MICRO-523: Optical Detectors

Week Four: Photoemissive detectors (Solutions Ex4)

Claudio Bruschini

Institute of Electrical and Micro Engineering (IEM), School of Engineering (STI)

Ecole polytechnique fédérale de Lausanne (EPFL), Neuchâtel, Switzerland

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TAs: Samuele Bisi, Yazan Lampert

EPFL

Outline

Exercise 4.1: The Detection Limit of a PMT

Consider a PMT with the following characteristics:

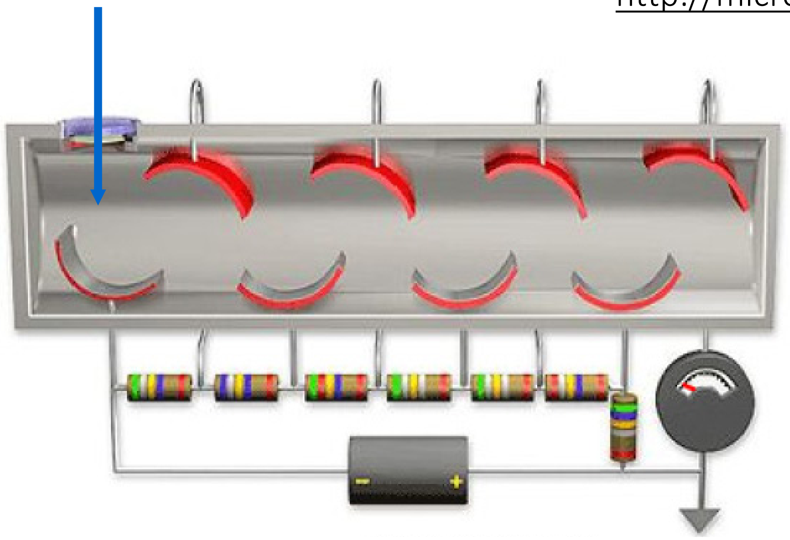
- Photocathode surface area: 2 cm^2
- Bandwidth: 100 Hz
- Temperature: 300K
- Work function: 1.25 eV
- Quantum Efficiency: 10% at 550nm
- Same sensitivity as the human eye.

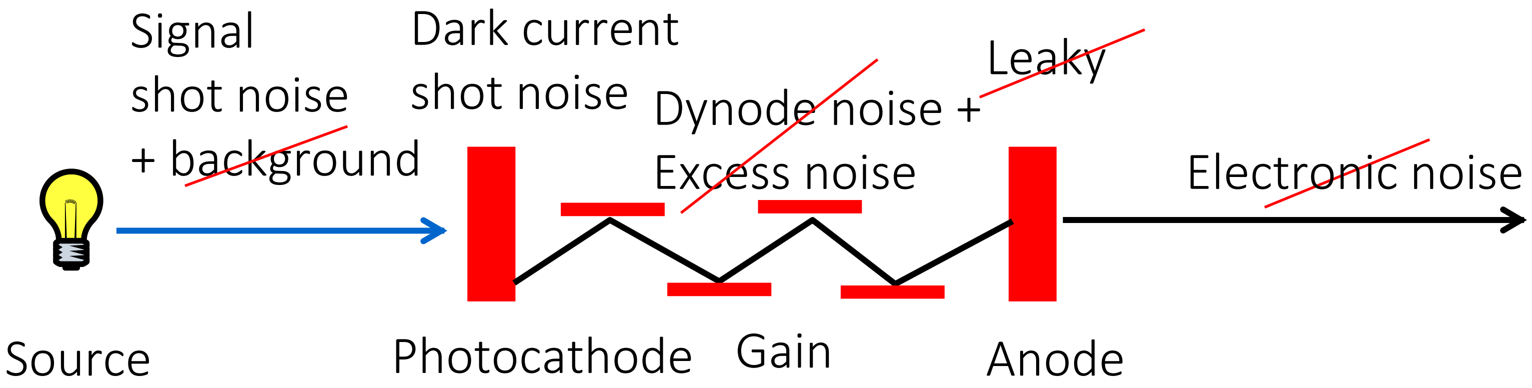
A) What is the NEP if the PMT is limited by the shot noise from the dark current? (consider the excess noise factor to be equal to 1)

B) At what distance L does a candle have to be placed in complete darkness to match this NEP ?

