Optical Wireless Communication

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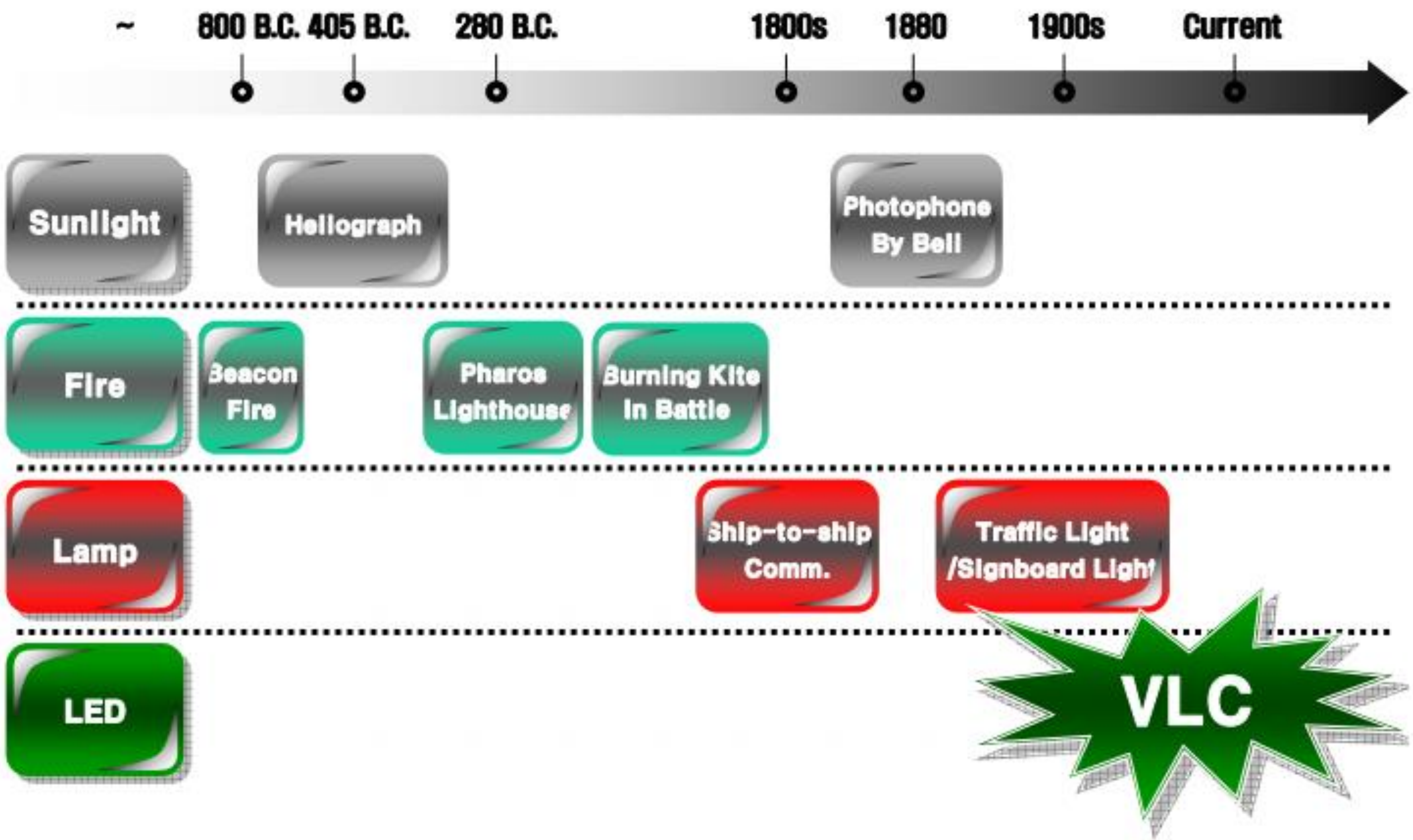
OWC Topics

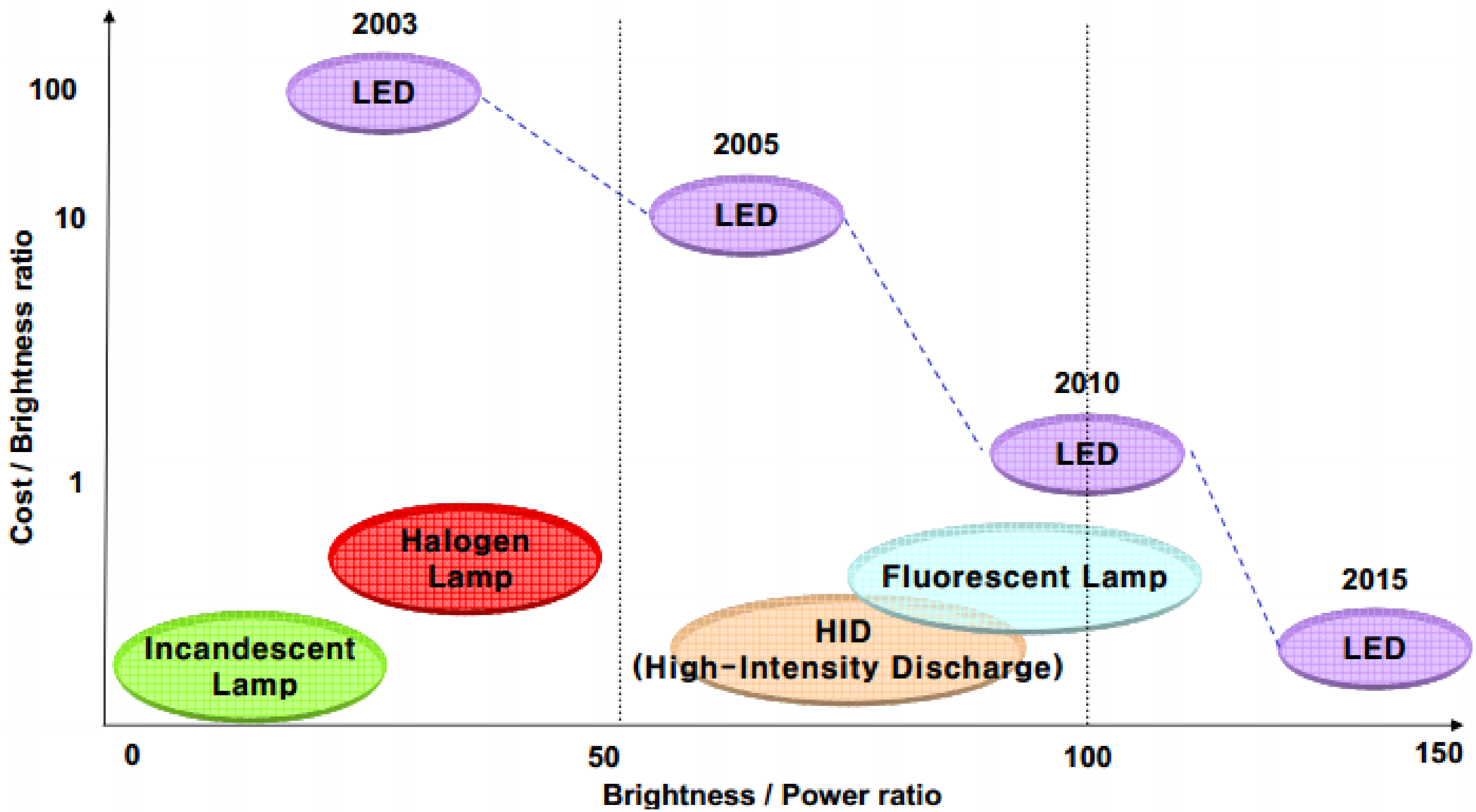
- History
- Why LED?
- Definition/Classification
- Transmission Ranges
- OWC vs RF
- Indoor Systems
- Modulation
- QPSK
- Conclusion

