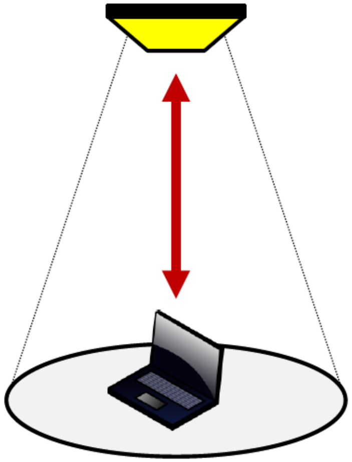
Topic 11

11. Visible Light Communication



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Current challenges of Wi-Fi (I)

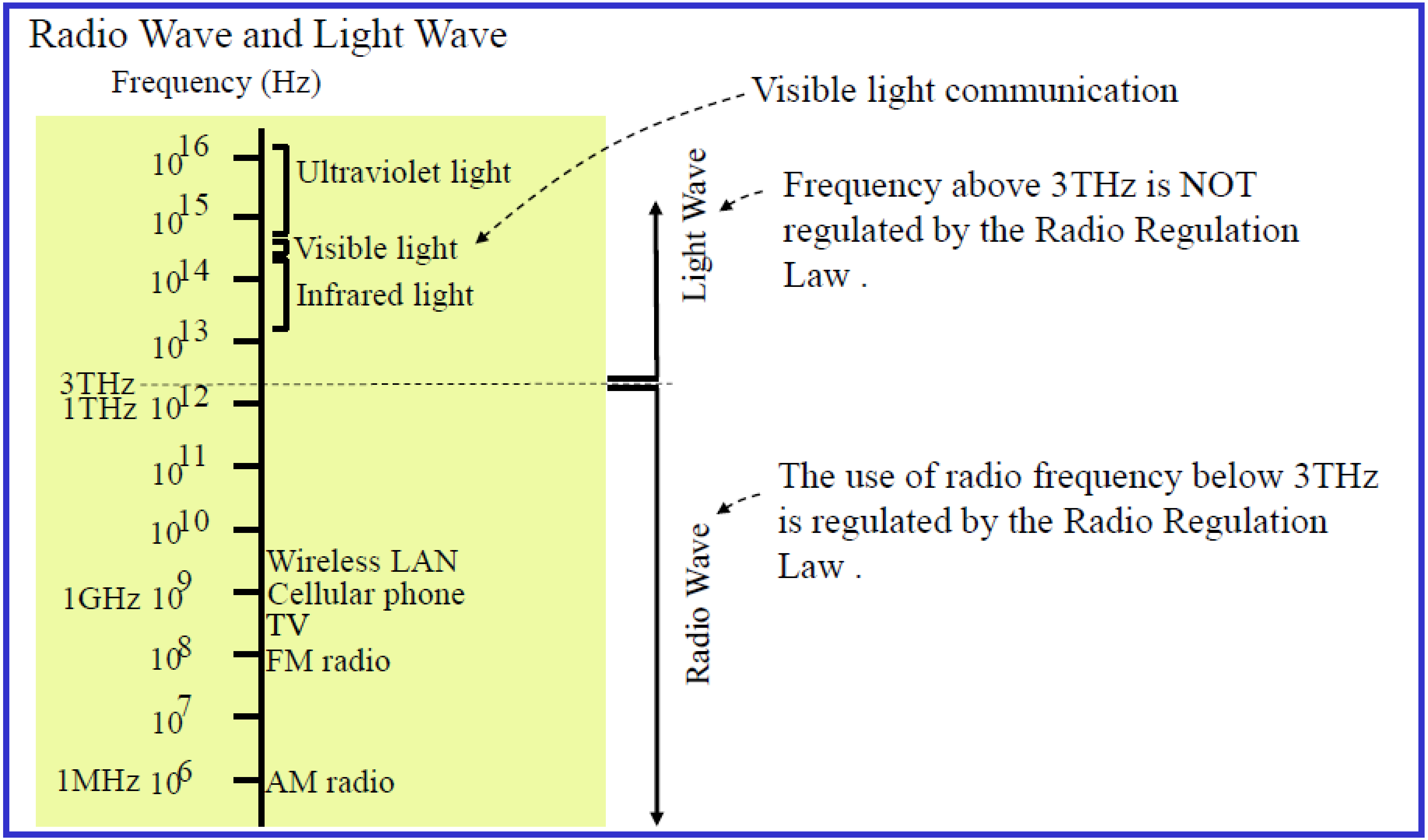
- **Very crowded frequency spectrum, leading to limited access to the frequency**
- **Very limited radio frequency bandwidth: 3 kHz to 300 GHz limited bandwidth.**

$$\boxed{|\Delta \nu| = \left(\frac{c}{\lambda^2}\right)|\Delta \lambda|}$$

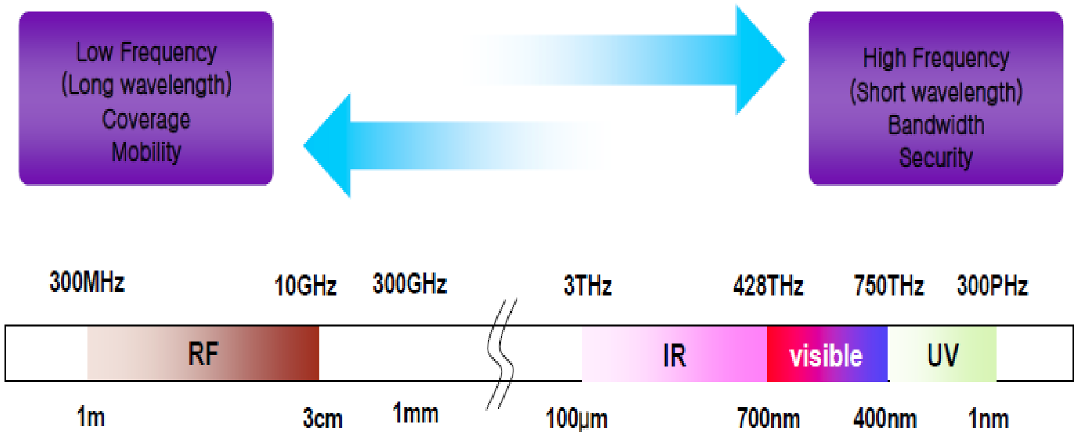
The above equation indicates: bandwidth can be increased by reducing wavelength, for visible light: 430 THz to 750 THz

