FROM RESEARCH TO INDUSTRY

cea tech

Leti

LIFI AT LETI

MARTIN GALLEZOT

23 NOVEMBRE 2015

LETI KEY FIGURES

- **CEA Institute founded in 1967**
- **Director : Dr Marie-Noëlle Semeria**
- **1,800 collaborators**
  1,270 permanent staff
  250 PhD + 40 post-doc, 37% foreign students
- **2800 patents**
  311 registered in 2014
  40% under licensing
  680 publications per year
- **Budget : 318 M€**
  CapEx: 39 M€
  80% from external revenue
- **8,500 m² clean rooms**
  For 200 and 300 mm wafer fab, operated 24/7

LETI WITHIN CEA

- **16 000 collaborators**
  - 10 % PhD and post-doc
- **10 research centres**

Nuclear Energy Division

Defence and Security Division

Technological Research Division

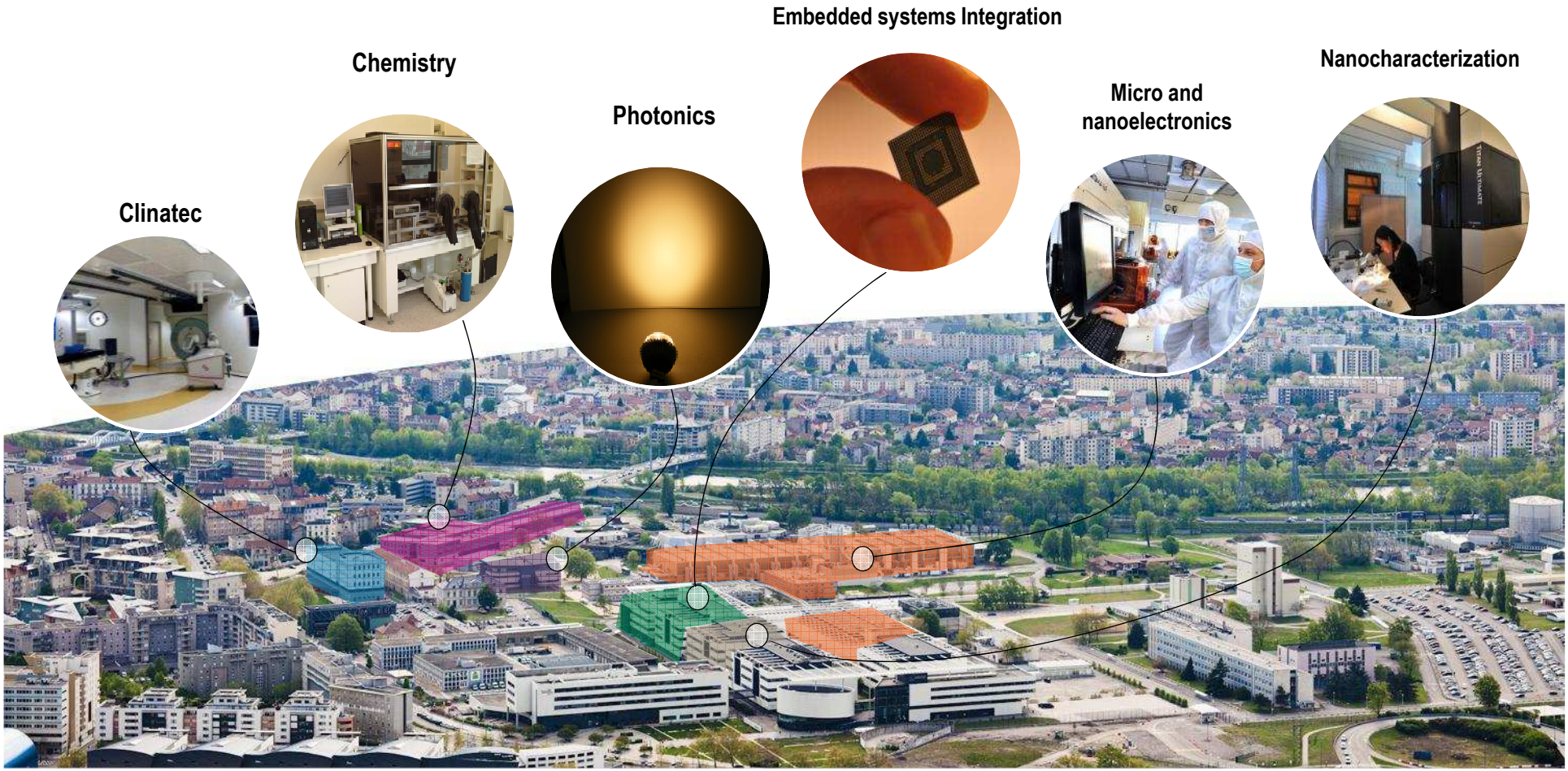
leti Electronic and information technologies

liten New Energies

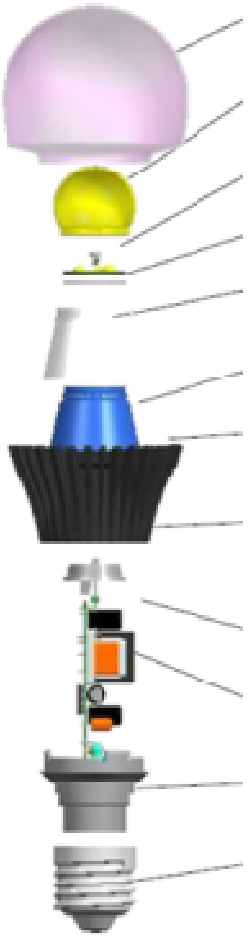
list Software

Basic Research Division (Life sciences and Physical sciences)

OUR RESEARCH PLATFORMS



Mastering technology combination… makes the difference!



Optics

Color conversion

LED

Heat sink

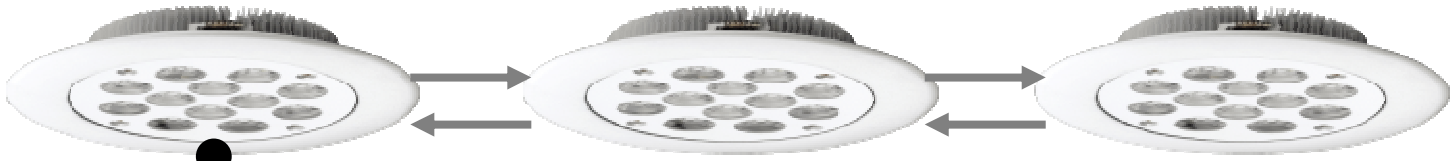
Electronics

Power

Assembly

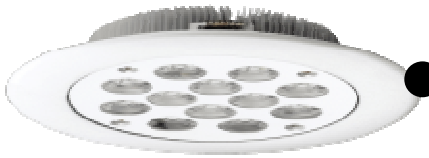
Digital Light Era

FROM LED TO SMART LIGHTING



Lighting systems

- Luminaire network
- Communication: *luminaire to luminaire, luminaire to building…*



