Wysips®Connect, the first solution for the indoor/outdoor VLC lighting saturation problematics

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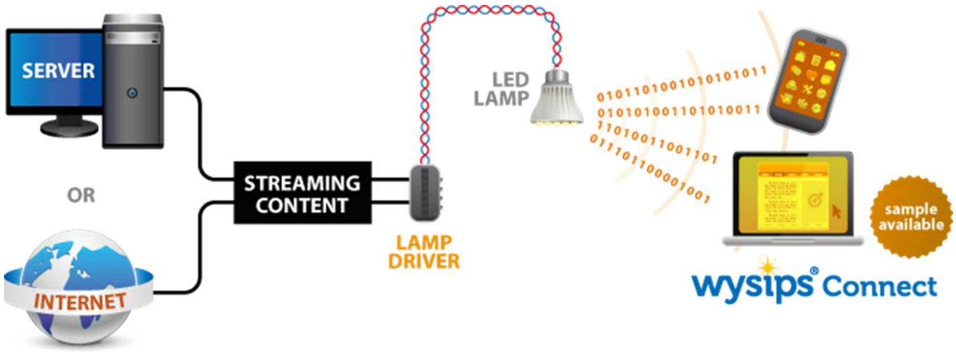
The communication technology, which uses LEDs for both illumination and data transmission, is called Visible Light Communication (VLC) or Light-Fidelity (LiFi). In order to enhance the users mobility for indoor or outdoor environment, it is essential to choose the most appropriate receiver. In this paper, we present LiFi performances of several Wysips®Connect receiver based on Wysips®Crystal/Cameleon/Graphics technologies. These performances allow HD video streaming. Furthermore we proove that Wysips®Connect do not suffer from high ambient lighting saturation. This type of receiver can be used both very close to the sources and in high ambient lighting environment such as in full sun without deteriorating transmission.



1. Introduction

Recently, research on light-emitting diodes (LED) has been strongly growing. The LEDs' low energy consumption, long lifetime have enabled them to become the preponderant lighting source in the last decade. Furthermore, light intensity emitted from LEDs can be modulated at high speed, allowing optical data-transmission in addition to classical illumination. The communication technology, which uses LEDs for both illumination and data transmission, is called Visible Light Communication (VLC) or Light-Fidelity (LiFi).

The LiFi technology uses classical LED light bulbs. A specific LiFi driver monitors the LEDs in order to transmit encoded data through the visible light. An optical sensor like a photodiode is used to receive data. This sensor translates the luminous data into electrical data which is decoded by a LiFi modem.

LiFi is an alternative to conventional wireless communication such as WiFi because LiFi brings some specific advantages :

- LiFi does not create electromagnetic interferences and proposes safe communication for sensitive environments like hospitals, nuclear powerplant, airplanes' instruments without adding too many cables.
- The visible bandwidth is totally unlicensed.
- There are no health regulations today that constraints data transmission through illumination as it is the case for IR communications: visible wavelength does not harm the human skin and does cause any health issue.
- Optical communication provides higher security than RF communication because the signal does not go through walls.
- LiFi could be used to face spectrum congestion in WiFi/5G traffics.

For all this reasons, the LiFi technology is taking more and more importance. A great challenge is to integrate receiver in mobile devices such as smartphone without adding too many constraints. A good receiver :

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- should be thin, omnidirectional, energy sufficient, integrated on all kind of surface,
- should have great LiFi bandwidth, large surface, good sensitivity,
- should be able to decode LiFi signals even in ambient lighting environments,
- should generate a sufficient signal that could directly be used by LiFi modems without adding amplifiers.

That is currently a big challenge for LiFi!

SunPartner Technologies completely understands the LiFi problematics and has been developping LiFi receivers for few years. Last year, for example, SunPartner Technologies has presented the first integrated photovoltaic LiFi receiver : Wysips®Connect. Today, our R&D LiFi staff is working on the LiFi technology development to improve the LiFi performances of the Wysips®Connect modules. That implies means of LiFi Wysips®Connect characterization. We decided to work in collaboration with the CEA-Leti, a French research institute which has developed a LiFi experimental testbed by mixing real optical front-end and simulated digital modems.

