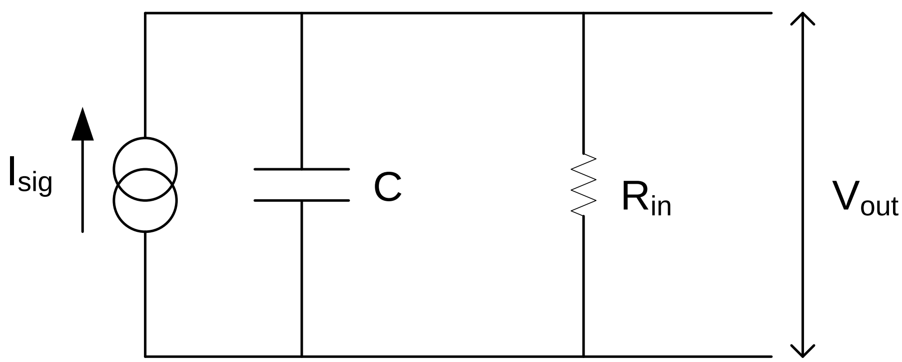
1. Cooling the receiver requires extra expense and maintenance.

2. A high input impedance for the transimpedance amplifier will slow the response of the photodector so that it may not be able to resolve optical pulses at high data rates.

Equivalent Circuit and RC Time Constant for a Photodiode Plus Transimpedance Amplifier



B= 6.2 GHz



Take C = 0.2 pF
Then R_{in} = 50 ohm gives and RC time constant of 10 psec,
but R_{in} = 50 ohm gives RC = 200 psec -> too slow