Optimal detector size for Optical Wireless Communication links with wide coverage

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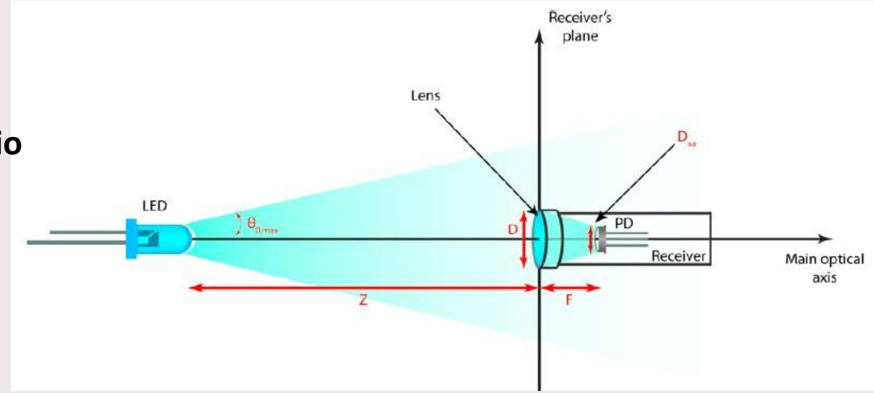
Lev Azarkh, Doctoral Candidate, Xiaochen Liu, Doctoral Candidate, Jean-Paul Linnartz prof.dr.ir.

Electrical Engineering, Signal Processing Systems

Signify TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Area of the detector A_D to bandwidth f_{PD} trade-off

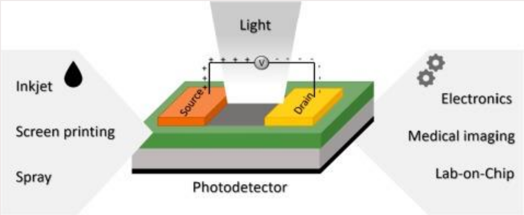


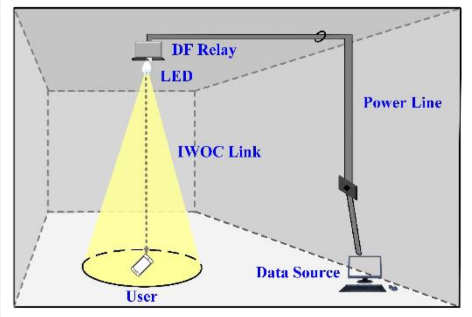
If the **detector size A_D** is *bigger* → *better* **signal-to-noise ratio**

but Large A_D → Large capacitance C_S → Small f_{PD}

If the **detector size** is *smaller* → *larger* **bandwidth**

but Small A_D → Small **signal-to-noise ratio**





Transmitter side

For beams with uniform distribution

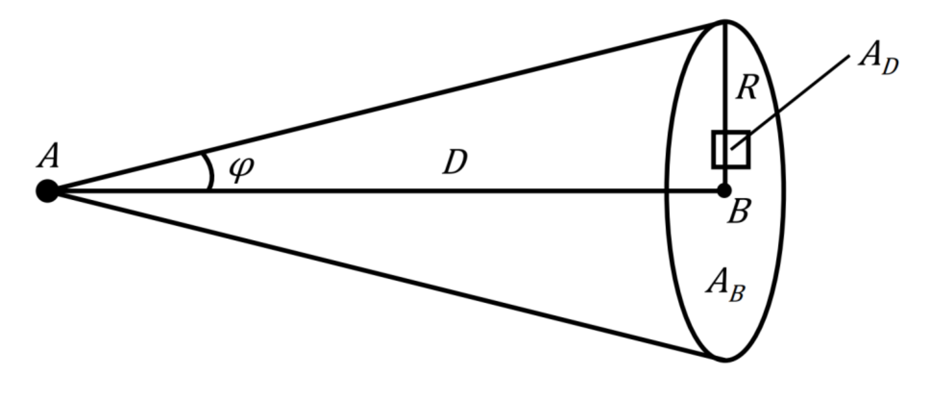
$$P_{R,opt} = \frac{A_D}{A_B} P_{T,opt} = \frac{A_D}{\pi D^2 \tan^2 \varphi} P_{T,opt} \quad (1)$$

For beams with Gaussian distribution

$$P_{R,opt} = P_{T,opt} \left(1 - exp\left(-\frac{A_D}{A_B}\right)\right) \quad (2)$$

