Silicon Photomultipliers as Optical Wireless Receivers in Ambient Light

Oxford
Engineering
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W. Matthews
DPhil Candidate
Supervised by Prof. Steve Collins
Optical Wireless Communications
Engineering Science
University of Oxford

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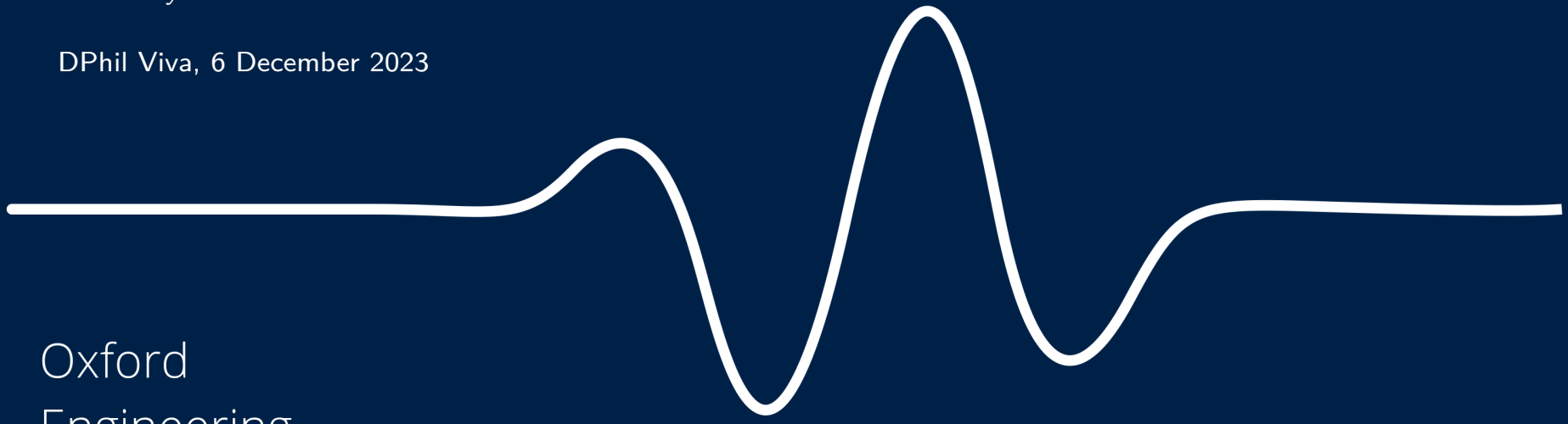

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- Visible Light Communications (VLC) have been proposed as a technology to replace or augment existing RF wireless communications.
- Silicon Photomultipliers (SiPMs) have been proposed as a means of improving the SNR of VLC links[1].
- SiPMs can detect individual photons, however doing so creates a nonlinear response.
- This nonlinearity is worsened by the introduction of ambient light.

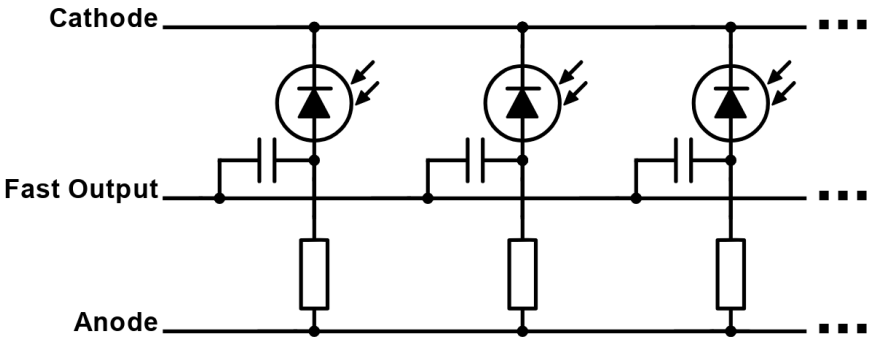
1

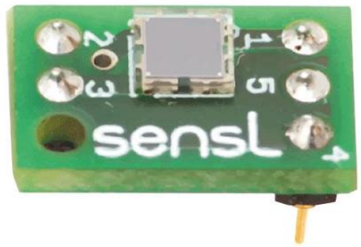
W. Matthews, et al. A 3.45 Gigabits/s SiPM-Based OOK VLC Receiver. in IEEE Photonics Technology Letters, vol. 33, no. 10, Institute of Electrical and Electronics Engineers, 2021, pp. 48790.