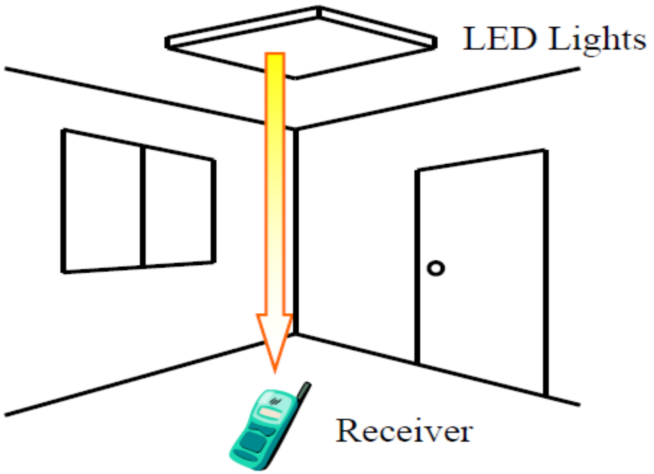
- **Radio waves generate electromagnetic interference, and thus cannot be used in aircraft and hospital**
- **Radio waves generate healthy concern**
- **Radio waves cannot be used for underwater communications due to strong absorption.**

Current challenges of Wi-Fi (II)



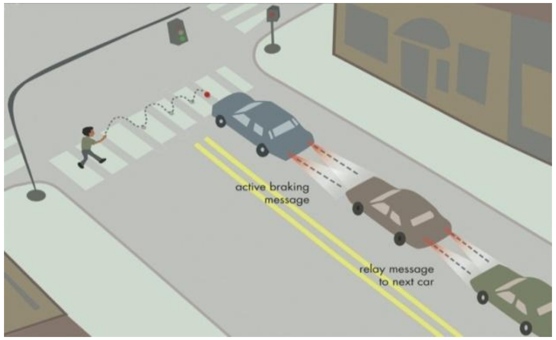
Introduction

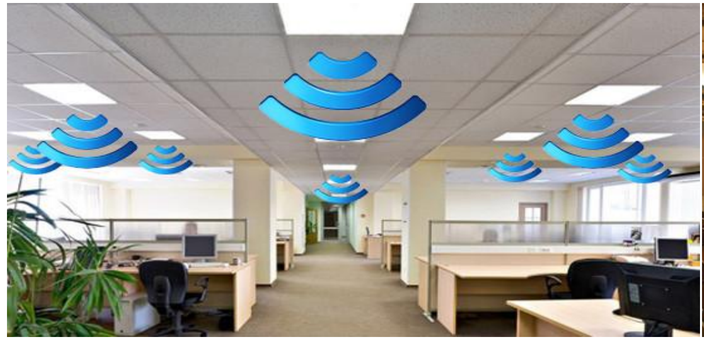


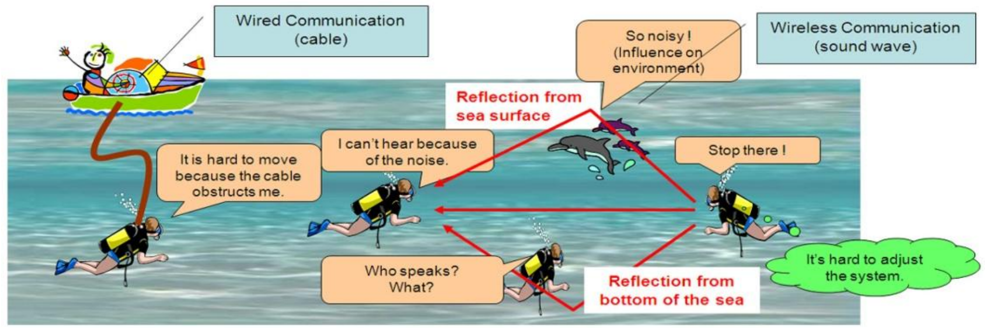


- VLC is an optical wireless communication technology using visible light sources as transmitters (780 nm-380 nm)
- White LED intensity is modulated by controlling its current in order to transmit data.
- LEDs can be switched on/off so fast the eye cannot feel. Therefore, white LEDs serve as lighting sources for simultaneous general illumination and wireless communication
- White LEDs are made of a blue LED surrounded by a yellow phosphor, which emits white light.

Applications-I



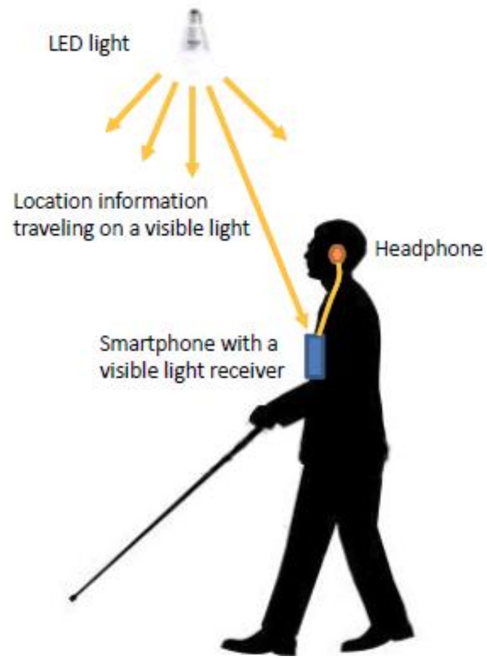


VLC can provide network access at

- Home/officer/shopping centre/plane/Convention Centers: both general illumination and Wi-Fi
- Hospital: avoid RF interference
- Underwater communications:
- Transport systems: brake lights "tell" drivers to stop; VLC could send a signal to engine-control units for collision avoidance.