Exercise 4.1: Noise analysis

http://micro.magnet.fsu.edu/primer/flash/photomultiplier





Exercise 4.1: Detection Limit of a PMT

A) Dark current

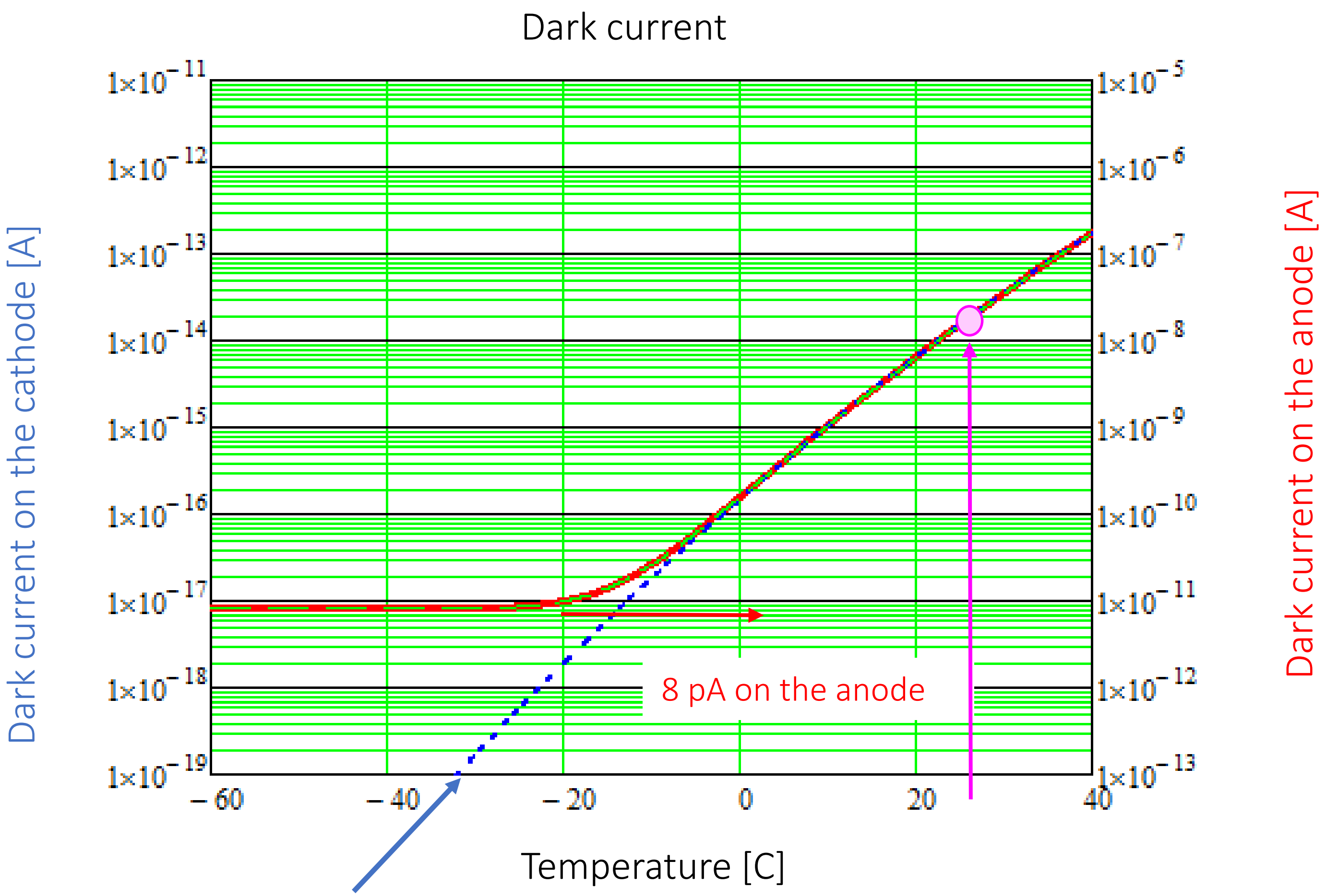
$$I_{dark,cat} = S_d \cdot A_0 T^2 e^{(-W/kT)} = 2 \cdot 120 \cdot 300^2 \cdot e^{\left(-\frac{1.25}{0.0258}\right)}[A] = 20\ [fA]$$

Remark: a typical value for the gain is 10^6
→ the dark current on the anode is approximately: 20 [nA]