Silicon Photomultipliers

What is a SiPM?

- SiPMs are made of an array of microcells.
- A microcell is an avalanche photodiode (APD), with a quench circuit.
- Applications in LIDAR, time of flight PET, lifetime fluorescence spectroscopy as well as astrophysics and high energy physics.



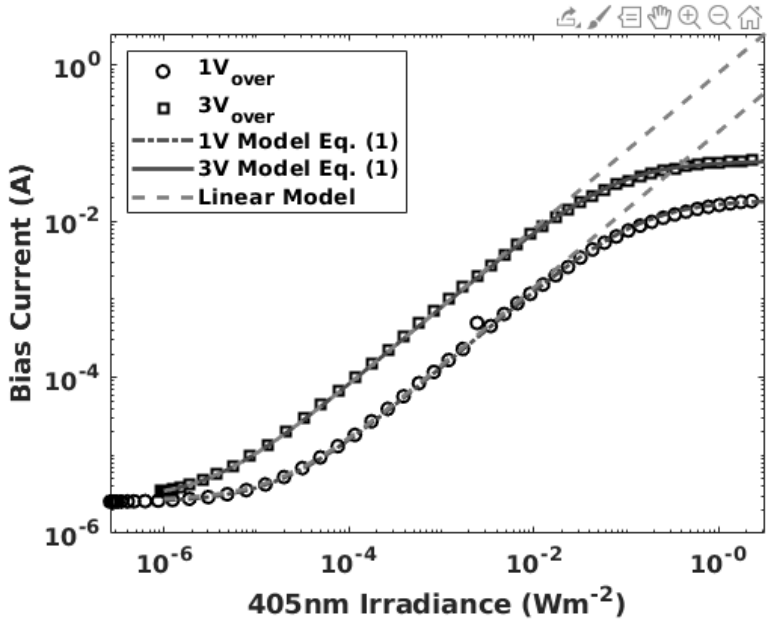


J-30020 SiPM on a SMTPA evaluation board

SiPM Nonlinearity

Device saturation

- SiPMs are count rate limited.
- The device becomes saturated when the microcells are unable to recharge before the next photon arrives.
- Onsemi J-30020 SiPMs were characterised.
- J-Series SiPMs shown to not be paralysable.