History



~
800 B.C.
405 B.C.
280 B.C.
1800s
1880
1900s
Current
Sunlight
Heliograph
Photophone By Bell
Fire
Beacon Fire
Pharos Lighthouse
Burning Kite In Battle
Lamp
Ship-to-ship Comm.
Traffic Light /Signboard Light
LED
VLC

Why LED?


2003
LED
2005
LED
2010
LED
2015
LED
100
10
1
Cost / Brightness ratio
Halogen Lamp
Incandescent Lamp
Fluorescent Lamp
HID (High-Intensity Discharge)
0
50
100
150
Brightness / Power ratio

What is Optical Wireless Communications?

Optical Wireless Communications, or OWC, is a form of optical communication in which unguided visible, infrared or ultraviolet light is used to carry a signal

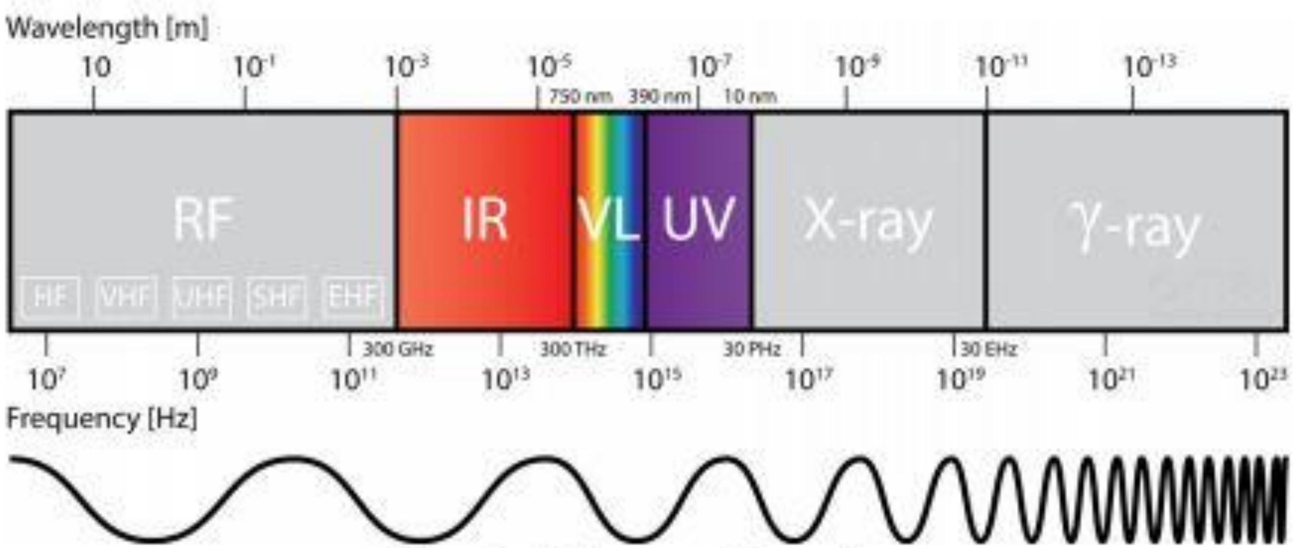
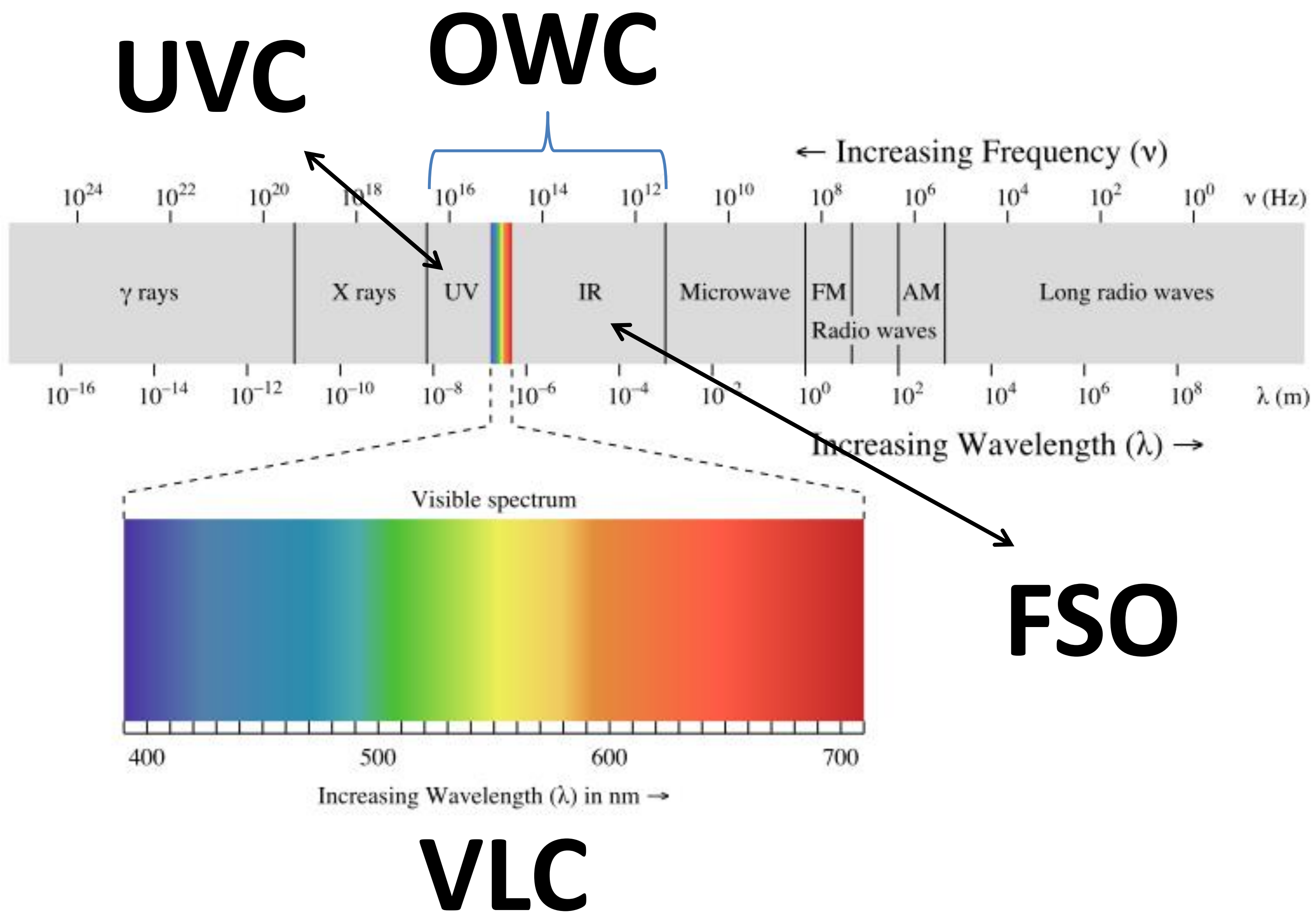