Luminaire

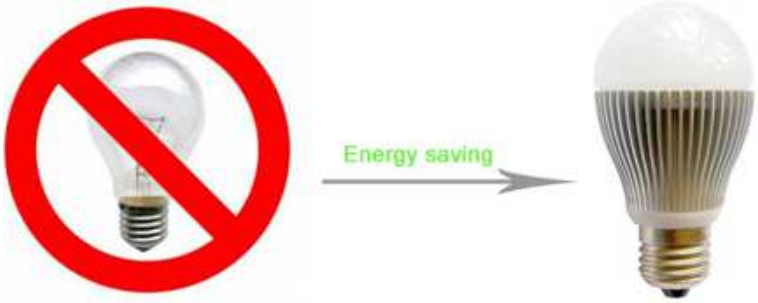
- Light source
- Optics : *no glare, beam quality, flux, efficiency…*
- smart sensors integrated: *presence, ambient light, activity, time...*
- Driver, dimming, CCT adjustment…
- Communication means

- LED chip
- Heat management
- Smart devices

LED

A REAL OPPORTUNITY FOR VLC

RF spectrum saturation and growing demand



LEDification in progress

SSL offers a dense network

- In every place
- A strategic position
- Energy for free

(SOME) ADVANTAGES OF LIFI

- Transmission with no RF emission
- No sensitivity to RF interferences
- Will benefit from LED massive deployment: 70% of lighting market in 2020
- Security: walls block LiFi signals
- “You see what you get” effect

APPLICATIONS

Hospitals

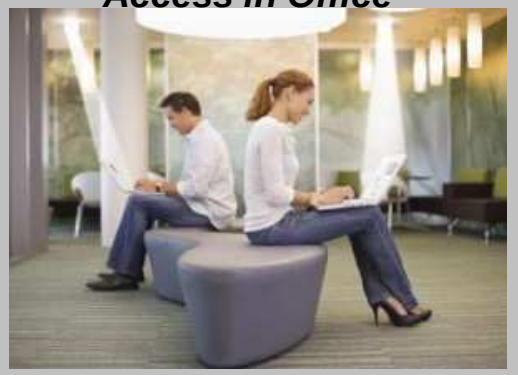
Aeronautic

Retail/Museums

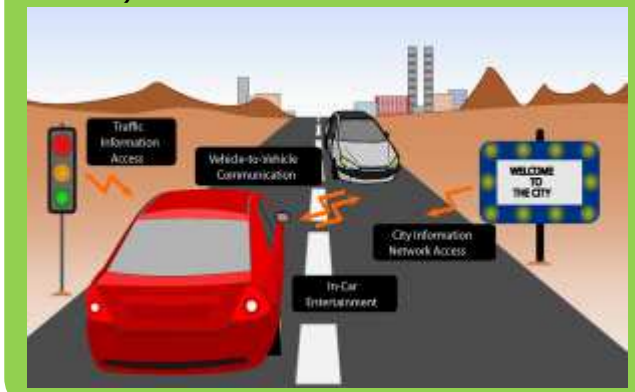
Indoor GPS

Home high data rate access

Access in Office



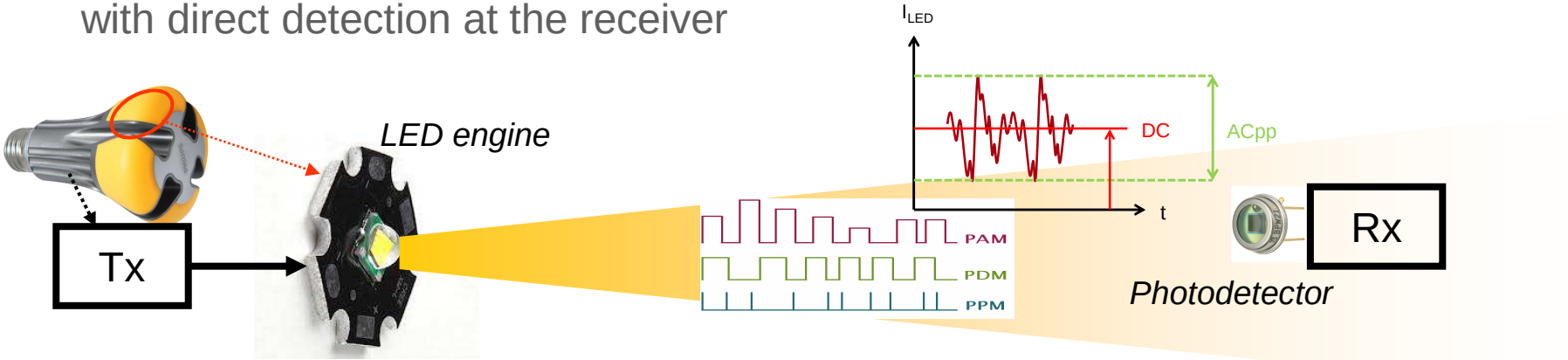
V2V, V2Infra communications



Pour transmettre des données en LiFi, une LED posée au plafonnier et un capteur intégré à la tablette suffisent. © PSA Peugeot Citroën

Intensity Modulation on LED forward current

- LiFi uses a real baseband signal to achieve intensity modulation on LED current with direct detection at the receiver

