A Differential Optical Receiver For Free Space Laser Communications

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Abstract

Photo detectors are used to detect laser signals to support high-speed data communications for Unmanned Aerial Vehicle (UAV). However, there is one potential problem, which is the unwanted ambient light that causes detector to saturate. This is not a problem at night-time. However, at day time, the sun-light causes a D.C photo current and causes the photo detector to saturate and makes the laser signal undetectable. While optical filters are used to reduce the problem, additional techniques are needed to further reduce this problem. In this paper, we present a differential optical receiver to cancel ambient light and other atmospheric noise. In the proposed technique, two photo diodes are configured as a differential receiver to cancel ambient light. Experimental results are presented to validate the concept.

Introduction

Free space laser communications provides wide bandwidth and high security capabilities to Unmanned Aircraft Systems in order to successfully accomplish Intelligence, Surveillance, Target Acquisition, and Reconnaissance missions [1-4]. Since bandwidth is scarce and therefore expensive in the typical wireless communication system [5-9], alternate techniques such as laser based communication, are highly desirable. For this application, optical receiver is a critical component and needs to be designed to avoid sun light and other ambient noise for reliable data transmission.

Current optical receivers use optical filters, colored and neutral density filters, and low, band pass, and high pass filters. Some receivers don't have any kind of filtering, and use computers to sift through all the signals to receive the correct one. All of these have the effect of reducing signals from unwanted bandwidths while keeping others, and when they are placed with photo-diodes, are often called 'daylight' filters. None of these truly cancel out all ambient signals; they only diminish the power of the unwanted bandwidths. The proposed differential receiver produces, when any amount of daylight or ambient signals are an input, a power lever that is or is close to zero. The input laser signal can then be received with little noise, and signal processing is made easier.

Typical Laser Receivers

Current optical laser receivers, in their most basic construction, consist of one photo-detector (Figure 1). In the absence of any kind of filtering, sunlight will produce a strong dc current. Strong sunlight will indeed overpower a laser signal, which may have been transmitted a great distance away.

$$V_O = (I_L + I_P)R2 \quad (1)$$

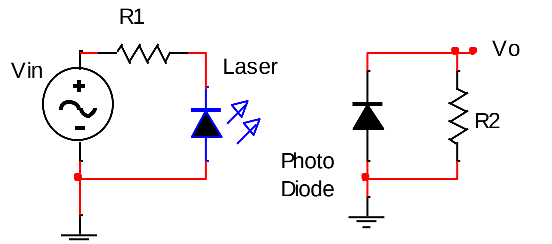


Figure 1: Typical optical receiver

All ambient light, including sunlight, will produce and output represented by Equation 1.
IL is the current due to the laser signal. Ip is the photo current due to sunlight, and all other ambient noise that is not the laser signal. Discerning a laser signal is difficult amid all the background noise received by the photo-detector. Current filters are simply not good enough to eliminate all the unwanted noise, including sunlight. A solution is needed to eliminate all of the unwanted signal.

The Proposed Differential Receiver

The proposed differential laser receiver [10], in its most basic construction, cross couples two photo-receivers, the effect being that the net output power is or is close to zero (Figure 2). The laser signal is then transmitted only into one of the receivers. With all other signals being cancelled out, the laser signal is an overwhelmingly dominant signal.

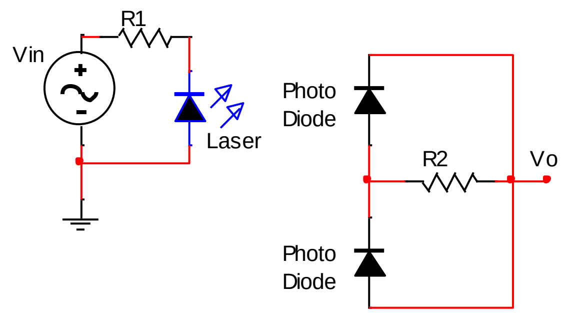


Figure 2: Proposed optical receiver

The output is governed by Equation 2, where the photo current due to sunlight and any other ambient signals is canceled, due to the fact that the two photo-receivers

$$V_O = I_L R2 \quad (2)$$

It is fairly clear from the figure above that when two signal generating photo-receptors are arranged such that when they are opposed to one another, the effect is a cancelation, if and only if the both photo-receptors receive the same amount of input.

