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[OWPT-2-02] Free Space Optical Link for Simultaneous Power and 1 Gb/s Data Transmission

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We study the trade-off between power and data transfer for a two-meter wireless gallium-arsenide laser and photovoltaic link. The use of orthogonal frequency-division multiplexing with adaptive bit and power loading results in a peak data rate of 1041 Mb/s. The photovoltaic receiver is shown to offer simultaneous power harvesting with 41.6% efficiency under the irradiance of 0.3 W/cm^2 and a data rate of 784 Mb/s.

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Free Space Optical Link for Simultaneous Power and 1 Gb/s Data Transmission

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***Abstract**: We study the trade-off between power and data transfer for a two-meter wireless gallium-arsenide laser and photovoltaic link. The use of orthogonal frequency-division multiplexing with adaptive bit and power loading results in a peak data rate of 1041 Mb/s. The photovoltaic receiver is shown to offer simultaneous power harvesting with 41.6% efficiency under the irradiance of 0.3 W/cm^2 and a data rate of 784 Mb/s.*

1. Introduction

The simultaneous optical wireless data and energy transfer has been acknowledged as a potential technology for enabling the era of Internet of Things (IoT) and next-generation backhaul communications [1-4]. A power splitting solar panel receiver was used, for the first time, in [1] with the ability to separate the alternating current (ac) from the direct current (dc). Also, the use of optimum bit and power loaded orthogonal frequency-division multiplexing (OFDM) was shown to provide a data rate of 12 Mb/s. At the same time, the silicon solar panel was shown to be capable of harvesting 30 mW of electrical power. The use of an organic solar cell as a data detector was investigated in [2]. The achieved data rate was 34.2 Mb/s with a harvested power of 0.4 mW. Triple-cation perovskite solar cells were used for data detection in [5]; a maximum data rate of 53 Mb/s and a harvested power of 3.3 mW were demonstrated.

Photovoltaic (PV) cells obtain the maximum power conversion efficiency under monochromatic radiation because transmission and thermalization losses can be minimized by proper energy matching of the photons and absorber bandgap [6, 7]. In [4], we reported the highest data rate of 1041 Mb/s of all PV detectors by using a gallium arsenide (GaAs) PV cell attached to an ac/dc separation circuit as that used in [1, 8]. Also, we studied the trade-off between energy harvesting and data communication of the PV receiver. The experimental setup and results given in [4] are summarized in this paper.

2. Experimental setup

An arbitrary waveform generator (AWG) is used to create the OFDM signal. A power supply is used to provide the dc bias to an 850 nm vertical-cavity surface-emitting laser (VCSEL). The dc electrical power at the transmitter $P_{\mathrm{Tx,dc,elec}}$ is set to 10 mW. This is to ensure that the VCSEL is biased in the middle of its linear dynamic range. A bias tee combines the incoming ac and dc signal and feeds their summed signal to the VCSEL. The optical power $P_{\mathrm{Tx,dc,opt}}$ of the laser is measured to be 2.6 mW. The peak-to-peak (pp) voltage of the generated ac signal u_{g} is set to 0.125 V, 0.25 V and 0.5 V. The maximum input pp voltage of 0.5 V ensures that negligible clipping is induced by the dynamic range of the LD to the ac signal. Since the output laser beam is divergent, a plano-convex lens is used to collimate the beam in free space. The laser beam is eye safe and the designed system is classified as Class 1/1M [4]. An aspheric condenser lens is placed at 2 m from the transmitter lens to focus the beam on the GaAs PV cell. The PV cell is based on a positive-negative (p-n) GaAs homo-junction capped with a 400 nm thick $Al_{0.5}Ga_{0.5}As$ window layer (doping concentration: $N_A=1\times10^{20}$ cm^{-3}) to facilitate lateral conduction [9]. The PV cell features a circular active area of 0.8 mm^2. The optical power impinging on the GaAs PV cell is measured to be $P_{\mathrm{Rx,dc,opt}}=2.4$ mW. The receiver circuit uses two electrical branches to separate the dc from the ac signal, as shown in Fig. 1. The first branch consists of an inductor with a value $L=680$ μH and a variable resistor R_{l} with an upper limit of 10 kΩ; the generated dc voltage V_{l} across the load resistance R_{l} is measured to determine the harvested electrical power $P_{\mathrm{Rx,dc,elec}}$ by using $P_{\mathrm{Rx,dc,elec}}=V_{\mathrm{l}}^2/R_{\mathrm{l}}$ and the total link or end-to-end dc power efficiency η_{t} by using $\eta_{\mathrm{t}}=P_{\mathrm{Rx,dc,elec}}/P_{\mathrm{Tx,dc,elec}}$. The second branch consists of a capacitor with a value $C=1$ nF and a variable resistor R_{c}; the value of R_{c} is set to 7.3 Ω because it has been shown to optimize data rate [3]. The ac voltage signal $v(t)$ is amplified by using a radio-frequency amplifier. The received analog signal is converted to a digital one by using an oscilloscope.

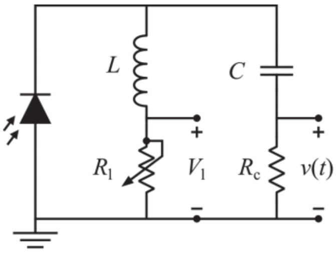

Fig. 1. Electrical circuit of the photovoltaic receiver [4].

The digital OFDM signal is processed in a laptop using Matlab. The laptop is connected to the AWG and the oscilloscope. Details of the process of the generation and reception of the discrete OFDM signal along with relevant parameters can be found in [3].