2. Wysips® technology

2.A. Wysips®Connect based on Crystal technology

Wysips®Crystal is a device combining optical and photovoltaic technologies. Its first function is to produce electricity from a natural or artificial light source. It is ultra thin and transparent, so it can easily be incorporated into screen as it presented on Fig. 1. It works with all kinds of screen technology, including MEMS, bistable, LCD, OLED, and optical screen. The Wysips®Connect version is also LiFi compatible, enabling screens and mobile device to receive and transmit data over visible light waves.

(a) Wysips®Crystal (b) Integration into a phone

Fig. 1. Wysips®Crystal module and integration

The Wysips®Crystal module is based on a-Si (Amorphe Silicium) classical structure. We use this Technology to develop Wysips®Connect based on Crystal technology in order to use this kind of device as receiver LiFi. Their current-voltage curves are measured in indoor (Fig. 2).

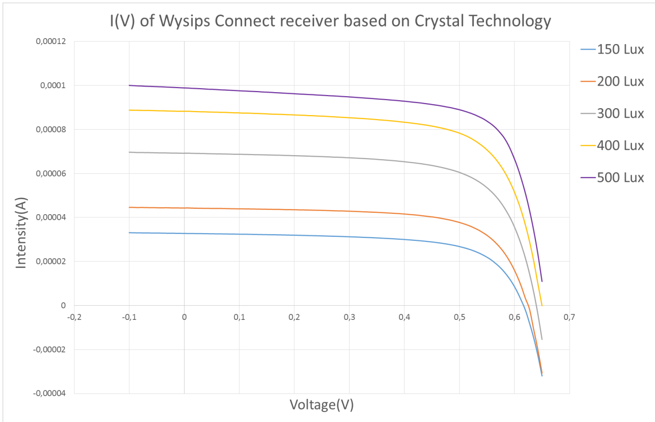
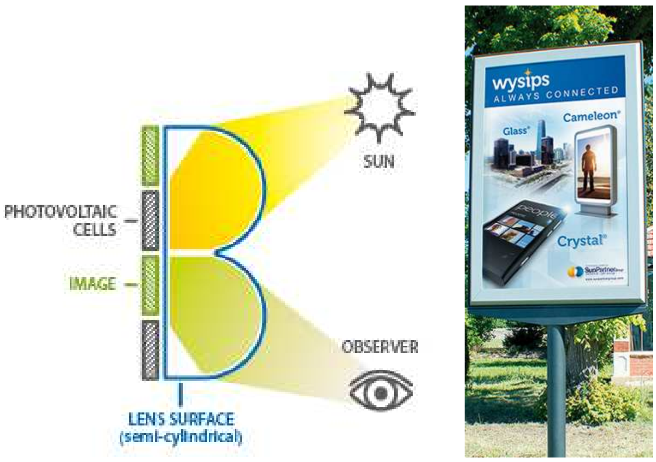


Fig. 2. Wysips®Connect Crystal : indoor I(V)

2.B. Wysips®Connect based on Cameleon/Graphics technology

Wysips®Cameleon combines photovoltaics and optics technology to make PV cells invisible as it can be seen on Fig. 3(a). The component can be integrated to the surface or into structure of any kind of material: metal; wood, plastic, and composites. It allows the display to generate its own electricity, so it can power its own mechanical system, lighting, or any other feature that consumes a lot of energy.



(a) Principle (b) Example

Fig. 3. Wysips®Cameleon principle and example

The Wysips®Cameleon module caracterized is based on CIGS (Copper Indium Gallium Selenide).

Their current-voltage curves are measured in indoor (Fig. 4) and outdoor (Fig. 5) conditions.