Applications-II



- **Indoor Navigation System for the Visually Impaired people**

By combining a LED which emits visible light with location data and a smartphone as a receiver, an optimal path to a destination can be calculated, and then is passed the visually impaired through a headphone

- **Visible Light Communication using Image Sensor as Receiver**

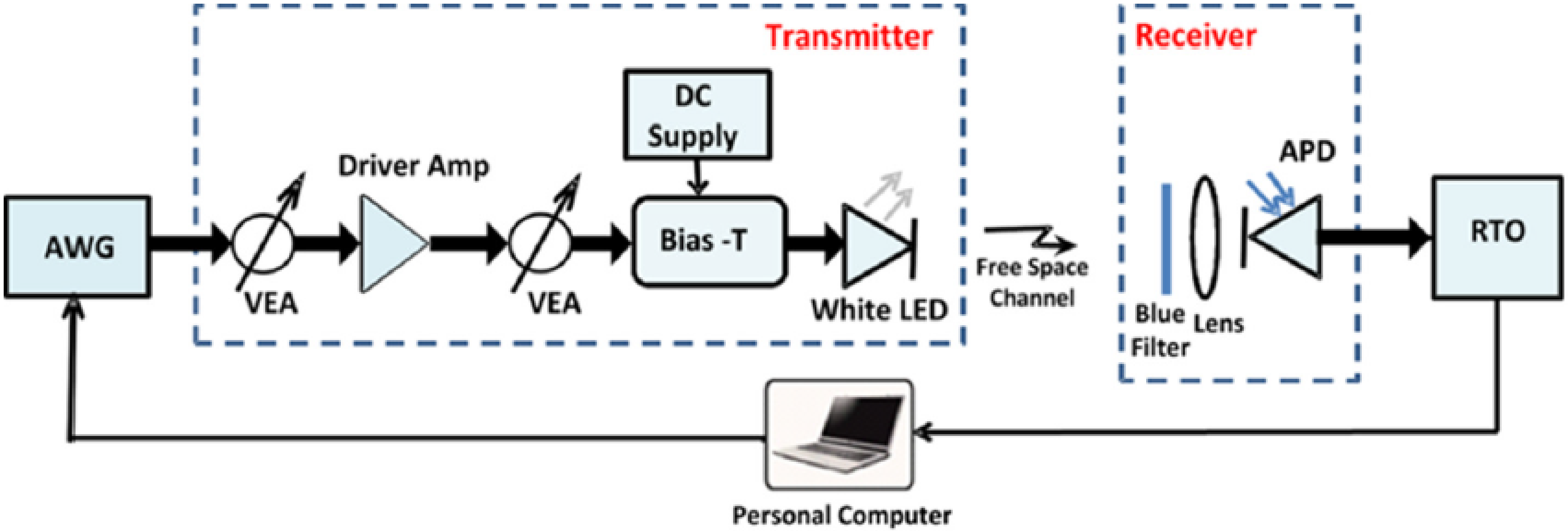
detect both incoming data and direction of incoming signal

Advantages of VLC

VLC has a number of major advantages over the present-day radio *frequency* (RF) based Wi-Fi technology:

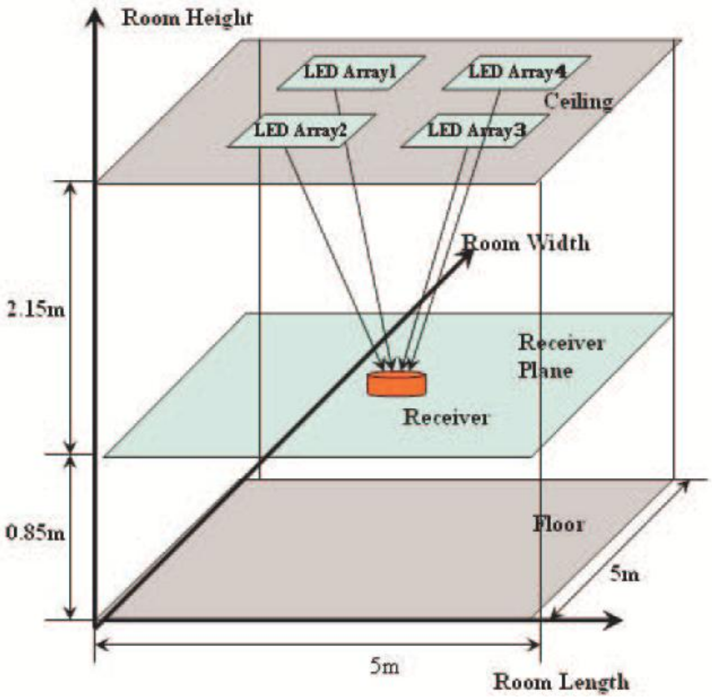
- VLC doesn’t cause malfunction of sensitive aircraft or medical instruments, and thus can be safely used in aircrafts and hospitals;
- VLC can be used in hazardous environments, such as oil, gas, petrochemicals; where RF radiation can potentially cause a high risk
- VLC is free of any health concern, while there are always concerns in the RF radiations on health;
- VLC doesn’t need to follow the Radio Regulation Law, while the use of the RF technology does due to electromagnetic interference;
- VLC can be used for underwater communication, while the RF cannot because the RF radiation can be heavily absorbed by water.
- Using visible light is less dangerous for high-power applications as humans can perceive it and act to protect their eyes from damage.
- VLC: Confined to small geographical area, thus secure

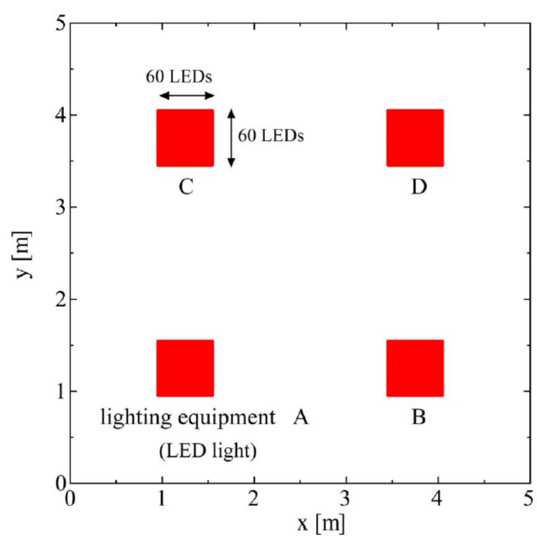
Schematic of a VLC system using white LEDs-I



- AWG: artitrary waveform generator; VEA: Variable electrical attenuator; RTO: real-time oscilloscope
- Optical source: Blue LEDs+Yellow phosphor
- Blue filter: remove yellow emission (why?)