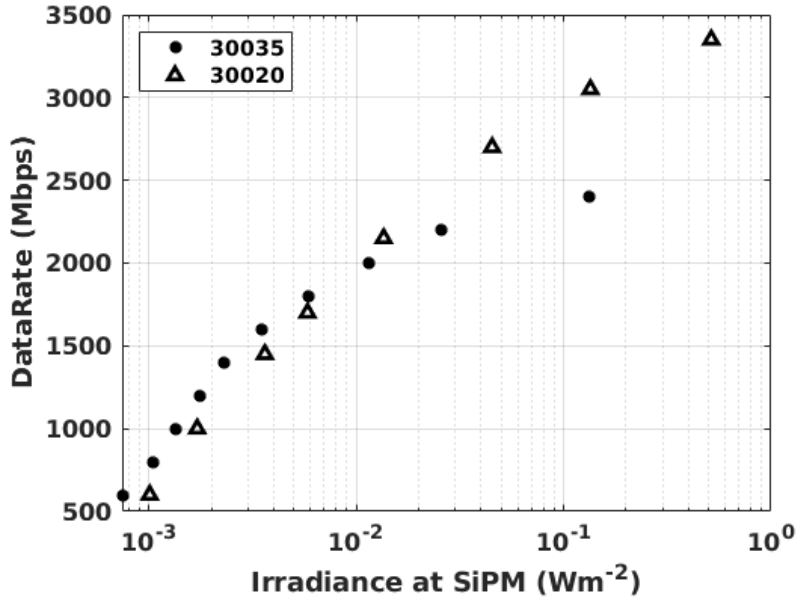


SiPM saturation curve for two different overvoltages

Data Transmission Results

SiPMs as OWC Receivers

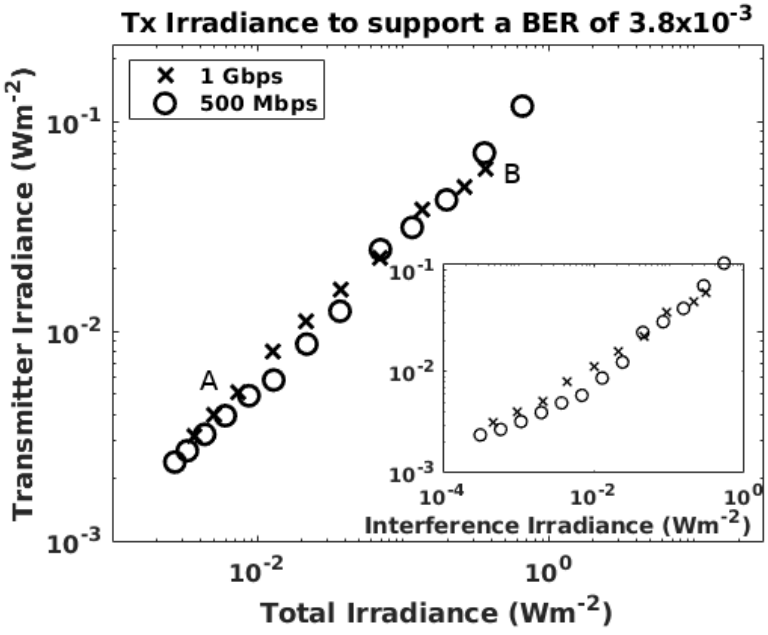
- A world-record data rate of 3.45 Gbps was achieved using a SiPM receiver.
- Limited by the count rate of the SiPM.
- Impact of ambient light was investigated.



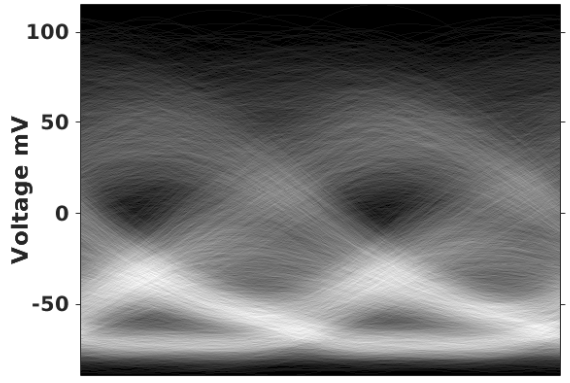
Data rate as a function of irradiance with no ambient light

Data Transmission Results

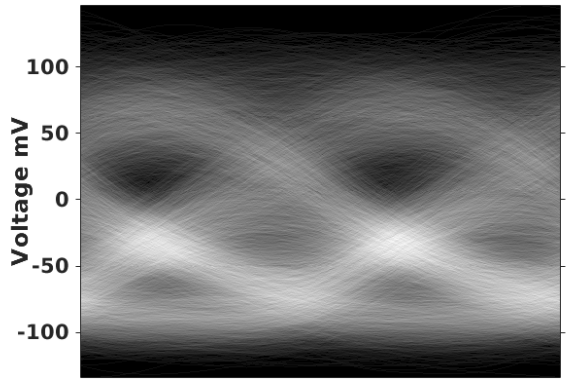
Transmitter penalty versus background irradiance