Figure 1. Electromagnetic spectrum.

Optical Wireless Types



History

- Up to late 1990s – Infrared Communication
- Early 2000s – VLC was implemented
  - Started with 100 Kbps
  - Now over 800 Mbps for short range*

Transmission Ranges

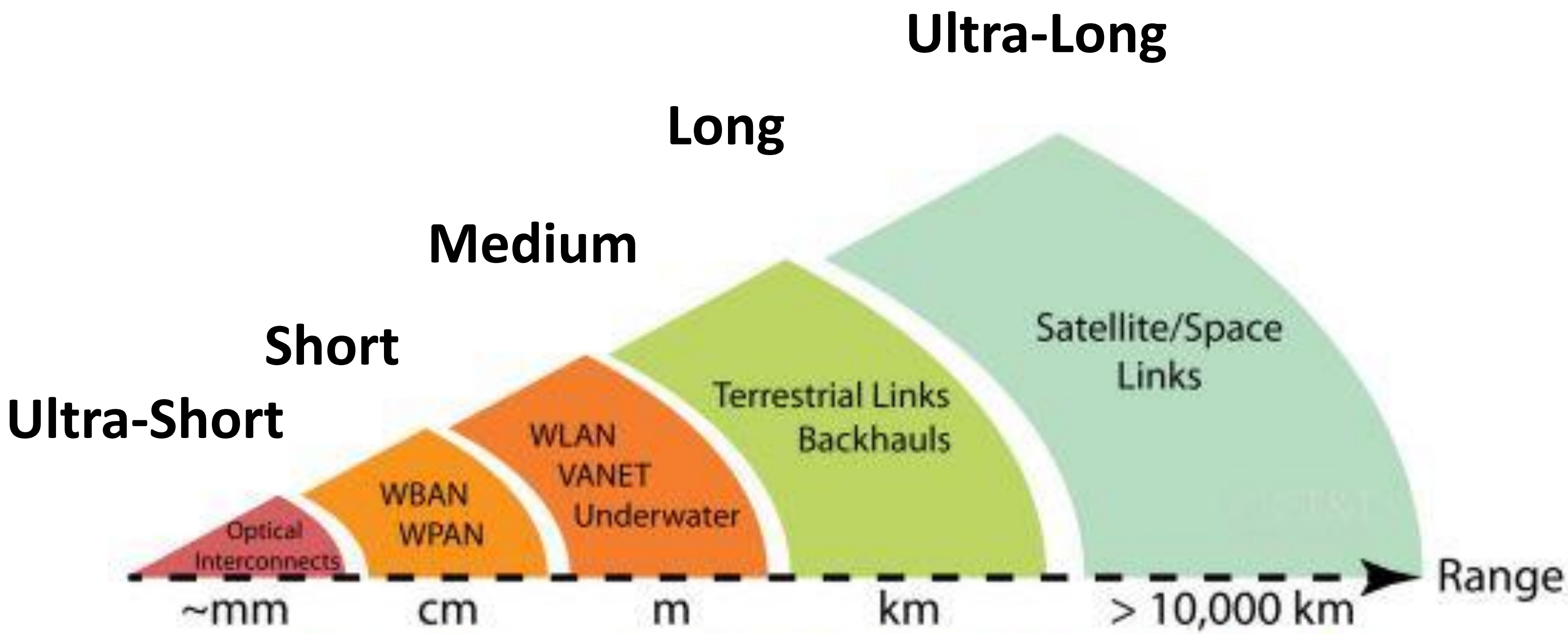


Figure 2. Categorization of OWC applications based on the transmission range.