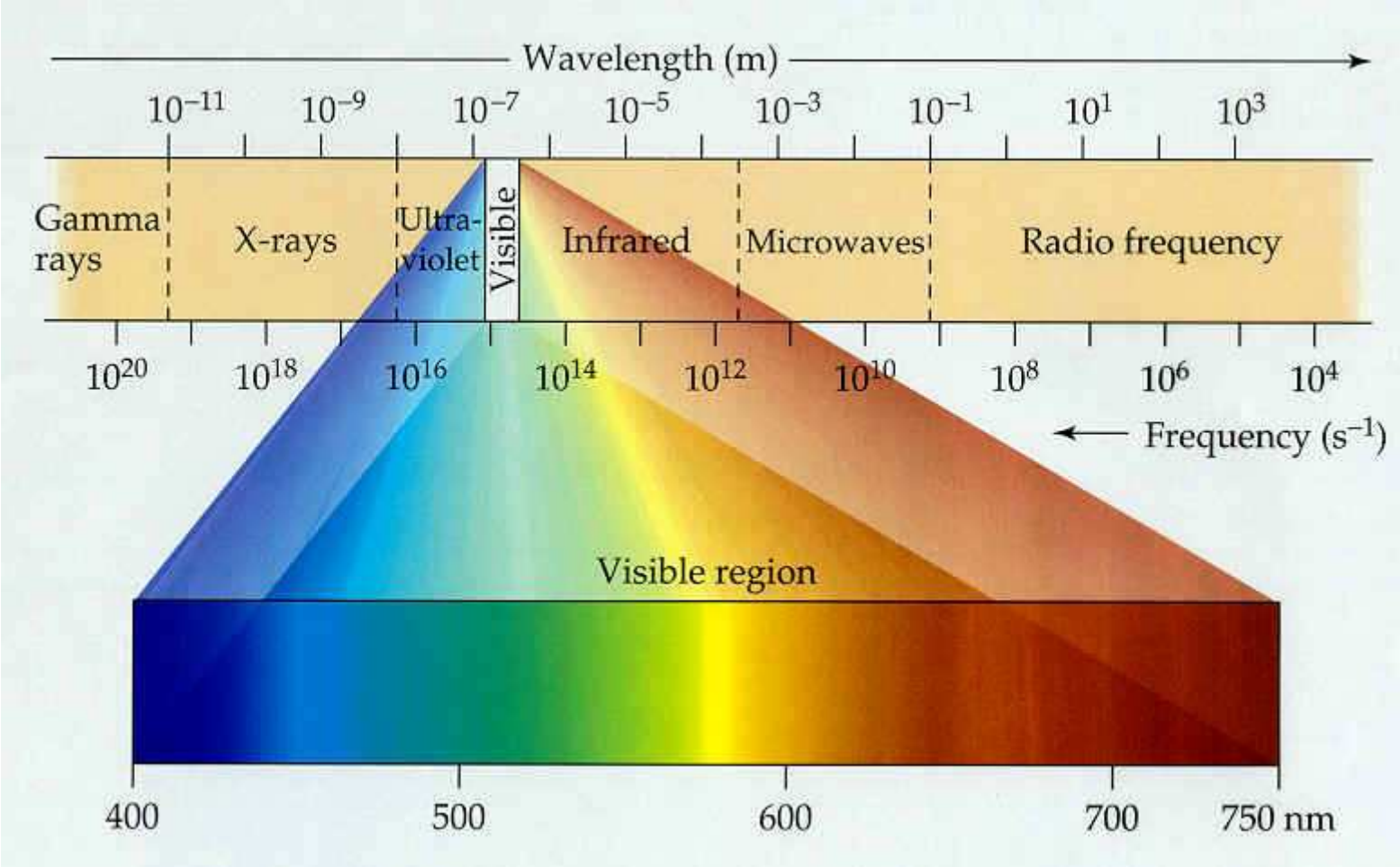


- Goal: use good properties of LED to be modulated at high frequency to transmit information at very high data rate and/or high ranges

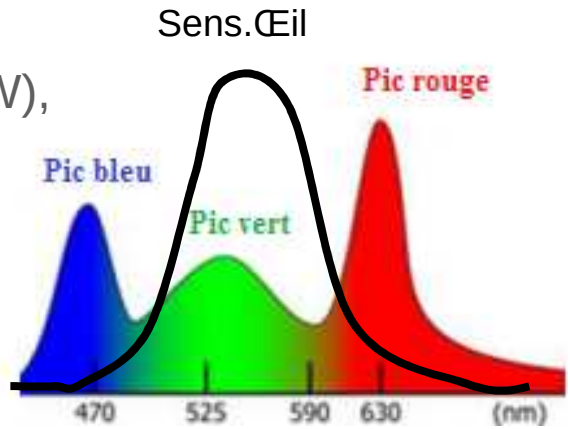
- Digital modulations
  - OOK, NRZ, …
  - Pulse: PAM, PPM, PWM,…
  - CSK
  - Multi-Carrier modulation: OFDM, DMT, …

- Standardization (IEEE 802.15.7): no multi-carrier waveform up to now

Intensity Modulation on Visible Spectrum



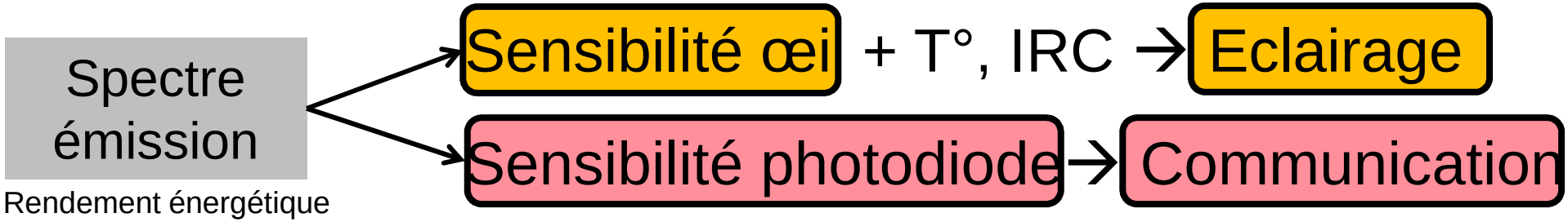
- **R. lumineux des LEDs monochrom.:**
  - Faibles pour les LED bleu (30lm/W) et rouge (50lm/W), élevé pour les LED vertes (100lm/W):
    L'œil a un pic de sensibilité dans le vert (555nm)



Rendements énergétiques

- **R. lumineux des LED blanches:**
  - Dans le commerce: entre 50 et 130lm/W
  - En labo: 200lm/W
  - Limite théorique (1W $_{élec}$ →1W$_{opt}$): 250lm/W

- **Eclairement: Lux = lumen / m², densité spatiale de puiss.**



Rendement énergétique

2 façons de produire un éclairage à LED blanc:

- LED bleue + Luminophore
  - Avantage: utilisation du fort rendement énergétique du bleu
- LED RGB/RGBA
  - Avantage: pas de luminophore (dégradation par vieillissement)

LEDs RGBA minoritaires car:

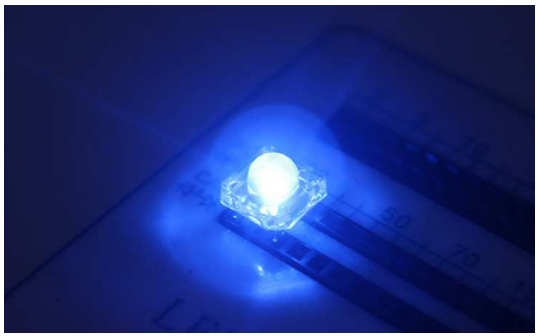
- Coût > au bleu+P car hybridation de LED de matériaux diff. (GaP, GaS, GaN,…)
- Blanc difficilement maintenable en temps et en T° (rendements variables)

LEDs bleu+P majoritaires car:

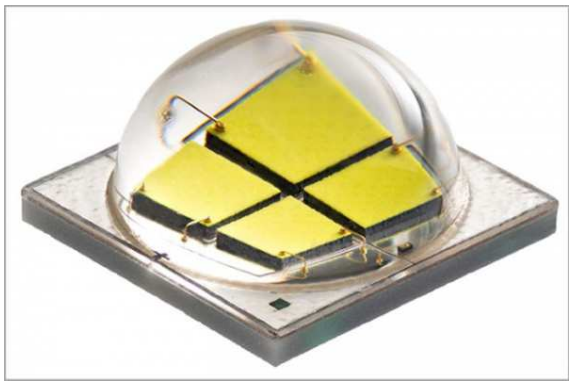
- Loi de Haitz: performances doublées tous les 3 ans (voire 2 ans)
  - Mais la fin est là: limite labo 200lm/W, limite théorique 250lm/W (blanc)
- Prix divisé par 10 tous les 10 ans.