3. Results and discussion

In Fig. 2, the data rate γ and generated current I_{l} are given as a function of the load voltage V_{l}. The maximum power point (MPP) is achieved for the current and voltage I_{mp}=1.1 mA and V_{mp}=0.9 V, respectively. The maximum harvested power is $P_{\mathrm{mp}}=I_{\mathrm{mp}}V_{\mathrm{mp}}\approx 1$ mW. Thus, the maximum total link efficiency and power conversion efficiency of the PV cell are calculated to be 10% and 41.6%, respectively; the maximum power efficiency of the cell is determined using $\eta_{\mathrm{pv,max}}=P_{\mathrm{mp}}/P_{\mathrm{Rx,dc,opt}}$. For voltages above V_{mp}, the generated current drops rapidly towards zero.

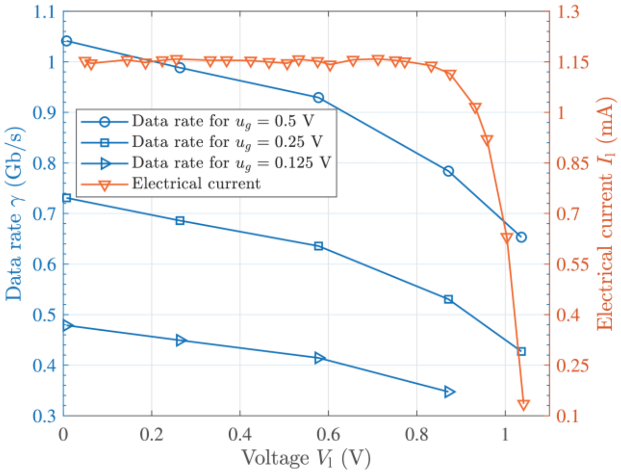

Fig. 2: Data rate and dc electrical current as a function of load voltage [4].

The increase in the generated dc voltage across R_l causes a decrease in the data rate. This is because of the corresponding decrease in the voltage of the junction that results in a lower mean pp voltage of the OFDM signal and, thus, a reduced signal-to-noise ratio (SNR). As the input mean pp voltage of the OFDM signal increases, the achieved data rates are shown to increase. This is because the relevant SNR increases. For u_g = {0.125 V, 0.25 V, 0.5 V}, the maximum data rates γ = {478.7 Mb/s, 730.8 Mb/s, 1041.3 Mb/s}, respectively are obtained under short-circuit conditions. However, no energy is harvested at short circuit. At the MPP, the electrical receiver circuit is shown to provide data rates of 347.3 Mb/s, 530.4 Mb/s and 783.8 Mb/s.

In Fig. 3, the estimated and power loaded SNR and the number of loaded bits are given as a function of frequency for R_l=7.3 Ω and u_g=0.5 V. This measurement results in the very high data rate of 1041.3 Mb/s; to the best of the authors' knowledge, this is a world-record value reported in the literature of optical wireless communications using PV cells as data receivers. The frequency profile of SNR is shown to be in accordance with that of a band-pass filter. The attenuation of SNR in frequencies below 20 MHz is attributed to the ac-coupling capacitor in the receiver circuit; an increase in capacitance C is expected to reduce the dc-wander effect [1]. It is observed that bit and power loading is complete at 237.2 MHz, whereas the estimated SNR keeps rolling off from 6 dB to 0 dB at the frequency of 337.7 MHz. This means there is margin to transmit subcarriers of a single bit of information in the estimated SNR region between 3 dB and 6 dB thus further increasing the achievable data rate.

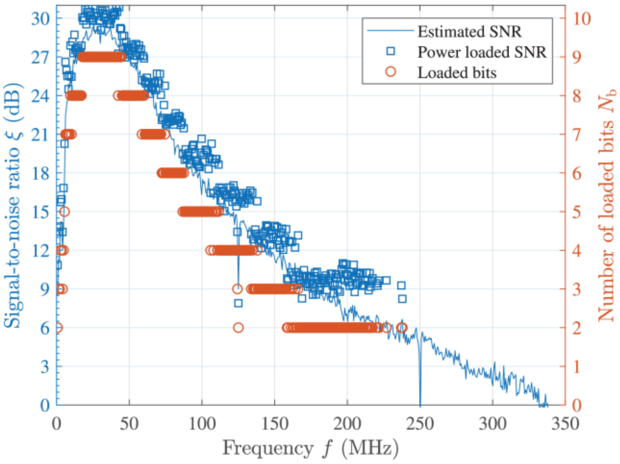

Fig. 3: Estimated and power loaded signal-to-noise ratio (SNR) and number of loaded bits as a function of frequency for the load resistance R_l=7.3 Ω and u_g=0.5 V [4].

4. Summary and conclusion

In this paper, the trade-off between energy harvesting and data communication was investigated for a 2 m eye-safe infrared wireless link using a GaAs VCSEL and PV cell. The developed ac-dc separating receiver was shown to achieve a world-record data rate of 784 Mb/s and a harvested power of 1 mW at the same time. A potential application scenario is the provision of wireless power and data to IoT devices. During periods that the IoT device exclusively required very-high-speed communication, the receiver would be tuned to short-circuit condition; this was shown to offer a maximum data rate of 1041 Mb/s but with diminished electrical dc power. If the IoT sensor required maximum power, the receiver could be configured to operate close to the MPP by using a digital potentiometer. The use of multiple VCSELs and PV cells of high efficiency and bandwidth is envisioned to enable energy autonomous fifth generation and beyond backhaul communications.

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