COST Action IC1101 - OPTICWISE:

shaping the future of Optical Wireless Communications

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With sincere acknowledgement of

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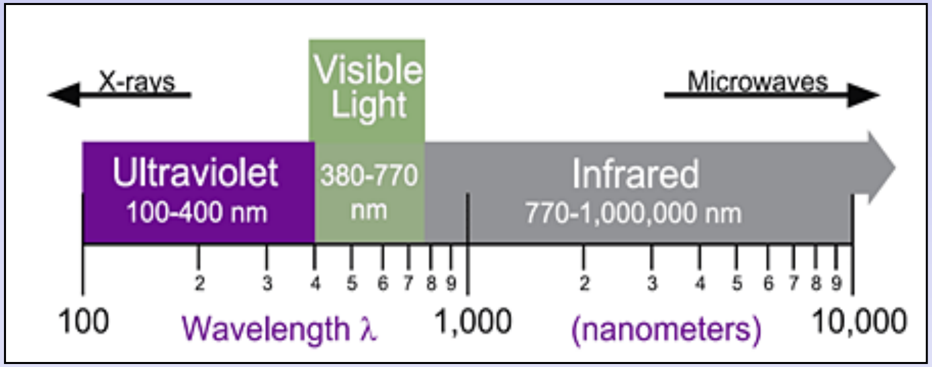
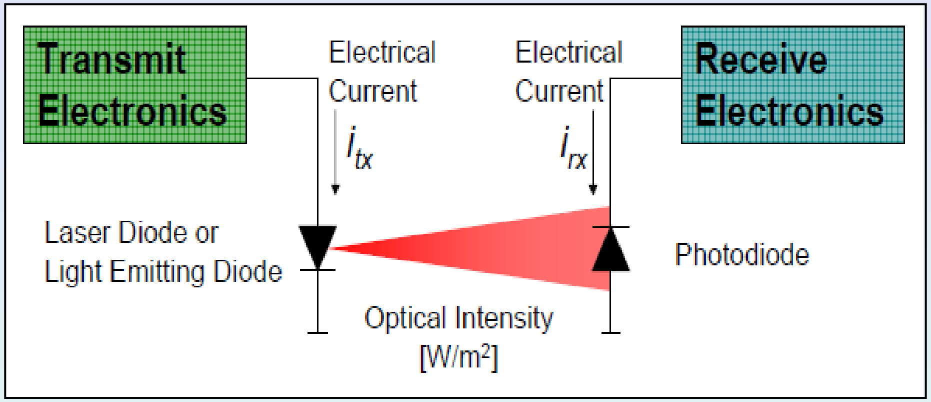
Outline

- **Optical Wireless Communications**
  - History
  - Advantages
  - Applications
- ***OPTICWISE***
  - Objectives
  - Strategies
  - Scientific Scope
  - Working Groups
  - Special Interest Groups
  - Dissemination Activities
- **Examples of work done within *OPTICWISE at Warwick University***
  - Free space
  - Underwater
  - In vehicles – automotive, and otherwise.
  - 3D optoelectronics

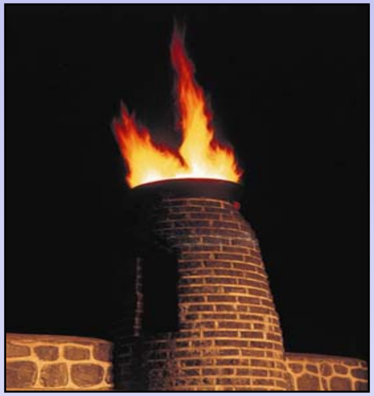
Optical Wireless Communications (OWC)

- **OWC:** Wireless (unguided) transmission through the deployment of optical frequencies
  - Infrared (IR)
  - Visible (VL)
  - Ultraviolet (UV)
- Intensity Modulation/Direct Detection (IM/DD)
- Amplitude constraints
  - Non-negativity of the signal
  - Eye-safety regulations



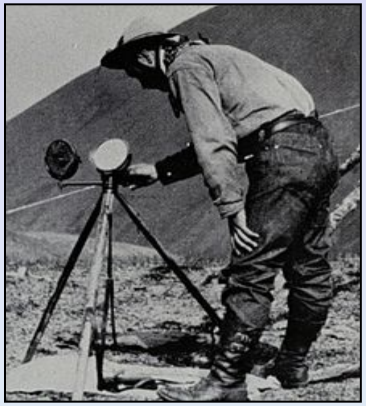


OWC History

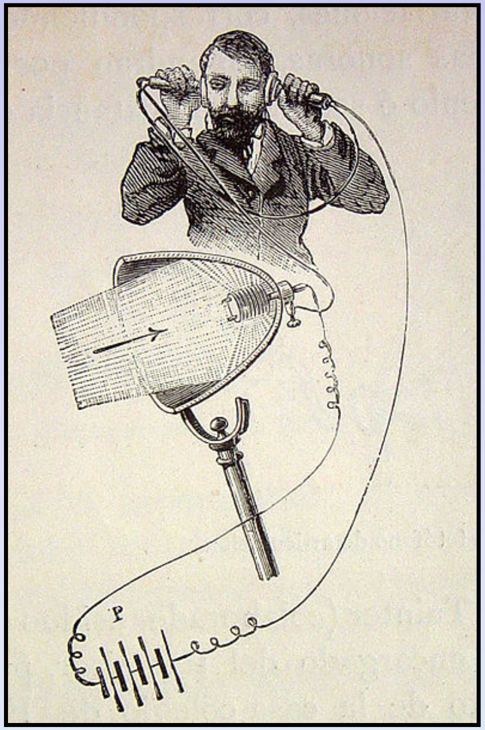
- The use of sunlight
  - **Heliograph** (*Information delivery using the mirror reflection of sunlight*)
- The use of fire or lamp
  - **Beacon fire**
  - **Lighthouse**
  - **Signal lamp for ship-to-ship communication**

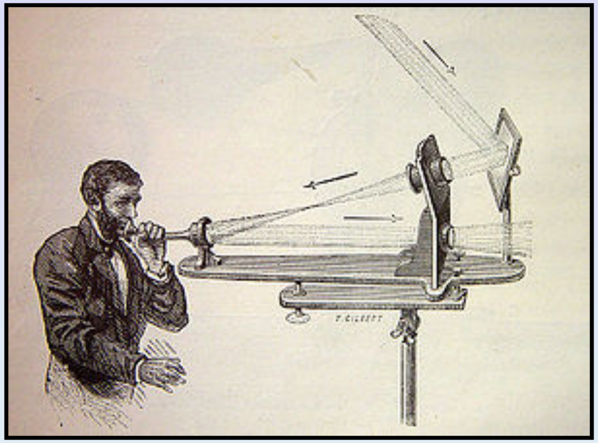




OWC History

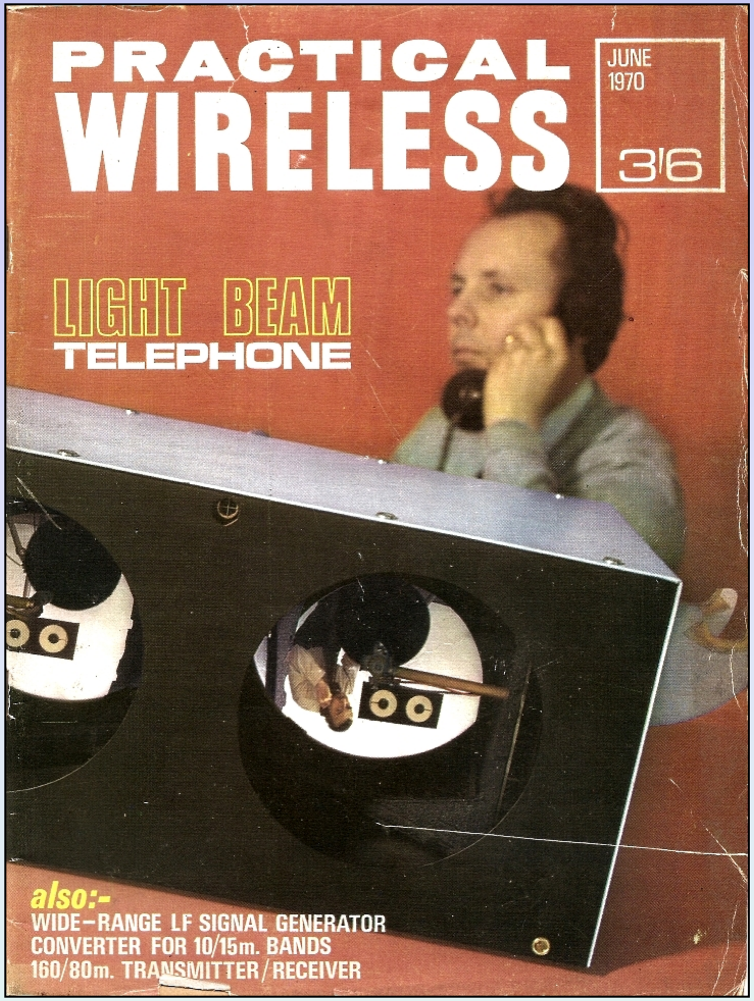
- **Graham Bell's "Photophone" (1880)**
  - First wireless phone message
  - Optical source: Sunlight
  - TX: Vibrating mirror   RX: Parabolic mirror
  - Distance: 700 ft (213m)



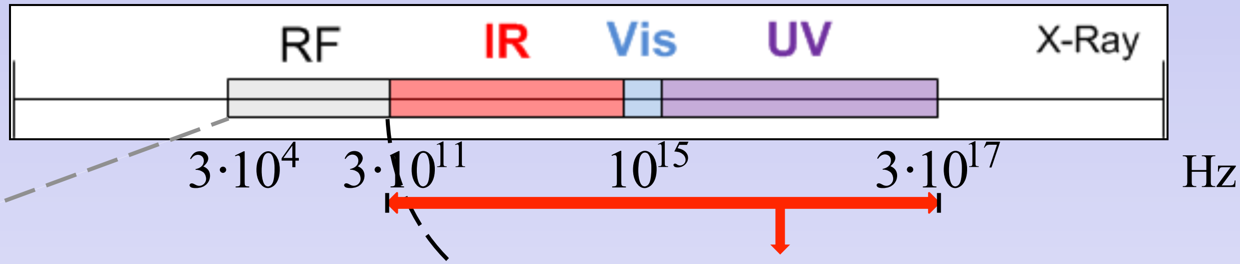


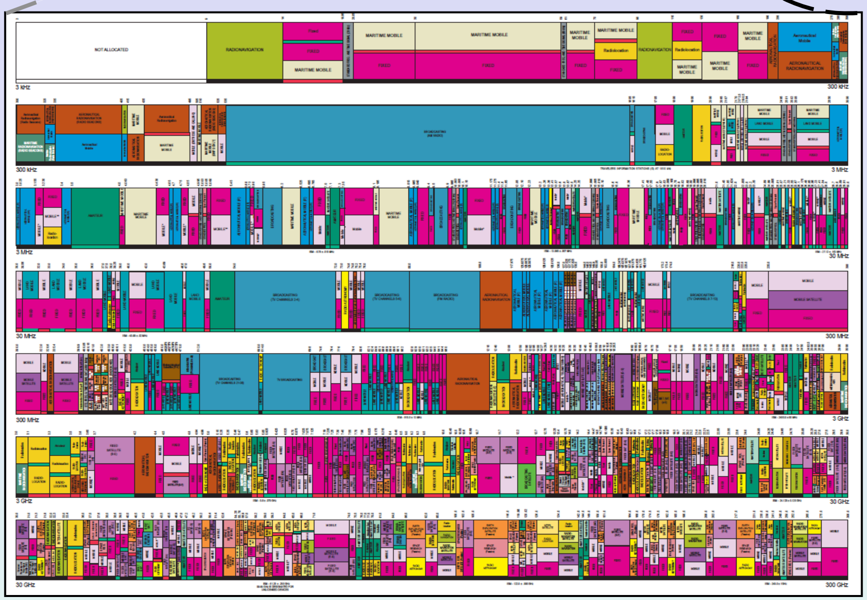
- In his writings, Bell referred to the Photophone as *"the greatest invention [I have] ever made, greater than the telephone".*

Even when I was in my teens I was interested in optical wireless …. !