Experiments and Results

The experimental setup used is diagramed in Figure 3, and shown in Figure 4. The receivers used in the experiment were solar panels: One pair manufactured by Sanyo Energy, model number AM-1801CA, 53mm X 25mm, and another pair manufactured by Parallax Inc., model number 750-00030, 125mm X 63 mm. There were two lasers used, a 532 nm laser (green), model number

CPA-LP0080-2, and the white light from an Illumin laser keychain light, model ESP 006.

Data was collected using a National Instruments myDaq. The signal generator used was a KandH IDL-800 Digital Lab, and the transmitters used were a Green Laser 532 nm Astronomy Grade Class 3a, model number CPA-LP0080-2, and the white light from an Illumin laser keychain light, model ESP 006.

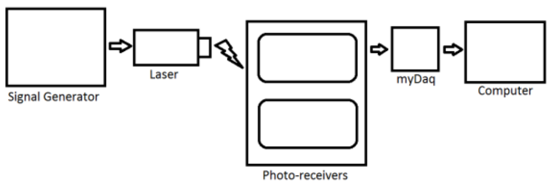


Figure 3: Block diagram of the experimental setup

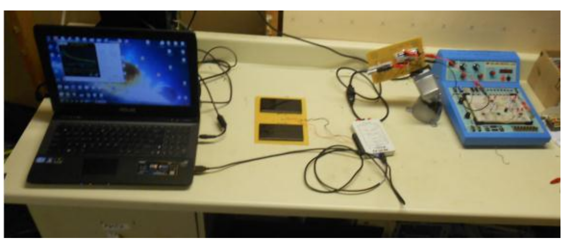


Figure 4: Photograph of the experimental setup

The laser transmitter, which is not discussed in this paper, is held by a vice grip, and the results were collected using a National Instruments myDaq connected to a laptop computer. A 1 kHz sine wave was generated using a K and H IDL-800 Digital Lab, and transmitted via laser and white light LED. The power of the frequency components of the total incoming signal was examined for a two cases: with and without cancelation using photo-receivers.

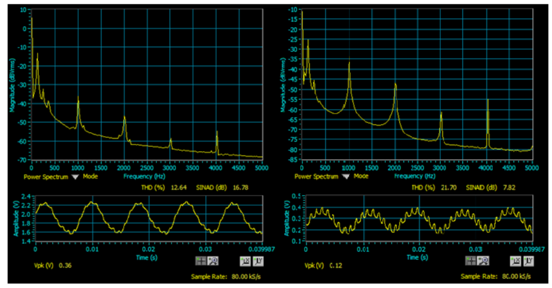


Figure 5. The green laser is transmitting a 1kHz sine wave, and two 125 mm X 63 mm solar panels constitute the receiver.

When the test is carried out indoors, a 60 Hz or 120 Hz component is expected from the light bulbs. In Figure 5, we can see both the 120 Hz component and the 1 kHz component for when there is only one receiver, as in conventional systems, as well as when two receivers are canceling each other out. The 1 kHz component is at a strength of about -36 dB for both cases, but the 120 Hz component drops from a strength of -12 dB to -25 dB, a drop of about 4½ times. With two receivers canceling out each other, the power of what constitutes ambient light indoors (light bulbs) is significantly reduced. The 1k signal component is also much ‘cleaner.’