SiPM transmitter requirements were characterised



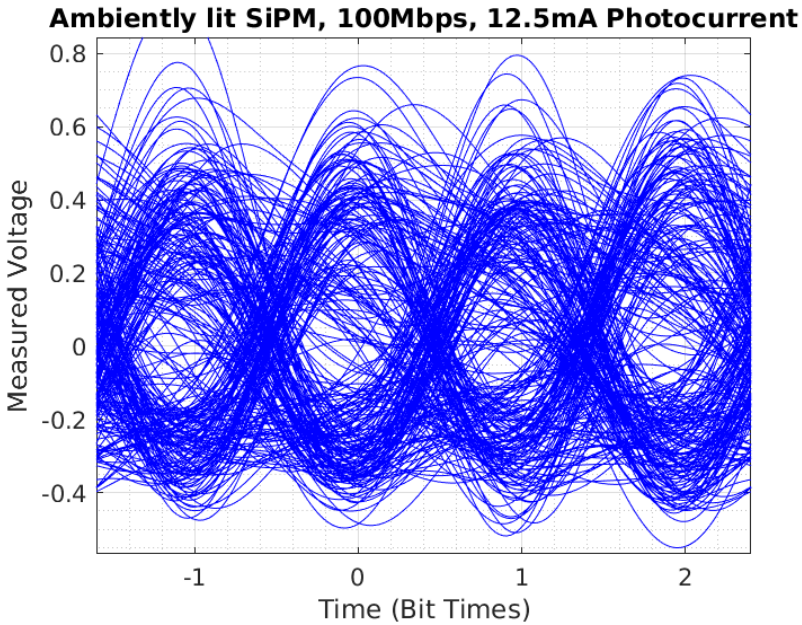
(A) 1 Gbps, $L_{\text{total}} = 6\text{mWm}^{-2}$



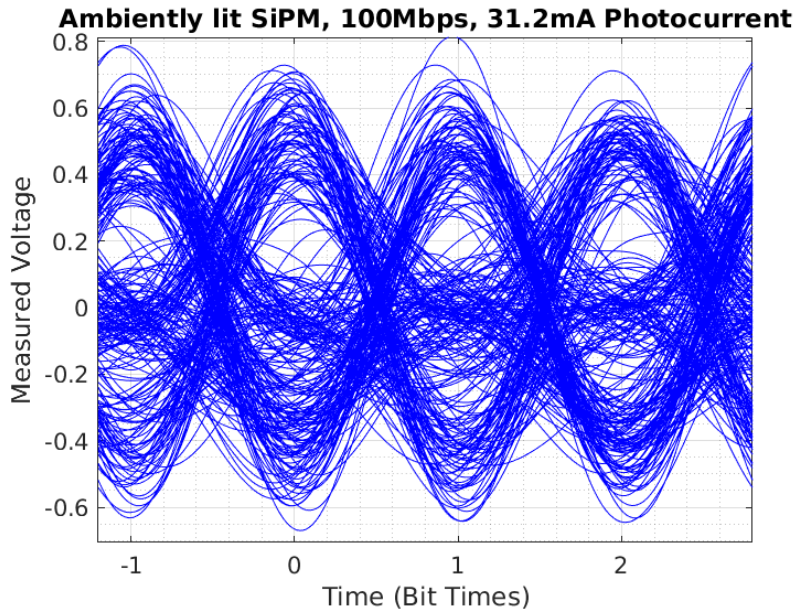
(B) 1 Gbps, $L_{\text{total}} = 470\text{mWm}^{-2}$

New ISI

A new form of Inter-Symbol Interference



SiPM fast output showing typical response

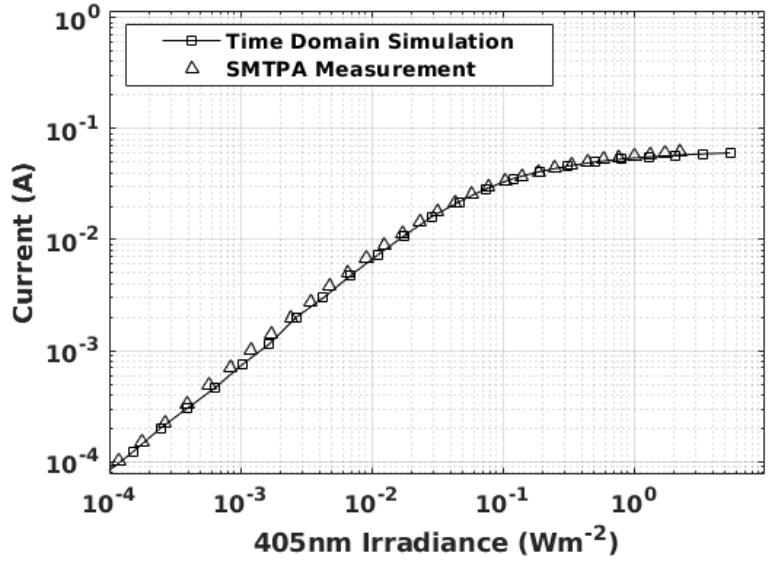


SiPM fast output showing new ISI

Simulation of SiPMs

The first fully experimentally validated SiPM simulation

- A Monte Carlo model was developed to simulate SiPMs.
- The model was validated against experimental data.
- Predicted saturation, and data link performance.
- Available as free open source software.