OWC - Advantages

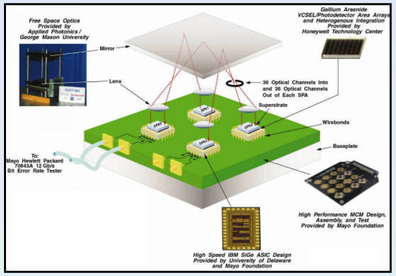


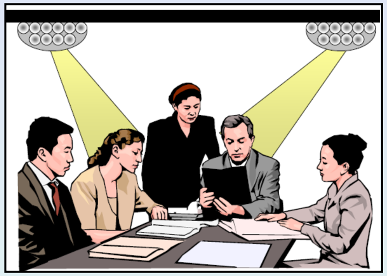


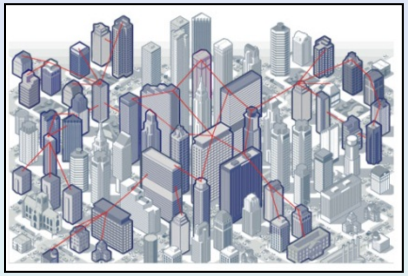
- Large bandwidth capacity
- High degree of spatial confinement
  - High reuse factor
  - Inherent security
  - Lower power requirements
  - Robustness to EMI
- Unregulated spectrum
- Easy-to-install, and also redeployable

OWC - application areas

- Depending on the intended application, OWC can serve as a powerful alternative, complementary or supportive technology to the existing ones : -
  - **Ultra-short range** (e.g., optical circuit interconnects)
  - **Short range** (e.g., WBAN, WPAN)
  - **Medium range** (e.g., WLAN, VANET)
  - **Long range** (e.g., inter-building connections)
  - **Ultra-long range** (e.g., satellite links)



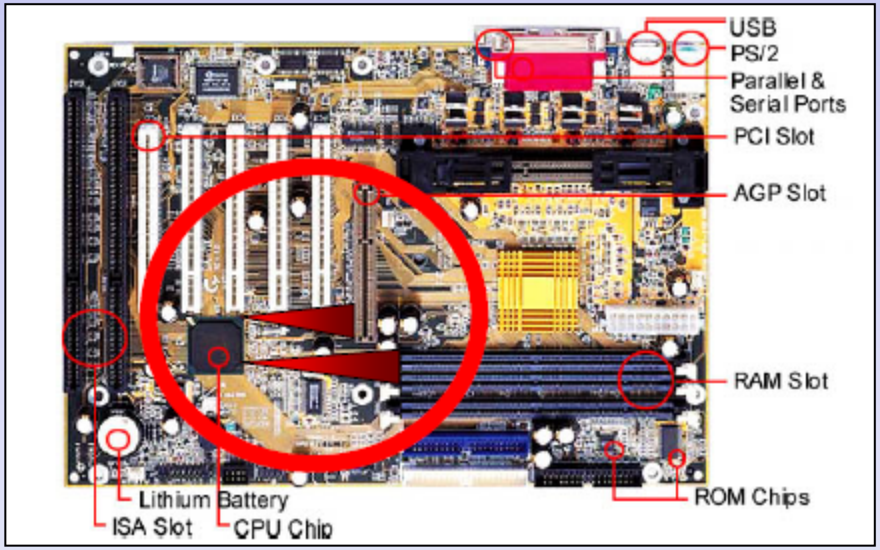


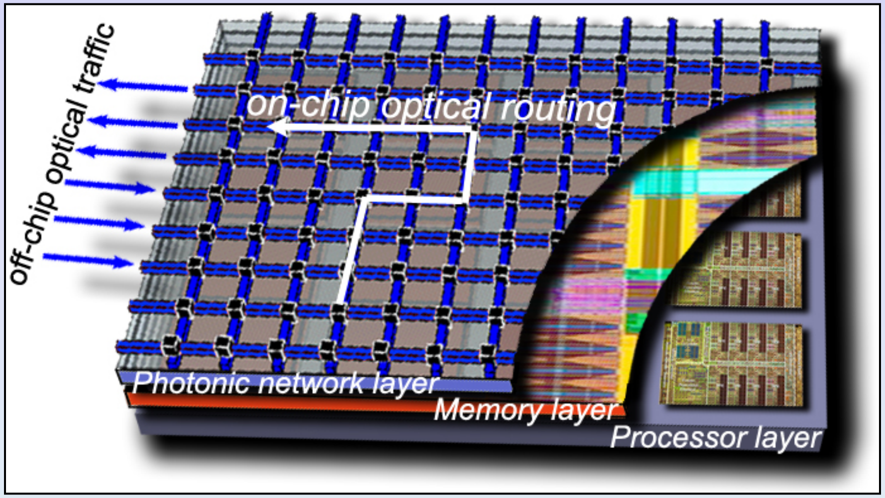


range ~mm m km >10,000 km

Ultra-Short Range OWC

- On-chip communications
- Chip-to-chip communications

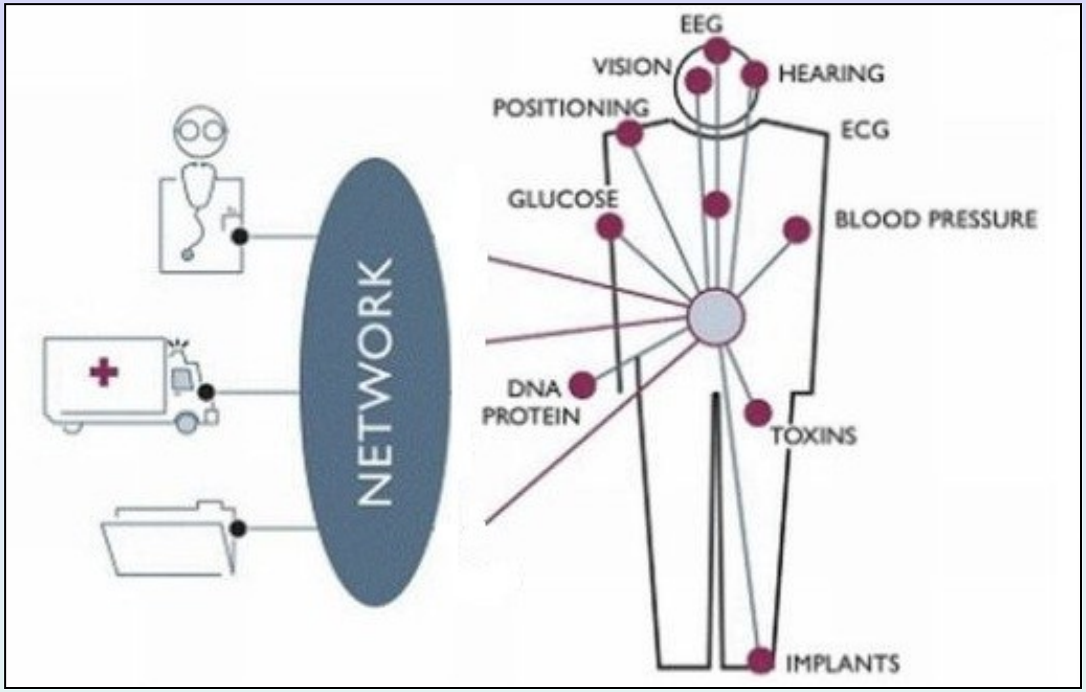




- High-performance computing at the **exaflop** [one quintillion 10^{18} floating operations per second] level

Optical Wireless Body Area Networks (O-WBANs)

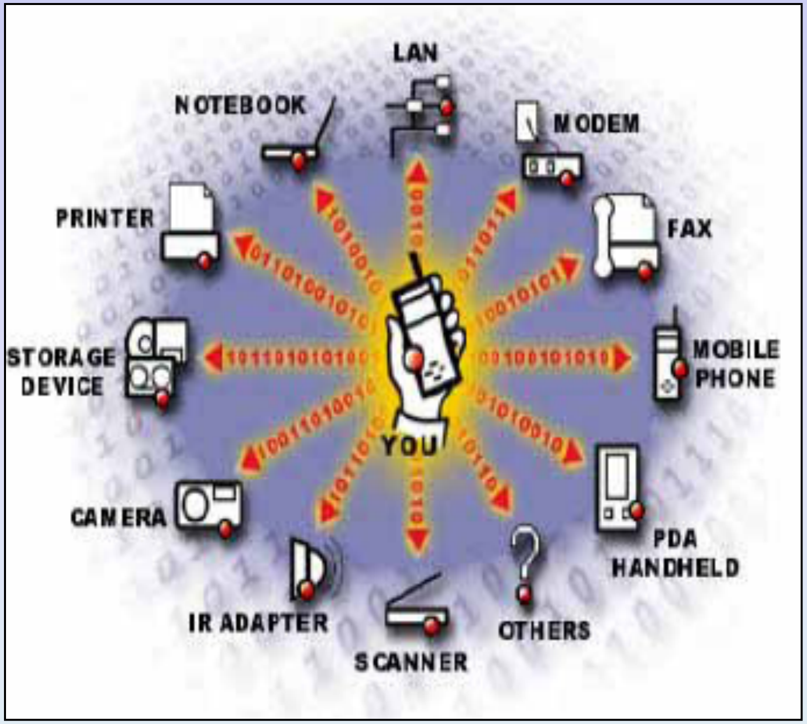
- Retrieval of physical and bio-chemical information of the individual through the use of wearable computing devices



Optical Wireless Personal Area Networks (O-WPANs)

- "Last metre" connectivity for interconnecting devices centred around an individual person's workspace

- **Infrared Data Association (IrDA)**

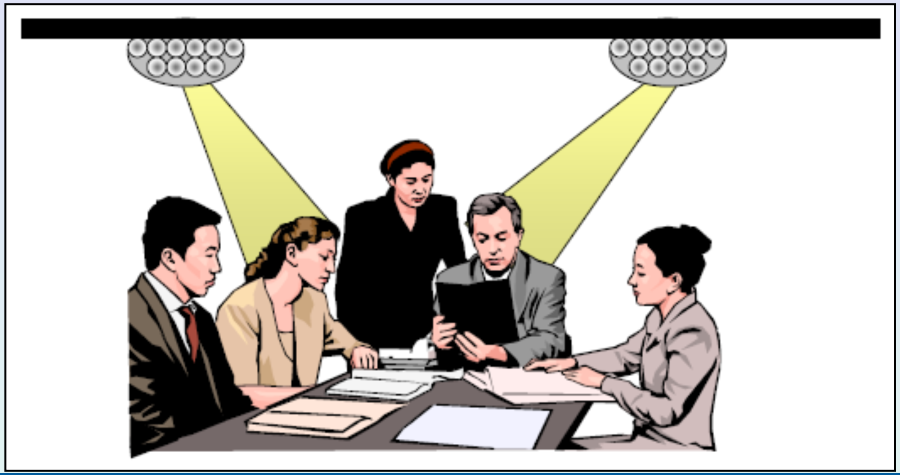


* Giga-IR ~ 1.25 Gb/s

* 10Gb/s IR under development

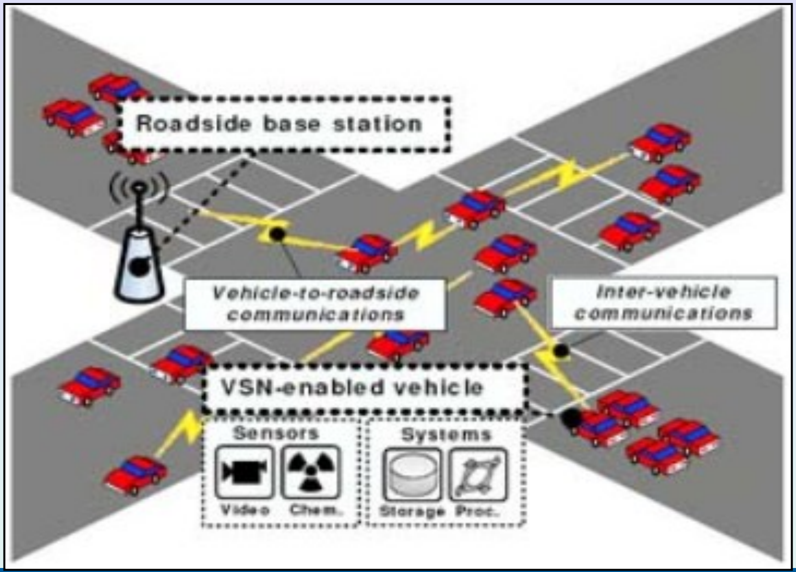
Optical Wireless Local Area Networks (O-WLANs)

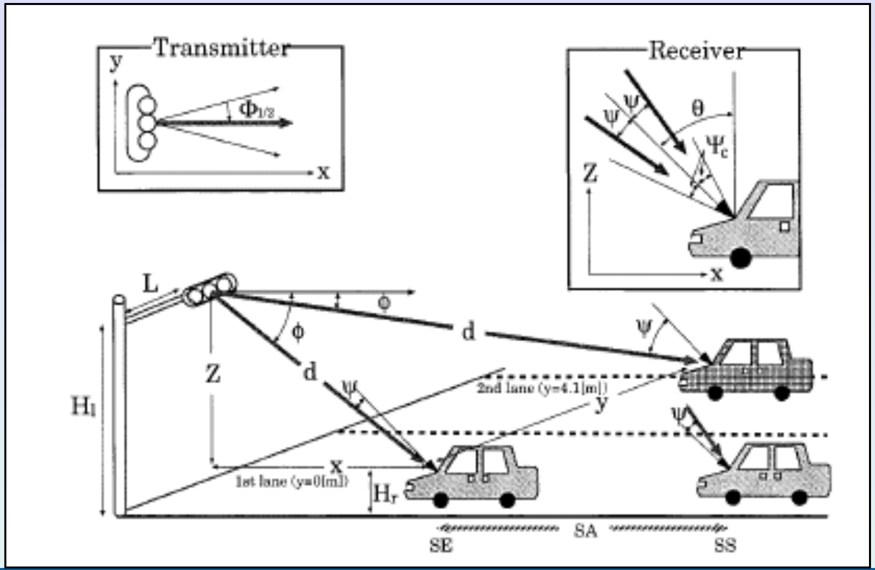
- Visible light communications
  - Dual use of lightning for illumination and communication
- IEEE Standard 802.15.7-2011 “Standard for Short-Range Wireless Communication using Visible Light”
- Li-Fi consortium founded in October 2011
  - http://www.lificonsortium.org/



Optical Vehicular Area Networks (O-VANETs)

- V2V communications via the use of headlights/ taillights
- V2R communications via traffic lights, broadcasting displays, etc
- In-vehicle MANETs etc (eg. *Warwick*)





Terrestrial OWC links

- Atmospheric line-of-sight (LOS) infrared communication also known as free-space optical (FSO) communications
  - metropolitan area network (MAN) extension
  - enterprise/campus connectivity
  - optical fibre back-up
  - cellular backhaul and coverage extension
  - wireless video surveillance and monitoring
  - temporary links for disaster recovery & emergency response (e.g., used in recovery efforts after 9/11, NYC)
  - HDTV transmission (e.g., BBC temporary studios in FIFA World Cup 2010)

Ultra-Long Range OWC

- Aircraft uplink/downlink and inter-aircraft link
- High altitude platforms (HAPs) and inter-HAP links
- Satellite communications (e.g., inter-satellite, earth-to-satellite)
- Deep-space link

Why the COST Action?

- ***OPTICWISE*** recognizes the great potential of optical wireless communication and aims to establish and consolidate OWC as a mainstream technology.

- In many respects, OWC research is still in its infancy and calls for extensive collaborative research efforts in distinct, but complementary fields.

- OPTICWISE serves as a high-profile scientific European platform for synergizing and coordination of OWC interdisciplinary research activities.