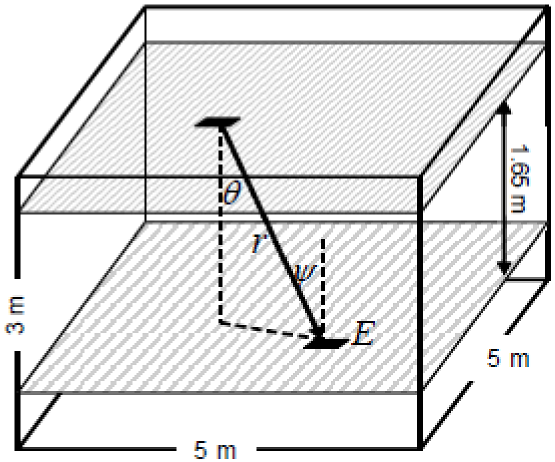
Schematic of a VLC system using white LEDs-II

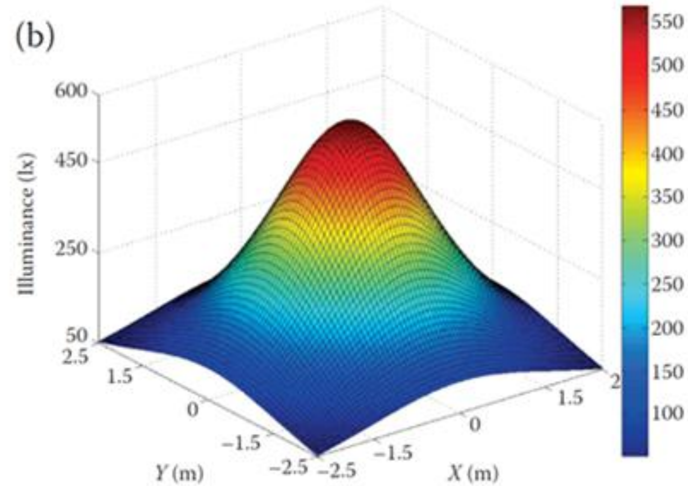




Parameters		Values
Room	Size	$5 \times 5 \times 3$ m^3
	Reflection coefficient	0.8
Source	Location (4 LEDs)	(1.25, 1.25, 3), (1.25, 3.75, 3), (3.75, 1.25, 3), (3.75, 3.75, 3)
	Location (1 LEDs)	(2.5, 2.5, 3)
	Semiangle at half power (FWHM)	70
	Transmitted power (per LED)	20 mW
	Number of LEDs per array	60×60 (3600)
	Centre luminous intensity	300–910 lx
Receive	Receive plane above the floor	0.85 m
	Active area (AR)	1 cm^2
	Half-angle FOV	60
	Elevation	90
	Azimuth	0
	Δt	0.5 ns

Illuminance distribution-I





• Distribution of illuminance at a desk surface: Luminous intensity depends on angle of irradiance θ, incident angle Ψ and distance r

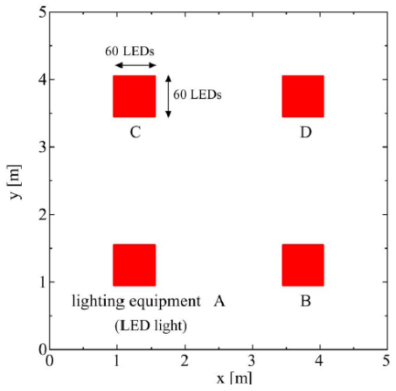
$$E_h = I_0 \cos^m(\theta) \cos\psi / r^2$$

I_0 : centre luminous intensity of LED

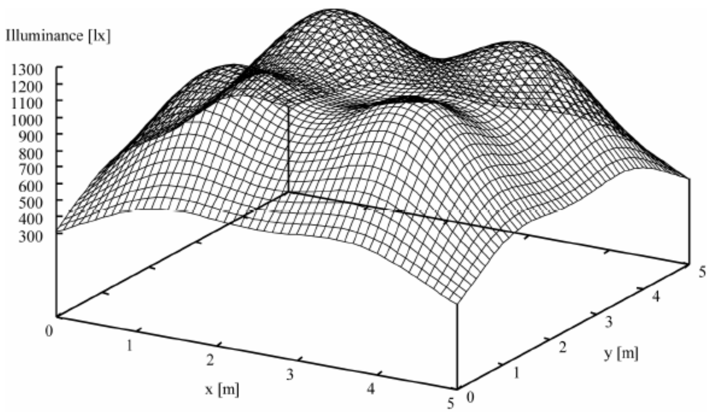
• White LED: assumed as Lambertian emission, described by Lambert index, m, defining the source radiation semi-angle. For example, 60^0 semi-angle at half power, corresponding m = 1.