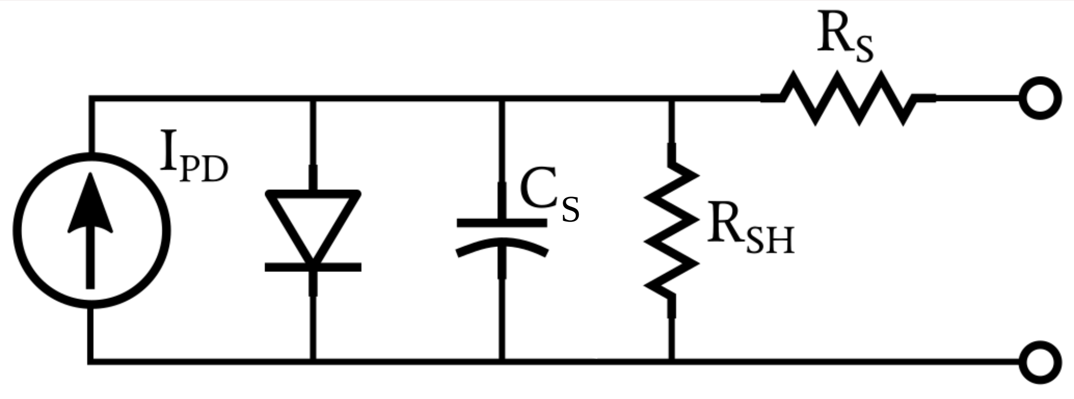
For small A_D:

$$P_{R,opt} \approx \frac{A_D}{A_B} P_{T,opt} \quad (3)$$



- $\boldsymbol{P_{R,opt}}$ is received power,
- $\boldsymbol{P_{T,opt}}$ is optical transmitted power,
- $\boldsymbol{A_B}$ is size of the beam (for Gaussian beam it is an area with radius $\boldsymbol{r_0}$ where intensity falls down to $1/e^2$ of the peak irradiance)
- $\boldsymbol{A_D}$ is the size of the detector
- $\boldsymbol{D}$ is distance between transmitter and detector
- $\boldsymbol{\varphi}$ is beam divergence

Receiver side



Bandwidth of the photodiode depends on two elements, source resistance R_S and its capacitance C_S

$$f_{PD} = \frac{1}{2\pi R_S C_S} = \frac{w}{2\pi R_S \boldsymbol{A_D} \varepsilon\varepsilon_0} \qquad (5)$$

Bandlimited effect due to size of the detector is in its capacitance

$$C_S = \frac{\varepsilon\varepsilon_0 A_D}{w} \qquad (4)$$

- ε is dielectric constant
- ε_0 is dielectric constant of vacuum
- A_D is detector size
- w is depletion width

Different strategies

Using bandwidth of PD

- Noise is flat below 3dB limit
- No filtering needed, so no noise enhancement occurs by it

Using transimpedance amplifier

- Improves bandwidth and noise performance

Using different modulation strategies

- OFDM with waterfilling
- Allows to use more effectively available bandwidth through power allocation

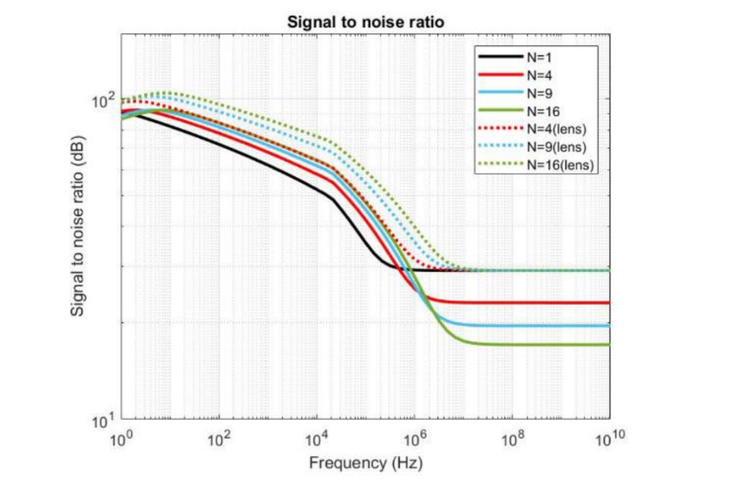


Fig. 7. Output Noise power spectral density from Different Noise Sources

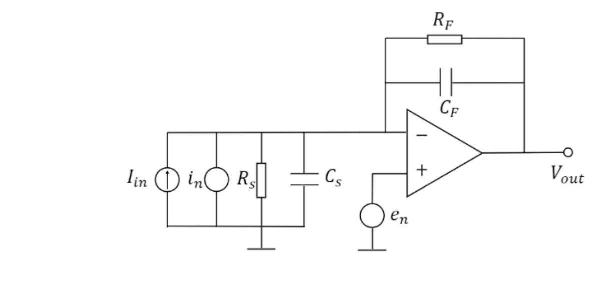


Fig. 11. Noise Model of Optical Receiver Front End

Throughput for *M*-PAM system

Throughput of *M*-PAM system can be expressed as

$$R_b = 2mf_{PD} = f_{PD}\left[\log_2\left(1 + \frac{h^2\sigma^2}{N_0\Gamma f_{PD}}\right)\right] \qquad (6)$$

where Γ is the modulation gap can be derived through BER.