OPTICWISE is
the very first
COST Action
solely dedicated to OWC

History of *OPTICWISE*

- Initial Proposal Submission: September 20, 2010
- Invitation for the Full Proposal: November 19, 2010
- Full Proposal Submission: January 14, 2011
- Presentation at DC Hearing: March 03, 2011
- Awarded: May 17, 2011
- Kick-off meeting in Brussels: November 11, 2011
- Grant Holder Agreement between OzU and COST Office signed: February 22, 2012
- 2nd MC meeting in Istanbul: March 19-21, 2012
- Subsequent meetings in Pisa and Northumbria
- International members include McMaster University, Canada (*Steve Hranilovic*) and Monash University, Australia (*Jean Armstrong*)

Objectives of *OPTICWISE*

- Make significant contributions to the scientific understanding and technical knowledge of the OWC field;
- Develop transformative and far-reaching OWC solutions as powerful alternatives and/or complements to existing technologies, and thereby help increase OWC market penetration;
- Serve as an internationally recognized reference point in the OWC field;
- Increase awareness of OWC in the scientific community and the general public;
- Influence decision makers at national and international levels;
- Attract and train graduate students and RAs for OWC field.

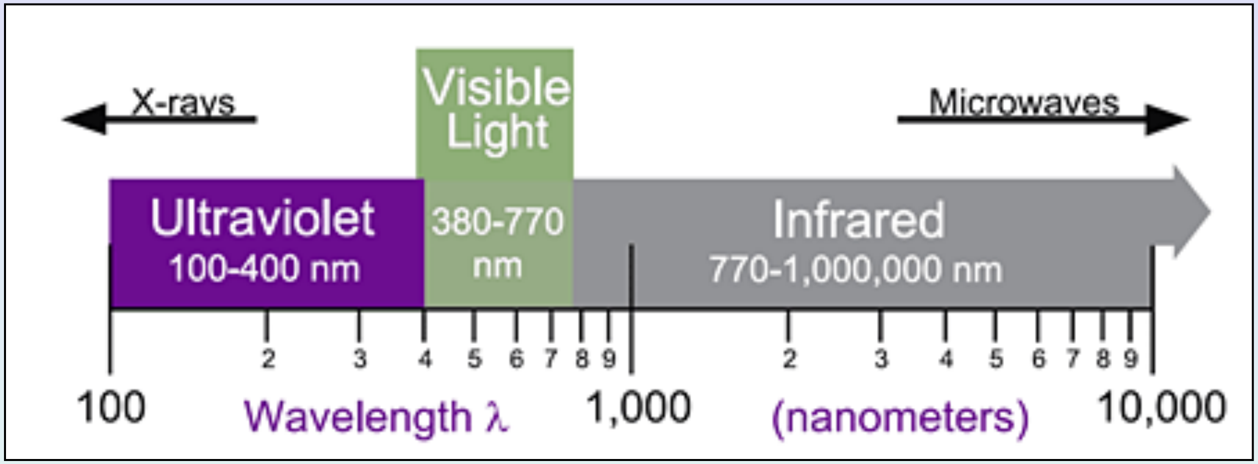
Strategies

Networking activities through ***OPTICWISE*** will

- synergize the interdisciplinary expertise in diverse fields ranging from atmospheric physics to photonic devices & systems.
- bridge the research efforts between academia and industry,
- avoid duplications within OWC research activities,
- increase the mobility of OWC researchers in Europe,
- provide opportunities for developing and sharing common software/hardware tools,
- enable timely diffusion of generated knowledge within the research community.
- provide training opportunities for graduate students and ESRs in the OWC field.

Scientific Scope

- The scientific focus of ***OPTICWISE*** is to explore and develop novel methods, models, techniques, tools and strategies in **infrared**, **visible** and **ultraviolet** spectral bands that will facilitate the implementation of state-of-the-art OWC systems for future generations of heterogeneous wireless communication networks.



Working Groups

- **WG1** Propagation Modeling and Channel Characterization
- **WG 2** Physical Layer Algorithm Design & Verification
- **WG 3** Networking Protocols
- **WG 4** Advanced Photonic Components

WG1

Propagation Modeling and Channel Characterization

- To develop, evaluate and validate statistical and empirical channel models for OWC applications and IR, VL, UV bands
  - Characterization of meteorological phenomena;
  - Development of novel statistical models for atmospheric channels;
  - Comparative evaluation of infrared, visible light and ultraviolet spectral bands;
  - Development of “hybrid” communication channel models;
  - Development of “effective” channel models incorporating the device imperfections;
  - Development of low-complexity ray-tracing models for indoor channels;
  - Experimental validation through field measurements.

WG2

Physical Layer Algorithm Design and Verification

- To elaborate an information-theoretical framework to determine the ultimate performance boundaries of OWC systems
- To develop advanced signal processing, modulation, coding, diversity and coherent/non-coherent detection techniques
- To extend and develop new analytical and algorithmic methods for OWC systems applying the principles of
  - Multi-input multi-output (MIMO) systems,
  - Cooperative (i.e., relay-assisted) transmission,
  - Multicarrier communication,
  - Adaptive transmission.
- To test and validate proposed techniques and algorithms through simulations and experiments

WG3

Networking Protocols

- To investigate upper layer protocols addressing the design of
  - Centralized and distributed OWC networks,
  - Topology control,
  - Routing and wavelength assignment algorithms,
  - Multiple access (spatial, temporal, wavelength, code)
  - Quality of service (*QoS*) management,
  - Cross-layer optimization
  - Channel-aware packet scheduling,
  - Fault detection, avoidance and recovery mechanisms
- To explore the co-existence and interoperability of OWC with other communication networks.

WG4

Advanced Photonic Components

- To develop innovative tools for efficient selection, characterization and design of optoelectronic and photonic components for OWC systems
  - Wavelength selection
  - Large-area photodetectors with a low capacitance
  - Highly sensitive optical receiver with optical amplifiers
  - Liquid crystal-based beam steering techniques
  - Integration of optoelectronic and electronics at substrate levels
  - FPGA and ASIC technology for high-performance coding
  - Investigation of device trade-offs

- To develop OWC prototypes and testbeds for the test and verification of the proposed techniques and algorithms in real-life environments.

Special Interest Groups (SIGs)

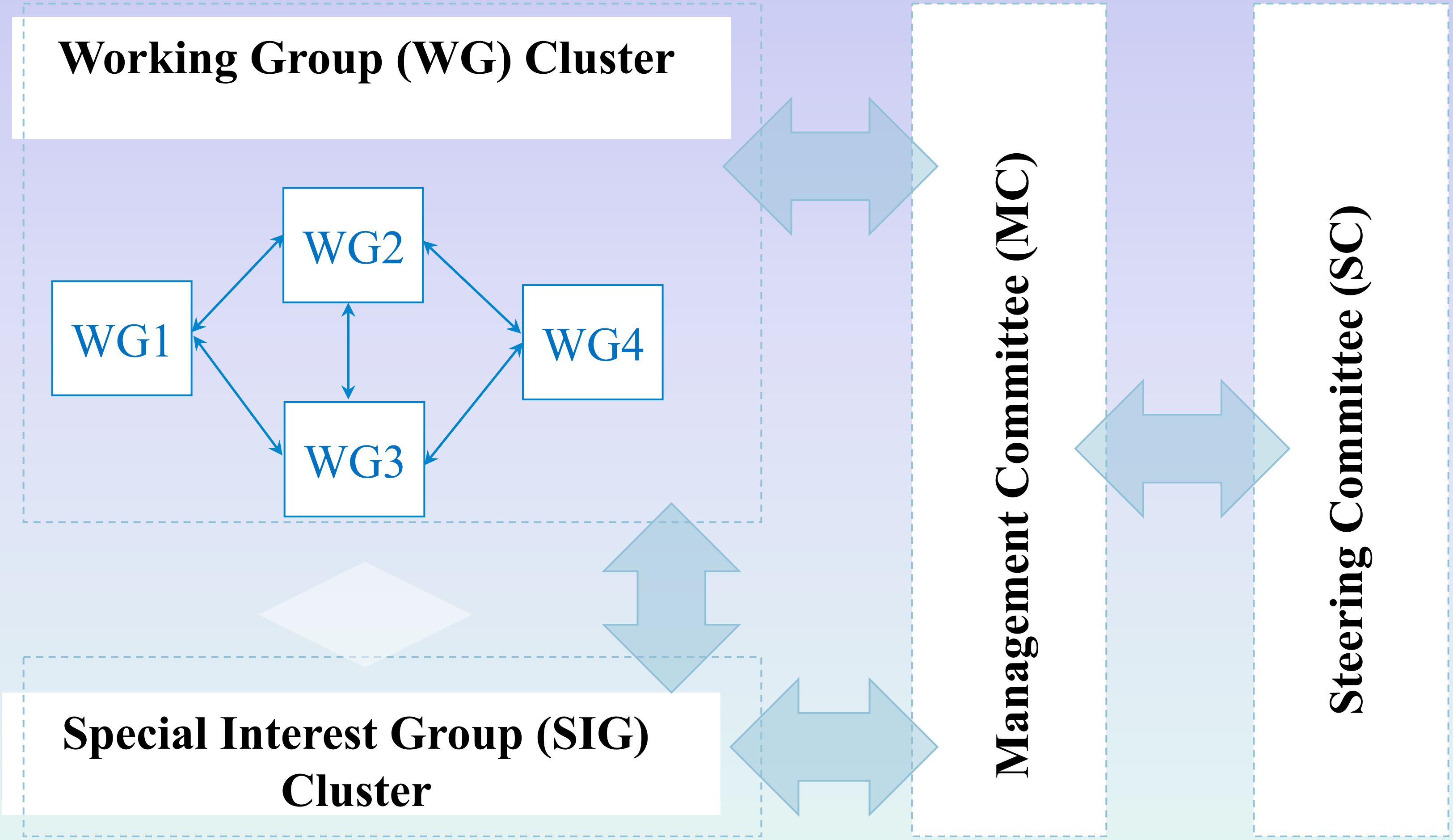
- **Techno-Economics, Industrial Standards & Future Trends in OWC (TESEO)** is the only permanent **SIG** in the Action.
- This **SIG** will
  - Deal with business and market issues related to OWC;
  - Participate to international standard bodies like ITU, ETSI, FSAN, WWRF and lead trends in emerging OWC applications;
  - Educate and influence decision makers at all levels of the OWC market chain.

SIGs (cont'd)

- Based on the needs and technical development trends, SIGs will be created addressing specific applications and involve members from more than one WG.

- At the MC meeting in Istanbul in 2012, two SIGs were approved:
  - SIG on Underwater OWC (U-OWC)
  - SIG on Visible Light Communications (VLC)

Organizational Structure



Dissemination Activities

- **Annual Workshop and Final Year Conference**
- **Action Website:** http://opticwise.uop.gr
- **Action Leaflet** will be ready for distribution soon …
- **Semi-Annual Action Newsletter** – Editor: Dr. Florian Moll (DLR)
- **Social Networking Tools** are being launched :-

Google groups   LinkedIn

facebook   twitter

WWRF white paper – to be revised :-

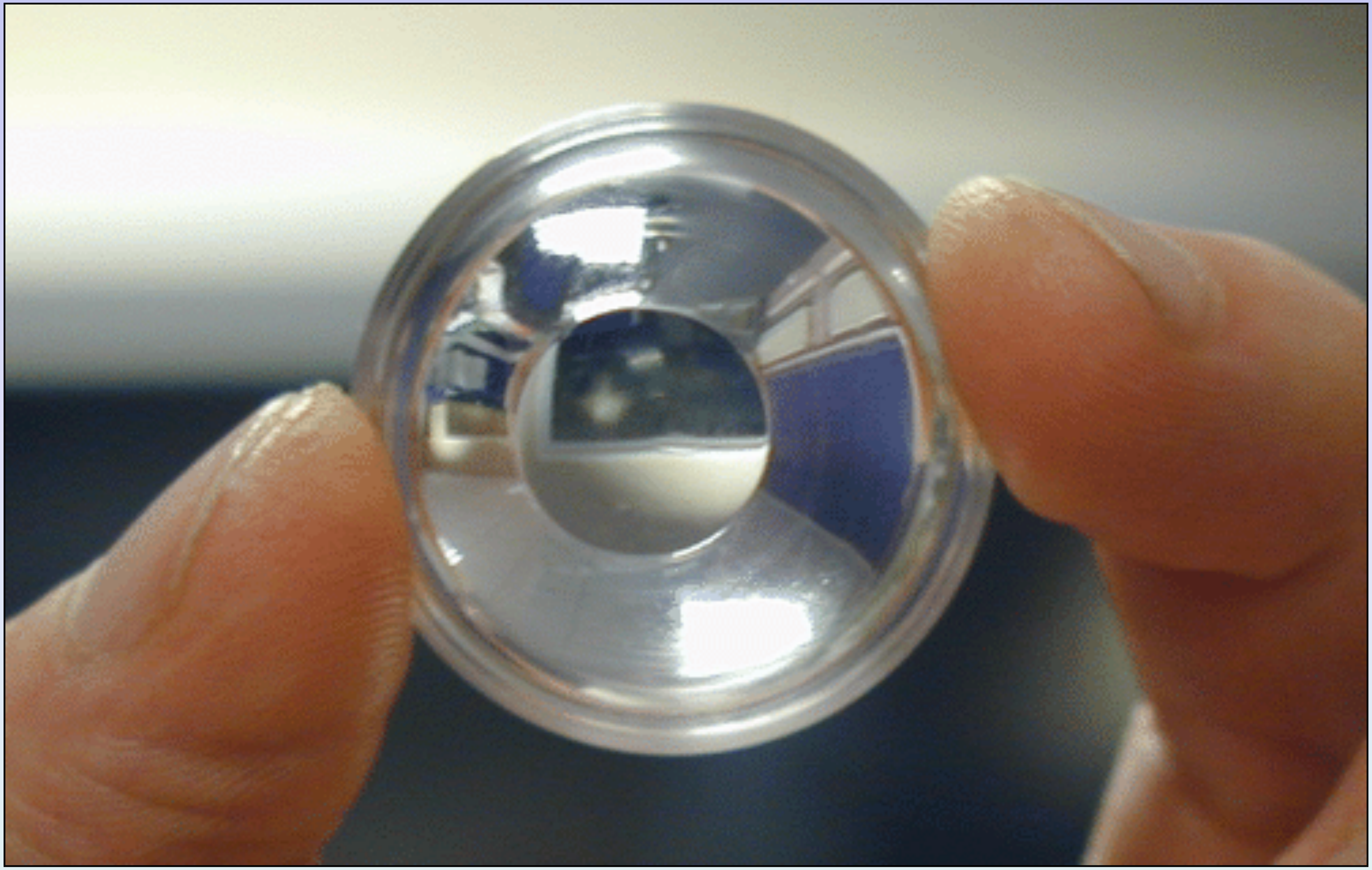
D. C. O'Brien, M. Katz, P. Wang, K. Kalliojarvi, S. Arnon, M. Matsumoto, **R. Green**, and S. Jivkova, "***Short-range optical wireless communications***," in "**Technologies for the Wireless Future**": ***Wireless World Research Forum*** (**WWRF**), Volume 2, vol. 2: Wiley, 2006, pp. 277-296.