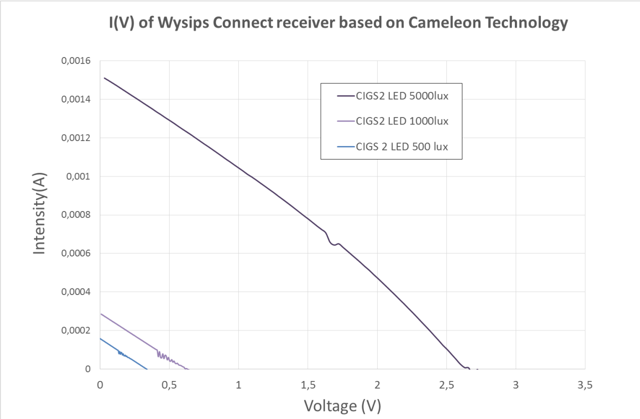


Fig. 4. Wysips®Connect Cameleon : indoor I(V)

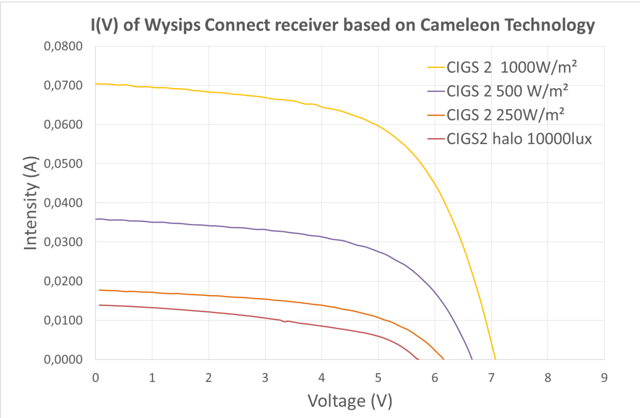


Fig. 5. Wysips®Connect Cameleon: outdoor I(V)

The Graphics technology is a bit different but the PV material is often the same as Cameleon technology. We use this technology to develop Wysips®Connect based on Cameleon/Graphics technology in order to use this kind of device as receiver LiFi. In this paper, we only investigate the LiFi performances of these modules, we do not study the part of energy harvesting.

3. LiFi measurements setup

In order to optimize our LiFi technology, we decided to characterize in details our first Wysips®Connect module based on Crystal or Cameleon technology. That's the reason why we decided to use the LiFi experimental testbed developed at CEA-Leti including both hardware components and proprietary OFDM simulator. This experimental testbed gives a spectral analysis of the complete system in terms of signal and signal-to-noise ratio. The measurements setup is detailed on the next section.

3.A. The LiFi experimental setup

The LiFi is a communication technology using visible light spectrum and light intensity modulation, which implies that only real and unipolar signals can be transmitted in order to allow both lighting and transmission functions. One method to have such signals is to polarize the LED (DC Voltage) before adding an analog bipolar OFDM signal. The experimental setup is shown in Fig 6. The OFDM signal is generated by Matlab with a 64-point FFT and carries 31 subcarriers from DC to 1.2 MHz, 2.4 MHz or 5.6 MHz function of the module capabilities. After a clipping at 80% of maximum value, the signal is then resampled and passed through an anti-aliasing filter. This discrete OFDM signal is sent to an Arbitrary Function Generator (Tektronix AFG 3102) which converts it into an analog signal with a 14-bit DAC resolution. A BIAS Tee (5575 A Picosecond model) then adds this analog OFDM signal to the DC component coming from a traditional constant-current driver limited at 350mA. The resulting AC+DC signal is injected into the LED lamp.