• International organisation standardisation: 300-1500 lx required for office work

Illuminance distribution-II



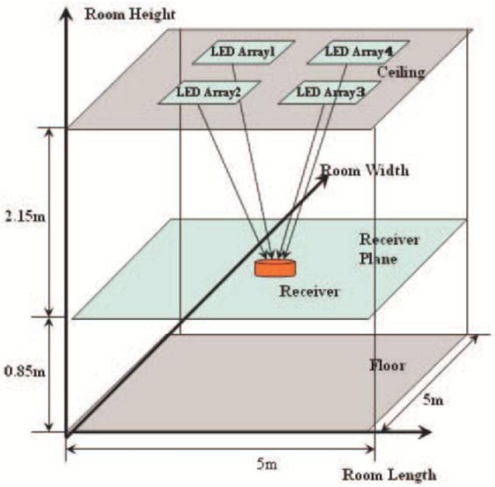
transmitted optical power	20 [mW]
semi-angle at half power	70 [deg.]
center luminous intensity	0.73 [cd]
number of LEDs	3600 (60 × 60)
LED interval	0.01 [m]
size of LED light	0.59 × 0.59



- **Design**: 4 LED arrays on 2.5 m celing, each consisting of 3600 (60 × 60) LEDs. Space between LEDs: 1 cm. Semi-angle at half-power of an LED: 70 deg; Center luminous intensity of an LED: 0.73 cd

This design leads to a distribution of illuminance of Min: 313.5 lx; Max: 1211.5 lx; Ave: 865.7 lx**.**

Received Power from LED light



FOV at a receiver	60 [deg.]
detector physical area of a PD	1.0 [cm^2]
gain of an optical filter	1.0
refractive index of a lens at a PD	1.5
O/E conversion efficiency	0.53 [A/W]

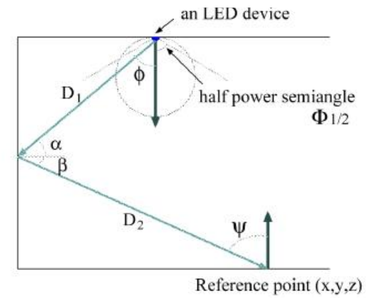
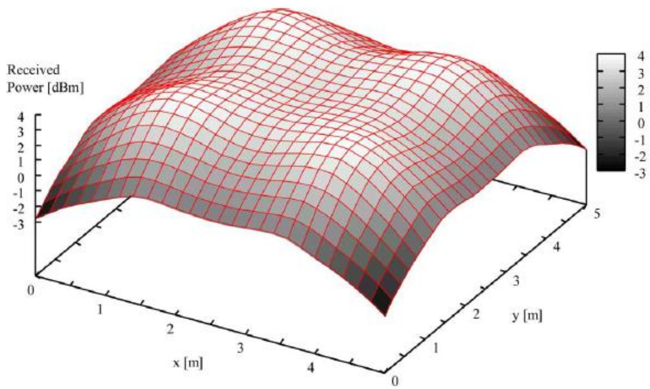
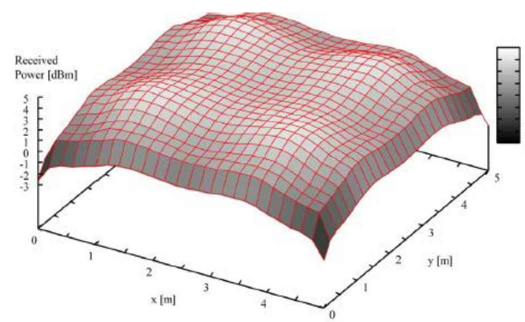


Fig. 5. Propagation model of diffused link.

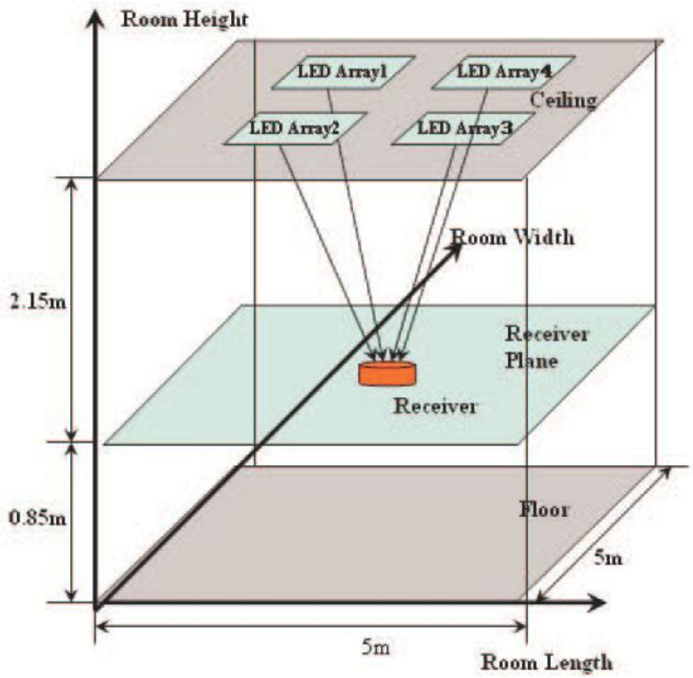


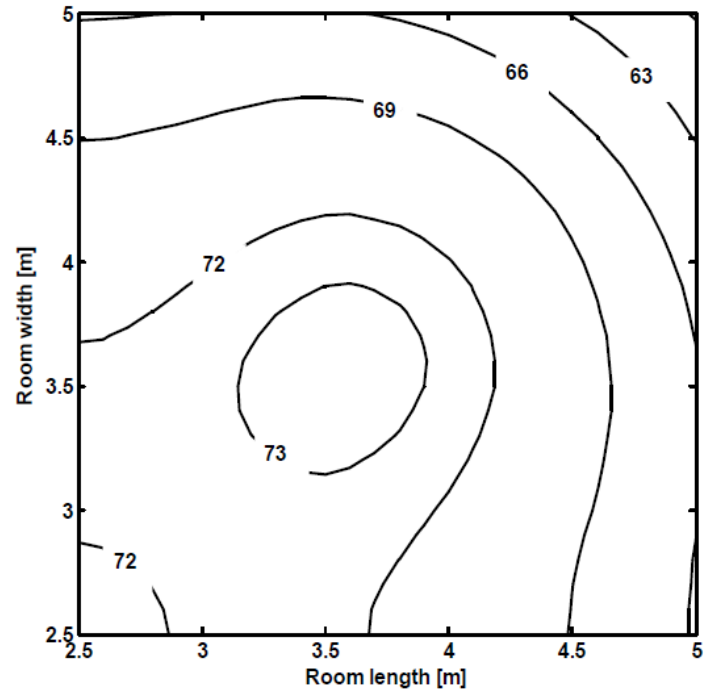


- Distribution of received power from LED lights: -2.8 to 4.0 dBm in all the places of the room