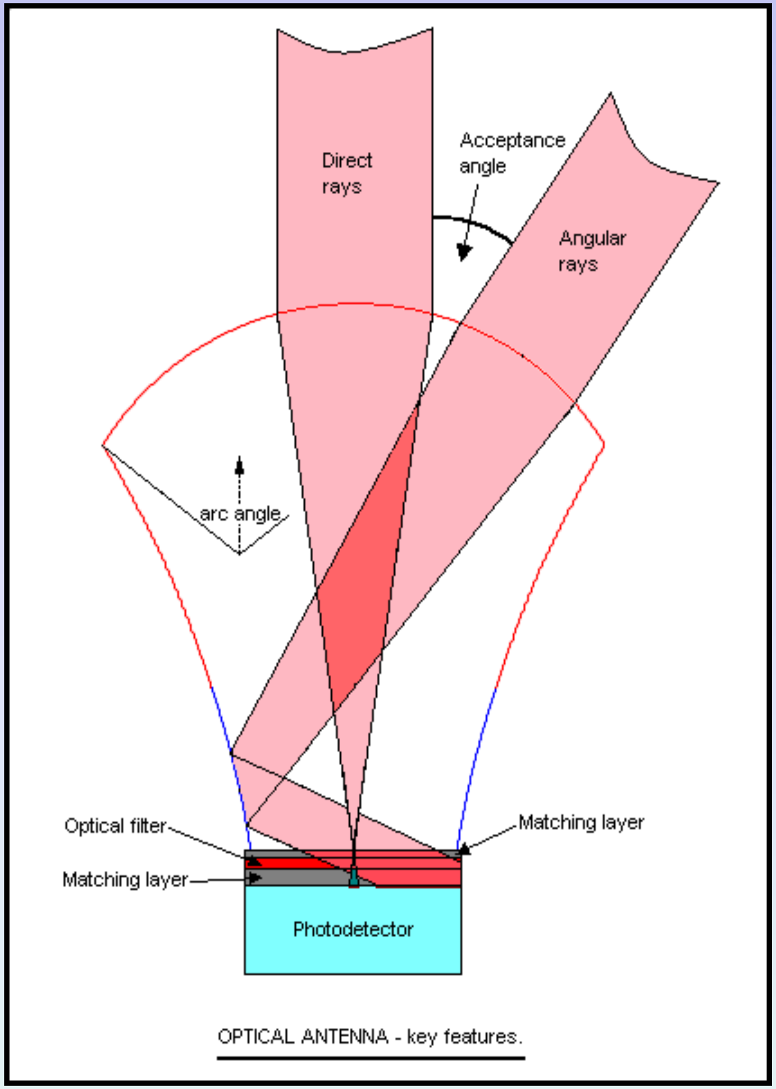
Warwick University COST IC101 activity

1. Specialised optics for optical wireless (WG4 specifically)
2. Modulation techniques (several WGs)
3. Enhanced receiver-amplifiers (several WGs)
4. Underwater optical sensor arrays and optical communications (SIGs : U-OWC, VLC)
5. 3D optoelectronics for transmission detection and sensing applications (WG4 specifically)
6. In-vehicle optical wireless networks (SIGs : U-OWC, VLC)
7. GSM over FSO
8. Other new developments at Warwick University

1. Specialised optics

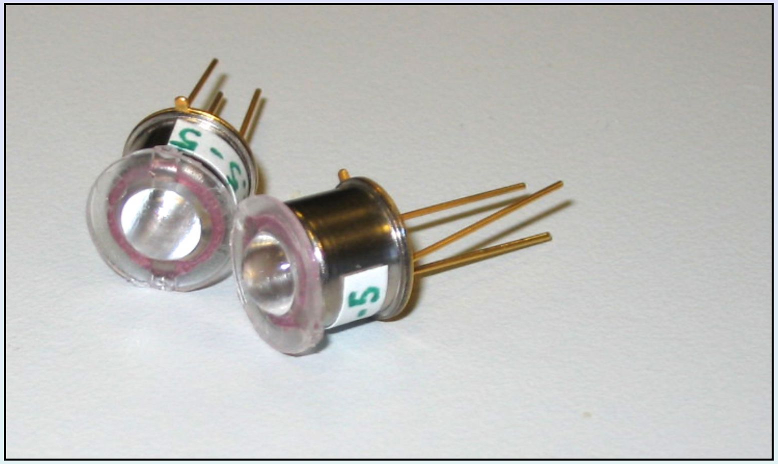
Optical antenna (*Ramirez-Iniguez, Green*)





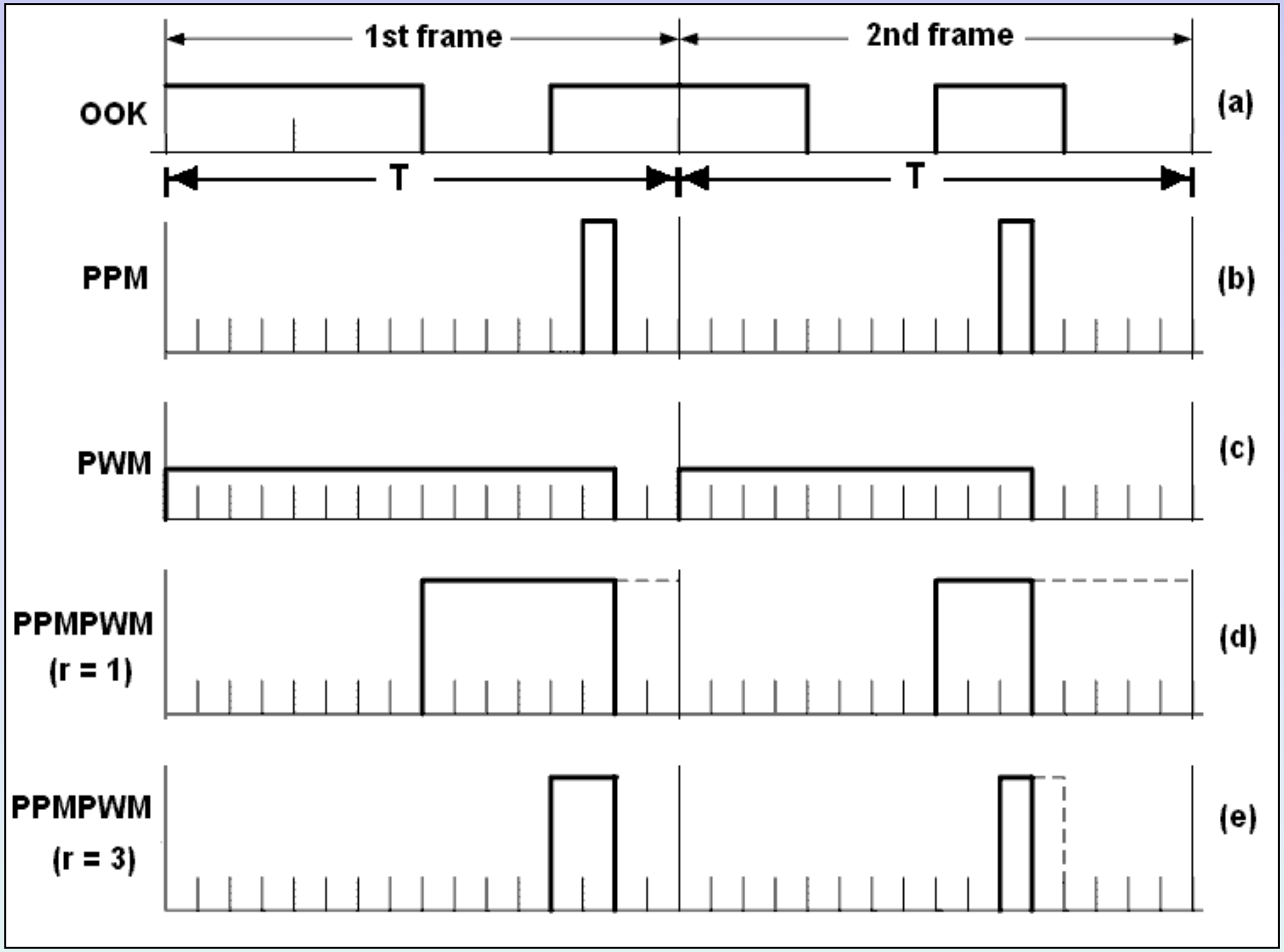
Optical Antenna

(Ramirez-Iniguez, Green)



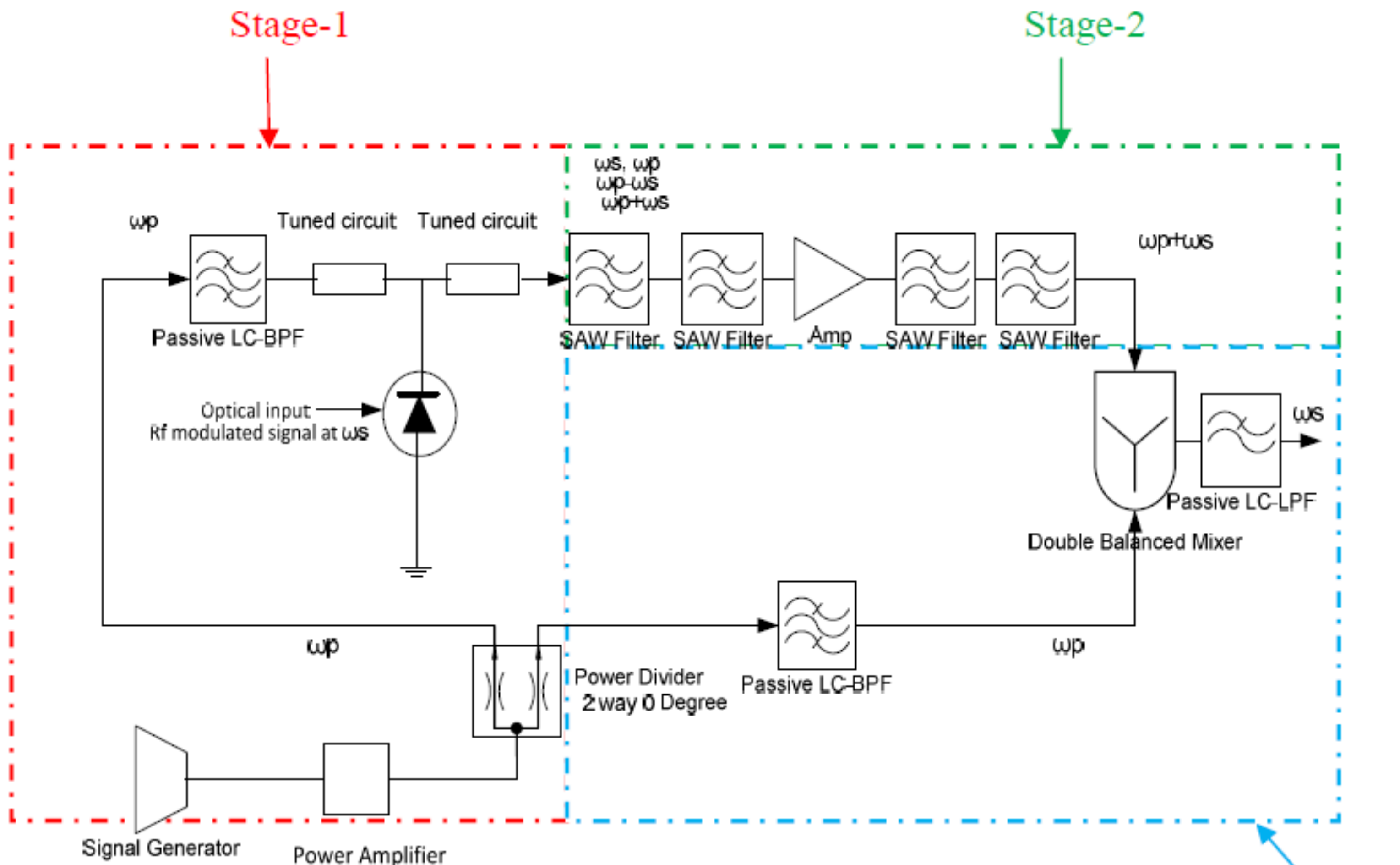
2. Modulation techniques

Novel hybrid optical wireless modulation scheme – PPMPWM *(Green, Zeng)*



3. Enhanced receiver amplifiers

Double Conversion Heterodyne Photoparametric Amplifier (DCHPPA)