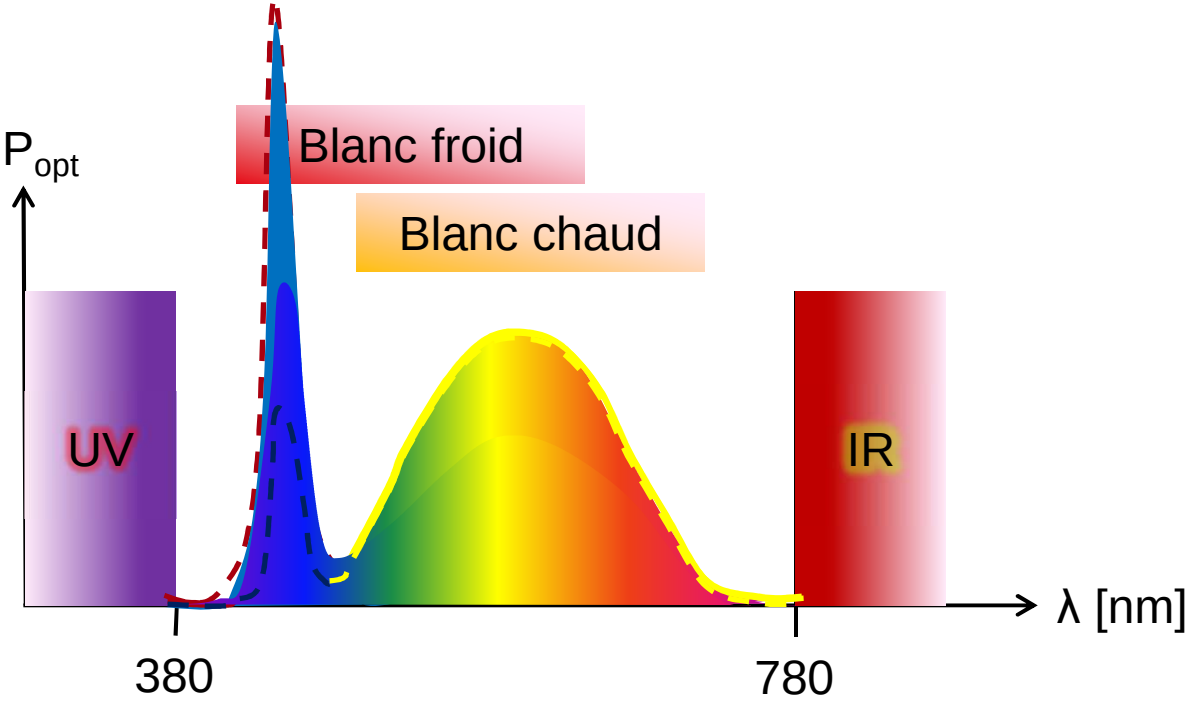
LED WHITE LIGHTING

LED bleue



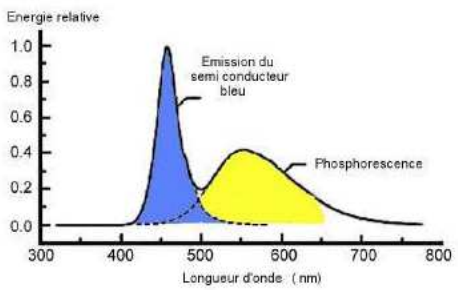
LED bleue + P

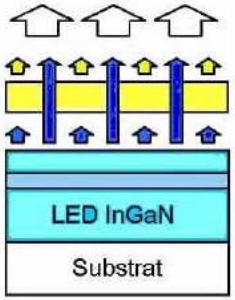




Impact du Luminophore:

- Une partie des photons bleus est modifiée par le luminophore pour faire des photons jaunes:
  - Modulation carrée → les photons observés à cette longueur d'onde ont des fronts beaucoup plus lents (temps d'absorption, ré-émission,…)
- Les photons bleus qui traversent le luminophote gardent des fronts très rapides

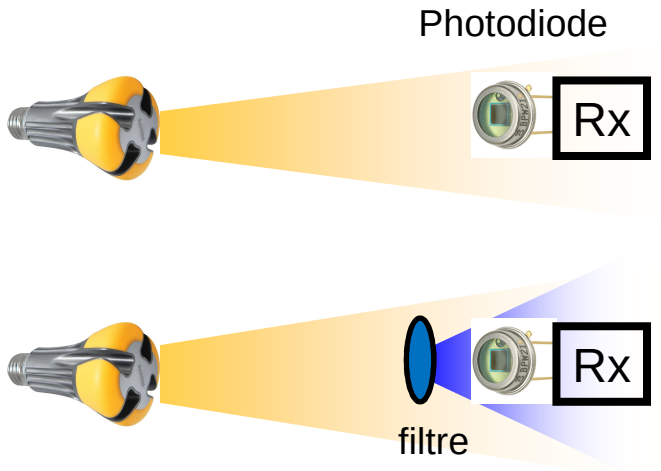




Conséquence à la réception, derrière une photodiode (PD)

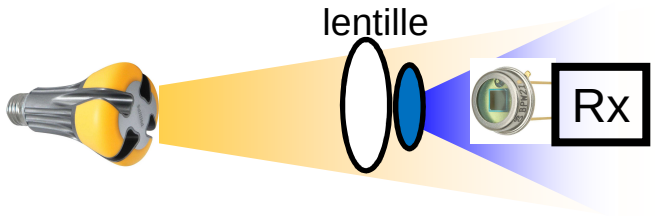
- En observant toute la lumière blanche
  → BW_{-3dB} = 2 à 3MHz seulement

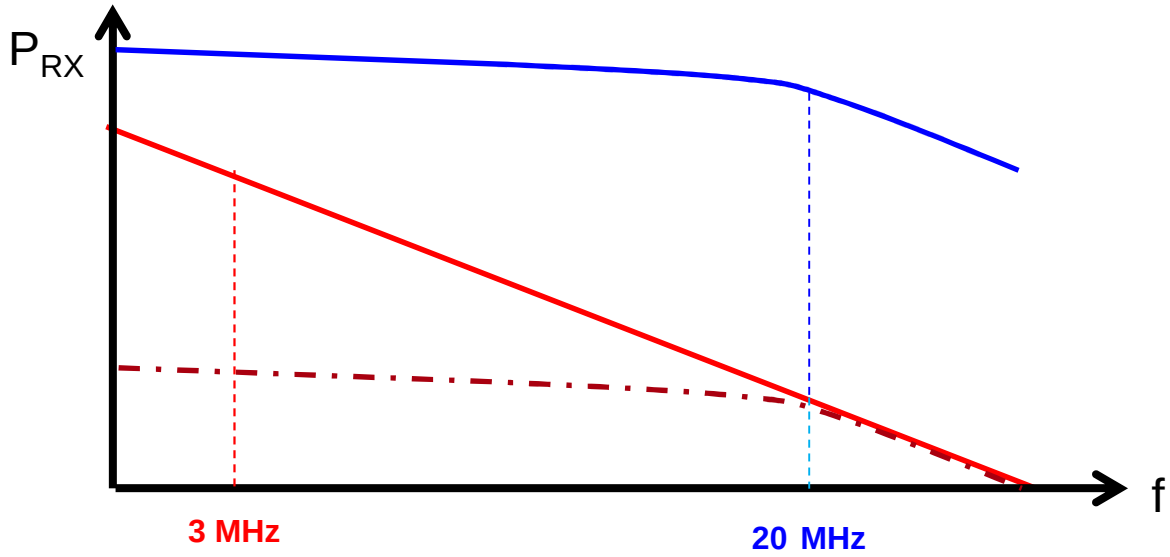
- En filtrant dans le bleu
  → BW_{-3dB} = 14 à 20 MHz,
  MAIS seulement 10 à 50% du signal