Ultra-Short Range OWC

- ~milimeters
- Replace copper-based interconnections
- Inter/Intra –chip communication
- High bandwidth
- Low latency
- Guided
- Unguided
    - FSOI
    - More flexible
    - Parallelism
    - Allow multi-dimensional device arrays

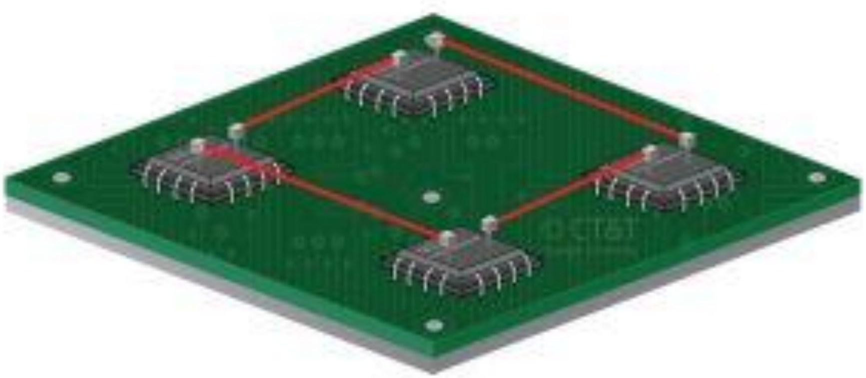


Figure 3. Illustration of free space optical interconnect.

Outlook Market Report Prediction
$520 million by 2019
$1.02 billion by 2021

Short Range OWC

- ~centimeters
- WPAN
  - Personal workspaces
  - “Last Meter” connectivity
  - IR LED
  - Up to 10 Gbps
- WBAN
- Current WBANs are RF based
- Problem in RF restricted areas
  - Hospitals
  - EMI

Figure 4. An envisioned cardio-stress test equipment based on VLC. The LEDs attached to sensor units communicate wirelessly with the receiver located on the equipment handle bar.

Medium Range OWC

~meters

Figure 5. A VLC-enabled hot spot where the VLC receiver in the form of an USB dongle communicates with the desk lamp acting as a VLC transmitter.

WLAN

Substitute for RF

Wi-Fi

LiFi

VLC

New technologies

Long life

High humidity tolerance

Lower power consumption

Reduced heat dissipation

Long Range OWC

- ~km
- "Last Mile" communications
- WMAN
- FSO
- Links are easy to install and redeployable
-
- 9/11

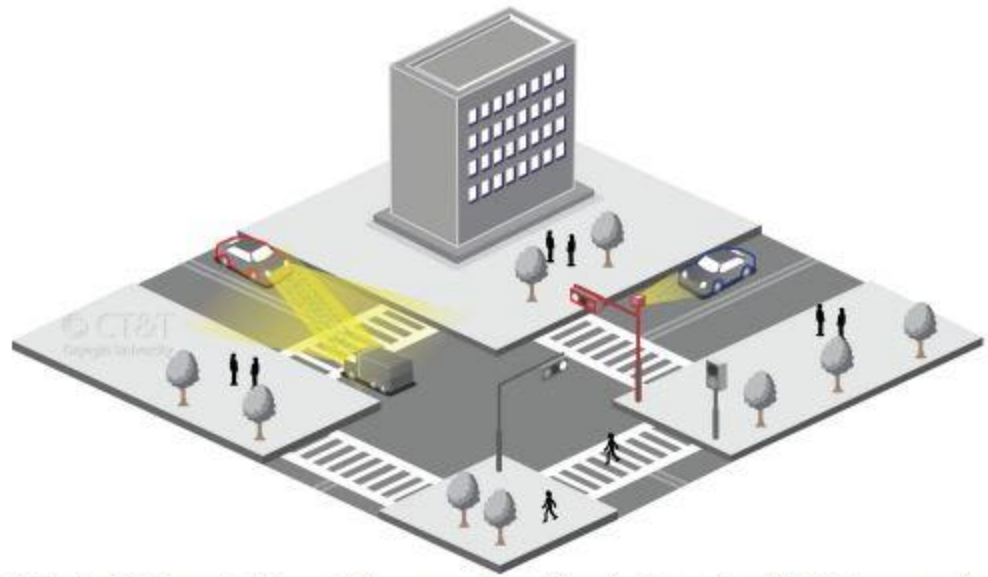


Figure 6. Vehicular VLC network where vehicles communicate with each other and roadside infrastructure through their LED-based front and back lights.