Experimental arrangement of the DCHPPA

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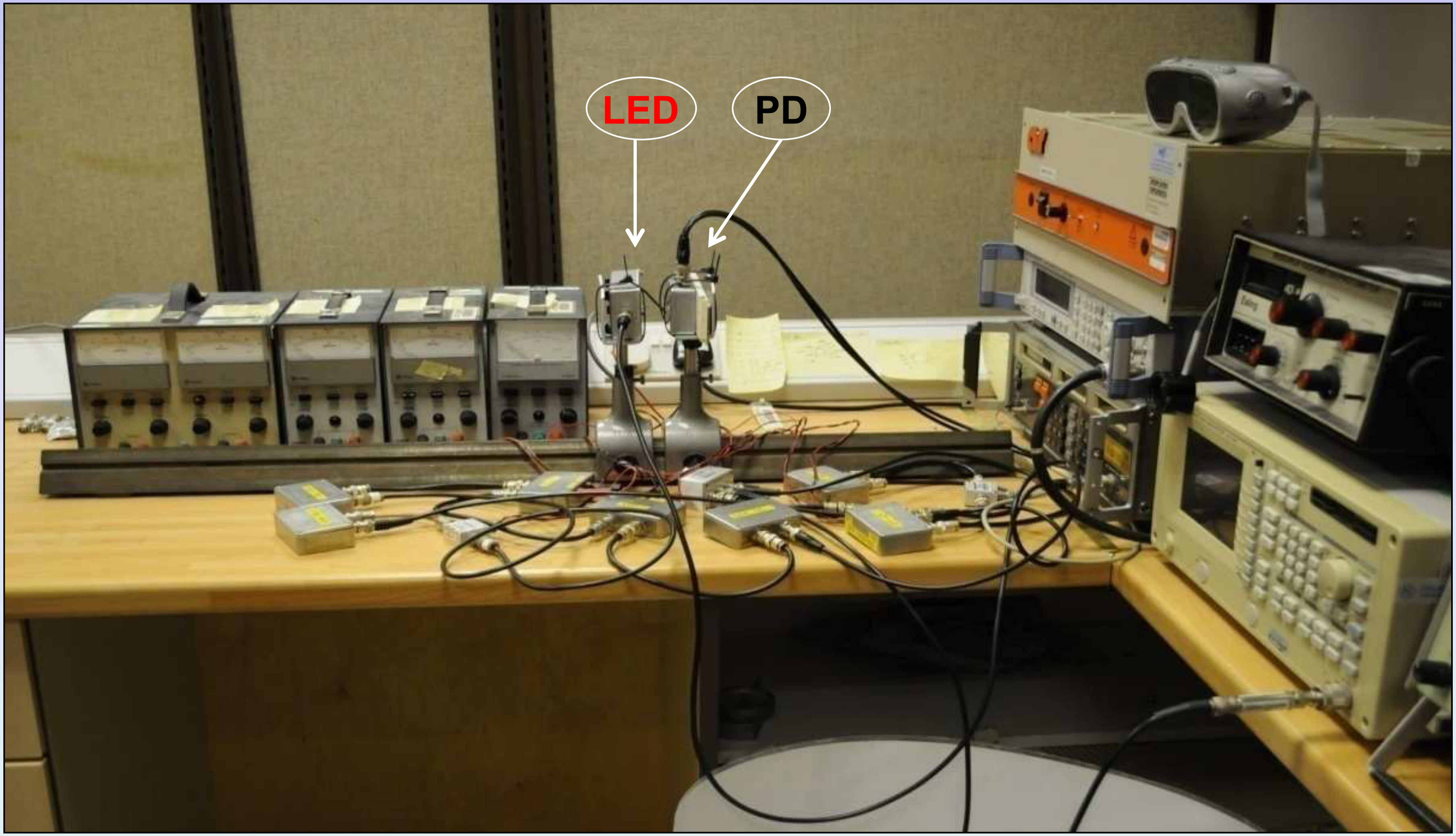
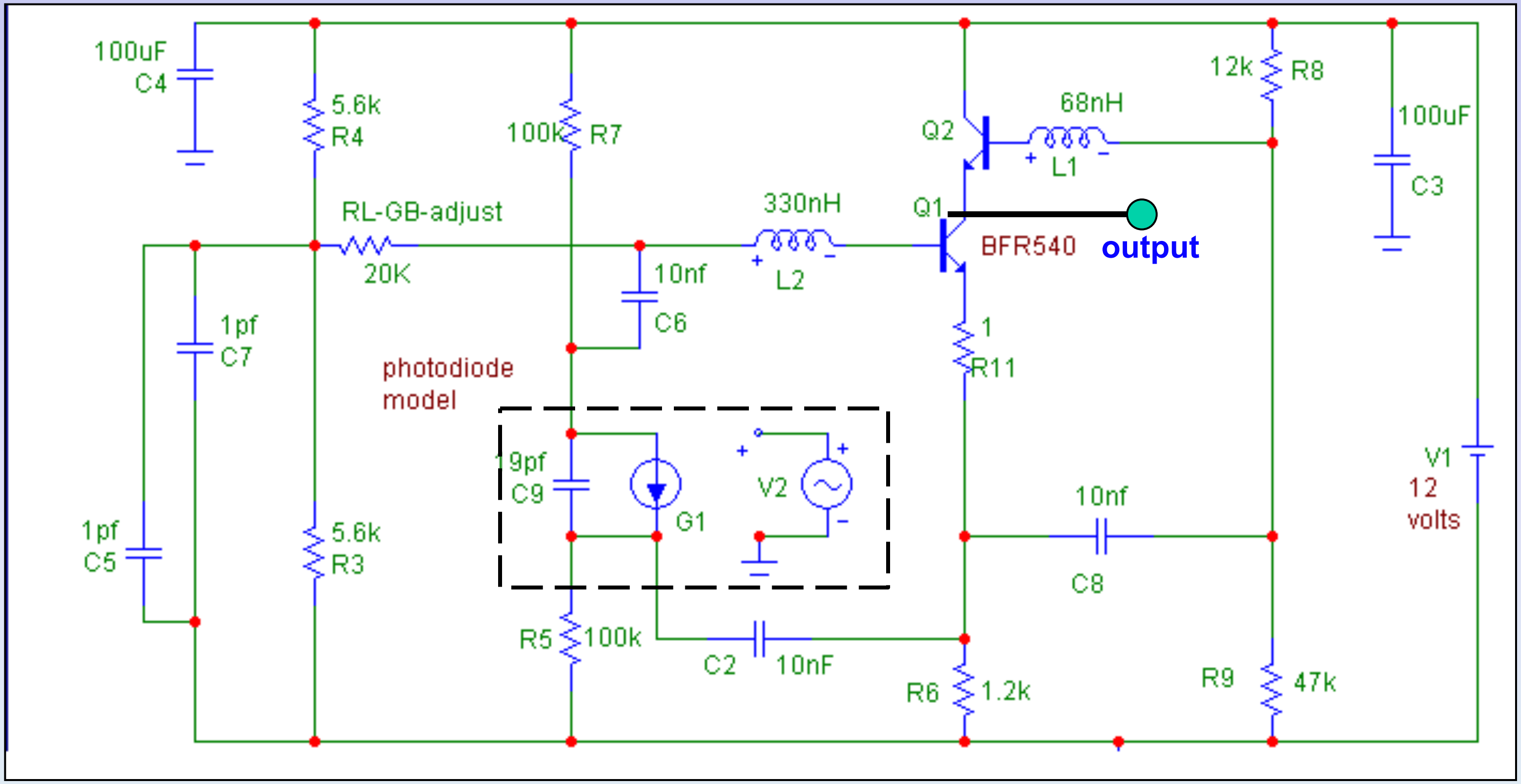
Experimental setup for the DCHPPA

(Alhagagi, Green)



Bandwidth extension bootstrapping

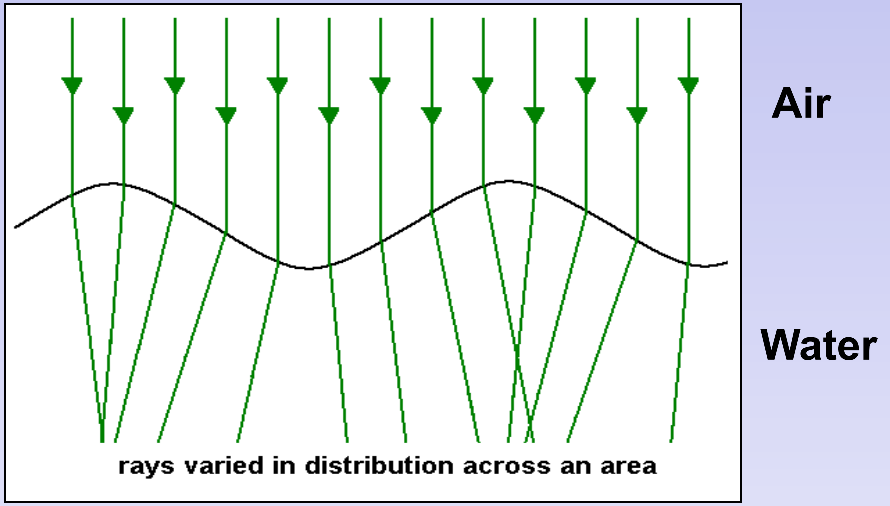


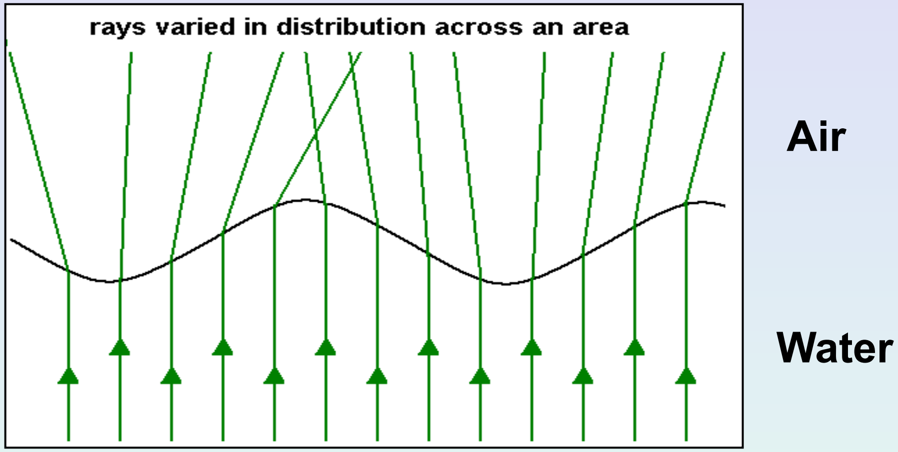
- Excellent dynamic range
- 1.3 GHz analogue bandwidth
- Low noise, high frequency RF devices used

4. Underwater optical wireless and sensor networking

The underwater channel

- Water can be manipulated to create turbidity conditions
- Variable air-water interface at both transmitter and receiver end
- 10 metre water tank available with wave motion drivers





Underwater Optical Wireless Sensor Network

(Ahmad, Green)

Objectives

Building a non-time critical, long-term, static underwater optical wireless sensor network to monitor and collect certain environmental data such as, temperature, pressure, salinity etc.

Challenges

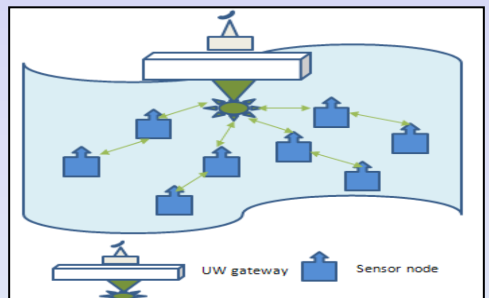
- Shorter communication range
- MAC layer protocol design
- Complexity of real deployment

Solutions

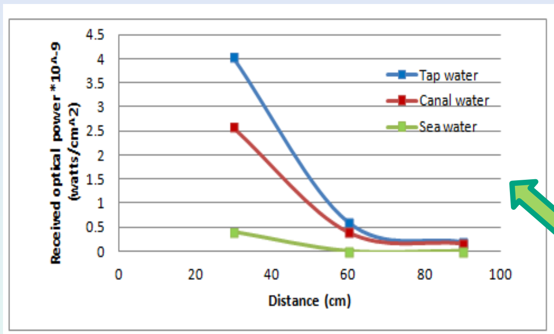
- Use multi-hop approach to increase the communication range
- TDMA based directional protocol

Approach

- Two type of transceivers were designed using blue and green LED.
- Design of a sensor node using green and blue transceivers to support full duplex communication.
- Design of a gateway node to collect and store sensor data.
- Design of a directional MAC protocol using TDMA approach
- Test the built protocol with tap, canal, and sea water



Network Architecture



Results and discussion

- Multi-hop approach can be a solution to increase the communication range.
- Water types, depth, even season can have a good impact on performance. System has to be designed accordingly.
- Received power through tap water is almost 10 times larger than through water from the Irish Sea

