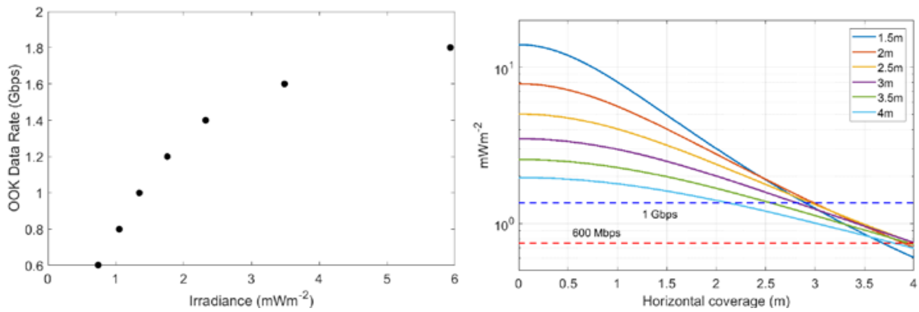
A SiPM receiver that is compatible with a low-power, exempt 405 nm transmitter.

Wajahat ALI, Grahame FAULKNER, Zubair AHMED and Steve COLLINS*
Department of Engineering Science, Parks Road, Oxford, OX1 3PJ, UK
* corresponding author: steve.collins@eng.ox.ac.uk

The capacity of a VLC system depends upon its bandwidth and the receiver's signal to noise ratio (SNR). One approach to improve the receiver SNR that is being investigated is to employ silicon photomultipliers (SiPMs)[1]. These devices are arrays of single photon avalanche diodes (SPADs) which are each capable of detecting single photons. In VLC systems, this allows links to operate closer to the 'quantum' limit dictated by Poisson/shot noise than other receivers[1]. Consequently, a receiver incorporating a SiPM has been shown to require 9 dB less power at 1 Gbps than the best receiver based upon an avalanche photodiode[1]. Two important factors that determine the performance of a SiPM receiver is its photon detection efficiency (PDE) at the wavelength of the transmitted light and the amount of ambient light reaching the SiPM. The PDE of the J series SiPMs manufactured by ON Semiconductor peaks at approximately 425 nm and the white LEDs that are increasingly used to generate ambient light emit less power at 405 nm than at 450 nm. Operation at 405 nm will therefore reduce the amount of ambient light reaching the SiPM but raises questions about the potential blue-light hazard of the transmitter. In this paper the irradiance required to transmit up to 1 Gbps to a SiPM using a 405 nm transmitter is compared to the irradiances that could be generated by a transmitter in the exempt group of the standards governing the photobiological safety of lamps and lamp systems[2].



(a) (b)

Fig. 1. (a) The irradiance required to transmit different OOK data rates to a J Series 30035 SiPM. (b) The irradiance from an exempt 405nm transmitter at various horizontal and vertical distances between the transmitter and the receiver. Also shown are horizontal lines showing the irradiances required to support 600 Mbps and 1 Gbps.

A 30035 J-series SiPM has been tested using a transmitter consisting of a 10 GHz Tektronix arbitrary waveform generator (AWG) and a ZFL-1000H+ amplifier. Once amplified the AWG output was combined with a DC bias voltage by a Mini-Circuits Bias-Tee (ZFBT-4R2GW+). This signal was then applied to a L405P20 405 nm laser diode, whose output power could be controlled using a wire grid polariser. The receiver in the experiment consisted of a Thorlabs FB405-10 bandpass filter, which rejected most of the 500 lux of ambient light from a white LED which illuminated the SiPM. The fast output from the SiPM was amplified by a ZX60-43S+ amplifier, captured by a MSOV334A 33GHz 80 GSps oscilloscope and analysed in MATLAB®.

With the target bit error rate (BER) set at 10^{-3} experiments were performed at seven data rates between 600 Mbps and 1.8 Gbps. At these data rates the finite width of the SiPM's output pulses caused inter-symbol interference and so the BER was measured after decision feedback equalisation (DFE). The results in Fig. 1 (a) show that for data rates between 600 Mbps and 1 Gbps the data rate is proportional to the irradiance at the SiPM. However, as the data rate increases above 1 Gbps the finite time that it takes each SPAD in the SiPM to recover means that the effective PDE of the SiPM is reduced. The relationship between irradiance and data rate then becomes non-linear.

The use of a 405 nm transmitter and optical filter helps to reduce the impact of ambient light. However, a potential concern with transmitting data using 405 nm light is eye-safety, in particular the blue-light hazard. The ultimate aim is to use a small, low-power LED as the transmitter and so guidance on measuring and determining the hazard of LEDs has been consulted[2] and used to calculate the results in Fig 1(b). In addition to describing how measurements should be performed this standard sets out the allowable exposure time for different risk groups. These risk groups include the exempt group (risk group 0) which includes LEDs that do not pose a retinal blue-light hazard. Using the exposure limit for this group and a half-angle divergence of 45^o the maximum allowed power at 405 nm is 65.8 mW. Figure 1(b) shows the irradiance from a 65.8 mW transmitter as a function of the vertical and horizontal distances between a transmitter and a receiver, calculated taking into account the projected area of the receiver. Also shown are the irradiances required by a 30035 to support 600 Mbps and 1 Gbps. When the vertical and horizontal distances are both 3 m the irradiance is 1.23 mWm^{-2}. The linear relationship between irradiance and OOK data rate between 600 Mbps and 1 Gbps in Fig. 1(a) means that the SiPM can support 900 Mbps at this irradiance. Rather than creating a photobiological hazard transmitting data using 405 nm therefore means that 900 Mbps can be provided to an area of 28 m^2 using a safe, exempt transmitter.

The results that have been presented show that existing SiPMs can receive OOK data at rates of up to 900 Mbps at irradiance levels that can be obtained from an exempt LED transmitter operating at 405 nm that covers 28 m^2. Currently, the filter at the SiPM used to achieve these irradiance levels restricts its field-of-view. However, other types of filters are available and experiments are planned to confirm that they can be used to achieve a similar performance without restricting the field of view of the receiver.

References

[1] Z. Ahmed, R. Singh, W. Ali, G. Faulkner, D. O'Brien and S. Collins, "A SiPM-Based VLC Receiver for Gigabit Communication Using OOK Modulation," in IEEE Photonics Technology Letters, vol. 32, no. 6, pp. 317-320, 15 March15, 2020, doi: 10.1109/LPT.2020.2973200.
[2] BSI Publication "BS EN 62471:2008 Photobiological safety of lamps and lamp systems." 2009.