Long Range OWC

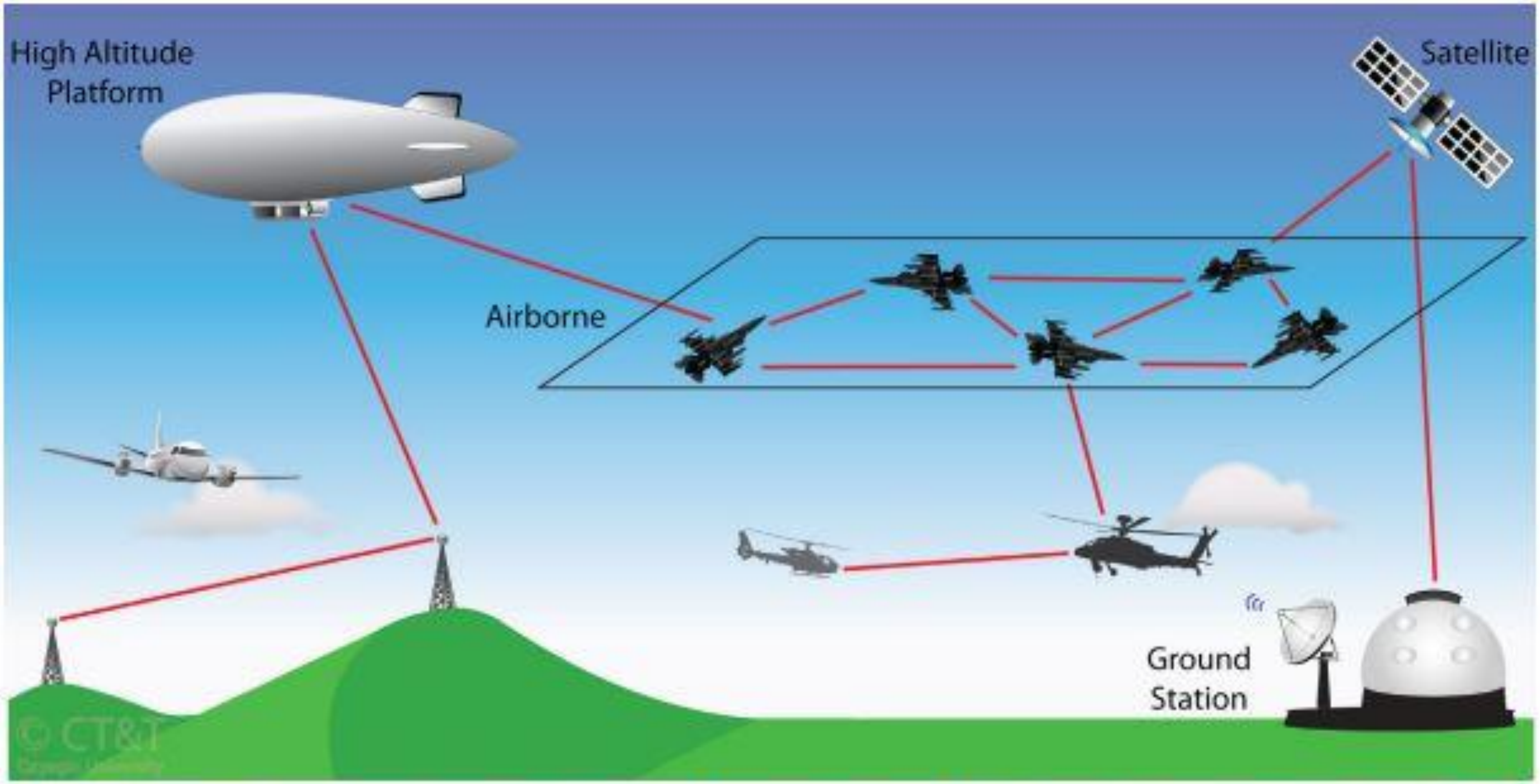
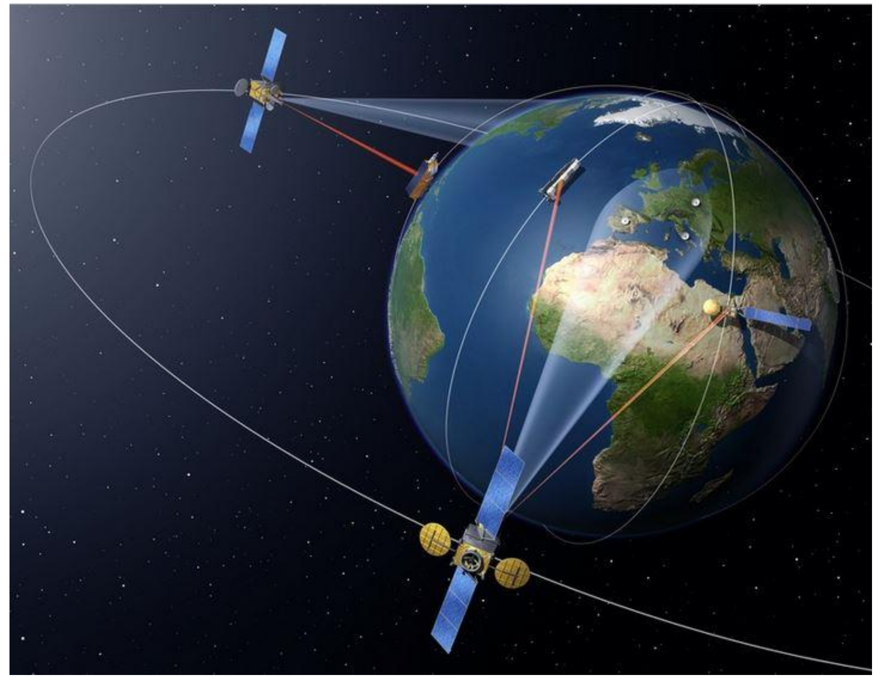


Figure 8. FSO can be deployed to support aircraft-to-aircraft, aircraft-to-HAP, aircraft/satellite/HAP-to-ground communication.

Pointing-acquisition-tracking algorithms

Ultra-Long Range OWC

- >10,000km
- Ground-satellite
- Satellite-satellite
- Intraplanet!



- 2001: 50 Mbps FSO between ARTEMIS geostationary satellite and SPOT-4 French Earth observation satellite
- Coherent modulation -> Gbps
- October 2013: NASA’s Lunar Laser Communication Demonstration – Moon to Earth (384600 km) achieved 622 Mbps

OWC vs. Radio

Table 1.1. Comparison of wireless optical and radio channels.