NEP

$$NEP_{dark} = \frac{\sqrt{\langle \Delta I^2_{dark,cat} \rangle}}{R_I} \cdot \sqrt{F} = \frac{\sqrt{2qI_{dark,cat}\Delta f}}{\frac{\eta q \lambda}{hc}} \cdot \sqrt{F} = 18\ [fW]$$

Exercise 4.1: Detection Limit of a PMT

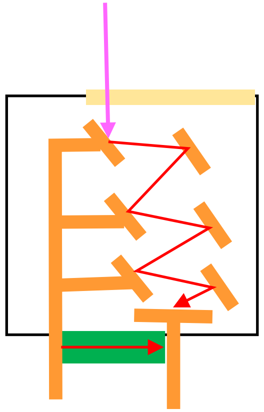


$$I_{d,cat} = S_d \cdot A_0 T^2 e^{(-W/kT)}$$

A_0=120 [A/cm^2 K^2]

S_d=2 cm^2
W= 1.25 eV
I_{leaky} = 8 [pA] on anode

(G=10^6)



$2 \cdot Q \cdot I_d \cdot \Delta f$

$2 \cdot q \cdot I_d \cdot \Delta f$

Exercise 4.1: Detection Limit of a PMT

B) Illuminance of a candle at 1 m: = 1 lux

Luminous flux of a candle at 1 m on the detector

$$P_0\ [lm] = 1\ [lux]\ \cdot\ S_d\ [m^2] \cong \frac{1}{683}\left[\frac{W}{m^2}\right] \cdot 2 \cdot 10^{-4} [m^2] = 290\ [nW]$$

To compare with 18 [fW]

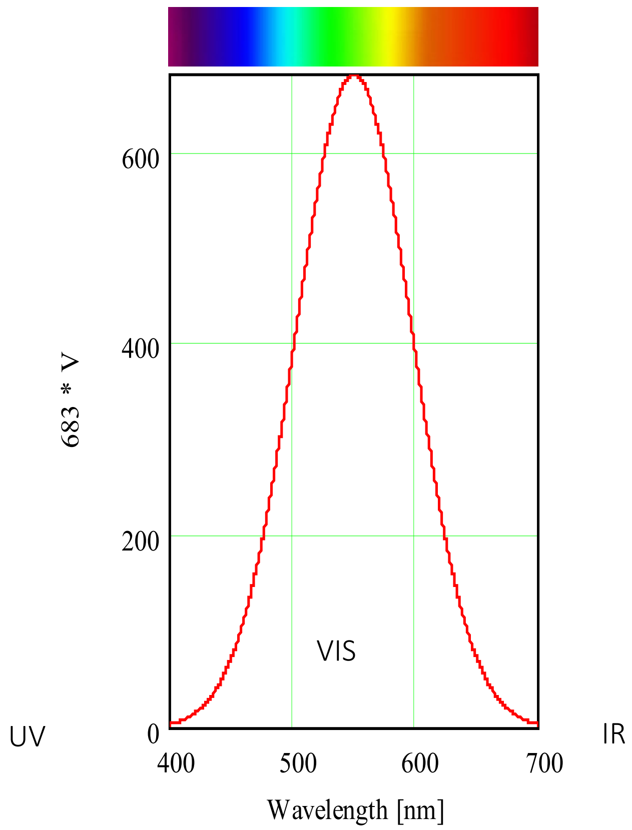
The intensity decreases with the square of the distance →