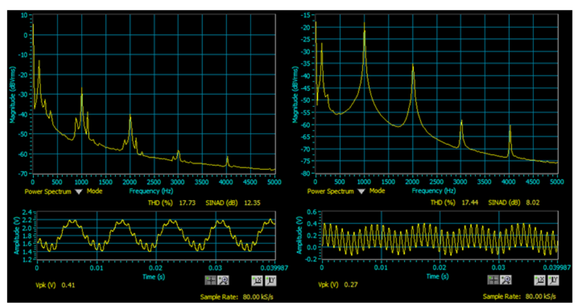
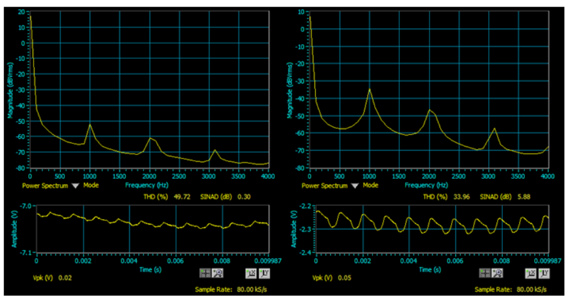


Figure 6. The white light LED is transmitting a 1 kHz sine wave, and two 125 mm X 63 mm
solar panels constitute the receiver.

We see a similar result with the white light LED in Figure 6 (which was used because it is unencumbered by the protection circuitry of the laser). Here we see not only a similar effect with respect to the 120 Hz light bulb signal, but also a gain from about -26 dB to about -18 db (a 2½ times increase), when the receivers are canceling each other out. We can see in this case that cross coupling two receivers not only reduces ambient light, but increases the gain from our intended signal (the white light covered the entire panel, whereas the green laser did not, so the effect of cancelation may be different on these two methods of input).



Only one receiver Both reveivers canceling out

Figure 7. The green laser is transmitting a 1kHz sine wave, and two 53 mm X 25 mm solar panels constitute the receiver.

With the smaller 53mm X 25mm solar panels, the effects are again similar, with the panels arranged in differential mode producing better results. The test of Figure 7 was done outside. Here there is no 120 Hz component. For a 1 kHz incoming signal, applying the cancelation affects from second photo-receiver as opposed to one increases the power of the 1 kHz signal from -51 dB to -35 dB, a more than 6 times increase. The waveform itself also has a much higher peak to peak amplitude.

Future Work

Solar Panels are not communication diodes. They have the benefit of having a large surface area, which makes targeting easier. They have, however, a relatively low response to higher frequencies. The reason for this is that the photo cells comprising the solar panels are PN junctions, which means there is a junction capacitor. The value of this capacitor is proportional to the area of the junction, so larger solar cells have worse bandwidths than smaller ones.

One way to mitigate this is to virtually eliminate the effect of the junction capacitor, which is done by connecting the photo diode between the negative and the positive input of an Operational Amplifier as shown in Figure 8. This can be done with an instrumentation amplifier, which is readily available off-the-shelf and is cost effective as well.

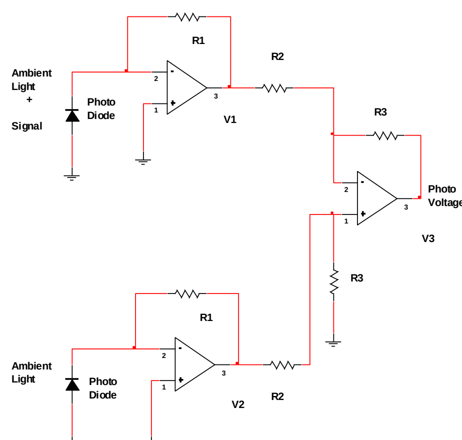


Figure 8: Modified differential optical receiver.

The output voltage is given by equation 3 and the gain by equation 4. The bandwidth is no longer limited when the receivers are set up this way by the solar panel, and is instead limited by the particular operational amplifier used. Therefore, we need high-speed operational amplifiers for this configuration.

$$V_3 = I_L R_1 R_3 / R_2 \quad (3)$$

$$A_V = (V_3 / I_L R_1) = R1 R_3 / R_2 \quad (4)$$

Conclusions

Cross-coupling two photo-receivers serves cancels out any common signal input. The laser signal is relatively stronger compared all other signals in differential mode, when compared to only a single photo-receiver. A technique to increase bandwidth by eliminating the parasitic capacitance was presented. This differential photo-receiver can be used in free space and deep space laser communications, where sunlight and other atmospheric noise are problems.

Acknowledgement

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