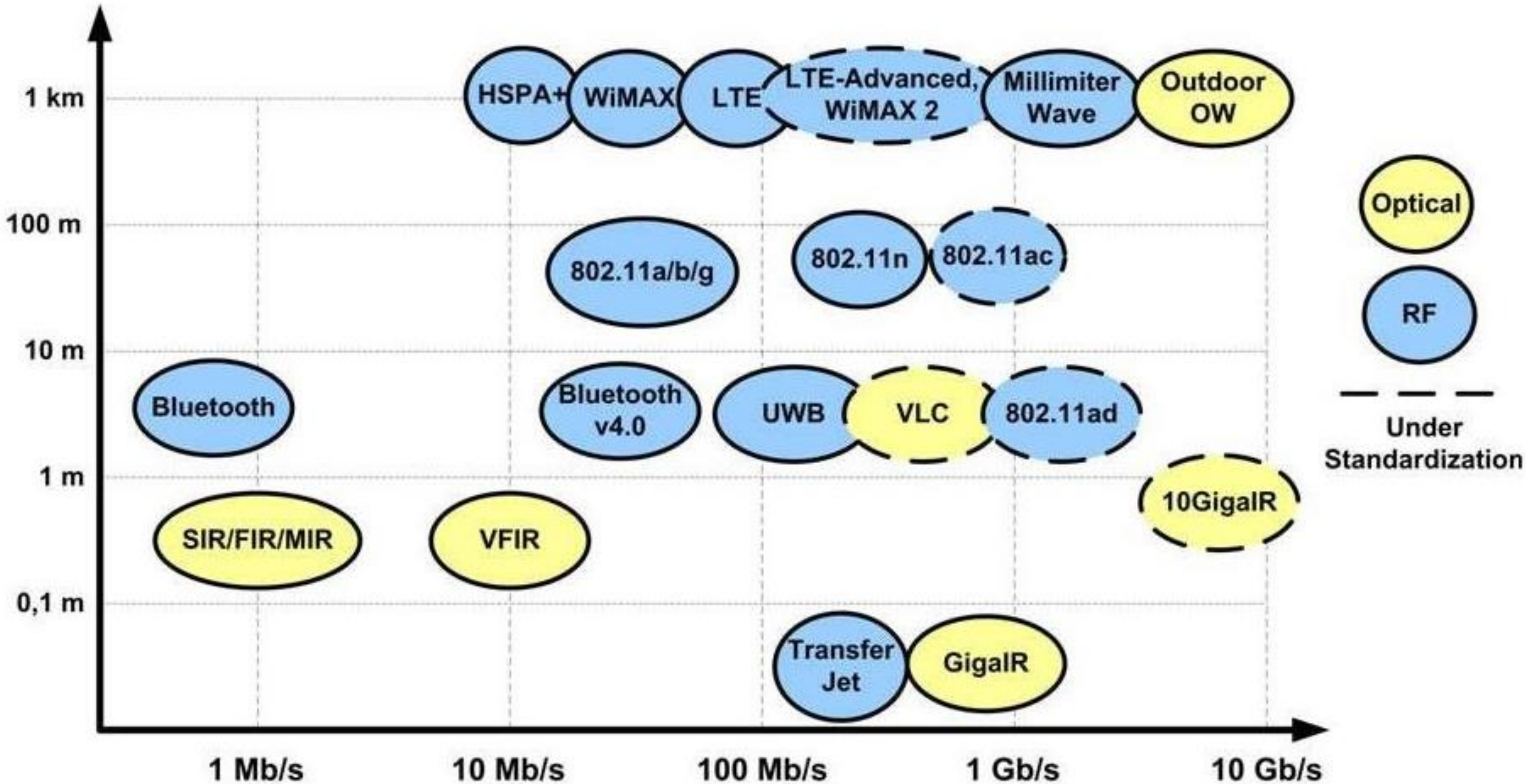
Property	Wireless Optical	Radio
Cost	$	$$
RF circuit design	No	Yes
Bandwidth Regulated	No	Yes
Data Rates	100's Mbps	10's Mbps
Security	High	Low
Passes through walls ?	No	Yes

OWC vs. Radio

Table 1 Comparison Between Radio and IM/DD Infrared Systems for Indoor Wireless Communication

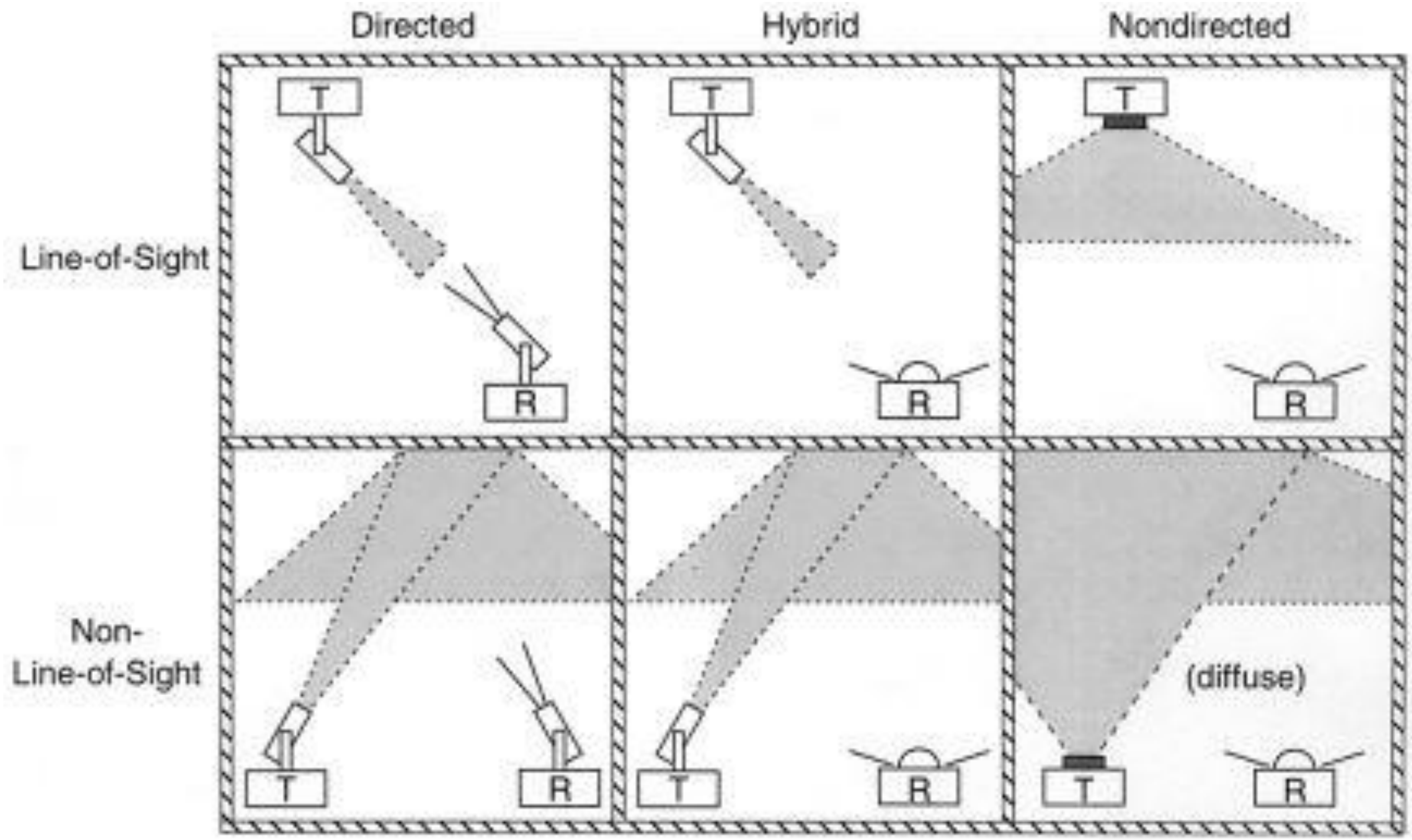
Property of Medium	Radio	IM/DD Infrared	Implication for IR
Bandwidth Regulated?	Yes	No	Approval not required. Worldwide compatibility.
Passes Through Walls?	Yes	No	Less coverage. More easily secured. Independent links in different rooms.
Multipath Fading?	Yes	No	Simple link design.
Multipath Distortion?	Yes	Yes	
Path Loss	High	High	
Dominant Noise	Other Users	Background Light	Limited range.
Input $X(t)$ Represents	Amplitude	Power	Difficult to operate outdoors.
SNR Proportional to	$\int \|X(t)\|^2 dt$	$\int \|X(t)\|^2 dt$	Hight transmitter power requirement.
Average Power Proportional to	$\int \|X(t)\|^2 dt$	$\int X(t) dt$	Choose waveform $X(t)$ with high peak-to-average ratio.