- Distribution of received power from LED lights: -2.8 to 4.2 dBm in all the places of the room

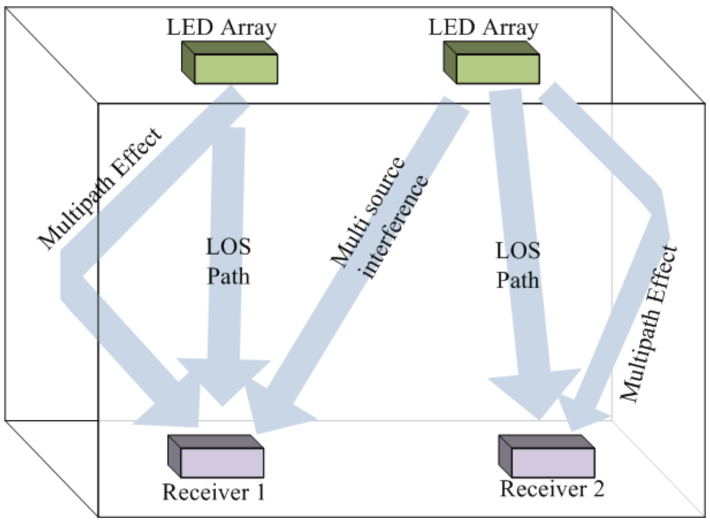
High signal to noise ratio

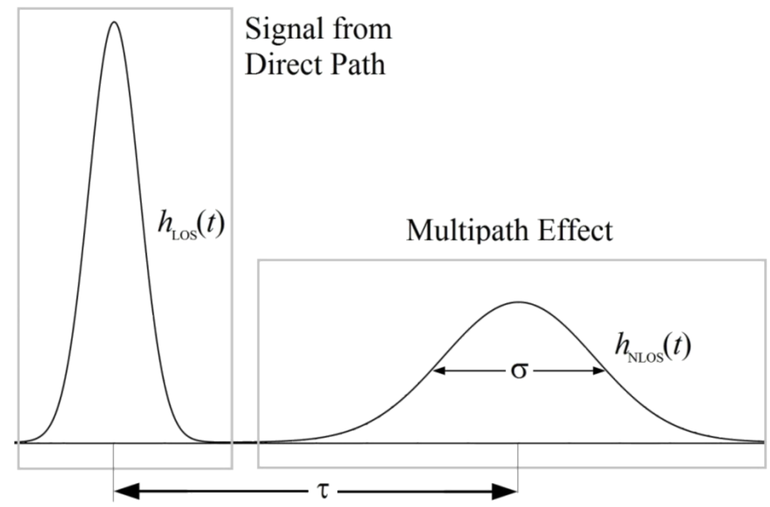




- Simulation of SNR distribution at the receiver surface in a worst scenario (full penetration of sun light into the room).
- SNR>60 dB throughout the entire room (Very high SNR!)
- Room illumination must meet minimum levels according to the standards, leading to a very high SNR
- Large number of superimposed LOS signals due to an indirect consequence of the illumination requirements, leading to a very high SNR

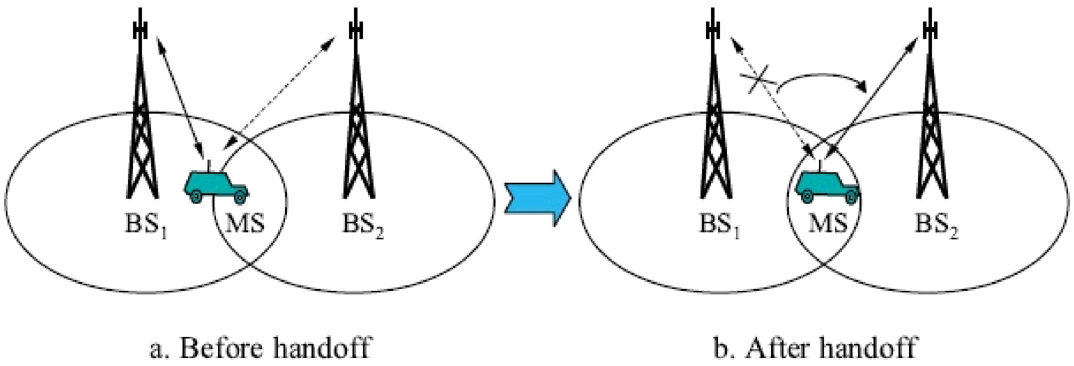
Multipath effect

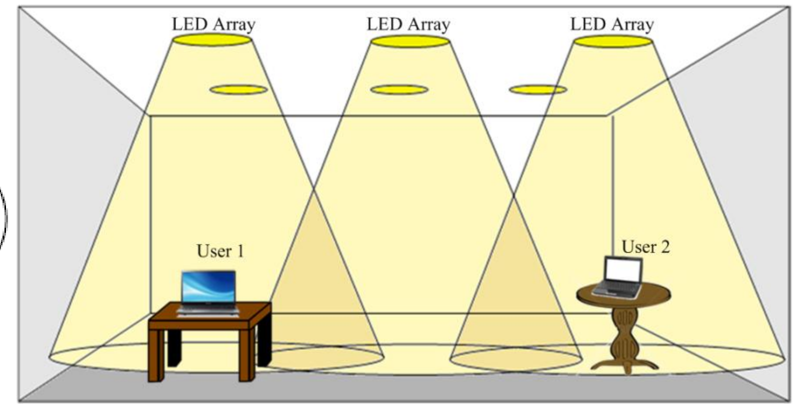




- Multipath effect limits the channel bandwidth
- Optical impulse response in VLC systems has two parts
  (1) Line-of-sight (LOS) part which is received via directed path
  (2) Multipath effect/NLOS path part
- The delay between the two parts: determined by room geometry and size
- Blocking the LOS part, and leaving the impulse response from NLOS part only

Issue on VLC connectivity





•This problem is similar to service disconnections due to mobility issues in mobile phone network when you move from one city to another area