Avantage:

- Profiter de la bande passante du bleu tout en éclairant au maximum la PD





Inconvénients:

1. Forte directivité : alignement Rx→Tx requis
2. Encombrement mécanique
3. Pas de profondeur de champ → perte par variation de portée

IEEE 802.15.7

PHY I

Modulation	RLL code	Optical clock rate	FEC		Data rate
			Outer code (RS)	Inner code (CC)	
OOK	Manchester	200 kHz	(15,7)	1/4	11.67 kb/s
			(15,11)	1/3	24.44 kb/s
			(15,11)	2/3	48.89 kb/s
			(15,11)	None	73.3 kb/s
			None	None	100 kb/s
VPPM	4B6B	400 kHz	(15,2)	None	35.56 kb/s
			(15,4)	None	71.11 kb/s
			(15,7)	None	124.4 kb/s
			None	None	266.6 kb/s

PHY II

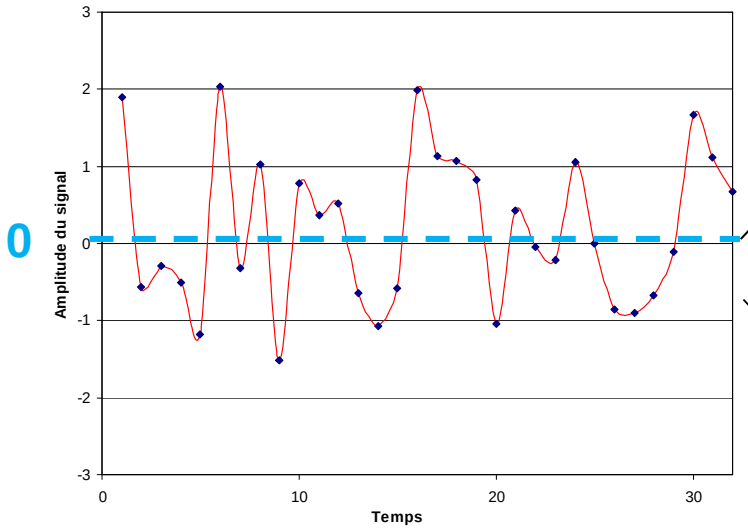
Modulation	RLL code	Optical clock rate	FEC	Data rate
VPPM	4B6B	3.75 MHz	RS(64,32)	1.25 Mb/s
			RS(160,128)	2 Mb/s
		7.5 MHz	RS(64,32)	2.5 Mb/s
			RS(160,128)	4 Mb/s
			None	5 Mb/s
OOK	8B10B	15 MHz	RS(64,32)	6 Mb/s
			RS(160,128)	9.6 Mb/s
		30 MHz	RS(64,32)	12 Mb/s
			RS(160,128)	19.2 Mb/s
		60 MHz	RS(64,32)	24 Mb/s
			RS(160,128)	38.4 Mb/s
		120 MHz	RS(64,32)	48 Mb/s
			RS(160,128)	76.8 Mb/s
			None	96 Mb/s

PHY III

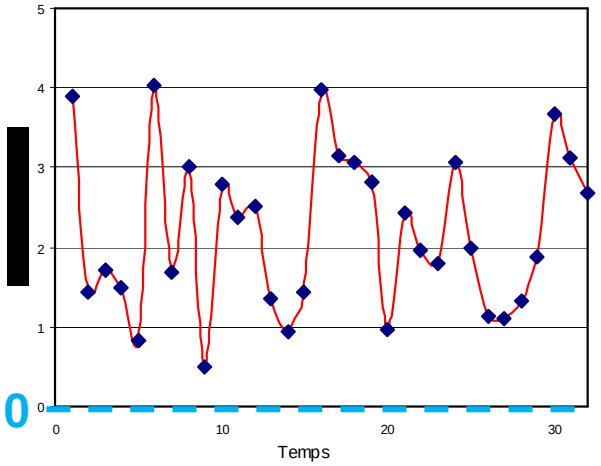
Modulation	Optical clock rate	FEC	Data rate
4-CSK	12 MHz	RS(64,32)	12 Mb/s
8-CSK		RS(64,32)	18 Mb/s
4-CSK	24 MHz	RS(64,32)	24 Mb/s
8-CSK		RS(64,32)	36 Mb/s
16-CSK		RS(64,32)	48 Mb/s
8-CSK		None	72 Mb/s
16-CSK		None	96 Mb/s

OFDM INTENSITY MODULATION

OFDM « RF »



DCO - OFDM

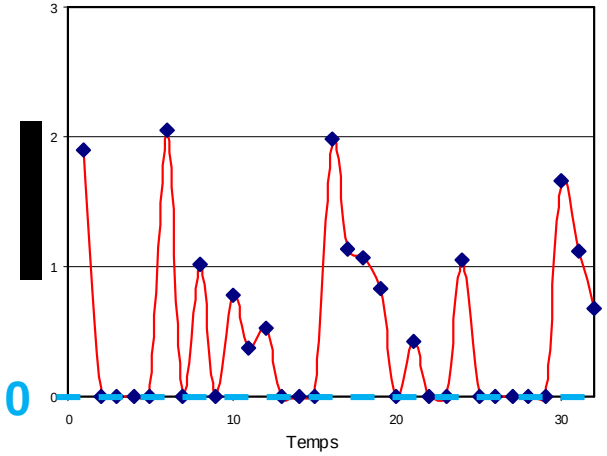


☺ Débit

☹ Amplitudes limitées

(☹ P élevée)