$$\frac{NEP}{P_0} = \left(\frac{L_0}{L}\right)^2 \qquad with \qquad L_0 = 1\ m$$

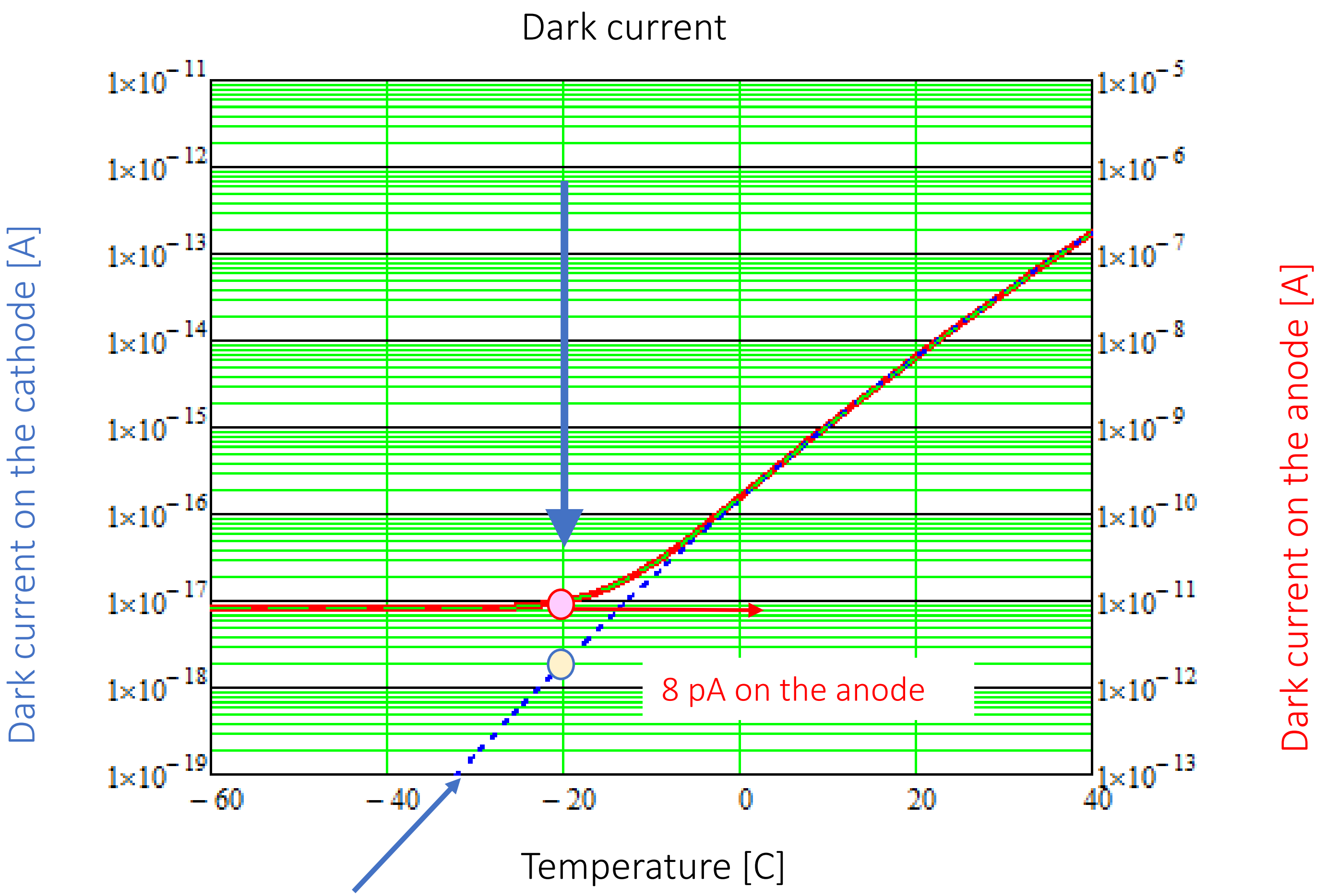
⇩

$$L = \sqrt{\frac{P_0}{NEP_{dark}}} \cong 4\ [km]$$

Lux = visible intensity per detector surface



Exercise 4.1: Detection Limit of a PMT



$$I_{d,cat} = S_d \cdot A_0 T^2 e^{(-W/kT)}$$

$A_0 = 120\ [A/cm^2\ K^2]$

$S_d = 2\ cm^2$

W= 1.25 eV

I_{leaky} = 8 [pA] on anode

($G=10^6$)

Exercise 4.1: Detection Limit of a PMT

Shot noise of the signal:

$$\frac{(\eta P)^2}{2 \cdot h\nu \cdot (\eta P) \cdot \Delta f \cdot F} = 1 \quad \Rightarrow NEP_{sig-shot} = \frac{1}{\eta} \cdot (2 \cdot h\nu \cdot \Delta f) \cdot F \cong 0.7\ [fW]$$

Dark current at T = -20C:

$$I_{dark,cat} = S_d \cdot A_0 T^2 e^{(-W/kT)} = 2\ [aA] \qquad I_{dark,ano} = \langle G \rangle \cdot I_{dark,cat} \cong 2\ [pA]$$

$$I_{leak,ano} \cong 8\ [pA]$$

Dark current and NEP at T = -20C:

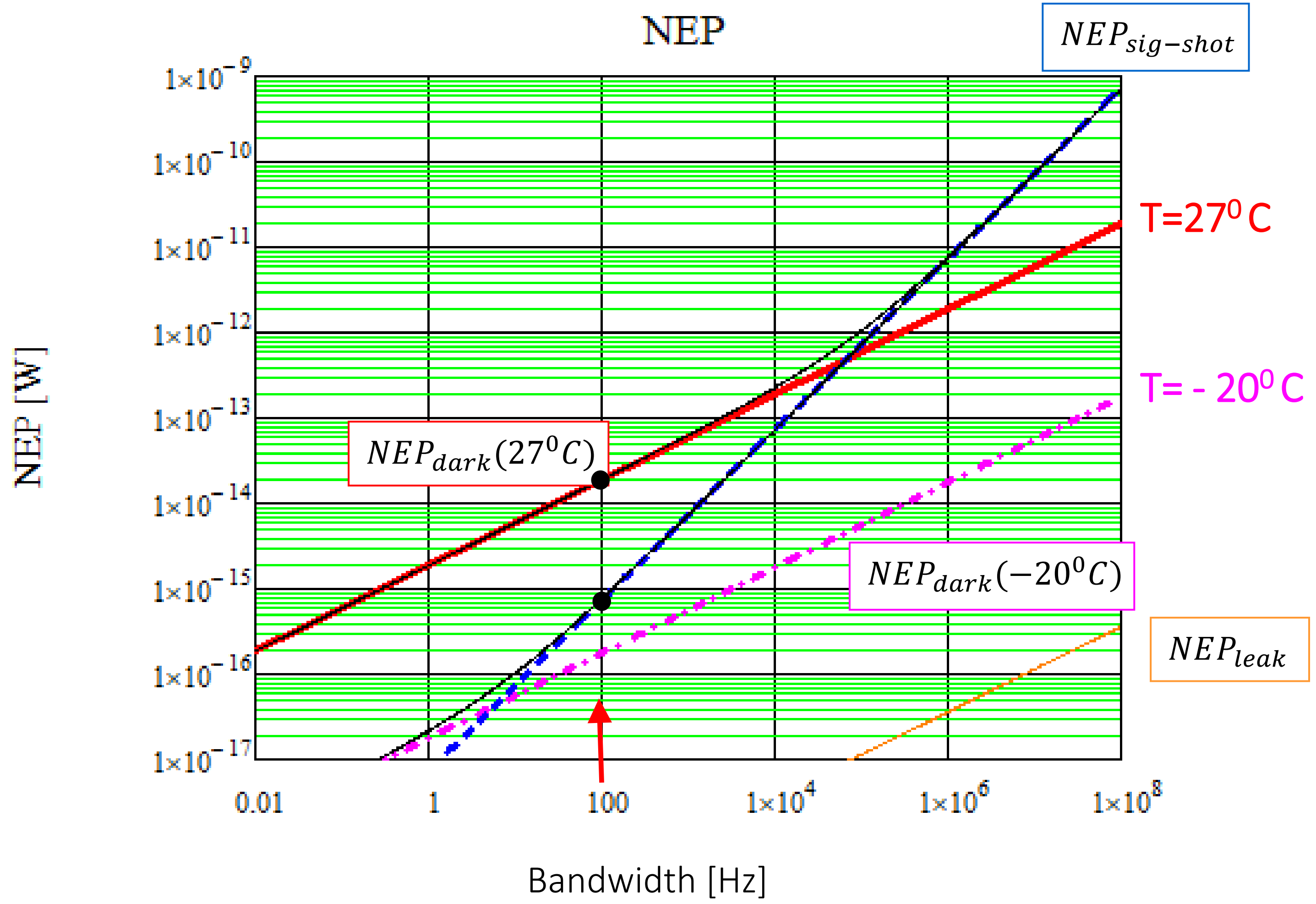
$$\frac{(R_I \cdot P \cdot \langle G \rangle)^2}{2q\ I_{dark,cat}\ \langle G \rangle^2 \Delta f \cdot F + 2q I_{leak,ano} \Delta f} = 1 \quad \Rightarrow \quad NEP_{dark} = \frac{\sqrt{2q\left(I_{dark,cat} \cdot F + \frac{I_{leak,ano}}{\langle G \rangle^2}\right) \cdot \Delta f}}{\frac{\eta q}{h\nu}} = 0.18\ [fW] < NEP_{sig-shot}$$

Detection distance (T = -20C):

See also slide 4.29

$$L = \sqrt{\frac{P_0}{NEP_{sig-shot}}} = \sqrt{\frac{S_d \cdot \eta \cdot \lambda}{683 \cdot 2hc \cdot F \cdot \Delta f}} \cong 20\ [km]$$