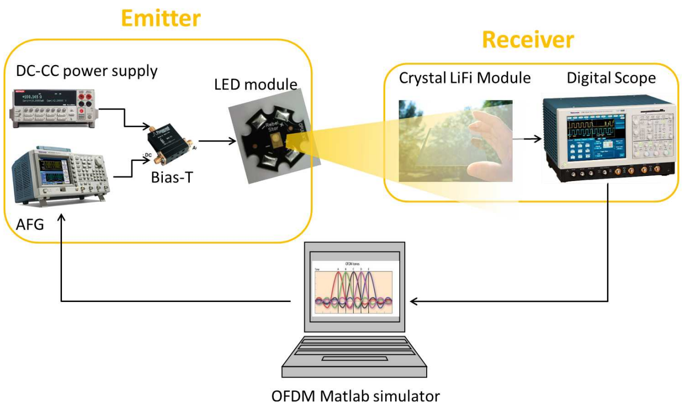


Fig. 6. OFDM LiFi characterization testbed by CEA-Leti

We chose the spotlight Nova Polaris form Novaday (reference ND-MR-003-830-30-DR). At the receiver side, the Hamamatsu C5331-12 photodetector (made of an avalanche photodiode and an integrated transimpedance amplifier) which recovers the light oscillations and removes the DC component, is used as reference receiver. Different kinds of Wysips®Crystal modules are tested. For these modules, the DC component is removed by the Matlab simulator. The receiver module was in front of the LED and aligned to it to ensure the direct line-of-sight between the LED module and the photodetector. The output of the photodetector is then sampled by a digital oscilloscope (Tektronix DPO 7054) triggered by the AFG to emulate a perfect synchronization. The acquisition signal is then sent back to the Matlab simulator to perform data processing for the receiver path. For each frame, both channel estimation and zero-forcing equalization are done. Then the Signal-to-Noise Ratio (SNR) on each sub-carrier is estimated.

3.B. Data rate estimations

The data rate was estimated through the SNR and the spectral efficiency. The CEA Leti's digital processing allows a bit error rate (BER) lower than 10^{-3} if SNR>10dB and a spectral efficiency of **3bit/Hz/s**.

4. Wysips®Connect performances

The performances of receiver depend on several physical parameters of the device but they depend also on the lighting level. In LiFi communication, this issue is critical. If the receiver shows saturation, it deteriorates the signal and thus the transmission is affected. In the best case, only the available data rate decreases. That is why, a LiFi characterization is required to known the environmental conditions under which the receiver operation is possible. We did several experiments through the LiFi experimental testbed to determine this limit for our devices.

When studying the SNR curves vs LiFi method, the saturation conditions of photodetectors must be examined. One possible method is to compare the signal and SNR curves at different distances. A saturation occurs :

- when the distance between transmitter and receiver decreases, the signal curve is equal or lower than signal curves at higher distance.
- when the distance between transmitter and receiver decreases, the amplitude signal curve is equal or lower than signal curves at higher distance.

This saturation could be done :

- when the OFDM signal is to strong (such as too short distance for example),
- when the ambient sources (such as indoor lights, sunlight ...) bring too much DC intensity.

In order to clarify these points, we used the Hamamatsu photodetector as saturation referent photodetector and we compared its performances to two Wysips® modules. In the next figure, Hamamatsu receiver is abbreviated by Ham, and Wysips® Connect Cameleon by Cam.

4.A. Performances VS OFDM signal level

In the first experiment, Wysips®Connect Cameleon Performances was studied against a classical photodetector using LiFi experimental setup to compare their performances at different distances and so for different lighting levels. The results are presented in Fig. 7 and the performances are summarized in table 1 and 2. The Hamamatsu bandwidth allows 5MHz between 2.5m to 25cm. Under this distance, near the source, the performances are deteriorated and under 12cm the receiver can not retrieve the LiFi Signal. Wysips®Connect based on Cameleon technology does not decrease the data rate under 2m and 4 MBit/s are guarantee. If the OFDM signal is upper than 1 equivalent sun, the performances decrease slowly. (10).

Wysips®Connect based on Cameleon technology allows classical HD video streaming.