which effectively can be seen as (the impact of the detector):

$$R_b \approx \frac{1}{\boldsymbol{A_D}}\left[\log_2\left(1 + \frac{\boldsymbol{A_D^2}\sigma^2}{N_0\Gamma\frac{1}{\boldsymbol{A_D}}}\right)\right] \qquad (7)$$

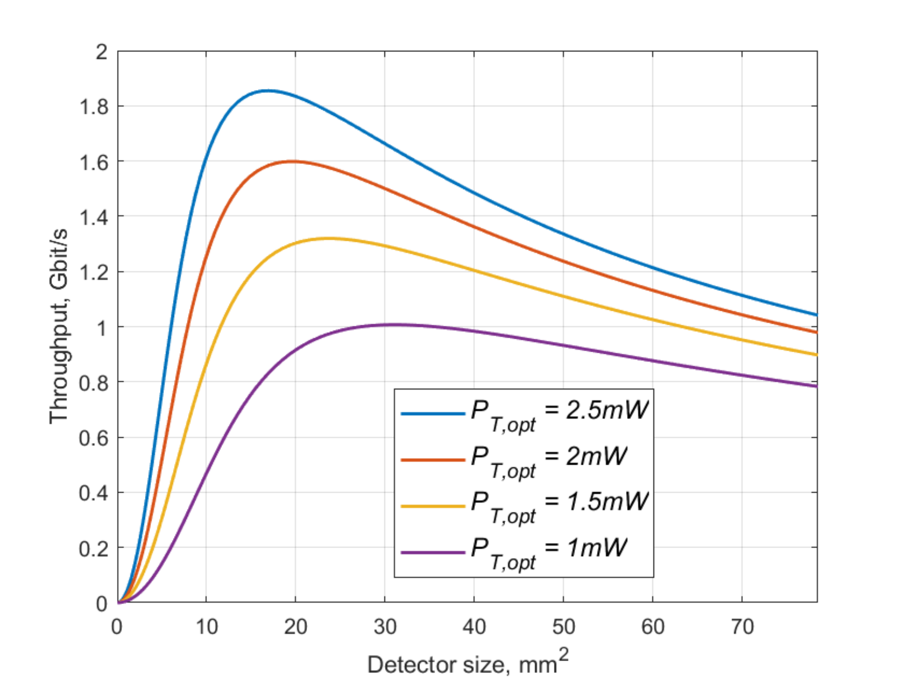
Parameter	Value
Transmitted power $P_{T,opt}$	2.5 mW
Beam size	78.5 mm^2
Modulation gap Γ	4 (6dB)
Noise spectral density N_0	10^{-17} W/Hz

- $m = \log_2 M$ is amount of bits
- f_{PD} is bandwidth of the photodiode
- h is the pathloss
- N_0 is noise spectral density
- ϵ_N is energy per dimension
- BER is bit error rate
- A_D is the size of the detector

Optimal detector size for $f = f_{PD}$

$$R_b \approx \frac{1}{\boldsymbol{A_D}}\left[\log_2\left(1 + \frac{\boldsymbol{A_D^2}\sigma^2}{N_0\Gamma\frac{1}{\boldsymbol{A_D}}}\right)\right]$$

- Results are limited by $P_{T,opt} = 2.5mW$ as it is absolute limit for eye-safety
- For infrared, power limits are higher
- There is no noticeable difference in behavior for Gaussian beams and for beam with uniform distribution
- For lower transmit powers or for higher attenuation, the optimal size is larger than for strong signals



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Conclusions

There is an optimal detector size for non-imaging OWC systems. But system only uses bandwidth strictly below 3dB limit.

- Noise is flat below 3dB bandwidth
- Optimal detector size depends on the parameters of the system
- For weak signals, optimum is less clear as negative effects of capacity on the throughput are less

Next steps to optimize and improve the model will be:

- Receiver design that includes transimpedance amplifier (TIA)
- Include imaging systems
- Improvement of bandwidth and noise performance
- Different modulation strategies

Thank you for your attention

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Lev Azarkh, Doctoral Candidate