ACO - OFDM

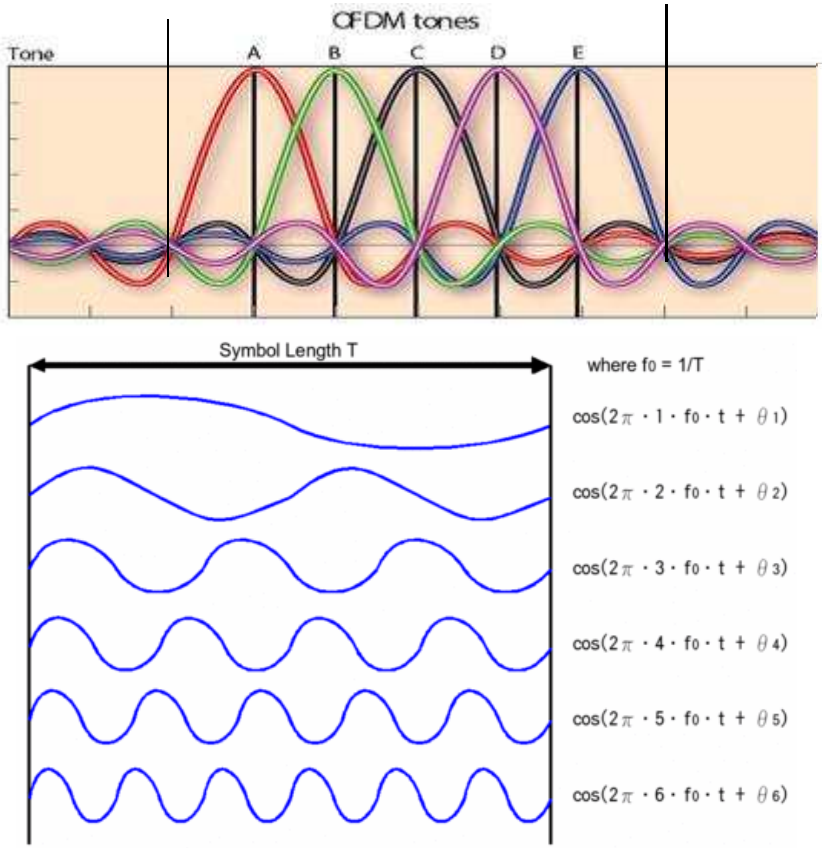


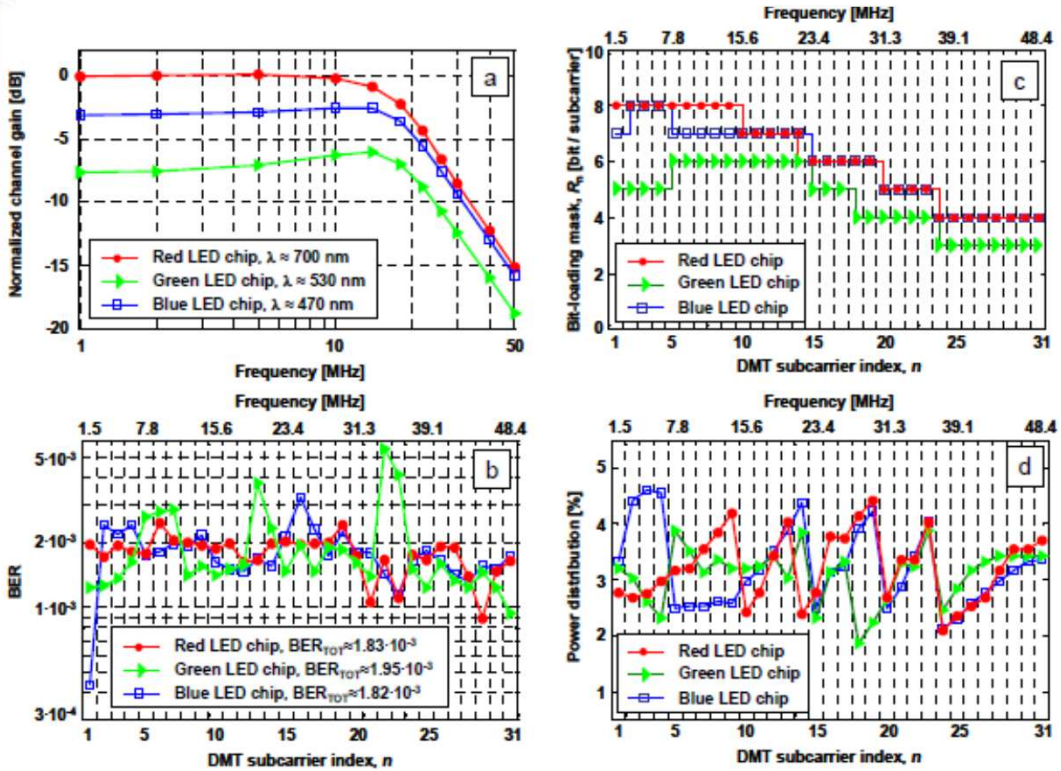
☹ Débit / 2

☺ Amplitudes maximales

(☺ P minimale)

OFDM + Bit & Power Loading:





Driver de LED non LiFi:

- Régulation du courant DC
- Dimming :
  - majoritairement « digital » par PWM, car plus linéaire
    → PWM > 400Hz (pour rentrer dans les gabarits de flickering: <1% entre 1 et 400Hz)
  - certains analogues: AM, CCR

Driver LiFi:

- SC: prendre en compte le flickering
- OFDM: Définir un clipping et profondeur de modulation:
  - Non Linéarités des LED
  - Accélération du vieillissement des LED