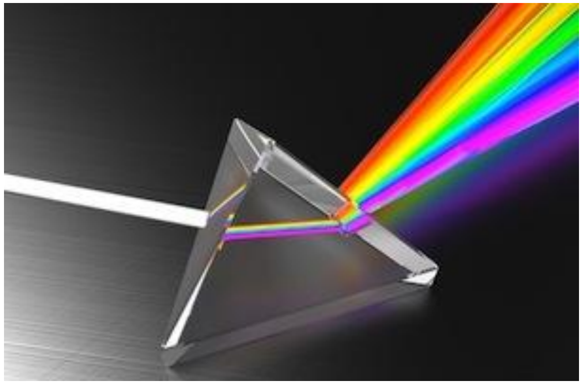
• A switching process from one serving network to another is required, and it is called "Handover" (HO) technique

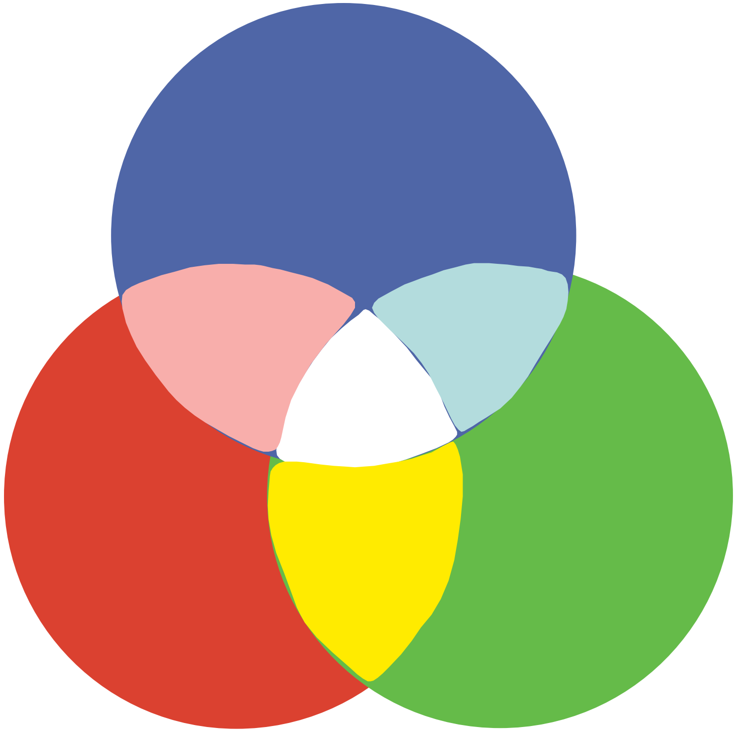
• HO allows connectivity switching whenever a mobile terminal moves from an access point to another without changing the service access network

•HO is done in the area that two LED arrays share common coverage, and users can be transferred from one light source to another in the area that is under the coverage of both

White lighting

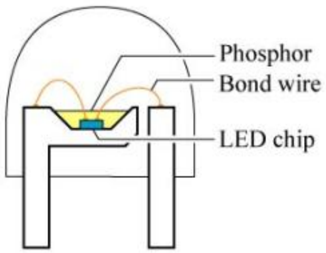
- Red + green: yellow
- Red + blue: magenta
- Green + blue: cyan
- Yellow (Red+ green)+ blue: white

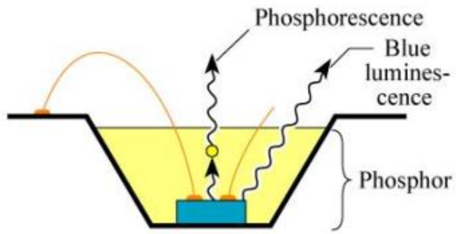


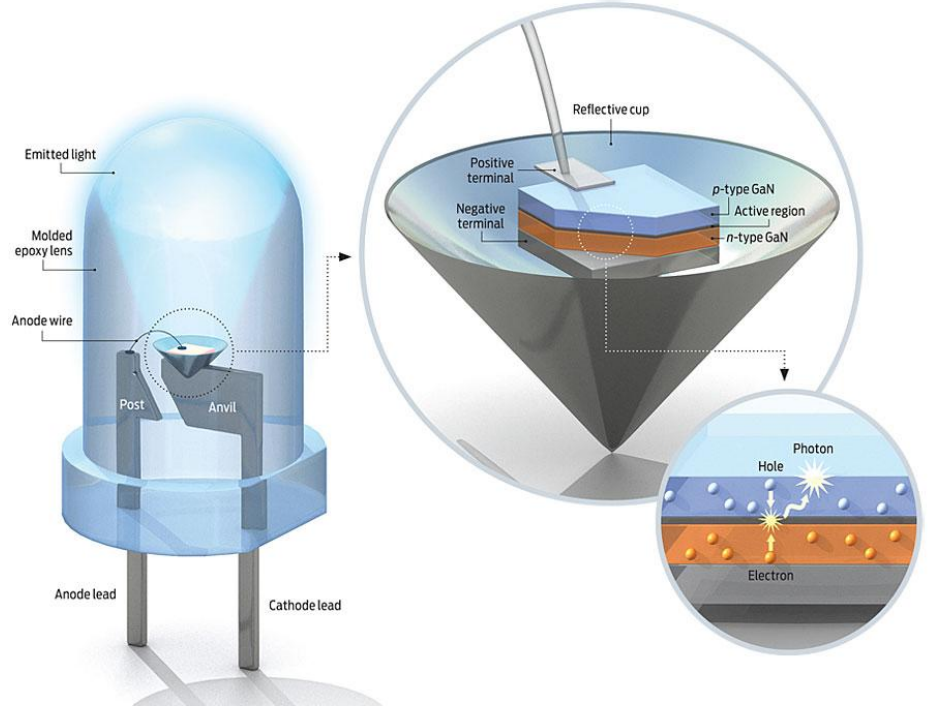


Newton originally (1672) divided the solar spectrum into 5 main colours (red, yellow, green, blue and violet). Later he included orange and indigo.