$3V_{over}$ simulated SiPM saturation curve, using time domain model

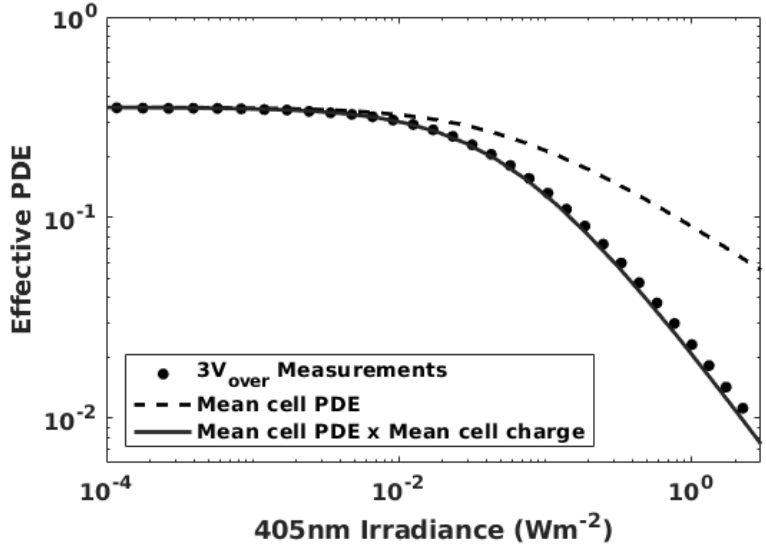
SiPM Saturated Response

Device saturation and Effective PDE

- ePDE model:

$$\eta_{\text{eff}} \approx \frac{E_p I_{\text{bias}}}{Q_{\text{cell}} A_{SiPM} \cdot (L + L_{\text{dark}})}$$

- A 20dB/decade rolloff was measured in η_{eff}, however the mean cell Photon Detection Efficiency (PDE) rolled off at 10dB/decade.
- Rather than being count rate limited, the gain per photon decreases, also at 10dB/decade.

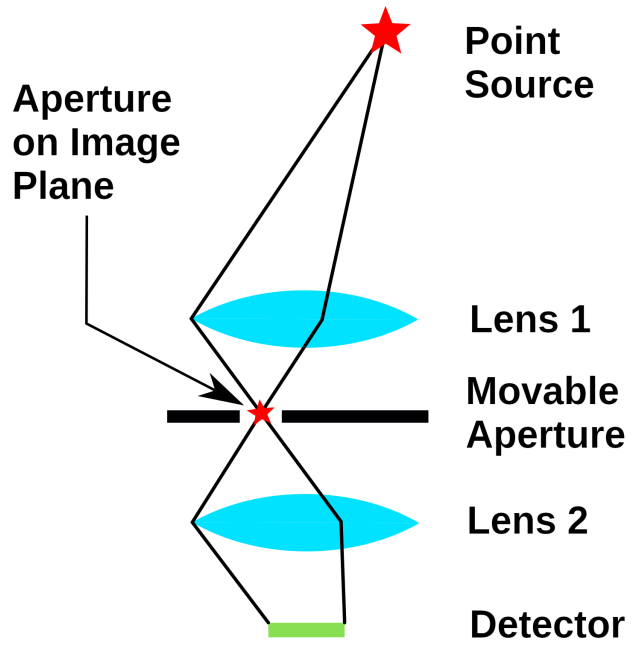


Effective PDE simulation vs measurement

Field of View Selective Device

Design and Implementation

- Novel method for selecting small FoV over a wide FoR.
- Solid state design.
- A high-resolution LCD aperture is used to select the FoV.