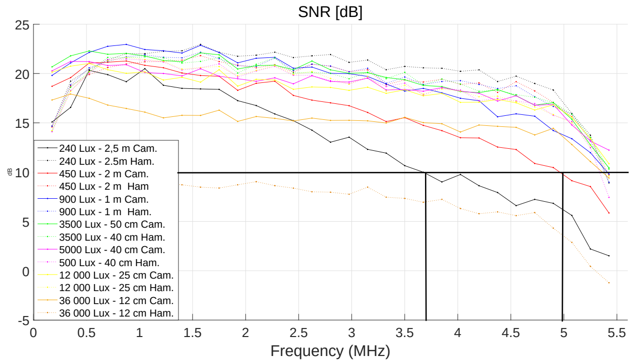


Fig. 7. Comparison between a classical receiver and a Wysips®Connect device

Distance	Lighting	Bandwidth	Data rate
25cm≤D≤250cm	12 000≥D≥240 Lux	5MHz	15 Mbit/s
≤ 12 cm	36 000 Lux	No	0 Mbit/s

Table 1. LiFi Hamamatsu receiver performances

Distance	Lighting	Bandwidth	Data rate
250 cm	240 Lux	3.6 MHz	10.8 Mbit/s
≤200 cm	≥450 lux	5 MHz	15 Mbit/s

Table 2. LiFi Wysips®Connect Cameleon performances

In the next section, the condition of OFDM saturation problematics are studied in detail.

4.B. OFDM saturation problematics

To observe influences of OFDM saturation onto available data rate, we decreased the distance between the OFDM emitter and the receiver in order to increase *OFDM Lux*. We presented the results of Wysips®Connect based on Crystal technology and based on Cameleon technology (the same type of results have been obtained with Wysips®Connect Graphics). In the second experiment, we compared the OFDM saturation effects on Wysips®Connect based on Crystal technology and the Hamamatsu receiver (Fig. 8 and 9). The Hamamatsu SNR decreases rapidly when the OFDM level is larger than 16 000 Lux :

- at 16 000 lux (21.5cm), the bandwidth is around 1.4 MHz,

- at 16 300 lux (21cm), the bandwidth is around 1.15 MHz,
- at 17 800 lux (21cm), the bandwidth is around 0.6 MHz,
- at 20 100 lux (18 cm), there is no bandwidth, so no data rate.

On contrary to, the Wysips®Graphics Connect @ 1,4 MHz does not suffer such OFDM saturations. Until 20 cm (about 18 000 lux), the data rate is not degraded. Under 20 cm, the SNR decreases when the distance decrease, but the SNR is still good and the data rate does not change (if we consider a constant spectral efficiency) until 1 cm that means under 1 Sun OFDM lighting. We did the similar experiment with our Wysips®Connect Cameleon module. We proved that under 169 000 Lux (around 1 equivalent sun in terms of energy), we conserve a minimum of 1.4 MHz bandwidth.

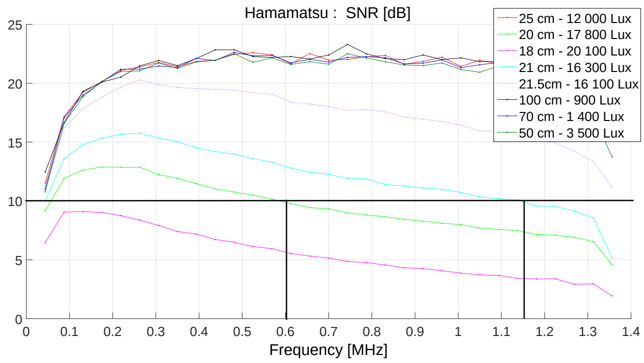


Fig. 8. Hamamatsu receiver and OFDM saturation effects

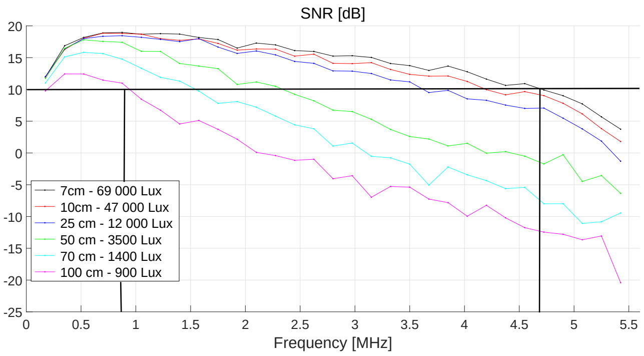


Fig. 9. Wysips®Connect based on Crystal technology and OFDM saturation effects

4.C. Ambient saturation problematics

In this experiment, we added a huge constant ambient signal produced by a LED downlight Nova Atria Direct R170 to an OFDM LiFi signal about 1900 lux. We