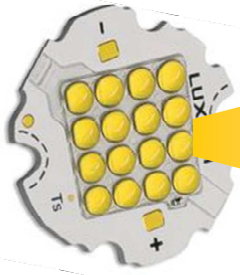
LIFI CHARACTERISATION TESTBED

Power supply

Arbitrary generators

Coupler,
Bias-T

LED engine

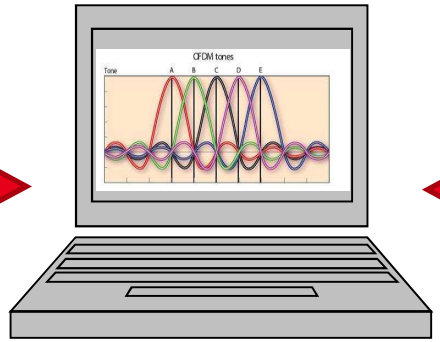


Photodiodes

Filters,
lens

Oscilloscopes

Analyzers

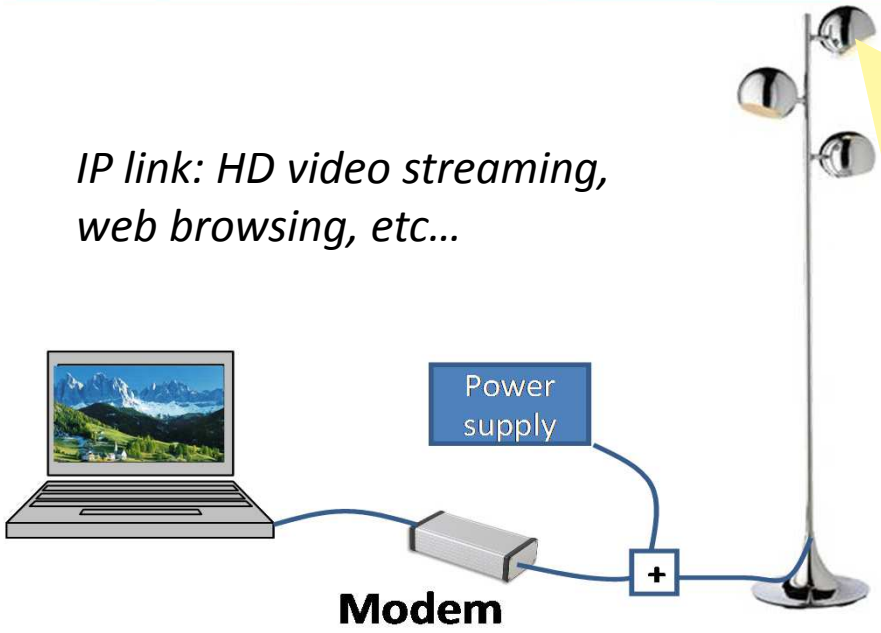


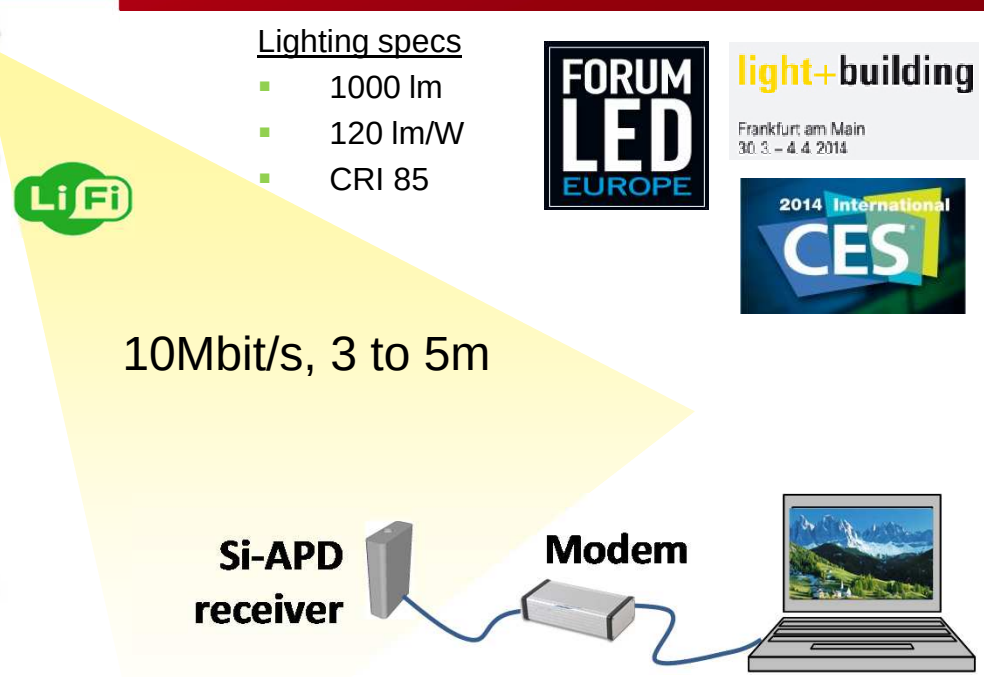
- Optical Hardware qualification
- Optical propagation channel analysis
- Algorithms with hardware-in-the-loop

Software-based modems
with spectral analysis (signal, SNR)

FIRST CEA-LETI'S HW DEMONSTRATOR

IP link: HD video streaming, web browsing, etc…





Lighting specs

- 1000 lm
- 120 lm/W
- CRI 85

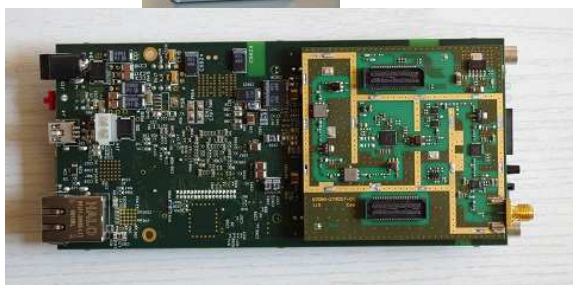
FORUM LED EUROPE

light+building Frankfurt am Main 30.3. – 4.4.2014

2014 International CES

Modems (FPGA+ARM) (Q1 2014)

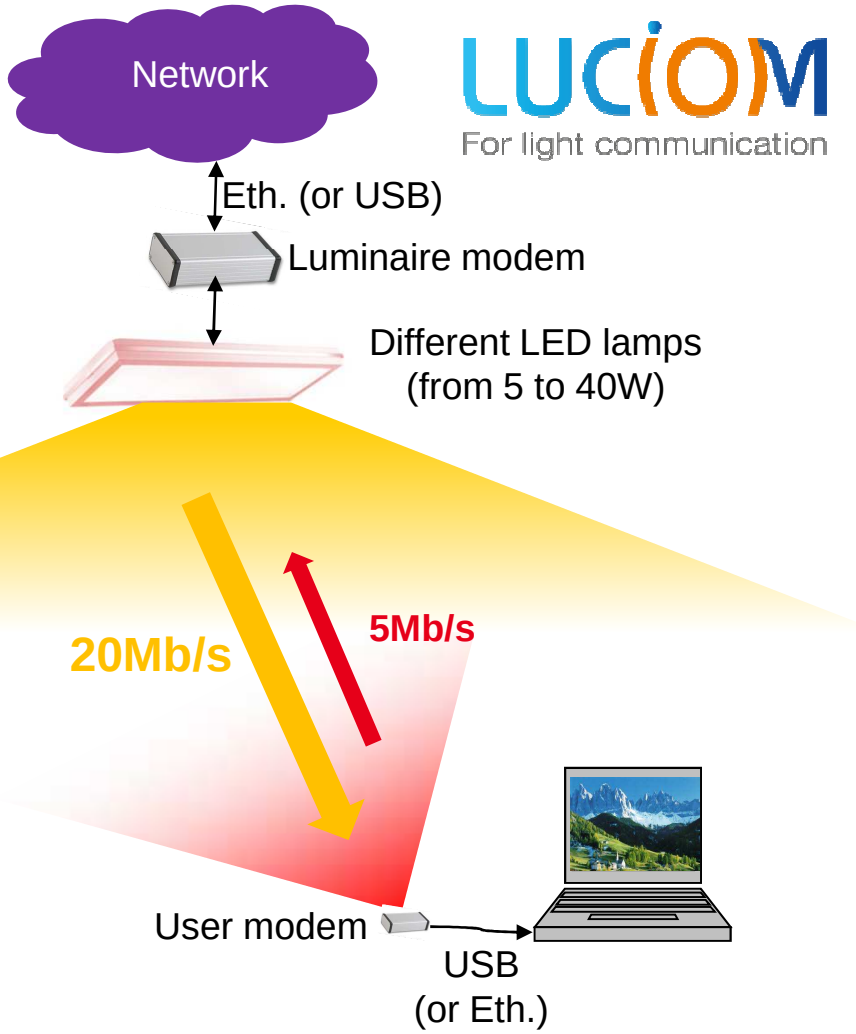
- Multicarrier waveform – 8MHz BW
- QPSK up to 64 QAM modulation
- Synchronization, AGC, channel equalization, ….
- Up to 30 Mbps (64-QAM 3/4)



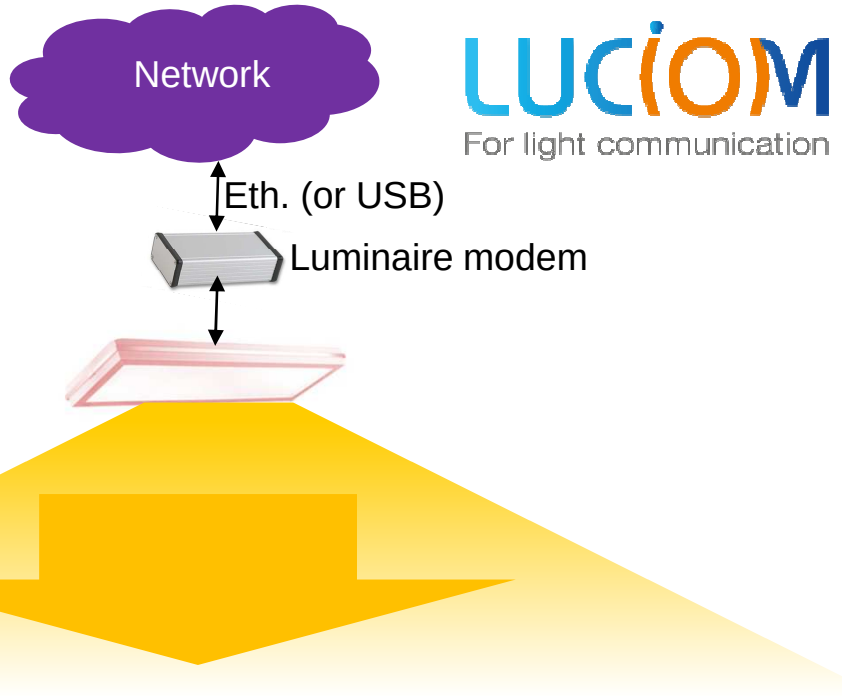
1ST VERSION OF LIFI HIGH DATA RATE MODEM (AVAILABLE AS POC, JULY 2015)