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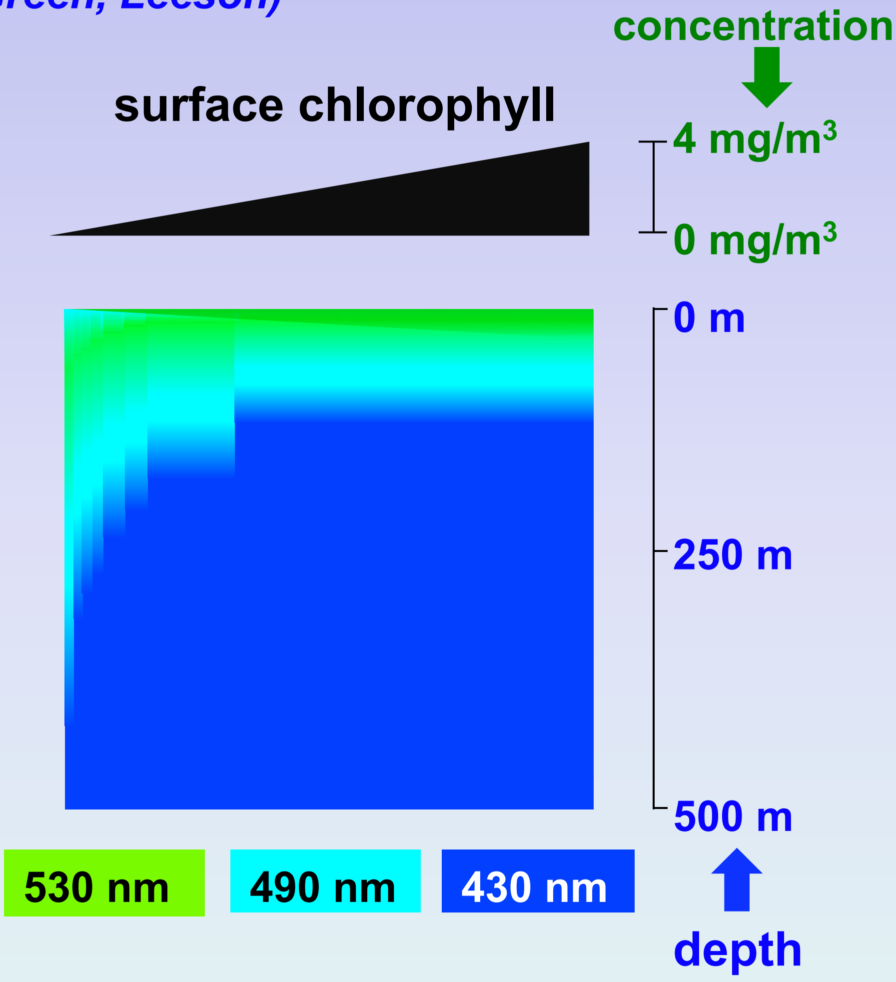
Deep Sea Underwater Optical Wireless

(Johnson, Green, Leeson)

Issues:

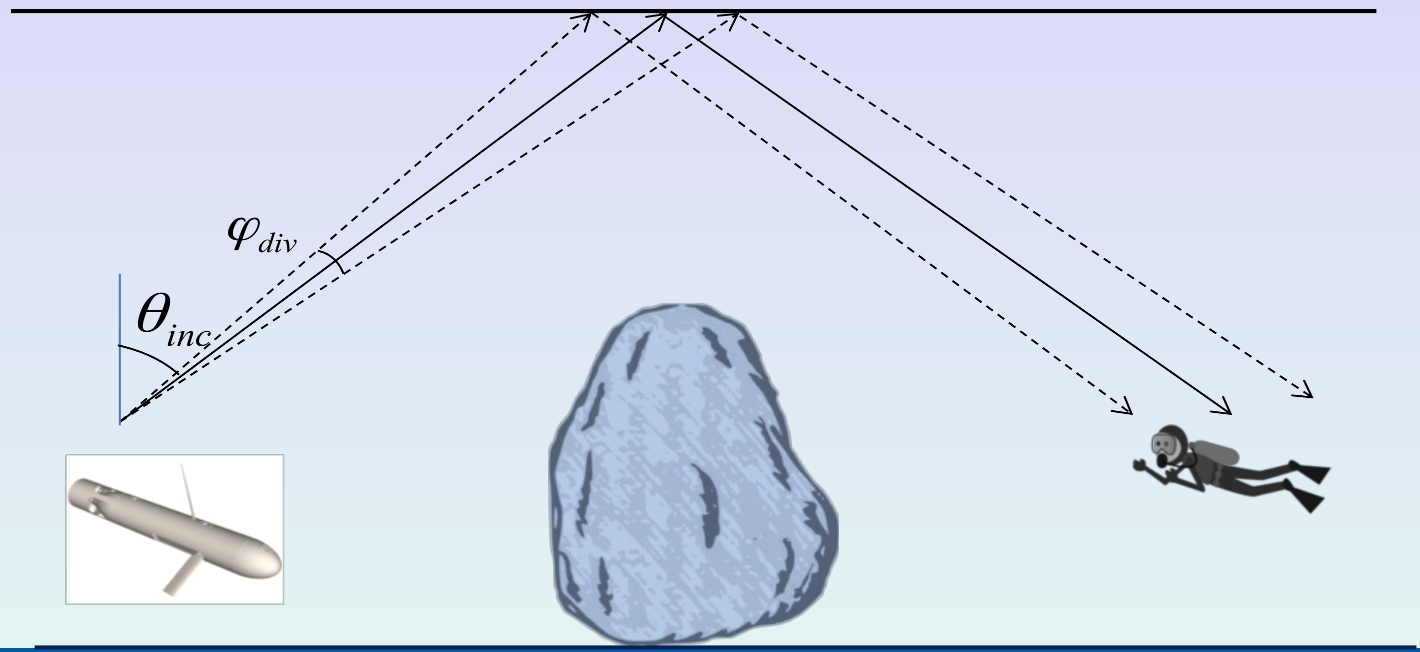
- Local and regional attenuation variation caused by composition
- Beam deviation due to refractive index changes
- Turbulence
- Chlorophyll



Reflective NLOS underwater optical wireless communication

Link configuration

- Reflective communication link can be used whenever line-of-sight is not available due to obstructions, or deliberate scattering
- The direction of light is defined by maximum and minimum angles θ_{max} and θ_{min}.



NLOS underwater communications continued …

Underwater wireless communications using visible light is the enabling technology for many scientific, environmental, commercial, safety and military applications. This is because acoustic links suffers from limited capacity and long propagation delays. Thus, there is a need to provide higher bandwidth links to support video and real time applications.

Objectives

1) To model and characterize the NLOS channel by using Monte Carlo simulation and experimental methods

2) To derive the mathematical model for the link performance

3) To compare experimental measurements with theoretical predictions

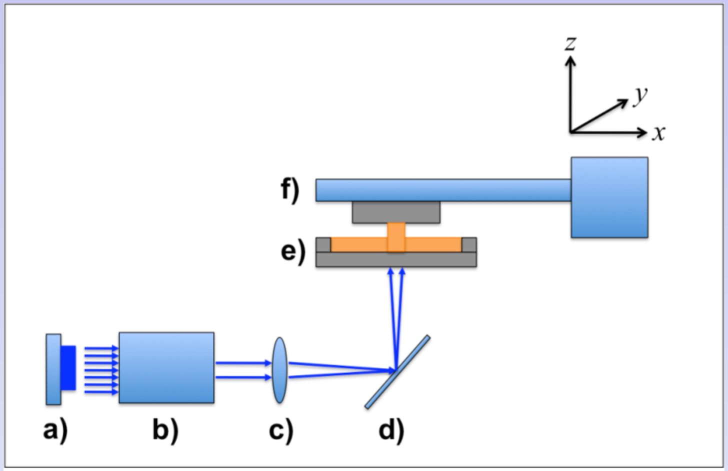
5. 3D optics and optoelectronics

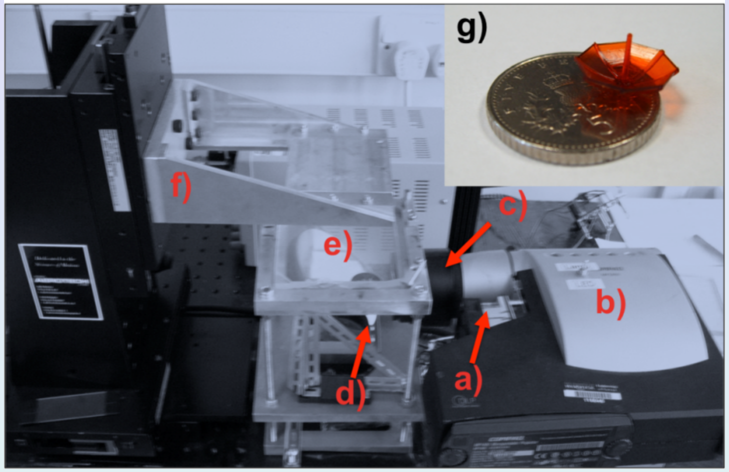
Microstereolithography for 3D rapid prototyping of micro-optics and sensors/transducers

For total flexibility with the manufacturing process we have designed and built our own MSL systems that allow us to control all parameters during fabrication.

Below is a coffee cup fabricated on one of the systems built here. The techniques are being used to implement 3D systems for optical wireless rapidly

System schematic





Facilities…

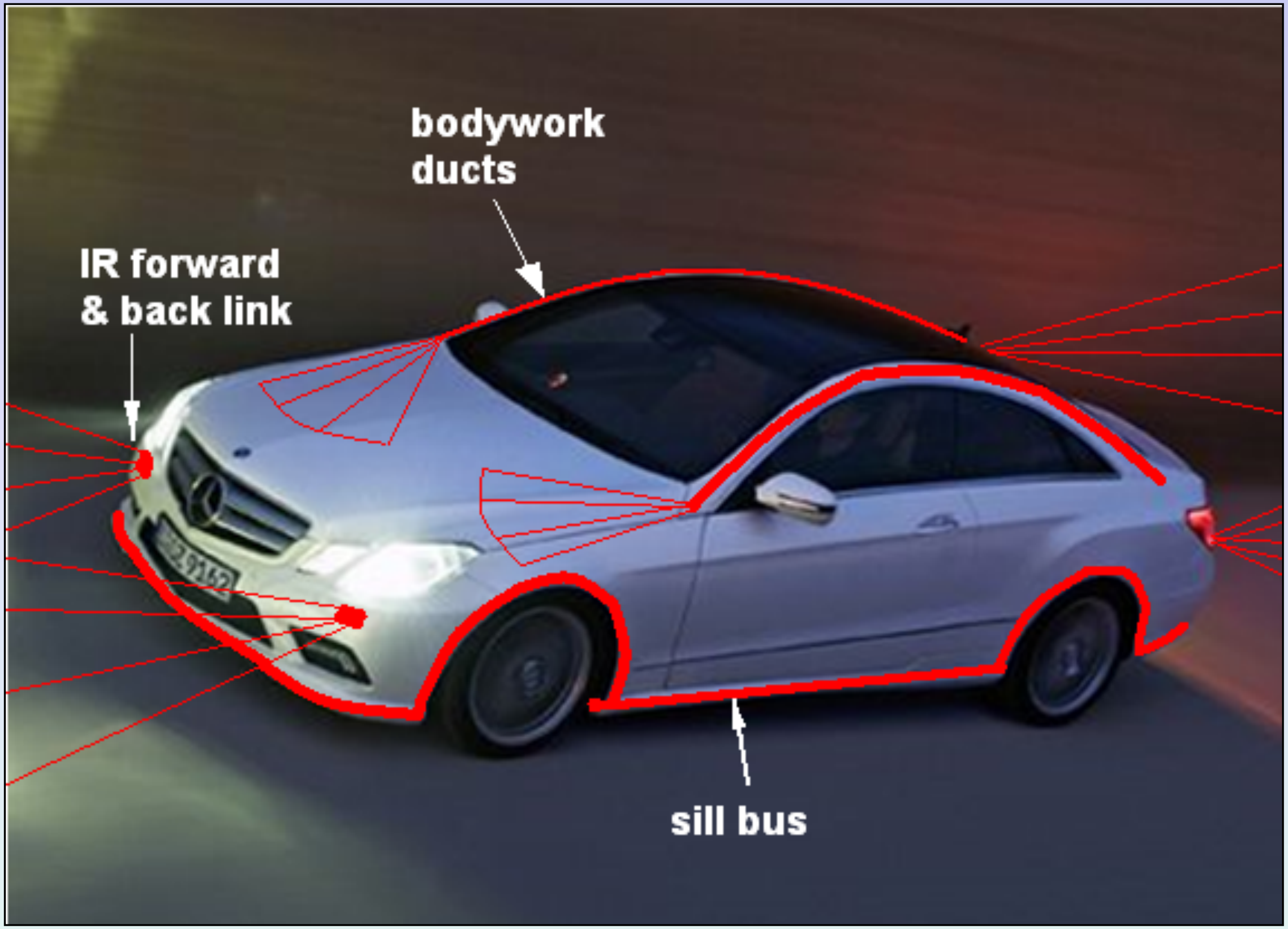
CAD & Electronic design

3D microfabrication facilities

Class 1000 Clean room
New clean room in development

6. In-vehicle optical wireless networks

Concepts *(Green, Mutalip, Rihawi)*



Intra-Vehicle Communication Networks (IVCN)

(Mutalip, Green)

Networking

- FlexRay • CAN • LIN
- SAFE-by-WIRE Plus
- MOST • 1394

  etc.

Body and Comfort

- Dashboard
- Adaptive front lighting system
- Door • Seat • Power window
- Wiper • Air conditioning
- Intelligent key

  etc.

Powertrain

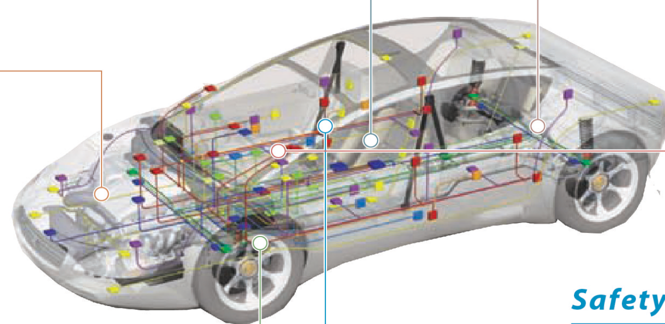
- Engine control
- Transmission control
- Torque distribution system
- Hybrid electric vehicle

  etc.

Infotainment

- GPS navigation
- Automotive audio
- Telematics
- Bluetooth

  etc.



Safety

- Pre-crash safety • Laser radar • Lane keeping
- Millimeter-wave radar • Parking assist • Air bag
- Anti lock brake system • Electric stability control
- Tire pressure monitoring system
- Occupancy detection

  etc.

Chassis

- Electric power steering
- Brake • Suspension

  etc.