Exercise 4.1: Detection Limit of a PMT



A = 120 [A/cm² K²]

S = 2 cm²

W = 1.25 eV

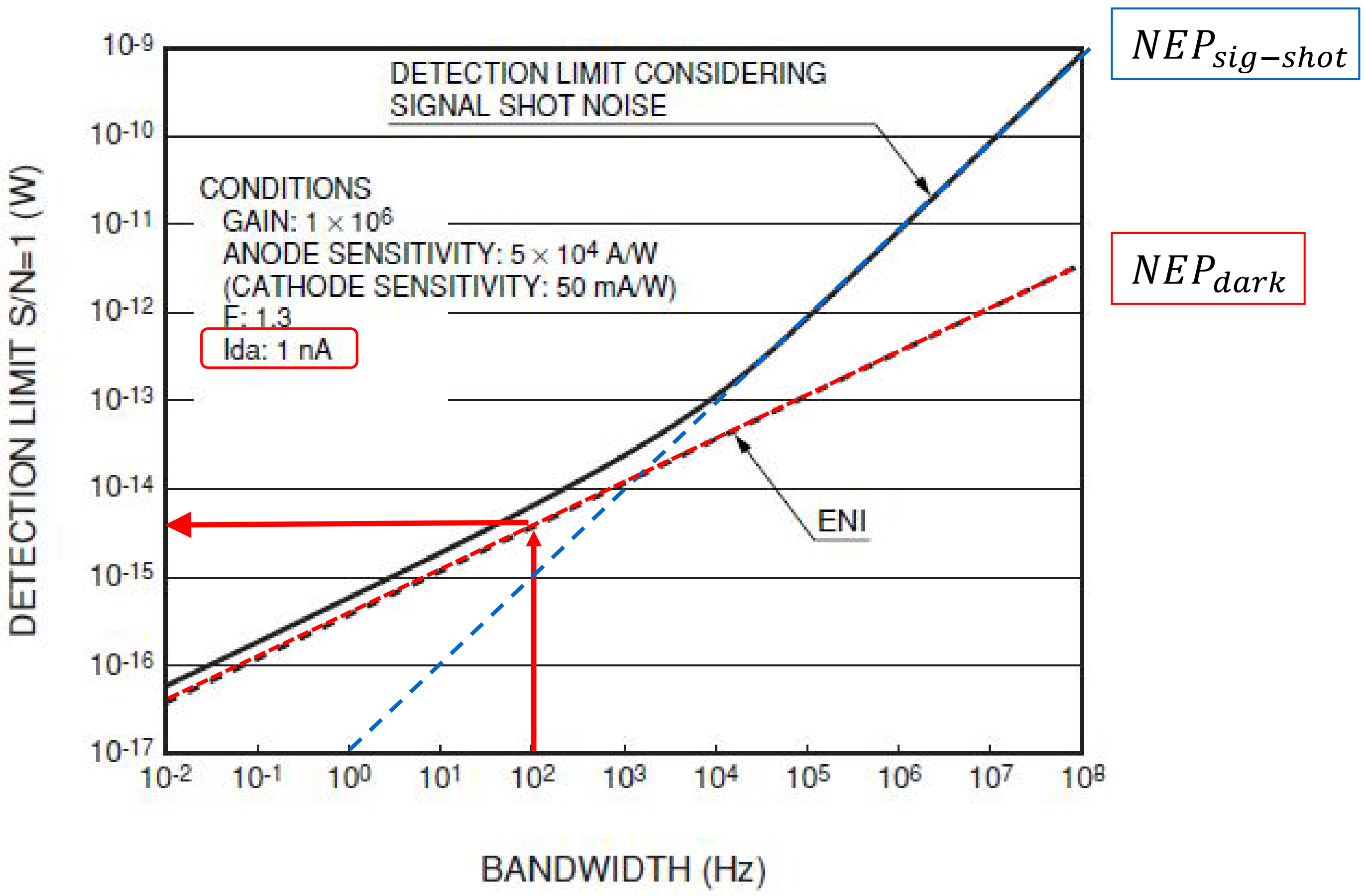
I_{leaky}= 8 [pA] on anode

F = 1

η = 10%

λ = 550nm

Exercise 4.1: Hamamatsu Handbook: NEP



Adapted from the Hamamatsu catalog

ENI= "Equivalent Noise Input" = NEP_{dark}