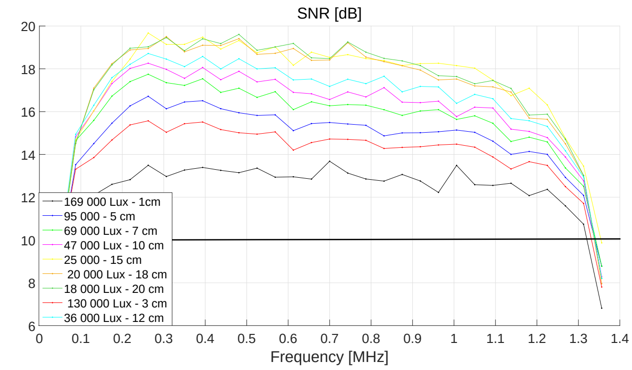


Fig. 10. Wysips®Connect based on Cameleon technology and OFDM saturation effects

showed the DC saturation of the Hamamatsu in comparison with the non-DC saturation of Wysips® module. Even if we presented only the Wysips® Connect Cameleon results, the results are the same for all kinds of Wysips® modules. The Hamamatsu delivers a LiFi signal until 19 000 lux DC. If the ambient lighting is upper than 19 000 lux, the Hamamatsu LiFi signal decrease. In terms of communication, the data rate is divided by a factor 2.5 if the ambient lighting is about 32 000 lux. The Hamamatsu receiver does not retrieve LiFi signal if the ambient lighting reaches about 50 000 lux. On the contrary, the Wysips® Cameleon Connect is not affected by the ambient lighting until 50 000 lux as it shown on Fig: 11.

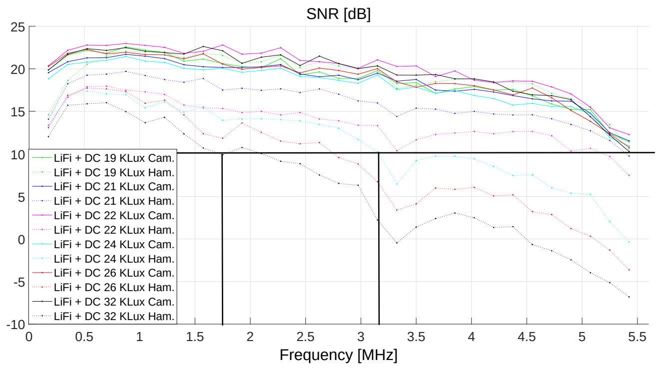


Fig. 11. Ambient saturation effects on receivers

5. Conclusion

This paper presents experimental investigations on the possibility of using Wysips®Connect Crystal/Graphics/Cameleon module in a LiFi OFDM system under different lighting environment. The available bandwidth of the Wysips®Connect Crystal is about 1 MHz and allows data rate of up to 3 Mbit/s. The available bandwith of the Wysips®Connect Cameleon/Graphics is about 5 MHz and allows data rate of up to 15 Mbit/s until 2.5 m corresponding to 240 Lux OFDM. We proved that these modules are not affected by lighting saturations in opposite to classical photoreceivers. They do not deteriorate signal both in strong OFDM lighting and strong ambient lighting as in full sun. Wysips®Connect Crystal/Graphics/Cameleon modules are high LiFi performance receivers and present great advantages in comparison with classical photodiode. It can be included on any surface, it is thin, omnidirectional and energy sufficient. To the best of our knowledge it is the only receiver which does not degrade LiFi signals when it works in full sun condition. In addition to communication, the feasibility of energy harvesting of this type of communication system is under investigation in our Laboratory. The aim is to optimize LiFi data rate and energy harvesting in the same time both in indoor and outdoor environments.

Acknowledgment

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