IVCN - continued

(Mutalip, Green)

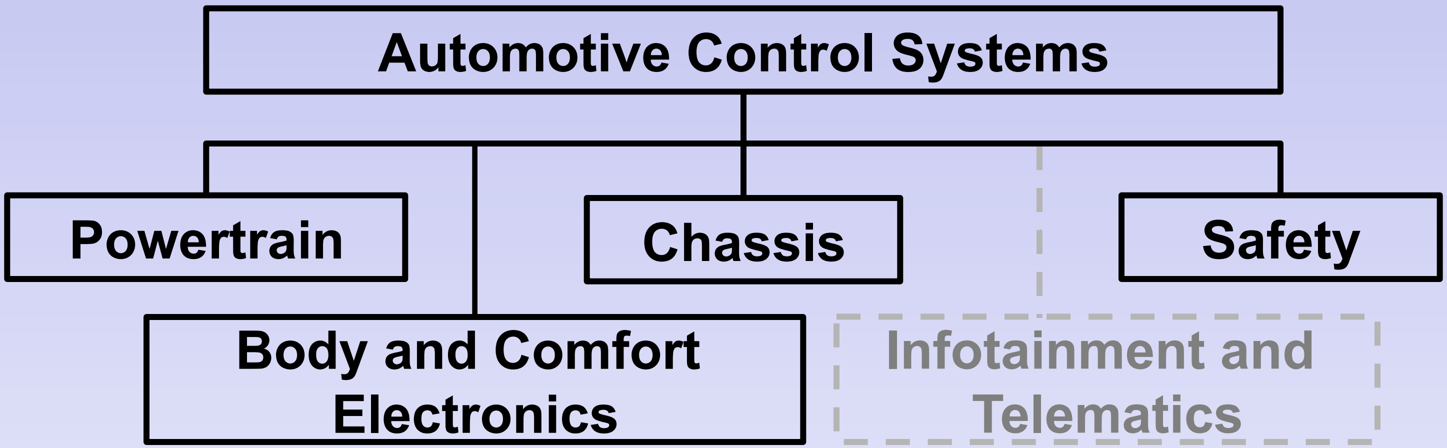


Table 1: SAE subsystem communication requirements [2]

	Powertrain	Chassis	Body & Comfort Electronics	Safety
Bandwidth	500 kbit/s	500 kbit/s	100 kbit/s	22 Mbit/s
Number of ECU	3 - 6	6 - 10	14 - 30	4 - 12
Safety requirements	high	high	low	low

7. RF over FSO

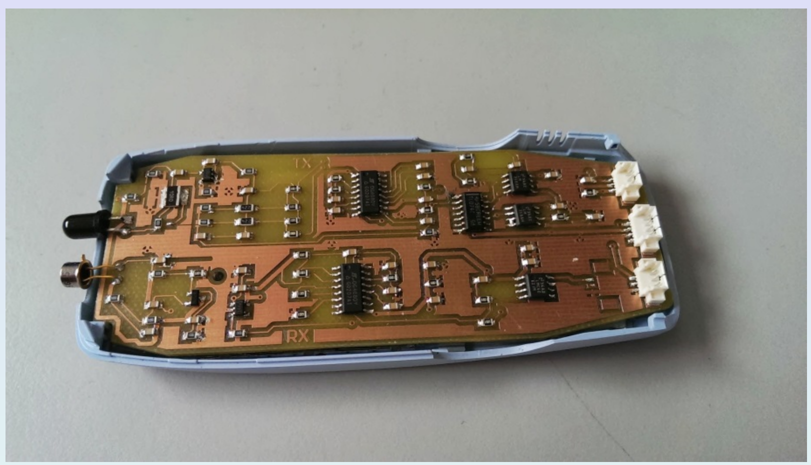
Radio over FSO cell phones

(*Vijay, Green*)

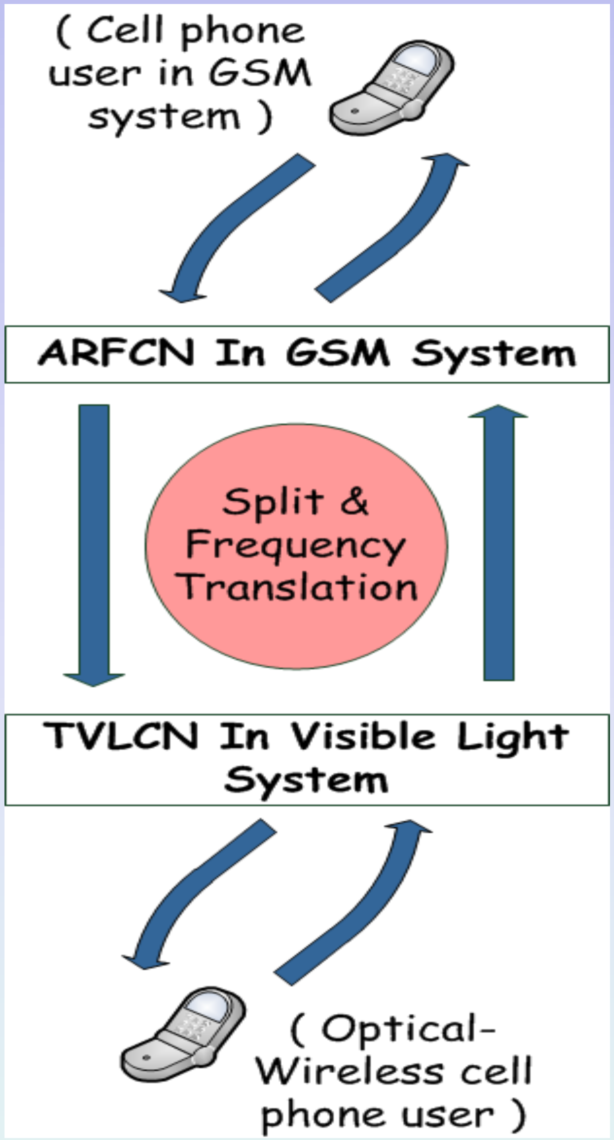
A GSM cell phone

can become

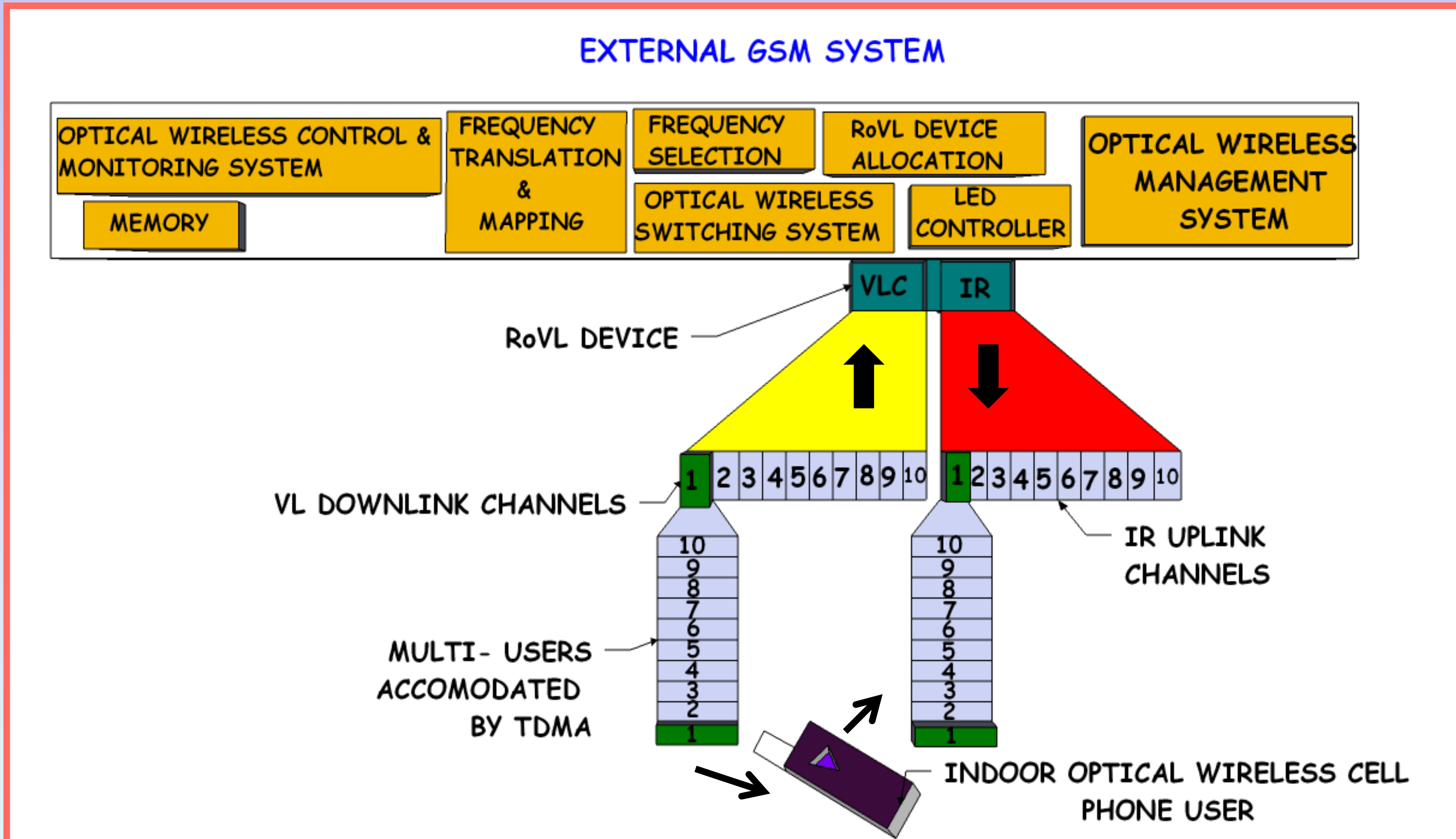
An FSO cell phone!



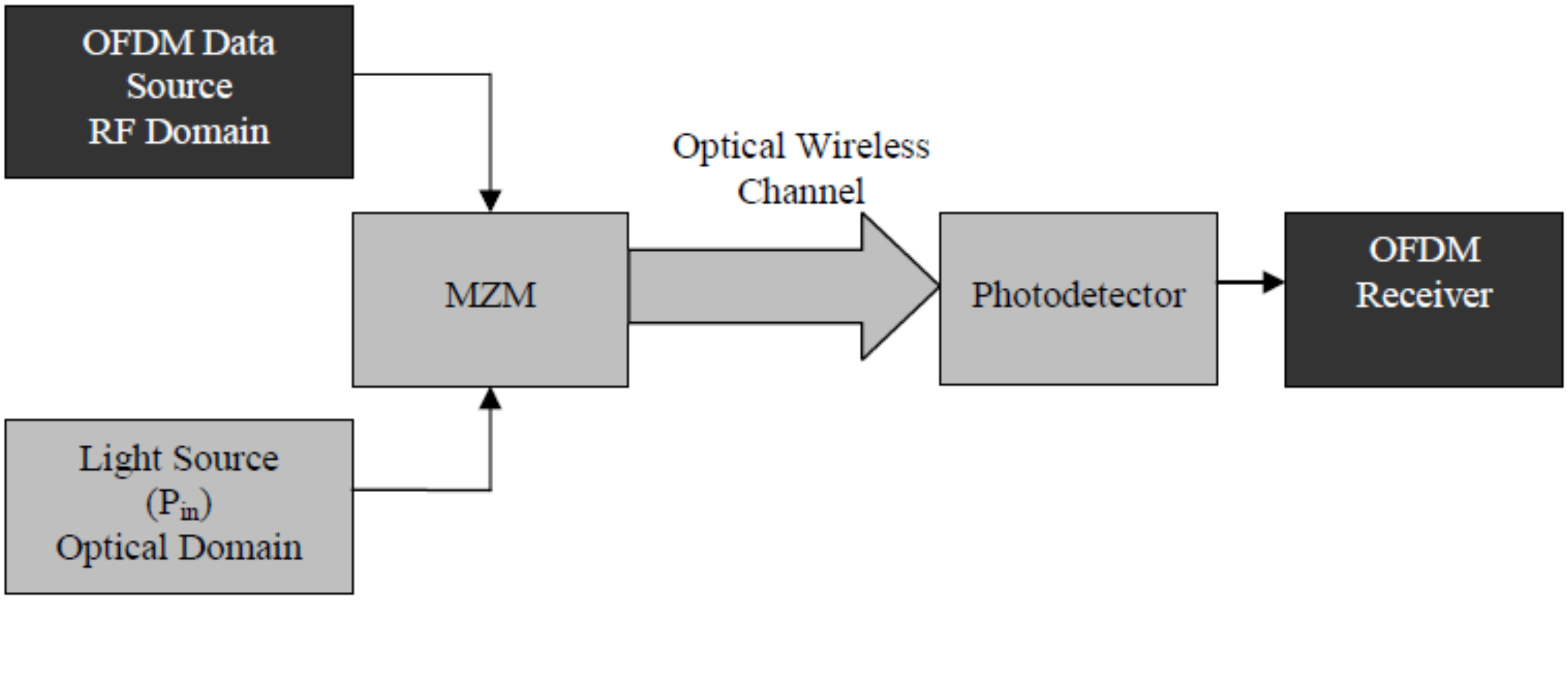
Connecting external caller through optical wireless