OWC vs. Radio



RF and OW technologies as defined in standards and deployed in commercial products.

Directed	- Maximizes power efficiency
	- Minimizes path loss
	- Minimizes ambient light noise
Nondirected	- Wide angle transmitters/receivers
	- No pointing needed
	- More convenient
Hybrid	- Combination



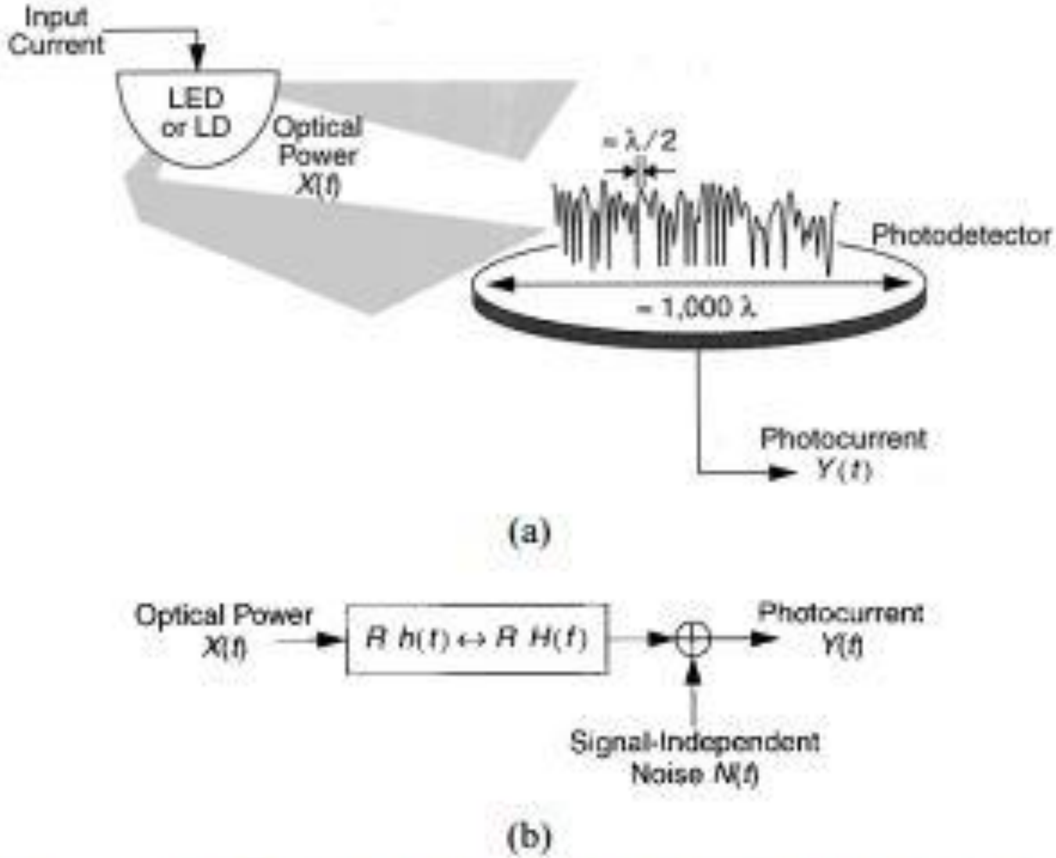


Fig. 2. (a) Transmission and reception in an infrared link with IM/DD. (b) Modeling link as a baseband linear, time-invariant system having impulse response $h(t)$, with signal-independent, additive noise $N(t)$. The photodetector has responsivity R.