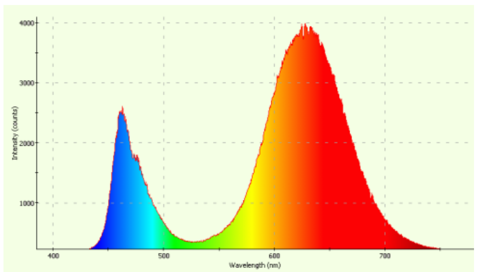
Turning blue LEDs to white LEDs







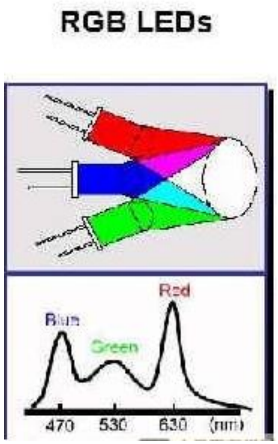
White LED

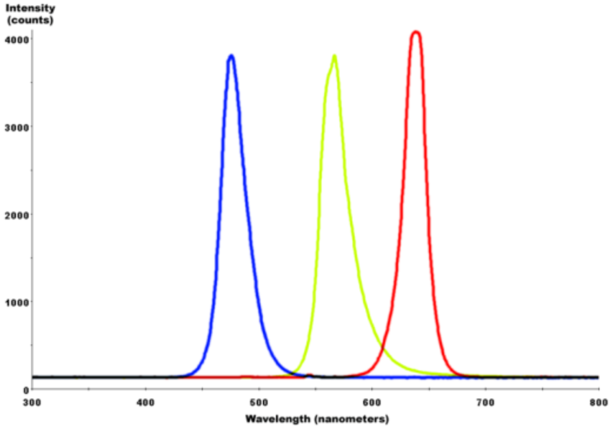


Blue LED

InGaN based luminescence conversion white LED

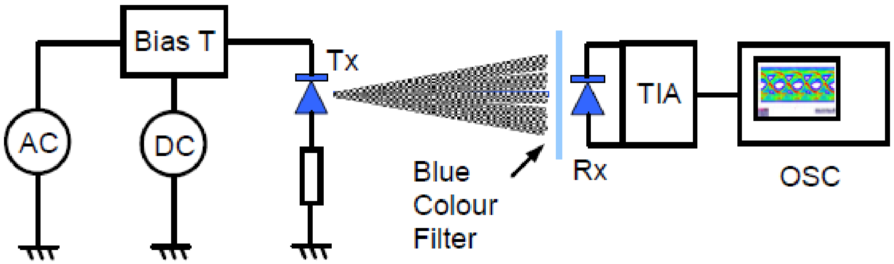
Trichromatic LED (RGB approach)

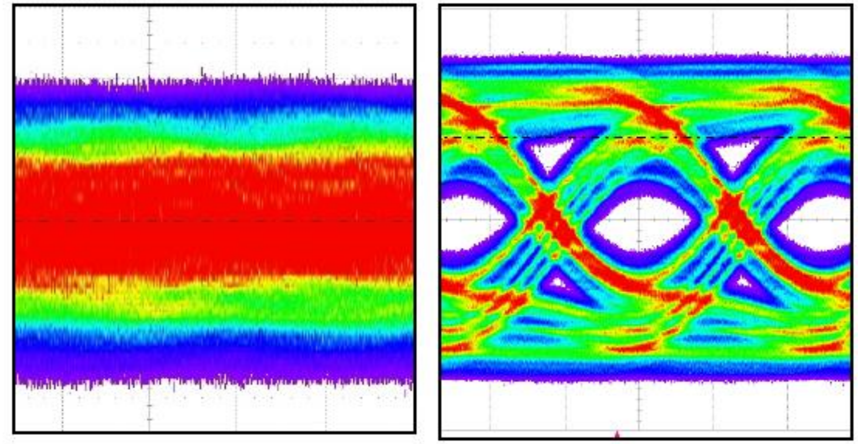




- 3 color LEDs: Red (~625 nm), Green (525 nm) blue (470 nm) (RGB) in a correct proportion
- Color tunability
- Best color rendering index; Enables color control
- Fast response time, as a result of avoiding long response time of yellow phosphor, which perfectly meet VLC requirements
- Great challenges and high costs in fabrication, in particular, single chip with 3 colors

Issue with current white LEDs (Blue+Yellow)





•**A single white-light LED** is provided by a DC and an AC source which is the output of an arbitrary-waveform generator (ARB).

• Light is directed through a **blue-colour filter** onto a PIN diode, recorded **by a real-time oscilloscope**.

• The distance between the LED and the PIN diode: 1 cm, ~700 lx at the detector plane.

• Eye diagrams for the received signals at 40 Mbit/s (left) without: completely distorted and (right) with blue filter: pretty good

• The distortion is due to a very long response time of yellow phosphor

Current challenges in White LEDs

- The most important factor in VLC is the switching properties of the visible LEDs, namely, Modulation speed

- Modulation speed is inversely proportional to carrier recombination lifetime in blue LED and response time of yellow phosphor, (f $\sim 1/\tau$).

- Modulation speed of white LEDs is limited by the relaxation time of the LEDs

$$\tau^{-1} = \tau_{rad}^{-1} + \tau_{non-rad}^{-1}$$

✓ Trichromatic LEDs < 20 MHz: blue LED of typically radiative recombination lifetime of 10-100 ns (blue LEDs grown on c-plane leads to piezoelectric fields)

✓ phosphor-based LEDs < 5 MHz: due to slow response of phosphor (on the order of μs)

T11 Summary

- Challenges of RF-based Wi-Fi system
- Definition of VLC; Structure of VLC;
- Major advantages of VLC compared with RF system
- Key components of VLC: white LEDs
- Challengs and solution of VLC
- Fundamental limits of current white LEDs and future development of white LEDs

T11 Tutorial Questions

1. State the reason why a blue filter is required for current VLC
2. State the reason for a very high SNR of VLC system
3. How to fabricate white LEDs
4. Describe and design a standard VLC system