INDOOR OPTICAL WIRELESS - GSM SYSTEM

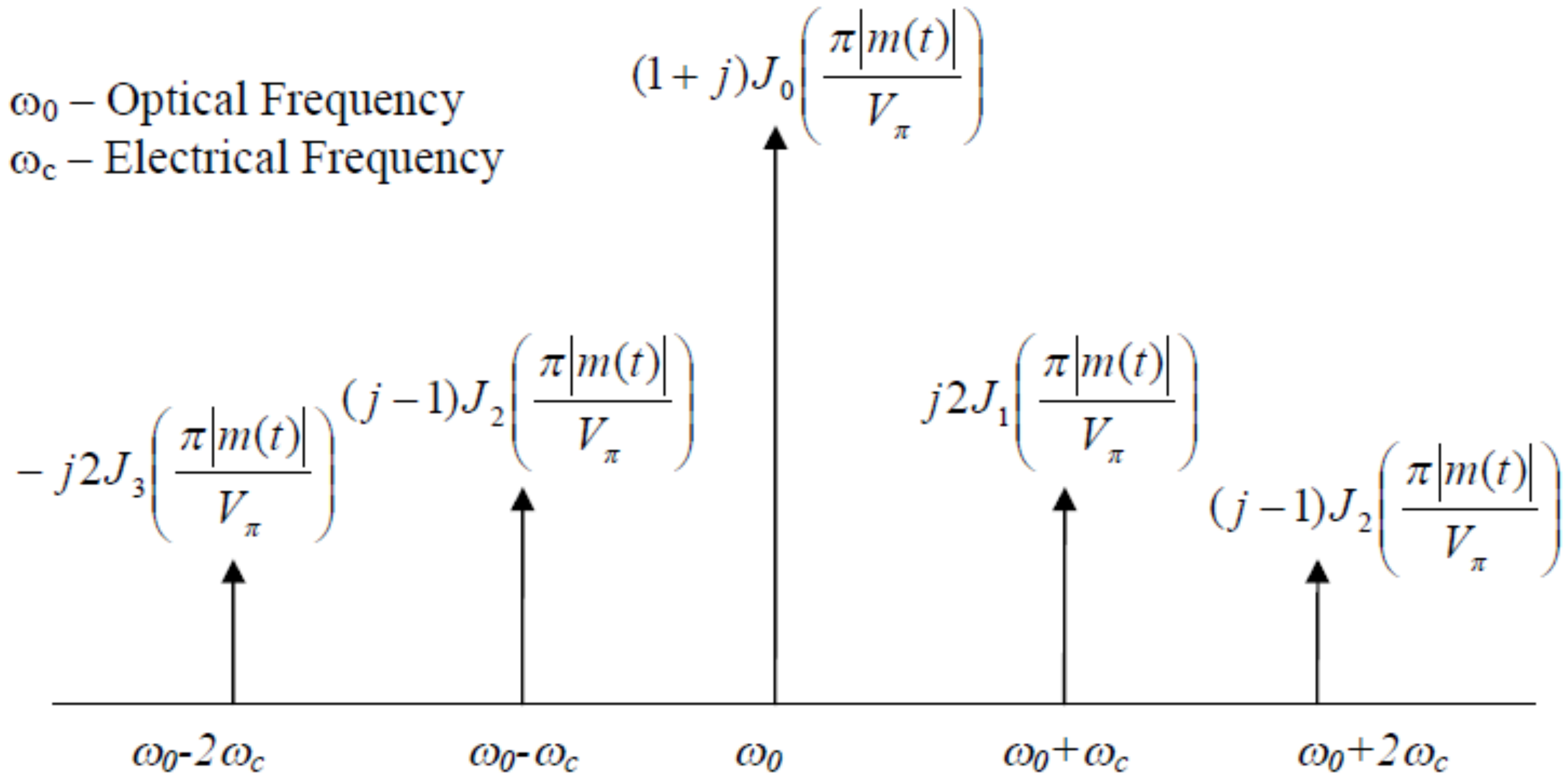


OFDM through external modulators for Optical Wireless *(Joshi, Green)*



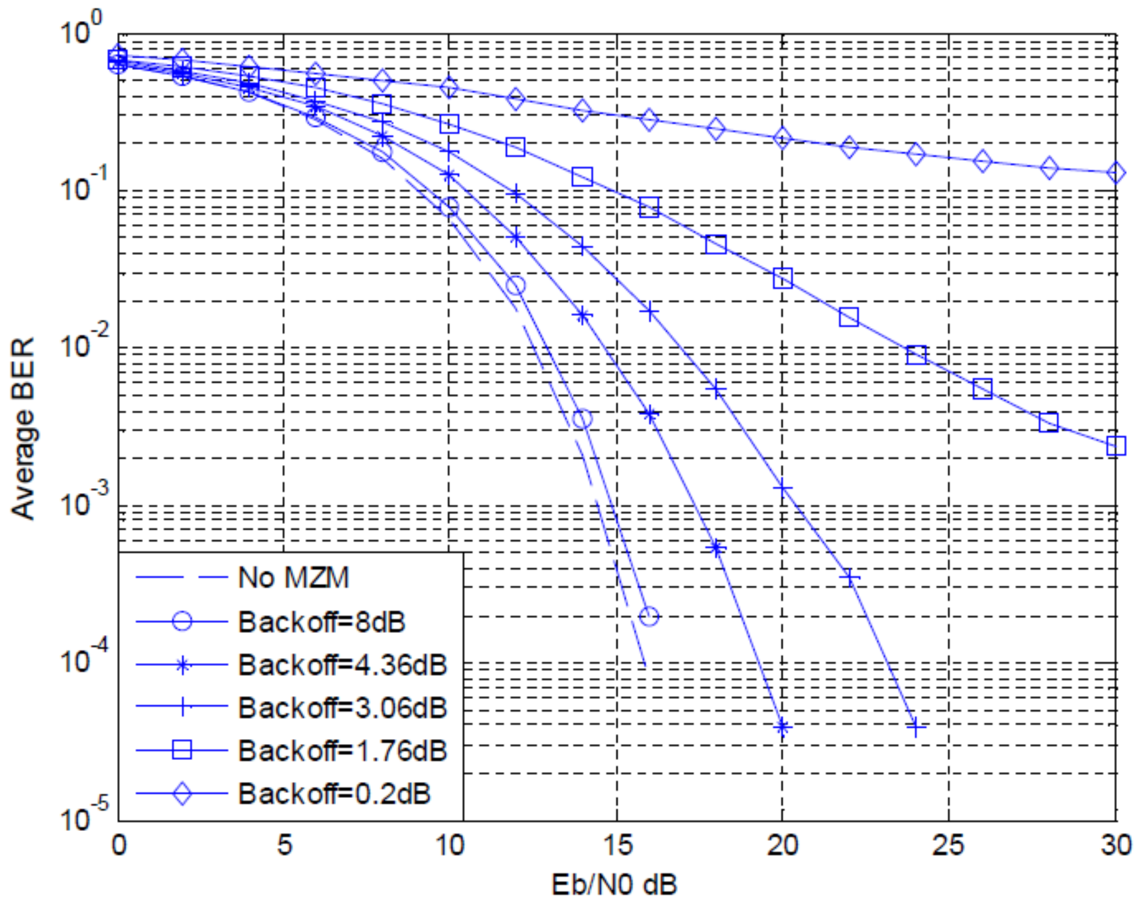
Block Diagram of an Optical Wireless Link Employing an MZM

Intermodulation aspects of an MZM



Spectrum of P_{out} after photodetection

Back-off versus power aspects to reduce BER

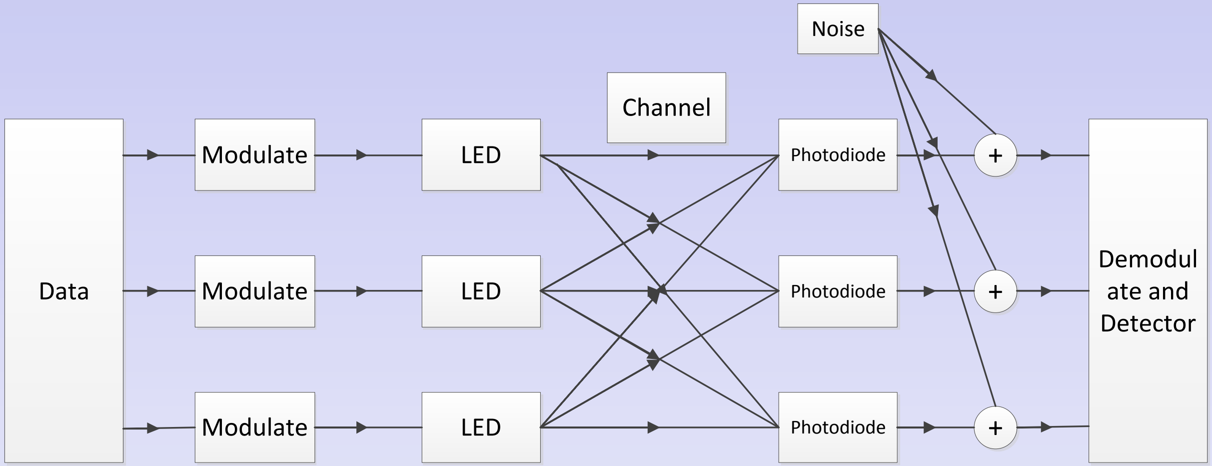


Average Bit-Error-Rate Vs Eb/N0 as a Function of MZM Backoff for LOS OW Link

8. Other new developments …

Optical Wireless MIMO System

(Hao Du, Green)



An infrared MIMO-based communication system, with 4 transmitters and 4 receivers, was built. Each was fixed on a track, whereas the receiver stand could be moved in parallel (±10cm). Experiments were conducted to evaluate BER performance and other performance measures

Energy conscious adaptive security

(Taramonli, Green, Leeson)

Aim: Optimal security mode selection with respect to energy consumption

Objective: Trade-off between energy consumption and encryption strength

Outcome: A global quality factor that describes all encryption parameters and their impact on energy consumption

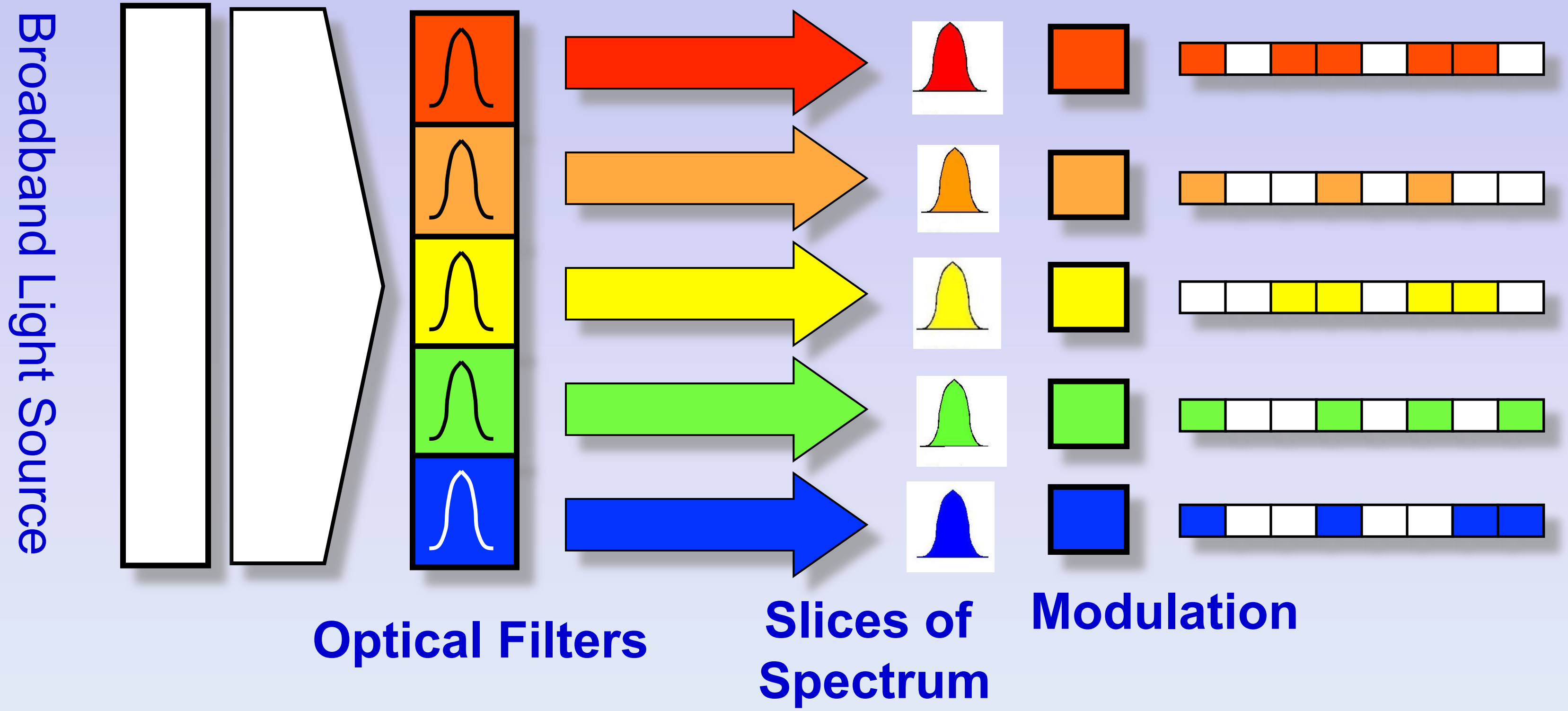
Contribution: Minimum energy needed to achieve a desired security level

1. Encryption strength is adjusted according to the severity of the requested service

2. For battery-powered devices data is encrypted according to a specified threshold or to the battery level

Methods used: Reliability, Chernoff bounds, Regression analysis

Spectral slicing to multiplex from cheap optically-broadband sources *(Leeson, et al)*



- ✓ **Inexpensive**
- ✓ **Channels at multiple wavelengths**
- ✓ **Tunable filters**

A recent PhD from my group …

Performance Prediction, Parameter Selection, and Channel Adaptation in the Line-of-Sight Outdoors Optical Wireless Channels Using Intelligent Systems

By

Adnan El. Yakzan

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Good books about the topics discussed …..

1. "Wireless infrared communications", by **John R. Barry**, published by Kluwer Academic Publishers, 1994, and arguably the "Bible" of optical wireless communications.
2. "Wireless optical communication systems", by **Steve Hranilovic**, published by Springer, 2005.
3. "Optical wireless communication systems: IR for optical wireless", **Roberto Ramirez-Iniguez, Sevia M. Idrus, and Ziran Sun**, published by CRC Press, 2008 (*all former PhD students of RJG* !).
4. "Communication in transportation systems", edited by **Otto Strobel**, published by IGI Publishers, 2013 (*contains a chapter by RJG et al within, on optical wireless within vehicles* !)
5. "Advanced optical wireless communication systems", edited by **Shlomi Arnon, John R. Barry, *et al*,** published by Cambridge University Press 2012, (*a chapter by RJG within* !).

Thank you for your

attention !