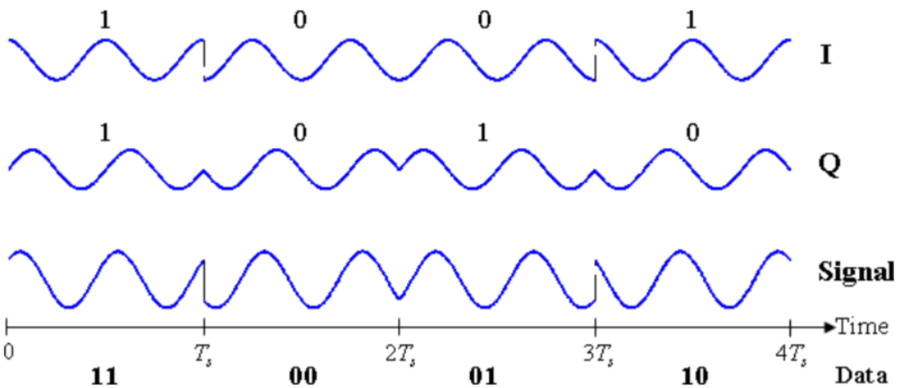
Y(t) = Instantaneous current in the receiving photodetector

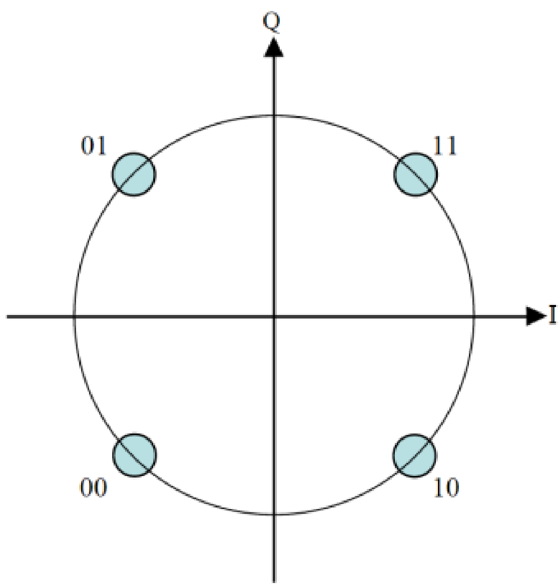
X(t) = Instantaneous optical power

Modulation

- Intensity Modulation (IM)
  - Desired waveform is modulated onto the instantaneous power of the carrier
- Direct Detection (DD)
  - Photo detector producing a current proportional to the received instantaneous power
- IM/DD
  - Does not offer immunity to turbulence-induced fading channels
  - Instead: phase and frequency
- Phase Shift Keying (PSK)
- Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying





QPSK

$$I_i = \cos(\varphi_i)$$
$$Q_i = \sin(\varphi_i)$$

where $\varphi_i = 2\pi\,(i-1)/M$, M=4 and i=1, 2, 3, 4.

Table I: I and Q signal as per the incoming symbol

Symbol	I Signal	Q Signal
00	1	0
01	0	1
10	0	-1
11	-1	0

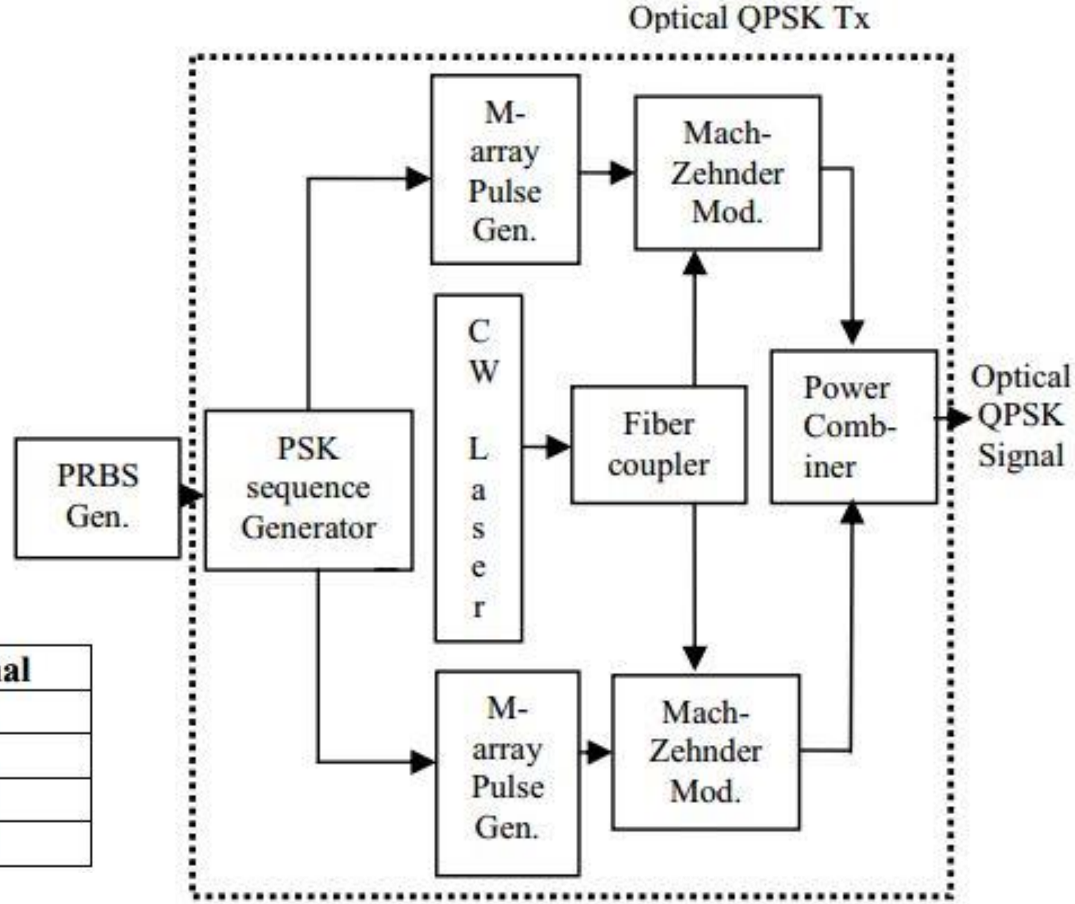


Fig. 1 Block diagram of coherent optical QPSK transmitter

Conclusion

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Questions?