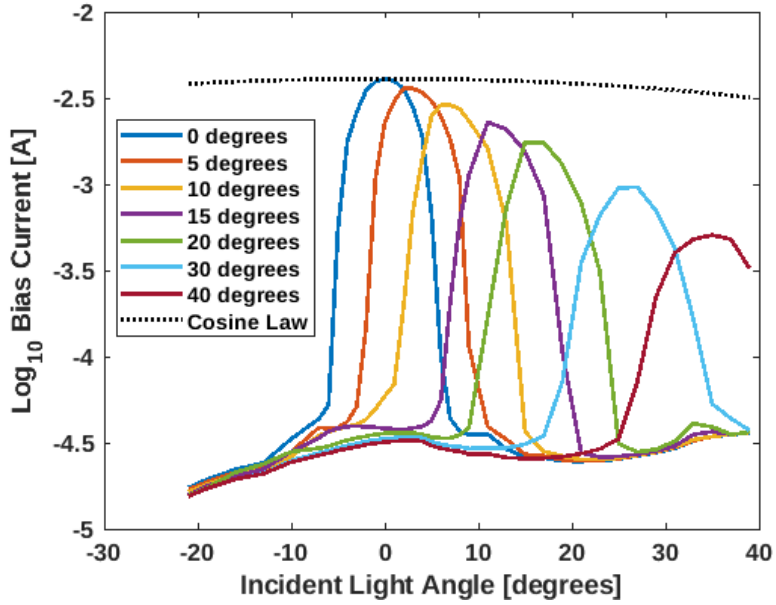


FoVSD Diagram

Field of View Selective Device

Performance

- Shown to be effective in rejecting:
  - Lambertian light sources.
  - Point sources.
  - Unwanted transmitters.
- Tested in a range of lighting conditions, including daylight.
- Solves the problem of multiple transmitters in VLC systems.



Selected point source vs angle

Conclusion

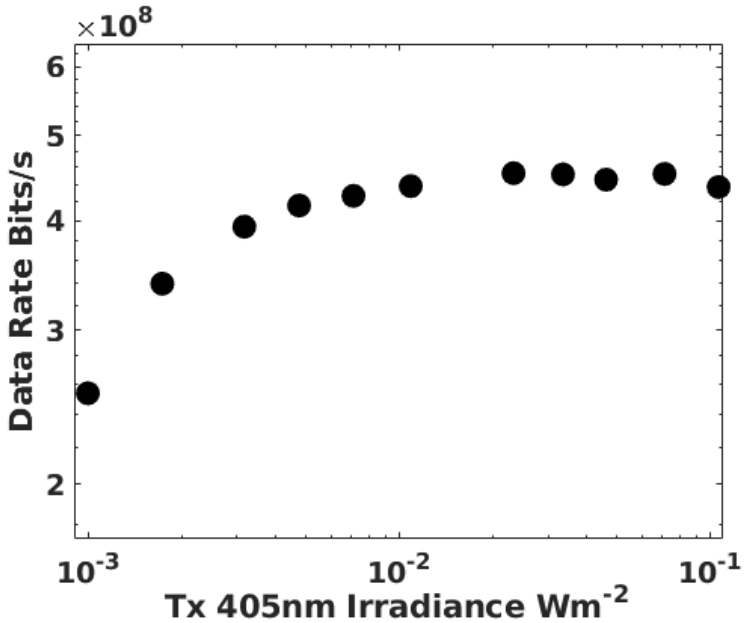
Key Results

1. **Publications:** 13 papers published, 3 in preparation, and 3 conferences attended.
2. **Record Achievement:** Achieved a world-record OOK data rate of 3.45 Gbps using a SiPM receiver.
3. **New ISI:** Documented a new form of ISI in SiPMs and explained its origin.
4. **Nonlinearity Study:** Characterised nonlinearity and developed a model to predict effective PDE.
5. **Simulation:** Created a Monte Carlo model for SiPM, aiding in performance prediction for communication systems.
6. **Field of View Control:** Developed a novel method for selecting transmitters.

Data Transmission Results

Orthogonal Frequency Division Multiplexing

- The experimental setup was tested with OFDM, *with no ambient light*.
- OFDM has high peak powers and is sensitive to nonlinear characteristics[2].
- Despite increasing transmitter power, the data rate saturates.



SiPM Bias current against 405nm Irradiance

2

W. Matthews, C. He and S. Collins, "DCO-OFDM Channel Sounding with a SiPM Receiver," 2021 IEEE Photonics Conference (IPC), 2021, pp. 1-2, doi: 10.1109/IPC48725.2021.9592851.