Current LiFi HDR modem specs:

- **Full IP transparent link to the network**
- **Plug-&-play connection**
- **Good mobility, large FoV**
- **20Mb/s downlink at 3m**
- **5Mb/s uplink (infrared spectrum)**
- **I/O interfaces: Ethernet or USB**
- **Support of different kinds of luminaires**
- **Reduced consumption:**
  - USB power supplied at user side
  - About 2.5W (500mA at 5V)
- **Form factor:**
  - 8x8x3cm at user side:

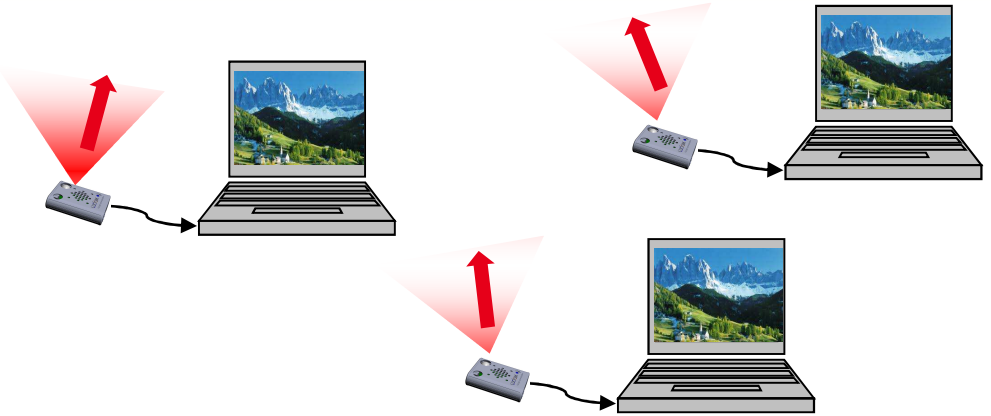


2ND VERSION OF LIFI HIGH DATA RATE MODEM (END OF 2015)



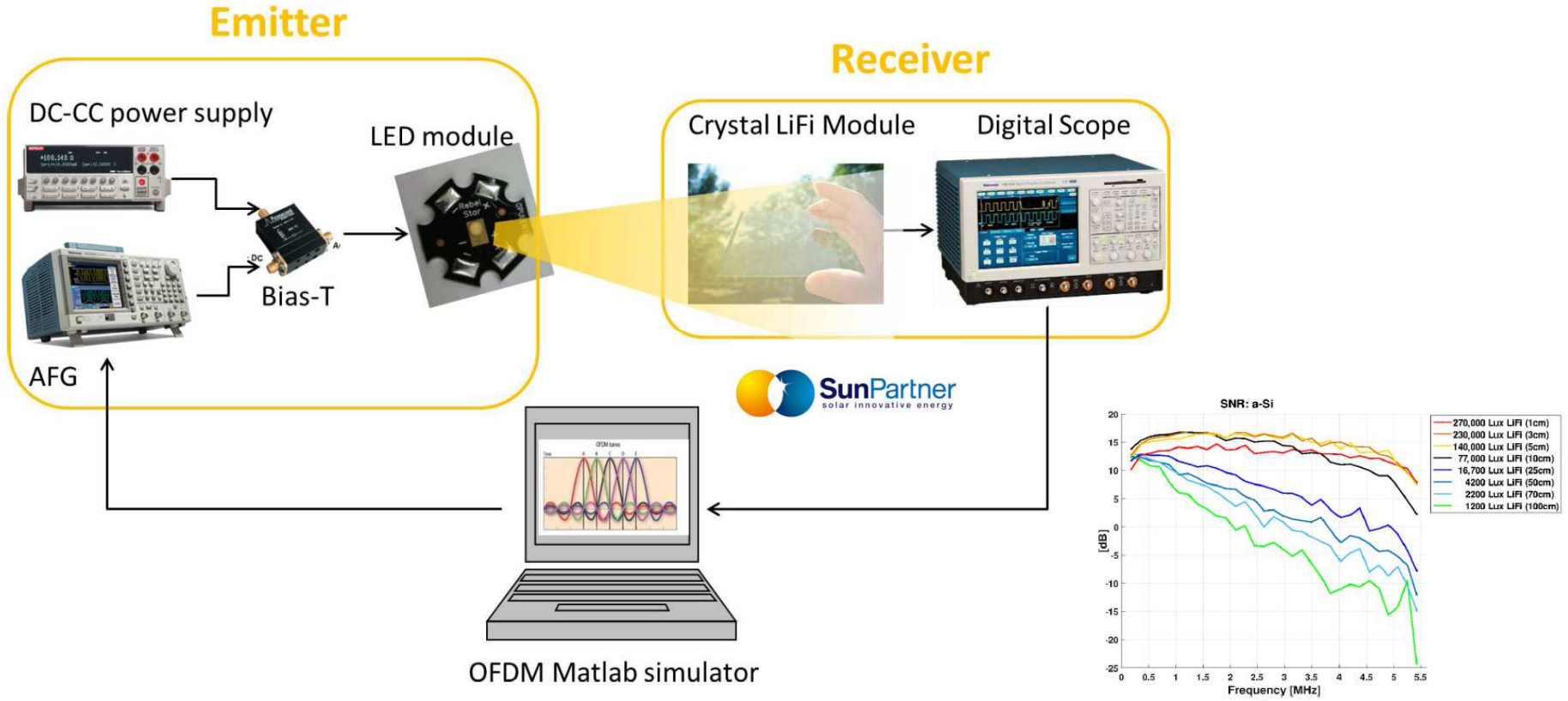
- **Multiple Access functionality:**
  - Up to 15 users per lamp
  - Adaptive throughput per user

- **Reduced form factor:**
  - 70x45x17mm at user side



COLLABORATION WITH SUNPARTNER TECHNOLOGIES

→ Indoor/Outdoor VLC High Data Rate Reception Using Semi-Transparent Photovoltaic Modules



REMAINING CHALLENGES

Communication

- Uplink performances: above 10Mbps
- Downlink performances: above 100Mbps
- Single Point to Multi point
- Multipoint to Single point
- MIMO
- Channel Interferences
- Throughput / Range
- Dimming compatibility
- Backhaul

Optical

- Eye safety, flickering
- Keep good IRC: color rendering, temperature
- Maintain life span of LED
- Work on RGBA Tx and Rx
- Work on components (high speed LED in AsGa,…)